Fractional Frequency Reuse (FFR) Usability Improvement in LTE Networks

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Summary

Femtocell networks can be a potential method for increasing the capacity of LTE networks, especially in indoor areas. However, unplanned deployment of femtocells results in co-tier interference and cross-tier interference problems. The interference reduces the advantages of implementing femtocell networks to a certain extent. The notion of Fractional Frequency Reuse (FFR) is proposed in order to reduce the impact of interference on the system's performance. In this paper, a dynamic approach for efficiently partitioning the spectrum is suggested. The goal is to enhance the capacity of femtocells, which will improve the performance of the system. The suggested strategy allocates less resources to the macrocell portion of the network, which has a greater number of femtocells deployed to maximize the utilization of available resources for femtocell users. The spectrum division would be dynamic. The proposed strategy is evaluated through a simulation using MATLAB tool. In conclusion, the results showed that the proposed scheme has the potential to boost the system's capacity.

Keywords: *LTE, Femtocell, FFR, Interference*

1. Introduction

In recent years, there has been a growth in the need for high levels of Quality of Services (QoS) and capacity for mobile applications. Therefore, intensive research has been conducted to investigate the concept of femtocell networks. Dense deployment of femtocells requires massive amount of radio resources. Thus, to improve the efficiency of the network, radio resources can be reused wireless networks due to the limitation of the dedicated spectrum [1][2]. Femtocell base stations can be installed in indoor environments or dead zones to improve the system's performance by offloading traffic loads from microcell base station to distributed femtocell base stations. Femtocells can also be used to boost the system's performance in dead zones. As a result, the throughput and coverage of macrocell will be increased due to the fact that distributed femtocells can handle a large amount of traffic. Because of the cheap cost of implementation and ability of femtocells to offload more than half of the traffic from macrocell, deploying a femtocell base stations is considered as cost-effective option [3] [4]. According to the requirements of the Third Generation Partnership Project (3GPP), the architecture of femtocell networks is composed of three primary components, which are the femtocell management system (FMS), femtocells, and femtocell user equipment (FUE) [4]. The femtocell end user is the person who is linked to the femtocell through the air interface. Accordingly, FMS entity is responsible for managing and controlling a group of femtocell base stations, which are located within a defined geographical region. Moreover, FMS connects femtocells to the Internet through backhaul connections.

Because a femtocell might be installed by an end user, the deployment of femtocells is inefficiently controlled. As a result, dense and unplanned deployment of femtocells reduces the predicted benefits of employing femtocells. Interference is a significant difficulty for femtocell networks, as it has a negative impact on the network's performance, particularly when the coverage of nearby femtocells overlaps. Interference occurs when the same frequency of radio resources is assigned to multiple FUEs, which are coupled with distinct femtocells and are positioned in overlapping regions. This could cause interference among them [5]. Co-tier interference and cross-tier interference are two types of interference that are classified according to the network tier in which it is occurring [6]. Co-tier interference happens when two nodes, the source and the victim, are both categorized in the same network tier at the same time. As a result, when a significant number of femtocells are densely deployed, a severe co-tier interference will be generated. Also, cross-tier interference happens when the source and victim nodes are located in separate network tiers from one another.

According to the literature severl solutions for dealing with the interference problem have been presented in previous studies. Those systems include numerous antennas, transmission power regulation, and spectrum partitioning, the latter of which is the primary subject of this investigation. The FFR concept motivates the interest of researchers in both the academic and industrial environments. The basic concept behind the idea of FFR is to make use of various reuse factors values for UEs located in the cell center and UEs located in the cell edge.

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Therefore, the cell coverage area is divided into two regions: the cell center region and the cell edge area. As a result, both soft frequency reuse (SFR) and partial frequency reuse (PFR) have been developed and introduced [7][8]. In [9], the authors proposed an adaptive frequency reuse system for femtocell networks, with the goal of preventing the development of co-interference and cross-interference between the cells. The subchannel is categorized into primary and secondary subchannels. This classification was to maximize the number of allocated subchannels for each femtocell in use. The primary subchannels are assigned distributed among femtocells. The secondary subchannels are assigned to the selective femtocells when there is no conflict with neighboring femtocells to address the problem of the interference. In [10], a clustering-based strategy is also introduced to control interference in densely and unplanned distributed femtocells, with the goal of reducing interference. Thus, the femtocells are divided into several groups based on the degree to which one femtocell interferes with the others. In [11], a resource sharing method based on the FFR paradigm is presented. The goal of the method is to enhance spectral efficiency while minimizing interference caused by femtocells. This means that the femtocell will be restricted from utilizing the same frequency as neighboring UEs are used for all UEs, which are served by the serving macrocell.

In [12] the genetic algorithm and the graph-annealing algorithm are integrated and employed to intelligently split the spectrum between cell center area and cell edge area. The goal is to increase the cell's average throughput and reduce outage risk, particularly for the UEs located near the cell edge. According to [13], a dynamic frequency reuse (DMFR) technique has been proposed. The DMFR allocates the spectrum across various portions of the cell depending on the number of UEs in each area. The authors of [14] presented an adaptive resource allocation strategy that is based on the dispersion of femtocells. Essentially, the proposed technique enables the femtocell to access the whole dedicated bandwidth if there are no macro UEs in the coverage region of the cell. According to [15], the FFR systems are studied and evaluated according to certain parameters. The authors also choose the SFR scheme and optimize it in order to create a better trade-off between fairness and high throughput while still maintaining fairness.

In this paper, a Dynamic Frequency Partitioning Scheme is suggested. Increased capacity of the femtocell network is one of the goals of the proposed strategy, which aims to boost the overall system capacity. The primary concept behind the suggested strategy is to allocate radio resources to the macrocells' area of the network that has the greatest number of femtocells in order to reuse unused resources for the femtocells that are located in the same part of the network. The remainder of this work is structured in the following manner. The system model is presented in the second section as well as the problem formulation. Section three provides a more in-depth explanation of the proposed approach. The fourth part contains a description of the experiment that was carried out in detail. The conclusion is provided in the last portion of the paper.

2. System Model and Problem Formulation

2.1 System Model

Unplanned deployment of indoor femtocells is taken into consideration in this research project. In addition, the Femto-Gateway device is used to connect a number of femtocells in a specific region together. FGW unit communicates with femtocells through the S1 interface, which is used for data transfer. In this study, the concept of FFR is also taken into consideration. In FFR, the macrocell dominating region is separated into four sub-areas: the center and three edges. The cell center region receives half of the spectrum as illustrated in Fig.1. The other half of the spectrum is allocated to the rest of three other sub-areas (three edges), as shown in Fig.1.

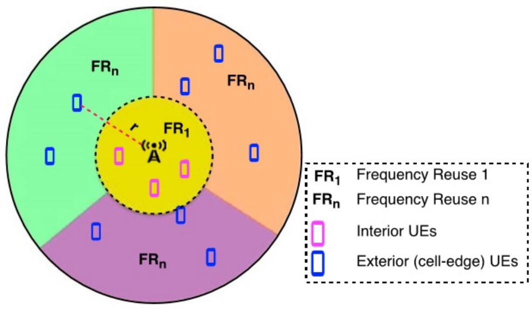

Fig. 1 FFR Model [18].

Article [16] provides the path loss model between a serving macrocell and its outdoor Macro UE (MUE) as follows:

$$PathLoss_{dB} = 15.3 + 37.6\, log_{10}\,(R) \qquad (1)$$

While the path loss model for indoor UEs is given as follows:

$$PathLoss_{dB} = 15.3 + 37.6\, log_{10}\,(R) + L \qquad (2)$$

(R) represents the distance between the transmitter and the receiver in meter. L represents the penetration loss caused by the wall.

The received SINR is modeled as follows [17]:

$$T_{i,s} = \frac{\gamma_{m,s} G_{i,m,s}}{\sum_{m'} \gamma_{m',s} G_{i,m',s} + \sum_{F} \gamma_{F,s} G_{i,F,s} + N_0 \Delta f} \quad (3)$$

the transmitting power for serving macrocell m on subcarrier s and the transmitting power for adjacent macrocells m' on subcarrier s are represented by $\gamma_{m,s}$ and $\gamma_{m',s}$, respectively. The channel gain is indicated by $G_{i,m,s}$, where m represents serving macrocell, i represents macrocell's UE, and s represents received subcarrier. The channel gain $G_{i,m',s}$ indicates interfering signal received from adjacent macrocell, where m' represent adjacent macrocell, i represent UE, and s represents the subcarrier. Also, in case of receiving interference from femtocells, which are adjacent to macrocell's UE i, $\gamma_{F,s}$ indicates femtocell's F transmission power on subcarrier s, and $G_{i,F,s}$ indicates gain of received subcarrier s. Spacing of subcarrier is indicated by Δf and white noise power spectral density is indicated by N_0.

Also, the channel gain of an UE is expressed by [17]:

$$Gain = 10^{-PathLoss/10} \quad (4)$$

The estimated capacity of any UE u on any subcarrier s is given as follows [17]:

$$C_{u,s} = \Delta f \log_2 (1 + \alpha T_{u,s}) \quad (5)$$

here α indicates BER. In this work, its target is considered to be 10^{-6}. The cell overall throughput model is expressed as follows [17]:

$$E = \sum_{u} \sum_{s} \beta_{u,s} C_{u,s} \quad (6)$$

where $\beta_{u,s} = 1$ if particular subcarrier s is allocated to UE u; otherwise it is set to be $\beta_{u,s} = 0$.

In the next sub-section, problem optimization is formulated. The aim of this problem is to maximize the total throughput.

2.2 Problem Formulation

E_f represents overall throughput of femtocell. Also, E_m represents overall throughput of macrocell.

$$E_f = \sum_{u} \sum_{s} \beta_{u,s} C_{u,s} \quad (7)$$

$$E_m = \sum_{u} \sum_{s} \beta_{u,s} C_{u,s} \quad (8)$$

In (7) and (8), $\beta_{u,s}$ denote to whether a subcarrier is assigned to femtocell's UE and macrocell's UE or not. If $\beta_{u,s}$ equals to 1 that means this particular subcarrier is assigned to UE of femtocell or macrocell.

It is assumed that the macrocell's area is divided into multiple sub-areas included in set X. Sub-bands that are allocated to femtocells, which are positioned in sub-area X, is represent as f_X. The problem is expressed as follows:

$$Maximize_{Fx} \; E = E_m + E_f \quad (9)$$

$$Subject \; to:$$

$$\sum_{um}^{nm} \sum_{s} P_m^s \beta_{um}^s = P_m \quad (10)$$

$$\sum_{f \in x} \sum_{s} P_f^s \beta_{uf}^s = P_f \quad (11)$$

$$\sum_{um=1}^{nm} \beta_{um}^s = 1, \quad \forall s, \quad (12)$$

$$\sum_{f \in x} \beta_{uf}^s = 1, \quad s \in F_x \quad (13)$$

$$\beta_{um}^s, \quad \beta_{uf}^s \in [0,1], \forall [m,f] \quad (14)$$

where nm is the number of macrocell' UEs. P_m is the level of transmitted power of macrocell and P_f is the transmission power of femtocell. Also, P_m^s is the power, which is assigned by macrocell, to subcarrier s. P_f^s is the power, which is assigned by femtocell, to subcarrier s.

Constraints (12), (13) ensures that subcarrier would be only assigned to a single macrocell's UE or femtocell's UE. However, solving NP-Complete problem would not be evident. Therefore, a scheme is proposed in next section.

3. Dynamic Frequency Partitioning Scheme

In this work, the DFPS scheme is introduced to enable the macrocell partitioning its resources and maximizing the femtocells' throughput. This would also increases the average throughput of the macrocell. The basic concept of FFR is to partition the macrocell's dominant area into four parts due to mitigate the co-tier interference as well as the cross-tier interference. Fig.1 depicts the four different parts of the macrocell and the spectrum is divided among those parts. However, the spectrum division is fixed for all four parts. The aim of DFPS is to enhance the FFR by dynamically dividing the spectrum among the four parts based in cost function, which is the amount of distributed femtocells in each part. Basically, the dedicated portion for a certain part is scheduled and assigned for MUEs, which are positioned at the same part. The other three parts of the spectrum are dedicated to the femtocells positioned in the same part to avoid cross-tier interference between MUEs and FUEs.

Let $N_1^n = [f1, f2, f3, \ldots fn]$ be a set of all femtocells in the system where Ftotal is the total number of femtocells and $F_{total} = n$. Also, the macrocell area is divided into four different parts $[A, B, C, D]$, and A is the center cell area. In addition, the spectrum is divided into four different parts. Accordingly, each part of the macrocell has its dedicated spectrum portion, and it contains certain number of femtocells. $A_{M\,s}$, $B_{M\,s}$, $C_{M\,s}$, $D_{M\,s}$ are the dedicated frequency parts for MUEs, which are positioned at areas A, B, C, D, respectively. Also, the following sets $\theta_1^{an} = [fa1,\ fa2,\ fa3,\ \ldots\ fan]$, $\theta_1^{bn} = [fb1,\ fb2,\ fb3,\ \ldots\ fbn]$, $\theta_1^{cn} = [fc1,\ fc2,\ fc3,\ \ldots fcn]$, and $\theta_1^{dn} = [fd1,\ fd2,\ fd3,\ \ldots fdn]$ are the set of femtocells, which are positioned in area A, B, C, D, respectively. Consequently, $AF\ s, BF\ s, CF\ s, DF\ s$ are the dedicated frequency part for FUEs that are associated with femtocells positioned at A, B, C, D areas, respectively.

The number and the positions of femtocells in each area is steady where the number of MUEs is unstable. Therefore, DFPS divides the whole spectrum among the macrocell's area based on the number of femtocells in each part. Furthermore, the objective of DFPS scheme is to maximize the capacity of the femtocells, which increase the capacity of the entire system.

The process of the scheme is based on the follows. The entire spectrum is divided among the four parts A, B, C, D equally. Then, each part i should configure its cost function, which is defined as follows:

$$\Omega_i = \frac{\theta_{in}}{F_{total}} \qquad (15)$$

where θ_{in} is the total number of femtocells, which are positioned at certain part i, and the F_{total} is the number of all femtocells in the system. Then, the available resources ψ is divided equally among the four parts. Consequently, the dedicated resources for each part computed as follows:

$$I_{Ms} = \psi \times (0.25) \qquad (16)$$

Where I_{Ms} is the dedicated portion of the spectrum for MUEs positioned at part i. Accordingly, the femtocells, which positioned at part i, can schedules their attached FUEs for one of the other three different portions, so I_{FS} can be one of the rest resources parts [I' , I'' , or I''']. If I = A, I' = B, I'' = C, I''' = D.

The cost function Ωi needs to be applied in order to configure an appropriate amount of resources for both I_{Ms} and I_{FS} in part i. The value of cost functions varies based on the number of femtocells in each part i, so the cost function for part i is increased when more femtocells are inserted and positioned in part i. Actually, the value of the cost function Ωi for certain part i would be the satisfied percentage level of the spectrum that needs to be considered in order to increase the capacity of the femtocells. The satisfied portion I_{FS} that should dedicated for femtocells in part i can be given by:

$$\lambda_{Fsi} = \psi \times (\Omega_i) \qquad (17)$$

where λ_{Fsi} is the maximum amount of resources that can be dedicated for femtocells, which are positioned at part i. Once the system configures the Ωi and λ_{Fsi} it is possible to get an appropriate I_{MS} and I_{FS} for part i. The objective of the DFPS is to increase the femtocells capacity. Therefore, I_{FS} is increased by decreasing I_{MS} for part i.

At the beginning both I_{MS} and I_{FS} will be the same for part i as well as all other parts of the macrocell. After first step, the cost functions of all parts is sorted in descending way. We start with the highest cost function Ωi and compare the satisfied amount of resources λ_{Fsi} with current amount of resources I_{FS}. The following expression must be satisfied:

$$I_{FS} \geq \lambda_{Fsi} \qquad (17)$$

The condition can be satisfied by applying the cost function on I_{MS} for the next iterations as follows:

$$I_{Ms}(t+1) = I_{Ms}(t) - [I_{Ms}(t) \times \Omega_i] \qquad (19)$$

where t is the iteration time. This step will be repeated till it satisfies the condition of (15), and the remain resources will be given as:

$$\sigma = I_{Ms}(t) - I_{Ms}(t+1) \qquad (20)$$

and it is added to $\psi(t+1)$. Then,

$$\psi(t+1) = [\psi(t)] - [I_{Ms}(t+1)] + [\sigma] \qquad (21)$$

where $\psi(t+1)$ is divided among other three parts. If the condition of (15) is met, the next highest Ωj is considered and the same steps will be repeated to the last part, which has lest Ω level. The pseudo code for the proposed scheme is provided in Algorithm 1.

Algorithm 1: DFPS

$N_1^n = [f1, f2, f3, \ldots fn]$
$F_{total} = n$
$\theta_1^{an} = [fa1, \quad fa2, \quad fa3, \quad \ldots fan]$
$\theta_1^{bn} = [fb1, \quad fb2, \quad fb3, \quad \ldots fbn]$
$\theta_1^{cn} = [fc1, \quad fc2, \quad fc3, \quad \ldots fcn]$
$\theta_1^{dn} = [fd1, \quad fd2, \quad fd3, \quad \ldots fdn]$
For $i \leq 4$ ***do***
  $\Omega_i = \dfrac{\theta_{in}}{F_{total}}$
  $I_{MS} = \psi \times (0.25)$
  $I_{FS} = \psi \times (0.25)$
  $\lambda_{Fsi} = \psi \times (\Omega_i)$
End For
For $i \leq 4$ ***do***
  While $I_{FS}(t) \leq \lambda_{Fsi}$
   If $I_{Ms}(t) \geq (\psi \times (0.10))$
    $I_{Ms}(t+1) = I_{Ms}(t) - [I_{Ms}(t) \times \Omega_i]$
    $\sigma = I_{Ms}(t) - I_{Ms}(t+1)$
    $\psi(t+1) = [\psi(t)] - [I_{Ms}(t+1)] + [\sigma]$
    $I_{Fs}(t+1) = \dfrac{\psi(t+1)}{3})$
   End If
  End While
End For
End

Table 1: Simulation Parameters

Parameters	*Value*
Macrocell Radious	500 m
Femtocell Radious	5 m
Frequency	2 GHz
Macrocell Transmission Power	46 dBm
Femtocell Transmission Power	21 dBm
Bandwidth	20 MHz
Spacing between Subcarriers	15 KHz
White Noise Power Density	-174 dBm/Hz

4. Simulation Results

The modeled system, which is described in further detail in the second half of this study, is simulated to evaluate the mechanism that has been proposed. The simulation was conducted with the MATLAB software. Table 1 summarized the simulation parameters that were taken into consideration for this experiment.

Also, femtocell network model which is known as (5 × 5 grid model) [19] is adopted in this work. In this model, a building includes about 25 neighboring apartments is considered. Each apartment covers area of 100 m^2. (5 × 5) grid model is shown in Fig.2. Each part of the macrocell area contains one building, and it is randomly paced.

The femtocell base station is installed at the center of each apartment. There is at least one FUE associated to a certain femtocell in an indoor setting. The macrocell offloads at least one indoor MUE into each newly inserted femtocell. For the sake of comparison, the proposed FFR is measured in terms of throughput in comparison to the fixed FFR fixed frequency reuse. In this simulation, the system assumes a single macrocell base station as well as up to thirty femtocell base stations.

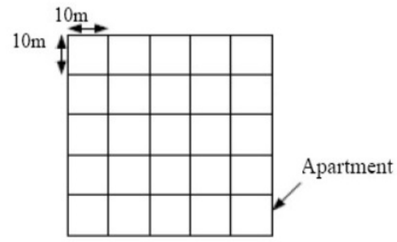

Fig. 2 Grid Model [19].

The average throughput of the entire cell is illustrated in Fig. 3. When only a slight number of femtocells are placed in the system, the typical FFR method operates well. However, the proposed technique performs better when a high number of femtocells are placed. The unfavorable impact of the interference between femtocells can also be shown in Fig.4, which depicts the throughput of the femtocells network in real time. It is undeniable that the predicted advantages of installing femtocells are proportional to the number of femtocells that are deployed. The throughput of the femtocell network is reduced when a large number of femtocells are deployed in a dense and unplanned manner. However, the suggested approach can preserve capacity more effectively than the fixed FFR. In addition, as the number of deployed femtocells in the system is raised, the predicted acquired capacity of deploying femtocells is lowered.

The expected capacity that may be achieved by the deployment of femtocells is depicted in Fig.5. It is possible to boost the system's capacity when the macrocell offloads the indoor MUEs to a femtocell. When the number of inserted femtocells is less than twenty, the amount of extra throughput that is added by femtocells of both schemes might be the same. Increasing the number of femtocells in the system, however, results in more extra capacity being delivered by the proposed architecture.

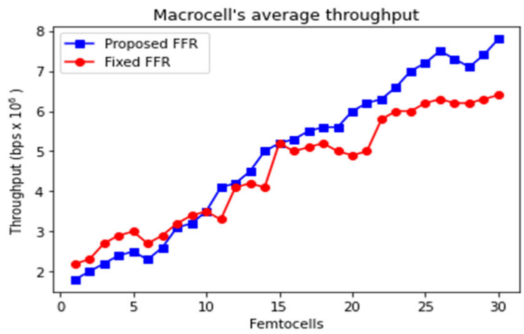

Fig. 3 Average Throughput of the Network.

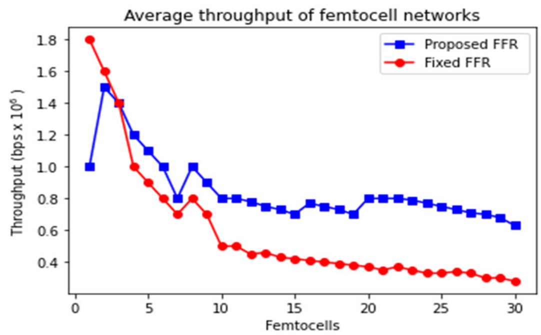

Fig. 4 Average Throughput for femtocell network.

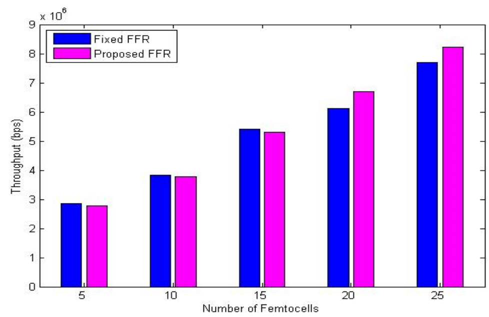

Fig. 5 Additional Gained Throughput.

5. Conclusion

Because of the unwanted effect of interference, an unplanned and dense deployment of femtocells has a negative influence on the system's performance. The FFR idea is developed to decrease interference between macrocells as well as interference caused by the of femtocells and macrocells. Addressing interference impact is necessary to improve overall network performance. In this paper, the DFPS mechanism is presented for the sake of increasing the capacity of femtocells. The suggested scheme's goal is to enhance the capacity of the femotcells network, which will result in an increase in the total throughput of the system. Fundamentally, the goal is to provide additional radio resources to femtocells based on a predefined cost function. The proposed strategy would assign more radio resources for femtocells according to their cost function, which is computed for their region. The region, which has highest level of cost function value, comprises the maximum number of femtocells compared to other regions. Consequently, the fewer radio resources would be allocated for that region with less number of femtocells. Also, more radio resources would be allocated for femtocells, which are positioned in the region that has more femtocells. To evaluate the performance of the proposed strategy the throughput is used as metric. Also, a MATLAB simulation is conducted for this reason. The proposed mechanism outperforms the fixed FFR in terms of performance. The Intercell Interference between macrocells will be considered in the future work. An optimization solution will be considered to solve the frequency partitioning problem, which arises when this proposed scheme is implemented. Therefore, a heuristic search approach would be designed to solve the problem.

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