Performance Evaluation of Cell-Edge Femtocell Densely Deployed in OFDMA-Based Macrocellular Network

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***Abstract*—The demands for the better quality of services and system capacity are continuously increasing for the cellular wireless communication industry. Femtocell is a promising solution to enhance the capacity and coverage of cellular networks. Femtocell densely deployed in existing conventional macrocell or microcell of cellular networks which is known as Ultra Dense Networks (UDNs) is one of key technologies for 5G and beyond wireless cellular network. One crucial problem of UDNs is co-tier interference (femtocell to femtocell interference) and cross-tier interference (femtocell to microcell/microcell interference) that can cause performance degradation of the network. This paper investigates the co-tier and cross-tier interferences of UDNs in uplink transmission in which femtocells are located on the edge of microcell cellular networks. By this scenario, thus the users on the cell-edge of the neighborhood macrocells can contribute severe interferences to the evaluated cell-edge femtocells. And then, this paper evaluates the performance of aforementioned network scenarios through simulation experiments. Signal to Interference Noise Ratio (SINR) is used as a performance parameter. Two UDNs network scenarios are evaluated in the simulation, first scenario is 100 femtocells deployed randomly within the whole coverage area of macrocell and the second one is 100 femtocells deployed in outer area of macrocell which represents cell-edge of macrocell. The distribution of SINR of these two scenarios are measured in the simulation. The simulation results show that the performance degradation is much by cell-edge users of neighborhood macrocells (achieving 20%) which become important results for the further study in mitigating the interference problems of cell-edge femtocells in the UDN.**

Keywords*—*Ultra Dense Networks, cell-edge femtocells, cell-edge users, uplink transmission, SINR performance

I. Introduction

Inevitably the cellular wireless communication industry is known as a fastest growing technology in communication technology. The demands for the higher quality and capacity grow exponentially for this type of wireless communication technology over few last decades. Hence, the researchers from academia dan industry work together to develop a way to improve and to enhance the capacity and quality of cellular wireless communication services. Femtocells or small cells have received much attentions as the promising solution to increase capacity, quality, and coverage of larger cells (microcell and/or macrocell) in mobile wireless cellular networks [1]. Femtocells that are deployed densely in the area of macrocells create Ultra Dense Networks (UDNs) which is seen as one of key technologies for the 5G or beyond wireless cellular networks [2]. One of problems that need to be taken into account when deploying femtocells are the interferences. In light of this femtocell shares the same radio resources with the existing macrocells/microcells where it is deployed. The interferences can occur between same type of cells i.e. between femtocell to femtocell (co-tier interference) and different type of cells i.e. between macrocell/microcell to femtocell (cross tier interference). The interferences can occur in both uplink and downlink transmissions.

There are many solutions available proposed in the literatures to manage the interferences in such multi-tier or heterogeneous networks (refers to more than one type of cells appearing in the network) creating interference management techniques for such multi-tier or heterogenous cellular networks, such as by our power control [3-6], by radio resource allocation algorithm [7-8], etc. Excellent survey paper for the interference management for the femtocells is presented in [1].

Most of literatures about the interference management for UDNs was proposed considering the downlink transmission, just few to mention as in [7-8], whereas few literatures considered the uplink transmission for the UDNs [9-10]. In [11] the interference problems for the downlink transmission has been considered in UDN. The performance improvements have been performed by using clustering method using for cell-edge user K-Nearest Neighbor (KNN) algorithm. The simulation has been carried out and the results showed that the performance improvements was gained for the cell-edge and average users. However, the interference problems in [11] is different to the problems that we consider in this paper. Other researchers that considered the interference problems in UDN for the downlink transmission is the authors in [12]. They have considered two step joint scheduling and clustering scheme namely TJSC to improve the performance in heterogeneous wireless cellular network. A novel load-aware clustering is performed at the first step and then a fair graph-coloring based inter-cell resource scheduling is carried out to optime the use of resources. Their simulation showed its results close to the optimal.

However, it is necessary to investigate the interference models in UDN, especially for the femtocells are located in the cell-edge of macrocell for the uplink transmission. How much the performance degradation of cell-edge femtocell is subject to further investigation. This paper is purposed to address this research question. This paper uses the Signal to Interference Noise Ratio (SINR) as the performance parameter to be evaluated. In [2], the authors proposed the SINR's prediction algorithms for the uplink transmission in UDN. However, the authors in [2] considered the co-tier interferences only in their system model. This paper considers both of co-tier and cross-tier interferences for the femtocells in the uplink transmission densely deployed in macrocells of OFDMA-based cellular networks in which in the uplink

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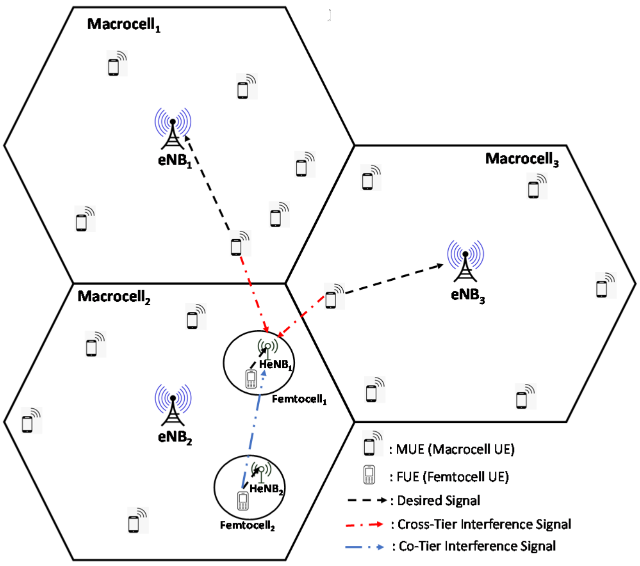

Fig. 1. Interferences on the uplink transmission observed on a femtocell.

transmission system uses Single Carrier Frequency Division Multiple Access (SC-FDMA).

This paper is structured as the following. Following this introduction section, the details of the considered system model in this paper is described in Section II. Section III discusses the system model for the simulation, its simulation parameters, simulation results and its discussion. Section IV concludes the paper as well as giving the future work.

II. SYSTEM MODEL

This paper considers the system of three urban macrocells of OFDMA-based cellular network. The system is granted to use a certain frequency bandwidth. The frequency bandwidth is divided into three bands of frequencies. Each macrocell uses different frequency radio resources and hence it uses the reuse factor of 3. In order to evaluate the femtocells' performance, one of those three macrocells (called as Umbrella Macrocell or UM in this paper) is deployed a certain number of femtocells within its coverage area and the other two macrocells have no femtocells deployed. The femtocells in the macrocell are assumed to have the reuse factor of 2 which use the same radio resources with the other two neighborhood macrocells, and hence the femtocells always use the different radio resources with its UM. By this model, co-tier interference (femtocell to femtocell interference) occurs between femtocells where femtocells exist in the same UM, but there no cross-tier interference (macrocell to femtocell interference) that is caused by the transmissions from/to UM. Each macrocell is deployed a certain number of User Equipments (MUEs). Uplink transmissions are considered in macrocells and femtocells. When femtocells perform uplink transmissions and all macrocells are also in uplink transmissions, therefore there are likely the interferences *(cross-tier interferences)* coming to Home e*nhanced* Node B (HeNB) of femtocells caused by MUE(s) communicating to its e*nhanced* Node B (eNB) of its macrocell (i.e. neighborhood macrocell of observed femtocells/macrocells), besides the co-tier interferences among femtocells that use the same radio resources. Fig. 1 shows the illustration of co-tier and cross-tier interferences occurring as described above. Blue and red lines indicate the co-tier and cross-tier interferences for the illustration purposes.

A. Channel Models

This paper uses the following pathloss models of the uplink transmission in the urban area which are according to 3GPP TR 36.814 version 10.2.0 Release 10 [13] and 3GPP TR 36.922 version 10.0.0 Release 10 [14].

Pathloss model for the uplink transmission in femtocell can be calculated using Eq. (1) [14].

$$L_{femto} = 15.3 + 37.6 \log(d) \quad \text{(dB)} \tag{1}$$

For the uplink transmission in macrocell can be calculated using Eq. (2) [13].

$$L_{macro} = 127 + 30 \log\left(\frac{d}{1000}\right) \quad \text{(dB)} \tag{2}$$

The symbol d in Eq. (1) and Eq. (2) is the distance between transmitter and receiver in meter.

B. Signal to Interference plus Noise Ratio Analysis

In the system model mentioned previously, when a femtocell serves its UE (called as Femtocell UE/FUE) with the UE's transmit power of P_{FU} i.e. on uplink transmission, it suffers the interferences coming from other femtocells (co-tier interference) that are using the same radio resources and also coming from MUEs with its transmit power of P_{MU} in the neighborhood macrocells (cross-tier interference), i.e. other macrocells on uplink transmission as well. The Signal to Interference plus Noise Ratio (SINR) at the observed HeNB of femtocell is defined as a ratio of a received power signal strength from the desired user (UE) to the other power signal strengths (Interferences) plus Noise power. Therefore, SINR can be calculated using the below equation [3].

$$SINR = \frac{P_{rx}}{\sum_{x=1}^{n} I_x + \sum_{y=1}^{m} J_y + N} \tag{3}$$

where,

P_{rx} : the received power on the HeNB of observed femtocell (in mWatt)

I_x : the co-tier interference from FUEs in other femtocells (in mWatt)

J_y : the cross-tier interference from MUEs in other macrocells (in mWatt)

N : power of thermal noise in the system (in mWatt).

The received power (P_{Rx}) on the observed femtocell from the desired FUE (the desired signal) or other FUEs in other femtocells (as the co-tier interferences) can be calculated as below [3].

$$P_{Rx}(\text{dBm}) = P_{FUE}(\text{dBm}) - L_{femto}(\text{dB}) \tag{4}$$

where P_{FUE} is the transmit power on FUE or other FUEs in dBm.

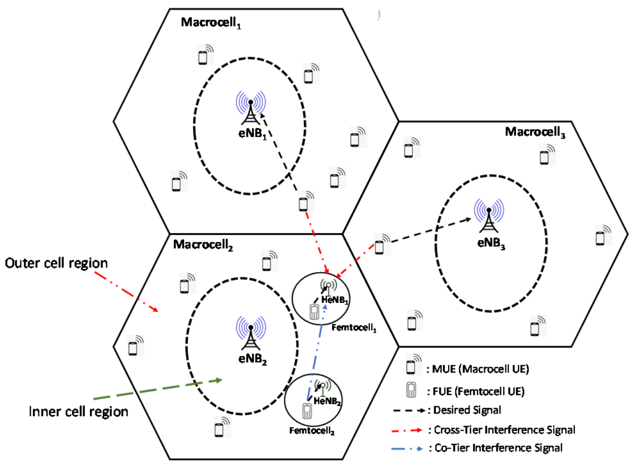

Fig. 2. The scenario to observe the cell-edge femtocells regarding the effects of co-tier interference and cross-tier interference caused by cell-edge MUEs.

The cross-tier interferences coming from MUEs are calculated as [3]:

$$J_k(\text{dBm}) = P_{MUE}(\text{dBm}) - L_{macro}(\text{dB}) \quad (5)$$

where P_{MUE} is the power transmit of MUE in dBm.

III. Simulation Setting, Parameters, and Results

In the simulation, two system scenarios have been considered. The first scenario is as shown in Fig. 1. A certain number of femtocells and MUEs are deployed randomly in the whole coverage area of one macrocell. In other two macrocells, a certain number of MUEs are deployed randomly without femtocells deployed. The second scenario is shown in Fig. 2. Each macrocell is divided into two areas (outer cell and inner cell regions) which is bordered with a circle (with the certain radius long that is smaller than the radius of macrocell) as shown in Fig. 2. Not as in the first scenario, in the second scenario the femtocells and MUEs are deployed only in the outer cell regions of a macrocell. It is purposed to observe the performance of cell-edge femtocells in regards to the cell-edge MUEs. For both scenarios, in each femtocell's coverage area it is randomly deployed one FUE which is always active (i.e. transmitting the signal to HeNB). In this paper, the scenario in Fig. 1 and Fig. 2 are called as System A and System B, respectively.

A. Simulation Parameters

The simulation programming codes has been developed to simulate the aforementioned scenario models using MATLAB software. In the simulation, the number of macrocells generated is 3 with the reuse factor of 3. In one of three macrocells, a number of femtocells and a number of MUEs are deployed. The femtocells is applied the reuse factor of 2. In the simulation, the number of femtocells and the number of MUEs are increased in step from 1 until 100 femtocells and from 1 to 100 MUEs. The system bandwidth is set to 10 MHz. The radius of macrocell and femtocell are given to 1 km and 30 metres, respectively. The radius of a circle that divides a macrocell area to inner and outer cell regions is set to 750 metres. The system noise (thermal noise) has power spectrum density of -174 dBm/Hz. SINR values are collected for each number of femtocells and then the Cumulative Distribution Function (CDF) of SINR when the femtocells and MUEs are one hundred each is analyzed. Note that all simulation results were collected by running the simulation program for 100 times and the SINR values are averaged and presented. The parameters used in the simulation are summarized in Table 1.

TABLE I. Simulation Parameters

No.	Parameter	Value
1.	Number of macrocells	3
2.	Number of femtocells and MUEs (in step)	100 (Maximum)
3.	System bandwidth [15]	10 MHz
4.	The radius of macrocell [16]	1 km
5.	The radius of femtocell [16]	30 metre
6.	Reuse factor for macrocell	3
7.	Reuse factor for femtocell	2
8.	The radius of circle to border inner and outer of macrocell [16]	750 metre
9.	The transmit power of MUE and FUE [14]	23 dBm
10.	Noise Power Density [3]	-174 dBm/Hz
11.	The number of iterations	100 times

B. Simulation Results and Discussion

As mentioned earlier, in the first experiment the number of femtocells and the number of MUEs are in step increased. And then, the SINR values of each number of femtocells collected in the simulation. Fig. 3 shows the simulation results for the performance of SINRs versus the number of femtocells. As the number of femtocells is increased, the SINR performances decrease for both systems A and B. It is understood that it is due both interferences; co-tier and cross-tier interferences, are proliferated. As expected, the SINR performances for the System B is worse than the System A. It means that the cell-edge femtocells suffer much interferences than the femtocells are located randomly in the whole area of macrocell (including in the region of inner cell). The major interferences are from the MUEs located in the outer cell region of macrocells (cell-edge MUEs).

Figs. 4 and 5 depicts the Probability Density Function (PDF) of SINR and the Cumulative Distribution Function (CDF) of SINR when the number of femtocells and MUEs are one hundred each, respectively. It can be seen (from Fig. 5) that in general the distribution of SINR in System B is worse than System A. In average, the mean of SINR achieved 5 dB for the System B and 9 dB for the System A. If we target the SINR of 10 dB to serve a certain type of service, therefore

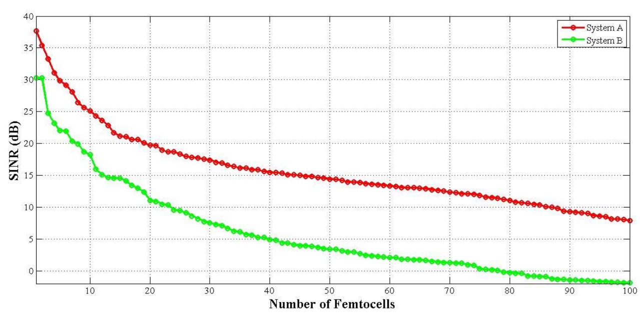

Fig. 3. Simulation results for the SINR performances of System A and System B with the effect of the number of femtocells increased.

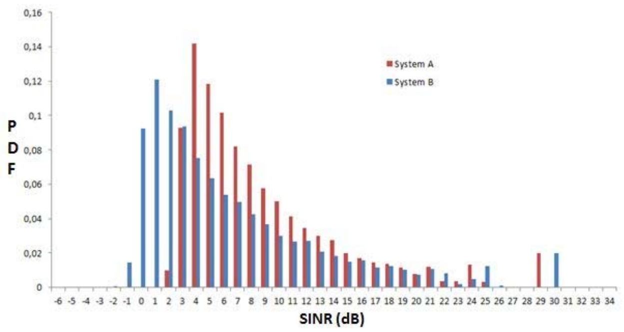

Fig. 4. The comparison of Probability Density Function (PDF) of SINR for System A and System B.

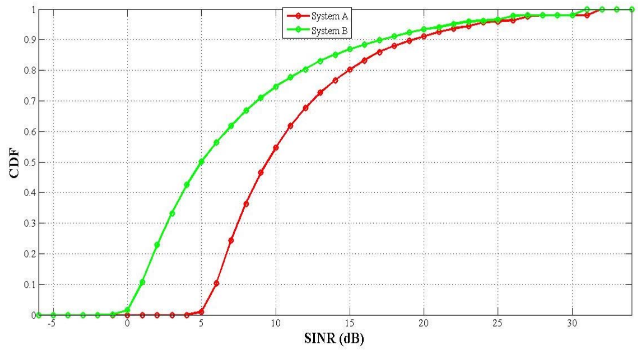

Fig. 5. The comparison of Cumulative Distribution Function (CDF) of SINR for System A and System B.

55% of femtocells in System A is not catered, whereas for the System B, 75% of femtocells has the SINR below 10 dB. In other word, it can be said that the SINR performance for the femtocells which are located only on the cell-edge of macrocell (System B) degrades 20% compared with the randomly located femtocells in the whole area of macrocell. This result is useful to be taken as a consideration in deploying the femtocells in the cell-edge area of macrocell and to explore the solution to address it. One possible solution to design is a radio resource allocation algorithm, by so it is expected that the co-tier and cross-tier interferences can be reduced. It is a subject to our on-going study.

IV. Conclusion and Future work

This paper evaluates the performance of femtocells densely deployed in the macrocell of OFDMA-based cellular network, especially the femtocells in the cell-edge locations of macrocell coverage (System B). The paper considers uplink transmissions on both of femtocells and macrocells. The simulation experiments have been carried out in MATLAB and the simulation results were compared to the femtocells and MUEs which are deployed randomly in the whole area of macrocells (System A). The performance parameter that is used to evaluate the performance of the systems is SINR. The simulation results show that the performance of the system with the femtocells located on the cell-edge area of macrocell degrades much. The SINR performance of System B degrades 20% compared with the system A. The performance degradation is caused much by the cell-edge MUEs of neighborhood macrocells. This result is expected to be useful in considering to deploy the femtocells (or other type of small cells) in the cell-edge areas of existing macrocells or microcells as well as to find the solutions to cope with. Finding the solution is the subject for our future studies.

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