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Utilization of Framework for Wireless Service Providers in Hybrid Access

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Abstract: Femtocell technology addresses the problem of poor indoor coverage, benefiting both wireless service provider (WSP) and end users. With the founding of the femtocell, the cross- tierkumar interference between macro link and Femto link becomes a major factor which greatly affects the network performance. Different access control approaches, by generating different interference patterns, also severely affect the overall throughput of the network and need to be carefully investigated. Among all the access control mechanisms, hybrid access is the most promising one, which allows roaming unregistered users (referred to as macro users) to access the nearby Femto base station (BS) while reserving certain resource for registered home users (referred to as Femto users), improving overall network capacity. However, to successfully leverage hybrid access is challenging because the Femto holders (FHs) are selfish, unwilling to share their Femto facilities and spectrum resource with macro users without any incentive mechanism. In this paper, we propose a novel utility-aware refunding framework to motivate hybrid access in femtocell. Within the framework, both WSP and FHs are assumed to be selfish, and target at maximizing their own utilities. WSP provides certain refunding to motivate FHs to open their resource for macro users. FHs decide the resource allocation among Femto and macro users according to the amount of refunding WSP offers. Under this framework, the optimal strategies of both WSP and FHs are analyzed by formulating the problem as a Stackelberg Game. A unique Nash Equilibrium is achieved and a hybrid access protocol is designed according to the analysis. Extensive simulations have been conducted and the results show that the utilities of both WSP and FHs are significantly improved exploiting the hybrid access mechanism.

Keywords: Femtocell, Hybrid Access, Refunding Framework, Stackelberg Game.

I. INTRODUCTION

By shortening the distance between base stations and end users, femtocell provides increased data rate and better indoor coverage. The minuscule size of femtocell also improves spectrum reuse, which leads to higher spectrum efficiency. Femtocell technique offers WSP an exciting and promising market. On the one hand, the enhancement of indoor service quality increases WSP's competitive edge by reducing the churn rate (the probability of users leaving the network) of macro users. On the other hand, WSP may transfer some traffic from expensive macro cell to the low-cost femtocell. In this way, more users can be served with existing macro cell infrastructure. Femtocell also benefits end users from various aspects. Users can enjoy better-performance, high-speed 3G voice and data services through femtocell. Compared with existing WI-Fi technology, femtocell operates on licensed spectrum with guaranteed quality of service (QoS) and users do not have to have a dual-mode mobile phone. Due to the above mentioned benefits, a number of WSPs around the globe have already launched their Femto products. On March 24th, AT&T released 3G Micro Cell, its first femtocell. In the UK, Vodafone offers its users with Femto device called Sure Signal. Nevertheless, femtocell still faces several fundamental technical and commercial challenges which haven't been well addressed.

The co-existence of femtocells and macro cells introduces cross-tier interference between concurrent Femto transmissions and macro transmissions, which severely affects the overall network performance. The choice of access control mechanism in femtocell is crucial, because it determines whether a user can access a nearby Femto BS or not, thus ascertaining the level of interference. There are three

International Journal of Advance Research in Computer Science and Management Studies
Volume 1, Issue 4, September 2013 pg. 40-48

categories of access control mechanisms that have been proposed: closed access, subject access and hybrid access. In case of closed access, only a few Femto users who have been authorized by FHs can leverage Femto BS for transmission, while macro users are not permitted to access the Femto BS. Closed access is easy to implement and control. Besides, privacy and performance of Femto users can be guaranteed.

Consequently, some existing femtocells that have been put into market adopt closed access, such as the Sure Signal of Vodafone. However, closed access suffers from dead-zone problem, which arises because macro users who are far away from macro BS but close to a Femto BS receive strong Femto-macro interference in both uplink and downlink. Open access is just the opposite of closed access, where any wireless users can make use of the Femto BS to transmit data. Open access of femtocell is a good solution for the dead - zone problem. Usually the Femto BSs deployed by WSP as a supplement for macro BS in some rural areas adopt this access control mechanism.

However, lack of access control in case of open access may result in traffic congestion, putting heavy pressure on the backhaul and leading to QoS degradation. As both closed and open access has drawbacks, hybrid access is proposed to exploit the benefit of the two yet overcome their shortcomings. On the one hand, roaming macro users are allowed to employ Femto BSs for transmission with the permission of FHs. On the other hand, hybrid access allows FHs to reserve part of the capacity for their Femto users to ensure their performance. Hybrid access provides improved overall network operation while ensuring the QoS of Femto users. Existing works [2] [3] have shown that hybrid access outperforms closed and open access by greatly reducing cross layer interference and guaranteeing the performance of the Femto users. Due to these benefits, we focus on this kind of access control mechanism in this paper. In spite of all the merits of hybrid access, to boost its adoption is challenging, because FHs have no incentive to share their Femto facilities and spectrum resource with macro users altruistically. Since the capacity of a femtocell is bounded by bandwidth, transmission time, channel condition etc, if a proprietary Femto BS opens to macro users, the utility of Femto users will be lessened because part of the Femto resource is occupied by macro users. So, FHs naturally favor closed access instead of hybrid access, if they cannot get any reward for providing macro users with Femto resource. However, as far as we know, there is no existing work on hybrid access addressing this problem. In this paper, we propose a utility-aware refunding framework that promotes the adoption of hybrid approach. Under this framework, both WSP and FHs are assumed to be rational and selfish entities, which merely care about their own interest. To enhance the overall network performance, WSP is willing to offer a certain amount of refunding to FHs which adopt hybrid access and open their resource for macro users' access. The FHs, with the expectation to obtain refunds, are also willing to open their redundant Femto facilities and spectrum resource to macro users. Consequently, both WSP and FHs have the incentive to exploit hybrid access.

Nevertheless, there are still several questions need to be resolved under this framework. The more refunding provided, FHs are more willing to help with the macro users' transmission. But WSP will lose more money. Second, how should FHs allocate the resource among Femto users and macro users? The more a FH reserve for its Femto users, the better performance the Femto users can achieve, however, the money it receives from the WSP will reduce due to decremented contribution to macro users. Moreover, what's the impact of refunding the amount selected by the WSP on the resource allocation decision made by the FHs? We will answer all the questions by leveraging game theory analysis. We will formulate the refunding framework as a Stackelberg game and analyse the game by reverse induction. The optimal strategies for both WSP and FHs are achieved and a sophisticated protocol based on game theory analysis is designed to help WSP and FHs exchange certain information in order to make right decisions.

The main contributions of the paper are as follows:

1) Proposing a utility-aware refunding framework to motivate both WSP and FHs to be engaged in the hybrid access in femtocell network. As far as we know, it is the first framework that addresses the incentive problem of hybrid access. Within the refunding framework, WSP provides certain refunding to motivate FHs to open their resource for macro users. FHs allocate their resources among Femto and macro users according to the amount of refunding WSP provides. Both WSP and FHs are selfish, targeting at maximizing their own utility by selecting the optimal strategies.

2) Formulating the framework as a Stackelberg game, in which WSP acts as leader and FHs act as followers.

3) Analysing the cooperation and competition relationship between FHs and WSP through different stages of the game. Backward induction is used to obtain the Nash Equilibrium and we prove that the Nash Equilibrium is unique.

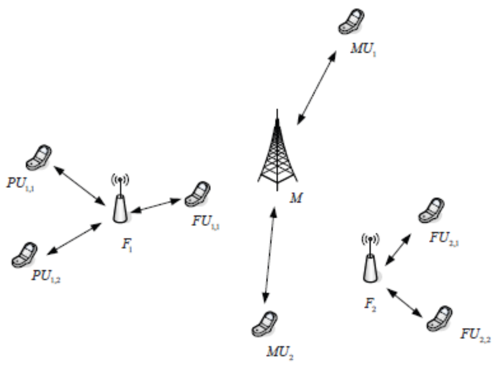
4) Designing a protocol to implement the utility-aware refunding framework. The protocol is based on the game theory analysis, which enables WSP to determine the optimal refunding amount and also allows FHs to decide which access control mechanism to adopt and how to assign transmission time to Femto and macro users in case of hybrid access. By carrying out the protocol, both WSP and FHs can achieve maximum utility.

5) Conducting numerical simulations to evaluate the refunding framework. The results verify that the utilities of both WSP and FHs are notably enhanced, which provides strong motivation for WSP to implement the refunding policy and FHs to adopt hybrid access.

This paper is organized as follows. First, we describe the System Model in section II, The Refunding Framework is proposed in section III, Game Theory Analyse in section IV, We propose a Hybrid Access Protocol in section V, Extensive Simulations are Presented in section VI, We review the Related Work in section VII and finally summarize our work in section VIII.

II. System Model

In this section, we describe the system model of our problem, including network architecture, channel model and basic parameters. Fig.1 depicts a two-tier macro-Femto network, consisting of a macro BS, which is owned by WSP, and a number of Femto BSs, which are possessed by FHs. There are K Femto- BSs in total, denoted by $\{F_i\}_{i=1}^{K}$, and correspondingly their holders $\{FH_i\}_{i=1}^{K}$. A Femto BS can serve multiple users who have been authorized by FH to get access to the femtocell.



Figuere.1 System model for femtocell hybrid access

Let $\{FU_{i,j}\}_{j=1}^{K_{fi}}$ represent the Femto users of Femto BS F_i, in which K_{fi} is the number of Femto users supported by F_i. To guarantee QoS, a Femto BS supports a maximum number of $K_{fi,max}$ Femto users so that $K_{fi} \leq K_{fi,max}$. Macro users who happen to be in the vicinity of a Femto BS hope to transfer their traffic to that Femto BS in order to have higher signal-to-interference ratio (SINR). Assume that there are K_{mi} macro users near F_i who may get permitted to access F_i and $K_{mi} \leq K_{mi,max}$ to avoid traffic congestion. Let $\{MU_{i,j}\}_{j=1}^{K_{mi}}$ denote these macro users. Time division multiple access (TDMA) strategy is utilized for data transmission. Data transmission is divided into frames, which are further divided into time slots. FH_i is in charge of distributing time slots to users who are transmitting through F_i. Each frame consists of two parts, namely the transmission period reserved for Femto users and a transmission period open to passer-by macro users.

III. Refunding Framework

In this section, we propose a utility-aware refunding framework within which WSP hopes to motivate FHs to adopt hybrid access through refunding. By utilizing Femto resource, WSP is able to expand its network capacity and increase user satisfaction. FHs trade spare Femto resource for refunds, improving their utilities on the whole. In this way, a win-win situation establishes between WSP and FHs. Both WSP and FHs are selfish and rational. WSP has a strong wish to get support from Femto BS to aid in macro users' data transmission, especially when there is great traffic demand from macro users and the macro backhaul is under great pressure. Nevertheless, the utility of FHs will diminish if macro users take up the transmission time available for Femto users. Thus, it is impossible for FHs to be so altruistic as to allow macro users to access Femto BSs without any remuneration.

A refunding mechanism can be designed to solve these problems, which enables WSP to compensate FHs who perform hybrid access and spare transmission time to macro users. We assume that WSP puts forward a total sum of m refunding amount, which is further distributed among FHs who open their BS to macro users. As different FHs allow macro users to transmit for different fractions of time α_i within a frame, it is reasonable to split the refunds in the way that the FH who contributes the most time achieves highest refunds and who contributes the least achieves lowest. A simple way is to distribute the refunds proportional to the open time of individual Femto BSs.

The refunds obtained by each FH can be derived as the total amount of refunds multiplies the ratio of individual open time to the sum of open time of all Femto BSs. Larger amount of refunds will stimulate more hybrid access adoption among FHs and yield more benefit for WSP due to capacity expansion and satisfaction improvement of macro users. However, only when such benefit exceeds the refunds itself will it is profitable for WSP to carry out such refunding mechanism. For this reason, further analysis should be conducted to determine the quantity of m in order to come up with the optimal refunding mechanism that generates maximum utility for WSP. Once the refunding amount m is broadcast by WSP, FHs react by making a decision about whether closed access or hybrid access is more favourable and how much time should be contributed by macro users for data transmission if hybrid access is chosen. Based on the refunding policy of WSP, each FH's utility does not only depend on their own behavior but also affected by the decision of other FHs. Given the same αi, if FHj, j _= i chooses a longer open time, FHi gets less refunds, vice versa. Every FH tries to maximize its own utility under this condition.

A. *The Utility Function of WSP*

The utility function of WSP is defined as the benefit from reduced user can rate minus the refunds given to FHs. Poor QoS causes user dissatisfaction, ending up in user switching WSP for better coverage. If Femto BSs are leveraged to increase the capacity of macro BS, WSP is able to provide better QoS; thereby more macro users are willing to stay with the WSP. The Sigmoid function has been widely used for estimating the satisfaction of users with regard to service quality. The churn rate can be expressed as c =11 + e−a (b−λ), where a represents the user's sensitivity towards QoS increment and b is the reserved traffic demands of macro users. λ is the achievable data rate for macro users. It is obvious that $c \in (0, 1)$. If macro users leverage Femto BS for transmission, the achievable data rate λf can be derived as λf =_Ki=1Rm, i + λ0, in which λ0 is the capacity of macro BS. If all Femto BSs are set to closed access, macro users can only transmit through macro BS with a limited capacity λ0. If some Femto BSs share part of the resource with macro users, the achievable data rate increases, resulting in the reduced churn rate of macro users. Since most macro users require voice service, when the capacity provided by Femto BS is already high, further increase in the capacity will contribute little to the decrease of churn rate.

The Sigmoid function can perfectly capture this trend. It can be easily derived that the percentage of macro users who stay with the WSP is 11+e−a(λ−b). The more sensitive users are towards upgraded QoS, the more steeper the churn rate falls when the transmission rate goes up, thus the refunding mechanism will be more effective.

B. *The Utility Function of FH*

The utility function of FHi consists of two aspects: the transmission rate that Femto users have attained and the refunds gained from WSP by opening part of transmission time to macro users. As Femto users mostly demand data service from Femto BSs, the more capacity they can achieve, the more satisfied they will be. So we assume that the utility of FHs is linearly increasing with the transmission rate of Femto users. Uf,i = $wfRf$, i + mi, where wf denotes equivalent revenue the FH receives on one unit transmission rate for Femto users.

IV. Game Theory Analysis

In this section, we formulate the refunding framework as a Stackelberg game, in which the WSP acts as the leader and the FHs act as the followers. We prove that a unique Nash Equilibrium exists in the game, which defines the optimal strategy for the WSP and the FHs. Since both WSP and FHs are selfish and rational entities who target at utility maximization, it is apparent that game theory is the most appropriate tool to analyse the problem. The game should involve two phases, in which WSP initiates the promotion of hybrid access of femtocell by announcing the refunding mechanism and FHs respond to it. Thus, it is reasonable to formulate the process as a Stackelberg game. The Stackelberg game proceeds through two stages. In the first stage, the WSP attempts to maximize its utility by selecting best refunding amount, being aware of the influence of its own decision on the behaviour of FHs. The refunding amount is then broadcast to all FHs. In the second stage, based on the information on refunding amount, every FHs determines concurrently what access control mechanism is more beneficial and how to distribute transmission time between macro users and Femto users to achieve maximum utility for itself. As FHs are selfish and rational players who independently make decisions and are concerned about self-interest only, we use non-cooperative game to analyse their behaviour. We use a backward induction method, a common tool to study the Stackelberg game. To begin with, we show that in the non

International Journal of Advance Research in Computer Science and Management Studies
Volume 1, Issue 4, September 2013 pg. 40-48

cooperative game among FHs, there exists Nash Equilibrium which is further proved to be unique. Then, we give the optimal refunding strategy for WSP based on the analysis of non-cooperative game among FHs.

A. Non-Cooperative Access Control Mechanism Selection Fame of FHs

We first analyse the decision making process of FHs. The utility of a specific FH does not only depend on its own choice but also subjects to the behavior of other FHs. Given other FHs' decision, an FH makes effort to seek for the best response that maximizes its utility. The non-cooperative access control mechanism selection game (NAMG) among FHs can be expressed in normal form as $G = (\{FHi\}, \{Ai\}, \{ui(\cdot)\})$. $\{Ai\}$ is the pure strategy space of FHi, which corresponds to $0 \leq \alpha i \leq 1$. When FHi chooses the closed access, αi is simply set to be 0. Therefore, the joint set of the strategy space of K FHs is $A = A1 \times A1 \times ... \times AK$. We denote the pure strategy space of FHs that are competitors of FHi as $A-i = A \backslash Ai$. $\{ui(\cdot)\}$ is the set of utility function that FHs want to maximize. Given the strategy $\alpha - i$ of all its components, FHi always chooses the strategy αi that can yield maximum utility, namely αi = arg max $0 \leq \alpha i \leq 1 ui(\alpha i, \alpha - i)$. This strategy is often called the best response of FHi. In a non-cooperative game, FH has no incentive to deviate from their best response because any variation will decrease the utility.

Proposition 1: Given α−i, the best response of FHi is We can see from (9a) that under certain circumstances, the best response of FHi is αi = 0, indicating that FHi cannot get higher utility by exchange femto resource for refunds so FHi chooses closed access. Therefore, macro users around Fi can only leverage macro BS for transmission. When αi > 0, it is more beneficial for FHi to adopt hybrid access, in this case, the best response αi is not only related to the condition of Fi but also dependent on the decision of other FHs, i.e., the choice of αj, j _= i. than zero so that ui is concave in αi. If K_j_=iαj < mwfCf,i,maximum ui can be achieved when the first derivative of ui with respect to αi equals zero. However, if K_j_=iαj > mwfCf,i,ui monotonically decreases as the open time αi increases. In this case, the best strategy for FHi is to adopt a closed access and exclusively serves the Femto users. If every FH employs the best response with regard to other FHs' decisions, no FHs have motivation to alter their strategy unilaterally. In this case, the NAMG reaches the Nash Equilibrium.

Proposition 2: There exists a unique Nash Equilibrium for NAMG and the optimal open time for FHi.

Proof: In order to achieve the Nash Equilibrium, every FH must adopt their best responses. Otherwise, there will be FH who has intention to adjust its strategy for higher utility Jointly consider the best response of every FH, that is, sum up all the K equations regarding each FH, we obtain A∗ =(K−1)mwfK_j=1Cf,i. Then we can easily calculate α∗i for each FH.

B. Utility Maximization for WSP

Once the WSP declares the refunding amount m, the FHs react by choosing access control mechanism and distributing transmission time among Femto and macro users. As the leader of the game, WSP is aware of the impact of refunding amount m on FHs' choice. Taking into consideration the possible response of FHs, WSP is able to derive optimal refunding amount m to procure maximum utility. When the NAMG of FHs reaches Nash Equilibrium, the utility of WSP can be further derived as respect to m is always negative so Uwsp is concave on m. We can get optimal m by assigning the first derivative of Uwspto is 0. When B > 12 (1 + e−ab), it can be easily proved that m∗ > 0. WSP gets maximum utility as U∗wsp = Uwsp(m∗). If it is actually that λ0 < ln 2 a +b, We can derive from (19) that as m increases, Uwsp falls down at the beginning, then at a certain point, Uwsp starts to go up and at last, Uwsp becomes a decreasing function. In this case, the maximum Uwsp can be achieved either in the local maximum point in (17) or the boundary when m equals zero. When m = 0, namely there is no refunding policy, no FHs are willing to contribute part of the transmission time to macro users free of charge. WSP can only leverage macro BS for data transmission, which yields utility U0 = wm1+e−a(λ0−b). If U0 > Uwsp(m∗), the refunding framework is not feasible because WSP is unable to raise its utility and has no incentive to put forward the refunding mechanism.

V. HYBRID ACCESS PROTOCOL

In this section, we propose a protocol for WSP to implement the refunding mechanism to promote hybrid access in femtocell networks. The protocol enables the WSP to dynamically adjust the refunding amount m and the FHs to respond to what they have observed through access control mechanism selection and open time determination. The protocol is designed based on the Stackelberg game analysis. By applying the protocol, WSP and FHs are able to get maximum utility. Since the proposed refunding framework is based on static game, WSP and FHs reach Nash Equilibrium in only two steps. Once the external wireless environment changes, WSP and FHs can also quickly adapt their strategy to re-reach Nash Equilibrium. According to the game theoretical analysis, both the optimal refunding for WSP and the choice of access control mechanism for FHs are determined by two kinds of factors: • Independent factors. For instance, w_f, w_m, K, b, a, which are either common knowledge or can be estimated through data mining on historical collected data or investigation, generally speaking, these parameters are relatively static and tend to stay the same over a long period. • Interdependent factors. For WSP, to compute the optimal refunding m, the aggregated achievable data rate of macro and femto users transmitting through every femto BS, i.e. $C_{m,i}$, $C_{f,i}$, must be procured. The transmission rate depends on the transmission power, the channel condition and the position of the user. As the channel condition changes dynamically, these two parameters may fluctuate dramatically, strongly affecting the decision made by WSP. In order to figure out the accurate optimal refunding amount $m*$, WSP should periodically collect information about the entire network of both macro cell and femtocell, possibly with the help of FHs. For FHs, their strategies are determined by K_j=1Cf, j and the total refunding amount m. Although FHs choose the access control mechanism in a distributed way and private information about individual FHs should not be disclosed, statistics in terms of the entire network, in particular K_j=1Cf, j , can be proffered to FHs to help them make decisions. The protocol consists of two parts: Optimal Refunding for WSP and Access Control Mechanism Selection for FHs. It enables WSP and FHs to interact with each other to realize the hybrid access.

<u>Optimal Refunding for WSP</u>

• Each femto BS periodically collects information about the channel condition of femto users it support and macro users within its coverage; Then, they piggyback the gathered information of channel condition $\eta_{f,ij}$, $\eta_{m,ij}$ on the data frame to WSP through the broadband line.

• With the information from FHs, WSP is able to compute $C_{m,i}$, $C_{f,i}$. WSP first checks whether conditions are satisfied. If not, it is unprofitable for WSP to run refunding policy, thus m = 0; If conditions are satisfied, WSP computes the best refunding amount m, which yields highest utility for itself.

• WSP broadcasts the refunding amount m to FHs. • FHs who have chosen hybrid access decide the fraction of transmission time α_i that will be open for macro users.

• Further scheduling among macro and femto users supported by each femto BS is performed by its holders.

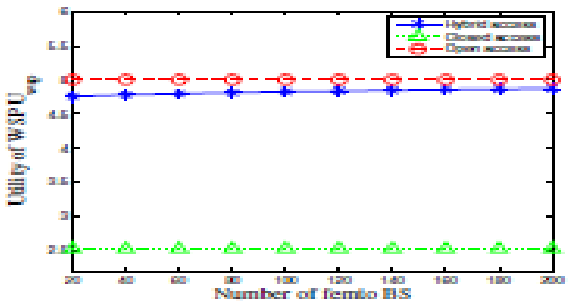


Figure.2 Utility of WSP versus number of femto BS.

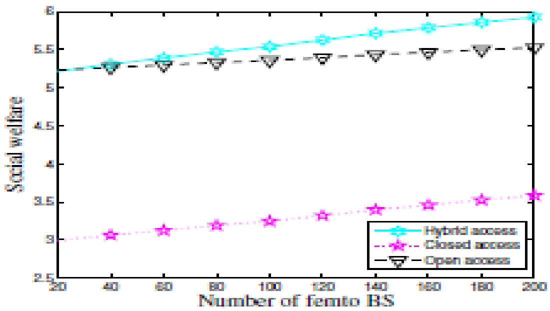


Figure.3social welfare versus femtocell BS

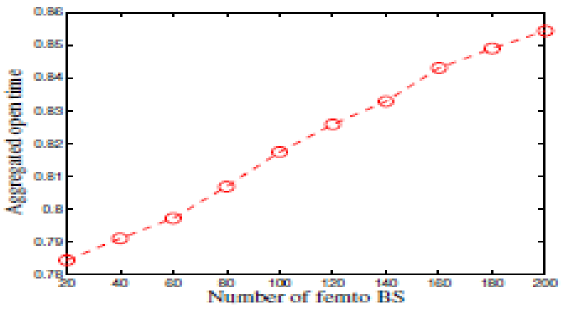


Figure 4 open time versus number of femto BS

VI. SIMULATION RESULTS

The simulation settings are as follows: There are a total number of 100 Femto BSs owned by different FHs. The targeted data rate of Femto users of each Femto BS follows a Gaussian distribution with mean 10 and variance 1. The data rate that FHs offered macro users once these users are permitted to access Femto BSs follows a Gaussian distribution with mean 5 and variance 1. The equivalent revenue gained from unit data rate is wf = 0.1 for femto users and wm = 5 for macro users. Without the assistance from femto BS, macro cell can only provide $\lambda 0$ = 0.21 traffic capacity. Unless explicitly stated otherwise, the basic traffic demand of macro users is set to be b = 0.2 and the sensitivity of macro users towards QoS enhancement a = 2. Intuitively, if there's no refunding policy, open access will not be adopted by FHs. However, in order to compare the social welfare in case of three access mechanisms, we assume that FHs equally distribute access time between femto and macro users in open access. We also define the social welfare as the summation of WSP's utility and all the FHs' utility. Above parameters stay the same for the following simulations unless otherwise stated. The number of femto BS, also the number of FHs, is a highly influential factor as it determines the density of femtocell. Fig.2 shows the utility of WSP when hybrid access, open access or closed access is adopted by FHs. Without the stimulation of refunding policy, no FHs are willing to let macro users access the femto BS. But the utility of WSP is the highest if open access is somehow forced to be implemented. In case of closed access, the burden of macro traffic is entirely borne by macro cell that has a fixed capacity $\lambda 0$, which is not affected by the number of femto BS. Therefore, even if the number of femto BS rises, the utility of WSP stays the same. By comparison, the utility of WSP is much higher when hybrid access is promoted by the refunding policy. Although WSP pays FHs for undertaking traffic of macro users, it gets reciprocated as the macro users' churn rate decreases, leading to increasing revenue. The utility of WSP goes up along with the number of femto BS because there are more FHs who will adopt hybrid access and more macro traffic is transferred to femtocell. From Fig.3 we can see that social welfare is the highest in case of hybrid access because both the utilities of WSP and FHs are improved compared to closed access. Although WSP can receive higher utility in open access, FHs have to sacrifice considerably without compensation so they simply will not adopt this access mechanism. Fig.4 shows that the aggregated open time keeps rising along with the number of femto BS. Therefore, it is greatly beneficial for WSP to carry out the refunding policy. Fig.5 shows that the refunding amount m abates when the number of the femto BS increases. As the refunds slightly decreases, the open time of each femto BS also declines. However, the growth of number of femto BS is so enormous that the aggregated open time still comes up in spite of the low refunds. This indicates that WSP also has the motivation to promote the deployment of more femto BSs. A major reason for WSP to advocate hybrid access in femtocell is the limited capacity of macro cell with regard to the ever increasing traffic demand of macro users, which is represented by parameter b in our analysis. Because of the limitation on the number of figures, we only show the utility of WSP versus b. fortunately; in case of hybrid access Femto BSs help to slow down the falling trend by undertaking some of the macro traffic. However, in case of closed access, the increasing traffic demand brings about significant utility reduction. The larger the traffic demands, the more eager WSP is to encourage Femto BS to share some of the macro traffic burden. Hence, both the refunding amount m and the aggregated open time increase. In order to analyse the utility gain and open time αi of a specific Femto holder FHi, we adjust the simulation as follows. A total number of K = 6 Femto BSs are in the network. The achievable transmission rate of FHj, j _= I is held as constant, i.e., Rf,j = 10, j = i.

Femto users' targeted data rate Rf,i is varied to analyze the trend of ui and αi. Other simulation settings remain unchanged. Utility gain of FHi decreases as the targeted data rate of femto users Rf,i increases. If femto users demand a lower targeted data rate, FH tends to share more of their resources. As long as the requirement of femto users is satisfied, FHs are willing to trade transmission time for refunds from WSP. Therefore, the utility gain is more appreciable when Rf,i is low. Also, the utility gain is more considerable when the traffic demand of macro users is high since WSP raises the refunding amount m in order to encourage FHs to take over more macro traffic.

VII. Related Work

Under femtocell networks, there are three access control mechanisms that have been proposed: closed access, open access and hybrid access. An overview of access control mechanism is presented in. The basic scenario for hybrid access is introduced in but no framework for implementing hybrid access is given. Still, hybrid access is not taken into consideration. The benefits of hybrid access have been investigated by several works. If the level of hybrid access to femtocell network is adaptively controlled as a function of factors including the instantaneous load on the femtocell, network performance is better than those of open and closed access. By exploiting the frequency management techniques offered by OFDMA, hybrid access is able to reduce cross-layer interference while guaranteeing a minimum performance to the Femto users. However, all these papers focus on the technical aspects, mainly using information theory to analyse the performance gain. Unlike the existing works, the framework proposed by us involves multiple decision-making entities (FHs and WSP), considering not only network performance but also individual economic benefit. Game theory has been widely applied to ad hoc networks. Various works have used the Stackelberg game as an analytical tool to study the cooperation and competition between primary users and secondary users in cognitive radio networks. A non-cooperative model is proposed for power control of closed access femtocell networks in a distributed way. However, as far as we are concerned, there is no work that addresses the issue of hybrid access in femtocell from a game theory perspective. In this paper, we propose a novel utility aware refunding framework for hybrid access in femtocell and formulate it as a Stackelberg game. While the aforementioned works developed a one-stage game where only the FHs are the players, our work takes into account WSP and FHs, who are both decision makers, and analyses the interaction between WSP and FHs through different stages of the game.

VIII. Conclusion

In this paper, we propose a utility-aware refunding framework, which enables WSP to compensate FHs for taking over macro traffic and encourages FHs to share Femto resource with macro users. In this way, hybrid access can be achieved which creates a win-win situation for both WSP and FHs. Game theory, in particular Stackelberg game model, is used to analyse the optimal strategies for WSP and FHs to gain maximum utility. A feasible protocol based on the theoretical analysis is proposed to put the refunding framework into practice. Simulation results have illustrated that both WSP and FHs can achieve considerable utility gain under the refunding framework. The more femto BSs there are, the more intensely FHs compete for the refunding and the more macro traffic is transferred to femtocell. The refunding amount decreases with femto BS density and macro users' sensitivity towards QoS enhancement but increases with the macro users' demand. Also, a specific FH is more willing to open its resources when its femto users require lower data rate.

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