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Incentive Mechanism for Hybrid Access in Cognitive Femtocell Networks

Lin Shi[◆], Sang-Jo Yoo[°], Myunghwan Seo[*], Hyung-Weon Cho[*]

ABSTRACT

In this paper, we propose a new incentive mechanism for hybrid access in cognitive femtocell networks. The purpose of the proposed incentive mechanism is to guarantee the QoS of macro user equipments (MUEs) and to increase femtocell capacity. MUEs channel condition report triggers bidding procedure by neighbor femtocell base stations (FBS). Macro base station (MBS) can offer some subchannels as rewards to encourage FBSs to reliably support its MUEs. Simulation results validate the effectiveness of our proposed scheme.

Key Words : Cognitive radio, Femtocell, Hybrid access, Incentive mechanism.

Ⅰ. Introduction

To deal with the explosively increasing demands of indoor users, numerous technologies have been developed which include femtocell technology. Femtocell base station (FBS) with a plenty of remarkable advantages has become popular among indoor users, which has made the femtocell networks become denser and denser[1]. Cognitive femtocell well solves the sharing problem of limited spectrum resource between two tiers applying opportunistic spectrum access[2].

There are three basic access control mechanisms in femtocell, which are open access, closed access and hybrid access[3]. Hybrid access aims to guarantee MUE performance and at the same time to increase the femtocell throughput.

In this paper, we propose a new incentive-based hybrid access that can provide guaranteed service to MUE for any channel conditions and meet femtocells' current demand with negotiable price. In the proposed incentive mechanism, by offering extra subchannels as rewards, MBS not only spur FBSs to accept the MUE but also select the best FBS that requires smallest incentive. After MBS and the selected FBS reach an agreement, the FBS will first guarantee the MUE's Quality of Service (QoS) as promised and then use the additional rewards to increase the femtocell capacity in a fair way.

Ⅱ. System Model

In our system model, multiple cognitive femtocells coexist within a macrocell range. The cognitive FBS is denoted $i \in \Psi$, where $\Psi = \{1, 2, \ldots, M\}$ is the set of FBSs. There are multiple MUEs in the system and each MUE $j \in \Omega$ is allocated N_j subchannels by MBS. The cognitive femtocells sense spectrum and utilize the vacant channels that is not used by MBS. Even though precise sensing is applied, there may exist possible co-channel interference between CR FBS and MBS. In this paper, we propose an additional resource sharing scheme, in which MBS allocate dedicated resources to CR FBSs as incentives.

The MUEs that are experiencing bad channel conditions (e.g., SINR is less than the predefined threshold) report the current channel situation to the serving MBS and request to access some nearby FBSs to achieve better performance. However, to guarantee the QoS of the femto user equipments (FUEs), not all FBSs are willing to cooperate with the MBS and accept the MUEs. Therefore, we have classified FBSs in the network into three types based on their cooperation intentions: i) *Acceptant*

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◆ First Author : Inha University, Department of Information and Communications, s.lin0413@163.com, 학생회원
° Corresponding Author : Inha University, Department of Information and Communications, sjyoo@inha.ac.kr, 종신회원
* Hanwha Thales Co., Ltd. myunghwan.seo@hanwha.com, 정회원, hyungwon.cho@hanwha.com
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FBS that is willing to accept the MUE generously. The acceptant FBS notify the desired additional resources and the actual reward is decided by MBS. ii) *Negotiable FBS* may accept MUE after negotiation. It accepts the MUE only if MBS satisfies its requirement. iii) *Reluctant FBS* will not accept MUE under any circumstances.

In the proposed model, the MUE that experienced low QoS level from the MBS initiates sending a report message to the MBS and also the message is overheard by the nearby FBSs. The *acceptant FBS*s and *negotiable FBS*s will reply their decisions to the MBS using the predefined control channel between FBSs and MBS while *reluctant FBS*s do not response to the MUEs message after a quick assessment of their subscribers' performance and other factors. These replies should announce not only their states but also some important conditions.

Ⅲ. Proposed Incentive Mechanism

In the dense femtocell network scenario, there may be more than one FBSs that can response to the MUE's request. The aim of the proposed mechanism is to find out the most appropriate FBS with minimum extra cost and to support the desired QoS level to the MUE.

When MUE j's SINR is lower than a threshold, it reports to the MBS and request to access to nearby FBS. FBS i who heard the request will assess their state and reply a message including $\Theta_{i,j} = \{s_i, N_{d,i}, w_{i,j}\}$ to the MBS. s_i represents the state of FBS i ($s_i = 0$ is negotiable, $s_i = 1$ is acceptant), while $N_{d,i}$ stands for the expected reward of FBS i which is given by desired number of subchannels. The MBS computes $w_{i,j}$, which is the weight of FBS i for MUE j as in (1).

$$w_{i,j} = \frac{N_{d,i}}{\omega_m H_{M,i,j} + \omega_f H_{F,i,j}} \quad (1)$$

where $H_{M,i,j}$ and $H_{F,i,j}$ are the expected capacity enhancement of MUE j and FBS i, respectively, when the expected reward $N_{d,i}$ is given to FBS i. The capacity of MUE can be enhanced by joining the near FBS and the FBS capacity is also increased by receiving additional resource incentive. ω_m and ω_f are influencing factors of $H_{M,i,j}$ and $H_{F,i,j}$, where $\omega_m + \omega_f = 1$. The influencing factors capture the importance of capacity enhancement of MUEs and FUEs. The incentive mechanism not only cares about the QoS of MUE, but also takes the capacity gain of cooperate FBS into consideration.

According to the replied messages of FBSs, the MBS selects one favourite FBS from the candidates and grants some subchannels to spur this FBS to accept its MUE. Among the candidates, if there is any *acceptant FBS*, perform Procedure A first; if the replied FBSs are all *negotiable FBS*s, then takes Procedure B.

Procedure A: Among the *acceptant FBS*s candidates, select the one with minimum $w_{i,j}$. $N_a = \min(N_{\max}^a, N_{d,i} + N_j)$ subchannels is allocated to the selected FBS, where $N_{\max}^a = qN_j$ $(q \geq 1)$ is the maximum number of subchannels to the acceptance FBS that MBS can afford for MUE j. If $q = 1$, then it indicates MBS does not give any incentive to the acceptant FBS and it only allocates the resource N_j that is already given to MUE j.

Procedure B: Among the *negotiable FBS*s, compare their demands with MBS's affordable price (additional subchannels), and select the one with minimum $w_{i,j}$. If for all *negotiable FBS*s, $N_{\max}^n < N_{d,i} + N_j$ $(N_{\max}^n > N_{\max}^a)$, then the negotiation will be failed and the MBS keeps the connection with the MUE. Otherwise, the MBS allocates $N_n = N_{d,i} + N_j$ to the selected FBS.

To guarantee the performance of MUE, the subchannels used by MUE j before the handover will still be assign to it. As for the reward, in order to maintain a fair allocation among FUEs, the additional subchannels can be allocated to the FUE with the lowest data rate one by one. It should be also noted that the incentive resource is allocated to

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FBSs only when the quality for the serving MUEs is not degraded.

Ⅳ. Simulation Results

In this simulation study, there exist one macrocell and 500 femtocells as shown in Fig. 1. The transmission ranges of MBS and FBS are 500m and 20m, respectively. Among the FBSs, we define the portions of acceptant, negotiable and reluctant FBSs are 50%, 40% and 10%, respectively. The influencing factors ω_m and ω_f are 0.7 and 0.3, respectively. The maximum affordable price ratio of MBS is $q=2$. The portion of total number of MUEs and FUEs is 1:1. For each MUE, a subchannel $(N_j=1)$ is allocated. To evaluate the performance of the proposed mechanism, we compare the incentive scheme with the traditional scheme without incentive[3], in which only acceptant FBSs are considered without asking for extra reward and MUE selects a FBS from nearby acceptant FBSs.

Fig. 2 shows the number of additional

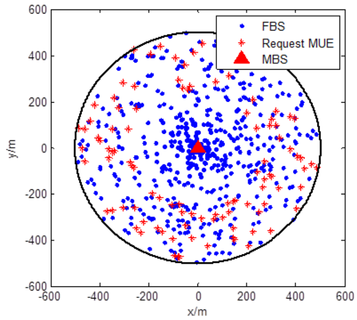

Fig. 1. Network Topology.

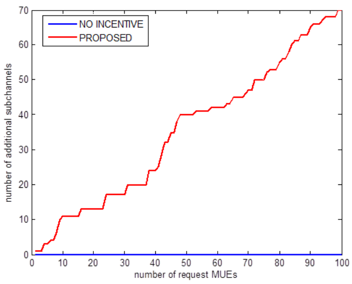

Fig. 2. The number of additional subchannels vs. number of request MUEs.

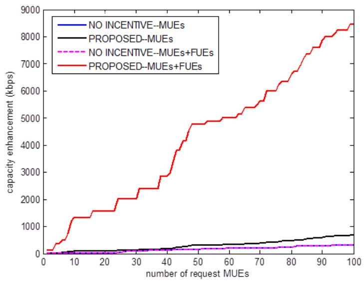

Fig. 3. Capacity enhancement vs. number of request MUEs.

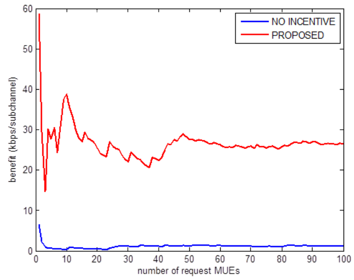

Fig. 4. Capacity enhancement per subchannel.

subchannels that MBS has to spend for reward to FBSs with increasing number of request MUEs. Since in the conventional method no extra incentive is given to FBSs, the number of additional subchannels is 0. Fig. 3 shows the total capacity enhancement of MUEs and FUEs. As we can see, the proposed mechanism can achieve much higher capacity enhancement for both MUEs and FUEs. In Fig. 4, the capacity enhancement per used subchannel is shown. Even though the proposed mechanism spends additional subchannels for the reward to FBSs, the benefit in terms of capacity enhancement per each subchannel outperforms the no incentive method, which illustrates that the incentive is well worthy.

Ⅴ. Conclusion

In this paper, we proposed an incentive mechanism for hybrid access in cognitive femtocell network. The proposed mechanism motivates the FBSs to adopt hybrid access by offering extra reward. We applied different incentive scheme according to the types of candidate FBSs.

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Simulation results demonstrated that the proposed mechanism is effective.

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