A Self-Organized Femtocell for IEEE 802.16e System

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Abstract— **Femtocell is a small base station with low power which can be installed by users to get better data rate in the indoor environment. The power control scheme of the femtocell BS is the most important issue in the femtocell implementation but there still exist deadzones if macrocell users are located very close to the femtocell. In this paper, we have proposed a new frame structure for the IEEE 802.16e based femtocell. Self-initialized segements selection and preamble allocation scheme are also proposed. Using the proposed preamble structure and self-initialization scheme, macrocell users can detect a macrocell BS even though they are located very close to the femtocell. The simulation results show that macrocell users can survive and communicate with the macrocell BS even though they are in the femtocell coverage. Additionally, it is shown that the proposed system provides the highest throughput of the macrocell and the femtocell inside the femtocell coverage.**

I. Introduction

Recent research shows that more than 50% of voice calls and more than 70% of data traffic are generated indoors [1][2]. The users of cellular wireless system in the indoor environment have difficulty in receiving high-speed service due to low-quality signals from the outdoor base station. Femtocell has been considered as a new technology to solve deadzone problem in the indoor environments. Femtocell is a low-power, short-range, low-cost small base station (BS) which is connected to a wired broadband system to serve the users in small areas such as home or office. As femtocells are installed by customers in exiting networks, such as IEEE 802.16e, HSDPA, a two-tier network is created between a macrocell and a femtocell. A femtocell can use two types of channel assignments to operate in a macrocell network: dedicated-channel assignment and co-channel assignment. In the dedicated-channel mode, the different frequency channel is assign to the femtoccell and the macrocell. The dedicated-channel is free from the interference problem between the macrocell and the femtocell but this method might waste additional frequency resource. On the other hand, co-channel method assigns the same frequency channel to the femtocell and the macrocell. The co-channel assignment results in efficient use of the frequency resource, efficient hand-off and easier cell search, but the interference between the femtocell and the macrocell may generate other deadzones.

The key issue in the implementation of femtocells is on how to deal with the interference between macrocells and femtocells. Previous studies have been interested in how to control the interferences from femtocells and macrocells. As showed in [3], the implementation of femtocells in the IEEE 802.16e system results in 20% performance loss in downlink when femtocells operate in a co-channel manner. The power control method is considered the first step to manage the interference issue [4],[5],[6],[7]. [4],[5],[6] show the power control method of a femtocell BS and its performance when the femtocell is using the same frequency channel with the macrocell. [7] shows the power control method of a femtocell mobile station (MS) when the femtocell MS operates in a co-channel manner. The previous studies show the overall performance of the femtocell and the macrocell. Even though the power control of the femtocell BS and MS is properly executed, the macrocell users who are very close to the femtocell BS may suffer a high interference, which makes it impossible for them to communicate with the macrocell BS. Also, the macrocell users very close to the femtocell BS generate extremely high interferences to the femtocell BS.

This paper proposes a new preamble structure for the IEEE 802.16e based femtocell. The proposed preamble enables a macrocell MS to detect a macrocell BS in vicinity when it is located close to the femtocell BS. Also, we propose a self-organized preamble selection algorithm of the femtocell BS. As the femtocell is installed by an end-user, operators cannot control each femtocell. Consequently, self-initialization and self-organization are essential functions of the femtocell. In section II, the system model for the proposed preamble structure is described. In section III, the self-organized preamble selection algorithm is proposed. Section IV, the simulation results are presented and discussed. Section V contains the summary and the conclusion.

II. System Model

A. System Model

One of the essential requirements in the implementation of a femtocell is that the same terminal must be used for the femtocell and the macrocell. Therefore, the system model considered in this paper is based on the IEEE 802.16e OFDMA (Orthogonal Frequency Division Multiple Access) system. The frame structure of the proposed system is same as the IEEE 802.16e system [8]. The minimum modification of conventional preamble is proposed in this paper. In the

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operation of femtocells, there are two kinds of user selection policies: open access policy and closed access policy. The closed access policy enables only authorized users to connect to the femtocell. On the other hand, any users can connect to the femtocell under the open access policy. Even though the open access policy can be a solution to the interference problem of the femtocell, operators prefer the closed access policy due to business issues. In this paper, we consider the closed access policy. Therefore, the unauthorized macrocell users near to the femtocell are unable to communicate with the femtocell.

B. Power control algorithm

In previous studies show that the power control method of femtocell BS is needed to minimize the interference to macrocell users while achieving the femtocell coverage. In this paper, the power control method proposed in [4] is used. Even though the OFDMA system can allocate different power throughout the subcarriers of an OFDMA symbol, we considered fixed power allocation of each subcarrier of an OFDMA symbol. In the proposed system, the transmit power of the femtocell per subcarrier, P_f, is given as

$$P_f(dB) = \min(P_{m-rx} + L(d) + G, P_{f-\max}), \qquad (1)$$

where P_{m-rx} is the received power from the macrocell BS, $L(d)$ is the propagation loss between the femtocell BS and the place $d(m)$ far from the femtocell BS, d is the coverage of the femtocell in meters, and G is the femtocell gain and $P_{f-\max}$ is the maximum power of femtocell BS per subcarrier. Based on (1), the transmit power of the femtocell BS adaptively changes according to the coverage of the femtocell and the received power from the macrocell which is mostly determined by the distance between the macrocell and the femtocell. The femtocell which is close to the macrocell transmits relatively high power to achieve its coverage and that which is far from the macrocell transmits relatively low power to achieve its coverage and minimize the interference to macrocell users.

C. The proposed preamble structure

In the IEEE 802.16e system, the first symbol of every frame is located to specify the cell segment and the cell ID [8]. There are 3 segements and 114 preamble sets in the IEEE 802.16e system, which means 38 preambles per segment. The subcarrier sets per segment, s, is given as

$$P_s = \{86 + s + 3k | k \in \{0, 1, ..., 283\}\}, \qquad (2)$$

which allocate non-overlapping subcarriers for the different segments. Subcarriers of the preamble are allocated according to the cell specific segment. Thus, preamble signals using the same segment interfere each other, which causes severe degradation.

If there exist many femtocells nearby, there might be high probability of using the same segment with the neighboring femtocells which may cause performance degradation in femtocell search. Therefore, the punctured preamble is proposed in this paper. The exiting preamble is punctured into predetermined manner resulting into virtual segments of exiting segments. Fig. 1 shows the example of the proposed preamble punctured by factor 2. The two consecutive subcarriers are punctured to use differential vector in preamble selection algorithm. The puncturing factor can be extended to 3 and 4, where 4 and 6 consecutive subcarriers are punctured to make 3 and 4 subsegments. Fig. 1-(b) and Fig. 1-(c) are two virtual preambles from one preamble which are punctured in two different patterns. These two preambles do not have overlapping subcarriers. Thus, femtocells using different virtual preambles in same segment make two subsegments which do not interfere each other. Extending the number of virtual segments by using the proposed preamble may result in low probability of two adjacent femtocells using the same segement.

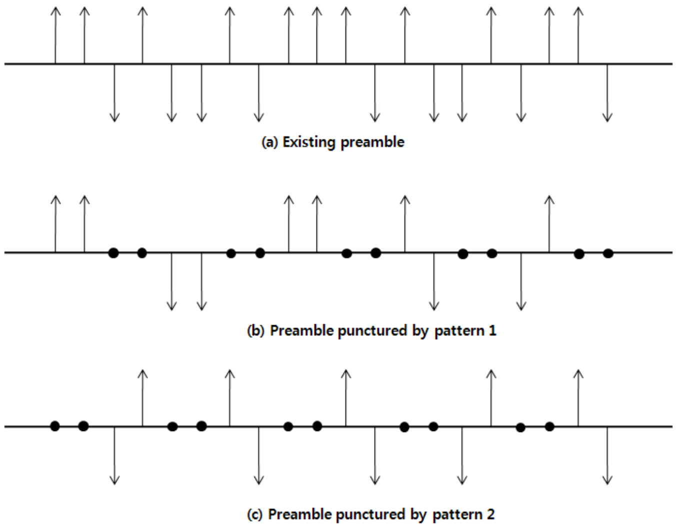

Fig. 1. The example of the proposed preamble punctured by factor 2.

III. Self-initialization algorithm

As the femtocell is installed by an end-user, operators cannot control each femtocell from the central control unit. Thus, the femtocell should recognize its circumstance and allocate the cell segment and preamble without the help of the macrocell. This paper proposes a self-initialization algorithm for the femtocell. Fig. 2 shows the overall process of the proposed self-initialization.

First of all, a femtocell should adjust its transmit power according to the method mentioned in II-B. After the femtocell allocates its power based on its situation, the femtocell measures the energy of each segment and the subsegment with the least power is selected as the femtocell segment. Once the segment is selected, the femtocell selects the preamble based on cross-correlation between the received signal and the femtocell.

A. Subsegment selection

The femtocell measures the energy level of each subsegment defined in II-C. The energy of each subsegment, E_s, is given

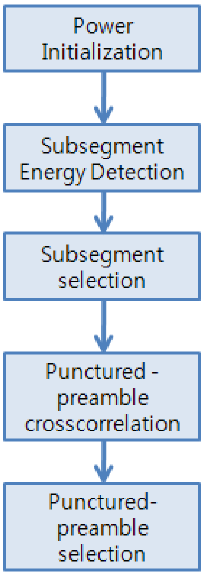

Fig. 2. The process of the proposed self-initialization.

by

$$E_s = \sum_{k \in C_s} |Y_k^s|^2, \quad (3)$$

where C_s is the subcarrier set of s^{th} subsegment, k is the k^{th} index of subcarrier set C_s and Y_k^s is the k^{th} received symbol in the frequency domain of s^{th} subsegment. After measuring the energy of each subsegment, the femtocell selects the subsegment with the least energy which gives the least interference to the femtocell. Thus, the allocated subsegement of femtocell, s, is given as

$$s = \arg\min_s E_s \quad (4)$$

B. Punctured-preamble selection

After the femtocell selects its subsegement, the femtocell should select its punctured-preamble among the set of punctured-preambles in the selected subsegment. The femtocell selects a punctured-preamble which shows the least cross-correlation value with the received symbol [9]. We defined a punctured preamble selection metric using differential vectors. In the initial state, the femtocell does not have any information about the macrocell, which makes the channel estimation of the macrocell impossible. Therefore, a differential vector is used to alleviate the channel impairments. The differential vector is expressed as

$$R_k = Y_{2k}^s Y_{2k+1}^{s\ *}. \quad (5)$$

$P_{j,k}$, the differential vector of j^{th} preamble sequence of k^{th} signal in frequency domain, is given as

$$P_{j,k} = D_{j,2k} D_{j,2k+1}, \quad (6)$$

where $D_{j,2k}$ is a k^{th} normalized preamble pattern of the j^{th} preamble sequence in the frequency domain.

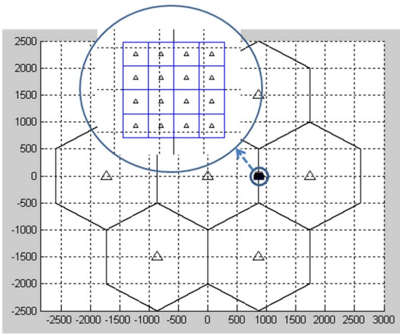

Fig. 3. Macrocell and femtocell environments .

TABLE I
SIMULATION ENVIRONMENTS.

Parameters	Values
Radius of the cell	$1000m$
Number of macrocells	7
Tx power of macrocell	43 dBm
Width and length of femtocell	40m
Max. tx power of femtocell	20 dBm
Wall loss of femteocell	5 dB
Fading channel	Veh A channel
Pathloss component	4
Lognormal shadowing	8dB
OFDMA FFT size	1024

Here, the cross-correlation metric, η_j, for using differential vector is define as

$$\eta_j = \frac{\left\{ \sum_{k=0}^{K/2-1} \mathrm{Re}(R_k) P_{j,k} \right\}^2}{\left(\sum_{k=0}^{K/2-1} \{\mathrm{Re}(R_k)\}^2 \right) \left(\sum_{k=0}^{K/2-1} |P_{j,k}|^2 \right)} = \frac{\left\{ \frac{2}{K} \sum_{k=0}^{K/2-1} \mathrm{Re}(R_k) P_{j,k} \right\}^2}{\frac{2}{K} \sum_{k=0}^{K/2-1} \{\mathrm{Re}(R_k)\}^2}, \quad (7)$$

where j denotes a preamble index.

The femtocell selects the preamble index, $\hat{j}$, which has the least cross-correlation metric value. Thus, the femtocell selects the preamble index within the preamble set of the selected segment. The number of preambles in the selected preamble set is dependent on the puncturing factor, p, of each preamble.

$$\hat{j} = \arg \min_{j \in \{0, \ldots 38*p\}} \{\eta_j\} \quad (8)$$

IV. Simulation Results

The performance of the proposed self-initialization algorithm using punctured-preamble is evaluated in this section. The system parameters are shown in Table I. The simulation parameters are base on the IEEE 802.16e system. As shown in Fig. 3, we assumed that there are 7 hexagonal macrocells. The

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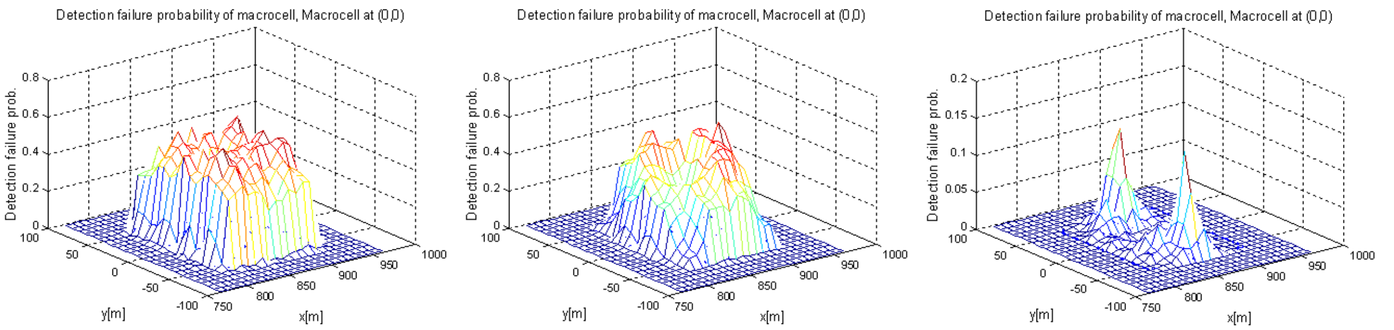
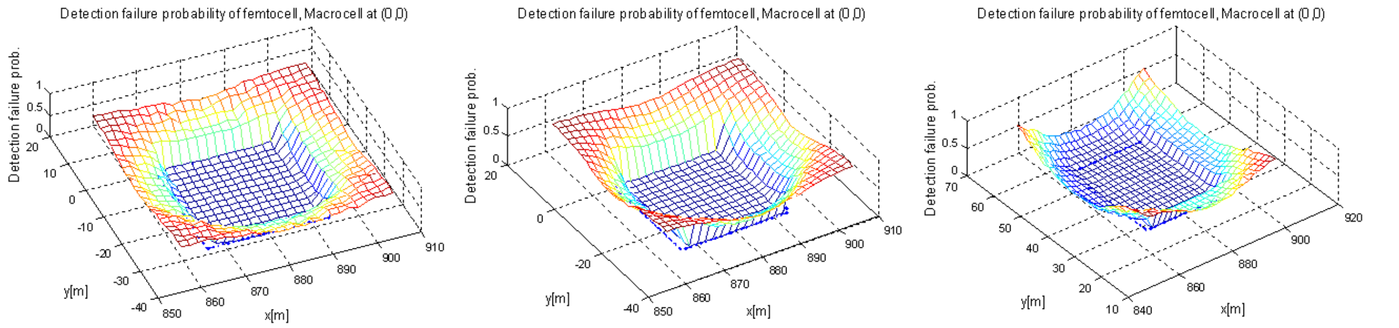


(a) Power control only (b) Self−initialization w/o punctured preamble (c) Self−initialization with punctured preamble

Fig. 4. The detection failure probability of macrocell around the femtocell.



(a) Power control only (b) Self−initialization w/o punctured preamble (c) Self−initialization with punctured preamble

Fig. 5. The detection failure probability of femtocell.

16 adjacent femtocells are gathered into a square. A femtocell BS is located in the center of each femtocell building with a width and length of $40m$. The propagation loss exponent of the macrocells and the femtocells is set as 4. We assumed ITU-R Veh. A channel is considered as a fading channel. The lognormal shadowing factor is set as 8dB.

The preamble detection failure probabilities of the macrocell and the femtocell are examined in this paper. We have compared the performance of the proposed system with the system with power control only and the system using the proposed self-initialization without punctured preamble. Fig. 4 shows the preamble detection failure probability of the macrocell in and around the femtocells. In the simulation, the first macrocell is located at $(0, 0)$ and the femtocells are located between two cells as shown in Fig. 3. Even though the system with power control only can detect the macrocell preamble just beside the femtocells, the system with power control only and the system without punctured preamble have difficulty in detecting the macrocell inside the femtocells. The proposed system with punctured preamble has high probability of allocating different segment with the macrocells. Fig. 5 shows the preamble detection failure probability of the femtocell. The femtocell with conventional power control system can achieve its coverage. But in case there is adjacent femtocells nearby, it is difficult to detect the preamble outside the wall. The proposed system can provide wider coverage than the system with power control only and the system without punctured preamble. This is because the proposed system has less chance of using the segments of adjacent femtocells due to subsegment expansion.

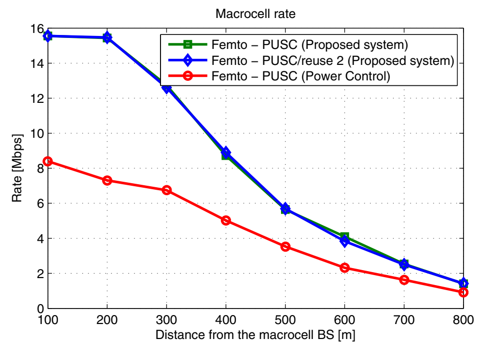


Fig. 6. The cell throughput of macrocell inside the femtocell .

Fig. 6 shows the downlink rate of the macrocell when the macrocell MS is located at the corner of the femtocell. Here, we assumed that there is only one macrocell MS in the macrocell and PUSC (Partial Usage of Subchannels) allocation scheme is used [8]. Femtocell BSs are also using PUSC allocation scheme. The x-axis of Fig. 6 represents the distance between the home macrocell and the femtocell group.

Fig. 6 shows that the rate of the proposed system is twice as high as the system only with the power control only.

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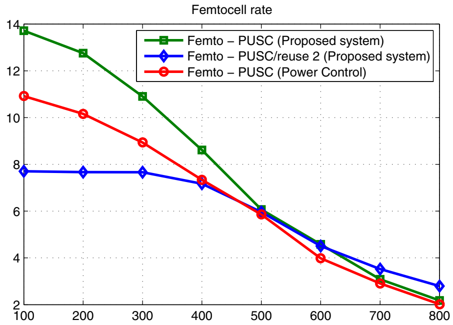

Fig. 7. The cell throughput of femtocell inside the femtocell .

The PUSC with reuse 2 means that the femtocell is using PUSC type subchannel which is divided into 2 based on the subsegment of the femtocell. From Fig. 6, it is shown that the reuse factor of the femtocell does not effect macrocell rate.

Fig. 7 shows the downlink rate of the femtocell when the femtocell MS is located at the corner of the femtocell. Here, we also assumed that there is only one femtocell MS in the femtocell. As same as the macrocell rate, the proposed system shows higher femtocell rate than the system only with the power control. When femtocell is close to the macrocell, it has to transmit its signal with high power and as a result, the proposed system without frequency reuse shows the highest rate. If the femtocell is located far away from the macrocell, the femtocell transmits it signal with low power due to the power control scheme. Because of the low transmit power, the femtocell might exist in noise-limited region. Therefore, the proposed system with reuse factor 2, which transmits twice higher power than the proposed system without reuse, shows the higher rate at the cell egde.

V. Conclusion

In this paper, the new preamble design and the self-initialzation scheme for the IEEE 802.16e based femtocell were proposed. As shown in various studies, we adopted the self-organized power control scheme previously presented. By adopting the proposed preamble design, the exiting segment in the IEEE 802.16e can be divided into subsegments. This results in low probability of the femtocell allocating the subsegments that are already allocated to the adjacent femtocells. The self-initialization scheme is proposed to select a subsegment and a proposed-preamble without help of central control units. The simulation is performed in the situation that various femtocells are adjacently located. The results show that the coverage of the femtocell can be achieved only by the power control scheme but without the usage of the proposed system, it is hard for the macrocell MS in the femtocell range to detect the macrocell BS. Also, the usage of proposed preamble and self-initialization scheme extends the coverage of the femtocell outside the building. Moreover, it is shown that the downlink macrocell rate and the downlink femtocell rate of the proposed system are greater than those of the system with power control only.

ACKNOWLEDGEMENT

This research was supported by the MKE(Ministry of Knowledge Economy), Korea, under the ITRC(Information Technology Research Center) support program supervised by the IITA(Institute for Information Technology Advancement)(IITA-2009-C1090-0902-0005)

References

[1] Femtocell forum, http://www.femtoforum.com

[2] J. G. Andrews, and A. Gatherer, Femtocell networks: a survey, *IEEE Comm. Magazine*, vol. 46, no. 9, pp. 59-67, Sept. 2008.

[3] Y. Sung, N. Jeon, B, Yoon, J. Lee and S. Kim, "Femtocell/Macrocell Interference Analysis for Mobile Wimax System," *Proc. 5th IEEE VTS Asia Pacific Wireless Communication Symposium (APWCS 2008)*, vol. 1, Sendai, Japan, August 2008.

[4] H. Claussen, "Performance of Macro- and Co-channel Femtocells in a Hierarchical Cell Structure," *Proc. IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2007)*, vol 1, pp. 1-5, Athens, Greece, September, 2007.

[5] T. W. Lester and H. Claussen, "Effects of User-Deployed, Co-Channel Femtocells on the Call Drop Probability in a Residential Scenario ," *Proc. IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2007)*, vol 1, pp. 1-5, Athens, Greece, September, 2007.

[6] H. Claussen, T. W. Lester and L. G. Samuel, "Self-optimization of Coverage for Femtocell Deployments," *Proc. Wireless Telecommunication Symposium 2008 (WTS 2008)*, vol 1, pp. 278-285, Ponoma, CA, U.S.A., April, 2008.

[7] H. Jo J. Yook, C. Mun and J. Moon, "A self-organized uplink power control for cross-tier interference management in femtocell networks," *Proc. Military Communication Conference 2008 (MILCOM 2008)*, vol 1, pp. 1-6, San Diego, CA, U.S.A., Nov, 2008.

[8] IEEE 802.16e/D5-2004, Air Interface for Fixed and Mobile Broadband Wireless Access Systems - Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands, November 2004.

[9] K. J. Kim, H. G. Hwang, K. J. Jeon, J.B. Park and K.S Kim, "Cell Scanning Algorithm Using Multiple Frame for IEEE 802.16e OFDMA System ," *Proc. 5th IEEE VTS Asia Pacific Wireless Communication Symposium (APWCS 2008)*, vol. 1, Sendai, Japan, August 2008.