
Enhanced Fractional Frequency Reuse in LTE-A Heterogeneous OFDMA Network

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ABSTRACT

With the increase of smart phones, tablets and internet-connected devices, data and voice traffic are increasing day to day. To address the current exponential growth in the demand for voice and data traffic, underlying low power femto-cells to an existing macro cells will increase operator's network capacities. Due to densely deployment of femto network, interference becomes a challenge. Fractional Frequency Reuse (FFR) is a well-known technique use to mitigate interference in Heterogeneous Network (HetNet). In this paper we evaluate the performance of an Enhanced Fractional Frequency Reuse (EFFR) scheme using Genetic Algorithm (GA) in a HetNet scenario by simulations (in MATLAB) in terms of network throughput (or network sum rate), and spectral efficiency. The EFFR enhanced the throughput and reduced interference especially in the cell edge users. It is beneficial if the EFFR is applied to an OFDMA-LTE Network.

Keywords: femto cell, fractional frequency Reuse (FFR), interference LTE-A.

INTRODUCTION

Mobile phones are very important in our modern-day society as it is very uncommon to see a person without access to a mobile phone. Research from ITU [1] reveal that by the end of 2013, there was 6.8 billion mobile phone users and by 2014 this will exceed the world population. Since the introduction of smart phones in early 2000s the numbers of online users have grown rapidly and with that the data rates in cellular networks have increased to greater proportions [2]. A study by [3] shows that in the future, more than 50% of voice calls and more than 70% of data traffic are expected to originate from indoor users. Another survey shows that 30% of business and 45% of household

users experience poor indoor coverage. With the increase in the number of users in communication networks and new types of multimedia users' equipment like smart phones, laptop and iPad have led to a high rate of data usage in the presences of scarce spectrum. These increases have led to high demand for capacity, high signal to interference and noise ratio (SINR), low throughput, poor indoor coverage, large number of base station deployment, High quality of services (QoS) for edge users, high demands for higher data rate [4].

To solve these problems, the 3rd generation partnership project (3GPP) Release 8-10 has introduced advanced features of LTE, referred as LTE-Advanced, which includes the Carrier Aggregation

(CA), Heterogeneous Networks (HetNets), Cooperative Multi-Point (CoMP) communication, enhanced MIMO, enhanced ICIC. This enhanced system is referred as the LTE-Advanced (LTE-A) system [5].

Heterogeneous Networks (HetNets) has been seen as a reliable method to increase capacity, throughput and better spectrum utilization [5]. HetNet comprises of high power macro cell which is under laid with various low power cells. Examples of the low power (micro-cell, Pico-cell, femto-cells, remote radio heads RRH) are shown in figure 1.

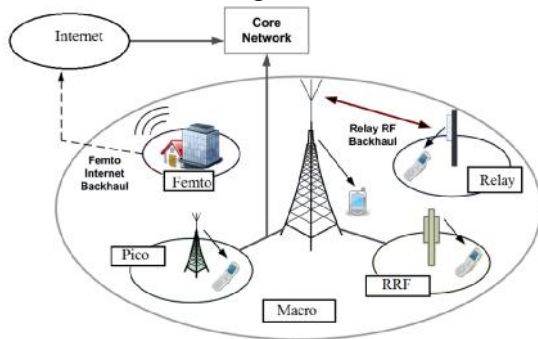


Figure 1: Heterogeneous Network

HetNet have the potential of significantly increasing network performance, capacity, and throughput, HetNet also benefit from transmitter-to-receiver distance reduction and enabling better reuse of the spectrum [7]. HetNet transfers users on to the under laid low power cells [7]. HetNet would also be beneficial for the cellular operators in the form of increased revenue and reduced churn. The basic problem of HetNet is interference among the various cells, poor coverage for indoor users and edge users. Obviously, it would be very expensive to have a large number of outdoor BSs to meet the needs of a high capacity network and this warranted the need for having some indoor coverage solutions, which are usually located inside large buildings to

serve as hotspots for users (e.g airports, shopping malls, universities).

LTE-A Femto-cell networks shown in figure 2 is the proposed solution to provide high quality wireless links and good spatial usage for both indoor users and edge users of a network [8].

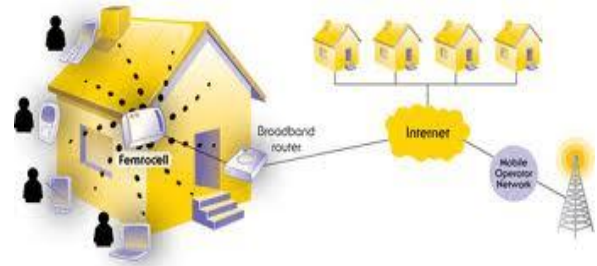


Figure 1 Connecting UE to mobile core network through FBS [3]

Femto-cell are low-power base stations working in a licensed spectrum, giving improved indoor coverage with greater performance; functioning with the operator’s approval; providing improved voice and data services at a low cost [4]. The advantages of femto-cell are that they are small plug and play devices, cheap, completely users dependent and they can use existing backhaul links such as digital subscriber line (DSL), optic fiber, microwave antenna etc. With a densely deployed femto-cell, especially in indoor urban set up, radio resource allocation becomes a challenge. Other major challenges include the impact of interference, penetration losses, less capacity, low throughput etc. However, interference is capable of plaguing network performance, hence, there is need to devise a technique to mitigate the interference within femto-cells network [6].

Consequently, an interference avoidance approach where a user avoids rather than suppress mutual interference is more likely to work well in femto-cell networks, Frequency Reuse and power

control have been seen as a promising technique to mitigate interference in LTE-A femto cell. In this work, we look to enhanced an already known Frequency Reuse techniques using Genetic Algorithm (GA) to cope with the co-tier and cross-tier interference problem. With this enhancement scheme, the network capacity and coverage areas will be increased and will benefit both the subscribers and the operators.

Problem Statement

With the densely deployment of femto-cell network, interference becomes a challenge. Fractional Frequency Reuse is a well-known technique used to mitigate interference in Heterogeneous Network, however throughput is reduced. The need to enhance the technique to increase throughput is imperative.

Previous Studies

Interference management for macro-femto cell scenario has been widely discussed by various researchers but as the technologies kept growing from 1G to 4G, the user equipment became more advanced, so the need to provide good quality of services.

The authors in [8] carried out a comparison of SINR in femto cell and macro cell network. In the macro cell environment, the author evaluated the SINR performance of femto cells in presence of macro cell, minimized the interference between macro and femto in order to improve the performance, analyzed the outage probability in femto cell network and finally considered the power consumption of femto cell network. The simulation results showed an optimum combination of ranges for lowest interference for femto cell users. The finding shows that deployment of femto

cell reduces power consumption and improves the coverage of the network. However, this technique needs to deploy efficiency first, then the performance in terms of power and coverage can be improved later.

“Analytical Evaluation of Various Frequency Reuse Schemes in Cellular OFDMA Network” was carried out by [9]. The author studied the different frequency reuse schemes in Orthogonal Frequency Division Multiple Access (OFDMA) network such as the LTE in order to mitigate Co-Channel Interference (CCI) problem. The total frequency band was divided into several sub-bands and each cell is allocated with the dis-similar sub-band as a way of reducing the interferences. The authors presented expressions of SINR as well as cell data rate for Integer Frequency Reuse (IFR), FFR and Two-Level Power Control (TLPC) schemes were offered as an analytical approach based on the fluid model. The results show that intra-cell interference is removed and the inter-cell interference is significantly reduced.

The authors in [10] looked at a Hybrid access control with modified SINR association for future heterogeneous networks”. The authors investigated a coverage radius base on adaptive power control scheme to mitigate interference for blindly placed LTE femto cells. The author used a system level simulator to analyze a single and multi-cell scenario. The simulation results show that the proposed scheme has an improved value for cross-tier SINR, throughput and lowers co-tier SINR. The adopted system was compared with a baseline and existing adaptive interference mitigation schemes; the results shows that the proposed scheme does not require FAPs to be relocated on

optimal locations for effective interference mitigation.

Also, the authors in [11] investigated a Femto cell power control methods based on user's context information in two-tier heterogeneous networks. A femto cell power adjustment method whose main objective is to surge the average throughput of non-CSG MUEs by preventing the amount of interference caused by femtocells is proposed. However, the proposed priority weights used in the femtocells' Score Functions provides an efficient means for achieving the desired level of macro-cell/femto-cell throughput trade-off.

While these authors [12] researched on the Optimization of Fractional Frequency Reuse in Long Term Evolution Network. A method to optimize FFR scheme selection based on the mean user throughput or user satisfaction is proposed. Fractional Frequency Reuse (FFR) was used to partitions each cell into two regions; inner region and outer region and allocates different frequency band to each region. Since the users at the inner region are less exposed to inter-cell interference, the frequency resources in each inner region can be universally used. Based on this frequency band allocation, FFR may reduce channel interference and offer large system capacity. This paper proposes a mechanism that selects the optimal FFR scheme based on the user throughput and user satisfaction. In detail, the mechanism selects the optimal size of the inner and outer region for each cell as well as the optimal frequency allocation between these regions that either maximizes the mean user throughput or the user satisfaction.

Authors in [13] looked at LTE based femtocells. The total available frequency band is divided into several bands. One

band is used for the inner coverage area and has a reuse factor of 1. The femtocells in the outer coverage area can use any other band except the band that has been allocated to the outer converge area.

In [14], the authors proposed a hybrid recourse management algorithm (HRMA), which is also based on FFR. In addition to the division of the whole frequency band into several bands, the proposed algorithm also keeps a reserved frequency band FR, which is used to settle severe interference problems between femto cells.

An optimal static FFR (OSFFR) scheme is proposed by [15]. The authors compare the proposed scheme to three different FFR schemes namely, strict FFR, soft FFR, and FFR-3 schemes. The proposed scheme outperforms other three schemes in terms of outage probability, average network sum rate and average spectral efficiency.

The author in [16] investigated inter-cell coordination for interference mitigation in multi-tier wireless network. The objective of this research is to investigate the difficulty of reasonable radio resource partitioning among the cell edge and cell center regions for the downlink of a SISO-OFDMA cellular system. This research work was adopted fractional frequency reuse (FFR) where tunes the values of α and β to achieve fairness. The finding shows that the mathematical relationship between network resources partitioning parameters can minimize the throughput margin among cell edge and cell center with 3 sectorizations. to cope with the co-tier and cross-tier interference problem. With efficient interference management schemes, the network capacity and coverage can be increased that benefit both the subscribers and the operators. To implement femto cells in realistic scenarios

novel algorithms to Enhance already exciting Frequency Ruse technique are still needed to cope with the issues of interference.

System Model for a Femto-Cell

In HetNet networks, interference mitigation techniques employing fractional frequency reuse involve the partitioning of frequency resources into two aspects. The first aspect is the partitioning of frequency resources among networks belonging to the same tier of the network and the second aspect involves cross-tier frequency resource partitioning. A framework that tackles the cross-tier and co-tier interference at the center and edge regions as implemented by [17,18,19 and 20] is shown below. while its enhancement using genetic algorithm (GA) is implemented here

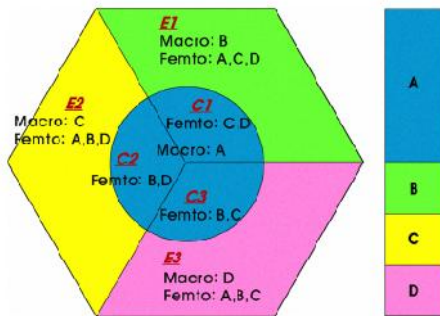


Figure 3. The proposed FFR Scheme

Performance Evaluation

We formulate system throughput and downlink signal to Interference and Noise Ratio (SINR).

- i. Calculation of SINR for macro users

The overall network is composed of many femtocells, and two-tier 19 macro-cells are randomly deployed over the macro-cells. From neighboring 18 macro-cells a macro user is interfered and all of the adjacent

femtocells. Due to small transmit power, only the femtocells which are located within the one-tier macro-cell area give interference to the macro users. The received SINR of a macro user *m* on sub-carrier *k* can be expressed as [40].

$$SINR_{m,k} = \frac{P_{M,K}G_{m,M,k}}{N_0\Delta_f + \sum(P_{M',k}G_{m,M',k}) + \sum(P_{F,k}G_{m,F,k})} \tag{1}$$

Where, $P_{M,K}$ and $P_{M',k}$ are transmit power of serving macro-cell *M* and neighboring macro-cell *M'* on sub-carrier *k*, respectively. $G_{m,M,k}$ is channel gain between macro user *m* and serving macro-cell *M* on a sub-carrier *k*. Channel gain from neighboring macro-cells are denoted by $G_{m,M',k}$. Similarly, $P_{F,k}$ is transmitting power of neighboring femtocell *F* on a sub-carrier *k*. $G_{m,F,k}$ is channel gain between macro user *m* and neighboring femtocell *F* on sub-carrier *k*. N_0 is white noise power spectral density, and Δ_f sub-carrier spacing.

- ii. Calculation of SINR for femto users

In case of a femto user, it is interfered from all 19 macro-cells and adjacent femtocells. Similarly, the received SINR of a femto user *f* on sub-carrier *c* can be given by

$$SINR_{mk} = \frac{P_{F,K}G_{f,F,K}}{N_0\Delta_f + \sum(P_{M,k}G_{f,M,k}) + \sum(P_{F',k}G_{f,F',k})} \tag{2}$$

The channel gain *G* dominantly affected by path loss (*PL*), which is different for outdoor and indoor. For outdoor the path loss is modeled as

$$PL_{outdoor} = 28 + 35 \log_{10}(d)db \tag{3}$$

where d is the distance from a user to a base station in meters. Otherwise, indoor model is

$$PL_{\text{indoor}} = 38.5 + 20 \log_{10}(d) \text{db} + L_{\text{walls}} \quad 4$$

where is 7, 10, and 15 dB for light internal, and external walls, respectively [43]. So, the channel gain G can be expressed as

$$G = 10^{-PL/10} \dots \dots \dots \quad 5$$

- iii. Calculation for Practical capacity m for sub-carrier k

$$C_{m,k} = \Delta f \cdot \log_2 (1 + \alpha \text{SINR}_{m,k}) \quad 6$$

Where

α = is a constant for Target Bit Error rate (BER)

$$\alpha = \frac{-1.5}{\ln(5\text{BER})}$$

Here we set BER to 10^{-6}

7

- iv. Calculation for overall Throughput of serving macro cell M

$$T_M = \sum_m \sum_k \beta_{m,k} C_{m,k} \quad 8$$

Where, $\beta_{m,k}$ notifies the sub-carrier assignment for macro users. When $\beta_{m,k} = 1$, the sub-carrier K is assigned to macro user m . Otherwise, $\beta_{m,k} = 0$.

From the characteristics of the OFDMA system, each sub-carrier is allocated only one macro user in a macro-cell in every time slot. It implies that $\sum_{m=1}^{N_m} \beta_{m,k} = 1$. Where N_m is the number of macro users in a macro-cell.

Similarly, expression for femto users related to the practical capacity and the overall throughput is possible except

$\sum_{f=1}^{N_f} \beta_{f,k} = 3$. N_f is the number of femto users in a macro-cell. This implies that the proposed scheme in a macro-cell reuses the full frequency band three times.

Operational Algorithm

We evaluate the performance of the FFR schemes in a HetNet scenario by simulations (in MATLAB) in terms of network throughput (or network sum rate), and spectral efficiency. We formulate downlink Signal to Interference and Noise Ratio (SINR) and system throughput. The overall network is composed of two-tier 19 macro-cells. A macro user is interfered by 18 macro cell and all of the adjacent femto cells. Below is the enhanced algorithm for the proposed FFR scheme.

Algorithm 1. Enhance FFR using GA

1. Start
2. Lunch the GUI
3. Set initial parameters
4. Select location of femto-cell and macro-cell
5. Select location of users
6. Calculate distance of users from femto cell
7. While (no of femto-cell is < maximum)
 - i. Compute center and edge SINR
 - ii. Compute capacity of the users
 - iii. Compute initial throughput
 - iv. Optimize total throughput
8. End while

Application of Genetic Algorithm (Ga)

Our approach is to apply GA to enhance the total throughput by reducing SINR

Overview of Genetic Algorithm

GA is a member of the evolutionary algorithms family. It is a method that uses genetics as its archetype for problem solving. GA is based on the survival of the best individual in a population [21]. Each

individual or solution represents a chromosome in a population. Then based on a specific fitness function, all individuals undergo a test to measure their fitness. For each population and depending on the selection rate and style, individuals having the highest fitness are more likely to be selected as parents to go through the reproduction process. The effect of reproduction is very important since it produces children that inherit a combination of good characteristics from two different parents. Finally, mutation is performed to avoid pre-mature convergence. It is applied to the children before including them in the new population (22).

The following steps is performed to solve a problem using GA:

Algorithm 2. Application of GA to FFR

1. Start
2. Objective function

$$\{T_M = \sum_m \sum_k \beta_{m,k} C_{m,k} \}$$
3. Initialization
4. Encode the solution into chromosomes
5. Generate initial population
6. Set initial crossover and mutation probability
 While ($t < \text{max number 2 generate}$)
 Generate new solution for crossover and mutation
 - If $P_c < \text{rand}$, perform cross over, end if
 - If $P_m < \text{rand}$, perform mutation, end if
 - Accept new solution if the maximum throughput is greater than pervious
 - Select the correct best for new generation
7. End while

Simulation

Table 1. Summary of Proposed and Comparison Schemes

Schemes	Macro user		Femto user	
	Frequency	Amount	Frequency	Amount
Proposed With GA	EFFR	1	Divide center and edges	3
FFR Without GA	FFR		Divide center and edges	
Note: Amount column implies value of $\sum_{n=1}^{N_f} \beta_{n,k}$ and $\sum_{f=1}^{N_f} \beta_{f,k}$ for Macro and femto users, respectively.				

The simulation was done in a MATLAB interface and all base stations are operated by OFDMA, with the network comprising of a two-tier macro-cell and a random deployed femto-cell.

Table 2. Simulation Parameters

Parameters	Values	
	Macro	Femto
Number of cells	19 (2-tier)	30-180/macro
Cell coverage (Radius)	250 m	30 m
BS transmit power	15W, 22 W	20 mW
Number_of_Users in one macro cell	180	180
Bandwidth	5 MHz	
FFT size	512	
Number of occupied sub-carrier	300	
Sub-carrier spacing	15KHz	
White noisespectra density	-17dBm/Hz	
Size of center zone	0.63 of macro coverage	
Channel model (path loss PL)	$PL_{Outdoor} = 10 \log_{10}(d) \text{ db}$ $PL_{Indoor} = 38.5 + 20 \log_{10}(d) \text{ db} + L_{walls}$ $L_{walls} = 7 \text{ dB}$, if d in (0,10) $L_{walls} = 10 \text{ dB}$ if d in (10,20) $L_{walls} = 15 \text{ dB}$ if d in (20,30)	

we evaluate the proposed scheme by maximizing throughput with GA while reducing SINR. We also concentrate on the performance of indoor users and edge users. The proposed scheme is compared with FFR scheme without GA. The features are summarized in table 1 while the simulation parameter is shown in table 2.

RESULT AND COMPARISON

The result on figure 4 shows the throughput of macro users located in the center and edge region as the number of femto-cells varies. The results show that when the FFR scheme is optimized using GA, interference in the center and edge users is greatly avoided thereby increasing the throughput

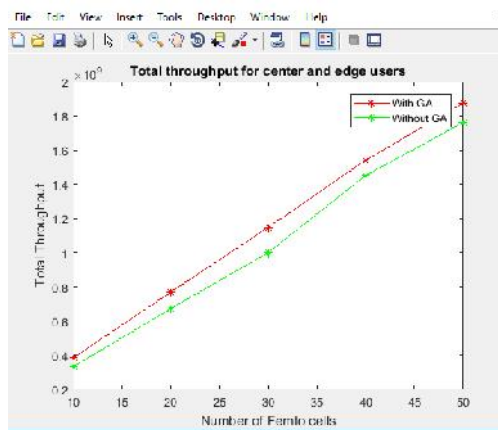


Figure 4: throughput of macro users located in the center and edge region as the number of femto-cells varies.

While the result in figure 5 describe the throughput of total users located at the edge region only. Without optimization the performance was poor but after applying GA the throughput of the edge is improved.

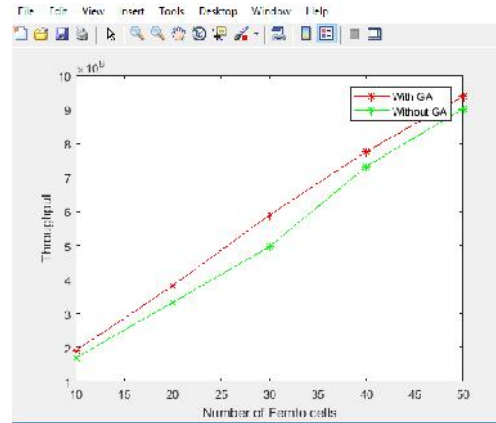


Figure 5: throughput of total users located at the edge region as femtocell varies.

CONCLUSION

In this paper, we propose an interference avoidance management scheme in an LTE femto-cell system using an Enhanced Fractional Frequency Reuse. The EFFR using enhanced throughput and reduced interference especially in the cell edge users. It is beneficial if the EFRR is applied to an OFDMA-LTE Network.

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