Femtocell Deployment to Minimize Performance Degradation in Mobile WiMAX Systems*

Chang Seup Kim, Bum-Gon Choi, Ju Yong Lee, Tae-Jin Lee, Hyunseung Choo, and Min Young Chung**

School of Information and Communication Engineering
Sungkyunkwan University
300, Chunchun-dong, Jangan-gu, Suwon, Kyunggi-do, 440-746, Korea

Abstract. Femtocell is one of the promising technologies for improving service quality and data rate of indoor users. Femtocell is short-range, low-cost, and low-power base stations (BS) installed by the consumer indoors. Even though femtocell can provide improved home coverage and capacity for indoor users, it causes interference to macrocell users when femtocell uses the same frequency band of macrocell. To reduce the interference between macrocell and femtocell, it is needed to analyze the characteristic of macrocell and femtocell considering various interference scenarios. In this paper, we investigate the uplink and downlink capacity of macrocell and femtocell according to the strength of femtocell transmit power and the number of femtocells through simulations. Simulation results show that femtocell transmit power and the number of femtocells affect the performance of macrocell. From the results, we find the adequate femtocell transmit power which minimize the performance degradation of macrocell and femtocell. We also investigate capacities of macrocell and femtocell according to the locations of femtocell BS and macrocell UE.

Keywords: Femtocell, Macrocell, Co-Channel Interference, Power control.

1 Introduction

Mobile WiMAX (IEEE 802.16e) based on IEEE 802.16e standard has been commercialized in 2006 with rapid growth of various multimedia applications [1,2]. Recently, user demands for various multimedia services such as mobile IPTV are continuously increasing. On the other hand, it is expected that 60 percent of voice calls and 90 percent of data services will take place in indoors [3], and in current mobile communication systems, the signal strength transmitted from base station (BS) can be very low in indoor environments because the signal

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** Corresponding author.

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strength may be severely attenuated when it penetrates the obstacles such as walls. Thus, providing high data rate services to indoor users is difficult only in mobile WiMAX systems. Therefore, the mobile WiMAX has performed femtocell standardization in two phases . The first phase of a WiMAX femtocell system, which requires no air interface or UE change, is expected to be available in the near future. More advanced and optimized femtocell features in phase 2 will be available upon completion of IEEE 802.16m and as part of WiMAX Release 2.0 with target deployments [4].

Femtocell is connected to IP based backhaul such as digital subscriber line (DSL) or cable modem, which provides lower cost than wireless mobile communication systems. Femtocells can achieve a high signal-to-interference-plus-noise ratio (SINR) with low transmit power because the distance between transmitter and receiver is short. In addition, the operators can save costs when femtocell accommodates traffic concentrated to macrocell of current mobile communication. On the other hand, users can receive improved data speeds and service quality with inexpensive costs. Although femtocell has many advantages in indoor environments, some technical issues, such as spectrum assignment of femtocell, access policy, network synchronization, handover, self-optimization, and self-configuration, should be solved to be effectively deployed in existing mobile WiMAX systems [5]. Especially, spectrum assignment for avoiding interference between macrocell and femtocell is an important issue since interference may causes severe degradation of throughput and service quality [6,7,8].

In mobile WiMAX system, throughput is determined by radius of macrocell, distribution of femtocell, and density of femtocell [9]. The interference characteristics under co-channel environments are presented in [10]. If femtocells are deployed in mobile WiMAX systems, interference from femtocells can affect the performance of mobile WiMAX systems. In this paper, we evaluate uplink and downlink capacity of macrocell and femtocell by simulation under various interference scenarios. We investigate the adequate femtocell transmit power level, which minimizes the performance degradation of mobile WiMAX system and can achieve enough femtocell throughput. Also, we examine the effect of the locations of femtocell BS and macrocell UE.

The rest of this paper is organized as follows. Section 2 provides interference scenarios in the environment where femtocells and macrocells coexist. Section 3 describes the system model and propagation models. In Section 4, we examine the uplink and downlink capacity of the macrocell and femtocell according to the strength of femtocell transmit power, number of femtocells, and locations of femtocell BS and macrocell UE. Finally, we conclude in Section 5.

2 Interference Scenarios of Femtocells in Mobile WiMAX Systems

When femtocells operate in the same spectrum in mobile WiMAX systems, the characteristic of interference depends on the method for channel assignment [11][12]. Channel assignment method for macrocell and femtocell is classified into orthogonal and common channel assignment. Orthogonal channel assignment does not cause co-channel interference between the macrocell and femtocell because the femtocells use different channels with macrocell. However, orthogonal channel assignment has a low spectrum efficiency because frequency resources for the macrocell and femtocell are different. On the other hand, common channel assignment has a high spectrum efficiency because macrocell and femtocell can use all of the spectrum. However, there exists a problem of co-channel interference in common channel assignment method.

In common channel assignment, co-channel interference between macrocell and femtocell should be reduced to guarantee service quality of users. We analyze the co-channel interference between macrocell and femtocell according to link direction and the locations of femtocell BS and macrocell UE. Co-channel interference scenario between macrocell and femtocell is shown in Fig. 1. In case of uplink, interferences of macrocell and femtocell are caused by femtocell UE and macrocell UE, respectively. Similarly, in downlink, interferences of macrocell and femtocell are caused by femtocell BS and macrocell BS. If macro/femtocell UE is close to femto/macrocell BS, interference between macrocell and femtocell becomes large. Thus, the channel capacity of macro/femtocell may be significantly deteriorated.

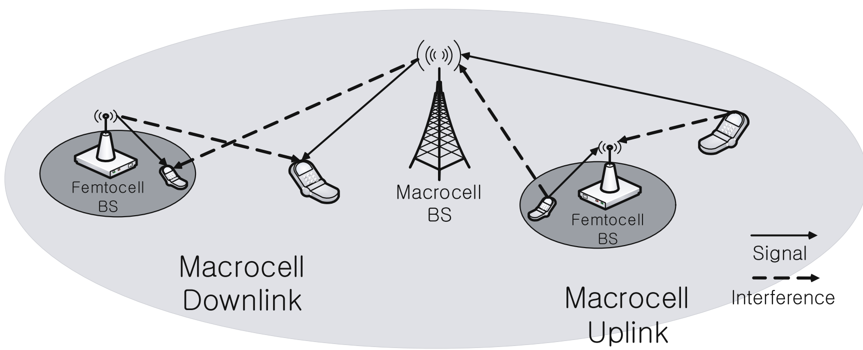


Fig. 1. Co-channel interference scenario between macrocell and femtocell

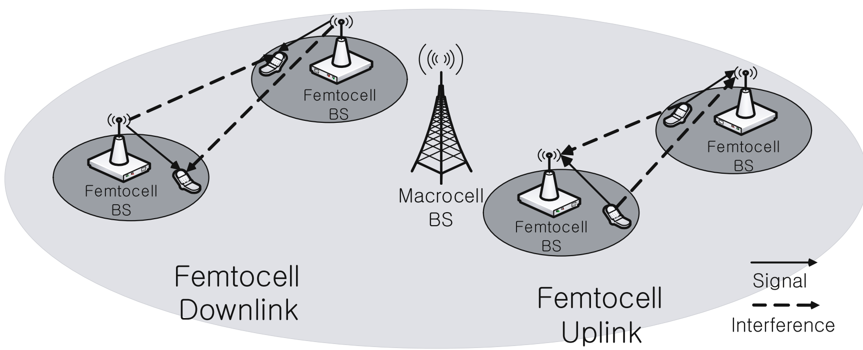


Fig. 2. Co-channel interference scenario between femtocells

When femtocells are deployed in a macrocell, we should also consider co-channel interference among femtocells as shown in Fig. 2. Interferences are caused by neighboring femtocell BS and femtocell UE. Especially, when the distance between femtocells is short, the impact of interference from neighboring femtocell may be high. That is, co-channel interference between femtocells can be a serious problem when a lot of femtocells are concentrated in a small area.

3 System Model

To analyze the performance when femtocells are deployed in mobile WiMAX systems, we consider a system model with 19 macrocells as shown in Fig. 3. In our model, femtocells are uniformly deployed in the centered macrocell 1. The attenuation of transmitted signal, called path loss, can differ according to channel environment (e.g., indoor or outdoor). As path loss models, we apply Wireless World Initiative New Radio (WINNER) II model to evaluate the throughput [13]. Simulation parameters are in Table 1 [14].

To calculate the path loss between macrocell BS and UE, we use non-line of sight (NLOS) outdoor propagation model. Also, we use NLOS indoor propagation model for calculating path loss between femtocell BS and UE. Path loss of the indoor and outdoor signal is given as [13]:

$$PL_{in}(d) = 36.8 \cdot \log_{10}(d) + 37.78,$$
$$PL_{out}(d) = 35.74 \cdot \log_{10}(d) + 35.68,$$

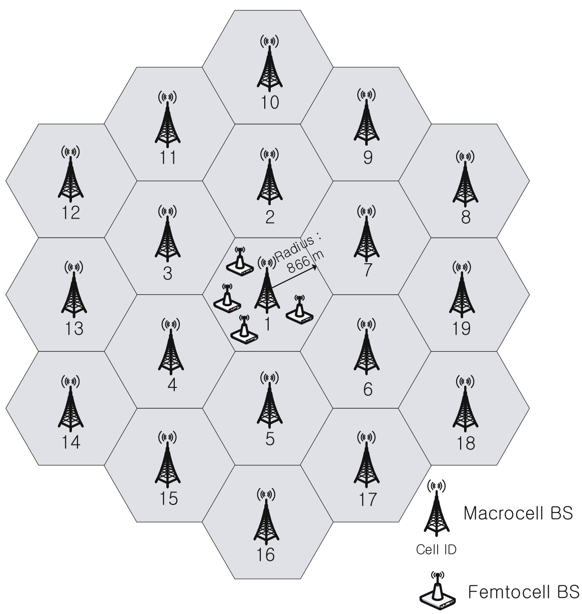


Fig. 3. Cell structure for simulation

Table 1. Simulation parameters

PARAMETER	VALUE	PARAMETER	VALUE
Carrier frequency	2.5 GHz	Channel bandwidth	10 MHz
Radius of macrocell	866 m	Radius of femtocell	10 m
Maximum power of macrocell BS	20 W	Maximum power of femtocell BS	0.1 W
Maximum power of UE	0.2 W	Antenna gain of macrocell BS	15 dBi
Antenna gain of femtocell BS	2 dBi	Antenna gain of UE	-1 dBi
Lognormal std. dev. (outdoor)	8 dB	Lognormal std. dev. (outdoor to indoor)	10 dB
Lognormal std. dev. (indoor)	4 dB	Lognormal std. dev. (indoor to outdoor)	7 dB

where d is the distance between the transmitter and the receiver in meter. In order to reflect the interference between macrocell and femtocell, indoor to outdoor and outdoor to indoor path loss model are considered as follows [13].

$$PL_{in\_to\_out}(d_{out}, d_{in}) = PL_{out}(d_{out} + d_{in}) + 14 + 15(1 - cos(\theta))^2 + 0.5d_{in},$$

$$PL_{out\_to\_in}(d_{out}, d_{in}) = PL_{out}(d_{out} + d_{in}) + 13.8 + 0.5d_{in},$$

where d_{out} is the distance between the outdoor node and the wall nearest to the indoor node, d_{in} is the distance from the wall to the indoor node, and θ is the angle between the outdoor path and the vertical direction of the wall. In the simulation, θ is assumed to be 0 degree.

The received signal to interference ratio (SIR) is defined as the ratio of a signal power to the interference power. Let P_s^r and I_s^r be strengths of received signal and interference from sender s to receiver r, and M and F be the number of macrocells and femtocells.

SIR of user l in the downlink at macrocell BS i is:

$$SIR^l_{macroBS^i} = \frac{P^l_{macroBS^i}}{\sum_{j=1}^{F} I^l_{femtoBS^j} + \sum_{k=1,k\neq i}^{M} I^l_{macroBS^k}},$$

where $I^l_{femtoBS^j}$ is the interference which occurs due to the signal transmited to the macrocell user l in the femtocell BS j and $I^l_{macroBS^k}$ is the interference which occurs due to the signal transmited to the macrocell user l in the macrocell BS k. SIR of user l in the uplink at macrocell BS i is:

$$SIR^i_{macroUE^l} = \frac{P^i_{macroUE^l}}{\sum_{j=1}^{F} I^i_{femtoUE^j} + \sum_{k=1,k\neq l}^{M} I^i_{macroUE^k}},$$

where $I^i_{femtoUE^j}$ is the interference which occurs due to the signal scheduled to transmit from the femtocell UE j to the macrocell BS i, and $I^i_{macroUE^k}$ is the interference which occurs due to the signal scheduled to transmit from the macrocell UE k to the macrocell BS i. SIR of user l in the downlink at femtocell BS i is:

$$SIR^l_{femtoBS^i} = \frac{P^l_{femtoBS^i}}{\sum_{j=1,j\neq i}^{F} I^l_{femtoBS^j} + \sum_{k=1}^{M} I^l_{macroBS^k}},$$

SIR of user l in the uplink at femtocell BS i is:

$$SIR^i_{femtoUE^l} = \frac{P^i_{femtoUE^l}}{\sum_{j=1,j\neq l}^{F} I^i_{femtoUE^j} + \sum_{k=1}^{M} I^i_{macroUE^k}}.$$

The received SIR is used to calculate channel capacity with the Shannon-Hartley theorem. Channel capacity C is calculated as follows.

$$C = BW \cdot \log_2(1 + SIR),$$

where BW is channel bandwidth in Hz.

4 Performance Evaluation

Fig. 4 shows uplink and downlink channel capacity of macrocell according to the number of femtocells. As the number of femtocell increases, the uplink channel capacity of macrocell steeply decreases, but downlink channel capacity of macrocell decreases more slowly than uplink channel capacity. The reason is that uplink transmit power of macrocell UE is lower than downlink transmit power of macrocell BS and strength of uplink interference is similar to strength of downlink interference. In order to maintain uplink and downlink channel capacity of macrocell high, the maximum transmit power of femtocell BS and UE is controlled. We set the transmitted power of femtocell BS and UE to 0.1 W, 0.01 W, and 0.001 W in the simulation. When the transmitted power of femtocell UE uses 0.001 W, the decreasing slope of uplink channel capacity of macrocell is reduced because co-channel interference from femtocell UE is decreased. On the other hand, macrocell UE in the downlink can get higher SIR than uplink of macrocell due to a high signal strength of macrocell BS. However, the downlink channel capacity of macrocell has smaller improvement than uplink of macrocell even if the transmitted power of femtocell BS uses 0.001 W.

Compared with the channel capacity of macrocell as shown in Fig. 4, uplink and downlink channel capacity of femtocell is high as shown in Fig. 5. Femtocell has a high received SIR because the distance between femtocell BS and UE is shorter than the distance between macrocell BS and UE. Since transmitted power of macrocell UE is low compared with macrocell BS, co-channel interference from macrocell UE is relatively low. Although the transmitted power of femtocell's UE is weakened, the uplink channel capacity of femtocell maintains high. Accordingly, we can increase the uplink channel capacity of macrocell. The downlink channel capacity of femtocell is constant because interference

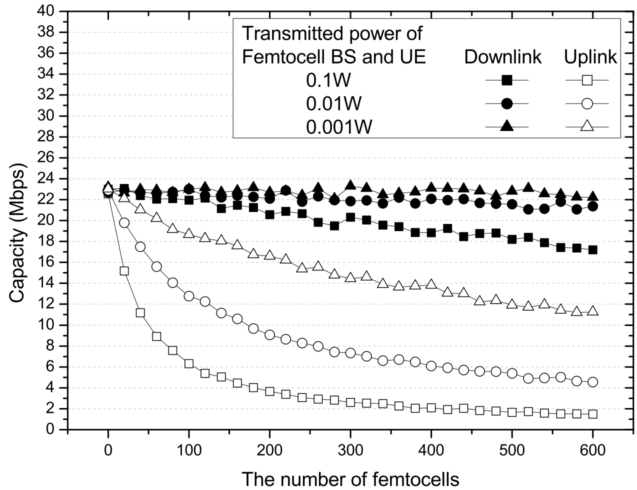


Fig. 4. Uplink and downlink channel capacity of macrocell

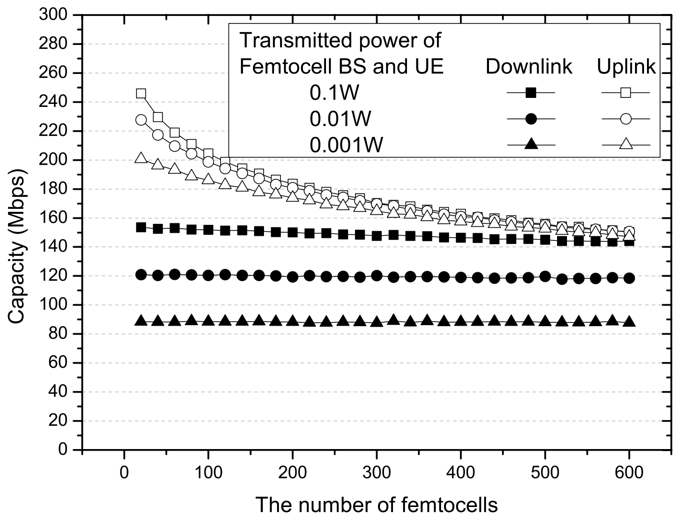
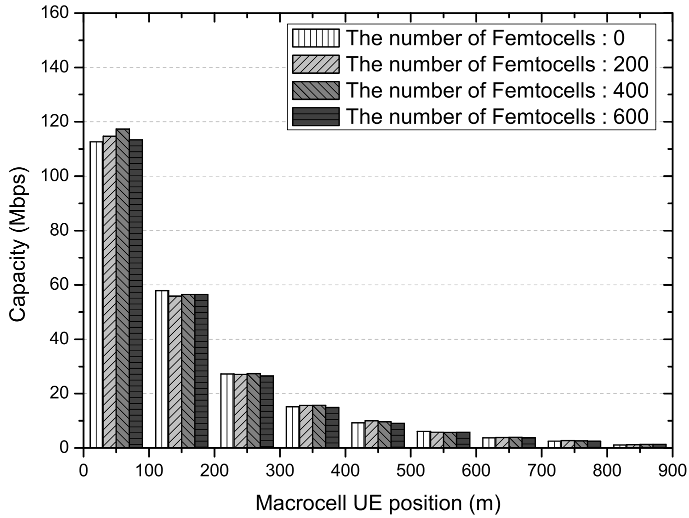


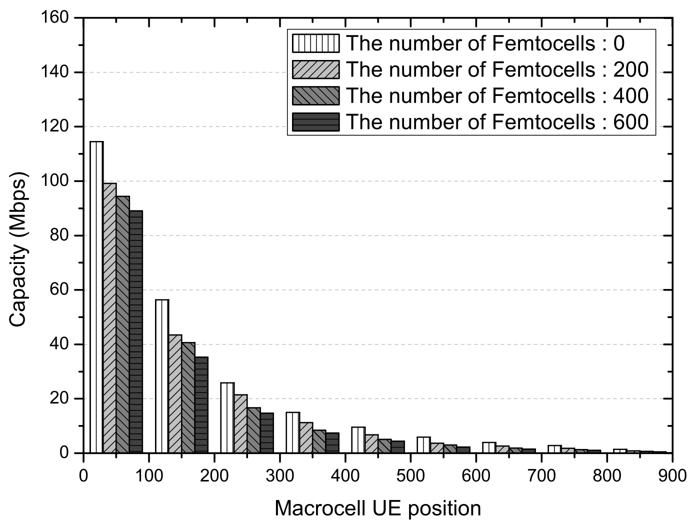
Fig. 5. Uplink and downlink channel capacity of femtocell

from macrocell BS is more dominant than interference of neighboring femtocells. When the transmitted power of femtocell BS uses 0.001 W, the downlink channel capacity of femtocell is about 90 Mbps. In this setting, femtocell can provide subscriber with enough service quality and data speed while minimizing the performance degradation of macrocell.

We consider the environment where transmitted power of femtocell BS and UE is fixed to 0.001 W. Fig. 6 shows downlink and uplink channel capacity

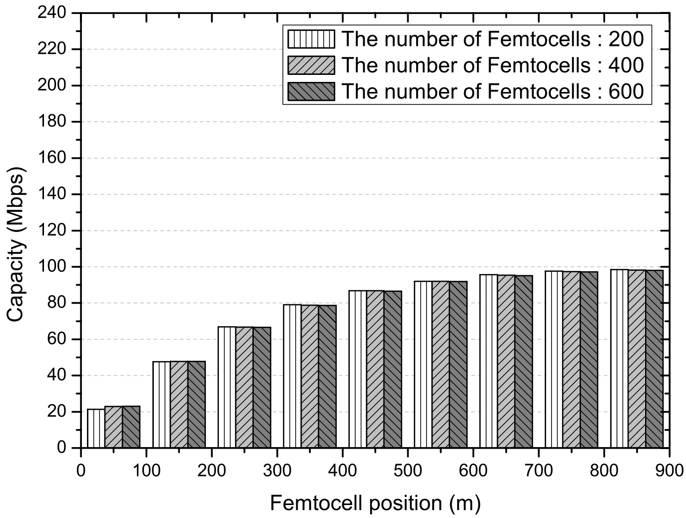


(a) Downlink

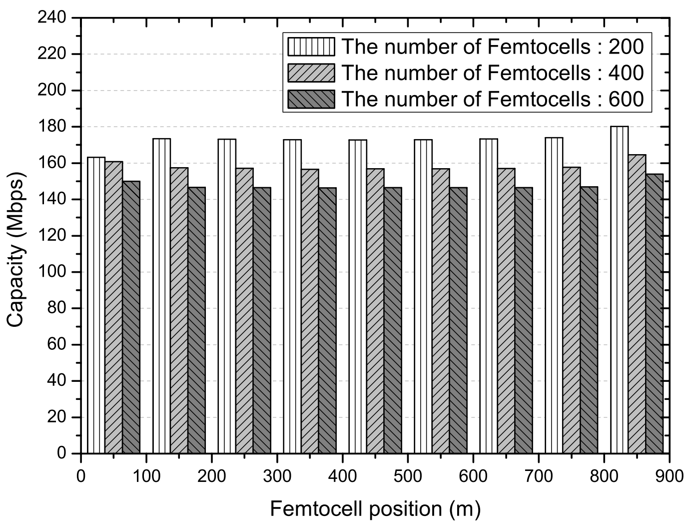


(b) Uplink

Fig. 6. Channel capacity of macrocell UE according to locations (The transmitted power of femtocell BS and UE is 0.001 W)



(a) Downlink



(b) Uplink

Fig. 7. Channel capacity of femtocell UE according to locations (The transmitted power of femtocell BS and UE is 0.001 W)

of macrocell according to the locations of macrocell UE. Macrocell UE has a high channel capacity when the location of macrocell UE is close to macrocell BS. The downlink channel capacity of macrocell is not influenced by co-channel interference of femtocell because the transmitted power of macrocell BS is high and the transmitted power of femtocell BS is low as shown in Fig. 6(a). On the other hand, co-channel interference according to the number of femtocell UEs highly affects the uplink channel capacity of macrocell UE since the signal strength of macrocell UE is low as shown in Fig. 6(b).

Fig. 7(a) shows the downlink channel capacity of femtocell according to the locations of femtocell. Femtocells close to macrocell BS has a low channel capacity because the transmitted power of macrocell BS becomes a strong interference to femtocell. If the location of femtocell is far away from macrocell BS, femtocell has a high channel capacity. Fig. 7(b) shows uplink channel capacity of femtocell according to the locations of femtocell. The uplink channel capacity of femtocell does not depend on the distance between macrocell BS and femtocell. However, the uplink channel capacity of femtocell decreases as the number of femtocells increases.

5 Conclusion

In this paper, we investigated channel capacity of macrocell and femtocell according to the number and power level of femtocells when femtocells are deployed in mobile WiMAX systems. When femtocell uses high transmit power, the channel capacity of macrocell severely decreases due to high interference from femtocell as the number of femtocells increases. In our simulation environment, the adequate transmit power of femtocell BS and UE is 0.001 W. This power level minimizes the performance degradation of macrocell while achieving enough femtocell throughput. With this femtocell transmit power, we also examined the effect on the locations of femtocell BS and macrocell UE.

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