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System Capacity Improvement by Sectored SFR scheme for Femto-cell based LTE networks

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Abstract : **Long Term Evolution (LTE) has presented Femtocells technology in a cellular mobile communication system in order to meet the ever growing bandwidth demand and to improve the indoor coverage. The Femtocells can be effectively deployed without requiring a centralized planning, to provide high data rate connectivity with a limited coverage. In this way, the overall capacity of the cellular network can be greatly improved. However, the impact of Femtocells on the performance of the conventional Macrocell system leads interference problem between Femtocells and pre-existing Macrocells as they share the same licensed frequency spectrum. In order to mitigate interference, various techniques have been proposed. This paper examines one group of these techniques, static frequency reuse, In this proposed scheme, a novel frequency planning is proposed for two tiers cellular networks using frequency reuse technique where Macro base stations allocate frequency sub-bands for Femtocells users through Femtocells base stations. This novel frequency reuse technique aims to mitigate interference by improving system throughput. The performance of the Femtocell were obtained by measuring the SINR and the throughput.**

Keywords: ***Frequency Reuse (FR); resource allocation; Femtocells; interference management; Long Term Evolution (LTE); OFDMA; Macrocell***

1. INTRODUCTION

In recent years, telecommunication operators experience tremendous demands from the mobile applications of broadband networks. Effectively dealing with the issues of the lacking coverage has become the challenging task. The Femtocells are presented as one of the candidates by the Third Generation Partnership Project (3GPP) Long-Term Evolution (LTE) [2, 3]. Femtocell is the latest step towards improving the quality of service for cellular users and enhancing the system capacity of a wireless network. A traditional cellular network overlaid with Femtocells can provide better system capacity, quality of service and enhanced coverage. The Femtocells Serving as the small-scale base stations, are embraced to enhance the system throughput by extending the coverage of the domestic areas such as offices, hotspots, residences and apartments. The dead zones can be covered and the spectral utilizations can be enhanced for cellular systems [4]. As opposed to conveying more Macrocells, the deployment of Femtocells is an economical option due to its low power consumption and low cost.

Interference between Femtocell and Macrocell has been noticed by many alliances and has been solved to some extent but there are still some issues such as co-channel interference between Macrocell and Femtocell still needs to be addressed. Thus, in this section an effort is made to understand and analyze the work carried out by different authors on to mitigate the interference and different approaches used by them to suppress the co-channel interference between Macrocell and Femtocell. To mitigate the interference, several adaptive approaches have been proposed. Some of these approaches are: fractional frequency reuse (FFR) method [9-10], soft frequency reuse (SFR) method [11], semi static frequency reuse method [12] and adaptive frequency reuse method [13]. Fractional frequency reuse (FFR) [14] and soft frequency reuse (SFR) [15] methods have been proposed to achieve frequency reuse factor I and reduce ICI in LTE networks.

In FFR, the system spectrum is divided into two non-overlapping bands, referred to as inner and outer bands. The inner band is reused in every inner cell region to serve users near the cell center while the outer band is shared by outer cells to serve users located in cell edge, with a reuse factor greater than 1. SFR scheme has been proposed as an alternative to FFR scheme [14], [15]. SFR differs from FFR in that the whole spectrum can be reused in every cell. In SFR the spectrum in each cell is divided into two groups, major and minor subcarriers. The major subcarriers can be used by users located in both inner and outer cell regions and they are orthogonal to each other in adjacent cells. The minor sub-carriers have lower transmit power than the major subcarrier's and are used only by inner cell users. The ratio between minor and major subcarrier transmit powers is referred to as power ratio [15]. Simulation results in [14] showed that SFR achieves higher spectrum efficiency than FFR.. However, the spectrum and power allocation for major and minor subcarriers in the SFR schemes are fixed. In [8] a hybrid frequency assignment for Femtocells in co-channel operation system has been proposed. Co-channel operation is only allowed in the edge zone, while Femtocells in the center zone use a dedicated frequency band which is not used by Macrocell users.

2. BACKGROUND

2.1. Reuse-I

In the next generation cellular systems, spectral efficiency is given a high accentuation on the grounds that these systems aim at giving high data rates for the users,[6]. It is very well known that frequency is limited and effective utilization of resources is critical in cellular networks. The easiest way to utilize the available spectrum in a cellular OFDMA network is (Reuse-I) the frequency reuse one approach. In Reuse-I approach the whole bandwidth or spectrum is reused in various cells. On deployment of the cellular systems, every single base stations are permitted to utilize the same cellular spectrum. Reuse-I approach is illustrates in Fig. 1. As shown in the Fig. 1 in the 7 cell layout, all cells utilize the whole available bandwidth with same power levels in their sub-carriers for their down link. In other words, all RBs in the cellular spectrum are accessible to all cells to be allocated to users.

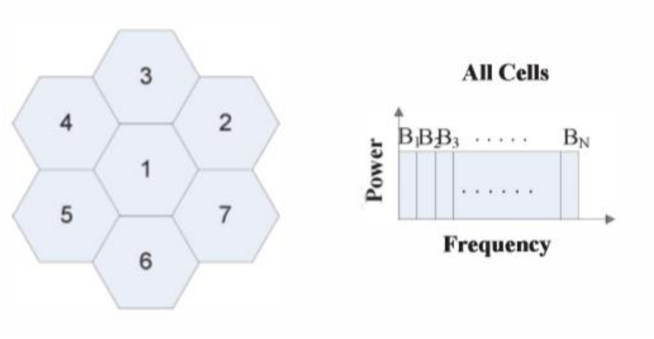

Figure.1.1. Reuse-l scheme deployment[6]. In this scheme all the cells transmit on all available sub-carriers in the spectrum with the same power

It is realized that utilizing a frequency Reuse-I methodology targets for the higher spectrum efficiency and system capacity by reusing the limited resource available for all cells. On the other hand, it is almost certain that Reuse-1 can causes considerable amount of inter-cell interference when the adjacent cells are allocated with the same frequency. This interference enormously constrains the spectral efficiency and capacity of the users by significantly decreasing the SINR values of users, particularly for the users that are located at the edge of cells.

2.2 Fractional Frequency Reuse (FFR)

It is derived from the above discussion that while the Reuse-n approach tackles the issue of interference, it is not bandwidth efficient [8],[9]. One type of ICI coordination techniques, known as Reuse Partitioning (RUP) or Fractional Frequency Reuse (FFR) which aims to effectively mitigate the ICI by applying various frequency reuse factors to user terminals situated in distinctive regions in each cell [8][11]. Generally, in a multi-cellular networks, the closer those user terminals situated to the cell edge, stronger they are afflicted with ICI.

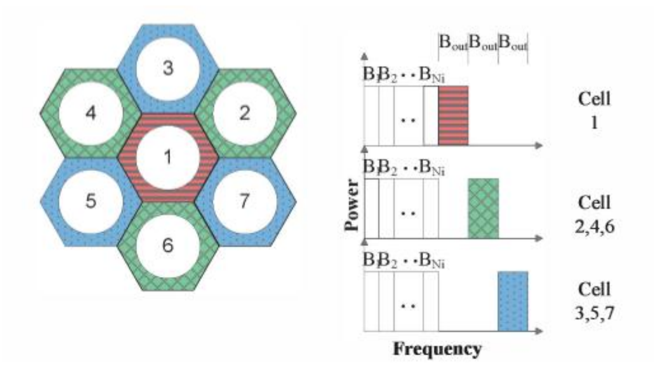

Figure. 1.2. FFR scheme[8]. In FFR, the reuse factor for interior users is 1 and the reuse factor for exterior users is 3.

Thus, the FFR scheme, as shown in Figure 1.2, geographically separates each cell of the system into two concentric zones. User terminals close to their Base Stations and with the best available received signal quality in inner zone are allowed to use the frequency resources with the smallest FRF, though those UTs which are far away from their Base Stations in the outer zone are assigned the frequency resources with the largest FRF. Thusly, the ICI in the outer regions are simply mitigated by allocating orthogonal frequency resources. And the UTs, who are less vulnerable to ICI in the inner regions, have much more frequency resources than that of using static Reuse schemes with FRF greater than 1, so that the spectrum efficiency can be enhanced.

The complete edge spectrum is further divided into three sections, corresponding to the Reuse- 3. $,B_1$, $,B_2$, ... $,B_{Ni}$ represent the resource blocks available for each center zone, where Ni is the total number of inner RBs. For the outer region, $,B_{OUT}$ represents total number of RBs for each edge region in a cell. As a result of splitting the spectrum for inner and outer regions of a cell so that interior users do not share any spectrum with exterior users, significant inter-cell interference reduction, particularly for cell-edge users, is achieved [11]. The FFR approach with its simple design can be realized effortlessly with lower system complexity. However, the design also leads to the lower spectral efficiency compared with the Reuse-1 scheme and losses in frequency selective gain, since for serving UTs in the regions with higher FRFs there is only a limited part of the total frequency spectrum that are available for scheduling.

2.3. Soft Frequency Reuse (SFR)

The fundamental idea of the SFR scheme is to apply FRF of 3 to the Cell-Edge Users (CEUs) and FRF of 1 to the Cell-Centre Users (CCUs)[11].But only the one third of the total available bandwidth named as Major Segment are utilized by CEUs. On this Major Segment the packets are send with a higher transmission power. To realize greater FRF for CEUs, the Major Segments among directly neighbouring cells must be orthogonal. In inverse to CEUs, CCUs can have access to the entire frequency resources, however, with lesser transmission power to avoid gating too much ICI to co-channel users in neighbouring cells. Furthermore, on the Major Segment, CEUs always take priority over the CCUs at resources access.

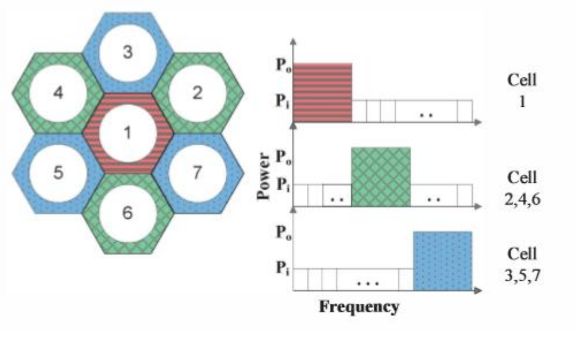

Figure 1..3. SFR scheme[6]. In this scheme inner RBs transmit with a higher transmit power than RBs used for cell-edge users.

SFR divides the available band and RBs into two areas: outer band and inner band. similarly, users in a cell are grouped into two classes. The users closer to the center of the cell are grouped into cell-center or inner users, and the users close to the edge of the cell are grouped together and are called cell-edge or outer users. The cell-edge users are confined to utilize only the cell- edge band. The cell-center users have access to the cell-edge band, and with lower need, they have access to the cell-edge band[11].

Figure.1.3 represents the SFR deployment. As shown in the figure, the cell is divided into two zones they are, a cell-edge zone where only a portion of the spectrum is available and a center zone where all of the spectrum is available. The cell-edge band is transmitted with a higher power level whereas the cell-center band is transmitted with a reduced power level.

3. SYSTEM MODEL AND RADIO RESOURCE ALLOCATION

3.1 system model

A number of randomly distributed indoor and outdoor environments with Macrocells, Femtocells and mobile stations are defined. A cell layout consists of seven hexagonal Macrocells environment, each of them is divided by central zone and edge zone. Edge zone is divided into three sectors. Each sector has 600 meters radius with 10 MHz bandwidth. The Macrocells are located in residential area where Femtocell base stations are installed in a random location within Macrocells range. Femtocell ranges are around 10 meters. Only one Femtocell user for each Femtocell BS is considered in an indoor environment. Each Macrocell contains a three floor building with a number of apartments. There is a street between the two stripes of these apartments. Assume that the Femtocell BSs from different blocks are not too close to each other. All Femtocells users are located within Femtocell range and Macrocell users are normally located randomly throughout the cell.

The proposed idea of this scheme is to mitigate downlink interference from Femtocell BS to MUEs and FUEs through channel allocation. Soft Frequency Reuse (SFR) method is considered here. For SFR usually the cell-center users are not affected by other cell-center users even though they share the same PRB because cell-center users are limited to a lower level power and the distance between a cell-center user and the adjacent eNodeB's is usually long enough to ensure large path loss, thus further reducing the received interfering power. Therefore, we only consider the mutual interference between serving cell-edge users and cell-edge users from different cells while simultaneously using the same PRB is considered here.

3.1.1 Channel Model

SINR

For Femtocell user FUE F received SINR[13] is given as follows:

$$SINR_{F,K} = \frac{P_{F,K}.P_{l,F,m,k}.X_{F,k}}{N_0 + \sum_{F'} P_{F',k}.P_{l,F'.m,k}.X_{F',k} + \sum_M P_{M,m,k}.P_{l,M,m,k}.X_{M,m,k}}$$

where,

$P_{F,K}$, $P_{F',k}$ and $P_{M,m,k}$ denote the transmit powers from serving Femtocell Base Station (SFBS), neigbour Femtocell Base Stations (NFBS) and Macrocell Base Stations (MBS) respectively on PRB k.

$P_{l,F,m,k}$represents the path loss between FUE F and its serving BS l

$P_{l,F'.m,k}$ represents path loss between FUE F and its neigbour Femtocell BS which is known as interfering signal on F.

$P_{l,M,m,k}$ represents path loss between FUE and neighbor Macrocell BS.

$X_{F,k}$=1 when FUE F requests PRB k from Macro BS through Femto BS to occupy PRB k and then SINR will be calculated for FUE F on PRB k. When $X_{F,k}$=l, then $X_{F,k}$=0 and $X_{M,m,k}$ =0 because one PRB cannot be shared by more than one user at a time. If $X_{M,m,k}$=O, it means there is no PRB occupied by the user F and then SINR for the user F will be zero.

Path Loss

Path loss models are used to represent indoor, outdoor, and indoor-to-outdoor (and vice versa) channel environments. These are best suited for a dense urban Femtocell deployment.

Path loss LS is determined by the distance between the transmitter and receiver for each subcarrier. Three models for the channel path loss [15] are described here

- **UE to Femto-BS:** The path loss LS for interfering and non-interfering links between a Femto UE or a Macro UE and a Femto-BS is expressed as

  $$LS = 127 + 30log10\,(d/1000)$$

  where path loss LS is in dB, d (meters) is the distance between receiver and transmitter.

- **Outdoor UE to Macro-BS:** Path loss for non-interfering link between outdoor M-UE and serving M-BS as well as interfering links between outdoor Macro-UE and neighbouring Macro BS is calculated as

  $$LS = 15.3 + 37.60log10\,(d)$$

- **Indoor UE to M-BS:** This path loss model takes into account the wall penetration loss (Lw) as the signal travels from indoor to outdoor and vice versa between an indoor located UE (Macro-UEl Femto-UE) and MacroBS. This is calculated as

  $$LS = 15.3 + 37.60\,log10\,(d) + Lw$$

Throughput Calculation

Throughput is calculated as follows using Shannon capacity formula[13].

$$C_{user} = \sum_{n=1}^{N} B_0 \log_2(1 + SINR)$$

The throughput of base station is the sum of its serving UEs and Bo is the bandwidth of one PRB.

Transmitted power

Transmitted power on each PRB is given as $P_t = P_{total}/N_c$. In SFR, edge or outer RBs and center or inner RBs transmit at different power levels[11]. If the power on edge PRBs is denoted as $P_{edge}$and the power on inner PRBs is denoted as P_{in}, then each can be calculated as

$$P_{edge} = \frac{nP_{total}}{N(1+\beta(n-1))}$$

$$P_{in} = \beta P_{edge}$$

where n is the reuse factor, and β is defined as the power ratio. The power ratio β has a range $0 < \beta < 1$. If β = 1, the scheme becomes a Reuse-I scheme where all the RBs, inner and outer, transmit using the same power level.

3.2 Radio resource allocation

In radio resource allocation is done in three phases, first phase is cell sectoring, the second phase is ICIC scheme using a soft frequency reuse method(SFR). The third phase is PRB assignment. The proposed idea of this scheme is to mitigate downlink interference from Femtocell BS to MUEs and FUEs through on request channel allocation. Soft Frequency Reuse (SFR) method is considered here. Here the mutual interference between serving cell-edge users and cell-edge users from different cells while simultaneously using the same PRB is considered here.

3.2.1 cell sectoring

The Macrocell coverage is divided into centre zone and edge zone. Edge zone has three sectors covers 120 degree each denoted by sub-area A, B, C. Each sub area has 60 degree virtual sub sectors denoted in small letters a, b and c which are allocated as the same frequency sub-band and power of A, B and C respectively.

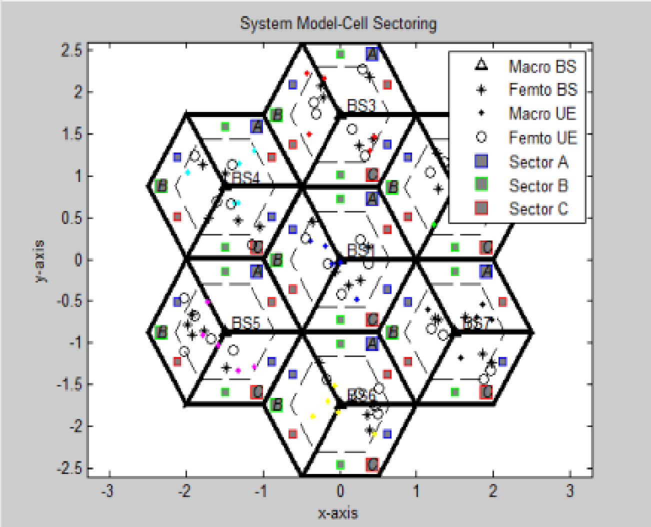

Figure 3.2 system Model-Cell Sectoring

3.2.2 Interference Cancellation

Figure 3.1 shows that the sector A has 2 virtual sub-sectors, c and b. Consider, sector A has a frequency sub-bands which is used only by Macrocell users located in this sector. On the other hand, frequency sub-bands allocated for B and C sectors used by Femtocell or Macrocell cell edge users are located in virtual sub-sectors 'b' and 'c' respectively.

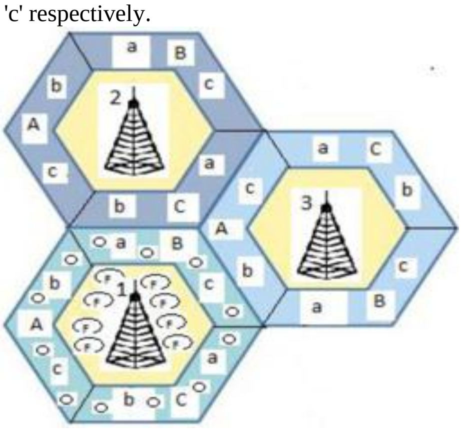

Figure.3.1 Femtocells deployment in Macrocells

So there will be no interferences between Macrocell users and Femtocell users as they use different frequency sub-bands (PRBs). Same technique is applicable for Sector B which has 2 virtual subsectors 'a' and c and Sector C which has 2 virtual sub-sectors 'a' and 'b'. In above figure the small stars indicate Femtocells in different sectors.

3.2.3 Channel Allocation

For Macrocell, different frequency subband (PRBs) is allocated to the each Macrocell sub-area according to the SFR. Consider that the total number of PRBs is N. $\frac{2}{3}N$ Number of PRB are allocated for the center zone and $\frac{N}{3}$ number of PRBs for edge zone. Also consider $\frac{N}{3}$ number of PRBs is the sum of PRB N_1, N_2 *and* N_3 allocated for sub-area A, B and C respectively. As mentioned earlier, only edge zone is considered and it is focused on only one sector, i.e. A for PRB allocation. The other two sectors are treated in a similar manner. The total number PRBs of N_1 can be used at Macro layer.

The algorithm is divided into three main steps as described below.

1) When a Macrocell user or Femtocell user attempts to make a call, it then measures the signal strength receiving from nearer BSs. Say, T1 signal is received from its serving BS and T2, T3, T4 signals are received from other BSs.

2) If T1» T2 or T3 or T4 in terms of signal strength then user is allocated PRBs from its serving BS.

3) If T1 > T2 or T3 or T4 OR T1 < T2 or T3 or T4 in terms of signal strength then user is allocated PRBs from either virtual sub-sector A or virtual sub-sector B on request basis.

TABLE I. SIMULATTON PARAMETERS

Parameters	values	
	Macro	Femto
Number of cells	7	40
Radius	600m	20m
BS transmitted power	20W/16W	20mW
Topology	3 sector 7 hexagonal cell	Density of 5 per Macrocell
Number of UE	5 per Macro	1 per Femto
*Bandwidth	10 MHz	
*Number of total PRBs	24 PRBs (PDSCH), 1PRB (PDCCH)	
*Subcarrier Bandwidth	375Khz	
*Subcarrier spacing	15Khz	
Carrier frequency	2GHz	
Channel Model	3GPP Typical urban	

4. Results and Discussion

4.1 Simulation Parameters

Table I shows the simulation parameters used for the experiment. The transmit power of the Femto BS is 20 mW and the Macro BS transmits for the edge region with 22W and for the center zone with 17W. Furthermore we consider a system with 10MHz divided into 25 sub carriers of 375 kHz of bandwidth and 15 kHz of subcarrier spacing (*As per LTE specifications). In this work, however, all the cells are consider in a hexagonal layout, and evaluate the overall system throughput and average PRB efficiency of the SFR schemes discussed in section II.

The proposed sub-band allocation scheme with equal power distribution for edge and center Macro users(MUE) for the average cell capacity of Macrocell system has been compared with the FFR-3 scheme and the average cell capacity of Macrocell edge user with equal power distribution and with varied power distribution are compared with the average PRB efficiency of the system with equal power distributions is compared with the schemes:(1) RAFF-LL and (2) DRA- HL.

4.2 Average Cell Capacity of the system

Figure 4.1 shows the average cell capacity of Macrocell system. The average system capacity is increased when the number of Femtocell users is reduced in the Macrocell edge zone area. Specifically for the case of 50 to 100 Femto users, the capacity of the Femto user is satisfactory as up to this number of Femtocells is enough to share a specific number of frequency channels without any interference. Thus the average cell capacity of the proposed scheme is higher as compared to Femto 3 sector and FFR-3.

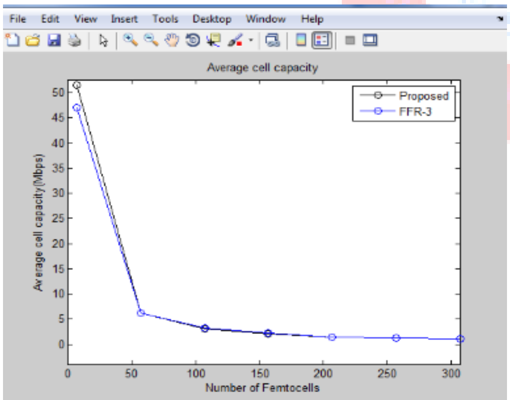

Figure 4.1: Average Cell Capacity Of Macrocell System.

4.2.2 Average Cell Capacity of Macrocell edge users

Figure 4.2 shows the average cell capacity of Macrocell edge users. The simulation result shows a significant improvement in the capacity of Macrocell edge users with varied power distribution with power ratio $\beta = 0.8$ fixed value for the simulation . The average throughput decreases for larger β values. This is due to the increase in interference, or decrease in SINR for cell-edge users. SINR for cell-edge decreases because of the increase in transmit power on inner PRBs as β increases.

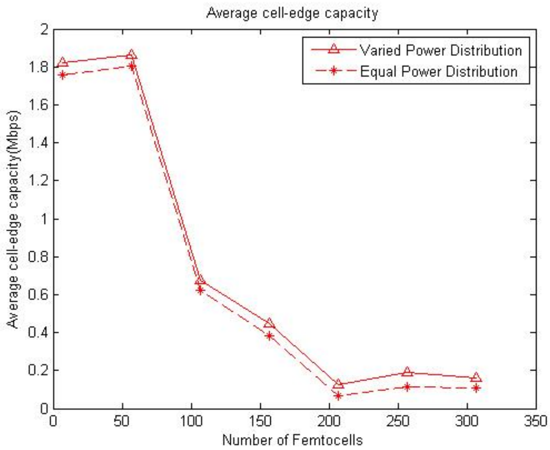

Figure 4.2: Average Cell Capacity of Macrocell edge users

The result shows a improvement in the capacity of Macrocell edge users when there is increase in power of the PRBs allocated to the cell edge users. When the transmit power on edge PRBs for a cell increases, SINR for outer-cell users decreases by reducing the interference from adjacent cells. The resulting decrease in SINR leads to the increase in the number of edge PRBs and the increase in resource could mitigate the resource shortage by the increase in inner cell area, which increases the number of outer cell users, that it increases the average user throughput.

4.3 Average PRB Efficiency of the System:

Figure 4.3 shows the average PRB efficiency with respect to the number of Femtocells. The simulation result shows a significant improvement by proposed method in the average PRB efficiency. Our proposed scheme has lower average PRB efficiency compared with DRA-HL and RAFF-LL when the number of Femtocells is between 30 and 50; however, the average PRB efficiency still improves 11 % by the proposed method. The PRB efficiency is higher when the number of Femtocell is between 200 and 250 compared with DRA-HL and RAFF- LL

Figure 4.3 illustrates the average PRB efficiency under different number of Femtocells. When the number of Femtocells is 100, the resource frame is not fully occupied and the resources are still sufficient to provide services.

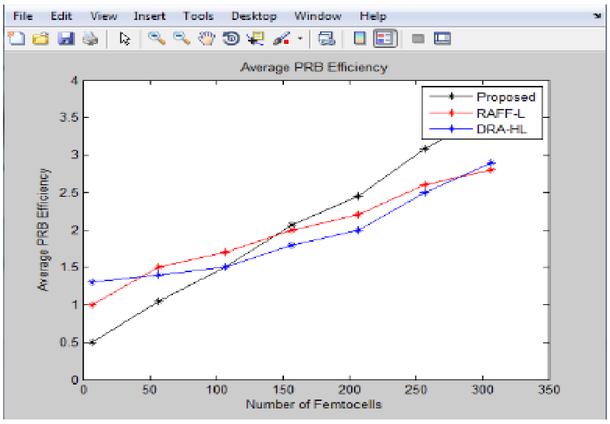

Figure. 4.3 Average PRB efficiency

However, when the number of Femtocells is more than 150, the network is congested and the resources allocated by RAFF and DRA are limited by the size of the resource frame.

5. Conclusion

LTE Femtocell combination provides very effective solution for wireless communication networks. Thus, Femtocells could be viewed as a promising option for next generation wireless communication networks such as OFDMA-based LT E networks. However, there is interference problem due to lack of proper frequency band allocation method. In this paper, an interference mitigation technique based on channel allocation knowledge is proposed that allows the Femtocells or Macrocell edge users to access PRBs to satisfy the increasing demand on higher data rate. This work evaluate soft frequency reuse (SFR), that are used as inter-cell interference avoidance techniques in the OFDMA cellular downlink with varying input parameters for Femto cells. The simulation results have shown that the proposed method can reduce the interferences through increasing the throughput. Furthermore, this increase is obtained without any decrease in the quality of service.

The power ratio has a severe impact on the performance of the SFR scheme, With a careful selection of power ratios, the SFR may gain benefits in overall cell throughput. The Simulation results show that the proposed scheme can achieve significant performance improvement for cell-edge users and desirable performance for cell-center users compared with the reference schemes. Therefore, the proposed resource allocation scheme can yield balanced performance between cell-edge and cell-center users, which allows for future wireless networks to deliver consistent high performance to any user from anywhere.

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