Resource Allocation Method Using Channel Sensing and Resource Reuse for Cognitive Femtocells

Sukgi Hong, Chang-Yeong Oh, and Tae-Jin Lee

***Abstract*—A cognitive femtocell is a new small cell based on a smart home base station to solve the spectrum-scarcity problem. Recently, dedicated resource allocation for cognitive femtocells is extensively researched to mitigate the co-channel interference. However, the cognitive femtocell may suffer from the lack of frequency resource for its users due to high data traffic load of the macrocell. In this paper, we propose a novel resource allocation scheme based on the channel sensing and the spatial radio resource reuse mechanism, which enables femto users in the cognitive femtocell to obtain more feasible radio resource. The simulation results show that the capacity of the cognitive femtocell can be improved under high data traffic load of the macrocell compared to that of the conventional scheme.**

***Index Terms*—Cognitive femtocell, channel sensing, frequency reuse, resource allocation.**

I. Introduction

According to recent surveys, the majority of data services take place indoors. Moreover, multimedia applications and high data rate (HDR) services in mobile networks have been drastically increased in recent years [1]. Femto Access Points (FAPs) are small, short-range, and low-power access points to provide improved indoor wireless coverage and increased throughput for mobile data services [2]. FAPs are typically installed in the subscriber's home or office and are connected to the core network of a mobile operator via broadband communications links (e.g., Digital subscriber line (DSL) or cable modems). Both operators and users can provide and experience improved quality of service (QoS) and increased data rate by utilizing highly efficient wireless links of femtocells and existing wired broadband networks [3].

Additional radio resources may be allocated for deployment of FAPs, which raises the spectrum-scarcity problem. The co-channel interference (CCI) between macrocells and femtocells also needs to be properly handled. In an effort to tackle the issue, cognitive femtocells, i.e., a new indoor cellular network employing the cognitive radio technology [4] are introduced. The cognitive femtocell can solve the spectrum-scarcity problem and it can be effective to mitigate the CCI interference in a macro-femto overlay network [5].

In [6], Y.-Y. Li et al. describe the autonomous spectrum management based on the cognitive interference recognition and adaptive channel management. In this scheme, a cognitive FAP classifies the status of radio channel into hard interference channel, soft interference channel, and free interference channel. The cognitive FAP allocates spectrum resource to femto users (FUs) according to the status of the radio channel assuming channel sensing information is provided. In [7], S.-Y. Lien et al. introduce the radio resource management, which adopts the cognitive and game-theoretical technology to guarantee the QoS of FUs. When the feasible radio resource for femtocells is insufficient due to the increase of data traffic of macrocells, the performance degradation in femtocells may occur. The authors in [8] newly propose a power control algorithm using fractional power control (FPC) and introduce a resource allocation method using dynamic spectrum sensing based on the cognitive femtocell, which can improve the throughput and outage probability. When the feasible resource in femtocells is little, performance degradation requires cares. In [9], S. Kaimaletu et al. propose an interference management scheme for heterogeneous cellular networks under the closed access mode. It considers the potential to cause interference to other associated user equipments (UEs).

In this paper, we focus on a method to obtain additional radio resource for femtocells when the feasible radio resource is insufficient due to the increase of data load of macrocells. We propose a novel resource allocation scheme using a channel sensing scheme and a spatial radio resource reuse mechanism, which enables FUs in a cognitive femtocell to obtain more feasible radio resources. Our proposed scheme can boost the femtocell capacity although the orthogonal radio frequency resource for the femtocells is insufficient. The simulation results show the capacity of the cognitive femtocell can be improved by the proposed resource allocation and channel sensing scheme even if the data traffic load of the macrocell increases.

The rest of this paper is organized as follows. In Section Ⅱ, we describe the proposed channel sensing and resource allocation scheme for the cognitive femtocells. Section Ⅲ evaluates the performance gain of the proposed scheme by simulations, and finally Section Ⅳ concludes.

II. Proposed Channel Sensing and Resource Allocation

A. System Model and Network Environment

Our system model considers the 3GPP Long-Term Evolution (LTE). There are two types of base-stations in the 3GPP terminology: evolved-NodeB (eNB) for macrocells and home evolved-NodeB (HeNB) for femtocells. Especially, we consider HeNB with the cognitive radio functionality as CR-HeNB. The eNBs and CR-HeNBs are located at the center of their cell areas and serve their own macro user

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The authors are with the College of Information and Communication Engineering, Sungkyunkwan University, Jangan-gu, Suwon-si, Gyeounggi-do, Korea (e-mail: {iamhsg, ocynesl08, tjlee}@skku.edu).

equipments (MUEs) and femto user equipments (FUEs). And MUEs and CR-HeNBs are assumed to be uniformly distributed within the macrocell area. The FUEs are also uniformly distributed within the femtocell coverage area they belong to.

Algorithm 1. Sensing Adjacent MUEs Algorithm

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//M: set of MUEs
//K: set of CR-HeNBs
Initialize M_adj^k = φ, k ∈ K
while M ≠ φ do
    Compute Γ_K^M, m ∈ M
    if Γ_K^M ≥ Γ_threshold then
        Update M_adj^k ← M_adj^k ∪ {m}
    end if
    Update M ← M − {m}
end while
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The LTE frame consisting of two types of resource blocks (RBs), i.e., control RBs and data RBs, contains several channels to exchange control information and to forward data traffic between an eNB (or a HeNB) and MUEs (or FUEs). The data channels are physical downlink shared channel (PDSCH) in downlink (DL) and physical uplink shared channel (PUSCH) in uplink (UL), which are constructed by the data RBs. And the control channels are physical control format indicator channel (PCFICH), physical hybrid ARQ indicator channel (PHICH), and physical data control channel (PDCCH) in DL and physical uplink control channel (PUCCH) in UL, which are based on the control RBs. Especially, PDCCH includes the DL and UL scheduling information being addressed to a specific UE and contains control information for data reception and demodulation [10]. UEs periodically transmit the sounding reference signal (SRS) to the eNB (or HeNB) in order to report the link quality. The SRS is transmitted to the eNB (or HeNB) using the sounding reference signal bandwidth (SRS BW), which is uniquely assigned to each UE for SRS transmission [11]. And we consider the rate-sensitive (RS) service in an LTE system to compare the proposed scheme with the conventional scheme. For the RS service, the required bit error rate (BER) or the minimum required transmission rate as the QoS requirements is generally used [12].

B. Proposed Resource Allocation Scheme Using Channel Sensing and Spatial Radio Resource Reuse

In the traditional cognitive radio networks, primary networks, i.e., macrocells, generally have the priority of radio resource usage over secondary networks, i.e., femtocells. Also the secondary network is prohibited from affecting the performance of the primary network, i.e., delay and throughput. Once the radio resource status of the macrocell is sensed, the idle radio resource can be utilized by femtocells. The amount of radio resource for femtocells may be insufficient if the data traffic load of the macrocell is high and there are no dedicated radio resources for femtocells. It can cause performance degradation of femtocells due to the lack of radio resources. We propose a novel radio resource allocation scheme for cognitive femtocells based on spatial radio resource reuse, which aims to provide more radio resources to femtocells. We first describe the proposed channel sensing scheme, which aims to determine the spatially reusable radio resource for femtocells. CR-HeNBs should consider adjacent MUEs that may experience severe CCI for radio resource reuse. In the proposed channel sensing scheme, the CR-HeNB can find adjacent MUEs by sensing the SRS of MUEs in UL frames. After obtaining the information about the adjacent MUEs, the CR-HeNB can get the scheduling information of the adjacent MUEs through PDCCH in DL frames. Thus, the CR-HeNBs can get the additional feasible radio resource for FUEs in a distributed manner. The interference power of MUEs located far from the CR-HeNB is attenuated by the effect of wall-loss and long distance between the MUEs and the CR-HeNB. The additional feasible radio resource obtained by the channel sensing scheme causes low CCI to the macro-femto overlay network. The algorithm to decide the existence of adjacent MUEs is described in Algorithm 1. In the Sensing Adjacent MUEs Algorithm, we define the set of CR-HeNBs as K, the set of MUEs in the eNB as M, and the set of adjacent MUEs M_{adj}^k at the CR-HeNB K. The SRS from MUE m to CR-HeNB k represents Γ_k^m. When the CR-HeNB senses the SRS of MUEs in UL, the CR-HeNB measures its signal strength and computes Γ_k^m. If $\Gamma_k^m \geq \Gamma_{threshold}$, the set of adjacent MUE M_{adj}^k is updated by $M_{adj}^k \leftarrow M_{adj}^k \cup \{m\}$. The parameter $\Gamma_{threshold}$ is the threshold to decide whether the MUE m is nearby or not at the CR-HeNB k.

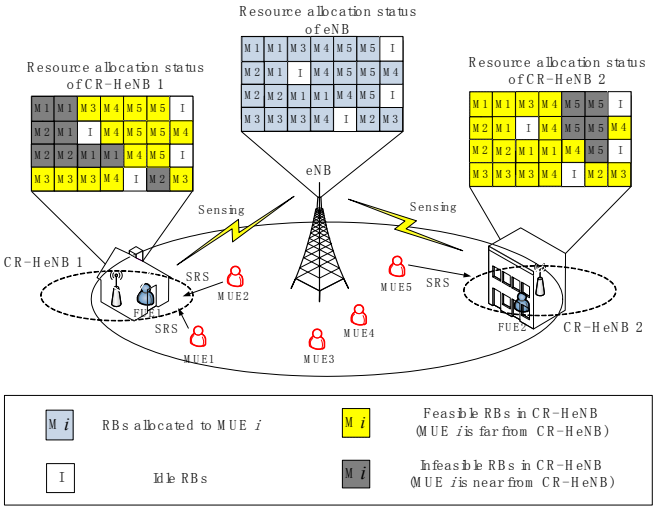


Fig. 1. An example of the proposed resource allocation scheme using channel sensing and spatial radio resource reuse in a given macrocell and femtocells.

In Fig. 1, an example of the proposed resource allocation scheme based on channel sensing and radio resource reuse is described. Each CR-HeNB can utilize the idle RBs and feasible RBs obtained by the channel sensing scheme for FUEs. The MUEs and CR-HeNBs are located in a macrocell region. The CR-HeNBs can acquire the scheduling information of all MUEs from PDCCH in the DL frame. Also the CR-HeNBs sense the UL frame and measure their signal strength from each MUE to the CR-HeNB. CR-HeNB 1 measures the signal strength of the SRS from MUE 1 and that of SRS from MUE 2. CR-HeNB 2 also measures the signal strength of the SRS from MUE 5. Each CR-HeNB can perceive the existence of the adjacent MUEs. CR-HeNB 1

can determine that MUE 1 and MUE 2 are the adjacent MUEs. The CR-HeNB 2 can also determine that MUE 5 is the adjacent MUE. Thus, CR-HeNB 1 uses idle RBs and reuses the RBs occupied by MUE 3, MUE 4, and MUE 5 except the RBs occupied by its adjacent MUEs, i.e., MUE 1 and MUE 2. CR-HeNB 2 uses idle RBs and reuses the RBs occupied by MUE 1, MUE 2, MUE 3, and MUE 4 except the RBs occupied by its adjacent MUEs, i.e., MUE 5. The idle RBs cause no interference and the spatially reused feasible RBs cause low interference to the macro-femto overlay network. Thus, we can solve performance degradation by the scarcity of feasible radio resource for femtocells.

III. Simulation Results

In this section, simulation results are provided. The simulation parameters are listed in Table I . The path loss is modeled as COST 231 Walfish-Ikegami for outdoor and COST 231 Multi-Wall for indoor [13]. In order to evaluate the performance of the proposed resource allocation scheme, we consider the Required Minimum Capacity (RMC) in a frame for MUEs.

TABLE I: Simulation Parameters

Parameters	Value
System bandwidth	10 MHz
Radius of a macrocell	577 m
Radius of a femtocell	20 m
eNB power	20 W
CR-HeNB power	200 mW
MUE power	2 mW
FUE power	2 mW
Number of sub-carriers	660
Subcarriers spacing	15 KHz
Standard deviation of log-normal shadowing	10 dB
Wall loss (Light type / Heave type)	-5 dB / -10 dB
Thermal noise	-174 dBm/Hz

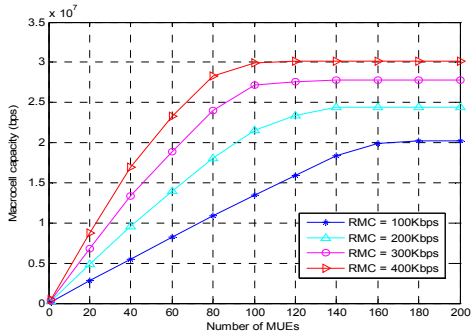


Fig. 2. Simulation results of the macrocell capacity for the RMC condition under the PF scheduling policy.

Fig. 2 shows the average macrocell capacity under the RMC conditions versus the number of MUEs. The average macrocell capacity increase as the number of MUEs increases and finally saturates. Before the average macrocell capacity is saturated, it shows the value over the required capacity of MUEs in all the RMC conditions. When the average macrocell capacity is saturated, the numbers of MUEs are different for diverse RMC conditions. Especially when the number of MUEs is 100, the average macrocell capacity under the RMC condition of 400Kbps is saturated and when the number of MUEs is 160, the average macorcell capacity under the RMC condition of 100Kbps is saturated. It is because that the number of MUEs to satisfy the required capacity per frame in the RMC condition is limited.

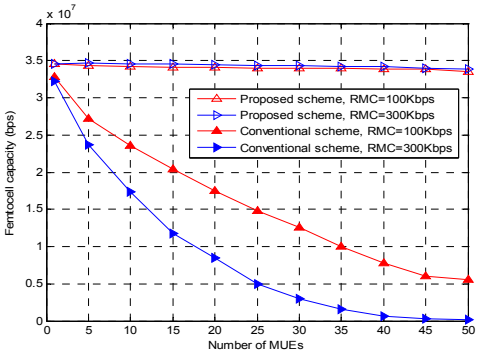


Fig. 3. Simulation results of the femtocell capacity for the number of MUEs under the RR scheduling policy.

Fig. 3 shows the average femtocell capacity according to the number of MUEs under Round Robin (RR) scheduling policy [14]. For comparison with the conventional resource allocation scheme, we choose two RMC conditions of 100Kbps and 300Kbps. Although the number of MUEs increases (i.e., traffic load of macrocell increases), the capacity of the proposed resource allocation scheme is maintained, while the capacity of the conventional resource allocation scheme is severely degraded. Especially, the average femtocell capacity of the conventional resource allocation scheme under the RMC condition of 300Kbps decreases more compared with the RMC condition of 100Kbps since the required capacity of MUEs in a frame under the RMC condition of 300Kbps is higher than that of 100Kbps. Moreover, when the condition of RMC is 300Kbps and the number of MUEs is 50, the average femtocell capacity of the conventional resource allocation scheme is very small. But the average femtocell capacity of the proposed resource allocation scheme is about 33Mbps. The increase in the number of MUEs denotes that the traffic load in the macrocell is large. It may cause the scarcity of usable resource for femtocells.

Fig. 4 shows the average femtocell capacity with the number of MUEs under the Proportional Fair (PF) scheduling policy. We have considered the PF scheduling policy for multi carrier systems [15]. We also select two RMC conditions of 100Kbps and 300Kbps to compare with the conventional resource allocation scheme. The average femtocell capacity of the conventional resource allocation scheme under the RMC condition of 300Kbps shows less performance than the RMC condition of 100Kbps. When the number of MUEs increases, the average femtocell capacity of the conventional resource allocation scheme gradually decreases. When the number of MUE is 50 and the RMC condition is 300Kbps, the average femtocell capacity of the conventional resource allocation scheme is very small since feasible radio resource for femtocells may be insufficient by little idle radio resource of macrocells. However, the average femtocell capacity of the proposed resource allocation scheme is about 52Mbps.

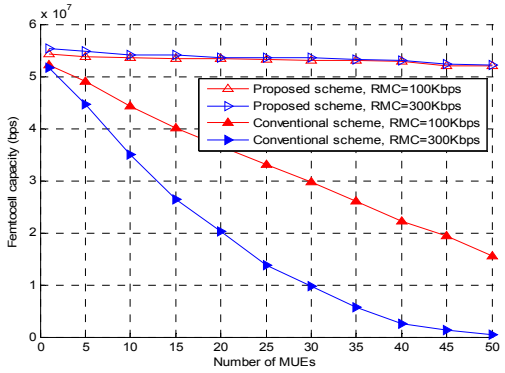


Fig. 4. Simulation results of the femtocell capacity for the number of MUEs under the PF scheduling policy.

Comparing Fig. 3 with Fig. 4, one can also observe that the average femtocell capacity with the RR scheduling policy is lower than that of the PF scheduling policy. Since the PF scheduling allocates resource to users using the PF metric information based on channel status between an eNB (or a HeNB) and MUEs (or FUEs). Also it is shown that the PF scheduling policy is more efficient than the RR scheduling policy to meet the RMC condition for MUEs. We note that the average femtocell capacity of the conventional resource allocation scheme under the RR scheduling policy decreases more than that under the PF scheduling policy as the number of MUEs increases.

IV. Conclusions

In this paper, we have proposed a novel resource allocation scheme for the LTE cognitive femtocell. The proposed resource allocation algorithm is based on channel sensing and spatial radio resource reuse. It aims to improve the femtocell capacity in a macro-femto overlay network. Especially, it is efficient when the feasible radio resource for the femtocells is insufficient due to high data traffic load of the macrocell. We can obtain the feasible radio resource for femtocells using the proposed channel sensing and resource allocation scheme. Simulation results show that the proposed resource allocation scheme can meet the QoS of FUEs when the radio resource of femtocells is insufficient. As the number of MUEs increases, the performance gain by the proposed resource allocation scheme increases.

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References

[1] G. Mansfield, "Femtocells in the US Market-Business Drivers and Consumer Propositions," Femto Cells Europe, ATT, London, U.K., Jun. 2008.
[2] V. Chandrasekkhar, J. Andrews, and A. Gatherer, "Femotocell Networks: A Survey," *IEEE Communications Mag*, vol. 46, no. 9, pp. 59-67, Sept. 2008.
[3] D. Knisely, T. Yoshizawa, and F. Favichia, "Standardization of Femtocells in 3GPP," *IEEE Communications Mag*., vol. 47, no. 9, pp. 68-75, Sept. 2009.
[4] Y. C. Liang, K. C. Chen, G. Y. Li, and P. Mahonen, "Cognitive Radio Networking and Communications: An Overview," *IEEE Trans. on Vehicular Technology*, vol. 60, no. 7, pp. 3386-3407, Sept. 2011.
[5] S. A. Rubaye, A. A. Dulaimi, and J. Cosmas, "Cognitive Femtocell," *IEEE Vehicular Technology Mag*., vol. 6, no. 1, pp. 44-51, Mar. 2011.
[6] Y. Y. Li, M. Macuha, E. S. Sousa, T. Sato, and M. Nanri, "Cognitive Interference Management in 3G Femtocells," in *Proc. of IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, pp. 1118-1122, Sept. 2009.
[7] S.-Y. Lien, Y. Y. Lin, and K. C. Chen, "Cognitive and Game-Theoretical Radio Resource Management for Autonomous Femtocells with QoS Guarantees," *IEEE Trans. on Wireless Communications*, vol. 10, no. 7, pp. 2196-2206, Jul. 2011.
[8] G. W. O. D. Costa, A. F. Cattoni, V. A. Roig, and P. E. Mogensen, "Interference Mitigation in Cognitive Femtocells," in *Proc. of IEEE Globecom*, pp. 721-725, Dec. 2010.
[9] S. Kaimaletu, R. Krishnan, S, Kalyani, N. Akhtar, and B. Ramamurthi, "Cognitive Interference Management in Heterogeneous Femto-Macro Cell Networks," in *Proc. of IEEE International Conference on Communications*, pp. 1-6, Jun. 2011.
[10] A. Ghosh, R. Ratasuk, B. Ondal, N. Mangalvedhe, and T. Thomas, "LTE-advanced: Next-generation Wireless Broadband Technology," *IEEE Wireless Communications*, vol. 17, no. 3, pp. 10-22, Jun. 2010.
[11] S. Stefania, T. Isssam, and B. Matthew, *LTE - The UMTS Long Term Evolution*, Wiley, 2009.
[12] W. Chung, C. Chang, and L. Wang, "An Intelligent Priority Resource Allocation Scheme for LTE-A Downlink Systems," *IEEE Wireless Communications Letters*, vol. 1, no. 3, pp. 241-244. Jun. 2012.
[13] E. Damosso, "Digital Mobile Radio towards Future Generation Systems," COST 231 final report, 1998.
[14] A. Kunz and C. Stepping, "Overview and Implementation of Scheduling Algorithms for Wireless Environments," in *Proc. of Personal Mobile Communications Conference*, pp. 441-446, Apr. 2003.
[15] K. Zhenm, Y. K. Kwok, and W. Jiangzhou, "A Low-Complexity QoS-Aware Proportional Fair Multicarrier Scheduling Algorithm for OFDM Systems," *IEEE Trans on Vehicular Technology*, vol. 58, no. 5, pp. 2225-2235, Jun. 2009.



Sukgi Hong has received the B.S. degree in information and control engineering from Kwang woon University, Seoul, Korea in 2011 and he is currently pursuing his M.S. degree in department of IT convergence at Sungkyunkwan University since March 2011. His research interests include femtocell networks, cognitive femtocell networks, resource allocation, and interference management.



Chang-Yeong Oh has received the B.S. degree in electronics, electrical and computer engineering from Hanyang University, Seoul, Korea in 2008 and the M.S. degree in mobile systems engineering from Sungkyunkwan University, Suwon, Korea in 2010. He is currently pursuing his Ph.D. degree in department of mobile systems engineering at Sungkyunkwan University since March 2010. His research interests include femtocell networks, resource allocation, wireless cooperative communications, and wireless LAN.



Tae-Jin Lee received his B.S. and M.S. in electronics engineering from Yonsei University, Korea in 1989 and 1991, respectively, and the M.S.E. degree in electrical engineering and computer science from University of Michigan, Ann Arbor, in 1995. He received the Ph.D. degree in electrical and computer engineering from the University of Texas, Austin, in May 1999. In 1999, he joined Corporate R&D Center, Samsung Electronics where he was a senior engineer. Since 2001, he has been an Associate Professor in the School of Information and Communication Engineering at Sungkyunkwan University, Korea. He was a visiting professor in Pennsylvania State University from 2007 to 2008. His research interests include performance evaluation, resource allocation, Medium Access Control (MAC), and design of communication networks and systems, wireless LAN/PAN/MAN, ad-hoc/sensor/RFID networks, next generation wireless communication systems, and optical networks. He has been a voting member of IEEE 802.11 WLAN Working Group, and is a member of IEEE and IEICE.