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Relay-Based Clustering Method for Interference Management in Heterogeneous Wireless Cellular Network

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Abstract— Femtocell is one of solutions to improve quality of services and network capacity for users in indoor areas. Radio resources used by femtocells are shared from macrocell network, thus it saves the use of frequency spectrum. However, one of problems in deploying femtocells within coverage area of macrocells is interference due to radio resources sharing between femtocells and macrocells. It creates interferences called as cross-tier (macrocell-femtocell/femtocell-macrocell) and co-tier (macrocell-macrocell/femtocell-femtocell) interferences. This paper proposes a relay-based clustering method to mitigate interference in femtocells located in the whole edge area of macrocell and the cell edge area of sectorized macrocells. Relay nodes are deployed statically (fixed location) in the neighboring macrocell area. Relay node will recruit their members based on the shortest distance. Certain relay node's members do not need to transmit large amounts of power to enhanced Node B (eNB), such that interference from Macrocell User Equipment (MUE) to Home enhanced Node B (HeNB) can be minimized. Simulation experiments has been carried out and optimistic results for the sectorized macrocells scenario show that Signal-to-Interference-plus-Noise-Ratio (SINR) of femtocells for the conventional system that does not reach the targeted SINR of 20 dB is 87%. Meanwhile, after applying the relay-based clustering method, SINR value of femtocells below or equal to 20 dB reaches 72%. Optimistic results for throughput and Bit Error Rate (BER) show improvement of 15% and 14%, respectively. It has been shown that the relay-based clustering method can provide better performance compared to the conventional system even for femtocells densely deployed.

Keywords— cross-tier interference, co-tier interference, relay-based clustering method, interference management, femtocell-macrocell network, cell edge area

I. INTRODUCTION

The advancements in cellular communication technology in the last few decades has encouraged the growth of data traffic greatly. High increase in data traffics makes a lot of demand from users to obtain excellent capacity and service quality provided by their mobile devices through the network. This demand mostly comes from users who are indoor residing at house and at office [1]. To achieve these requirements, some standards for high-speed communication have been developed. Some of these standards are 3GPPs High Speed Packet Access (HSPA), Long Term Evolution (LTE), and Ultra-Wide Band (UWB) [2]. However, indoor users cannot experience good quality of services from conventional macrocells of wireless communication networks due to blocking from some objects, (e.g., walls, doors, and windows) [3]. Therefore, some indoor users use a network of small cells known as femtocells that are connected to their preferred service provider. Femtocells can provide a robust network in indoor areas and provide superior quality of service for voice traffic [4].

Deploying femtocells within macrocell area needs often a trade-off. When a Home enhanced Node B (HeNB) or Femtocell Base Station (FBS) is placed in indoor area, some Macrocell Base Station (MBS) signals are transmitted from outdoor to indoor, and the signal from the FBS spreads to the outdoor area. This is why it causes unwanted signals to occur. It is referred to as interference. This leakage of signals from HeNB to eNB or vice versa can be caused many factors such as the unproper installation of the equipment, the material of surrounding building or objects, etc. Moreover, due to the limited frequency spectrum, femtocells and macrocells share the same radio resources and form a heterogeneous wireless cellular network. In other words, deploying femtocells in macrocell area creates interference issues [4].

To overcome the interference problems, several studies have proposed interference management such as using radio resource allocation methods to mitigate co-tier interference between femtocells [5] - [11]. Ref. [5] discusses equitable resource utilization in Long Term Evolution (LTE)/LTE-Advanced femtocell networks. The authors propose a radio resource allocation scheme based on a hybrid spectrum allocation approach. Ref. [6] proposed a semi-clustering of victim-cell (SCVC) approach for the utilization and management of radio resources in a highly congested network environment. The SCVC technique works in identifying the status of the victim's femtocell user whether it is critical or non-critical. In [7], the authors proposed an efficient method to take advantage of the availability of sub channels by identifying inter-femtocell interference by generating patterns that are received in Mobile Station (MS).

Ref. [8] proposed a distributed scheme for managing wireless resources on a heterogeneous network. In [9], the

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authors proposed two radio resource allocation schemes, namely optimization and heuristics schemes. The authors in [10] presented a clustering-based interference management scheme and radio resource allocation for a two-tier Orthogonal Frequency Division Multiple Access (OFDMA) femtocell network. In their study, the authors focused only on OFDMA-based downlink transmissions, where the frame structure can be viewed as time-based frequency resource blocks. Meanwhile, the authors in [11] proposed a dynamic resource allocation algorithm for heterogeneous networks. The authors considered the mobility of macrocell and femtocell users in an algorithm called as IWCA (Interference-Weighted Clustering Algorithm) and spectrum sharing algorithm was proposed for a better utilization of spectrum resources.

Based on several previous studies that have been described above [5] - [11], the resource allocation methods were proposed to mitigate co-tier interference in those references. Meanwhile, in our current study, we look for another way and propose a relay-based clustering method to mitigate the occurrence of cross-tier interference between femtocell and macrocell networks. This femtocell-macrocell network is referred as a heterogeneous wireless cellular network in our paper. In addition, the heterogenous wireless cellular network that we are considering includes the deployment of femtocells densely forming ultra-dense networks (UDN) phenomenon.

In addition to the resource allocation methods, to perform interference management on the femtocell network, we can use the power allocation method as discussed in [12] - [17]. Ref. [12] studied a distributed resource allocation consisting of subchannel-level allocation and power-level allocation in a two-tier cognitive femtocell network (CFN) during uplink transmission. Meanwhile, in [13] the authors proposed multi-objective optimization which aims to maximize the throughput value for each user. The authors in [14] proposed power control algorithm based on the virtual Proportional-Integral (PI) controller. This method aims to save energy on femtocell users.

Ref. [15] considered the optimal transmission power allocation strategy to maximize the aggregate communication rate in a multi-tier network. The simulation results showed that power allocation can improve femtocell performance by adjusting transmit power according to Quality of Service (QoS) requirements. Ref. [16] proposed annealing optimization algorithm by adjusting the transmission power of the femtocell base station. Although, the previous mentioned schemes were used for power management (power control) and were a centralized technique, the authors in [17] proposed an approach to power control and allocation of radio resources spread over femtocell and macrocell networks denoted by the Two-tier Cluster-based Resource and Power Allocation Scheme (TCRPA). However, the power control methods mentioned above need complicated hardware in their implementations. In addition, the disadvantages of the power control method are the decreases in cell coverage area, poor SNR for the users farthest to base station, signaling overhead that causes battery drain.

Refs. [18] - [20] used the fractional frequency reuse (FFR) method to perform interference management in femtocell network. In [18], the authors investigated the FFR method on an ultra-dense network (UDN) in the 26 GHz band. Ref. [19] proposed FFR with three sectors and three layers (FFR-3SL) to reduce co-channel interference (CCI) in heterogeneous networks. In [20] the FFR method was designed by properly dimensioning the center and edge of the cell, dividing and assigning the available total bandwidth between the two areas appropriately.

Meanwhile, in [18] the FFR method was used as a solution of interference management on the millimeter wave UDN network for the 26 GHz band. Dense small cell networks with short user distances and high-level sectorization (HOS) were the focus of [18]. Although the FFR methods are popular methods to avoid interference problems by differentiating the cell-edge and center cell of a cell, it is not preferrable methods for the femtocell-macrocell networks, especially for the femtocells that are deployed randomly and densely. For FFR methods there will be inefficiencies of the frequency bandwidth usage. It is because the FFR method divides the frequency bandwidth allocations among the different type of cells.

Our current paper aims to solve interference problems arising on femtocells deployed densely on the macrocell of wireless cellular networks by proposing a relay-based clustering method. More specific, we are targeting to reduce the effect of cross-tier interferences. This paper is an extension of a paper that has been presented in [21], where the relay-based clustering method was used for interference management in the femtocell-macrocell network. In that previous paper, the observed macrocells were divided into six sectors. In each sector, it was deployed by thirty-three femtocells. It is different from [21], in this current paper femtocells presents at two scenarios i.e., femtocells are deployed in the whole cell edge area of macrocells and the femtocells are deployed in the cell edge of macrocells in the sectorized macrocells consisting of six sectors. Our target is that relay-based clustering method is used to mitigate the interference of the femtocells being in the cell edge area. In summary, our current paper position to the previously mentioned literatures is shown in Table I.

The contribution of this paper is an interference management method using a relay-based clustering method in mitigating cross-tier interferences coming from Macrocell User Equipment (MUEs) in neighboring macrocells to the certain numbers of observed HeNBs. In our previous paper [21], the highest SINR value after applying the relay-based clustering method was 30 dB, while in this current paper it will be shown that the highest SINR value achieves 40 dB. This is because in the paper [21] the analysis focus is only on two sectors out of six sectors for sectorized cells. One sector of two sectors from the observed macrocell was very close to the edge of another macrocell. Meanwhile, another sector of those two sectors is very close to the cell edge of other different neighboring macrocell, considering three macrocells layout. Therefore, the interferences that occur at the HeNB is very large because femtocells are very close to the MUEs in the neighboring macrocell. In addition to the aforementioned scenario, in this current paper femtocells are deployed randomly and densely in the whole cell edge area of macrocell, not only concentrating on certain sectorized cell. By this setting, the interference coming from the MUEs in neighboring macrocells is not as large as the previous case. Note that our previous work is also included in this paper for the comparison purposes.

The rest of this paper is organized as follows. Section II describes the methods used to achieve the goal of this research including system model, the network scenarios that are going to be implemented in the simulation experiment, and the simulation parameters. Section III presents the simulation results and its discussion. Finally, we conclude the paper in section IV.

TABLE I. RESEARCH POSITION BASED ON METHOD AND RESEARCH RESULTS

Ref.	Method	Result
[5]	Resource allocation method to reduce co-tier interference	Proposed scheme achieves substantial throughput and improves Packet Loss Rate (PLR) performance
[6]	Semi-clustering of victim-cell (SCVC) Method to reduce co-tier interference	Average percentage of throughput reaches 185%
[7]	Interference identification and resource management method to reduce inter-femtocell interference	Throughput is increased by 20.64%
[8]	Cluster-based resource allocation method to reduce co-tier interference	Proposed resource allocation algorithm can reduce the lower interference between FUEs
[9]	Resource allocation method to reduce cross-tier interference	Total capacity of the proposed scheme decreased from 41% to 4%
[10]	Joint clustering and resource allocation to reduce intra-tier interference	Simulation results shown that the proposed method can increase the throughput of femto user (FU)
[21]	Relay-based clustering method to mitigate cross-tier interference	Simulation results shown that the proposed method can improve the performance of the femtocell access point (FAP) located on the cell edge

II. METHOD

This paper applies modeling and simulation as its research methodology to achieve its goal. The goal is the proposed method being capable to improve the performance of femtocells appearing at the cell edge of macrocell. To achieve the effectiveness of proposed solution, the design of two system models is carried out in which it is also applied as the simulation scenarios. The first considered system is a conventional system, where in this system there is no method of interference management applied. The second system is a system that applies the relay-based clustering method to mitigate cross-tier interference coming from the MUEs to the HeNB on the cell edge area of macrocell. For both systems, it is considered two scenarios of the femtocells deployments. First, femtocells are randomly and densely deployed in the whole cell edge area of macrocell i.e., macrocell uses omnidirectional antenna. Secondly, femtocells are deployed in the cell edge area of sectorized macrocell consisting of six sectors of macrocell. Therefore, there are four scenarios in total that are considered. Detail discussions for these system models of the considered simulation scenarios will be explained in the following two Subsections II (A) and (B).

A. System Model

Figure 1 shows a two-tier network of femto-macrocells in which we refer this network as a heterogeneous wireless cellular network. We consider three macrocells of OFDMA-based cellular networks. The total system bandwidth is divided into three frequency spectrums (three frequency bands). One macrocell out of three macrocells, i.e., macrocell A is deployed a number of femtocells in its cell edge area. Each of three macrocells is allocated a different frequency band in which it is referred as reuse factor of 3, whereas the femtocells in macrocell A will be assigned the same frequency band as used in the two neighboring macrocells (reuse factor of 2).

Femtocells are densely deployed in the whole cell edge area of macrocell A, as mentioned earlier. Meanwhile, for other two macrocells there are no femtocells deployed. However, these two neighboring macrocells are deployed a number of macro user equipment (MUEs). When the femtocell user equipment (FUE) sends the signal i.e., in uplink mode to Home enhanced Node B (HeNB) and at the same time the MUEs in the neighboring macrocell also communicate to Node B (eNB) i.e., in uplink mode as well, thus the observed HeNB suffers cross-

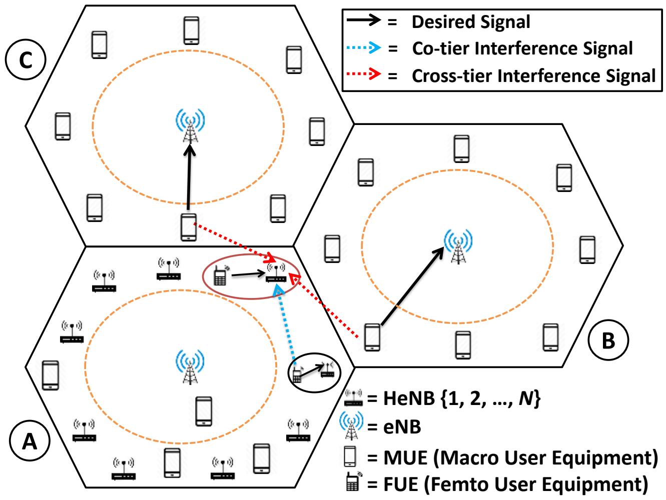

Figure 1. Conventional system model

tier interferences from MUEs as shown by the red line in Figure 1. This interference occurs because the femtocells likely use the same radio resources as used for two neighboring macrocells. Note that in our system model, we define cell edge area of macrocell by dividing a macrocell area into two areas by drawing an orange dashed circle (as shown in Figure 1) inside the macrocell area. It is virtually dividing macrocell areas into the inner cell area and outer cell area/cell edge area of macrocell. By this scenario setting, this can make the performance of the femtocells even worse, especially when it is very close to the cell edge area of the neighboring macrocells.

Besides getting cross-tier interferences, HeNB also suffers co-tier interference caused by other FUEs, because HeNBs share the same radio resources. In Figure 1, the co-tier interference is indicated by a blue line. The scenario that has been described in Figure 1 is also referred to as the first scenario in this paper for the conventional system.

The relay node functions as receiver and forwarder of the signals from the MUE to the eNB. The signal power transmitted by the MUE to the eNB via the relay node is not necessarily as large as without a relay node. Then, interferences caused by the MUE in the neighboring macrocells to the HeNB can be minimized. More detailed descriptions of the system using the relay-based clustering method is described in the following and it is illustrated in Figure 2.

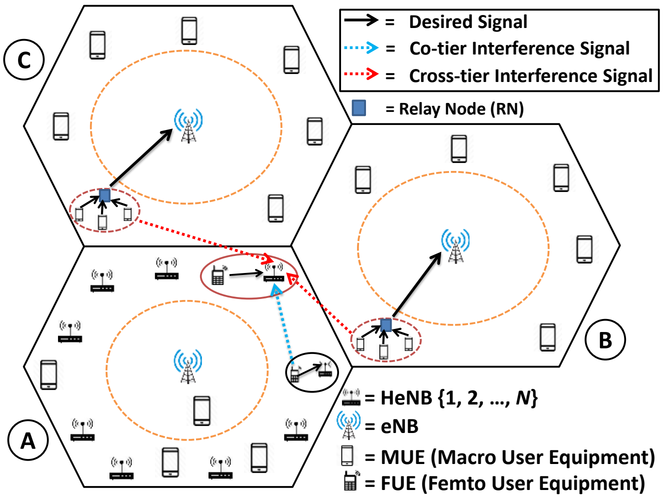

Figure 2. System with relay-based clustering method

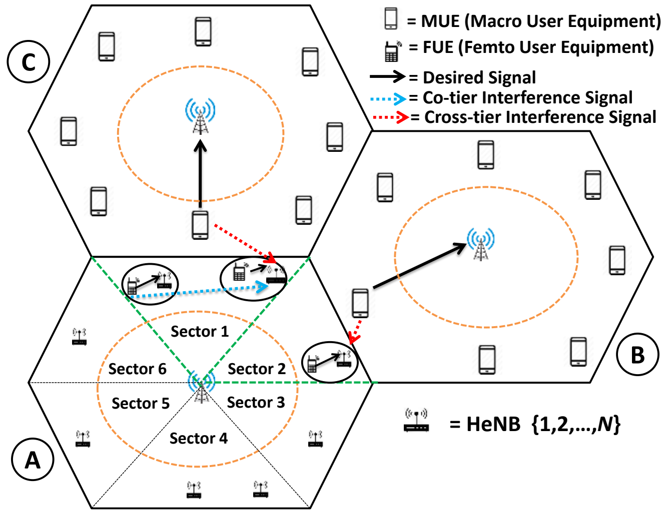

Figure 3. Conventional system model with sectorized macrocell consisting of six sectors [21]

In our previous paper [21] the relay-based clustering method was applied to mitigate the interference of femtocells deployed in macrocells which have been divided into six sectors. Furthermore, the focus of analysis in the paper [21] was only on two sectors of the observed macrocell area, namely sectors 1 and 2. Those two sectors are neighborhood of other two different macrocells accordingly. Each sector was deployed by thirty-three femtocells. Besides that, in this current paper, relay-based clustering is applied when femtocells are deployed in the whole cell edge area of the macrocell i.e., macrocell uses omnidirectional antenna.

There are some steps to apply the relay-based clustering method in the system. First, a number of relays is deployed statically (in fixed position) at two neighboring macrocells. In this paper, the relay nodes are placed on the positions of circle that indicate the border of the inner and outer macrocells (orange dashed circle). Those relay nodes that are deployed will recruit its corresponding members to be served consisting of several MUEs based on their closest distance to the certain relay node. It is assumed that one relay node can recruit a maximum of three MUEs. With this setting, the MUE does not need to transmit as a large amount of power to the eNB as the system without relay node, such that interference from neighboring macrocells' MUE to the observed HeNB can be minimized. The illustration of this second scenario can be seen in Figure 2.

As mentioned earlier, the goal of this research is to overcome the problem of interference in femtocells that its position is in the cell edge area. Hence, we also consider the scenario for femtocells deployed inside a macrocell that has been divided into six sectors in Figure 3. Since our goal is to improve the femtocells performances in the cell edge area of macrocell, we focus our analysis in sectors 1 and 2. It is because the femtocells deployed in sectors 1 and 2 of the macrocell are the areas that are most affected by interferences. Femtocells located in these two sectors are very close to the MUE which is also on the cell edge area of the neighboring macrocell.

Figure 3 is a conventional system scenario based on sector division, which means that this scenario has not applied any method. In this scenario, it can be expected that the performance of the femtocell is greatly decreased because it is affected by interference from the MUE in neighboring macrocells. To overcome this interference problem, we propose a scenario for the system with a relay-based clustering method as shown in Figure 4. Similar to the scenario in Figure 2, the relay node is deployed statically (in fixed position) in the neighboring macrocell area (macrocells B and C), but in this scenario the relay node is used to mitigate cross-tier interference on the femtocells that are deployed in sectors 1 and 2 of the cell edge of macrocell A's area. Note that we have presented the scenarios in Figures 3 and 4 in [21]. It is presented and discussed in this paper for the comparison purposes.

B. Channel Model

In order to simulate the considered system models, it is necessary to describe the channel models that are applied. The channel models are very important to get the simulation successful. The signal that is sent from the transmitter will get attenuated to the receiver because the signal is propagated on the transmission media. The signal strength that is received at the receiver side can be calculated by considering the propagation model that is assumed. In this paper, we consider two channel models including macrocells and femtocells in urban areas. The channel model that is used in urban macrocells is based on the standard 3GPP TR 36.814 version 10.2.0 [22]. Meanwhile, the channel model that is used for the femtocells in urban area is based on the 3GPP TR 36.922 version 10.0.0 Release 10 standards [23]. For the channel model that is used in urban femtocells, it can be calculated using (1) [23].

$$L_{femto}\ (dB) = 15.3 + 37.6\ log_{10}(x) \qquad (1)$$

Channel model used in urban macrocell can be calculated using (2) as the following [22].

$$L_{macro}\ (dB) = 127 + 30log_{10}\left(\frac{x}{1000}\right) + L_{\beta} \qquad (2)$$

where x in both (1) and (2) denotes the distance between the user to the HeNB or to eNB in meters, respectively, meanwhile L_{β} represents the penetration loss in which its value in this paper is assumed to be 6 dB [24].

C. Signal-to-Interference-plus-Noise-Ratio Analysis

For the model system that was described previously, in order to evaluate the signal quality of the observed HeNB at the femtocell, it can be determined from the Signal-to-Interference-plus-Noise-Ratio (SINR) value. SINR is the ratio of the desired signal coming from the FUE to the observed HeNB to the interference signal from the MUEs and other FUEs who are using the same radio resources as the observed HeNB used plus noise power. The SINR can be calculated using (3) as the following.

$$SINR = \frac{P_{rx}}{\sum_{x=1}^{n} I_{co\_tier} + \sum_{y=1}^{m} I_{cross\_tier} + N} \quad (3)$$

where P_{rx} is the desired power from FUE to observed HeNB (in milli Watt), I_{co_tier} is the interference signal from other FUEs to observed HeNB (in milli Watt) with *n* is number of co-tier interferences, I_{cros_tier} is the interference signal from MUEs to observed HeNB (in milli Watt) with *m* is number of cross-tier interferences, and *N* is the Noise Power in the system (in milli Watt).

The desired signal (P_{rx})from the served FUE or the co-tier interference signals caused by other FUEs (as co-tier interferences) can be calculated using (4).

$$P_{rx}(dBm) = P_{fue}(dBm) - L_{femto}(dB) \quad (4)$$

where $P_{fue}$is the transmit power that is transmitted from the desired FUE or other FUEs (as interference) in dBm. The cross-tier interference signals from the MUE can be calculated by using (5).

$$I_{cross\_tier} = P_{mue}(dBm) - L_{macro}(dB) \quad (5)$$

where $P_{mue}$is the transmit power that is transmitted by MUE to the eNB or the observed HeNB in dBm.

D. Simulation Parameters

As in the system models previously discussed, this paper considers three macrocells of OFDMA-based wireless cellular network, which each macrocell is assigned different radio resources or frequency reuse factor is equal to 3. The radius of each macrocell and femtocell are set to 1000 m and 30 m, respectively [25].

It is assumed that femtocells can serve just one femtocell user equipment (FUE) at one time duration for the shake of simplicity analysis. Two hundred femtocells are densely and randomly deployed increased in step of 1 from one until two hundred femtocells in the whole coverage area of macrocell, especially the macrocell edge area. We deploy 200 femtocells because with this number of femtocells it is enough to form the UDN network in which it is the focus of our study as well. According to Ref. [26] UDN is defined as the density of access points (APs) which are more than the number of users. The maximum powers that are transmitted by both FUE and MUE without relay node are set to 23 dBm both [10]. The total bandwidth for the system is set to 10 MHz [27]. All systems apply the modulation scheme of 16 Quadrature Amplitude Modulation (16 QAM). The inner and outer macrocell areas are bordered with a virtual circle of 750 m radius. A number of relay nodes is placed on this virtual circle which is equal to sixteen relay nodes. These sixteen relay nodes are determined and calculated to cover the border line of inner and outer areas of macrocell.

As relay nodes are deployed, MUEs belong to the member of a certain relay node do not need to transmit the signal as large as the system without relay node. Since the distance between relay node to the border of macrocell is quarter of macrocell radius, the transmit power of MUEs with relay nodes is set to 0.25 of MUEs' transmit power [28] without relay node, i.e., 50 mW (17 dBm). The simulation program was run for twenty times and the simulation results are averaged from these twenty times of simulation run. It is because the simulation experiment involves the random variables in the collected performance parameters, thus the results that are obtained are expected to be close to the expected values.

In the simulation experiments, firstly the SINR values are collected from the simulation to determine the signal quality when the number of femtocells is one femtocell. Then, the number of femtocells is increased by the factor of 1 until two hundred femtocells. Beside the SINR values, the performance parameters which are considered and collected are throughput and Bit Error Rate (BER). The cumulative probability of SINR and throughput values are described on the form of Cumulative Distribution Function (CDF) graph. Meanwhile, the cumulative probability of the bit error rate (BER) is illustrated on the Complementary Cumulative Distribution Function (CCDF) graph. The simulation program was run and the performance parameters were measured and averaged for two hundred observed femtocells. The simulation program was run for twenty times as mentioned earlier. Then, the results for averaged performance parameter values of two hundred femtocells were averaged for twenty simulation times. These simulation parameters mentioned above are summarized in Table II.

III. Results and Discussion

As previously described, the simulation experiments in this paper considers four scenarios. The first scenario is a conventional system or a system that does not apply the relay-based clustering method as shown in Figure 1. A number of femtocells are densely and randomly deployed in the whole cell edge area of macrocell A. Meanwhile, in macrocells B and C, the femtocells are not deployed, but within those two macrocells are deployed a number of macrocell user equipment (MUEs) at the cell edge area. We divide the cell area into two areas to describe the cell edge area (outer cell) and the center area (inner cell) of the cell as shown with orange dashed circle at the Figures 1 and 2.

The second scenario in the simulation system can be seen in Figure 2, which in this scenario the system is designed to improve conventional system using the relay-based clustering method. A number of relay nodes are deployed on macrocells B and C, with the expectation that the presence of relay nodes can mitigate the effect of cross-tier interferences coming from

TABLE II. Simulation Parameters

No.	Parameters	Value
1.	Radius of macrocell [25]	1000 m
2.	Radius of circle to border of the inner and the outer of macrocells	750 m
3.	Radius of femtocell [25]	30 m
4.	Number of macrocells and eNBs	3
5.	Number of femtocells in the first and second scenarios	200
6.	Total number of MUEs in macrocells B and C (for the Scenario in Figures 1 and 2)	100
7.	Total number of MUEs in each sector of macrocells B and C (for the Scenario in Figures 3 and 4)	33
8.	Number of relay nodes	16
9.	Maximum number of users in a relay node	3
10.	Total system bandwidth [27]	10 MHz
11.	Transmit power of FUE for the systems with and without relay node [10]	23 dBm
12.	Transmit power of MUE for the system without relay node [10]	23 dBm
13.	Transmit power of MUE for the system with relay node [28]	17 dBm
14.	Simulation times	20
15.	Modulation scheme	16 QAM

the MUEs to the HeNB. In the simulation, the maximum number of relay node members is set to three MUEs, taking into account the relay node recruits its members based on the shortest distance.

Figure 3 depicts third scenario for the simulation system. Femtocells are deployed in macrocells that have been divided into six sectors. To study the effectiveness of our proposed relay-based clustering method in the sectorized macrocell in the third scenario, we designed a fourth scenario in our simulation experiment which is depicted in Figure 4. This fourth scenario represents our focus on the effectiveness of proposed relay-based clustering method in reducing the effect of cross-tier interferences on the cell edge area.

The four scenarios described above are simulated using MATLAB software by writing the simulation program codes, with the simulation results presented in the graphical forms. Then, in the simulation results we will compare the system performance results of the system designed, namely the conventional system and the system that applies the relay-based clustering method. The system performances in Figures 1 and 3 are compared to the system performances in Figure 2 and 4, respectively.

We have carried out the simulation experiments extensively and then the simulation results are obtained. The simulation results are presented in Figures 5-8 of this section which we compare the results of the four designed system scenarios. In the simulation results, we will compare the CDF values of SINR and the throughput of each system. CDF indicates the cumulative probability of random variables which is less than or equal to a certain value, i.e., a constant value. In our case the random variables that are measured in CDF are the SINR and throughput.

Figure 5 shows the results for SINR as the number of femtocells is increased. In Figure 5 the *x*-axis indicates number of femtocells and the *y*-axis represents the SINR values for both conventional system and the system with relay-based clustering method. In general, the SINR performance of femtocells decreases as the number of femtocells increases for both systems. This SINR result implies that the performance of femtocells decreases as a result of the number of cross-tier and co-tier interferences increases. The interferences are originating from MUEs and other FUEs that use the same radio resources. The SINR values for the system that apply the relay-based clustering method outperforms the conventional system. It is because the transmit power of MUEs which caused the cross-tier interferences is decreased by the present of relay nodes. However, when we compare the SINR results for the proposed method in Figures 5 (a) and (b) we can see that the SINR values of our proposed method in Figure 5(a) is greater than the SINR values in Figure 5(b). It is because the femtocells deployed in sectors 1 and 2 within the cell edge of macrocell coverage area are located very close to the MUE on the cell edge of the neighboring macrocell. Consequently, the femtocells in sectors 1 and 2 are exposed to greater interferences than the femtocells that are randomly deployed in the whole cell edge area of macrocell, scenario in Figure 1.

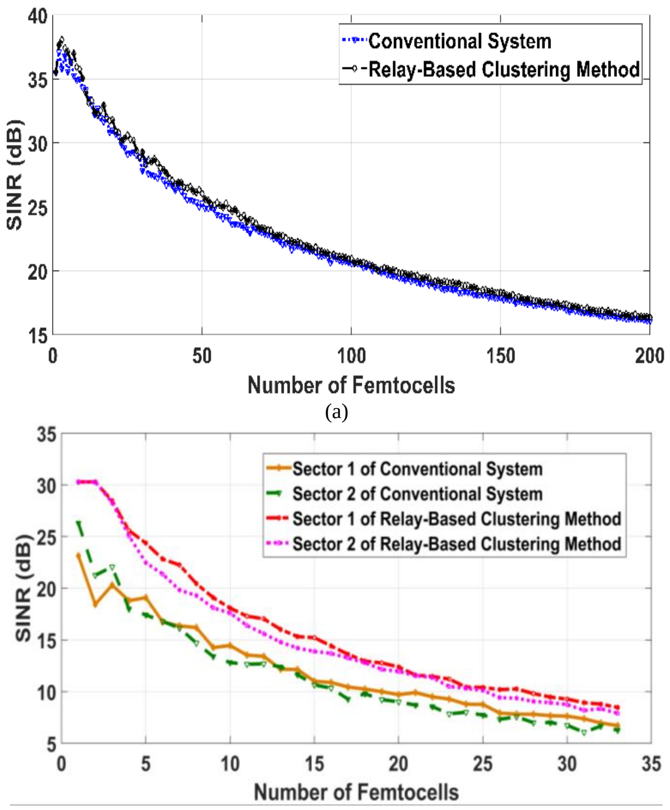

Figure 5. Simulation results for SINR performance: (a) comparison of conventional system and system with relay-based clustering method and (b) comparison of conventional system and system with relay-based clustering method based with sector division [21]

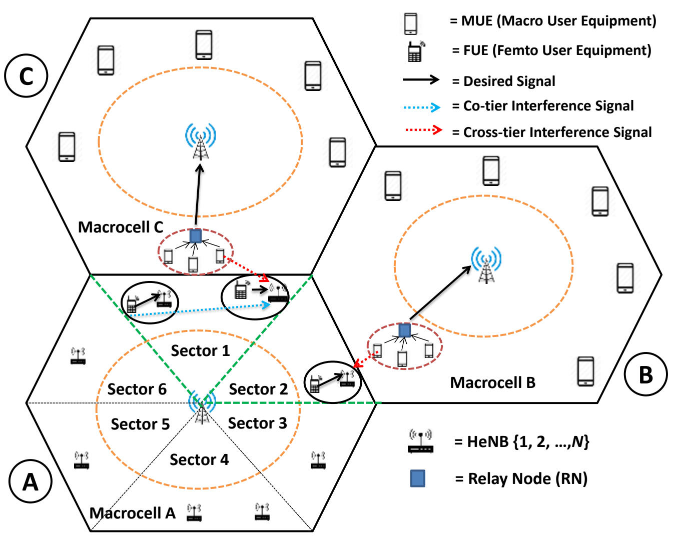

Figure 4. System with relay-based clustering method in the sectorized macrocell consisting of six sectors [21]

Figure 6 depicts the results for CDF of SINR which is a comparison of the CDF of SINR for all four scenarios of both systems; the conventional system and the system that applies the relay-based clustering method. Suppose we target a SINR value of 20 dB which is excellent target. It can be seen that the probability of SINR not reaching the target when femtocells are deployed in the whole coverage cell edge area of macrocell for conventional system and system with relay-based clustering method are 46% and 44%, respectively. It relates to the SINR value below or equal to 20 dB. Meanwhile, the probability of SINR not reaching the target for conventional systems in sectors 1 and 2 are both 87%. Furthermore, the probability of SINR not reaching the target for systems that use the relay-based clustering method in both sectors 1 and 2 are 72% and 75%, respectively. Optimistically, it can be said that our proposed system can improve the SINR performance up to 15%. It is achieved when we compare the CDF of SINR between sectors 1 in the conventional system and the system with relay-based clustering method. In general, it can be said from the

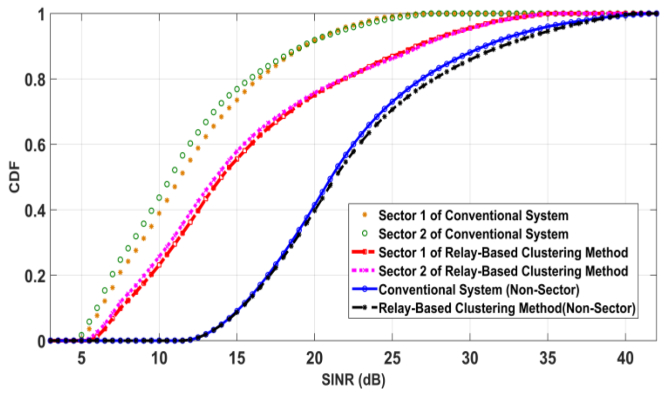

Figure 6. The comparison of cumulative distribution function (CDF) of SINR for conventional system and system with relay-based clustering method

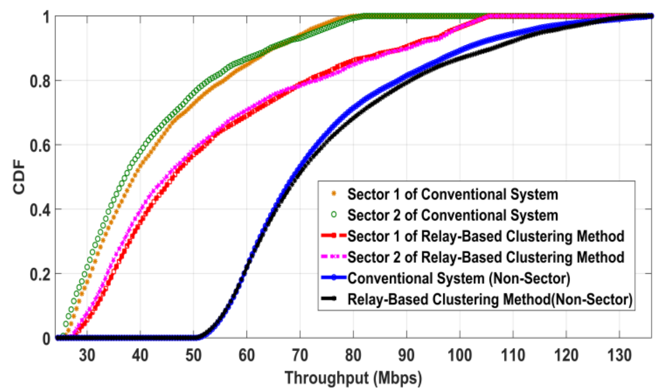

Figure 7. The comparison of cumulative distribution function (CDF) of throughput for conventional system and system with relay-based clustering method

results of the SINR probability that our proposed relay-based clustering method can improve the performance of femtocells located on the cell edge area of macrocells. We choose the value of 20 dB for SINR target because 20 dB for SINR is an excellent signal measurement level for the cellular communication systems defined by the vendors [29].

In ref. [30], the system that applies the power control method has a probability of the SINR value not reaching the target or below or equal to 20 dB reaching 65%. While ref. [31], the applied power control method considered partial pathloss compensation to calculate the minimum transmit power, thus inter-cell interference can be reduced. Simulation results in ref. [31] showed that the smaller the pathloss compensation value, the higher the SINR value. Thus, it can be understood that the relay-based clustering method outperforms conventional system and system that applied power control. In [18], to reduce cross-tier interference, a FFR method was applied. Furthermore, ref. [18] uses FFR on a millimeter wave network, where the outer cell and inner cell bandwidths were distinguished. The authors' goal was to reduce interference for cell edge users. Their simulation results showed that the applied FFR technique produced the lowest SINR of -4 dB and the highest SINR of 15 dB. In [32], the authors combined two methods, namely FFR and relay methods. Both methods were used to reduce interference for cell side users. The simulation results showed that the CDF of SINR value at 20 dB reaches 98% when the inner region radius was 0.5 km.

Based on the results of the studies above, it can be seen that femtocell performance can be improved, not only using techniques to reduce cross-tier interference, but also requires a technique to reduce co-tier interference. Due to the very close density of femtocells, dynamic frequency adjustment is to be required. Thus, the co-tier interference that occurs among femtocells can be reduced. However, it is not the focus of our current paper, since our target is to reduce the effect of cross-tier interferences by using relay-based clustering method, but at the same time the co-tier interference is still taken into account. We leave this theme as future works.

Figure 7 is a comparison of the CDF of throughput for both the conventional system and the system that applies the relay-based clustering method. When we notice the throughput target of 70 Mbps, the probability value of throughput below or equal to 70 Mbps for conventional system when femtocells are deployed in the whole coverage cell edge area of macrocell reaches 0.54 or 54%. Meanwhile, after applying the relay-based clustering method the probability of throughput value below or equal to 70 Mbps reaches 0.51 or 51%. In the meantime, the probability of throughput below or equal to 70 Mbps for conventional systems in both sectors 1 and 2 is 94%. In addition, the probability of throughput below or equal to 70 Mbps for systems using the relay-based clustering method in both sectors 1 and 2 reaches 79%. As we can see, the improvement of throughput for the conventional system is 15% by applying the proposed relay-based clustering method.

In ref. [33], interference management was carried out using interference identification and resource management techniques to reduce inter-femtocell interferences. The interference identification method produces patterns that are received by the user using Universal Serial Radio Peripheral (USRP) software. The simulation results in their study showed that the proposed method was able to increase throughput by 20.64%. Meanwhile, ref. [8] proposed a cluster-based resource allocation method to reduce interference among Femtocell Access Points (FAPs). Meanwhile, in our current work our goal is to reduce cross-tier interferences coming from MUEs in neighboring macrocells. It has different scope compared to ref. [8] in which their method can just reduce co-tier interference. The simulation results in [8] showed that as the number of FAPs increases, the data rate decreases. It is because the interferences among the closest FAPs increases. In addition to resource allocation methods, ref. [34] also reduced co-tier interference using greedy and graph-based technique (GBT) algorithms. Their simulation results showed that the greedy algorithm has the disadvantage of being inefficient in assigning random sub-bands.

From comparing with some of the results above, it can be said that the method that we propose in our current paper can only reduce cross-tier interference, while refs. [8], [31], [32] proposed the methods that can reduce co-tier interference only. As previously mentioned, to get optimal results on dense femtocell performance, a method that can reduce both interferences (co-tier and cross-tier) simultaneously is needed. However, it is not the focus of our paper, but it can be explored further as future works.

Figure 8 is a comparison of the CCDF of BER for both the conventional system and the system that applies the relay-based clustering method. CCDF means the cumulative probability of random variable that is greater than a certain value or a constant. We notice in Figure 8 that the probability of BER values above 0.01 for conventional systems when femtocells are deployed in the whole coverage cell edge area of macrocell is 0.71 or 71%. Meanwhile, after applying the relay-based clustering method the probability of BER values above 0.01 reaching 0.68 or 68%. In contrast, the probability of BER values above 0.01 for the conventional system when the femtocells are deployed in

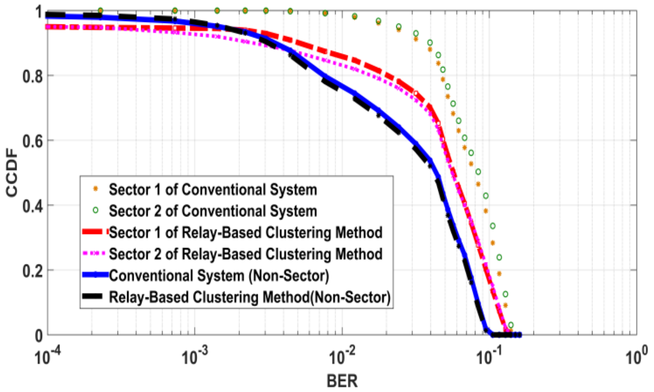

Figure 8. The comparison of complementary cumulative distribution function (CCDF) of bit error rate (BER) for conventional system and system with relay-based clustering method

macrocell sectors 1 and 2 is 97% both. After applying the relay-based clustering method, the probability of BER in sectors 1 and 2 becomes 86% and 83%, respectively. From these BER results, it can be said that the probability of errors that occurs in the system that applies the relay-based clustering method was smaller than the conventional system. The improvement achieves 14% in the case of sectorized macrocell at sector 2.

In ref. [27], cooperative relay method was used to reduce cross-tier interference for femtocells at the cell edge area. However, in their paper, the authors added a pre-coder and decoder algorithm for FAP, MUE, and cell-edge user (CUE) to minimize the number of mean square errors (MSE). The advantage of the cooperative relay technique over the relay technique that they proposed was that the cooperative technique made it possible to collect information about neighboring femtocells and allocated them by considering their effect on the neighbors.

The simulation results in [27] showed that the BER value was very minimum when the estimated value was added to the zero forcing (ZF) value. Although the application of ZF can reduce interference, but it increases noise power. Table III summarizes the comparisons of the results for the previous results on the literatures related to our discussion in this section.

Based on the simulation results that have been described previously, it showed that the system that applies the relay-based clustering method outperforms the conventional system. However, in the scenario where the femtocells are deployed in the whole coverage cell edge area of macrocell (scenarios in Figures 1 and 2), the differences in the probability of the SINR, throughput, and BER values between the two systems were not significant. It is because the power transmitted from the Macrocell User Equipment (MUEs) passing through the relay is only contributing to the reduction of the cross-tier interferences.

In our system scenarios, it is identified that the cross-tier interference was not dominant cause of interferences in our three macrocells layout with densely deployed femtocells (UDN). In our simulation scenarios, since we have considered femtocell densely deployed in macrocell that creates UDN, the higher contribution to the interference total in the system was caused by other femtocells (co-tier interferences). However, in the scenario of sectorized macrocell with femtocells deployed in it (scenarios in Figures 3 and 4), the improvements were significant.

It can be said that our results have good improvement to mitigate the cross-tier interferences even with UDN scenario. Our proposed system is superior even under UDN scenario. Our proposed relay-based clustering method promises as a solution to mitigate the cross-tier interference in UDN scenario. In addition, all performance parameters' results show the consistency of simulation experiments.

IV. Conclusion

This paper analyzes the interference that occurs in the femtocell-macrocell network, especially femtocells located at the cell edge area of macrocell. We propose the use of relay-based clustering method to reduce the effect of cross-tier interferences caused by the users located in the cell edge area of neighboring macrocells. We use MATLAB programming code software to examine the scenarios that have been designed. Extensive simulation experiments have been carried out. The performance parameters have been collected in term of SINR, throughput and BER. The simulation results show that the relay-based clustering method can improve the performance of femtocells located in the cell edge area. It can be proven that the presence of relay nodes distributed in neighboring macrocells can reduce cross-tier interference that comes from macro user equipment (MUE). The power transmitted by the

TABLE III. Comparison of Previous Research Results

Ref.	Method	Result
[30]	Power control method	Probability of the SINR value was not reaching the target or below or equal to 20 dB reaching 65%
[31]	Power control method considering partial pathloss compensation	Simulation shows that the smaller the pathloss compensation value, the higher the SINR value
[18]	Fractional frequency reuse (FFR) method to reduce cross-tier interference	FFR technique produced the lowest SINR of -4 dB and the highest SINR of 15 dB
[32]	FFR and relay methods	CDF of SINR value at 20 dB reaches 98% when the inner region radius was 0.5 km
[33]	Interference identification and resource management techniques to reduce inter-femtocell interferences	Proposed method was able to increase throughput by 20.64%
[8]	Cluster-based resource allocation method to reduce interference among Femtocell Access Points (FAPs)	Simulation results showed that as the number of FAPs increases, the data rate decreases, because the interference between the closest FAPs increases
[34]	Greedy and graph-based technique (GBT) algorithms to reduce co-tier interference	The greedy algorithm has disadvantage of being inefficient in assigning random subbands
[27]	Cooperative relay method was used to reduce cross-tier interference for femtocells in the cell edge area	BER value was very minimum when the estimated value was added to the zero forcing (ZF) value. However, the application of ZF can reduce interference but increase noise power

MUE to the eNB via the relay node is reduced, thus the cross-tier interference to the observed femtocell can be minimized. This is implied in the results of SINR, throughput, and BER parameters that were obtained in the simulation. The optimistic simulation results for the sectorized macrocells scenario show that Signal-to-Interference-plus-Noise-Ratio (SINR) of femtocells for the conventional system that does not reach the targeted SINR of 20 dB is 87%. Meanwhile, after applying the relay-based clustering method, SINR value of femtocells below or equal to 20 dB reaches 72%. Optimistic results for throughput and Bit Error Rate (BER) show improvement of 15% and 14%, respectively. Our system contributes a solution to mitigate the cross-tier interferences in the scenario of femtocells densely deployed in the macrocell cellular networks (Ultra Dense Networks/UDN). As our proposed relay-based clustering method focuses on the reduction of cross-tier interference effects, it can be suggested to study or to propose a scheme which is taking into account simultaneously both co-tier and cross-tier interferences as well as considering delay parameter as a consequence to apply relay node. We leave this theme as future works.

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