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Minimizing Interference in Ultra-Dense Femtocell Networks Using Graph-Based Frequency Reuse Technique

[1]Adebayo Adekunle and *[2]Abiodun Gbenga-Ilori

[1] Nigerian Building and Road Research Institute (NBRRI), Federal Ministry of Science and Technology, Sango-Otta, Nigeria
[2] Department of Electrical and Electronics Engineering, University of Lagos, Lagos, Nigeria
casio2022002@gmail.com | gbengailori@unilag.edu.ng

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Abstract- This paper investigates the performance of graph colouring schemes for frequency assignment in Long-Term Evolution (LTE) networks with ultra-dense femtocells. The aim of the study is to minimize interference in such networks while ensuring efficient spectrum use for these femtocells. The three schemes investigated are the conventional greedy graph colouring algorithm, the saturation degree algorithm and our proposed graph-based theory (GBT) algorithm. The process of frequency assignment is similar in the last two except that the proposed GBT partitions the femtocells into independent sets for an efficient frequency re-use. The performance of these three schemes was analyzed through extensive simulations to determine the SINR and network capacity that can be obtained with the deployment of these schemes using the ITU-R P1238-7 path loss model. The outcome of this study showed that with the absence of a dynamic frequency assignment scheme, interference level is increased as the number of femtocell users within a particular coverage is increased, leading to a reduction in the capacity of such networks. Simulation results showed that all three algorithms considered have the ability to allocate frequencies to femtocells and minimize interference in a densely deployed environment, thereby increasing network capacity. The proposed GBT assigned the least sub-band thereby ensuring spectral efficiency while minimizing harmful interference. Results show that the greedy algorithm has a disadvantage of inefficiently assigning sub-bands randomly, while the saturation degree assigns more sub-bands when compared with the GBT scheme.

Keyword- Femtocell, graph colouring, frequency assignment, LTE.

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1 INTRODUCTION

The expansion of mobile networks in recent years has been associated with an increase in demand for mobile data by subscribers in the telecommunication industry. Studies revealed that in the near future about 68% of voice traffic and 89% of data traffic will originate from indoor environments such as residential (Buttar, Goel, & Kumar, 2014). The use of macrocells to provide coverage for indoor users has some limitations in that signals sustain high losses when penetrating an indoor environment through external walls, especially buildings constructed with insulation materials that have high penetration losses. This building penetration loss has led to poor network coverage and mobile operators are forced to find a solution to providing reliable indoor coverage and improve network capacity in order to meet the ever-increasing traffic demand (Cao et al, 2011).

Femtocell has been used extensively in wireless communication systems due to its advantages such as improved indoor coverage, energy efficiency and low cost (Sghiri, & Ayadi, 2014). It is expected that the introduction of femtocells will address complaints from subscribers arising from poor indoor coverage. However, interference harmonization is a major issue that needs to be addressed especially since a large number of femtocells are expected to underlay the existing macro network in the nearest future. The deployment of femtocells in large numbers can raise the interference level of wireless networks. This interference is a key challenge for the successful deployment of femtocell networks, as it decreases the performance of the network especially when adjacent femtocell frequencies overlap.

Previous authors have considered the problem of interference in femtocell networks. A lot of these papers used the power control method to mitigate interference (Hassan, & Gao, 2019). Some also considered the use of channel assignment schemes to mitigate interference within the network (Rahman, Alam, & Chowdhury, 2015), (Ahmed et al, 2014), (Chowdhury et al, 2012).

This paper proposes a solution to the problem of interference in ultra-dense femtocell networks using graph-based frequency reuse techniques. Several-interference improvement schemes have been developed already to handle interference between a femtocell and the macrocell. However, intra-cell interference amongst femtocells has also become an unavoidable issue, especially when they are densely deployed since femtocells are user-deployed and do not require planning like macrocells. To address the problem of interference this paper simulates the deployment of femtocells within apartments using embedded graphs. The simulation was carried out using three graph-colouring algorithms that are presented. The performance of these algorithms in dense femtocell networks is investigated in terms of their interference mitigation ability and network capacity enhancement. The main objective of this research work is to minimize interference in a femtocell-based communication network through frequency reuse. The specific objectives are to:

1. deploy indoor femtocells underlaid in macrocell networks to enhance coverage,
2. model femtocell networks using Graph theory and minimize network interference through the use of two conventional algorithms and a newly proposed one, and
3. investigate the performance of the network with our proposed optimal algorithm while comparing its performance with the other two algorithms.

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*Corresponding Author

The rest of the paper is organized as follows: The system model is discussed in section 2 while the step by step procedure for constructing interference graphs and algorithms for assigning frequencies to femtocells is described in section 3. The simulation result and analysis are presented in section 4 and the conclusion and recommendations are presented in section 5.

2 SYSTEM MODEL

The main goal of this study is to enhance the quality of service for femtocell users by minimizing interference through the use of graph-colouring algorithms for frequency bands assignment to femtocells. Macrocell-Femtocell inter-tier interference network is excluded from this study and we have only considered intra-tier interference. The femtocells, which are the nodes in the graph, are connected using the channel state information obtained from the femtocells and their users. Frequencies are assigned to each base station to minimize interference using graph-colouring algorithms. In the graph-colouring algorithms deployed, each colour represents a distinct frequency band. The algorithms considered in this paper are the greedy algorithm, the saturation degree algorithm and a proposed optimal graph-based technique (GBT) algorithm. The system model is shown in Fig. 1.

The deployments of femtocells in apartments are carried out using graph theory where each apartment in a building has a square area of a^2 meter. The user equipment (UE) in these apartments obtains their signals from such femtocells deployed. Each user communicates with the femtocell from which it receives the strongest signal strength as shown in Fig. 1. The deployment of femtocells in apartments is assumed to have a dimension of *12 by 12* m² in this work as shown in Fig. 1.

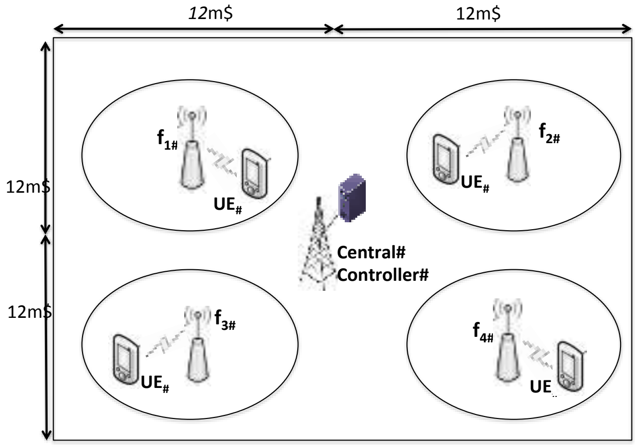

Fig. 1: System Model with the deployed femtocells

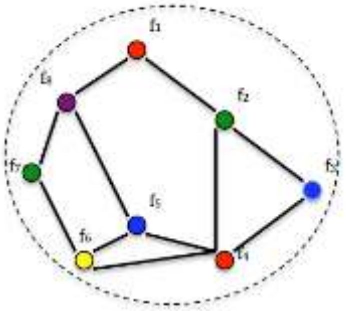

Fig. 2: Graph-based femtocell network

Fig. 2 shows a sample of a graph-based femtocell network. This study will be considering only femtocell networks. The femtocell network performs its operation through a central server which makes use of the channel state information (CSI) to control the sessions, handle registrations and communication with all femtocells (Zhang, & De la Roche, 2011). The information obtained from the femtocells is employed by the central controller to construct the interference graph. When the interference graph is constructed, any two femtocells with a direct connection serve as neighbours to each other. In case there is an addition of a new femtocell to the network, the central controller re-gathers data from individual femtocells and re-constructs a new interference graph. In the interference graph, each node represents a femtocell and edges connecting two nodes represent interference between two cells.

This interference graph is a simple and undirected graph in which both multiple edges and loops are disallowed. The simple graph is, therefore, the combination of a finite set of nodes V and a finite set E of edges that comprise two-element subsets of V such that $E = \{V_1, V_2\}$. In a simple graph with n nodes, the degree of every node is at most $n - 1$. Frequencies are assigned to femtocells based on the available sub-bands.

Two femtocells using the same frequency are prone to experience interference and the strength of this interference depends on the CSI. The signal-to-interference-plus-noise ratio (SINR) of femtocell f_1 can be expressed as:

$$SINR_{f_1} = \frac{P_{f_1} G_{f_{1,j}}}{\sum_{i=2}^{n} P_{f_i} G_{f_{i,j}} + \sigma_n}, \qquad (1)$$

where P_{f_i} is the transmission power of the femtocell f_i, σ_n is the noise power, $G_{f_{i,j}}$ is the gain between femtocell f_i and user j. The achieved transmission rate of a femtocell f_1 is R_{f_1} and can be determined by Shannon's formula as:

$$R_{f_1} = W \log_2 (1 + SINR_{f_1}), \qquad (2)$$

where W is the bandwidth in Hertz and $SINR_{f_1}$ is the signal to interference plus noise ratio for the femtocell f_1 in the network. Supposing that E_{XY} is used to denote the edges between two femtocell nodes X and Y, the interference I between the femtocells X and Y can be determined using (1). The interference threshold I_{th} is determined by the central controller, and it is the level above which interference is considered harmful. Using this threshold, an interference graph can then be constructed for different femtocell nodes. Therefore, the interference between the femtocells X and Y is:

$$E_{XY} = \begin{cases} 0 & I \le I_{th} \\ 1 & I > I_{th} \end{cases} \qquad (3)$$

3 GRAPH COLOURING ALGORITHMS

Graph colouring enhances sub-band assignment such that two femtocells connected in the interference graph must not use the same sub-band which is indicated as colours in the graphs. It also ensures that the numbers of colours or sub-bands assigned are minimized as much as possible to ensure an optimal frequency assignment. In other words, a minimum number of colours is used such that no two neighbour nodes have the same colour and each colour represents a distinct sub-band. In this work, we have considered three types of graph colouring algorithm: greedy algorithm, saturation degree algorithm, and our proposed graph-based technique.

3.1 GREEDY ALGORITHM

Greedy algorithm relies on a method of routing that assigns the smallest colour or sub-band to the available femtocells in order to produce an optimal frequency assignment in a network. This method is one of the most basic method of graph colouring. It assigns the smallest possible colour to vertices such that no conflict exists between the vertices and their coloured neighbours (Galán, 2017). The process is shown in Algorithm 1. For a given graph G, the set of vertices is described as $V = \{v_1, v_2, \dots\dots v_n\}$, the set of edges is described as $E = \{e_1, e_2, \dots\dots e_n\}$, the set of available frequencies is $F = \{f_1, f_2, \dots\dots f_n\}$ and the set of colors or sub bands for the nodes is described as $C = \{c_1, c_2, \dots\dots c_n\}$ where the total colours assigned in the graph network is $P = c_1 \cup c_2 \dots\dots \cup c_n$.

Algorithm 1: Greedy algorithm for frequency assignment

```
INPUT: $V, E, C, P, F$
OUTPUT: Assign frequencies to vertices (femtocells) using frequency reuse technique for optimal solution
    Step 1: Calculate deg $(v_i)$ for $i = 1,2, \dots, n$.
    Step 2: for $V := v_1$ to $v_2$
        a) Consider the currently picked vertex $v$ and assign the smallest possible colour $C_{min}$ that has not been used on any previously colored vertex adjacent to it,
        b) If all previously used colors appear on vertices adjacent to $v$, assign a new color to it. Then total colours become $P = P + 1$.
    Step 3: Assign $f_{min}$ to $f_{max}$ to all nodes
    Step 4: The algorithm terminates when all nodes have been assigned frequencies
```

3.2 SATURATION DEGREE ALGORITHM

This technique employs saturation degree (D) which is defined as the total number of adjacent coloured vertices to which an uncoloured femtocell or node is connected (Aslan, & Baykan, 2016).

Algorithm 2: Saturation degree algorithm

```
INPUT: $V, E, C, P, F$
OUTPUT: Assign frequencies to vertices (femtocells) using frequency reuse technique for an optimal solution
    Step 1: First assign $C$ to node with $deg(v)_{max}$
    Step 2: Arrange all uncoloured nodes in decreasing order of $D$
    Step 3: Pick node with $D_{max}$ and assign the available $C$
    Step 4: For nodes with equal $D$ values, choose the node having largest $deg(v)$
    Step 5: If there are available colors in $P$, assign $C$ to the chosen node otherwise increase $P$ by 1 such that $P = P + 1$
    Step 6: Assign $f_{min}$ to $f_{max}$ to all nodes
    Step 7: The algorithm terminates when all nodes have been assigned frequencies
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The algorithm is such that two adjacent femtocells in the interference graph must not use the same frequency band or color. The process is described in Algorithm 2. For the given graph, the sets V, E, C, P, F is as defined in section 3.1.

3.3 PROPOSED GRAPH-BASED TECHNIQUE (GBT)

In this proposed technique, the set of vertices V is partitioned into independent sets S where $V = S_1 \cup S_2 \dots\dots \cup S_k$ using the CSI. Vertices within a particular set S are unable to reuse frequencies but the independent sets $\{S_1, S_2, \dots\dots S_k\}$ can reuse frequency bands. This has the advantage of reducing latency within the network and capacity and efficiency is improved within the network. The channels are first partitioned using the CSI within the network and reuse of frequency can only take place in different sets. This makes it faster to assign a colour or frequency and network latency and efficiency are consequently improved. Thereby network process is optimised. For the given graph, the sets V, E, C, P, F is as defined in section 3.1. The process is described in Algorithm 3, (Adekunle, 2019).

Algorithm 3: Proposed Graph Based Technique (GBT)

```
INPUT: $V, E, C, F, P$
OUTPUT: Assign frequencies to vertices (femtocells) using frequency reuse technique for an optimal solution
    Step 1: Calculate deg $(v_i)$ for $i = 1,2, \dots. n$.
    Step 2: Select a node $v_i \in V$ with $deg\ (v)_{max}$
    Step 3: Assign $C_{min}$ to $deg\ (v)_{max}$
    Step 4: Partition $V(G)$ into independent sets $\{S_1, S_2, \dots\dots S_k\}$ using CSI
            $V(G) = \{S_1 \cup S_2 \cup \dots\dots \cup S_k\}$
            $S_i = \{V_1 \cup V_2 \cup \dots\dots \cup V_k\}$
            $S_j = \{V_3 \cup V_4 \cup \dots\dots \cup V_n\}$
            such that $S_i \cap S_j = \emptyset$, for all $i$ and $j$.
    Step 5: If there is no available color in $C$, assign a new color such that total colours becomes $P = P + 1$.
    Step 6: Assign $f_{min}$ to $f_{max}$ to all nodes
    Step 7: The algorithm terminates when all nodes have been assigned frequencies
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4 PERFORMANCE EVALUATION

The performance of the three frequency assignment techniques is investigated, evaluated and compared by performing simulations on MATLAB to determine downlink signal to interference plus noise ratio (SINR) and network capacity using appropriate path loss model. The ITU-R P1238-7 propagation model (Zyoud et al, 2013) is adopted for the path loss because it has an incorporated building penetration factor that compensates for losses due to walls and buildings. A network made up of a number of femtocells with one user per femtocell is deployed in each apartment. The three algorithms are employed to assign frequencies and minimize interferences as much as possible within the network. Simulations leading to determination of SINR and capacity obtained from the algorithms used are also presented. Authors also did some analysis to determine spectral efficiency of the three algorithms considered. The results obtained from these analyses are discussed.

The simulation parameters are shown in Table 1. The network is made up of a minimum of fifteen femtocells randomly deployed within apartments. Threshold interference is obtained as reference interference to draw interference graphs using parameters such as femtocell transmit power, femtocell radius, noise figure and received power. The system bandwidth is divided into the sub-bands which are used as colours in the algorithms and relevant performance parameters are obtained.

Table 1. Simulation Parameters (Valcarce, & Zhang, 2010; Hassan, & Gao, 2019).

Parameter	Value
Number of femtocells	20, 30, and 40
Femtocell transmit power	20mW
Carrier Frequency/Subcarrier Spacing	2GHz /15KHz
System Bandwidth	1.5GHz
User equipment noise figure	-45.26dB
Number of available channels	20
White noise power density	-174dBm/Hz
ITU-R P1238-7 Model	$PL = N\,Log\,d + L_f(n_w) + 20 * Log f_c - 28$ (Zyoud et al, 2013)

4.1 CAPACITIES OBTAINED USING ITU-R P1238-7 MODEL

The ITU-R P1238-7 path loss model is developed by the international telecommunication union radio and it is particularly useful for indoor environments by employing a floor compensation factor when there is a concrete wall between transmitter and receiver, (Zyoud et al, 2013). Fig. 3 shows the capacities of the three algorithms for 20 users in a particular coverage area using the ITU-R P1238-7 model. The capacities for all the three algorithms follow the same trend. The proposed GBT algorithm produced the highest capacities for the users ranging from 0.03 Mbps to 0.177 Mbps while the greedy algorithm produced the least capacities ranging from 0.02 Mbps to 0.12 Mbps. From the cumulative distribution function (CDF) shown in Fig. 3, it can be seen that about 35% of users with the proposed GBT algorithm have capacities beyond 0.12 Mbps; saturation algorithm has 12% while greedy algorithm has 3%.

Fig. 4 shows capacities of the three algorithms for 30 users in the same coverage area as 15 femtocells using the ITU-R P1238-7 model. The capacities for all three algorithms follow the same trend. The proposed GBT algorithm produced the highest capacities for the users ranging from 0.05 Mbps to 0.45 Mbps while the greedy algorithm produced the least capacities ranging from 0.03 Mbps to 0.27 Mbps. From the CDF shown in Fig. 4, it can be seen that only 35% of users with the proposed GBT algorithm have capacities beyond 0.3 Mbps, saturation has 15% while greedy algorithm has 0%. The same simulation was done without the use of frequency assignment algorithms and the increase in the deployment of users from 20 to 30 showed a general reduction in capacities due to an increase in interference within the network. However, the reverse is the case with the deployment of a dynamic frequency assignment algorithm.

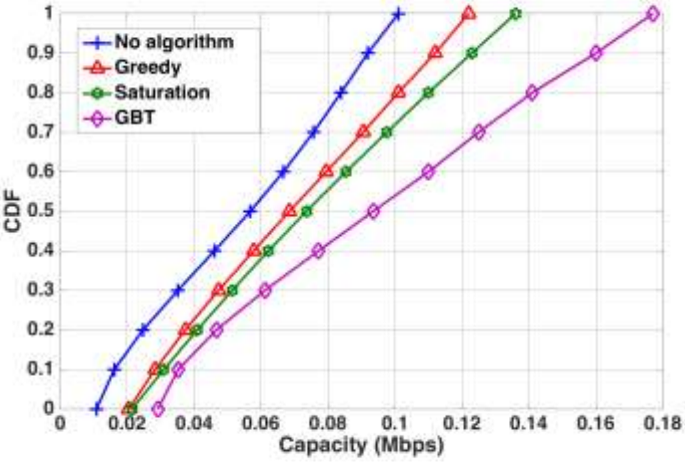

Fig. 3: Network Capacity for 20 users.

Fig. 5 shows the capacities of the three algorithms for 40 users in the same coverage area as 15 femtocells using the ITU-R model. The capacities for all the three algorithms follow the same trend. The proposed algorithm produced the highest capacities for the users ranging from 0.095 Mbps to 2.69 Mbps while the greedy algorithm produced the least capacities ranging from 0.059 Mbps to 1.1 Mbps. From the CDF shown in Fig. 5, it can be seen that only 25% of users with the proposed GBT algorithm have capacities beyond 1.5 Mbps, saturation algorithm has 15% while greedy algorithm has 0%. Again, the use of frequency assignment algorithms resulted in the increase in capacities due to a reduction in interference within the network.

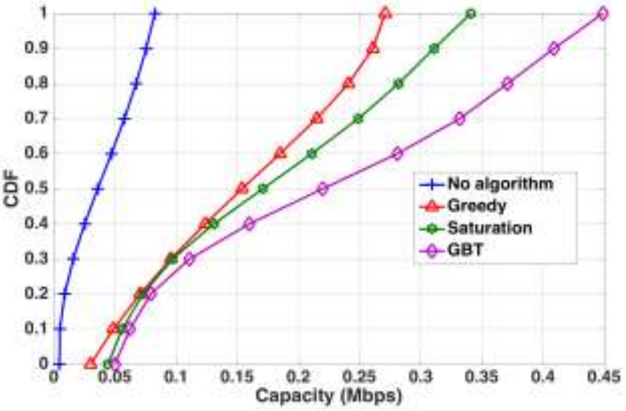

Fig. 4: Network Capacity for 30 users.

Fig. 6 shows the number of sub-bands assigned to the femtocells by each algorithm as the number of femtocell users is increased. The GBT algorithm consistently assigned the least sub-band because of its frequency re-use scheme thereby ensuring spectral efficiency. It also shows that the proposed GBT algorithm has the tendency of minimizing interference using minimal sub-bands compared to other frequency assignment techniques.

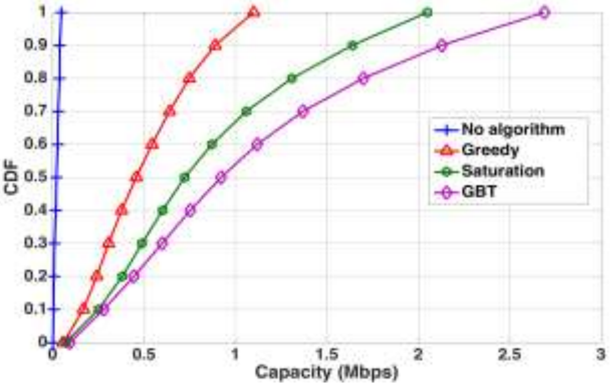

Fig. 5: Network Capacity for 40 users.

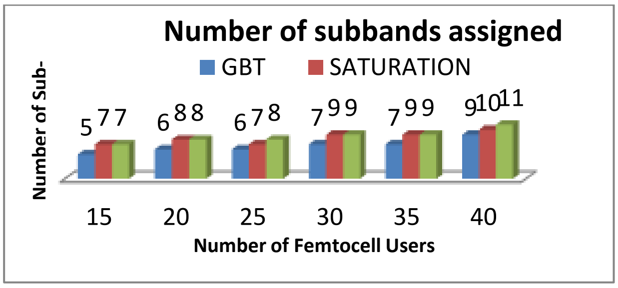

Fig. 6. Sub-bands Assigned by each Algorithm

5 CONCLUSION AND RECOMMENDATIONS

In this paper, we have discussed frequency assignment schemes that help to minimize interference and enhance throughput when there is a dense deployment of femtocells within an indoor environment. The frequency assignment schemes considered in this paper are: the greedy algorithm, the saturation degree algorithm, and a proposed graph-based technique. The outcome of this study shows that as the number of femtocells deployed within a particular coverage is increased, the interference level also increased when no dynamic frequency assignment scheme is deployed. This consequently affects the capacity of such a network. The paper showed that interference can be reduced and capacity increased by deploying a dynamic frequency assignment scheme. It further shows that all three algorithms considered have the ability to allocate frequencies to femtocells and minimize interference in a densely deployed environment. The proposed GBT technique, however, assigned the least sub-band thereby ensuring spectral efficiency and minimal interference. The paper shows that the limitation of the greedy algorithm is that it assigns sub-bands randomly while the saturation degree algorithm assigns more sub-bands when compared with the GBT algorithm. SINR and capacities were obtained using the ITU-R P1238-7 path loss model which is suitable for an indoor environment.

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