Downlink Power Control for Interference Management in Femtocell-Macrocell Cellular Communication Network

Misfa Susanto, Dika Fauzia, Melvi, Syaiful Alam
Electrical Engineering Department, University of Lampung, Jl Prof. Sumantri Brojonegoro No 1, Bandar Lampung 35145, Indonesia
misfa@eng.unila.ac.id

Abstract — **Deployment of femtocell in macrocell cellular network which forms two-tier femtocell-macrocell cellular network faces more complicated interference problems, since it uses the same licensed frequency spectrum as its macrocell. This paper addresses the interference problems for downlink transmission in such two-tier cellular communication network. In this paper, interference management using power control is proposed in that two-tier network. This paper considers multi-cell cellular network composing of three macrocell systems. Ten femtocells are deployed in each macrocell system. This paper takes worst case for the scenario that is all femtocells and macrocells in downlink transmissions. Simulation for the system without power control was carried out first as a baseline system. Then, two methods of power control called as PC-1 and PC-2 in this paper were explored to reduce the interference effects. The use of two power controls is to take a trade-off, the increasing of quality of service (QoS) in macrocell system while is not degrading much QoS in femtocell system. Both power control methods are based on the estimated Signal to Interference Plus Noise Ratio (*SINR*). Both of power control methods also ensure that the results of controlled transmitting power will not exceed the maximum or the minimum of allowable transmitting powers. Simulations have been carried out and performance parameter in term of Cumulative Distribution Function (CDF) of *SINR* have been collected for co-tier (femtocell-femtocell and macrocell-macrocell), cross-tier (femtocell-macrocell and macrocell-femtocell), and the total interferences. The simulation results show that both power control methods outperform the baseline system.**

Keywords—Cellular Communication Network; Femtocell; Two-Tier Cellular Network; Downlink Transmission; Interference Management; Power Control; Multi-Cell Scenario; SINR.

I. INTRODUCTION

Evidently, the cellular communication technology is one of technologies that their users grow up exponentially. It implies that the network operator has to increase their network capacity and quality of services. It is well-known that creating smaller cells can increase the capacity in cellular network. Femtocell is a small cell technology that has emerged as a promising small cell technology and received a lot of attentions recently from the academia, industries, and the standardization body. Femtocell can be defined as a cell with small radius of coverage (tipically 10-30 meters), low transmitting power, and low cost [1]. Femtocell base station can be designed and developed for various air interfaces of cellular networks including Fourth Generation (4G) cellular network in which femtocell base station is called as Home evolved Node B (*HeNB*) in 4G cellular networks.

In spite of the increase of capacity in cellular network, the deployment of femtocells in the macrocells' area (within the coverage area of an evolved Node B/*eNB*) of cellular network creates more complex interference problems. It is due to femtocells are allowed to use the same licensed frequency bands owned by a network operator [2]. The deployment of femtocells in the area of macrocell of cellular network constructs two-tier femtocell-macrocell cellular network. Macrocell network is considered as underlay network and femtocell network is as overlay network [3]. The interference in such two-tier network can come from the same tier, macrocell to macrocell and femtocell to femtocell, or from the different tier, femtocell to macrocell and vice versa. Those interference types are called as co-tier and cross-tier interferences, respectively [2]. The interference in two-tier cellular network can happen in the uplink and downlink transmissions. This paper focuses on the downlink transmission. In addition, the interferences become worst when two-tier networks allow having the frequency reuse of 1 as it is applicable in 4G cellular networks [4]. Thus, it is most crucial to mitigate such interference problem in two-tier femtocell-macrocell cellular networks. The ways to mitigate the interference problems can be done by interference management.

A straight forward way to manage the interferences for two-tier femtocell-macrocell cellular network is separating the frequency bands allocated for femtocells and macrocells. The frequency band are owned by an operator is partitioned into two parts, one for the femtocell usages and other one for macrocell usages. This method has been proposed in the literature and called as Fractional Frequency Reuse (FFR) [5]. Although this FFR method can reduce the effects of interferences in two-tier femtocell-macrocell cellular network, the method is less preferable by the cellular network operator, because the operator argues that it will come up the inefficiencies of the frequency band usages. The frequency band that is allocated for the femtocells will be wasted when there is no or rarely deployment of femtocells in the macrocell area.

There are other methods of interference management for two-tier femtocell-macrocell cellular network already proposed in the literatures. The authors in [2] surveyed it excellently and presented the remaining issues and open challenging in two-tier femtocell-macrocell cellular networks. One method of interference managements is power control. This paper focuses on the downlink transmission of two-tier femtocell-macrocell cellular network. This paper is to use power control as management interference for downlink transmission in two-tier femtocell-macrocell cellular networks. Two power control methods are explored in this paper in which the decisions to increase or to decrease the transmitting power of base station (*eNB*/*HeNB*) are based on the information of current estimated Signal to Interference plus Noise Ratio (*SINR*). Those two power control methods are called as power control 1 (PC-1) and power control 2 (PC-2). In this paper, the considered model for two-tier cellular network is multicell cellular network consisting three macrocell network with ten deployed femtocells in each macrocell. Certainly, there are a lot of works that are already proposed in the literatures for the power controls as management interference in OFDMA-based femtocell networks, such as in [6 – 9] just few to mention it. However, to the best our knowledge there are not much works considering multicell of macrocell models of two-tier cellular network in the literatures, such as in [10 – 11] the authors proposed the analytical model for two-tier femtocell-macrocell cellular network in multi-cell scenarios for the uplink transmission . It is different with this paper which this paper considers downlink transmission for multi-cell scenario.

The rest of this paper is organized as the following. After this introduction section, Section 2 overviews the system model and the considered power control methods. Section 3 describes the simulation settings, the simulation results, and discusses the finding of simulation results. Section 4 concludes this paper and gives the likely extensions of the simulation results for the future works.

II. SYSTEM DESCRIPTION AND MODELS

Multi-cell two-tier; femtocell-macrocell; cellular network is considered in this paper. The network consists of three macrocell systems underlying the network which all macrocells are in downlink transmissions. The base station of each macrocell is denoted as evolved Node B (*eNB*) as it is for Fourth Generation (4G) cellular network which for downlink transmission the system uses Orthogonal Frequency Division Multiple Access (OFDMA). In each macrocell, it is deployed a number of femtocells, *i*, randomly and each femtocell is on the downlink transmission as its co-located macrocell. Femtocell base station is indicated as Home *eNB* (*HeNB*). All femtocells are assumed in the indoor areas. In each macrocell and in each femtocell, it is randomly deployed *m* Macrocell User Equiptment (*MUE*) and *n* Femtocell User Equipment (*FUE*), respectively. Fig. 1 shows the considered system. Note that for the clarity it is depicted only one *HeNB* in each *eNB* and one *MUE* and one *FUE* only in each *eNB* and in each *HeNB*, respectively. In Fig. 1 the solid black arrows show the desired signals to MUE_1 and to FUE_1. When observing macrocell 1 and femtocell 1, accordingly; the desired signals are coming from the serving base stations, eNB_1 and $HeNB_1$, to MUE_1 and to FUE_1, respectively. At the same time, say in the same frame of transmission on other macrocells and femtocells, *eNB*s and *HeNB*s are serving their respective users. These signals from other *eNB*s and *HeNB*s are received by MUE_1 and FUE_1, since it is assumed to use the frequency reuse of 1. In this case, these unexpected signals at the same radio resources from other *eNB*s and *HeNB*s at MUE_1 or FUE_1 are considered as the interferences (shown the dashed blue and dashed red arrows in Fig. 1). Dashed blue and dashed red arrows denote co-tier and cross-tier interference signals accordingly in Fig. 1. By changing the indices of *MUE* and *FUE* to *k* for the generalisation purpose, the Signal to Interference plus Noise Ratio (*SINR*) at the observed macrocell user equipment *k* (MUE_k) can be expressed as below.

$$SINR_{MUE_k} = \frac{P_{rx_{MUE_k eNB_1}}}{I_{cross\_total}+I_{co\_total}+N} \tag{1}$$

where:

$P_{rx_{MUE_k eNB_1}}$: the received signal power at MUE_k for the transmitting signal power from eNB_1;
I_{cross_total} : the total power of cross-tier interferences at MUE_k caused by the surrounding femtocells;
I_{co_total} : the total power of co-tier interferences at MUE_k caused by the surrounding macrocells;
N : the system noise.

The received power, $P_{rx_{MUE_k eNB_1}}$, at MUE_k by the transmitting power of eNB_1, $P_{tx_{eNB_1}}$, can be calculated as below considering the path loss only.

$$P_{rx_{MUE_k eNB_1}} = \frac{P_{tx_{eNB_1}}}{L} \tag{2}$$

or in decibel scale (dB):

$$P_{rx_{MUE_k eNB_1}}(dBm) = P_{tx_{eNB_1}}(dBm) - L(dB) \tag{3}$$

where L denote the path loss of propagation channel which is characterized by the conditions of area where the system is located. In this paper, it is assumed that the system is located in the urban area and as mentioned earlier that femtocell is in the indoor area. Therefore, the path loss model that can be adopted is the model documented by 3GPP [12] and this path loss model is expressed as below.

For the macrocell system:

$$L_{eNB_1-MUE_k}(dB) = 15.3 + 37.6log_{10}(r) + L_{oth} \tag{4}$$

For the femtocell system:

$$L_{HeNB_1-FUE_k}(dB) = 127 + 30log_{10}\left(\frac{r}{1000}\right) \tag{5}$$

where:

r : the distance between the transmitter (eNB_1 or $HeNB_1$) to the receiver (MUE_k or FUE_k) in meters;
L_{oth} : the penetration loss caused by the wall between the path of transmitter and receiver.

When the femtocell user (FUE_k) is observed, the Eqs. 1 to 3 can be applied by changing the index MUE_k to FUE_k and eNB_1 to $HeNB_1$. Each co-tier and cross interference powers can be calculated using Eq. 3.

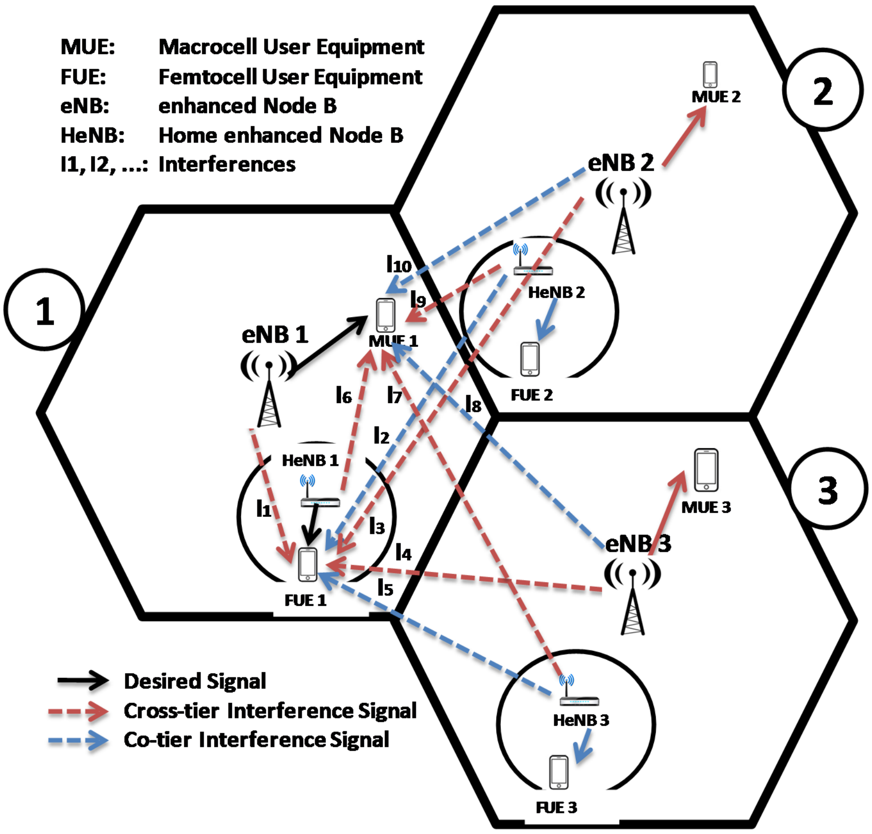


Fig. 1. Three Macrocell with One Femtocell Each: Colocated Femtocell and Macrocell on the Same Transmission Conditions, One Observed Macrocell and One Femtocell on Uplink Transmissions, Other Two Macrocells and Two Femtocells on Downlink Transmssions

2.1 Power Control Method

When power control method is not applied, the transmitting power of the transmitter remains constant. In this paper, the power control is applied frame time by frame time of transmissions to reduce the effects of interferences. At the next time of frame transmission (time of t_{j+1}, where t_j is the current time), the transmitting power will be changed accordingly based on the current *SINR* value. In this paper, two power control methods are explored and applied to the system. In this section, two power control methods are discussed. The command of power control can be decided by the *eNB* or *HeNB* through the feedbacks sent by the *MUE* or *FUE*.

2.1.1 Power Control Method 1 (PC-1)

The first power control is using a fixed value to increase or to decrease the transmitting power of *eNB* when the *MUE* is observed and the transmitting power of *HeNB* when the *FUE* is observed. First the system is calculating the estimated *SINR*. The resulting *SINR* is compared to the pre-determined target *SINR*. In this paper the target *SINR* ($SINR_{target}$) is determined to be 0 dB which is according to the required *SINR* for voice traffic (VoIP and Audio) [13]. When the estimated *SINR* is less than the target *SINR*, the transmitting power of *eNB* or *HeNB* is increased at the next time of frame transmission. When the estimated *SINR* is greater than the target *SINR*, the transmitting power of *eNB* or *HeNB* is decreased at the next time of frame transmission. If the estimated *SINR* equals to the target *SINR* ($SINR_{target}$), it is nothing to be done with the transmitting power of *eNB* or *HeNB*. Mathematically, the changing of this transmitting power can be expressed as below. Note that the below equation shows the transmitting power at *eNB*, for the transmitting power of *HeNB*, the indices is changed accordingly.

$$P_{tx_{eNB_1}}(t_{j+1}) = \begin{cases} min[P_{tx_{eNB_1}}(t_j)+\Delta, P_{\max}]; & \text{if } SINR_{est}(t_j) < SINR_{target} \\ P_{tx_{eNB}}(t_j); & \text{if } SINR_{est}(t_j) = SINR_{target} \\ max[P_{tx_{eNB_1}}(t_j)-\Delta, P_{min}]; & \text{if } SINR_{est}(t_j) > SINR_{target} \end{cases} \qquad (6)$$

where:

t_j and t_{j+1} : the current and next times of frame transmissions;
Δ : the constant that is parameter to increase or to decrease the power;
P_{max} : the maximum transmitting power allowed for eNB_1;
$SINR_{est}(t_j)$: the estimated *SINR* at the current time of frame transmission;
$SINR_{target}$: the target *SINR*;
P_{min} : the minimum transmitting power allowed for eNB_1.

2.1.2 Power Control Method 2 (PC-2)

The second power control is based on the difference between the estimated *SINR* ($SINR_{est}$) and the target *SINR* ($SINR_{target}$). First, the *SINR* is estimated at the current time of frame transmission to obtain $SINR_{est}$. Then, the diffence between the $SINR_{est}$ and the $SINR_{target}$ is calculated. Let state this difference is denoted as γ. This difference γ is used as a value to increase or to decrease the transmitting power at the *eNB* and *HeNB* in the next time of frame transmission. Mathematically, γ and the power control method 2 (PC-2) can be expressed as below.

$$\gamma = SINR_{est}\,(t_j) - SINR_{target} \tag{7}$$

$$P_{tx_{eNB_1}}(t_{j+1}) = \begin{cases} min[P_{tx_{eNB_1}}(t_j) + \gamma, P_{\max}]; & \text{if } \gamma < 0 \\ P_{tx_{eNB}}(t_j); & \text{if } \gamma = 0 \\ max[\,P_{tx_{eNB_1}}(t_j) - \gamma, P_{min}]; & \text{if } \gamma > 0 \end{cases} \tag{8}$$

This paper defines that the functions of $max[a,b]$ and $min[a,b]$ are the functions which return the maximum and the minimum values among the given set in the function's arguments (a and b), respectively.

III. SIMULATION SETTING, RESULTS, AND DISCUSSIONS

The extensive simulation has been carried out in this paper. The network scenario that was simulated using the scenario illustrated on Fig.1. Table 1 shows the parameters used in the simulation. The number of macrocells used is three. *eNB* for each macrocell is located at the centre of macrocell which is according to omni-cell. *eNB* has the maximum and the minimum transmitting powers of 46 dBm and 10 dBm [14], respectively. The radius of macrocell is set to 500 meters according to the radius of macrocell in dense urban area. In the simulation, initially the transmitting power of each *eNB* is set to 34 dBm both for the system without and with power control. For the system without power control, that transmitting power of *eNB* is constant throughout the simulation time, whereas the systems with power control the values of *eNB* transmitting power are changing according to the power control methods used. In each macrocell it is randomly deployed 30 *MUE*s. Ten femtocells are deployed randomly in the area of each macrocell and all femtocells are assumed in the locations of indoor area. The radius of each femtocell is specified in [1] that is 10-30 meters. In the simulation the radius of each femtocell is set up to 10 meters. In each femtocell, 4 *FUE*s are deployed randomly. The maximum and minimum of transmitting powers of *HeNB* are set to 20 dBm and -10 dBm [14], respectively. For both systems without power control and with power control, the transmitting power for *HeNB* was set up to 8 dBm and this value is changing throughout the simulation time for the system with power controls and is constant for the system without power control. This paper considered the white noise with the noise power density of -174dBm/Hz [12]. Total system bandwidth was considered to 20 MHz [14]. Penetration loss was assigned to 10 dB [15]. For the PC-1 method the value of Δ was given to 2 dB. *SINR*s were measured at *MUE*s in one of three macrocells (i.e. *MUE*s in eNB_1) and at *FUE*s in one of ten femtocells located in macrocell 1 (i.e. *FUE*s in $HeNB_1$). CDF of *SINR*s for the user equipments in eNB_1 and $HeNB_1$ (*MUE*s and *FUE*s) were analyzed. The simulations were repeated for 100 times and the average of CDF of *SINR*s was calculated and the simulation results are presented in Figs. 2 (a)–(c) considering co-tier, cross-tier, and total interferences, respectively.

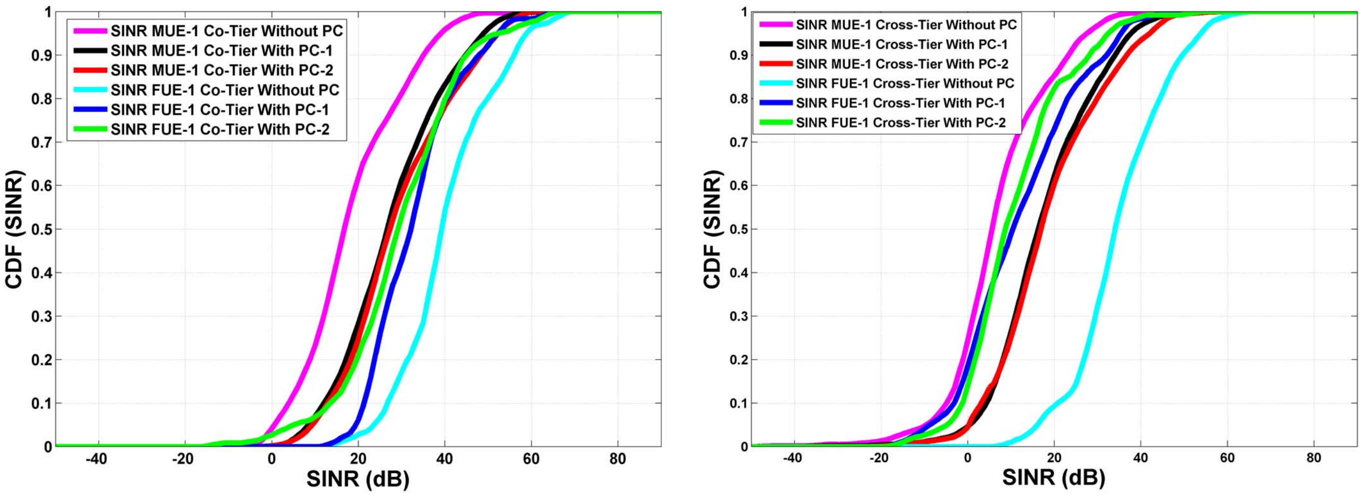
TABLE I. SIMULATION PARAMETERS

No.	**Parameter**	**Value**
1.	Number of Macrocells	3
2.	Radius of Macrocell	500 meters
3.	Number of *MUE* in each Macrocell	30
4.	Maximum Transmitting Power of *eNB*	46 dBm
5.	Minimum Transmitting Power of *eNB*	10 dBm
6.	Transmitting Power of *eNB* without Power Control	34 dBm
7.	Intital Transmitting Power of *eNB* with Power Control	34 dBm
8.	Number of Femtocells for each Macrocell	10
9.	Radius of Femtocell	10 meters
10.	Number of *FUE*s in each Femtocell	4
11.	Maximum Transmitting Power of *HeNB*	20 dBm
12.	Minimum Transmitting Power of *HeNB*	-10 dBm
13.	Initial Transmitting Power of *HeNB* with Power Control	8 dBm
13.	Noise Power Density	-174 dBm/Hz
14.	System Bandwidth	20 MHz
15.	Penetration Loss (L_{oth})	10 dB
16.	Δ for the Power Control Method 1 (PC-1)	2 dB
17.	Simulation Time (Number of Iterations)	100

The simulation results in Fig. 2 (a) show that both of the systems with power control methods, PC-1 and PC-2 outperforms the system without power control at CDFs of *SINR* 0 dB considering co-tier interference at *MUE*. At *MUE* both systems with PC-1 and PC-2 achieve CDF of 0 or 0% at *SINR* of 0 dB, whereas the system without power control achieves 0.04 or 4%. At *FUE*, CDF of *SINR* 0 dB achieved 0 or 0% for both the systems without power control and with PC-1 method, whereas for the system with PC-2 method achieved 0.02 or 2%.

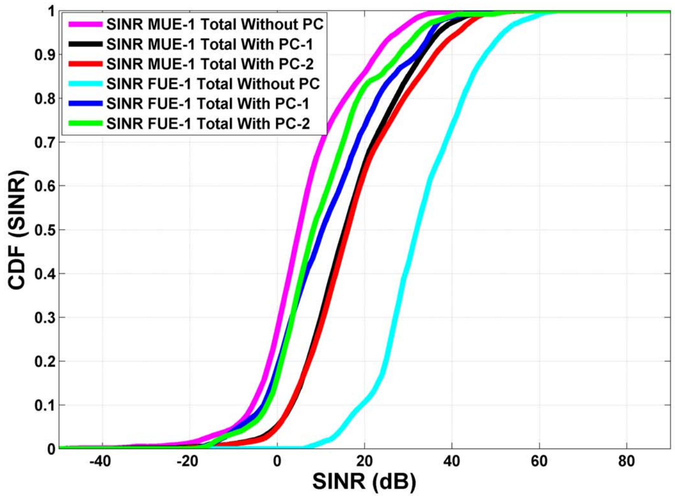
Considering cross-tier interference, at *MUE* the system without power control achieved the CDF of 0.24 or 24% at *SINR* of 0 dB, whereas for both systems with PC-1 and PC-2 achieved CDF of 0.04 or 4% at *SINR* equal to 0 dB. At *FUE*, CDF of *SINR* 0 dB achieved 0 or 0% for the system without power control and for the systems with PC-1 and PC-2 achieved CDFs of 0.2 (20%) and 0.275 (27.5%), respectively, at *SINR* equal to 0 dB.

For the total interference, both systems with PC-1 and PC-2 methods outperform the system without power control in terms of CDF of *SINR* at *MUE*. For the systems with PC-1 and PC-2, CDF of *SINR* 0 dB achieved 0.05 (5%) and 0.04 (4%), respectively, at *MUE*, whereas the system without power control achieved the value of CDF of *SINR* 0 dB at 0.28 (28%). At *FUE*, as expected the system without power control outperforms both systems with PC-1 and PC-2 methods. CDF of *SINR* 0 dB for the system without power control at *FUE* achieved 0 or 0%, whereas for the systems with PC-1 and PC-2 at *FUE* achieved the values of CDF of *SINR* 0 dB at 0.2 (20%) and 0.275 (27.5%), respectively.



(a) Co-Tier Interference

(b) Cross-Tier Interference



(c) Total Interference

Fig. 2. The Simulation Results for CDF of *SINR*: (a) Co-Tier Interference, (b) Cross-Tier Interference, and (c) Total Interference

From the simulation results, it can be said that both power control methods performs as expected. When the interferences are to large by so *SINR*s is degraded achieving below the target *SINR*, power control responses by increasing the transmitting powers resulting in the improved CDF of *SINR*. It can be seen from the simulation results for CDF of *SINR* at *MUE*. In contrast, when the estimated *SINR* achieves the values that are greater than the target *SINR*, the power control works by reducing the transmitting powers causing the reduced *SINR* values and hence decreases the CDF of *SINR*. It is reflected in the simulation results for the CDF of *SINR* at *FUE*. It is a trade-off by applying power control methods in two-tier femtocell-macrocell cellular communication networks. Improving the performance in one tier will be decreasing the performances in another tier.

IV. CONCLUDING REMARKS

This paper considers power control method for the purpose of interference management in two-tier; femtocell-macrocell; cellular networks. The downlink transmission has been taken into consideration. The network setting taken into account was multi cell scenario consisting of three macrocell in which each macrocell was deployed ten femtocells. All macrocells and femtocells were in the downlink transmissions. By this setting, two types of interferences have come out to the network namely co-tier and cross-tier interferences. This paper considered both co-tier and cross-tier interferences in addition to the total interferences at the downlink transmission for both users at macrocell and femtocell areas. Two types of power control methods called as PC-1 and PC-2 in this paper have been proposed and explored. Basically, both power control methods are based on the estimated *SINR* at the users of macrocell and femtocell, *MUE* and *FUE*. The feedback is needed in order the base stations, *eNB* and *HeNB*, to decide whether it is to increase or to decrease the transmitting powers of *eNB* and *HeNB* based on the estimated *SINR* at the current time and the target SINR. The extensive simulation was carried out and the results of network performance in terms of

SINR have been collected and analyzed and the simulation results are presented in term of CDF of *SINR*. The simulation results show that both power control methods work well in the simulation setting considered.

The simulation results in this paper can be extended for other network performance parameters such as Bit Error Rate (BER) and network throughput and it is as the near future plan. The extended work of this paper can also consider the fading channel to accommodate the mobility of users in femtocell and macrocells and in evaluating both power control methods more precisely.

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