Creating Interference Graph for Frequency Channel Allocation for Multi-Floor Buildings

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***Abstract*—The interference graph is an important input factor for efficient frequency channel allocation. This paper proposes the interference graph creation technique for frequency channel allocation. The indoor femtocell networks in multi-floor buildings are used for the study area with frequency channel allocation criteria consideration. The performance of network service is analyzed. There are the areas covered by the signal from femtocell base station and the interference signals from femtocell base station and signal quality in service areas. The simulation-based results of the proposed technique can support frequency channel allocation to each femtocell base station. It can finely detect interference link between femtocell base stations. Moreover, the performance of the studied femtocell networks in terms of signal quality and throughputs is increased, compared to other creating interference graph techniques in the literature review.**

***Index Terms*—femtocell networks, frequency channel allocation, interference graph creation**

I. INTRODUCTION

At the present day, the use of wireless communication devices such as smartphones or tablets is very popular. The number of worldwide subscriptions are 4.3 billion units in 2017 and will increase to 7.3 billion units in 2023 [1]. The demand for data traffic is increased related to the popularity of mobile terminals. Therefore, mobile phone network operators introduced femtocell base station (FBS), small size base station, to increase capacity and coverage for their indoor service area. However, there is the problem in terms of signal interference between femtocells which affect the signal quality in the mobile phone network.

The problem from the frequency channel assignment to base stations can occur when they are assigned the same frequency channel. Without frequency reuse, the signal transmitted from the same-frequency-channel base station makes an interference signal to each other [2]. From this problem, the service efficiency of the mobile phone network is seriously degraded. To avoid this problem, the network planner may define unduplicated frequency channels to each femtocell inside networks. However, this ideal solution requires too many frequency channels for every femtocell in networks which waste the frequency resource.

The interference graph method was mention in [3], [4] to define the interference between base stations in the service area. However, there are a few signal test points which are randomly placed instead of all users in the overall service area. In addition, they considered the signal to interference plus noise ratio (SINR) at each signal test points to judge the occurring of interference between base stations. These techniques had low feasibility to detect the interference. The frequency channel allocation considering interference graphs created form these techniques brings the low service efficiency to users in the service area.

This paper proposes the creating interference graph technique for frequency channel allocation. Our technique considers feasible places of users in the overall service area. The received signal strength level at each signal test point is considered. The judgment of interference occurring is considered based on the percentage of signal test point which can receive over-threshold signal level from two base stations.

The rest of this paper is organized as follows. The related work is mentioned in Section 2. Section 3 presents the path loss model. The process of creating the interference graph is presented in Section 4. Experimental environment and results are explained in Sections 5 and 6 respectively. The discussion is presented in Section 7. Finally, we conclude this paper in Section 8.

II. RELATED WORKS

From our literature review, one of many optimal solutions for avoiding interference for the frequency channel allocation process is considering the interference graph of wireless networks [5], [6]. The interference graph determines interference among femtocells or user devices in the service area. Then, the frequency allocation is implemented considering frequency reuse method to optimize the number of frequency channels in the network. We find that there are many research works focus on frequency channel allocation inside the building. Phimphahu *et al.* studied radio resource block assignment for 4G-LTE femtocell networks for multi-floor buildings [7]. This method can effectively reduce inter-cell interference and improve maximum downlink throughput. Research work in [8] proposed a signal interference management technique in LTE networks.

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The transmission powers controlling technique, the coverage planning techniques and frequency reuse scheme were deployed to avoid interference between macrocell and femtocell coverage. Moreover, there are several research works studied on the frequency channel allocation inside the building as follows. Liu *et al*. mentioned the radio resource allocation for femtocell inside the five floors building using the heuristic algorithm [9]. The objective was minimizing the number of used frequency channels. Cao *et al*. presented a frequency adjustment technique for LTE systems which consisted of frequency allocation algorithm and frequency reuse algorithm with interference graph consideration [10]. In addition,

From the existing research works related to frequency channel allocation for base stations in wireless networks, they paid attention to technical development and frequency channel allocation improvement for indoor and outdoor cellular networks. Their objectives were reducing signal interference and improving communication performance without interference graph creation consideration. On the other hand, there are few research works focus on the interference graph creation. Mengxian *et al*. proposed a new effective dynamic interference coordination scheme based on an innovative combination of soft frequency reuse and improved graph-based resource allocation in Orthogonal Frequency Division Multiplexing Access (OFDMA) macrocell-picocell network [3]. In addition, Shiyan *et al*. constructed an interference graph by mapping femtocells onto vertices and interference collision relationship between femtocells onto edges in the graph. The creating interference graph technique in these research works evaluated a few random points of users to evaluate the interference between base stations with the signal to interference plus noise ratio (SINR) threshold for user consideration [4]. To improve signal quality, every feasible point of users in the overall of the study area should be considered. Therefore, the interference graph creation using overlap technique is proposed. The interference between femtocells was evaluated with a condition of overlap percentage. Our research focuses on the study and the development of creating interference graphs for the frequency channel allocation of indoor femtocell networks in a multi-floor building. Our technique aims to reduce the signal interference between femtocells and reduce the number of frequency channels used in femtocell networks.

III. Path-Loss Model

In this paper a path-loss model is used to predict the loss of signal power. The loss of signal power is used to calculate received power at signal test points (STPs). Equation (1) and Table I explain the signal path-loss model which is defined by the 3GPP standard and applied to indoor femtocell networks [11].

$$P_L = 40.7412 + 20\log_{10}(R) + 0.7d_{2D,indoor} + 18.3n^{\left(\frac{n+2}{n+1}-0.46\right)} + qL_{iw} \quad (1)$$

TABLE I. Parameters Used for Signal Path Loss Model

Parameter	Definitions
R	Distances between femtocell and signal test point (m)
$d_{2D,indoor}$	The thickness of the walls inside the building. (0.18 m)
n	The number of penetrated through the floors.
q	The number of penetrated through the walls.
L_{iw}	The loss of the wall inside the building.

IV. Process of Interference Graph Creation

Interference graph is a technique applied with frequency channel allocation to increase its efficiency. The interference graph consists of “nodes” and “links”. The link between nodes which indicate interference is called “interference links”.

The process of creating the interference graph is explained as follows.

1) Define initial parameters.

2) Calculate distances (d) between femtocell base station (FBS) and STP.

3) Calculate received signal power (P_r) at STP as presented in (2).

$$P_r = P_t - P_L + G_t + G_r \quad (2)$$

where parameters denote the signal strength at STP. P_t represents transmit power from FBS, G_t and G_r denote the antenna gain at FBS and user’s devices respectively. The signal path-loss P_L is calculated based on (1).

4) Calculate overlap percentage value between two FBSs, defined as FBSa and FBSb, by (3).

$$\%\text{overlap} = \frac{X}{(X-Z)+(Y-Z)+Z} \times 100 \quad (3)$$

Here, parameters X and Y denote the number of STPs which their P_r levels are higher than the defined threshold and received from FBSa and FBSb respectively. Parameter Z represents the number of STPs which their P_r level received from both FBSa and FBSb simultaneously and higher than the defined threshold as shown in Fig. 1.

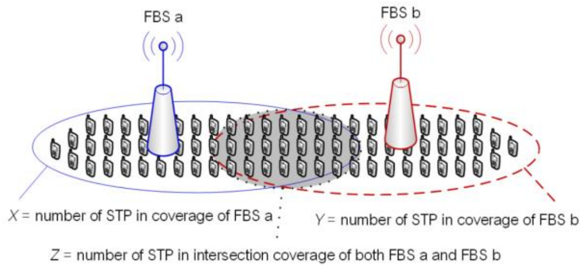

Fig. 1. Coverage consideration for overlap percentage calculation.

5) Define the overlap percentage threshold for creating the interference graph.

The interference between two FBSs occurs if overlap percentage value more than the defined threshold value. In contrast, the interference does not occur if the percentage lower than the threshold.

V. Experimental Environment

This section explains the experimental scenario setup, study area and initial parameters. For the study area, we

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used three floors building which shown in Fig. 2. Fig. 2 (a), (b) and (c) show the floor plan of first, second and third floors in the study area respectively. The positions of femtocells were placed by mathematical calculation using the optimization model [12] which are shown by red circle symbols. STPs were placed in grid pattern which represents user coverage in the study area. There were 11 FBSs and 972 STPs in our study area.

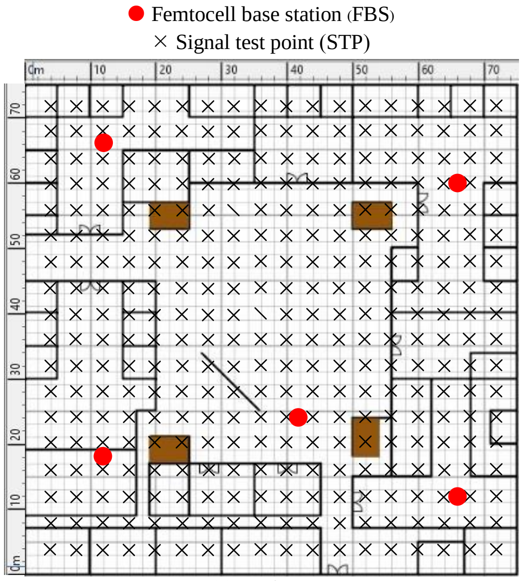
To evaluate our proposed technique, we compared with two related works which are Creating interference graph considering SINR of user (CI-SINRU) technique [4] and creating Interference graph considering the relationship of base stations and users (CI-RBU) technique [3]. The CI-SINRU created interference graph with noise consideration. In addition, both of related works random a few STPs for calculating interference graph. Table II presents initial parameters which are used in our experiments.

TABLE II. PARAMETERS USED FOR EACH INTERFERENCE GRAPH CREATION TECHNIQUES

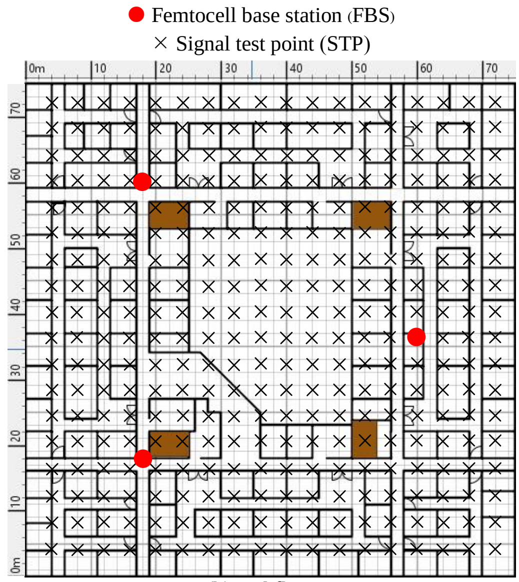
Parameters	Techniques		
	Overlap	CI-SINRU	CI-RBU
Signal frequency	2.6 GHz		
Transmit power	10 dBm		
Bandwidth	20 MHz		
FBS height	2 m		
STP height	0.8 m		
Received power threshold	-79.83 dBm	-	-
Overlap threshold	20%	-	-
SINR threshold for user	-	3 dB	5 dB
Service area	75 m × 75 m × 3 m		
Number of FBS	11		
Number of signal test point	972	33 (3 users/FBS)	44 (4 users/FBS)

Our overlap technique set receive signal and overlap threshold at −79.83 dBm [13] and 20% [14] respectively. The CI-SINRU technique and the CI-RBU technique set SINR threshold for users at 3 dB and 5 dB respectively. There were 972 STP placed in the grid pattern in our overlap technique. On the other hand, STP of CI-SINRU and CI-RBU technique was set at 3 and 4 STP per FBS which are randomly placed in each FBS coverage area.

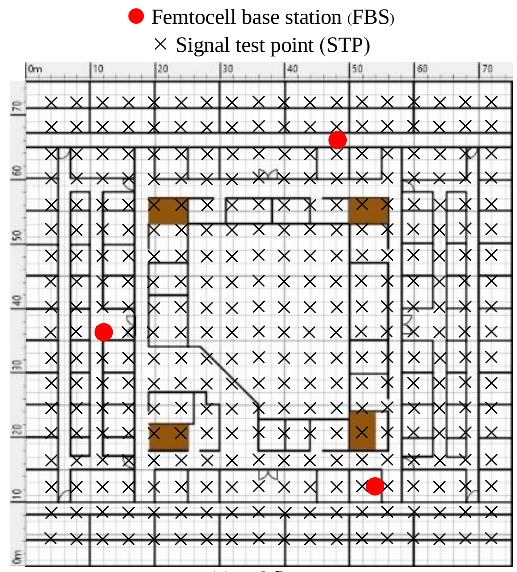
After defining the study area and initial parameters, we used overlap, CI-SINRU and CI-RBU technique for creating interference graphs. The result was the number of interference links from each technique. We used the number of interference links as an input of the frequency channel allocation process. The frequency channel allocation technique [9] which is the semi-static frequency reuse technique was applied to our experiment. The algorithm of this channel allocation technique was defined by the graph coloring problem. We used Integer Linear Programming (ILP) to solve the graph coloring problem in our experiment.



(a) 1st floor



(b) 2nd floor



(c) 3rd floor

Fig. 2. Position of FBS and signal test point placement in the study area.

VI. Experimental Results

From the creating interference graph techniques in the previous section. The results of interference graph creation are presented in this section. There are results in terms of the number of interference links from each creating interference graph technique and the number of frequency channels assigned in the study area. In addition, the performance of each creating interference graph technique was evaluated and presented in terms of signal quality.

A. Result of the Overlap Area

To calculate the overlap area, the path loss model from (1) with information of the study area in Table II were used to calculate the received signal at each STP. Then, we calculated the overlap area using (3).

Fig. 3 shows examples of contour plot for signal overlap area from our proposed overlap technique. The received signal that STPs received from FBSs is represented by color lines. The gray area represents the signal overlap area. Fig. 3 (a) presents the overlap area between the first and the third FBS, both FBSs placed on the first floor, which is 41.97%. Fig. 3 (b) presents 22.22% of the overlap area between the first FBS, placed on the first floor, and the seventh FBS, placed on the second floor. In Fig. 3 (c), there is no overlap area between the first FBS, placed in the first floor, and the eleventh FBS, placed on the third floor.

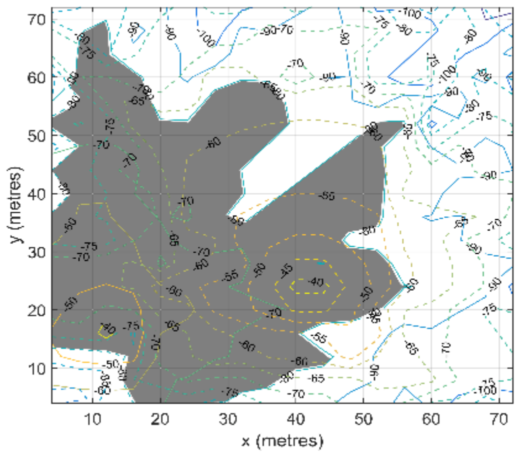
B. Interference Link and Channel Allocation

Results in terms of the number of interference links and number of frequency channel assigned in the study area from each creating interference graph technique are presented in this subsection. Matlab Simulink R2015a application installed on Lenovo Z40-70 laptop PC with 1.70 GHz CPU and 4.00 GB of RAM is our calculation machine. Interference link created from our proposed Overlap technique, CI-SINRU technique and CI-RBU technique are shown in Fig. 4 (a), (b) and (c) respectively. There are both intra-floor interference links and inter-floor interference links in every technique. Our proposed Overlap technique can detect the highest number of interference links (26 links). On the other hand, the CI-SINRU technique and CI-RBU technique detected 3 and 7 interference links respectively. The grid position of STP in the Overlap technique can effectively support the inspection of interference links between FBS. In contrast, a few STP in the related works can roughly inspect some interference links.

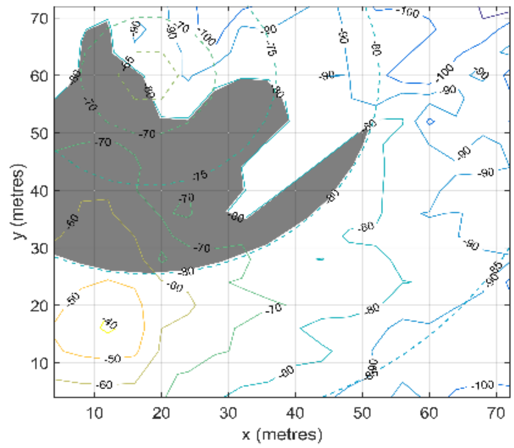
Based on the result of interference links, we allocated frequency channels to 11 FBSs in the study area by semi-static frequency reuse technique [9]. The ILP problems were solved with CPLEX 12.7 optimization solver. The computation was run on an Intel Core i5-6600 3.30 GHz and 16 GB of RAM. The number of interference graph and frequency channel from each technique are shown in Table III. From 26 interference links of our proposed Overlap technique, the frequency channel allocation technique assign four frequency channels to a set of FBS in the study area. In CI-SINRU and CI-RBU technique, there are two and three frequency channels respectively assigned to set of FBS. There are a few frequency channels assigned to FBS in each interference graph creation technique. The next subsection will present the result in terms of signal and service coverage.

Table III. Number of Interference Graph and Frequency Channel from Each Technique

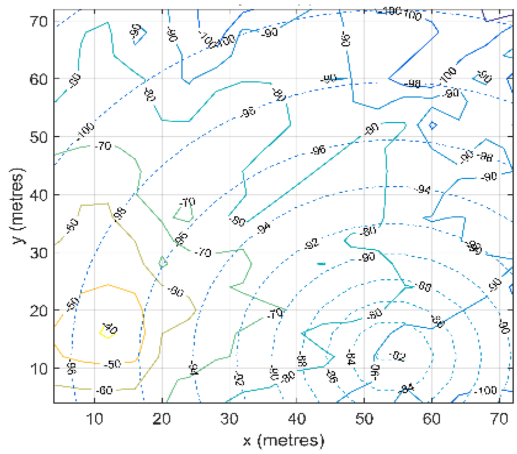
Parameters	Techniques		
	Overlap	CI-SINRU	CI-RBU
Interference link (links)	26	3	7
No. of Frequency Channel	4	2	3



(a) 1st and 3rd FBS

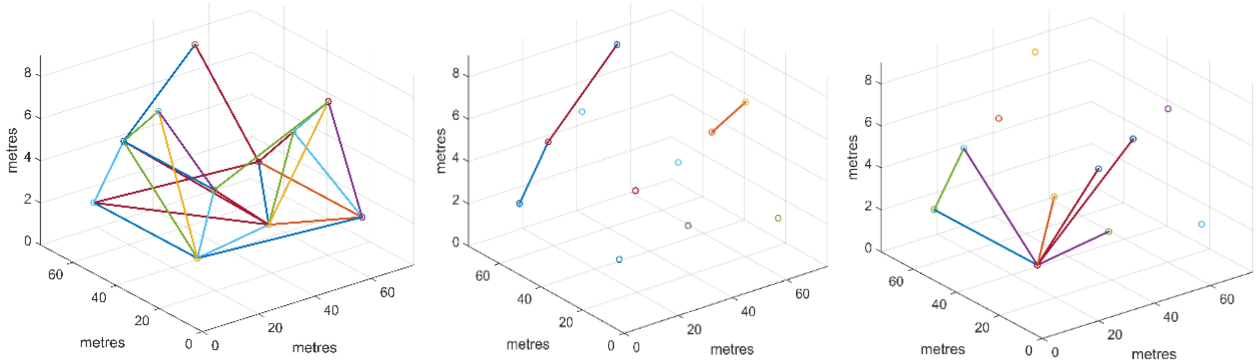


(b) 1st and 7th FBS



(c) 1st and 11th FBS

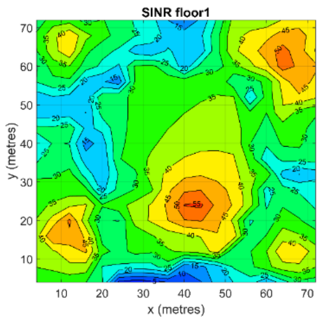
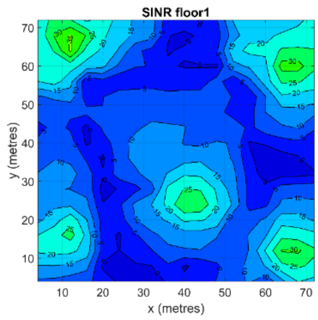
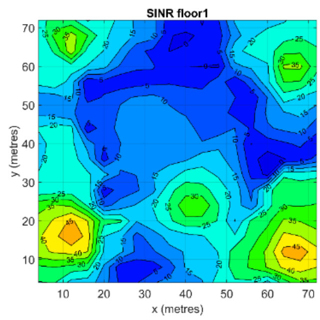
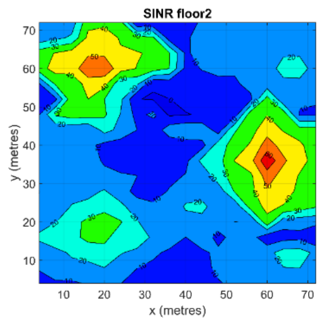
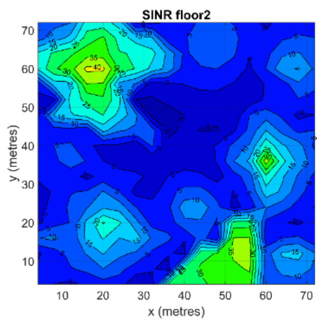
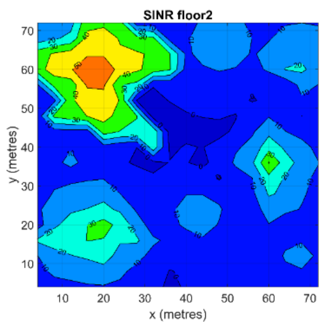
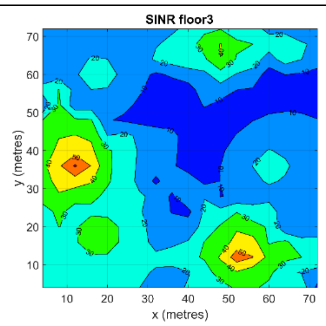
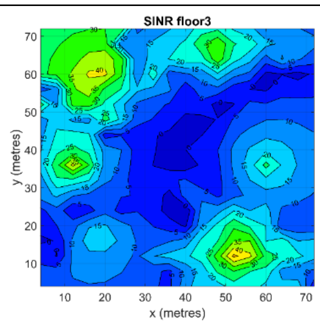
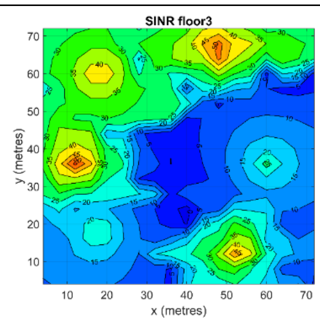
Fig. 3. Example of signal overlap area on the first floor.



(a) Overlap technique (b) CI-SINRU (c) CI-RBU

Fig. 4. Number of interference graph and frequency channel from each technique.

TABLE IV. SINR IN SERVICE AREA FROM EACH TECHNIQUE

	Overlap	CI-SINRU	CI-RBU
Fl. 1			
Fl. 2			
Fl. 3			

C. Signal, Service Coverage and Throughput

From frequency channel allocation using the interference graph in the previous subsection, we analyzed signal quality in the study area. SINR represented signal performance. Table IV present contour plot of SINR in each floor of our proposed overlap technique, CI-SINRU and CI-RBU techniques.

From Table IV, we observed that our overlap technique has the highest SINR level because there are four frequency channels assigned to the set of FBS. This can lead to a low number of duplicate frequency channels which lead to a low interference signal. On the other hand, the CI-SINRU and CI-RBU techniques have lower SINR compared to the overlap technique because they have fewer frequency channels. There are higher numbers of the interference signal in these techniques.

For easier comparison, we plotted SINR based on frequency channel allocation in each creating interference graph technique using the Cumulative Distribution

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Function (C.D.F.) graph which illustrated in Fig. 5. The black, violet and green lines represent SINR of overlap, CI-SINRU and CI-RBU respectively. When considering cumulative value at 0.5, 50% of STP in the study area, the overlap technique can possibly be served up to 23 dB of SINR. For CI-SINRU and CI-RBU technique, there are 21 and 9 dB of SINR respectively at the same cumulative value. These show the overlap technique can give the highest signal performance in terms of SINR compare to other techniques.

To consider coverage of SINR in the study area, we set the SINR threshold at 12.6 dB for guarantee the data rate at 80.64 Mbps for users in the study area [15]. Table V. illustrate average, Standard Deviation (SD.) and coverage percentage of SINR separated by each creating interference graph technique. Our overlap technique achieves the highest SINR coverage which is 77.98% which is double of CI-SINRU technique and 22% higher than CI-RBU technique.

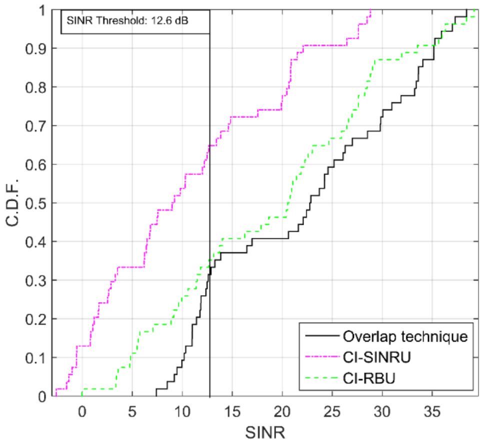

Fig. 5. C.D.F. graph of SINR from each technique.

TABLE V. NUMBER OF INTERFERENCE GRAPH AND FREQUENCY CHANNEL FROM EACH TECHNIQUE

Parameters	Techniques		
	Overlap	CI-SINRU	CI-RBU
Interference link (links)	26	3	7
Number of Frequency Channel (channel)	4	2	3
SINR Average (dB)	23.792	11.086	17.073
SINR SD. (dB)	12.547	10.054	12.443
SINR Coverage (%)	77.98%	36.83%	55.14%

Throughput is one of major factors to present efficiency of 4G-LTE services. Network operators try to provide sufficient throughput for their users. Fig. 6 present throughput of each technique with C.D.F graph. Based on SINR of each technique presented in Fig. 5, throughput is calculated by (4).

$$\text{Throughput} = \log_2(1+\text{SINR}) \tag{4}$$

Due to the interference link determination and number of frequency channels allocated to FBSs, our proposed overlap technique can serve the highest throughput among every presented technique. The CI-RBU technique can provide higher throughput than CI-SINRU technique but lower than the overlap technique. The technique which provides the lowest throughput is CI-SINRU technique because of fewest frequency channels number.

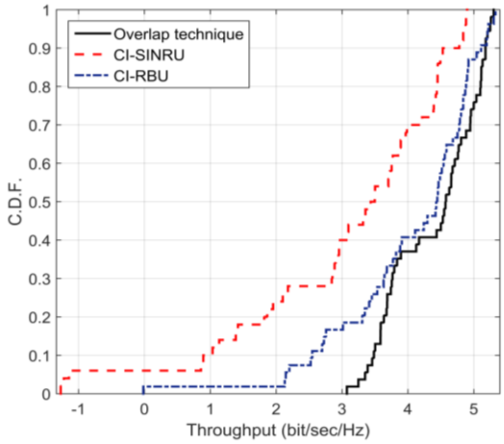

Fig. 6. C.D.F. graph of throughput from each technique.

VII. DISCUSSIONS

Our proposed overlap technique for creating interference graphs thoroughly considered overall feasible points of users in the study area is the important key to lead the service efficiency. The overlap technique can satisfactorily detect the interference links and lead the highest number of interference graph. This can bring the highest SINR coverage and throughput among every technique.

In contrast, the large number of interference link brought a higher number of frequency channels. Although the allocation considered frequency reuse method for the minimum number of frequency channels, the number of frequency channels related to the number of interference links. The network planner may make a decision on a tradeoff between budget from frequency channel license cost and signal quality.

VIII. CONCLUSION

This paper presented the technique and the process of creating interference graphs for the frequency channel allocation of the femtocell network in the multi-floors building. We designed processes for interference graph creation including parameters definition, distance and received power from FBS to STP calculation, overlap percentage between FBS calculation. We set three floors building which had 11 installed FBSs for being the study area. After created interference graph, we operated frequency allocation into each FBS in the study area. We presented overlap area examples, interference link, number of allocated frequency channels, signal coverage and throughput in our experimental results. For evaluation, we compared our proposed technique with two existing interference graph creation techniques from existing works. Our proposed technique can finely detect the highest interference link compared to the existing works. The allocated frequency channels related to the number of interference links. The result of frequency allocation showed that our technique allocates the highest number of frequency channels. Since reusing the highest number of frequency channels, the signal and service coverage results of our proposed technique is the most effective among every technique in the study area.

Our future work will focus on implementing heuristic algorithms to reduce the calculation time of problem-solving. This can optimally apply our proposed interference graph creation technique to the larger and more complex study area. Furthermore, the interference with outdoor macrocell should be considered to cover another perspective of interference graph creation and frequency channel allocation.

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