EXPLOITING THE ABILITY OF SELF-ORGANIZING NETWORKS FOR INTER-CELL INTERFERENCE COORDINATION FOR EMERGENCY COMMUNICATIONS IN CELLULAR NETWORKS.

A THESIS IN
Electrical Engineering

Presented to the Faculty of the University
of Missouri—Kansas City in partial fulfillment of
the requirements for the degree

MASTER OF SCIENCE

by

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Kansas City, Missouri

2014

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ABSTRACT

In the current scenario, radio planning of wireless cellular networks and analysis of radio performance should be agile because it is expected that in the near future we will be reaching to the point where there will be as many mobile devices as people in the world. So, there should be a rapid revolution in technology which can aid in the management of resources and maximization of throughput to satisfy users effectively. LTE and LTE-Advanced is designed to meet high bit rate service requirements; however, the initial challenge of the wireless channel, such as limited spectrum, leads to frequency reuse but also irrevocable interference.

This thesis gives a holistic conspectus of interference coordination in LTE cellular systems utilizing the ability of Self Organizing Networks (SON). LTE uses a universal frequency reuse concept and the only interference observed in LTE is inter-cell interference. In a network where users are randomly distributed over

three cells, it manages resources between the base stations by restricting some resource blocks for Cell Edge Users (CEU) of the neighboring cell and other resource blocks for Cell Center Users (CCU). This is done in a semi-static approach by taking into account the location of the user and varying channel conditions. Cell edge users and cell center users are distinguished based upon the SINR level. The management of the resources are regulated as per the user requirements and coordinated by the neighboring cells. The results have been simulated in two different ambiances viz., normal traffic and the emergency condition to show its performance in exigency. The throughput of the CCUs and CEUs in normal traffic has been compared. Also, the approach and results are shown to be highly reliable.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the School of Computing and Engineering have examined a thesis titled "Exploiting the ability of Self Organizing Networks for inter-cell interference coordination for emergency communications in cellular networks", presented by Siva Sai Karthik Kesanakurthi, candidate for the master of Electrical Engineering degree, and certify that in their opinion it is worthy of acceptance.

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ACKNOWLEDGEMENTS

I would like to take this opportunity to express my deep gratitude to my advisor and mentor Dr. Cory Beard for all his guidance during the project. I thank him for all the encouragement he had given me to finish the project successfully. I appreciate his valuable time and his useful critiques.

I would also like to extend my thanks to Dr. Deep Medhi and Dr. Ken Mitchell for serving as members of my thesis committee.

I would like to thank my parents Mr. K.N.V.Satyanarayana and Mrs.K.Rajya Lakshmi for their love and support. I would also like to thank my friends, Bhargava Thondapu and Haritha Rao for their outstanding support.

Also, I would like to thank University of Missouri – Kansas City for giving me this wonderful opportunity.

CHAPTER 1

INTRODUCTION

With the recent forecasts, it is obvious that smartphones and tablets will constitute 50% of the mobile subscriber population by 2016. The high data rate services such as mobile video blogging, interactive TV, multimedia gaming, etc. will dominate the normal voice traffic. To quench this immense outbreak of service demand, the fourth generation wireless communication systems, LTE and LTE-A emerged as an answer. The noteworthy components that make these wireless technologies more predominant over 3G technologies are Orthogonal Frequency Division Multiple Access (OFDMA) and Multiple Input Multiple Output (MIMO) smart antennas. Another important aspect of the aforementioned technologies is the deployment strategy of using heterogeneous networks which includes a hybrid of macro, micro, femto and relay base stations to improve spectral efficiency and provide a uniform broadband experience to the users [1]. As LTE is a flat architecture, the control functions are distributed between the eNodeBs (eNBs) (base stations in LTE) and they exchange their information through the X2 interface. The functions pertaining to the load balancing, resource management, configuration management, interference management etc. are handled by the Self Organizing Networks (SON) which is now considered as a promising concept for inter cell interference coordination.

1.1 Motivation and Goal of the Thesis

1.1.1 Motivation

The Motivation to work on this project comes from the fact that LTE is the interference limited wireless system and the cell edge users are more susceptible to the inter cell interference from the nearby cells in addition to the existing multipath loss, shadowing and path loss. Here, the cell edge user throughput is adversely affected, which results in low efficiency of the system. Also, in the emergency situations the public safety groups need to work more effectively where the interference should not be a barrier when the location is concerned.

1.1.2 Goal of the Thesis

The purpose of the thesis is to provide a clear picture of the inter cell interference coordination which is actually intelligent resource management in the downlink. The impact of inter cell interference coordination is investigated on the cell edge user throughput. To achieve this goal a semi static approach is been followed based upon the assumptions such as stationary mobiles, channel aware scheduling, a small-scale and large-scale fading resistant system and dynamic allocation of resource blocks. The throughput is been compared in normal traffic and in the emergency conditions. This project proposes a new framework for the interference coordination mechanism in which cell center throughput and fairness is been compromised to some extent but ultimately increases the cell edge user throughput. To perform this, several functions is been compared and simulated in MATLAB.

1.1.3 Scope of the Thesis:

This thesis is organized in 6 chapters. The rest of the chapters are organized as follows:

Chapter 2 gives an overview of LTE and related Background. Chapter 3 explains the related work on interference coordination and SON features. Chapter 4 explains the code implementation. Chapter 5 presents simulation results. Finally, chapter 6 draws the conclusion and gives recommendations for future works.

CHAPTER 2

BACKGROUND

2.1 Long Term Evolution (LTE)

Long Term Evolution (LTE) aims to provide seamless data connectivity, high data rate, low user latency, improved system capacity and coverage to the growing demand for network services without any interruption regardless of the user mobility. A key feature of the LTE is the adoption of advanced Radio Resource Management procedures in order to increase the system performance up to the Shannon limit [3]. LTE has the flat architecture as the eNBs are not controlled by any centralized entity. The LTE architecture consists of the radio

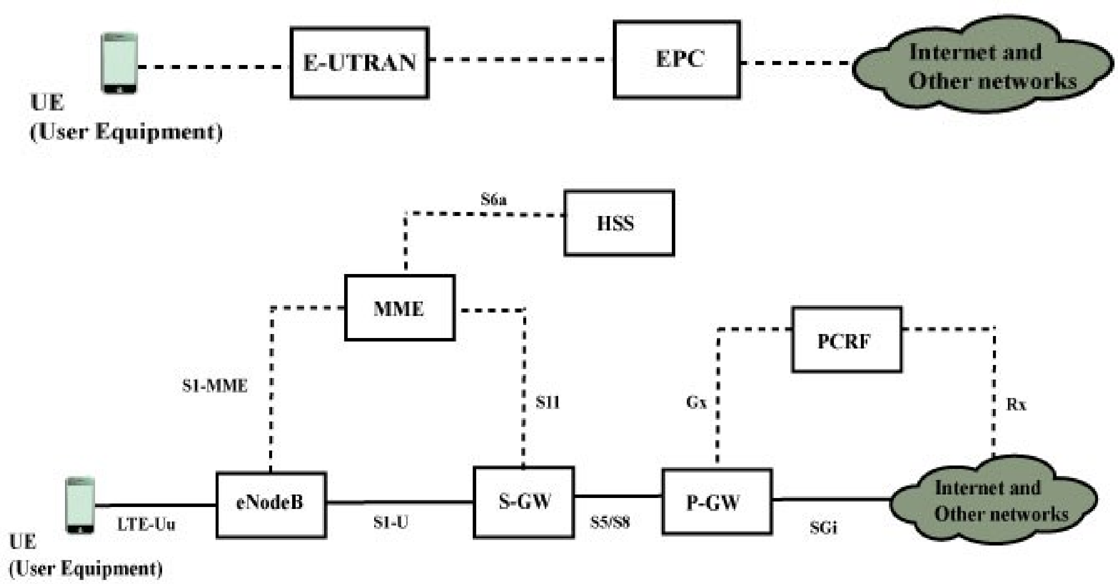

Fig. 1: LTE Architecture

access system called E-UTRAN (Evolved Universal Terrestrial Radio Access Network) which is further connected to the system with non-radio aspects known as EPC (Evolved Packet Core).

The EPC consists of several logical nodes like Mobility Management Entity (MME) for call control functions, S-GW (Serving Gateway), for IP connectivity to UE and data bearer management functions, P-GW (Packet Gateway) for IP address allocation, HSS (Home Subscriber Server) for authentication and PCRF (Policy control and Charging Rule Function) for QoS management while the access part consists of only the eNodeB which handles the scheduling and resource allocation. The LTE enhanced base station (eNodeB) and the user equipment (UE) exchange the data and control information which uses OFDMA in the downlink and SC-FDMA in the uplink. The major difference with earlier multiple access techniques, is that both OFDMA and SC-FDMA can possess dimensions of not only time and frequency but also space by means of MIMO [2]. On the other hand, the OFDM system provides a more feasible platform for the interference management. The OFDMA is described more in the next subsection.

LTE specifies nine standardized QCI (Qos Class Identifier) values with standardized characteristics, which are pre-configured at the network nodes.

The following table illustrates the standard QCI values.

Table 1: Standard QCI values [16]

QCI	RESOURCE TYPE	PRIORITY	PACKET DELAY BUDGET (MS)	PACKET ERROR LOSS RATE	EXAMPLE SERVICES
1	GBR	2	100	10^{-2}	Conversational voice
2	GBR	4	150	10^{-3}	Conversational video (live streaming)
3	GBR	5	300	10^{-6}	Non-conversational video (buffered streaming)
4	GBR	3	50	10^{-3}	Real-time gaming
5	Non-GBR	1	100	10^{-6}	IMS signaling
6	Non-GBR	7	100	10^{-3}	Voice, video (live streaming), interactive gaming
7	Non-GBR	6	300	10^{-6}	Video (buffered streaming)
8	Non-GBR	8	300	10^{-6}	TCP-based (for example, WWW, e-mail), chat, FTP, p2p file sharing, progressive video and others
9	Non-GBR	9	300	10^{-6}	

2.2 Orthogonal Frequency Division Multiple Access

The major factor for deciding the performance of a wireless communication is the choice of apt modulation scheme and multiple access technique.

Orthogonal Frequency Division Multiplexing (OFDM) has gained much interest among researchers and 3GPP LTE/LTE-A uses this as a downlink transmission. It is a FDM technique used as a digital multi-carrier modulation method which provides good spectral efficiency. Several closely spaced orthogonal sub-carrier signals are used to carry data over parallel streams and therefore mitigate interference among the adjacent sub-carriers in which each sub-carrier is modulated with QAM or PSK. In LTE, the resource allocation is done on per sub-band basis to users. The allocation of Resource Blocks (RBs) is for each time slot and one RB has a duration of one time slot (1milli second) and a bandwidth of 180 kHz. The RB is the smallest unit allocated by the eNB scheduler and is a combination of OFDM symbols and sub-bands in time and frequency domain respectively.

OFDMA has the ability to dilute the impact of multipath fading and Inter symbol Interference. 'The main advantages of OFDMA are scalability and robust nature towards multi-path fading [9]. OFDMA provides further benefits by allowing multiple users to schedule transmission on the subcarriers which are best for them at the time. OFDM also has a low complexity transceiver structure by using the Fast Fourier Transform (FFT). Despite these advantages, OFDM has also has some disadvantages; one of them is the high Peak to average power ratio (PAPR) and the other is the transmitter power may vary for each OFDM symbol which can weaken the RF transmitter power amplifier efficiency. Hence, OFDMA is used only for the downlink transmission in LTE as the power consumption will be the critical factor for UEs.

2.3 Fading and its Characteristics

Fading is considered as one of the key issues which affect the performance of a wireless channel. The signal from the base station is influenced by the obstacles like mountains, hills, buildings, man-made structures, environmental factors and leads to multiple paths occurred due to reflection, refraction, scattering and diffraction. Due to this, there will be fluctuations in the received signal strength which is often referred to the term “fading”. Fading usually distinguished as

- Short scale fading
- Small scale fading
- Large scale fading

Short scale fading is nothing but the general path loss present between the transmitter and receiver which results in the lowered gain and attenuation of the received signal. Small scale fading refers to the attenuation of the signal over small distances which is usually a multipath propagation caused by buildings, etc. This is observed in urban and sub-urban regions. Small scale fading can be described by Rayleigh distribution if the number of multiple reflective paths are more and line of sight signal propagation component is absent. But when such as line of sight propagation is present, the small scale fading envelope is described by Rician distribution.

Large scale fading is caused over large areas due to terrain contour like large buildings, mountains, hills etc. This is observed in small/ medium sized cities. This is also called as shadowing which can be expressed as a function of distance and a log normal distribution of mean path loss by Okumura-Hata model. The formula used to calculate the path loss using Okamura-Hata is:

$$Lp = 69.55 + 26.16 * \log(Fc) - 13.82 * \log(Hb) - a + (44.9 - 6.55 * \log(Hb)) * \log(d)$$

$$a = (1.1 * \log(Fc) - 0.7) * Hm - 1.56 * \log(Fc) - 0.8$$

Where

Lp is the Path loss in dB

Fc is the frequency in MHz

Hb is the height of the base station in meters (m)

Hm is the height of the mobile station in meters (m)

d is the distance between the base station and the mobile station in kilometers (km)

2.4 Scheduling

The process of choosing the users to whom the resource block will be assigned in a timely basis by taking several conditions into account like channel conditions, Qos(Quality of Service), user type, service type etc. is called scheduling. The packet scheduler works at the eNB and it is in the charge of assigning the portions of spectrum shared among users, by following specific policies [3]. Some scheduling schemes are designed to maintain fairness while some other scheduling schemes will be concentrating on maximizing throughput and other can fairness, throughput and spectral efficiency. Scheduling can either be persistent, semi-persistent or non-persistent. Basically, Scheduling schemes can be categorized into two types:

1. Channel Aware Scheduling schemes take the channel conditions into account and schedule the users according to it. Channel conditions consider the effects of channel fading. The following are the examples for channel aware scheduling schemes e.g. Proportional Fairness, Maximum Carrier to Interference Ratio (Max C/I), Modified Largest weighted Delay First Scheme (MLWDF). Generally, channel aware scheduling is adopted in the OFDMA systems like LTE because of the above reasons.

2. Channel Unaware Scheduling schemes don't consider the channel conditions for scheduling. They are scheduled by few metric values which don't consider the effects of fading and multipath. The following is the example for channel unaware scheduling scheme e.g. Round Robin. In coming sections these schemes are briefly discussed and were implemented in t his project.

In LTE systems, these cell resource assignment tasks can now be carried out on a fully automatic basis and distributed over the network by self-organizing networks (SON). This self-organization task requires suitable algorithms which coordinate and assign the resources among cells.

2.5 Inter Cell Interference Coordination

In OFDMA systems like LTE/LTE-A, it is extremely important to reduce interference between the neighboring cells, especially for the cell edge users, since the only interference in LTE is inter cell interference due to orthogonality of sub carriers [4]. As Signal to Interference plus noise ratio (SINR) is the key performance factor for a cell edge user, the inter cell interference has its influence on SINR. Thus, these coordination schemes are considered where all the RBs are usually not used in equal power in every cell. The restrictions are imposed on particular RBs of the neighboring cell and the usage coordination is followed by the eNBs in time wise. This time wise coordination between eNBs is provided by the self-organizing networks which actually exhibits an organized and coordinated behavior. This coordinated resource management can be achieved through fixed, adaptive or real-time coordination with the help of additional inter-cell signaling in which the signaling rate can vary accordingly. In general, inter-cell signaling refers to the communication interface among neighboring cells and the received measurement message reports from user equipments (UEs)[7]. In real systems, due to shadowing, interference profiles and cell shapes do not look that regular. However, there is a high probability that the strongest interferer to a mobile device at the cell border does not have the same restriction as the serving cell, so that an SIR improvement is achieved [5].

Three different approaches has been categorized based upon the traffic variations and mobility of a UE, they are static, semi static and dynamic approaches.

- Static approach: This approach does not vary according to the traffic variations. Its settings are fixed for a long period of time. So, its resource assignment is no longer suits urban traffic. The scheduler should be aware of the neighboring cell beforehand.

- Semi static approach: Unlike, static, it varies according to the channel conditions and traffic variations. Its time scale is much shorter than the static approach. Here, the lightly loaded will benefit the heavily loaded cell.

There will some restricted RBs in every cell which will be reserved for the cell edge users of the neighboring cells. Cell edge users and cell center users are distinguished based upon the SINR level. The heavily loaded cell will send a request on per RB basis to the lightly loaded cell to allocate the restricted RBs to the cell edge users of the heavily loaded cell. The restricted RBs will be different in every cell. If there are multiple requests from neighboring cells, it prioritize according to the metric which may be the function of importance of its benefit like application type, Qos, Cell load, Traffic distribution etc. So, by this the cell edge is benefitted and the Inter cell interference can be managed. This will be done for the type of services for a combination of GBR and Non-GBR bearers. The benefit of semi-static ICIC comes especially into play when fairness or balancing between cells is also taken care of [5].

- Dynamic approach: This is the most complex algorithm which is been implemented according to the dynamic variations of load and channel conditions. Here the time scale is much smaller when compared to the semi static and static approaches. This suits best to the fast moving urban traffic.

2.6 Self-Organizing Networks

With the current trends in the network traffic and the building pressure on the operators' business view, Self-Organizing Networks (SON) can provide a good hope to cope up this situation. As the networks are moving towards the flat architecture, there will be no centralized controller to manage resources and control functions. Also, the operation and maintenance will be the key issue. The main necessity of SON in cellular networks is due to following factors:

- Reduce the Operational Expenditure (OPEX).
- Unpredictable nature of spatio temporal dynamics with cellular networks.
- Due to the expansion of number of base stations.
- With the introduction of femto cells.

So, the self-organizing networks benefit this by distributing these functions to the eNBs or base stations by using the X2 interface. The SON handles functions such as Automatic neighbor relation (ANR), automatic software and configuration download, automatic tuning of parameters, automatic load and resource distribution, etc. Self-organizing functionalities such as Intelligence and autonomous adaptivity, cooperative, emergent behavior and distributed control will play a vital role in future wireless networks in order to manage the increasing complexity, to optimize the system performance and to reduce the cost of operation. With SON human effort is shifted to higher management level so that human operators' role is to monitor SON processes and intervene only when needed [6].

The SON can be implemented in three approaches namely centralized, distributed and hybrid SON and is sub-divided based on functionality wise into Self-Configuration, Self-Optimization and Self-Healing. In this project we are considering the distributed SON where the algorithms are implemented in the eNB. The characteristics explains that Self Organizing Networks should have,

- Scalability: The complexity should not vary with the scale or size of the system. The network should remain operational even if the number of entities leave or enter the system.
- Stability: The system should not oscillate between the states.
- Agility: The system should be responsive to the environment to the extent possible. It should not be inactive and hysterical.

These abilities provided by SON fit very nicely for the interference coordination which adapt dynamically to the situations and can utilize its full benefits.

CHAPTER 3

OUR WORK

A new scheme of resource provision is been introduced in which the resource blocks have been allocated in coordinated fashion. This intelligent and coordinated resource allocation is done in order to reduce the interference in the allocation process to the cell edge users. This is designed for a network where the eNBs are connected via X2 interface and the distributed SON feature is applicable in their functioning. Here, the users are classified as cell center users and cell edge users based upon their distance and location SINR values. The SINR and downlink throughput is been mapped along with the Modulation Coding Scheme (MCS) according to the table given below

Table 2. SINR to downlink throughput mapping [17]

SINR Range (dB)	AMC Mode	Efficiency (Bits/Sec/Hz)
3.39 ≥ SINR < 5.12	QPSK rate ½	1.0
5.12 ≥ SINR < 6.02	QPSK rate 2/3	1.33
6.02 ≥ SINR < 7.78	QPSK rate ¾	1.5
7.78 ≥ SINR < 9.23	QPSK rate 7/8	1.75
9.23 ≥ SINR < 11.36	16-QAM rate ½	2.0
11.36 ≥ SINR < 12.50	16-QAM rate 2/3	2.67
12.5 ≥ SINR < 14.21	16-QAM rate ¾	3.0
14.21 ≥ SINR < 16.78	16-QAM rate 7/8	3.5
16.78 ≥ SINR < 18.16	64-QAM rate 2/3	4.0
18.16 ≥ SINR < 20.13	64-QAM rate ¾	4.5
20.13 ≥ SINR < 24.30	64-QAM rate 7/8	5.25
SINR ≥ 24.30	64-QAM rate 1	6.0

In addition to this, the users are also divided into GBR (Guaranteed Bit Rate) users and (Non -Guaranteed Bit Rate) users based upon their requirement of RBs and the type of service requested.

- Guaranteed Bit Rate (GBR): GBR bearers are given higher data rates when resources are available in network else they are given guaranteed minimum bit rate.
- Non-Guaranteed Bit Rate (NGBR): NGBR bearers are not guaranteed to get minimum bit rate. It completely depends on eNodeB and load conditions in the cell.

The classification of GBR and NGBR user requirements including the QCI, priority, packet delay budget is given in the table 3.1.

Table 3. Priorities, weights and packet delay budget for corresponding applications.

QCI	Resource Type	Packet Delay Budget (ms)	Applications	Priority	Weight
1	GBR	100	Conversational Audio	1	10
2		150	Conversational Video (HD)	2	9
3		300	Video / Screen Sharing	3	8
4	NGBR	100	Buffered Video	4	4
5		300	FTP	5	3
6		300	Web Browsing	6	1

The eNB schedules the user based on the below priorities:

Table 4. Priorities for the eNB scheduler in the algorithm

Priority	User
1	Cell Edge User, GBR
2	Cell Center User, GBR
3	Cell Edge User, NGBR
4	Cell Center User, NGBR

This is because the GBR users should be satisfied first according to the table 4 as they are bearers with certain QoS requirements. In the access network, it is the responsibility of the eNB scheduler that it ensures the necessary Qos to the bearer over the radio interface. Each bearer is associated with the QCI and the Allocation and Retention Priority (ARP). Apart from this, the algorithm prioritize cell edge user over the cell center user because the concept of inter-cell interference arises in the case of cell edge user and the main objective of this scheme is to increase the cell edge user throughput by coordinating inter-cell interference among them.

Every cell in this network restrict some RBs for the sake of cell edge users of neighboring cell to help them in increase the user throughput. They allocate these resources in time of resource shortage to cell edge user and there will be no interference as different RBs are restricted in every cell. This restricted number of RBs can be increased or decreased depending upon its own cell requirement. So, if one cell has a cell edge user with GBR requirement to be allocated, it utilizes its neighboring cell RBs and if needed more, then the neighboring cell increases the restricted RBs and then it may request another neighboring cell. In this case, the total number of RBs per cell are 10 and the restricted RBs for a cell edge user are 3 and remaining 7 RBs are for the sake of cell center users. The RB tuning is possible by the Self Organizing Networks and they tune RBs based upon the requirement of a particular user and the particular service requested. For example, a cell edge user requested a normal voice call, since its priority is high and the required number of RBs will be 2 RBs, so it uses only 2 RBs out of the 3 restricted RBs. Hence there is an efficient use of the available bandwidth. This process is similar in all the cases based upon the given priorities, requested service and their location SINR. Also if there is a case such that there are two users with priority 4, then the neighboring cell chooses the user with the best SINR with respect to itself. If an eNB receives multiple requests form more than one cell, it prioritize between the requests based upon the grant metric. It benefits at the time of cell overload for load balancing.

There is also an emergency condition in which the inter-cell interference coordination can function more efficiently through SON. If the emergency happens in any of the three cells then the two cells collectively coordinates with the cell which has emergency and try to restrict as many RBs needed to schedule the users in the emergency cell. In this case, the remaining two cells will try to help the cell under emergency and will assign its minimum throughput to all the users irrespective of GBR or NGBR. The restricted RBs will be increased for the sake of the users under emergency. This type of scheduling is called coordinated scheduling.

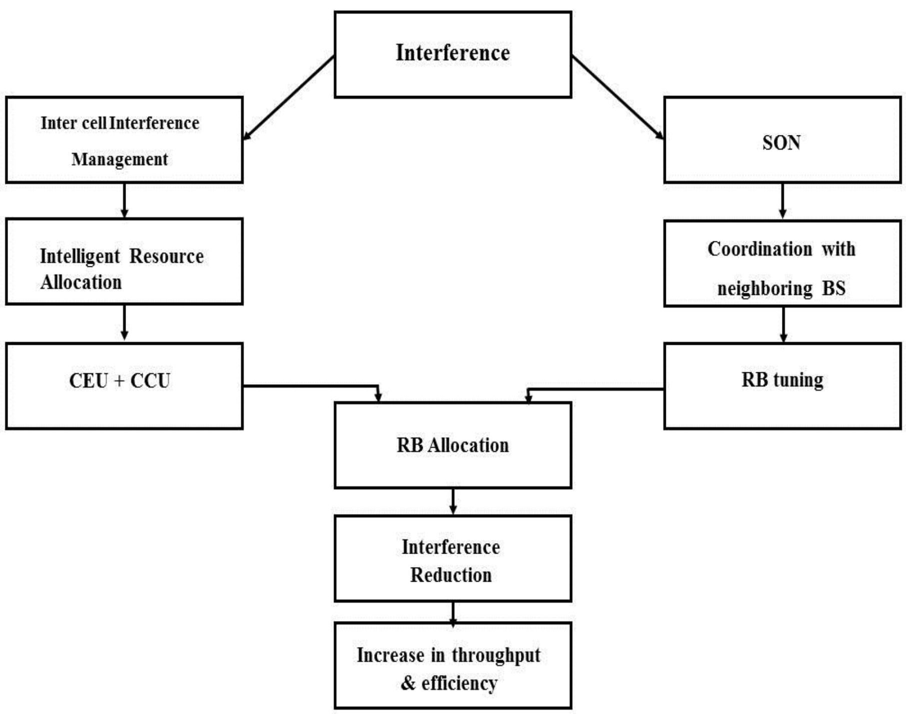

Fig. 2. Proposed Methodology

CHAPTER 4

MATLAB CODE IMPLEMENTATION

4.1 Introduction to MATLAB

This project used MATLAB as the programming tool to write and simulate the code. MATLAB is also known as matrix laboratory. It is a programming tool which has been developed by Mathworks. MATLAB is widely used in academic and research projects. MATLAB consists of hundreds of inbuilt functions which can be used to develop codes and also to plot the data. MATLAB is a user friendly tool and is capable of running several simulations which is the main reason for using it for this project.

4.2 Considerations

Some assumptions are made for this project. They are listed below

- Users are considered as the greedy sources and change their services for every 5000 time slots.
- All the UEs are considered stationary.
- Time domain and frequency domain scheduling is only limited to downlink
- Shadowing is not considered in this model.
- The fading model used in this project is more suited for sub-urban areas

- The distances between the user and eNBs was chosen at random, but then has been maintained the same for all the simulations to have consistency across all the results.
- Initially the nominal static ICIC is implemented in the scenario.

The following are presumed for SON in this project.

- The network dynamically adopts to the chances in the network.
- The distributed type SON is assumed to be implemented.
- eNB is self-established and has automatic neighbor relation management enabled in it.
- The overlapping coverage scenario is considered in optimization of load balancing and assumed that eNB effectively handles it.
- E-UTRAN Coverage holes without any other radio coverage scenario is considered in capacity and coverage optimization and is assumed that eNB can optimize them.
- Also, we consider that Hand Over parameter optimization has achieved detecting and mitigating too early HOs, too late HOs and HOs to a wrong cell.

4.3 Code Description

Below is the description of the code implemented for this project:

- A total number of 20 users are randomly distributed among three eNBs. Each eNB has its total cell area which is a combination of cell center area and cell edge area. The mobiles are assigned to the each eNB such that every eNB has its own CCU and CEU.

```
N=20;% number of mobiles
% Assigning mobiles to base station according to layout.
N1 = [5 6 7 13 15 18 19 ];
N2 = [2 11 12 14 16 17];
N3 = [1 3 4 8 9 10 20 ];
```

- For results with practical conditions, all the users are placed at certain distance (in km) from three eNBs in such way all users experience overlapping coverage. For this we plotted the users and three eNBs in rectangular coordinate system and calculated the distances of a user with respect to three eNBs.

```
% Location of Mobiles and Base Stations according to Layout.
% Mobile Location X Cordinate = MX.
MX = [-3 -3 -3 -3 0 2.5 -1 2 -4 7 4.5 -1 -1.5 1 -1 1 3 4 1 -2];
% Mobile Location Y Cordinate = MY.
MY = [7.5 -3 2.5 0.5 0 3 1 -4 4 -2 2 -3 0 -2 0 1 1 -1.5 0 -5];
% Location of Base Stations.
% Base Station Location X Cordinate = BX.
BX = [7 -2.5 -2.5];
% Base Station Location Y Coordinate = BY.
BY = [0 6 -6];
```

```
% Initialize several vectors for values for each node
% Distance from Base Station
% Location SNR
% Distances from Base Station.
distancefromBS1  = zeros(1,N);
distancefromBS2  = zeros(1,N);
distancefromBS3  = zeros(1,N);
% Location SNR
BS1locationSNR  = zeros(1,N);
BS2locationSNR  = zeros(1,N);
BS3locationSNR  = zeros(1,N);
BS1locationSINR = zeros(1,N);
BS2locationSINR = zeros(1,N);
BS3locationSINR = zeros(1,N);
% Calculating distances between each mobile and each base station.
for j=1:N
    distance1 =  sqrt(abs(((BX(1)-MX(j)).^2)+((BY(1)-MY(j)).^2)));
    distancefromBS1(j)= distance1;
    distance2 =  sqrt(abs(((BX(2)-MX(j)).^2)+((BY(2)-MY(j)).^2)));
    distancefromBS2(j)= distance2;
    distance3 =  sqrt(abs(((BX(3)-MX(j)).^2)+((BY(3)-MY(j)).^2)));
    distancefromBS3(j)= distance3;
end
```

- Okamura-Hata model has been used in this project to calculate large scale fading. Large scale fading observed over long distances. Based on the distances from the three eNBs, location SINR is calculated for each user using the Okamura-Hata model. The following is the code used for large scale fading:

```
for j=1:N
    Fc1=950;  % Carrier frequency for Base Station 1
    Fc2=920;  % Carrier frequency for Base Station 2
    Fc3=930;  % Carrier frequency for Base Station 3
    Hb1=30;   % Base station 1 antenna height
    Hb2=30 ;   % Base station 2 antenna height
    Hb3=30;   % Base station 3 antenna height
```

```
Hm=5;      % Mobile station antenna height
    EIRP=40;
    Gm=0;      % Antenna groupsin of the mobile (in dB)
    a1= ((1.1*log10(Fc1)-0.7)*Hm)-(1.56*log10(Fc1)-0.8);
    a2= ((1.1*log10(Fc2)-0.7)*Hm)-(1.56*log10(Fc2)-0.8);
    a3= ((1.1*log10(Fc3)-0.7)*Hm)-(1.56*log10(Fc3)-0.8);
    A1 = 69.55+26.16*log10(Fc1)-13.82*log10(Hb1)-a1;
    A2 = 69.55+26.16*log10(Fc2)-13.82*log10(Hb2)-a2;
    A3 = 69.55+26.16*log10(Fc3)-13.82*log10(Hb3)-a3;
    B1 = 44.9-6.55*log10(Hb1);
    B2 = 44.9-6.55*log10(Hb2);
    B3 = 44.9-6.55*log10(Hb3);
    C = 0;
    L1 = A1+B1*log10(distancefromBS1(j))+C;
    L2 = A2+B2*log10(distancefromBS2(j))+C;
    L3 = A3+B3*log10(distancefromBS3(j))+C;
    Pr1 = EIRP-L1+Gm;  % Received power
    Pr2 = EIRP-L2+Gm;
    Pr3 = EIRP-L3+Gm;
```

- In large scale fading the distance is inversely proportional to the SNR. Hence, more the distance from eNB less the SNR the user experiences.
- The Rayleigh fading model has been used in this project to calculate small scale fading. Rayleigh fading is simulated using Clarke's model [13].

```
fm = 100;  % Maximum Doppler shift
rmatrix=[];
rmatrix=ones(N,60416,N);
% RB=1:N;
% for RBnum=1:N
for RBnum=1:1
    %     RBNum
    for BSnum=1:3
        rmatrixrow=[];
        for usernum=1:N
            rtemp=[];
            for jj=1:ceil(60000/1024)
                r=rayleigh(fm);  % Get rayleigh values for fm
                % For fm = 100, this generates 1024 samples
```

```
                rtemp=[rtemp r];
            end
            rmatrixrow = [rmatrixrow rtemp'];
        end
        RB(RBnum,BSnum).rmatrixlevel=rmatrixrow;
    end
end
```

- After calculating each user's Location SINR using SNR obtained from large scale fading, Rayleigh fading or small scale fading is added to calculate actual SINR of a user with respect to three eNBs.
- The location SINR is been calculated as shown below.

```
SNR1 = Pr1-Pn;

    SNR2 = Pr2-Pn;

    SNR3 = Pr3-Pn;

    Pr1mag=db2mag(Pr1);

    Pr2mag=db2mag(Pr2);

    Pr3mag=db2mag(Pr3);

    SINR1 = SNR1-(20.*log10(Pr2mag+Pr3mag+1));

    SINR2 = SNR2-(20.*log10(Pr1mag+Pr3mag+1));

    SINR3 = SNR3-(20.*log10(Pr2mag+Pr1mag+1));

    BS1locationSNR(j)=SNR1;

    BS2locationSNR(j)=SNR2;

    BS3locationSNR(j)=SNR3;
```

```
    BS1locationSINR(j)=SINR1;

    BS2locationSINR(j)=SINR2;

    BS3locationSINR(j)=SINR3;
```

- The below table is used to map SINR to CQI classes and to DL throughput per Resource Block (RB). Different Modulation and Coding Schemes (MCS) can be used for different throughput. The services are mapped to their corresponding minimum and maximum throughputs as per the LTE standards.

```
SINRclasses=  [24.30 20.13 18.16 16.78 14.21 12.5 11.36 9.23 7.78 6.02 5.12
3.39];

CQI = [12 11 10 9 8 7 6 5 4 3 2 1];
%Channel Quality Indicators for corresponding SNR
DLthroughput=[1.080 0.945 0.810 0.720 0.630 0.540 0.480 0.360 0.315 0.270 0.199
0.180]; %Throughput per Resource Block (180KHz)
services = [1 3 4 8 9 10];
minthroughput=[0.21 0.21 0.9 0.7 1.3 0.1];
maxthroughput=[0.5 0.5 2.2 1.2 1.8 0.5];
for l= 1:length(services);
    serviceminthroughput(l)=minthroughput(l);
    servicemaxthroughput(l)=maxthroughput(l);
end
```

- The above DL throughput is calculated taking the sub carrier bandwidth of 180 KHz.
- The Cell Center Users and Cell Edge Users are categorized based on their location SINR values and is defined per eNB.

```
%Categorizing Cell Edge users and Cell Center Users.
u = 4; %temp variable to access users as below
BS1CCU = [10 11 17 18];
BS1CEU = [6 16 19 0];
BS2CCU = [1 3 9 0];
BS2CEU = [4 7 13 15];
BS3CCU = [2 12 20 0];
BS3CEU = [5 8 14 0];
```

- The weights are defined per service and the priorities are defined based upon the table2, table 3 and table 4 for CEU and CCU.
- Below code shows the weights and priority is been assigned to the users in eNB1. The same is followed for eNB2 and eNb3.

```
%###############For eNB 1#############################
    % Giving Weights and Priority
    for j=1:N
        if (i1<=kb)
            weight1 = data1(M,:);  % Mth row of data1
            BS1Weights = weight1;
        else
            kb = kb+servicechange;
            M = M+1;
            weight1 = data1(M,:);
            BS1Weights = weight1;
        end

        BS1Priority=zeros(1,N);
        for ceuindex=1:length(BS1CEU)
            ceumobile=BS1CEU(ceuindex);
            if ceumobile~=0
                if BS1Weights(ceumobile)>=8
                    % This user is cell edge and GBR
                    BS1Priority(ceumobile)=4;
                else
                    % This user is cell edge and NGBR
                    BS1Priority(ceumobile)=2;
                end
            end
```

```
        end
        for ccuindex=1:length(BS1CCU)
            ccumobile=BS1CCU(ccuindex);
            if ccumobile~=0
                if BS1Weights(ccumobile)>=8
                    % This user is cell center and GBR
                    BS1Priority(ccumobile)=3;
                else
                    % This user is cell center and NGBR
                    BS1Priority(ccumobile)=1;
                end
            end
        end
```

- The minimum throughput requirements and the maximum throughput requirements for the above services has been calculated and listed as follows

```
minthroughput=[0.03 1.2 0.4 0.512 0.128 0.128];

maxthroughput=[0.1 1.5 0.5 2 0.03 0.03];

for l= 1:length(services);
    serviceminthroughput(l)=minthroughput(l);
    servicemaxthroughput(l)=maxthroughput(l);
end
```

- The services used by the bearers are changed for every 5000 slots and we import this data which are randomly predesigned in excel sheet.

```
weight1 = zeros(1,N);%Import weights data from excel
weight2 = zeros(1,N);
weight3 = zeros(1,N);
data1 = xlsread('BS1Weights.xlsx');
data2 = xlsread('BS2Weights.xlsx');
data3 = xlsread('BS3Weights.xlsx');
timeslot=1e-3;
BS1CCU = zeros(1,N);
```

```
BS1CEU = zeros(1,N);
BS2CCU = zeros(1,N);
BS2CEU = zeros(1,N);
BS3CCU = zeros(1,N);
BS3CEU = zeros(1,N);
%For all the three base stations timeslots allocated
simulationtimeforBS = 20; % number of seconds for total simulation
transmissionblock_betweengroups = 1;  % Number of slots until a different
scheduling choice is made.
transmissionblock_ingroup = 1;  % Number of slots until a different scheduling
choice is made.
numtimeslots = simulationtimeforBS/timeslot; % number of packets to simulate.
%Change of subscrier's service
KB = 2000;
servicechange = 5000;
M = 1;
```

- Once the services are imported and are implemented now we map the minimum throughput and maximum throughput to the users depending upon the RBs availability or spectrum availability.
- After giving priorities to the user, the throughput is been assigned to all the users with respect to the three eNBs before the scheduling as there should be some amount of minimum throughput requirement for each user. This is termed as pre-assignment of throughput.

```
%Pre-Assigning throughput to all users with respect to eNB1 which has
        %overlapping coverage.
        % This gives actual SNR variation around the mean of locationSNR
        BS1actualSINR(j) = BS1locationSINR(j) + 10.*log10(rmatrix(j,j,1).^2);
        % SINR to CQI
        if (BS1actualSINR(j)>SINRclasses(1))
            BS1CQI(j) = CQI(1);
            for l = 1:6;
                if (BS1Weights(j)==services(l))
                    RB1s= ceil(servicemaxthroughput(l)/DLthroughput(1));
```

```
                    RBforBS1(j)=RB1s;
                    % Dynamnic RB Allocation.
                    if (RBforBS1(j)<=y11(s11))
                        x11(s11)= x1(s1);
                        y11(s11)= y1(s1);
                    elseif (RBforBS1(j)<=y11(s11+1))
                        x11(s11)= x1(s1+1);
                        y11(s11)= y1(s1+1);
                    elseif (RBforBS1(j)<=y11(s11+2))
                        x11(s11)= x1(s1+2);
                        y11(s11)= y1(s1+2);
                    elseif (RBforBS1(j)<=y11(s11+3))
                        x11(s11)= x1(s1+3);
                        y11(s11)= y1(s1+3);
                    end

                    if (RBforBS1(j)<= y11(s11))
                        BS1actualthroughput(j)= servicemaxthroughput(l);
                    else
                        BS1actualthroughput(j)= serviceminthroughput(l);
                    end
                end
            end
            H1=1;
        else
            for k=1:length(SINRclasses)-1
                if (BS1actualSINR(j)<=SINRclasses(k)) &&
(BS1actualSINR(j)>SINRclasses(k+1))
                    BS1CQI(j) = CQI(k+1);
                    for l = 1:6;
                        if (BS1Weights(j)==services(l))

RB1s=ceil(servicemaxthroughput(l)/DLthroughput(k+1));
                            RBforBS1(j)=RB1s;
                            H1=k+1;
                            % Dynamnic RB Allocation.
                            if (RBforBS1(j)<=y11(s11))
                                x11(s11)= x1(s1);
                                y11(s11)= y1(s1);
                            elseif (RBforBS1(j)<=y11(s11+1))
                                x11(s11)= x1(s1+1);
                                y11(s11)= y1(s1+1);
                            elseif (RBforBS1(j)<=y11(s11+2))
                                x11(s11)= x1(s1+2);
                                y11(s11)= y1(s1+2);
                            elseif (RBforBS1(j)<=y11(s11+3))
                                x11(s11)= x1(s1+3);
```

```
                            y11(s11)= y1(s1+3);
                        end

                        if (RBforBS1(j)<= y11(s11))
                           BS1actualthroughput(j)= servicemaxthroughput(l);
                        else
                            BS1actualthroughput(j)=serviceminthroughput(l);
                        end
                    end
                end
            end
        end
        if (BS1actualSINR(j)<SINRclasses(length(SINRclasses)))
            BS1CQI(j) = 0;
        end
        RB1s = ceil(BS1actualthroughput(j)/DLthroughput(H1));
        RBforBS1(j) = RB1s;
    end
end
```

- Now post assignment of throughput is done for each eNB along with the priorities.

```
%%%%%%%%%%%%%%%%  For eNB 2  %%%%%%%%%%%%%%%%
        % Add Rayleigh fading to each node and compute throughput
        if (BS2Priority(II2)==4) %CEU
            % This gives actual SNR variation around the mean of locationSNR
            BS1actualSINR(II2) = BS1locationSINR(II2) +
10.*log10(rmatrix(II2,II2,1).^2);
            BS2actualSINR(II2) = BS2locationSINR(II2) +
10.*log10(rmatrix(II2,II2,1).^2);
            BS3actualSINR(II2) = BS3locationSINR(II2) +
10.*log10(rmatrix(II2,II2,1).^2);

            % SINR to CQI
            %AS it is CEU of BS1, it takes the RBs from BS2 or BS3
            %Starting from BS2
            if (BS1actualSINR(II2)>SINRclasses(1))
                BS1CQI(II2) = CQI(1);
                for l = 1:6;
                    if (services(l) == BS2Weights(II2))
                        RB1s= ceil(servicemaxthroughput(l)/DLthroughput(1));
                        RBforBS1(II2)=RB1s;
```

```
                        % Dynamnic RB Allocation.
                        if (RBforBS1(II2)<=y11(s))
                            x11(s11)= x1(s1);
                            y11(s11)= y1(s1);
                        elseif (RBforBS1(II2)<=y11(s11+1))
                            x11(s11)= x1(s1+1);
                            y11(s11)= y1(s1+1);
                        elseif (RBforBS1(II2)<=y11(s11+2))
                            x11(s11)= x1(s1+2);
                            y11(s11)= y1(s1+2);
                        elseif (RBforBS1(II2)<=y11(s11+3))
                            x11(s11)= x1(s1+3);
                            y11(s11)= y1(s1+3);
                        end
                        if (RBforBS1(II2)<= y11(s11))
                            BS1actualthroughput(II2)= servicemaxthroughput(l);
                        else
                            BS1actualthroughput(II2)= serviceminthroughput(l);
                        end
                    end
                end
                H1 = 1;
            else
                for k=1:length(SINRclasses)-1
                    if (BS1actualSINR(II2)<=SINRclasses(k)) &&
(BS1actualSINR(II2)>SINRclasses(k+1))
                        BS1CQI(II2) = CQI(k+1);
                        for l = 1:6;
                            if (services(l) == BS2Weights(II2))
                                RB1s=
ceil(servicemaxthroughput(l)/DLthroughput(k+1));
                                RBforBS1(II2)=RB1s;
                                H1=k+1;
                                % Dynamnic RB Allocation.
                                if (RBforBS1(II2)<=y11(s11))
                                    x11(s11)= x1(s1);
                                    y11(s11)= y1(s1);
                                elseif (RBforBS1(II2)<=y11(s11+1))
                                    x11(s11)= x1(s1+1);
                                    y11(s11)= y1(s1+1);
                                elseif (RBforBS1(II2)<=y11(s11+2))
                                    x11(s11)= x1(s1+2);
                                    y11(s11)= y1(s1+2);
                                elseif (RBforBS1(II2)<=y11(s11+3))
                                    x11(s11)= x1(s1+3);
                                    y11(s11)= y1(s1+3);
                                end
```

```
                                if (RBforBS1(II2)<= y11(s11))
                                    BS1actualthroughput(II2)=
servicemaxthroughput(l);
                                else
                                    BS1actualthroughput(II2)=
serviceminthroughput(l);
                                end
                            end
                        end
                    end
                end
                if (BS1actualSINR(II2)<SINRclasses(length(SINRclasses)))
                    BS1CQI(II2) = 0;
                end
                BS2actualthroughput(II2)=BS1actualthroughput(II2);
                RBforBS1(II2) =
ceil(BS2actualthroughput(II2)/DLthroughput(H1));
                RBforBS2(II2)= RBforBS1(II2);
            end

            %CEU of BS1: If it donot have enough resources with BS2, it
            %tries with BS3

            if (RBforBS1(II2)>y22(s22))
                if (BS3actualSINR(II2)>SINRclasses(1))
                    BS3CQI(II2) = CQI(1);
                    for l = 1:6;
                        if (BS2Weights(II2)==services(l))
                            RB3s=
ceil(servicemaxthroughput(l)/DLthroughput(1));
                            RBforBS3(II2)=RB3s;
                            % Dynamnic RB Allocation.
                            if (RBforBS3(II2)<=y33(s33))
                                x33(s33)= x3(s3);
                                y33(s33)= y3(s3);
                            elseif (RBforBS3(II2)<=y33(s33+1))
                                x33(s33)= x3(s3+1);
                                y33(s33)= y3(s3+1);
                            elseif (RBforBS3(II2)<=y33(s33+2))
                                x33(s33)= x3(s3+2);
                                y33(s33)= y3(s3+2);
                            elseif (RBforBS3(II2)<=y33(s33+3))
                                x33(s33)= x3(s3+3);
                                y33(s33)= y3(s3+3);
                            end
```

```
                            if (RBforBS3(II2)<= y33(s33))
                                BS3actualthroughput(II2)=
servicemaxthroughput(l);
                            else
                                BS3actualthroughput(II2)=
serviceminthroughput(l);
                            end
                        end
                    end
                    H3 = 1;
                else
                    for k=1:length(SINRclasses)-1
                        if (BS3actualSINR(II2)<=SINRclasses(k)) &&
(BS3actualSINR(II2)>SINRclasses(k+1))
                            BS3CQI(II2) = CQI(k+1);
                            for l = 1:6;
                                if (BS2Weights(II2)==services(l))
                                    RB3s=
ceil(servicemaxthroughput(l)/DLthroughput(k+1));
                                    RBforBS3(II2)=RB3s;
                                    H3=k+1;
                                    % Dynamnic RB Allocation.
                                    if (RBforBS3(II2)<=y33(s33))
                                        x33(s33)= x3(s3);
                                        y33(s33)= y3(s3);
                                    elseif (RBforBS3(II2)<=y33(s33+1))
                                        x33(s33)= x3(s3+1);
                                        y33(s33)= y3(s3+1);
                                    elseif (RBforBS3(II2)<=y33(s33+2))
                                        x33(s33)= x3(s3+2);
                                        y33(s33)= y3(s3+2);
                                    elseif (RBforBS3(II2)<=y33(s33+3))
                                        x33(s33)= x3(s3+3);
                                        y33(s33)= y3(s3+3);
                                    end

                                    if (RBforBS3(II2)<= y33(s33))

BS3actualthroughput(II2)=servicemaxthroughput(l);
                                    else
                                        BS3actualthroughput(II2)=
serviceminthroughput(l);
                                    end
                                end
                            end
                        end
                    end
```

```
                    if (BS3actualSINR(II2)<SINRclasses(length(SINRclasses)))
                        BS3CQI(II2) = 0;
                    end
                    BS2actualthroughput(II2)=BS3actualthroughput(II2);
                    RBforBS3(II2) =
ceil(BS2actualthroughput(II2)/DLthroughput(H3));
                    RBforBS2(II2)= RBforBS3(II2);
                end
            end
```

This procedure is followed for all the eNBs and for each priority.

CHAPTER 5

RESULTS AND ANALYSIS

5.1 Comparison of Location SINR values

This section provides analysis of the performance of the functions developed in this project. The first step here is to understand the basic behavior of the approach.

In cases where the sum of total of the requirements is above capacity, different functions have various effects on how they share resources and which users meet requirements.

Let us consider the following simulation results.

Number of users, N = 20

Number of eNBs (BS) =3

Total number of Resource Blocks = 30

Consider users with different channel conditions.

In this section, we see the performance of the proposed scheme studied for this project. There are 20 users distributed around three eNBs.

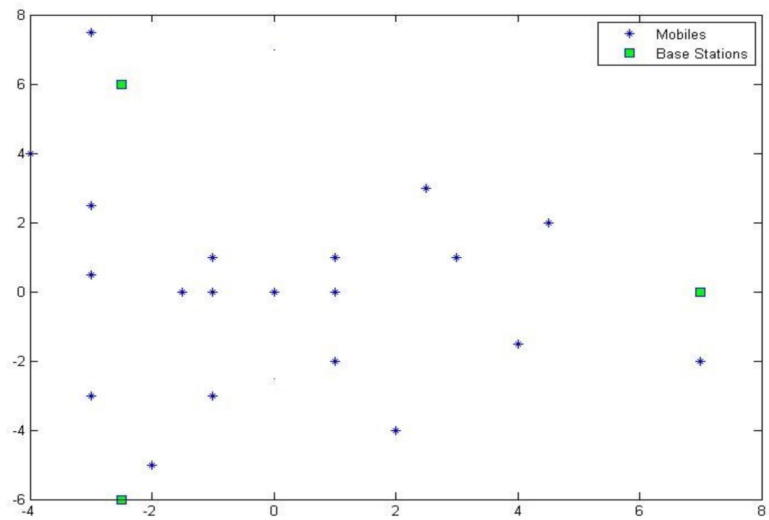

Fig. 3. User Locations in Coordinated axes

The respective mobiles are defined per each eNB as follows:

eNB1 CCU = 10, 11, 17, 18

eNB1 CEU = 6, 16, 19

eNB2 CCU = 1, 3, 9

eNB2 CEU = 4, 7, 13, 15

eNB3 CCU = 2, 12, 20

eNB3 CEU = 5, 8, 14

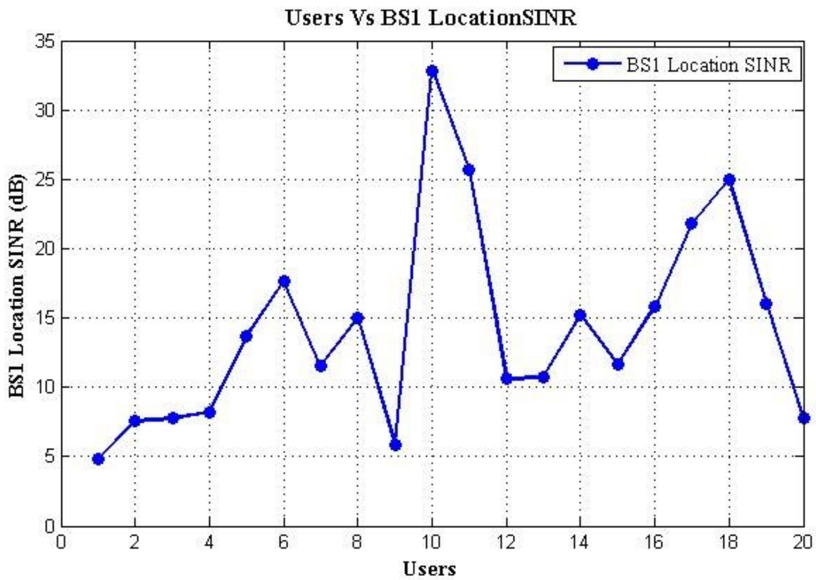

Fig. 4. Plot for the Users Vs. BS1 Location SINR

The above plot shows the location SINR values with respect to the BS1 or eNB1. Based upon this, the cell center and cell edge users of eNB1are defined.

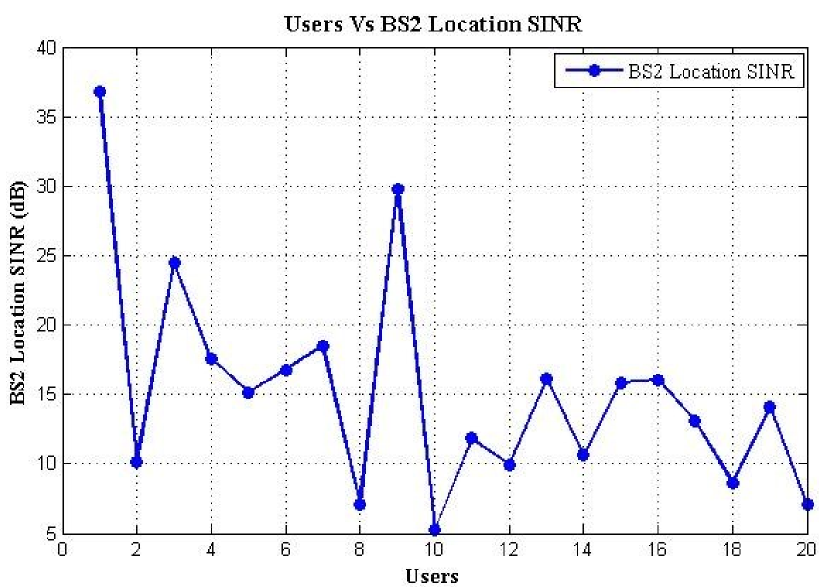

Fig. 5. Plot for Users Vs. BS2 Location SINR

The above plot shows the location SINR values with respect to the BS2 or eNB2. Based upon this, the cell center and cell edge users of eNB2 are defined.

The below plot shows the location SINR values with respect to the BS3 or eNB3. Based upon this, the cell center and cell edge users of eNB3 are defined.

From these three figures we can see that the location SINR of Users with respect to three eNBs are different. Here, some of the mobiles have low SINR from one eNB and have high SINR for the different eNBs. This is because of the concept of cell edge and cell center users. The users having very high SINR can be taken as cell center users and users having considerably low SINR can be taken as cell edge users.

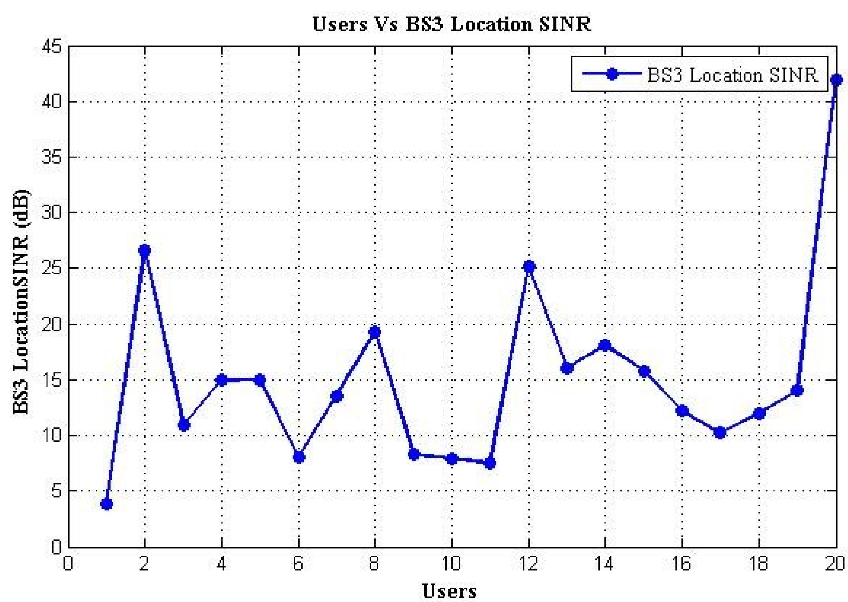

Fig. 6. Plot for Users Vs. BS3 Location SINR

The reason for this is there is an interference from the other two eNBs acting onto the cell edge users which exhibits the low SINR values.

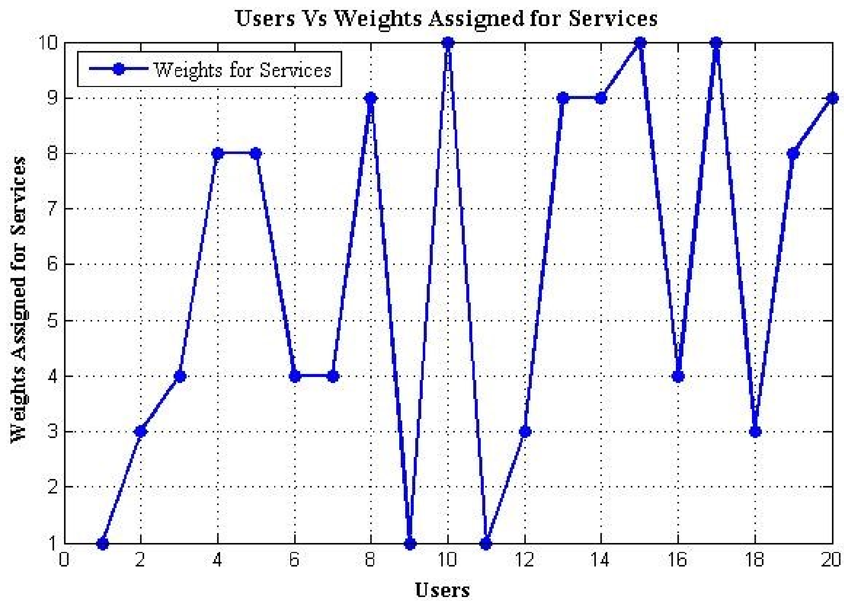

Fig. 7. Plot for Users Vs. Weights Assigned for Services.

The types of services used by the subscribers are given weights according to the standards of PCRF. The above plot shows the weights assigned to the users up to 5000 timeslots. As the service access is up to 5000 time slots, the user access the service and then the weights changes accordingly in the next timeslots.

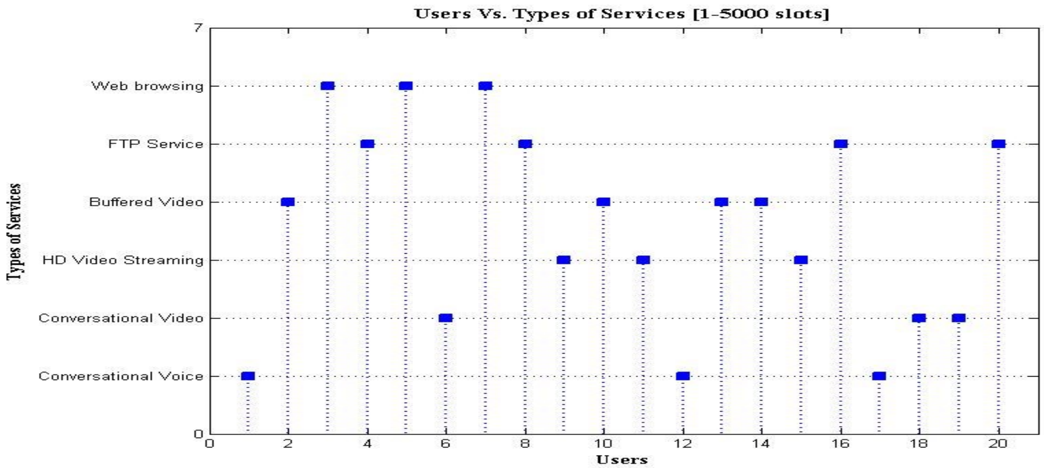

Fig. 8. Services Requested in first 5000 time slots

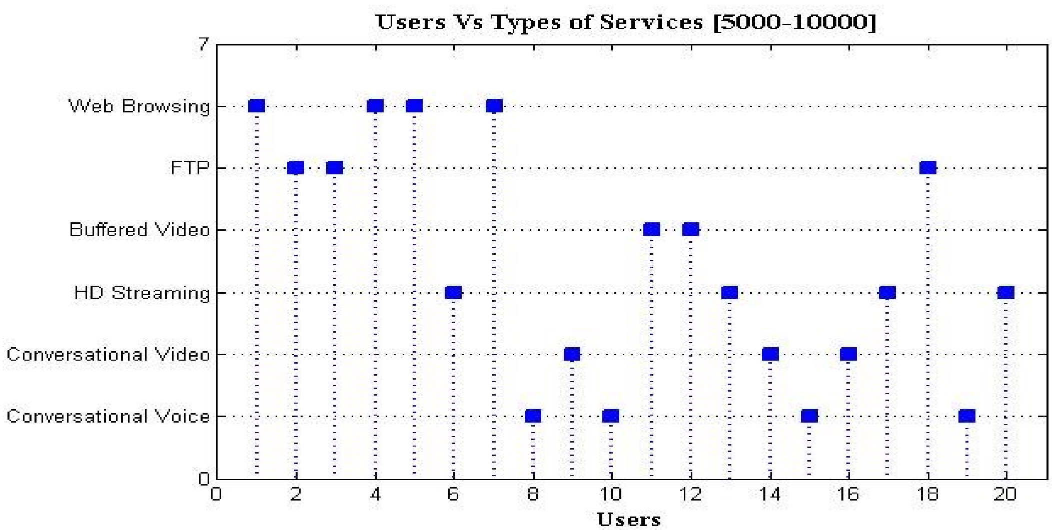

Fig. 9. Services requested in 5000-10000 time slots

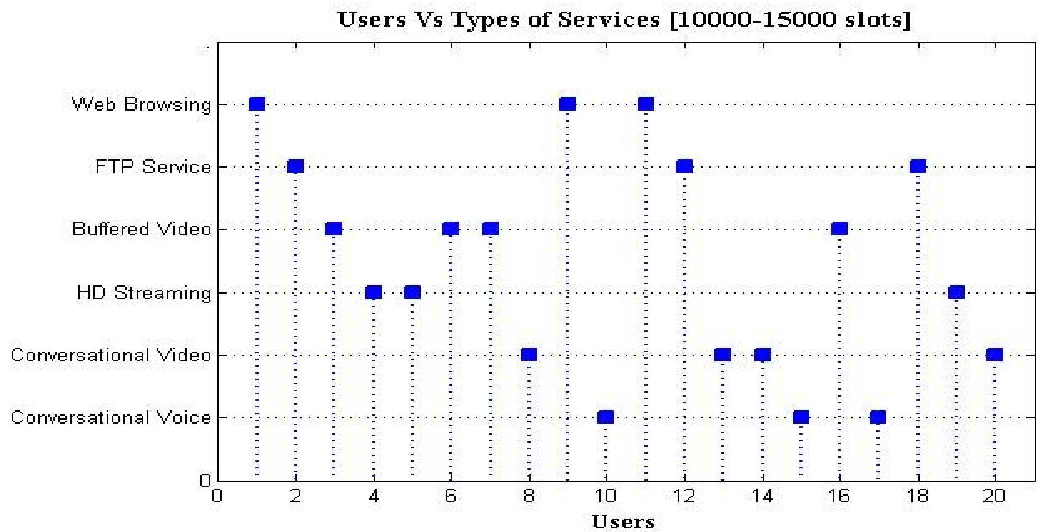

Fig. 10. Services Requested in 10000-150000 time slots

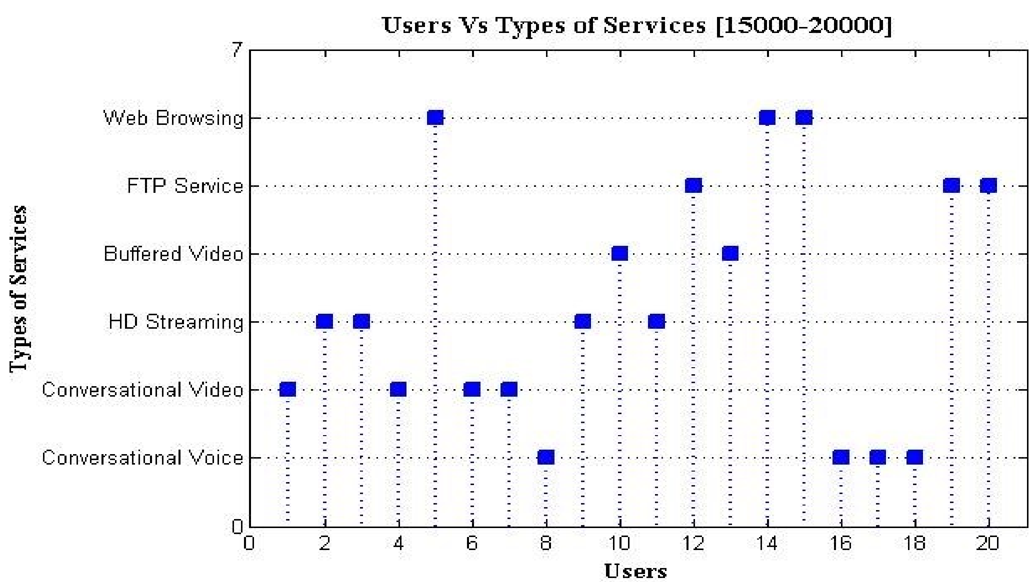

Fig. 11. Services Requested in 15000-20000 time slots

5.2 Comparison of allocated Resource Blocks and Throughput

The following plot shows the number of resource block assigned to the user accessing a particular type of service. If the user is a cell edge user and a GBR, then the scheduler gives the highest priority and takes the RBs from the neighboring eNB.

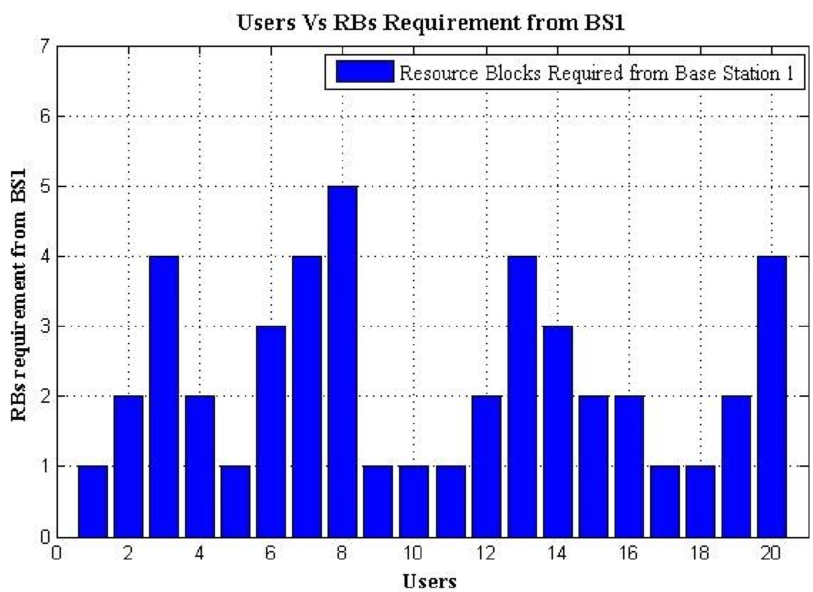

Fig. 12. Plot for Users Vs. RBs requirement for BS1

The RB tuning is done according to the user requirement as initially 7 RBs are assigned to the cell center users and 3RBs for cell edge users. So, in the 5000th time slot, mobile 19 is selected from eNB1 and mobiles 4 and 5 are selected from eNBs 2 and 3. These are cell edge users and using the GBR service which means they will get the first priority in scheduling. So mobile 19 gets 2 RBs as it is using the service with weight 8 which is a HD video calling and the corresponding throughput is been assigned. Based upon the availability of RBs, it assigns the maximum or minimum throughputs. The maximum throughput is 1.2 Mbps and minimum throughput is 0.7Mbps. This shows there is a considerable amount of increase in throughput for a cell edge user through interference coordination using SON. If the requirements of RBs are more than the tuning limit of the RBs that a particular cell center user or a cell edge user can adjust then the service minimum throughput is assigned and RBs are allocated accordingly. This is same for eNB2 and eNB3.

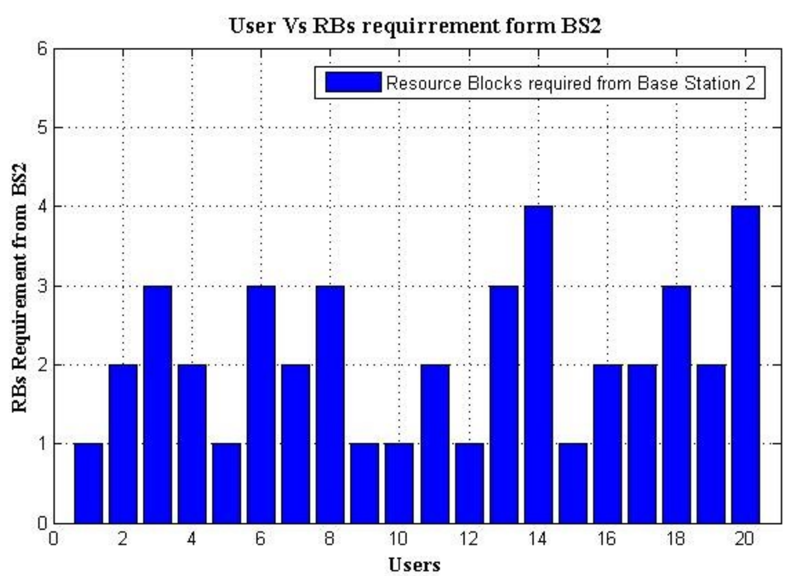

Fig. 13. Plot for Users Vs. RB Requirement for BS2

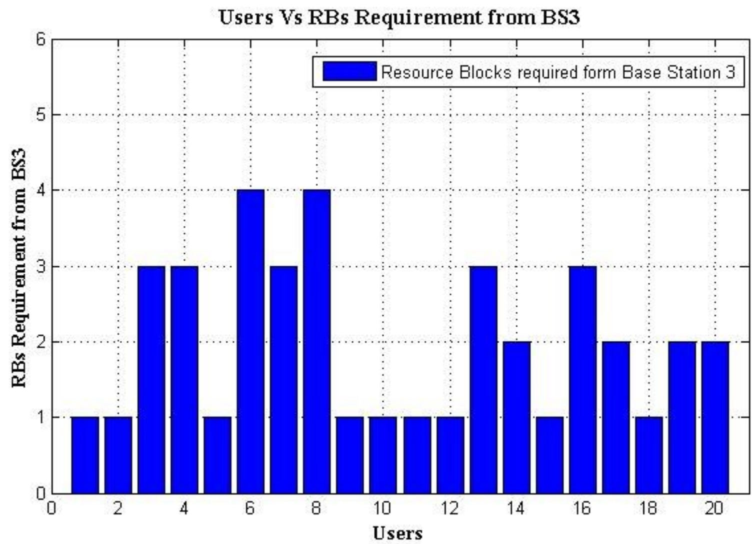

Fig. 14. Plot for Users Vs. RB requirement for BS3

Now, the RB requirement and allocation is been compared among the interference management and Max C/I scheduling algorithms. The MaxC/I allocates RBs based upon their SINR values. The cell center users gets always the maximum amount of resources and the cell edge users always gets the remaining resources. So, by comparing these two, the justified conclusion can be drawn for the interference management scheme by showing that the distribution of the resources is being done on a coordinated fashion according to the proposed algorithm. The RB requirement shown in the plots is the combined requirement of GBR and NGBR without any restrictions, where as the allocated is in accordance with GBR or NGBR along with the restricted RBs and RB tuning limit. This is the reason, for every mobile the requirement is much larger than the allocated.

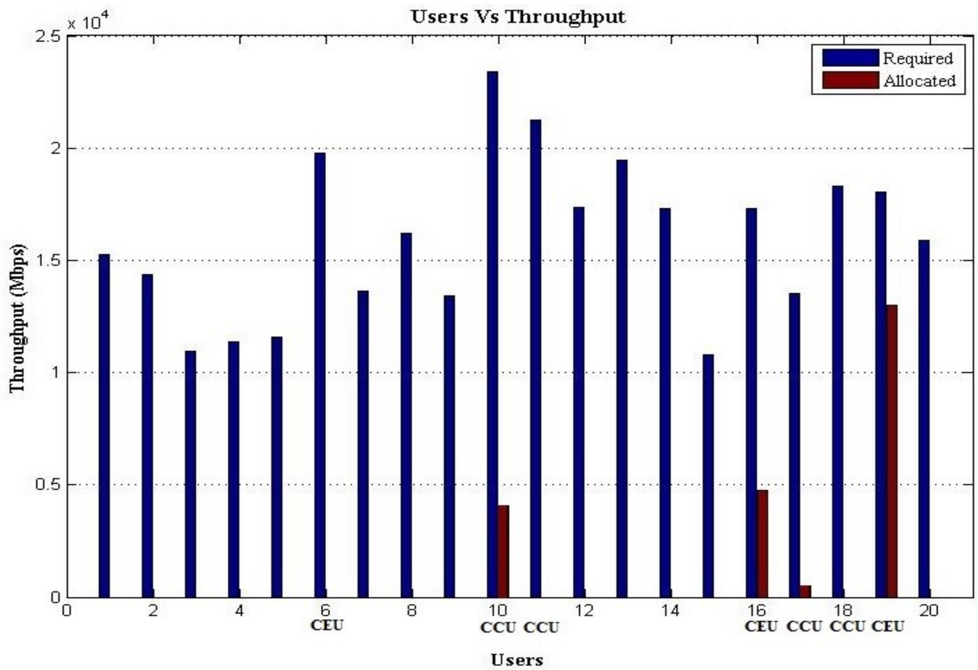

Fig. 15. Plot for Required and Allocated Throughput for BS1 in Interference Management

In the above plot, the mobile 19 and 16 are cell edge users with GBR requirement. The mobile 19 has high priority than mobile 16 and hence the amount of throughput allocated is more. Also, mobile 10 is cell center user, which is assigned its mapped throughput, as it is a GBR user. The mobile 16 is CEU with NGBR requirement with least priority and hence cannot get throughput in that timeslot whereas mobile 17 can get some resources even it is a cell center user because it has a GBR requirement with medium priority.

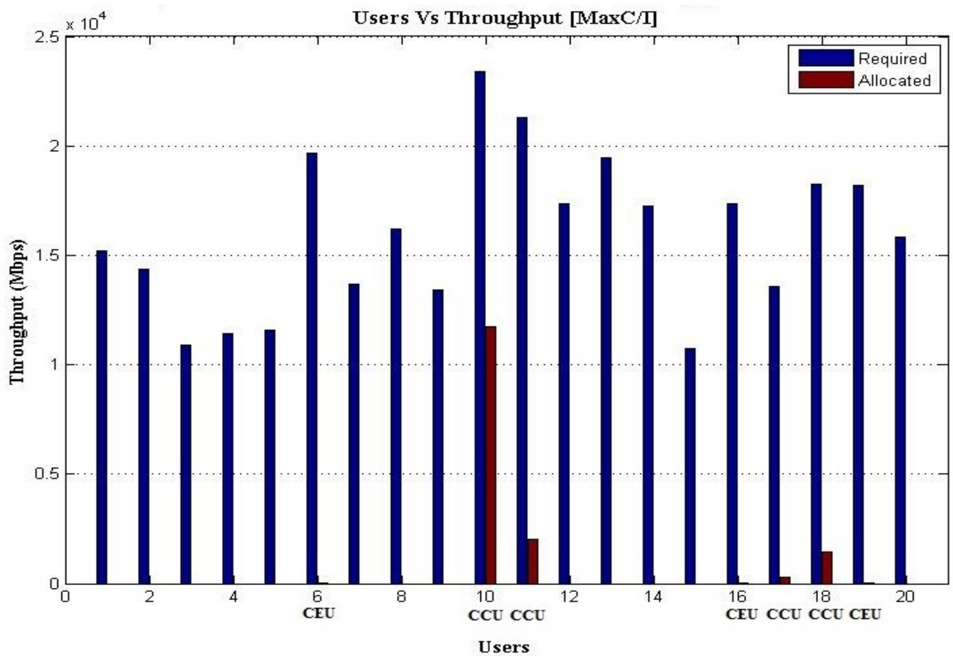

Fig. 16. Plot for Required and Allocated Throughput for BS1 in Max C/I

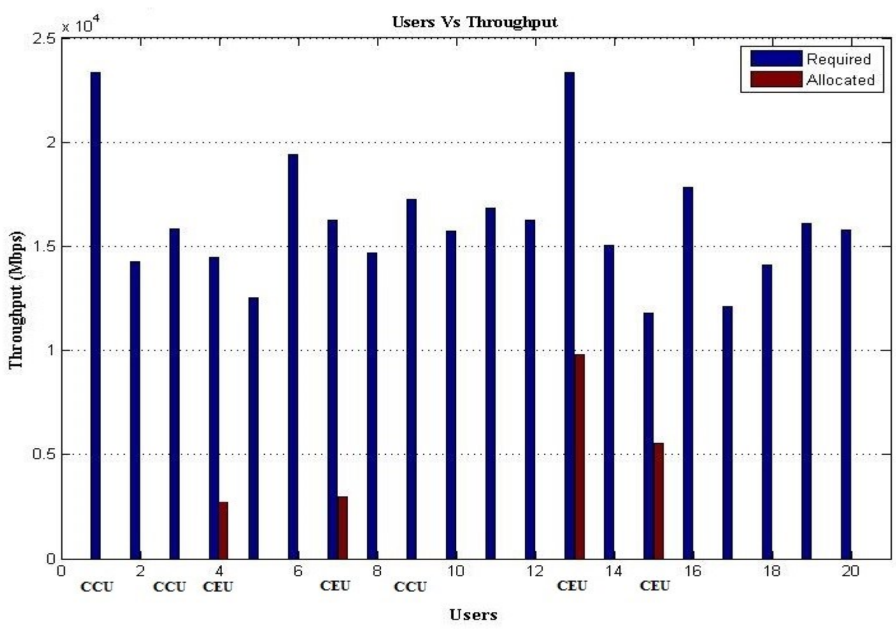

Fig. 17. Plot for Required and Allocated Throughput for BS2 in Interference Management

In the above plot, the mobile 13 and 15 are cell edge users with GBR requirement. The mobile 13 has high priority than mobile 16 and hence the amount of throughput allocated is more. Also, mobiles 4 and 7 are also cell edge users being allocated some resources. There are no cell center users requesting for the services in this time slot. Hence, for the case of Max C/I in the below plot, the same cell edge users are scheduled with change in throughput. This is done according to their SINR values.

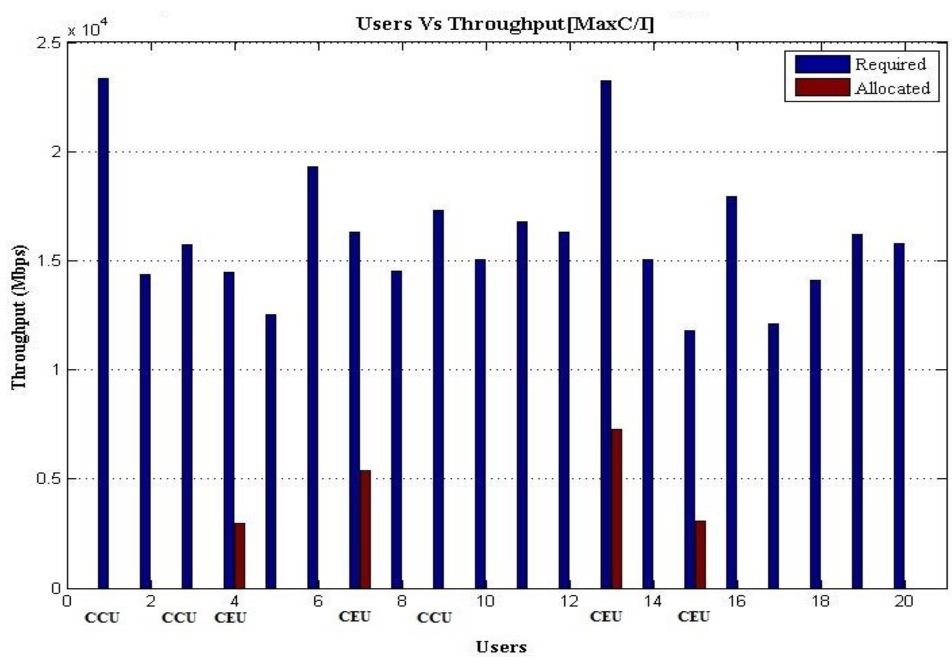

Fig. 18. Plot for Required and Allocated Throughput for BS2 in MaxC/I

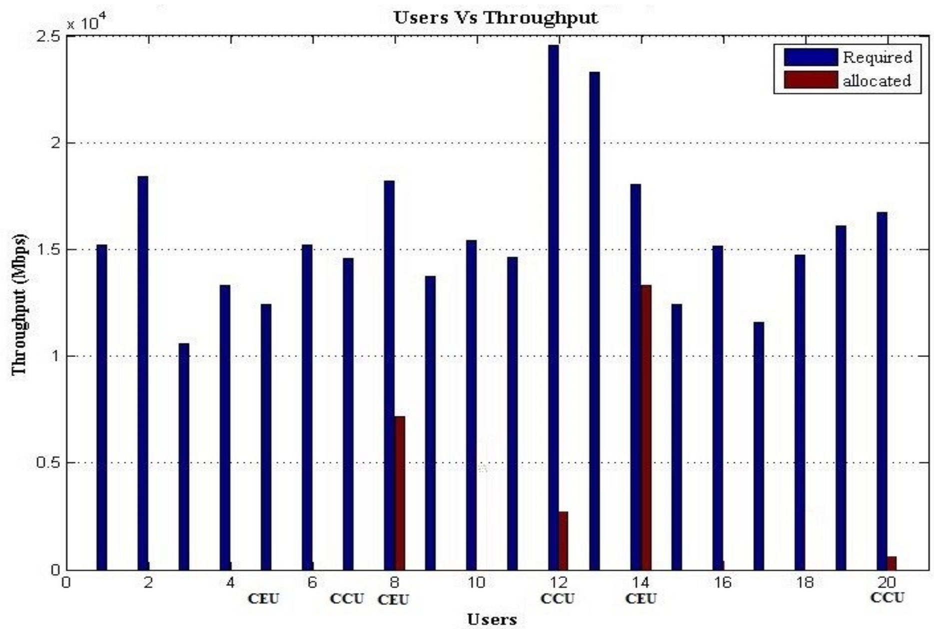

Fig. 19. Plot for Required and Allocated Throughput for BS3 in Interference Management

In this plot, the mobile 14 and 8 are cell edge users with GBR requirement. The mobile 14 has high priority than mobile 8 and hence the amount of throughput allocated is more. Also, mobile 12 is cell center user, which is assigned some considerable amount of throughput, as it is a GBR user. The mobile 5 is CEU with NGBR requirement with least priority and hence cannot get throughput in that timeslot whereas mobile 20 can get some resources even it is a cell center user because it has a GBR requirement with medium priority.

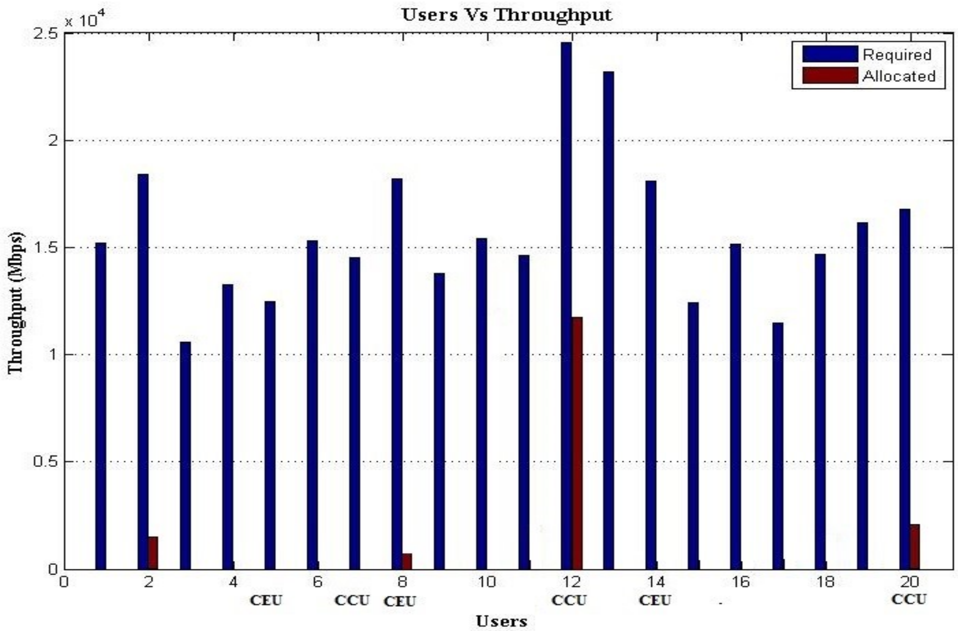

Fig. 20. Plot for Required and Allocated Throughput for BS3 in Max C/I

In this plot, the mobiles 12, 20 and 2 are cell center users and mobile 5 is a cell edge user. So, in this case all the cell center users can get some throughput and only one of the cell edge users can get very least throughput.

The next plot shows the combined total throughput for all the eNBs for the respective mobiles scheduled for the cases of interference management and Max C/I. The total throughput for cell center users and cell edge users for the two scheduling algorithms is been plotted in which for the case of interference management, there is a clear increase in throughput when compared to Max C/I for each eNB and for the respective mobiles scheduled for all the 20,000 time slots.

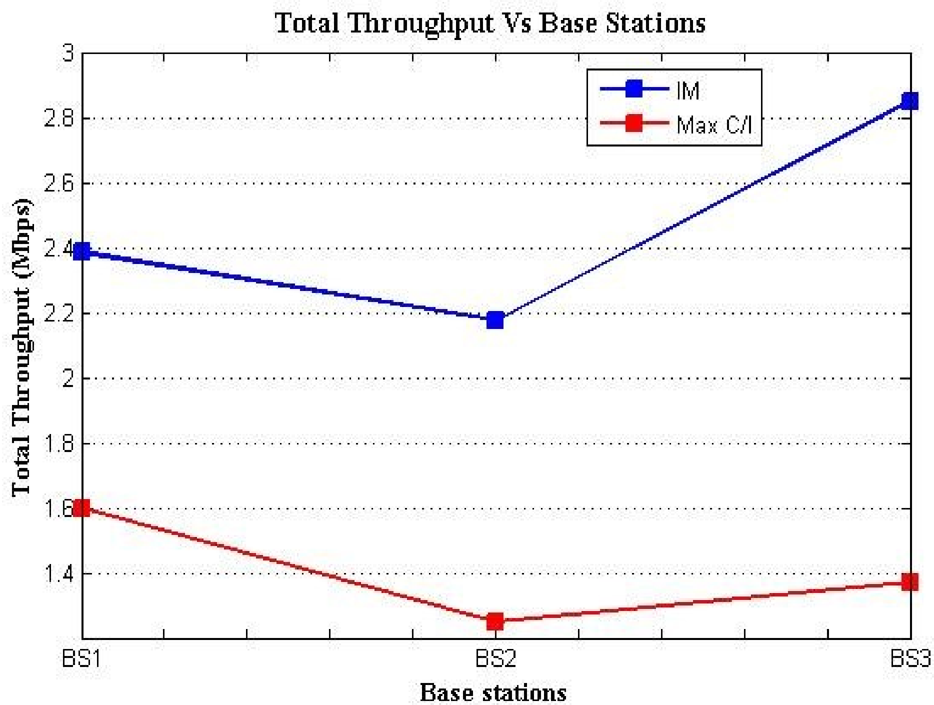

Fig. 21. Plot comparing the total throughputs for Interference Management and Max C/I Scheduling Schemes

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

The requirements of cellular networks are unachievable unless there is a good coordination in allocating the resources for proving high data rates, fairness and low latency. So, there should be an efficient and intelligent scheme in scheduling the users which can minimize the interference with the neighboring cells. The advanced technologies like MIMO, adaptive modulation and coding, OFDMA, Carrier Aggregation and Self Organizing Networks helps in meeting these demands. The inter-cell interference coordination with the help of SON is an efficient scheme in reducing the inter-cell interference in the cell edge area to most possible extent and increasing their throughput.

This thesis provide an interference coordination algorithm which is a complex yet efficient scheme to meet the throughput requirements of the cell edge users. The priority has been given to the GBR users along with the cell edge users to provide the necessary resources for coordinating with the neighboring cells. The algorithm is been designed so that it prioritizes between the type of services and between the requests sent by the neighboring eNBs. This simulator allocated one timeslot to one user at a time, but could easily be extended to a multicarrier OFDMA solution.

This project shows a clear distinction between the cell edge user and cell center user throughput for the interference management and the Max C/I cases. The same can be observed through the plots that there is an increase in the total throughput for interference management case. The interference is been coordinated in the cell edge user scenario by RB tuning for the neighboring cells and this resulted in the throughput increment. A brief picture in the emergency condition is also been mentioned in the project.

The goal of all of this work is to make the mobile data technologies that we use every day for personal and business functions become useful effectively without any stalls or crashes for even more important functions.

6.2 Future Scope

Future work that can be done based on this project includes

- Finding the optimal solution scheduler which can provide fairness in this case along with the interference coordination.
- Interference Coordination simulator for Emergency Communications.
- Adding the aspect of Multi user MIMO and beam forming techniques such as Coordinated Multipoint Transmission.
- Interference coordination in the case of relay nodes and heterogeneous networks involving small cells such as femtocells, picocells, and relays.
- Traffic offloading techniques to divert traffic onto non-LTE networks.
- Minimizing in case of VoLTE services and Rich Communication services (RCS).

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VITA

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