Interference Management Using Power Control for Uplink Transmission in Femtocell-Macrocell Cellular Communication Network

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Abstract — **Femtocell is a small cell of 10-30 meters radius deployed in the existing larger cell (macrocell) forming two-tier femtocell-macrocell cellular network. However, the deployment of femtocell into the existing macrocell cellular network is facing more complex interference problems. This paper focuses on interference management using power control methods for the uplink transmission of such two-tier cellular networks. Types of interferences considered in this paper are co-tier (femtocell-to-femtocell and macrocell-to-macrocell), cross-tier (femtocell-to-macrocell and macrocell-to-femtocell), and total interferences. This paper considers multi-cell scenario of cellular communication network consisting of three macrocell cellular networks in which each macrocell is deployed 10 femtocells. This paper analyzes one of three macrocells on the uplink transmission with the other two macrocells on downlink transmissions. All femtocells are on the same transmission conditions as its co-located macrocells. This paper observes one of ten uplink femtocells on the observed uplink macrocell. Through simulation, this paper firstly analyzes co-tier, cross-tier, and total interferences for the system without power control. The results of Signal to Interference plus Noise Ratio (SINR) in term of its Cumulative Distribution Function (CDF) for the system without power control are used as a baseline system. Then, this paper proposes the use of two power controls namely PC-1 and PC-2 in this paper which both power controls work based on the estimated current SINR. Both power control methods are also to make sure that the transmitting power of the users in the observed base stations (eNB/HeNB in 4G cellular network terminology) will not exceed maximum or minimum of its allowed transmitting power (uplink transmission case). The simulation has been carried out and the SINR results were collected and compared to baseline system. The simulation results show that PC-1 and PC-2 outperform the baseline system in terms of CDF of SINR.**

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

I. INTRODUCTION

Over last decades, cellular communications have been one of technologies that grows rapidly. It is evidently reflected by the high demands of user for new connections and services in terms of quality and capacity of the networks. The users' demands of cellular communication services suggest continuously the academia and industries to find the ways providing the high capacity and high quality of the system which is demanded almost similar to its counterpart of wired communication system.

It is well-known that making the smaller cell size in cellular communication system can improve the capacity of system. Femtocell has emerged as a small cell technology with 10-30 meters of radius, low-power, and low-cost to improve the quality of service in cellular communication system for the indoor users while at the same time it can enhance the capacity of the system [1]. Femtocell base station which is called as Home evolved Node B (HeNB) is normally deployed in the area of macrocell which the coverage area of macrocell is determined by the transmitting power of its base station called as evolved Node B (eNB) in Fourth Generation (4G) cellular communication network. Femtocell operates on the band of same licensed spectrums owned by the network operators and hence the same frequency band as their macrocell and connect to cellular networks through the fixed broadband access such as Digital Subscriber Line (DSL) [2]. The deployment of femtocells in the macrocell areas forms two-tier cellular networks; macrocell as the tier of underlay network and femtocell as the tier of overlay network. Due to the usage of same licensed frequency bands between macrocells and femtocells, two-tier femtocell-macrocell cellular network shows up more complex interference problems. The interference can emerge on the same tiers and different tiers which are called as co-tier and cross-tier interferences. Thus, it is important to manage the emerging interference problems in such two-tier femtocell-macrocell cellular networks. One can argue that the interference problems can be mitigated by separating the frequency bands for the usages between femtocells and macrocells so that the interferences can be minimized. However the way of such frequency band partitioning is not preferred by the cellular network operators. It is because of there will be inefficiency of frequency band usage allocated for the femtocells. When femtocells are rarely deployed in the area of macrocells, those frequency bands allocated for the femtocells will be wasted.

Managing the interferences problems in two-tier femtocell-macrocell cellular networks has received much attention by the researchers from academia and industries. In [3], the authors discuss the interference issues regarding to the deployment of femtocells in the macrocell for Orthogonal Frequency Multiple Access (OFDMA) cellular networks. And then, the authors present some approaches for the uplink and downlink transmissions available in the literatures and present

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the open challenges for the interference problems remaining in deploying the OFDMA-based femtocell over macrocell. One approach in managing the interference for two-tier OFDMA-based femtocell presented in [3] is power control.

The interferences in two-tier femtocell-macrocell cellular network can emerge in both uplink and downlink transmissions. This paper focuses on the interference problems for the uplink transmission in OFDMA-based two-tier cellular network in which in the uplink transmission uses Single Carrier Frequency Division Multiple Access (SC-FDMA) for 4G cellular network. The approach explored for the interference management in this paper is using power control. Two power control methods are proposed and studied namely power control 1, PC-1, and power control 2, PC-2. There is a significant number of power control methods proposed in the literatures for mitigating the interference problems due to the deployment of femtocells over macrocell that few to mention it are in [4-7]. To the best our knowledge, there are few literatures that have considered power control for the multicell cellular network scenario for the OFDMA-based femtocells, such as [5] and [8]. In [5] and [8], the authors presented the analytical model for two-tier femtocell-macrocell cellular network in multi-cell scenarios which is different with our paper in term of the methodology. Then, this paper studies the power control methods for the purpose of interference management in multicell cellular network scenario for two-tier femtocell-macrocell cellular network suitable for the usage in the cellular network that is likely applied the frequency reuse of 1 such as OFDMA-based cellular network in 4G cellular network.

The rest of this paper is structured as follow. Following this introduction section, Section 2 describes the system model considered in this paper. Section 3 describes the simulation parameters and settings, and also presents and discusses the simulation results. The paper concludes the findings and recommends the possible extending results in Section 4.

II. SYSTEM MODEL

In this paper, two-tier femtocell-macrocell cellular network is considered. Three macrocell systems are deployed as underlay network. One macrocell system is on the condition of uplink transmission, the other two macrocell sytems are on the downlink transmissions. The one that is uplink macrocell system is observed. In each macrocell, j femtocell systems are randomly deployed as overlay network. It is assumed that all femtocell systems are in indoor locations. Each femtocell system is on the same transmission conditions as its underlying macrocell system; femtocell systems which appear in uplink macrocell system are on the uplink transmission conditions and femtocell systems which are on the downlink macrocell system are on the downlink transmission conditions. In each macrocell and each femtocell are deployed randomly m macrocell user equipment (MUE) and n femtocell user equipment (FUE), respectively. Fig. 1 shows three macrocell systems: macrocell 1, macrocell 2, and macrocell 3 indicated by evolved Node B 1 (eNB_1), eNB_2, and eNB_3, as its base transceiver stations, respectively. For the clarity, in Fig. 1 it is depicted one femtocell only at each macrocell. Each femtocell is indicated by Home eNB: $HeNB_1$ in macrocell 1, $HeNB_2$ in macrocell 2, and $HeNB_3$ in macrocell 3. Let P_{tx} indicate the transmitting power by the transmitter (User Equipment: Macrocell User Equipment (MUE) or Femtocell User Equipment (FUE) for the uplink transmission case or $eNB/HeNB$ for the downlink transmission). Thus, the received power, P_{rx}, at the receiver side can be calculated as below [9].

$$P_{rx} = P_{tx}.K.d^{-\alpha}.Fd.Sd \qquad (1)$$

where:

P_{tx} : Transmitter's power (in the power unit)
K : a constant that characterizes the path loss
d : the distance between the transmitter and the receiver (in the length unit)
α : the path loss exponent ($3 \le \alpha \le 4$ for the urban area)
Fd : the fading effect component
Sd : the shadowing effect component.

In this paper, it does not consider the fading and shadowing effect components, so $Kd^{-\alpha}$ characterizes the path loss caused by the distance. In this case, $P_{tx}Kd^{-\alpha}$ denotes the received power at the distance d. By not considering fading and shadowing effects, $Kd^{-\alpha}$ can be denoted as a propagation model. Many propagation models have been proposed in the literatures. The one that is suitable and adopted in this paper is the propagation model documented in 3GPP document [10]. That propagation model in decibel (dB) unit is stated as follow.

For the macrocell system:

$$PL_{UE-eNB}(dB) = 15.3 + 37.6log_{10}(d) + L_{ow} \qquad (2)$$

For UE to the femtocell system:

$$PL_{UE-HeNB} = 127 + 30log_{10}\left(\frac{d}{1000}\right) \qquad (3)$$

where:

PL_{UE-eNB} : path loss from User Equipment (*MUE* or *FUE*) to *eNB*;
$PL_{UE-HeNB}$: path loss from User Equipment (*MUE* or *FUE*) to *HeNB*;
d : the distance between the transmitter and receiver (in meters);
L_{ow} : the penetration loss caused by the wall between the transmitter and the receiver.

On the observed macrocell system (eNB_1) the Signal to Interference Noise plus Noise Ratio (*SINR*) at eNB_1 for User Equipment k (UE_k) can be calculated as the following.

$$SINR_{UE_k,eNB_1} = \frac{P_{rx_{UE_k,eNB_1}}}{I_{cross\_total}+I_{co\_total}+N} \qquad (4)$$

where:

$P_{rx_{UE_k,eNB_1}}$: the received power at eNB_1 by the transmitting power from UE_k;
I_{cross_total} : the total of cross-tier interferences caused by the transmitting power of other surrounding *eNB* (eNB_2 and eNB_3);
I_{co_total} : the total of co-tier interferences caused by the transmitting power of other tier ie UE in femtocell and HeNB from other macrocell systems;
N : the power of system noise.

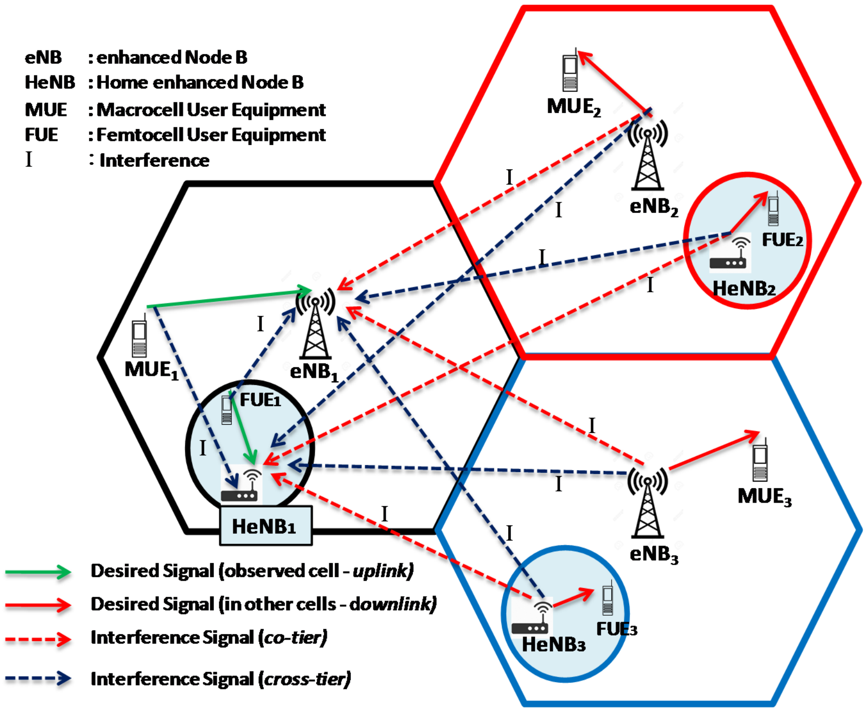


Fig. 1. Three Macrocell with One Femtocell Each: Co-located Femtocell and Macrocell on the Same Transmission Conditions, One Observed Macrocell and One Observed Femtocell on Uplink Transmissions, Other Two Macrocells and Two Femtocells on Downlink Transmissions

$P_{rx_{eNB_1UE_k}}$, each of cross-tier, and co-tier interferences *I* can be calculated by Eq. 1 considering the distance between the transmitter and *eNB₁*. In this paper, the SINR distribution of HeNBs in the observed macrocell is also analyzed and Eq. 4 can be used by changing the indices accordingly.

2.1 Considered Power Control Methods

Power control is used as interference management in this paper. In order to reduce the effects of interferences it can be done by controlling the transmitting power of the desired transmitter. It is the numerator of Eq. 4 containing the transmitting power of desired transmitter, P_{txUE_k}. The transmitting power of desired transmitter at the current time, $P_{txUE_k}(t_i)$, will be controlled, i.e. increased or decreased or remained the same at the next time of frame transmission resulting in a new value of transmitting power, $P_{txUE_k}(t_{i+1})$. In this paper it is introduced δ as a parameter of power control in increasing and decreasing the transmitting power. The δ will increase or decrease the transmitting power at the next time of frame transmission based on the estimated value of current time SINR ($SINR_{est}(t_i)$). $SINR_{est}(t_i)$ will be compared to the pre-determined $SINR_{target}$. According to this intuition, this paper introduces another parameter that indicates whether the value of δ will $+\delta$, $-\delta$, or 0. This parameter of indicator is to be denoted as *c*. In summary, the general expression of $P_{txUE_k}(t_{i+1})$ for power control is written as below.

$$P_{txUE_k}(t_{i+1}) = P_{txUE_k}(t_i) + c.\delta \quad (5)$$

The value of *c* will be determined according to the value of $SINR_{est}(t_i)$. There are three conditions of $SINR_{est}(t_i)$ that determine the value of *c*, i.e.: (1) if $SINR_{est}$ is equal to $SINR_{target}$, then value of *c* will be equal to 0; (2) if $SINR_{est}$ is less than the $SINR_{target}$, then the value of *c* will be +1; (3) if $SINR_{est}$ is greater than the $SINR_{target}$, then the value of *c* will be -1. The expression to determine the value of *c* is written as the following.

$$c = \begin{cases} +1; & \text{if } SINR_{est}(t_i) < SINR_{target} \\ 0; & \text{if } SINR_{est}(t_i) = SINR_{target} \\ -1; & \text{if } SINR_{est}(t_i) > SINR_{target} \end{cases} \quad (6)$$

Another condition has to be met by the power control method is that the value of $P_{txUE_k}(t_{i+1})$ in Eq. 5 cannot exceed the value of maximum of user equipment transmitting powers and cannot be lower than the minimum user equipment transmitting powers, P_{max} and P_{min}, respectively. Then, the final value of $P_{txUE_k}(t_{i+1})$ at the next time of frame transmission as the output of power control method will be determined based on the below expression. To avoid the misleading, $P_{txUE_k}(t_{i+1})$ that is calculated in Eq. (5) is re-denoted as $P'_{txUE_k}(t_{i+1})$ in the below expression.

$$P_{txUE_k}(t_{i+1}) = \begin{cases} min\left[P'_{txUE_k}(t_{i+1}), P_{max}\right]; & \text{if } SINR_{est}(t_i) < SINR_{target} \\ P'_{txUE_k}(t_{i+1}); & \text{if } SINR_{est}(t_i) = SINR_{target} \\ max\left[P'_{txUE_k}(t_{i+1}), P_{min}\right]; & \text{if } SINR_{est}(t_i) > SINR_{target} \end{cases} \quad (7)$$

The functions of $max[a,b]$ and $min[a,b]$ are the functions that return the maximum and minimum values, respectively, among the given set in the function arguments that are a and b.

In this paper, the variation of δ determine the power control methods that are explored. This paper considers two variations in determining the value of δ, and hence this paper calls it as power control method 1 (PC-1) and power control method 2 (PC-2) for each variation of δ. These two power control methods are discussed in the following.

Power control method 1 (PC-1) uses a constant value of δ. The value of δ is set to a fixed value in PC-1 and this value is to be a parameter in the simulation. In power control method 2 (PC-2), the value of δ is determined according to the absolute value of the difference between the value of estimated current SINR, $SINR_{est}(t_i)$ and the value of target SINR, $SINR_{target}$. In short, the value of δ for PC-2 is calculated according to the following expression.

$$\delta = \left|SINR_{est}(t_i) - SNIR_{target}\right| \tag{8}$$

III. SIMULATION PARAMETERS AND RESULTS

3.1 Simulation Parameters and Setting

Extensive simulation experiment has been carried out. This paper considers the network scenorio as shown in Fig. 1. Three macrocell are deployed with the positions of eNB at the center of each macrocell corresspondingly. Each macrocell has the radius of 500 meters which is relating to the macrocells in the dense urban area. For each macrocell, a number of MUEs are deployed. Some variations of MUE number have been done and the number of MUEs of 30 is determined to learn the CDF of SINR. Too litle MUEs that are deployed cannot achieve the goals of the study as well as too many MUEs that are deployed will not achieve this paper goal. A number of HeNBs with the radius of 10 meters [1] are deployed in each macrocell. Ten HeNBs have been determined due to the reasons of generated interferences. It is assumed that all HeNBs are in the indoor area. Each HeNB can support 3 – 5 FUEs [1]. Based on this specification, in the simulation it has been determined that 4 FUEs are deployed for each femtocell area. Furthermore, it is assumed that the frequency reuse factor is 1 and the macrocell and femtocell share the frequency resources. The maximum transmitting powers for eNB, HeNB, and user equipments (MUE and FUE) are set to 46 dBm, 20 dBm, and 23 dBm, respectively [11]. Meanwhile, the initial values of transmitting power for eNB and HeNB are set to 34 dBm and 15 dBm, respectively. Since this paper considers the uplink transmissions, those values will be kept constant during the simulation for both systems without and with power control methods. The initial value of transmitting power for the user equipment, both MUE and FUE, is set to 20 dBm. This value will be changing accordingly during the simulation time for the system with power control and be constant for the system without power control. The noise power density is set to -174 dBm/Hz [11]. The system bandwidth is 20 MHz [12]. The penetration loss (L_{ow}) is set 10 dB [9]. The value of δ for power control method 1 is set to 1 dB. Table 1 summarizes these simulation settings.

3.2 Simulation Results and Discussions

The simulation for the systems without power control, with power control method 1 (PC-1), and with power control method 2 (PC-2) have been carried out. For these three difference system conditions, the results for CDF of SINR for co-tier, cross-tier, and total interferences have been collected and compared. Since this paper considers uplink transmission, SINRs were measured at one of three eNBs, i.e. eNB_1 and one of HeNBs deployed in eNB_1 (namely $HeNB_1$). The simulation was run for 100 times of iteration. The average values of CDF of SINR for those 100 iterations are plot in Figure 2 (a), (b), and (c) for co-tier, cross-tier, and total interferences, accordingly.

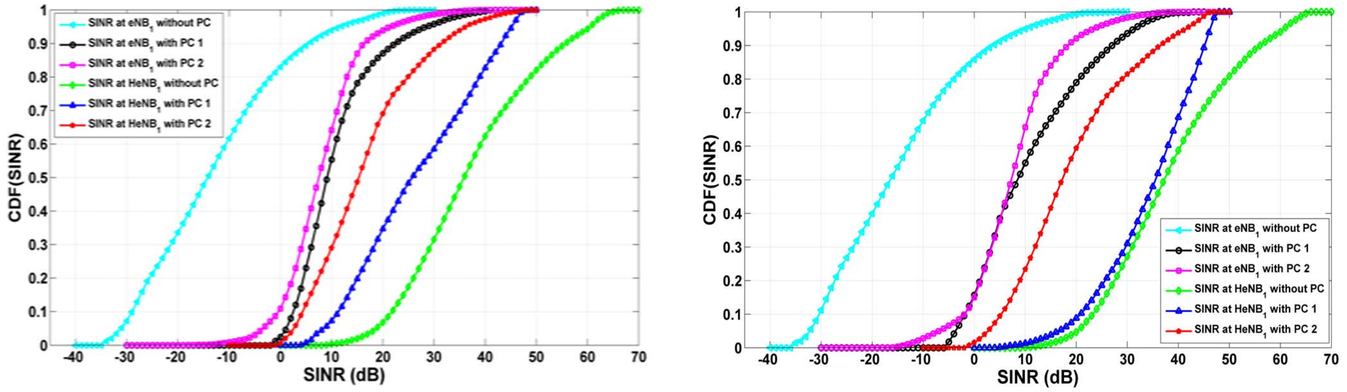
TABLE I. SIMULATION PARAMETERS

No.	Parameter	Value
1.	Number of Macrocells	3
2.	Number of Femtocells in Each Macrocells	10
3.	Number of Macrocell User Equipments (MUE)	30
4.	Number of Femtocell User Equipments (FUE)	4
5.	Radius of Macrocell	500 meters
6.	Radius of Femtocell	10 meters
7.	Maximum transmitting power of eNB	46 dBm
8.	Maximum transmitting power of HeNB	20 dBm
9.	Maximum transmitting power of User (MUE and FUE)	23 dBm
10.	Noise Power Density	-174 dBm/Hz
11.	System Bandwidth	20 MHz
12.	Penetration Loss (L_{ow})	10 dB
13.	δ for the Power Control Method 1 (PC-1)	1 dB
14.	Simulation Time (Number of Iterations)	100

In all Figs. 2 (a), (b), and (c), the cyan and green lines show the CDFs of SINR for the systems without power control at eNB and HeNB, respectively. Meanwhile, the black and dark blue lines depict CDFs of SINR for the systems with PC-1 method at eNB and HeNB, correspondingly and the magenta and red lines show CDFs of SINR for the systems with PC-2 method at eNB and HeNB, respectively.

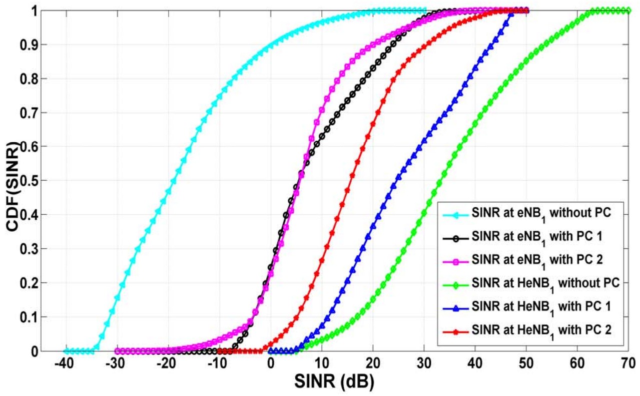
All simulation results show that as SINR increases, CDF of SINR raises. For co-tier interference in Fig. 2 (a), it can be seen that at eNB_1 both PC-1 and PC-2 methods significantly improve CDFs of SINR compared to without power control. At SINR of 0 dB, the system without power control achieves CDF of 0.82 or 82% which is reduced to 0.03 or 3% by using PC-1 method and to 0.1 or 10% by PC-2 method. The improvements of CDFs of SINR at eNB can be said achieving 79% and 72% by PC-1 and by PC-2, respectively. Comparing the achieved CDF by using PC-1 and PC-2, PC-1 outperforms PC-2 by 7%. At $HeNB_1$ and at SINR of 0 dB, all systems of without power control, with PC-1 and with PC-2 achieve CDF of 0% which means that improvements SINR perfomance at eNB by PC-1 and by PC-2 considering co-tier interference do not degrade the Quality of Service (QoS) at HeNB.

Considering cross-tier interference in Fig. 2 (b), CDFs of SINR at eNB_1 for the system without power control achieves 0.86 or 86%, meanwhile by using PC-1 and PC-2 methods CDFs of SINR of 0 dB are decreased 0.15 (15%) and 0.16 (16%), respectively. The systems with PC-1 and PC-2 methods outperform the system without power control by 70%



(a) Co-Tier Interference

(b) Cross-Tier Interference



(b) Total Interference

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

and 71%, respectively in terms of CDF of SINR at 0 dB. Comparing PC-1 and PC-2 methods, the system with PC-1 outperforms the system with PC-2 by 1%. At $HeNB_1$, CDFs of SINR of 0 dB achieve 0 (0%) for the systems without power control and with PC-1 method, while the system with PC-2 acvieve 0.02 or 2%. It means that improving SINR performance at eNB_1 for cross-interferences will not degrade the SINR performance at $HeNB_1$ with PC-1, but will be degrade slightly the SINR performance of the system with PC-2. It is as excpected. The power control works to keep the level of SINR to the SINR target.

Both interferences in Figs. 2 (a) and (b) are summed up to result in the total interference which is plotted in Fig. 2 (c). At eNB_1, the CDFs of SINR of 0 dB achieve 0.9 (90%), 0.25 (25%), and 0.22 (22%) for the systems without power control, with PC-1 method, and with PC-2 metod, respectively. Meanwhile, at $HeNB_1$, CDFs of SINR of 0 achieve 0(0%) for the system without power control, 0 (0%) for the system with PC-1 method, and 0.02 (2%) for the system for PC-2 method. It can said that considering total interferences, the system with PC-1 method outperforms the system without power control by 65% and outperforms the system with PC-2 method by 3%. Whereas, the system with PC-2 method outperforms the system without power control method by 68%.

IV. CONCLUDING REMARKS

This paper has been analyzed the interference problems in two-tier femtocell-macrocell cellular network at the uplink transmission. In this type of two-tier network, the co-tier and cross-tier interferences have been identified. For the purpose of managing the effects of those interferences in two-tier cellular network, this paper is studied the use of power control methods. Two power control methods have been studied called as PC-1 and PC-2. The extensive simulation has been carried out. Multi-cell scenario of macrocell cellular network has been considered composing of three macrocell with ten femtocells in each macrocell system. One of macrocell together with its ten femtocells is in the uplink transmission which this is the cells, one macrocell and one femtocell, that are going to be observed. Meanwhile, other two macrocells and its ten femtocells in each of these two macrocells are in downlink transmissions. The simulation results in term of SINR has been collected and analyzed. In this paper, the simulation results are presented on the graph of CDF of SNR. Three systems are analysed and compared; the systems without power control, the systems with PC-1, and with PC-2 for co-tier, cross-tier, and total interferences. The simulation results show that for co-tier interference, at eNB_1 both PC-1 and PC-2 methods significantly improve CDFs of SINR compared to without power control. It was the improvements of CDFs of SINR at eNB_1 achieving 79% and 72% by PC-1 and by PC-2, respectively. Whereas by both PC-1 and PC-2, the improvements SINR perfomance at *eNB*$_1$ by PC-1 and by PC-2 considering co-tier interference do not degrade the Quality of Service (QoS) at *HeNB*$_1$. For cross-tier interference, CDFs of SINR at *eNB*$_1$ for the system without power control achieved 86%, meanwhile by using PC-1 and PC-2 methods CDFs of SINR of 0 dB are decreased to 15% and 16%, respectively. The systems with PC-1 and PC-2 methods outperform the system without power control by 70% and 71%, respectively in terms of CDF of SINR at 0 dB. In this case improving SINR performance at *eNB*$_1$ for cross-interferences will not degrade the SINR performance at *HeNB*$_1$ with PC-1, but will be degrade slightly the SINR performance of the system with PC-2. It is as excpected. The power control works to keep the level of SINR to the SINR target. For the total interference, at *eNB*$_1$, the CDFs of SINR of 0 dB achieve 90%, 25%, and 22% for the systems without power control, with PC-1 method, and with PC-2 metod, respectively. Meanwhile, at *HeNB*$_1$, CDFs of SINR of 0 achieve 0% for the system without power control, 0% for the system with PC-1 method, and 2% for the system for PC-2 method. In considering total interferences, the system with PC-1 method outperforms the system without power control by 65% and system with PC-2 method outperforms the system without power control method by 68%. Overall, it can be concluded that PC-1 and PC-2 works well in the two-tier interference which give a good trade off between the performance in eNB and HeNB.

As for the near future plan, the simulation results can expanded with presenting and analyzing the other performance parameters. Other performance parameters can include bit error rate (BER) and throughput. This paper also can consider the mobility of user equipments which mean the channel modelling will include fading and shadowing. It is as the future works of this paper.

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REFERENCES

[1] J. Zhang dan G. D. L. Roche, “Femtocellss Technologies and Deployment”, John Wiley & Sons Ltd, United Kingdom, 2010.

[2] V. Chandrasekhar and J. G. Andrews, “Femtocell networks: a survey,” IEEE Communication Magazine, Vol. 46, No. 9, pp. 59–67, Sept. 2008.

[3] N. Saquib, E. Hossain, L. B. Le, dan D. I. Kim, “Interference management in OFDMA femtocell networks: issue and approaches”, IEEE Wireless Communication, Vol. 19, No. 3, pp. 86-95, June 2012.

[4] T. M. Ho, N. H. Tran, S. M. A. Kazmi, D. H. Kim, and C. S. Hong, “Distributed resource allocation for interference management and QoS guarantee in underlay cognitive femtocell networks”, 2016 18th Asia-Pacific Network Operations and Management Symposium (APNOMS), pp. 1-4, October 2016.

[5] F. Wang and W. Wang, “Analytical modeling of uplink power control in two-tier femtocell networks”, 2015 Wireless Telecommunications Symposium (WTS), pp. 1-6, April 2015.

[6] Q. Han et al., ”Hierarchical-Game-Based uplink power control in femtocell networks”, IEEE Transactions on Vehicular Technology, Vol. 63, No. 6, pp. 2819-2835, July 2014.

[7] T. M. Ho et al., “Power control for interference management and QoS guarantee in heterogeneous networks”, IEEE Communications Letters, Vol. 19, No. 8, pp. 1402-1405, August 2015.

[8] H. Y. Lee, Y. J. Sang, and K. S. Kim, “On the uplink SIR distributions in heterogeneous cellular networks”, IEEE Communications Letters, Vol. 18, No. 12, pp. 2145-2148, December 2014.

[9] J. M. Kelif, M. Coupechoux, and P. Godlewski, “On the dimensioning of cellular OFDMA networks”, Elsevier Physical Communication, Vol. 15, No. 1, pp. 10-21, February 2012.

[10] 3GPP TR 36.814 version 10.2.0 Release 10, “3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Further Advancements for E-UTRA Physical Layer Aspects (Release 9)”, European Telecommunications Standards Institute, March 2010.

[11] 3GPP TR 36.942 version 10.2.0 Release 10, “LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) System Scenarios”, European Telecommunications Standards Institute, May 2011.

[12] 3GPP TS 36.300 version 10.5.0, “LTE; Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description”, Stage 2 (Release 10), European Telecommunications Standards Institute, November 2011.