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Research on Power Control Algorithms Based on Stackelberg Game Model in Two-tier Network

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Abstract

With the continuous development of information, wireless network has become an integral part of people's everyday lives. With the explosive growth of data in wireless network, the interferences and competition for resources are more and more serious, especially in the intensive network scenarios. Power control can effectively reduce the interference to improve throughput, save energy and prolong the service life of equipment. This paper proposes a power optimization strategy for Femtocell base station in LTE-A, a two-tier network. It plans the problem into Stackelberg Game, as Stackelberg Game model well describes the user behaviors, making it an effective analysis tool. Then this paper researches the Stackelberg equilibrium and obtains the optimal power distribution and optimal power pricing method. Based on it, a distributed non-uniform pricing algorithm, DNP, is proposed for Femtocell base station deployment. It realizes the distributed deployment with low complexity and less information interaction, and also shows a good performance through simulation, thus having a guiding significance for the power control scheme of Femtocell base station deployment.

Keywords*: power control, Stackelberg Game, power pricing, distributed deployment.*

1. Introduction

To cope with the challenges of technology, the international communication standardization organizes 3GPP (Third Generation Partnership Project) launched the standardization process of LTE (Long Term Evolution) plan in 2004 [1], and LTE was called as 3.9G system. In 2008, LTE-Advanced program was developed in 3GPP. As the subsequent evolution of LTE, the technology of LTE-A has exceeded the minimum requirements of 4G standard of ITU (International Telecommunication Union). LTE-A introduces various novel key technologies [2], including CA (Carrier Aggregation), Enhanced MIMO (Multiple-Input Multiple-Out), Relay station and FBS (Femtocell Base Station). FBS is lately proposed to solve the indoor coverage problem, and has attracted industry and academic research because of its economical and efficient performance [3].

Statistics show that 2/3 of the voice business and more than 90% of the data services happen in doors, and 45% of households and 30% of enterprises have indoor coverage problems. With the increasing users and high data rate services, solving the indoor coverage problem is an important topic of the operators to ensure the service quality. According to the frequency planning, LTE-A system uses about 2GHz and higher frequencies, so the wireless signal penetration is bad. In the buildings with good shielding exterior wall, the signal will greatly attenuate, resulting in poor indoor coverage, shadow area and even blind area. Moreover, due to the base station is generally constructed in a higher position, multiple base station signals get indoors through refraction, reflection and diffraction, making the signals sometimes strong and sometimes weak with serious adjacent frequency interference. The emergence of the Femtocell provides new

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opportunities for operators to solve the indoor coverage problem, and it is more efficient in cost compared with other schemes [4].

This paper proposes a distributed non-uniform pricing power control algorithm. It firstly introduces the LTE-A two-tier network, its interference model and the Game theory. Then, we make reasonable assumptions based on the current researches and the system model is simulated. According to the system model features, Stackelberg Game model is applied, and DNP (distributed non-uniform pricing) algorithm is further derived. Lastly, the simulation platform is built to verify the algorithm performance.

2. Two-tier Network and Game Theory

2.1. Two-tier Network Introduction

Two-tier network refers to directly deploy FBSs in the area covered by MBS (Macrocell Base Station), as shown in Figure 1. FBS is a kind of small base station with low price, low power consumption, flexible deployment and self-organization characteristics. It is generally connected to operator core network via wired network. When the effective spectrums are deployed in the same channel, a large number of Femtocell break the original network structure, thus resulting in interference scenarios in the macrocells.

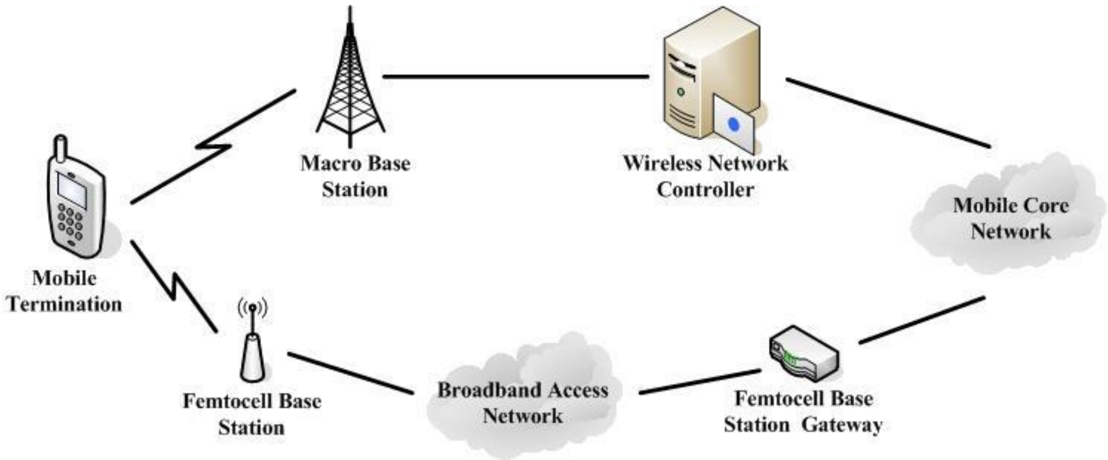

Figure 1. Two-tier Network Deployment Diagram

FBS includes all the functions necessary to a base station, RNC (Radio Network Controller) and core network elements also included. It can be connected to the Internet through DSL or means, and further connected to the core network of the operators. As to the channel deployment, it can be divided into public channel deployment and private channel deployment. The former refers to the FBS and MBS share the channel, which has high spectrum efficiency but serious interference; The latter refers to FBS has its private channel, which reduces the interference but has low spectrum efficiency. As to the access control, FBS has three user access methods: enclosed, open, and hybrid [4]. Only FBS authorized users can access to the family network is known as the enclosed access way; In contrast, all users authorized by the operators can access to any FBS network is known as the open access way; Hybrid access method is a compromise for the above two ways: FBS allows all users to access, but the priority of some specific users are higher than other users. This paper applies the public channel deployment and enclosed access method.

2.2. Interference Model of Two-tier Network

FBS is directly deployed on the original cell, which affects the network topology structure. The network becomes a two-tier network composed of marcocell and Femtocell.

To improve the spectrum efficiency and indoor coverage, Femtocell can be randomly deployed in the macrocell, and share channel with MBS. However, it brings a new problem, interlayer interference and inner layer interference. Before putting forward the interference avoidance scheme, the interference model in the two-tier network should be analyzed [5].

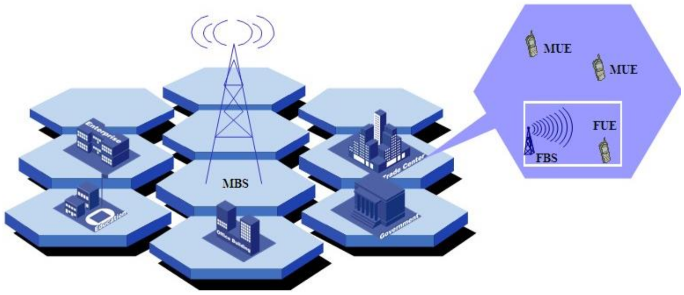

Figure 2. Femtocell Base Station Deployment Scenario

Figure 2 shows an intuitive system deployment scenario. Under the public channel deployment condition, FBS and FUE (Femtocell User Equipment) are covered by MBS, and parts of MUE (Macrocell User Equipment) are also covered by FBS. According to the interference source, victim, interference type and transmission mode, the interferences can be divided into 6 types, as shown in Table 1.

Table 1. Interference Type

Interference Source	Victim	Interference Type	Transmission Mode
MBS	FUE	Interlayer Interference	Downlink
MUE	FBS	Interlayer Interference	Uplink
FBS	MUE	Interlayer Interference	Downlink
FUE	MBS	Interlayer Interference	Uplink
FBS	FUE	Inner-layer Interference	Downlink
FUE	FBS	Inner-layer Interference	Uplink

2.3. Game Theory

Game theory, also called as countermeasure theory, is an important branch of applied mathematics. It mainly researches the decision-making process and the equilibrium problem of the parties when the interaction happens between two or more parties and any party's decision strategy cannot be completely independent of the other parties. Game theory has four elements [6]:

- Game Player.
- Game Strategy.
- Game Utility.
- Game Equilibrium

The players choose their own strategy, and the strategy brings utility. The final outcome of Game is to achieve equilibrium state. The types of Game can be divided into complete information Game and incomplete information Game according to the master degree of information, and also can be divided into static Game and dynamic Game according to the decision sequence. The Game theory for different scenarios has been more and more perfect, such as non-cooperative Game, cooperative Game, Bayes Game, and so on.

2.4. Stackelberg Game Theory

In non-cooperative Game, there may be grades between the players, and some players make decisions before others. In this condition, these players will impose their own strategies to others, thus making them in a strong position. Players in the strong position are called as leaders, and other players are called as followers. In some cases, multiple leaders and multiple followers participate in the Game.

Assume a two-person non- cooperative Game, one person is the leader, and other is the follower. S_1 and S_2 represent for their strategy sets. According to the above definition, after the leader make strategy, $s_1 \in S_1$, the follower can make the corresponding strategy, $s_2 \in S_2$, based on s_1, and strategy s_2 is made according to :

$$u_2(s_1, s_2) \geq u_2(s_1, t) \ \mathrm{t} \in S_2 \quad \text{(Equation 1)}$$

in which s_2 is called as optimal response of the follower to the strategy of the leader, and accordingly, S_2 is called as the optimal responses set.

As for the given $s_2 \in S_2$, it satisfies:

$$u_1(s_1^*, s_2) \geq u_1(s_1, s_2) \quad \text{(Equation 2)}$$

as for s_1^*, the optimal response is s_2^*, so we call (s_1^*, s_2^*) as an equilibrium solution to Stackelberg Game, also called as SE (Stackelberg Equilibrium) [7].

$$u_1(\mathrm{s}_1^*, \mathrm{s}_2^*) \geq u_1(\mathrm{s}_1, \mathrm{s}_2^*) \ s_1 \in S_1$$
$$u_2(\mathrm{s}_1^*, \mathrm{s}_2^*) \geq u_2(\mathrm{s}_1^*, \mathrm{s}_2) \ \mathrm{s}_2 \in S_2 \quad \text{(Equation 3)}$$

When the optimal response of the follower is unique as for all strategies of the leader, the utility of SE is not lower than the utility of NE (Nash Equilibrium). Stackelberg Game is easy to extend to the situation of a leader and multiple followers, ensuring the optimal response is unique at the same time. In this case, the follower makes strategy according to the strategy of leader and other followers to maximize its utility. This is the model applied coming up in this paper.

3. Power Control Model in Two-tier Heterogeneous Network

3.1. Research Background

Many interference cancellation schemes have been proposed for Femtocell deployment network, including spectrum allocation, power control and a combination of both.

In literature [8], Yi Wu et al. put forward a kind of spectrum allocation scheme. It divides the spectrum into macrocell private spectrum and public spectrum of MBS and FBS to reduce the uplink interlayer interference. In literature [9], the author puts forward a scheme based on pilot frequency detection to access FBS into the channel not used by the MUEs and abandon the channels with strong pilot signals. This scheme cancels both interlayer and inner-layer interference at the same time. In the literature [10], the author proposes a theoretical framework based on OFDMA in order to reduce the downlink interference. It applies the central controller for dynamic spectrum allocation after FBS clumping. Literature [11] gives a kind of interference coordination algorithm to improve the energy efficiency. FBSs are classified into different groups according to their geographical locations, and enter the low power operating mode when they do not need to run.

Power control is considered to be another effective way, and this paper focuses on the power control method based on Game theory. There have been a large number of researches on spectrum sharing scenario. In literature [12], Inosha Sugathapala and Nandana Rajatheva propose a capacity and power optimization algorithm for Femtocell deployment in OFDMA network. The authors present a non-cooperative Game model, in which the utility function is the capacity optimization function based on pricing. This algorithm can gain high uplink speed, but it needs too much information interaction and broadcasting. In literature [13], Qian Li, et al. proposes a distributed power control algorithm to solve the downlink interlayer interference problem. The authors plan the problem into the non-cooperative Game model, and prove it a super Model with Nash equilibrium while ignoring the inner-layer interference. Literature [14] plans a super Game which applies the de-centralization power control algorithm with unified pricing and designs a pricing function to ensure the fairness and avoid interference. Literature [15] puts forwards an algorithm based on Stackelberg model to maximize the utility of MBS and FBS. The algorithm provides both unified pricing and non-unified pricing schemes. The drawback of the algorithm is that there are too many operations on MBS and too many interactions between MBS and FBS.

3.2. System Model in Intensive Deployment Scenario

Intensive deployment scenario is one of the most important deployment scenarios for LTE-A two-tier network. In commercial or residential areas with high population density, a large number of users start the service requirements at the same time, so these areas need to deploy FBS to solve the poor indoor coverage problem. The deployment of FBS has influences on the original MBS, but due to the small power of user devices and the serious wall penetration loss, this paper ignores the uplink interference and considers the downlink interference only.

Assume that N FBSs are deployed in the coverage of a MBS: to simplify the analysis, we ignore the interferences between FUE and assume a FBS is applied by a FUE. MUEs are distributed evenly in the coverage of MBS and FBS (FBS is assumed as enclosed and share the public channel in this paper). Assume the system bandwidth is B, and the system RB (Resource Block) is N_{RB}. According to Shannon formula, the total throughput, r_i, of the ith FBS, FBS_i, is:

$$r_i = \frac{B}{N_{RB}} \sum_{m=1}^{N_{RB}} \log_2 \left(1 + \frac{p_{i,m}.H_{i,m}}{\left(\sum_{j=1, j\neq i}^{N} p_{j,m}.H_{j,m} + \frac{N_0.B}{N_{RB}}\right)}\right) \qquad \text{(Equation 4)}$$

in which $p_{i,m}$ and $p_{j,m}$ represent for the transmission power of FBS_i in the ith RB, RB_i, and the jth RB, RB_j. $H_{i,m}$ and $H_{j,m}$ represent for the channel gain of FBS_i in FUE_i and FUE_j. N_0 refers to the power spectral density of white Gaussian noise.

4. Stackelberg Planning and Equilibrium

4.1. Stackelberg Game Problem Planning

In two-tier network, the transmit power of FBS must be large enough to meet the QoS requirements. However, too large transmit power results in interlayer and inner-layer interferences, which in turn influences the MBS and FBS device performances. So the system should find a transmit power balance, both to satisfy the QoS requirement and reduce the interferences. According to the two-tier network characteristics, Stackelberg Game model is applied to solve this problem. As introduced above, Stackelberg Game model is a kind of non-cooperative Game model, in which some strong players are leaders and other weak players are followers. Leaders firstly make strategies, and then the followers make strategies according to the leaders' strategies.

This paper takes the central MBS as the leader and FBSs as the followers to construct the Stackelberg Game model with a single leader and multiple followers. In the Game, the leader gets its own utility by selling the power quota. As the different FUEs require different transmit powers with different interferences, it is more reasonable to apply different pricing means for different FBSs. With different pricing means, FBSs reduce the unnecessary transmit power and reduce the interlayer and inner-layer interferences with the QoS requirements of different FUEs satisfied, thus improving the whole network performance.

As planned above, the object of MBS, the leader, is to maximize its own utility by selling the power. The limitation of MBS is that the pricing factor cannot be much too high, making the transmit power too low to meet the QoS requirements, which can be expressed as:

$$Problem1: \quad \max U_{MBS}(\boldsymbol{\lambda}, \mathbf{p}) = \sum_{i=1}^{N} (\lambda_i . p_i) \quad \text{(Equation 5)}$$

$$p_i = \sum_{m=1}^{N_{RB}} p_{i,m} \quad \text{(Equation 6)}$$

$$s.t. \quad r_i \le \beta_i . R_i \quad \text{(Equation 7)}$$

In equation 5, $\boldsymbol{\lambda} = [\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_N]$ represents the power price vector of N FBSs, in which λ_i refers to the power price of FBS_i. $p = [p_1, p_2, p_3, \ldots, p_N]$ represents the transmit powers of N FBSs, in which p_i refers to the transmit power of FBS_i in the whole bandwidth, which is calculated with equation 6. In equation 7, r_i represents the throughput of FBS_i, which is calculated with equation 4. R_i represents the data rate request of FUE_i, and β_i is an adjustment factor about the fairness, which is a little larger than 1 and will be explained in details below.

Then consider the followers: FBSs need sufficient throughput, while pay the price for the potential interferences caused by power. For any FBS_i, the utility function can be defined into two parts: income and outcome. Income is the throughput obtained by FBS, and outcome is the linear function proportional to the power, namely the power multiplied by the pricing factor. As for each FBS, it can choose the optimal transmit power to maximize its own utility. Taking FBS_i as example, it can be expressed as:

$$Problem2: \quad \max U_{FBS_i}(\lambda_i, p_i) = r_i - \lambda_i . p_i \quad \forall i \quad \text{(Equation 8)}$$

$$s.t. \quad p_i \ge 0 \quad \text{(Equation 9)}$$

With Problem1 and Problem2, Stackelberg Game model with one leader and multiple followers is constructed. The SE problem will be discussed in the following section.

4.2. Stackelberg Equilibrium

The SE of Stackelberg Game is: as for both the leader and the followers, no one can gain its utility by changing its own strategy independently, which can be expressed as:

$$U_{FBS_i}(\lambda_i^*, p_i^*) \ge U_{FBS_i}(\lambda_i^*, p_i) \quad \forall i \quad \text{(Equation 10)}$$

$$U_{FBS_i}(\lambda_i^*, p_i^*) \ge U_{FBS_i}(\lambda_i^*, p_i) \quad \forall i \quad \text{(Equation 11)}$$

in which $\boldsymbol{\lambda}^* = [\lambda_1^*, \lambda_2^*, \lambda_3^*, \ldots, \lambda_N^*]$ represents the optimal power price vector of N FBSs, in which λ_i^* refers to the optimal power price of FBS_i. $\mathbf{p}^* = [p_1^*, p_2^*, p_3^*, \ldots, p_N^*]$ represents the transmit power vector of N FBSs, in which p_i^* refers to the optimal transmit power of FBS_i.

Given a price λ_i of FBS_i, we firstly solve the optimal response. By simple calculation, it can be obtained that the utility function $UFBS_i$ is a concave function for $p_{i,m}$. Solve the first and second derivative as for $p_{i,m}$, as shown in equation 12 and 13:

$$\frac{\partial U_{FBS_i}}{\partial p_{i,m}} = \frac{\frac{B}{N_{RB}} H_{i,m}}{\ln 2 \cdot (IN_{i,m} + p_{i,m} H_{i,m})} - \lambda_i \quad \text{(Equation 12)}$$

$$\frac{\partial^2 U_{FBS_i}}{\partial p_{i,m}^2} = \frac{-\frac{B}{N_{RB}} H_{i,m}^2}{\ln 2 \cdot (IN_{i,m} + p_{i,m} H_{i,m})^2} < 0$$ (Equation 13)

$$IN_{i,m} = \sum_{j=1 \neq i}^{N} p_{j,m} . H_{j,m} + \frac{N_0 \cdot B}{N_{RB}}$$ (Equation 14)

Equation 14 represents the total interference of FBS_i in RBm. Set the first derivative, equation 12, as zero, the optimal transmit power of FBS_i in RBm, $p^O_{i,m}$, can be obtained with the given power price, λ_i, as follows:

$$p_{i,m}^O = \frac{\frac{B}{N_{RB}}}{\lambda_i \cdot \ln 2} - \frac{IN_{i,m}}{H_{i,m}} \geq 0$$ (Equation 15)

Substitute equation 15 into Problem1, it can be transferred into:

$$\max \sum_{i=1}^{N} \lambda_i \left(\sum_{m=1}^{N_{RB}} \left(\frac{B}{N_{RB} \cdot \ln 2 \cdot \lambda_i} - \frac{IN_{i,m}}{H_{i,m}} \right) \right)$$ (Equation 16)

$$s.t. \quad r_i \leq \beta_i \cdot R_i$$ (Equation 17)

Decompose equation 16 and 17 into N sub-problems, as follows:

$$L(\lambda_i, p_i, \mu_i) = f(\lambda_i) + \mu_i (r_i - \beta_i \square R_i)$$ (Equation 18)

The sub-problems can be solved by Lagrangian method. Take FBS_i as example, its Lagrangian function is:

$$L(\lambda_i, p_i, \mu_i) = f(\lambda_i) + \mu_i (r_i - \beta_i \square R_i)$$ (Equation 19)

in which is the Lagrange multiplier.

Substitute equation 15 into equation 4, the throughput can be transferred into a function only related with λ, as follows:

$$r_i(\lambda_i) = \frac{B}{N_{RB}} \sum_{m=1}^{N_{RB}} \log_2 \left(\frac{B}{N_{RB} \ln 2} \frac{H_{i,m}}{IN_{i,m}} \right) - B \log_2(\lambda_i)$$ (Equation 20)

Then a variable, p, in the Lagrangian function can be eliminated, thus equation 19 can be simplified to be:

$$L(\lambda_i, \mu_i) = f(\lambda_i) + \mu_i [r_i(\lambda_i) - \beta_i R_i]$$ (Equation 21)

To get the optimal power price, solve the partial derivative respectively on λ_i and μ_i. Then set the two formulas as zeroes to get a system of linear equations with two unknowns, and the following results can be obtained:

$$\lambda_i^* = 2^{v_i}$$ (Equation 22)

$$v_i = \left(\frac{B}{N_{RB}} \sum_{m=1}^{N_{RB}} \log_2 \left(\frac{B / N_{RB}}{\ln 2} \frac{H_{i,m}}{IN_{i,m}} \right) - \beta_i R_i \right) / B$$ (Equation 23)

in which β_i is an adjustment factor, which is a protection for users with poor channel conditions. It fudges on part of QoS requirements to enhance the transmit power and improve the whole network fairness, which can be calculated as follows:

$$\beta_i = \begin{cases} \beta^*, & \sum_{m=1}^{N_{RB}} IN_{i,m} \geq IN_{th} \\ 1, & others. \end{cases}$$ (Equation 24)

in which β^* is the upper limit of the adjustment factor, β_i. INth is the interference threshold, which can be obtained by the central MBS broadcasting.

So far, all the sub-problems of FBS_i are solved, and the Stackelberg equilibrium, (λ_i^*, p_i^*), is obtained. After all the sub-problems of FBSs are solved, each FBS adjusts the transmit power, resulting in lower interferences of each FBS generally. Then the FBSs start a new adjustment, and will reach a steady state after several iterations.

4.3. DNP Algorithm

Based on the analysis in Section 4.2, we propose a distributed non-uniform pricing (DNP) algorithm. DNP mainly includes two sections: the calculation of transmit power and the calculation of power price. It realizes the above Game with the distributed method, including network initialization; transmit power setting, convergence of iteration and new FBS connecting to the network. It can be divided into four steps:

- Step 1: In the initialization process, the central MBS should broadcast some necessary parameters, such as β^* and IN_{th}, and the receivers are all FBSs in work. As for each active FBS_i, it calculates its β_i based on the received information and the channel state with Equation 24. Also, it sets the transmit power as the maximum value and distribute it randomly in the whole RB.
- Step 2: As for each active FBS_i, its power pricing can be calculated locally with Equation 22 and 23. The central MBS doesn't participate in the calculation, which greatly reduces the deployment difficulty and reduces the load delay of the signals.
- Step 3: Repeat Step 2 until Stackelberg Game reaches a steady state. In order to increase the convergence speed, its accuracy can be appropriately reduced.
- Step 4: As for the new FBS, it requests the initialization information by sending information to MBS, and realizes Step 3 after initialization.

5. Algorithm Simulation and Results Analysis

The simulation platform in this paper is established according to E-UTRAN physical layer standard [16], in which MBS applies the urban model, and FBSs are deployed in the coverage of MBS. The whole system simulates the intensive deployment scenario in city. Table 2 and 3 shows the parameters of base stations and users.

Table 2. Base Station Parameters

Parameter	Value	Parameter	Value
Carrier Frequency	2.0GHz	Cell User Numbers	10
Bandwidth	10MHz	FBS Antenna	Omnirange
Distances between Cell Centers	500m	Shadow Standard Deviation (FBS/MBS)	8dB/4dB
Cells Number	7	Antenna Gain	14dBi/5dBi
MBS Transmit Power	46dBm	Correlation of Shadow Fading	Cells Number: 0.5
FBS Transmit Power (Maximum, Minimum)	20dBm /0dBm		Sector Interval: 1

Table 3. User Side Parameters

Parameter	Value	Parameter	Value
Movement Speed	3km/h	Antenna Gain	0dBi
Antenna Number	2	Thermal Noise Density	-174dBm/Hz
Antenna Type	Independent	The Minimum Distance to MBS	35m
Penetration Loss	20dB		
Noise Coefficient	9dB	Sprinkle Method	Randomly Sprinkle

This paper verifies the performance of DNP algorithm from three aspects: cutting off rate of MUE, spectrum effectiveness of FBS and Fairness of FUE, which are compared with two power control methods:

- Without Power Control [17], short for Without PC, namely each FBS transmit in the maximum power.
- MUE-Protected [18], namely the transmit power is determined by the target SNR (Signal-to-Noise Ratio) of the FUEs. It is calculated as:

$$P_{FUE\_received} = 10\log_{10}(10^{I/10} + 10^{N_{noise}/10}) + x \quad \text{(Equation 25)}$$

$$P_{FBS} = \max(P_{\min}, \min(PL_{estimation} + P_{FUE\_received}, P_{\max})) \quad \text{(Equation 26)}$$

in which I represents the interference of FUE, N_{noise} represents the environment noise, x represents the target SNR of FUE, $PL_{estimation}$ is the estimated path loss between FBS and FUE, P_{max} and P_{min} respectively represent for the maximum transmit power and minimum transmit power of FBS.

5.1. Cutting Off Rate of MUE

Cutting off rate of MUE reflects the interferences of MUE. Figure 3 shows the simulation results of three methods, in which FDR represents for Femtocell deployment ratio. As Figure 3 implies, the cutting off rate increases with the increase of MUE indoor distribution. It is because that the resource competition becomes more intense and the interference is more serious with increasing users and limited wireless resources.

The performance of DNP algorithm is between Without PC and MUE-protected. Without PC applies the maximum transmit power, the interlayer inference of FBS makes the SNR of MUE decrease, so it has the worst cutting off rate. MUE-protected is designed mainly to protect the MUE performance, so it has the best cutting off rate. DNP algorithm in this paper considers the QoS of FUE, which decreases the interference of MUE while avoiding the transmit power dropping too low.

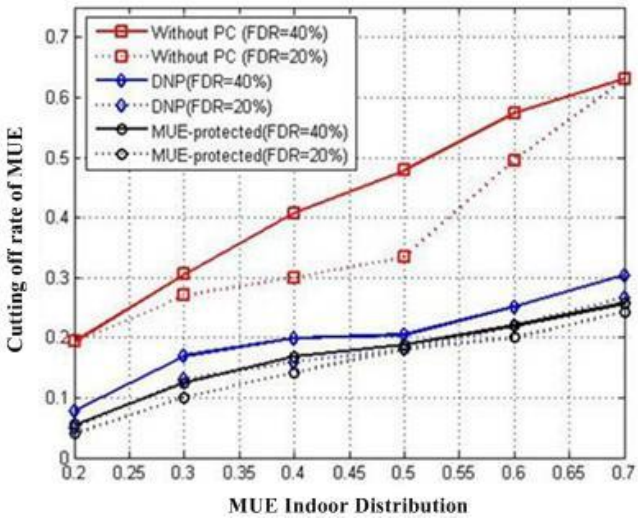

Figure 3. Cutting Off Rate of MUE of Three Methods

5.2. Spectrum Effectiveness of FBS

Spectrum effectiveness of FBS is an important measurement of network performance, which refers to the throughput obtained by the unit spectrum bandwidth.

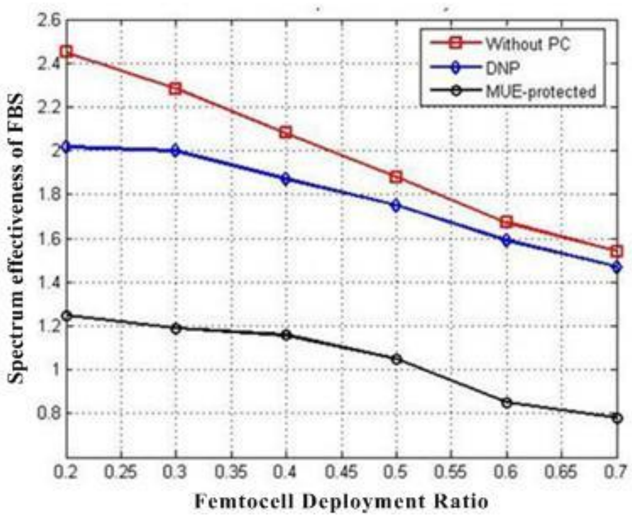

Figure 4. Spectrum Effectiveness of FBS of Three Methods

Figure 4 shows the simulation results of three methods, in which the FBS throughput of Without PC is the largest, while the FBS throughput of MUE-protected is much smaller than the other two. Without PC applies the maximum transmit power, making it have the largest throughput, at the expense of user performance, as analyzed in Section 5.1. The spectrum effectiveness of DNP algorithm gradually closes to Without PC when FDR is large. It is because that the inner-layer interference becomes more serious with the increase of FDR, while DNP algorithm can effectively reduce the inner-layer interference, and ensure the QoS of FUE at the same time.

5.3. Fairness of FUE

In order to evaluate the fairness of three methods, SFF, Satisfaction & Fairness Factor, is introduced. We firstly calculate the satisfaction of each FUE as follows:

$$S_i = \frac{r_i}{R_i} \qquad \text{(Equation 27)}$$

And SFF can be calculated as:

$$SFF = \frac{(\sum_{i=1}^{N} S_i)^2}{N \cdot \sum_{i=1}^{N} {S_i}^2} \qquad \text{(Equation 28)}$$

If all the data request rates of FBS are equal, SFF can be expressed as FF, Fairness Factor, as follows:

$$\text{FF=}\left(\sum_{i=1}^{m} R_i\right)^2 \Big/ \left(m\sum_{i=1}^{m} {R_i}^2\right) \qquad \text{(Equation 29)}$$

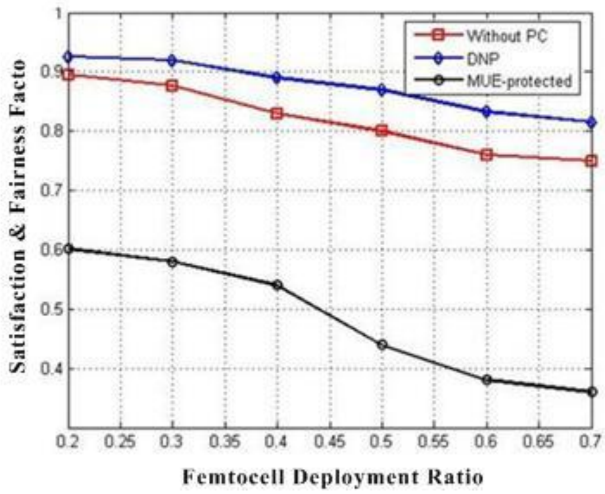

Figure 5. SSF of Three Methods

As shown in Figure 5, SFF reduces the increase of FDR in three methods, and the performance of DNP is the best. It is because that DNP considers the data request rate of FUE, and also introduces β to protect users with bad wireless channels, thus improving their QoS request by adjusting β.

6. Conclusions

This paper applies Stackelberg Game model to solve the power optimization problem in LTE-A network. It takes the central MBS as the leader and FBSs as followers. The leader gets its own utility by selling the power quota. Different FBSs apply different power pricing methods, so they try to reduce the unnecessary transmit power, thus reducing the interferences and improving the network performance. Then the Stackelberg equilibrium is analyzed to obtain the optimal power distribution and pricing way. Based on it, a distributed non-uniform pricing algorithm, DNP, is proposed for Femtocell base station deployment. It realizes the distributed deployment with low complexity and less information interaction, and also shows a good performance through simulation.

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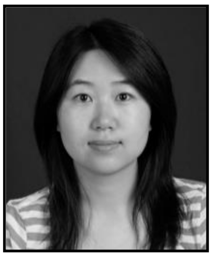

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