# GROUP SCHEDULING IN CELLULAR NETWORKS

A THESIS IN
Electrical Engineering

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MASTER OF SCIENCE

by

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GROUP SCHEDULING IN CELLULAR NETWORKS

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## ABSTRACT

With the ever increasing number of users and the usage of data in cellular networks, meeting the expectations is a very difficult challenge. To add to the difficulties, the available resources are very limited, so proper management of these resources is very much needed. Scheduling is a key component and having a scheduling scheme which can meet the Qos requirements such as Throughput, Fairness and Delay is important.

A new dimension to scheduling known as Group Scheduling has been designed in this project. Common scheduling schemes, which include Maximum Carrier to Interference, Round Robin, Proportional Fair and Modified Largest Weighted Delay First, have been studied and analyzed.

In a network where the users are divided into a number of groups, such as Public Safety which has Fire, Health and Police, the Group Scheduling scheme is designed to find the right balance between Throughput and Fairness. It allocates the resources to the best available group and the best available user inside that

particular group based on a contention mechanism which takes into account the location of the user and the fast varying channel conditions for that user. The Proportional Fair scheme has been used as the basis for this Group Scheduling scheme and results have been simulated to show that it performs better than the other scheduling schemes studied for this project. Also, the scheme has been 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 " Group Scheduling in Cellular Networks", presented by Rajesh kumar Srirambhatla, candidate for the master of Electrical Engineering degree, and certify that in their opinion it is worthy of acceptance.

<u>Supervisory Committee</u>

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CONTENTS

## ILLUSTRATIONS

Figure Page

TABLES

# ACKNOWLEDGEMENTS

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I would like to thank my parents MR.S.Ravinder and MRS.Vidya Ravinder for their love and support.

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# CHAPTER 1

# INTRODUCTION

Data usage has become very predominant in cellular networks. Almost all data applications such as VoIP, banking and online gaming are now available on smart phones. With limited spectral resources, it is becoming extremely difficult for the cellular operators to satisfy the data needs of users. The primary objective of the operator is to make an efficient use of the limited spectrum while ensuring certain QoS parameters such as throughput, fairness and delay. In order to meet these requirements, a wide range of new techniques have been introduced. These include

- OFDMA (Orthogonal Frequency Division Multiple Access)
- Multi User MIMO
- Beamforming

## 1.1 Orthogonal Frequency Division Multiple Access

Orthogonal frequency division multiple access is the technology that is being used in LTE and Wimax to get higher data rates over traditional Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). It is based on a multiplexing scheme that divides the bandwidth into multiple closely spaced sub carriers which are orthogonal to each other thus avoiding interference among the adjacent sub carriers. In this scheme, the available bandwidth is divided both in time and frequency. In LTE, resources allocated to users are in units of Resource Block which is a combination of OFDM symbols in the time domain and sub carriers in the frequency domain. The other notable advantages of OFDMA are its ability to reduce the impact of multipath fading and Inter symbol Interference. ‘The main advantages of OFDMA are scalability and robust nature towards multi-path fading’[11]. It uses parallel transmission of flows with long symbol times to overcome multipath.

## 1.2 Importance of Scheduling in Cellular Networks

The distribution of the radio resources in a cellular network is done by the base station based on a scheduling scheme. With the number of mobile users and the demand for higher data rates increasing every day, it is important to have a scheduling scheme which can meet the Quality of Service (QoS) requirements. These include

- Throughput
- Fairness
- Delay

Meeting the downlink QoS is largely dependent on the scheduling mechanism deployed at the base station. The scheduling schemes that have been studied for this project are

- Maximum Carrier to Interference ratio
- Proportional  Fair
- Modified Largest Weighed Delay First
- Round Robin

Opportunistic scheduling schemes such as maximum carrier to interference ratio assign the resources to the user with the best channel condition and therefore maximizing the throughput. With these scheduling schemes, fairness is not taken into consideration. On the other hand, there are scheduling schemes such as round robin and proportional fair which treat the users fairly but in this process do not achieve maximum throughput since the users at the edge of the cell are also given an equal amount of resources. We could see that based on the scheduling mechanism used at the base station there could be a tradeoff between throughput and fairness. Hence, having a scheduling scheme that could find the right balance among the QoS metrics is extremely important.

## 1.3 Project Proposal

A new dimension to scheduling known as group Scheduling has been proposed in this project. This scheduling scheme is designed for a network where the users are classified into groups such as public safety. The main objective of this scheme is to meet the QoS requirements at the group level and also at the user level. In our simulation, resources are allocated by the base station in time slots of 1ms windows. The group scheduling scheme is a two stage process. In the first stage, the base station chooses which one of the groups is to be given the time slot at any instant in time based on a metric which is a derived from the proportional fair scheduling metric. In the second stage, a particular user inside the chosen group is given the time slot based on different scheduling schemes which include maximum carrier to interference ratio, proportional fair and round robin. Results have been simulated and analyzed to show that proportional fair scheme performs better than round robin at the group stage.

Reliability is one of the key features of the scheduler at the base station. It is a necessity that a scheduling scheme is highly reliable and delivers the goods under any conditions. To meet this requirement, different environments have been simulated for this project that include

- increase in the number of users
- increase in the number of groups

- different channel conditions for the users in different groups
- groups of different sizes

Results have been simulated for the above conditions to prove that the proposed group scheduling scheme is highly reliable.

In addition to the group scheduling scheme, a new metric known as tunable proportional fair metric has been proposed in this project. This metric is a compromise between the Max C/I and the Proportional Fair schemes. Further research is required to find an optimal solution for the tunable PF metric.

# CHAPTER2

# BACKGROUND

## 2.1 Evolution of Cellular Networks

Around 1985, the first generation of cellular systems (1G) focused on analog systems which were voice only with no data. The critical problem in 1G was capacity. The main requirement was to increase it. These requirements brought several new technologies: TDMA, GSM, and CDMA. The promise was to significantly increase the efficiency of cellular telephone systems and to allow a greater number of simultaneous conversations.

Between 1992 and 2000, 2G was developed. It supported voice, SMS, WAP and 30-40Kbps of data. In 2001, 2.5G GPRS/1XRTT was introduced, improving data rates up to 100-200Kbps. By 2003, evolution into 3.0G-3.5G (UMTS/CDMA2000, HSDPA/HSUPA, 1xEVDO/Rev.A,B) provided advanced services such as video streaming, video conference, high speed packet data up to 1-5Mbps.

More recently around 2010, 4G LTE has proposed and promised up to 100 Mbps data transfer. If you notice, through cellular network evolution, the focus has been mainly on user satisfaction such as throughput and fairness. Data rate and data related services became of prime importance from the end user standpoint.

## 2.2 Fading

Fading is one of the key difficulties in wireless communications. The signal from the base station can reach the user in a number of different paths caused due to reflection, diffraction and scattering. These are also known as multi path components (MPC). Each MPC has its own length of travel and also direction from the base station to the mobile user which results in a different phase shift. So, when all these MPC's add up at the mobile user with different phase shifts, they could either make the signal strength at the receiver better or worse. This phenomenon of the deviation of the signal strength in wireless communications is known as fading.

Fading can be broadly classified into two types

- large scale fading
- small scale fading

Large scale fading as the name suggests is the attenuation of the signal considered over large distances.  For this project, the Okamura-Hata model is considered to demonstrate large scale fading. This model is commonly used on many real-world measurements. The key factors in this model are :

- frequency which ranges from 150MHz to 1500MHz
- height of the Base Station which ranges from 30m to 200m
- height of the Mobile User which ranges from 1m to 10m

- the distance from the Base Station which ranges from 1km to 20km
- the environment is a small/medium sized city

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)

Small scale is the deviation of the signal strength considered over very small distances. The profile of the multi path components which includes the phase shift could vary due to very small movements of the mobile user as small as 10cm which results in varying signal strength at the user. Rayleigh fading has been used to demonstrate small scale fading in this project. Rayleigh fading is best suited to sub-urban and urban areas where having a line of sight communication between the base station and the mobile user is very difficult because of all of the tall buildings in between and also in places where the originating signal from the base station takes multiple paths because of reflection and scattering from different objects.

## 2.3 Scheduling Schemes

'Packet scheduling mechanisms play an important role on how to distribute radio resources among a number of users taking into account channel conditions and QoS requirements' [4]. There is a trade off in spectral efficiency and fairness which is mainly based on scheduling. Some scheduling schemes are specifically designed to maximize the spectral efficiency, some are for fairness, and there are others which try to find a right balance between these two. All of these kinds are studied for this project and explained in the later sections.

Scheduling schemes can be broadly classified into two types:

- channel aware scheduling schemes
- channel unaware scheduling schemes

Channel Aware Scheduling schemes take the channel conditions into account. Channel conditions include the effects of large scale and small scale fading which is a result of factors which include

- channel fluctuations
- user mobility
- multipath effect

These scheduling schemes exploit the varying channel conditions to meet certain QoS parameters such as throughput, fairness etc.

Some of the channel aware scheduling studied for this project are Max C/I, Proportional Fairness and Modified Largest Weighed Delay First (MLWDF).

Max C/I, where C/I is the carrier to interference ratio, serves the user with the best channel condition in every time slot. This maximizes the overall throughput of the system. The disadvantage of using this scheme is that it does not treat the users fairly. There is a possibility that the user with poor channel conditions will not be given any bandwidth.

The Proportional Fair scheme, also abbreviated as PF, chooses the user with the best PF metric. The PF metric is defined as the throughput achieved by the user in the current time slot divided by the average throughput of that user. The PF scheme achieves high throughput while ensuring fairness among all the users. PF scheme exploits multi-user diversity by giving the time slot to the user who can make the best use of the channel at that instant. The formula used in Proportional fair scheme to choose a particular user is $\max \frac{Ri}{Ai}$ [7]

Where Ri is the rate achievable by user I and Ai is the average rate of user i.

The main function of the Modified Largest Weighted Delay First scheme is to give larger priority to the user with the largest waiting time in the given time slot. In this scheme delay is also taken as the QoS metric. The metric used in this scheme is the same as the PF metric times a factor of delay which makes a user much higher priority as it nears the deadline. ‘Modified Largest Weighted Delay

First is throughput optimal, namely it ensures that the queues are stable as long as the vector of average arrival rates is within the system maximum stability region' [9]. The formula used to choose a particular user in this scheme is

$$\max(\rho i * \left(\frac{Wi}{Di}\right) * (\frac{Ri}{Ai}))$$

Where pi is a constant, Wi is actual waiting time and Di is the deadline.

Round Robin (RR) is the channel unaware scheduling scheme studied in this project. The Round Robin scheme polls the Users one after the other sequentially. It does not take the channel conditions into account. It is an absolutely fair scheme where all the users are treated the same. As it does not take the fast varying channel conditions into account, the Throughput is very low. 'The Round Robin method is considerably simpler than earlier strategies to achieve global fairness' [10].

## 2.4 Public Safety

Public safety is one of the key sectors and it plays an important role in our day to day life. The key objective of public safety groups which includes fire, health and police is to respond to the emergency situations as soon as possible. Communication plays a vital role in this aspect. Quality of service which includes guaranteed throughput and fairness is very important in public safety communications. The scheduling scheme proposed in this project emphasizes on this aspect. 'The lack of interoperability between emergency response departments were not fully appreciated until recent crisis highlighted the importance of coordinated operations on a broad scale' [2]. This objective has been taken care of by the group scheduling developed in this project which unifies all the three departments in a single system and maintains the right balance while sharing the resources. 'In an envisioned future, public safety communications use the same technologies as the consumer market, allowing cost reductions and improved data service capabilities' [3]. These technologies include EVDO, HSPA and LTE. Since, the spectrum allocated for public safety is very limited, it is very important to use it very effectively while meeting the objectives. Reliability is one of the key factors for any means of communications and it is very important for public safety communications. The Group scheduling scheme developed in this project ensures that it is reliable under different conditions.

## 2.5 Related Work

There has been a lot of research and effort been put into scheduling in wireless and cellular networks. With the users and data usage increasing rapidly and the available resources such as spectrum being very limited, the main focus would be on spectral efficiency and fairness. Here are a few papers which talk about different methods how scheduling can effectively be used.

In paper [11], different scheduling mechanisms are studied that can be implemented in mobile Wimax networks to allocate resources to meet the QoS requirements such as delay, and throughput. These scheduling schemes include round robin and proportional fair.

In paper [5], the authors present the fair throughput scheduling model. This scheme allocates the resources to the user with the least average throughput in the past interval of time. It is also shown that using the fair throughput scheduling model, equal amount of resources will be allocated to all the users in the longer term.

In paper [4], an analysis of various scheduling schemes in LTE cellular networks is presented. It provides an overview of the key issues in the allocation of resources in LTE networks. The paper also presents the challenges of using a more complex scheduling algorithm for example modified largest weighted delay first which yields a better result in terms of QoS compared to a less complex round robin method. The authors present a thorough understanding of the resource sharing problem in LTE networks.

Scheduling proves to be one of the most challenging areas in wireless networks and lot of research has been put into this aspect. The concept of group scheduling is new, however, and is discussed in this project to add a new dimension to it which could be more prominent in areas like public safety communications. The proposed group scheduling scheme has good scope in it to attract the researchers to come up with even better results.

CHAPTER 3

# CODE IMPLEMENTATION

## 3.1 Introduction to MATLAB

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

## 3.2 Code Description

A group scheduling scheme to optimize fairness and throughput has been designed in matlab for this project. Below is the description of the code implemented for this project:

- a total number of 20 users are divided into two groups
- each user is placed at a certain distance(in km) from the base station

```
distancefromBS=[8 5 4 10 2 6 7 9 12 11 5.5 2.3 3.4 8 9.5 10.5 7 5 6
13];
```

- based on the distance from the base station, location SNR is calculated for each user using the Okamura-Hata model.

SNR: Signal to Noise Ratio is the ratio of the Signal power to the Noise power. The higher the ratio, the better is the quality of the signal.

Okamura-Hata model: This model has been used in this project to emulate large scale fading. Fading in wireless communications is the deviation of the signal strength over a period of time. It is broadly classified into large scale and Small scale fading. Large scale fading observed over long distances. The following is the code used for large scale fading:

```
for j=1:N
    Fc=950;
    Hb=60;
    Hm=5;
    EIRP=30;
    Gm=0;
    a= ((1.1*log10(Fc)-0.7)*Hm)-(1.56*log10(Fc)-0.8);
    A = 69.55+26.16*log10(Fc)-13.82*log10(Hb)-a;
    B = 44.9-6.55*log10(Hb);
    C = 0;
    L = A+B*log10(distancefromBS(j))+C;
    Pr = EIRP-L+Gm;
    Pn = -174+10*log10(200e3);
    % Pn = -174+10*log10(950e6);
    SNR = Pr-Pn;
    locationSNR(j)=SNR;
end
```

The main factor in large scale fading is the distance at which the user is from the base station. The greater the distance, the lower would be the Location SNR.

- After calculating each user's Location SNR using large scale fading, Actual SNR for each user is calculated and it is based on location SNR plus small scale fading. The Rayleigh fading model has been used in this project to emulate small scale fading. Small scale fading is caused due the multiple contributions of the signal coming in different directions which is a result of reflection, scattering and diffraction. A combination of all these factors results in the deviation of the received signal strength even when the user moves by a fraction of the wavelength. Rayliegh fading is simulated using Clarke's model [16]

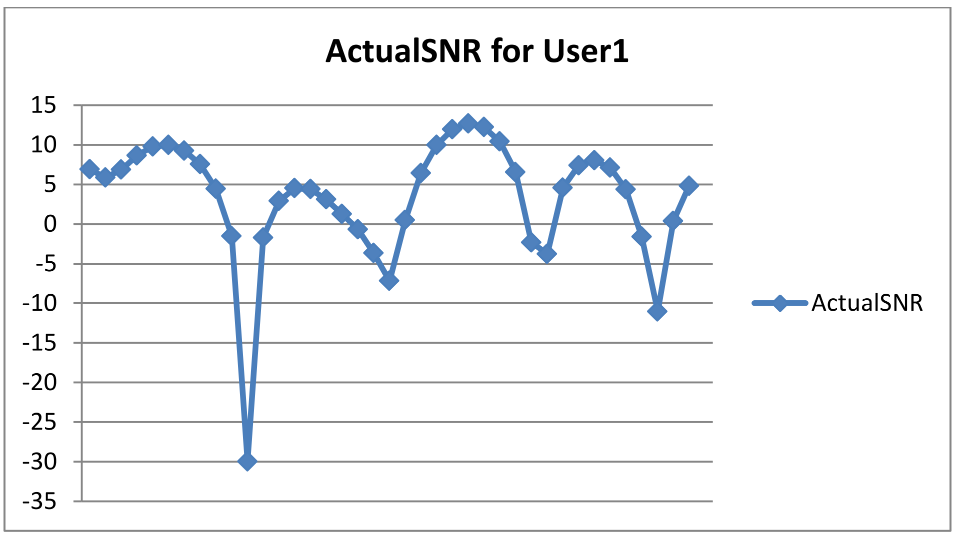


Figure 3.1 Plot for the ActualSNR of User1 for 40 time slots

- once the actual SNR has been calculated for each user, the downlink throughput for that user will be mapped based on the code and table below:

```
if (actualSNR(j)>SNRclasses(1))
                actualthroughput(j) = DLthroughput(1);
            else
                for k=1:length(SNRclasses)-1
                    if (actualSNR(j)<=SNRclasses(k)) &
(actualSNR(j)>SNRclasses(k+1))
                        actualthroughput(j) = DLthroughput(k+1);
                    end
                end
            end
            if (actualSNR(j)<SNRclasses(length(SNRclasses)))
```

```
            actualthroughput(j) = 0;
        end
```

This table is used to map SNR to throughput. Different modulation schemes can be used for different throughput. This table comes from Wimax documents [17]

```
SNRclasses=  [24.4  22.7 18.2 16.4  11.2  9.4  6.4];
DLthroughput=[14.26 12.6  9.5  6.34  4.75 3.17 1.41];
```

- The next step is to decide which one of the groups is given the instantaneous time slot. The proportional fair scheme has been used for this. PF metric for all the users is calculated for each time slot. The top three users with best PF metric in each group are chosen and added up to get the final metric for each group. The group with the best final metric is given the time slot.

```
PFmetric1 = sort(PFmetric(1:N/2),'descend');
PFmetric2=sort(PFmetric(N/2+1:N),'descend');
Finalmetric1 = PFmetric1(1)+PFmetric1(2)+PFmetric1(3);
Finalmetric2 = PFmetric2(1)+PFmetric2(2)+PFmetric2(3);
G = max(Finalmetric1,Finalmetric2);
```

- once the group has been decided, the next step is to choose a particular user inside that group which is based on the scheduling scheme used inside the group. Four kinds of scheduling schemes have been used inside the Group for this project.

    - Max C/I

```
[Ydummy,I]=max(actualthroughput(:,1:N));
```

- Round robin
- Proportional fair

```
PFmetric =
actualthroughput./(pastthroughput./(i*timeslot));
```

- Modified Weighed Largest Delay First

```
deadlinemetric=((timestamp-(Qgroup1-
packetdeadline))./packetdeadline).*actualthroughput1./(p
astthroughput1/(i*timeslot));
```

- The last step in the code is to calculate the group throughput which is summing up the user throughput selected for that group and also the total throughput, which is the addition of both the groups' throughputs. In addition to this, time slots that have been given to a particular user and also to the group are also calculated.

```
    timeslots(I) = timeslots(I)+1;
Group1throughput=Group1throughput+actualthroughput(I)*timeslot;
Group2throughput=Group2throughput+actualthroughput(I)*timeslot;
    Totalthroughput = Group1throughput+Group2throughput;
```

The code designed for this project is a bit complex since it involves computing all the above calculations for every 1ms window.

## 3.3 Assumptions

There have been some assumptions made for this project. They are listed below

- users have traffic inflow all the time (greedy sources)

- scheduling is only limited to downlink and this project does not cover uplink
- this simulation model does not include the effect of shadowing
- the fading model used in this project is more suited for sub-urban areas
- the distance between the user and the base station was chosen at random, but then has been maintained the same for all the simulations  to have consistency across all the results

CHAPTER4

# RESULTS AND ANALYSIS

## 4.1 Individual Scheduling Schemes

In this section, we see the performance of the individual schemes studied for this project. There are 20 users distributed around the base station.

### 4.1.1 Max C/I

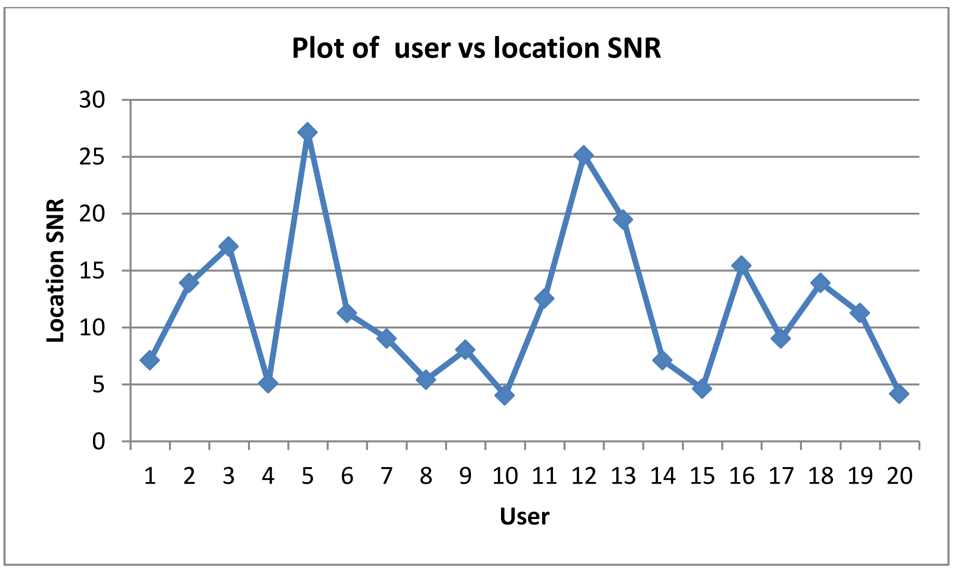


Figure 4.1 Plot for the location SNR of each user

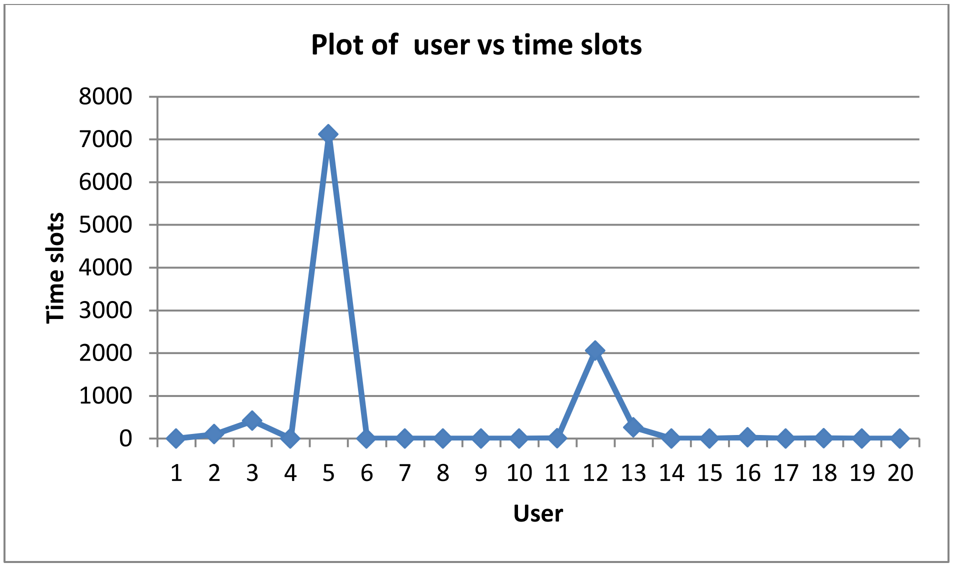


Figure 4.2 Plot for the time slots given to each user with Max C/I

From Figure 4.1 and 4.2, we can see that user 5, who has the best location SNR, has the maximum number of time slots. Users who have a very low location SNR did not get a considerable number of time slots. Some of them received zero time slots. Max C/I takes the channel conditions of each user into account and choose the user with the best conditions. The total throughput with Max C/I is 13.78Mbps.

### 4.1.2 Proportional Fairness Scheme

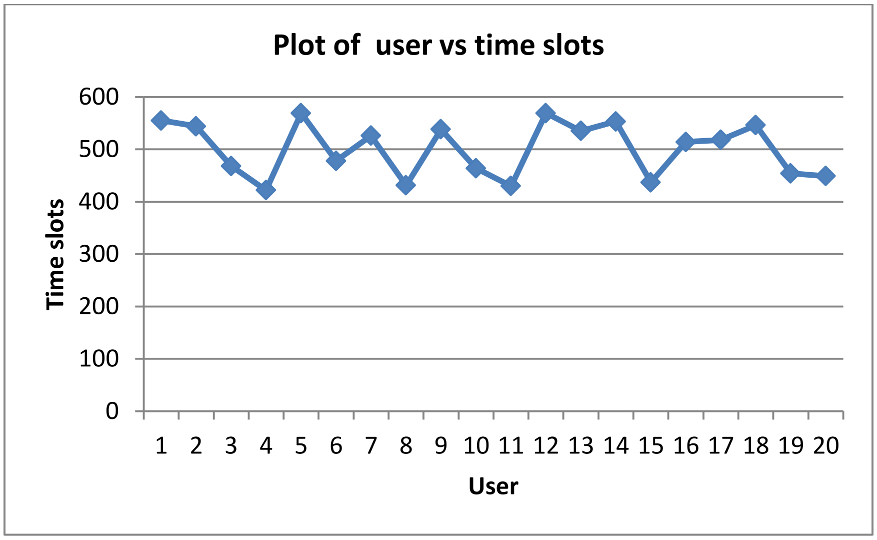


Figure 4.3 Plot for time slots of each user with PF

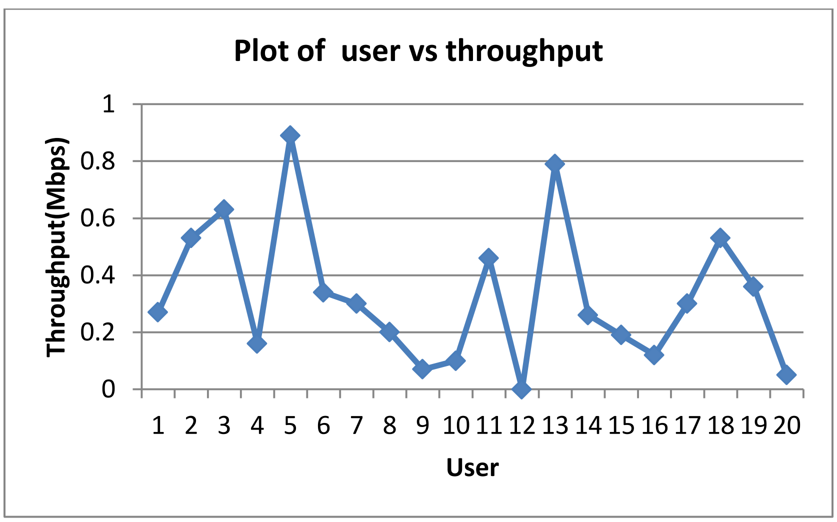


Figure 4.4 Plot for throughput of each user with PF

From the Figure 4.3, we can see that the minimum number of slots that a user has is 422 and the maximum is 569, which is very fair compared to Max C/I. Also, it can be seen that all the users have a fair share of slots but with a drop in total throughput from 13.78 for max C/I to 7.88Mbps.

### 4.1.3 Modified Largest Weighed Delay First Scheme

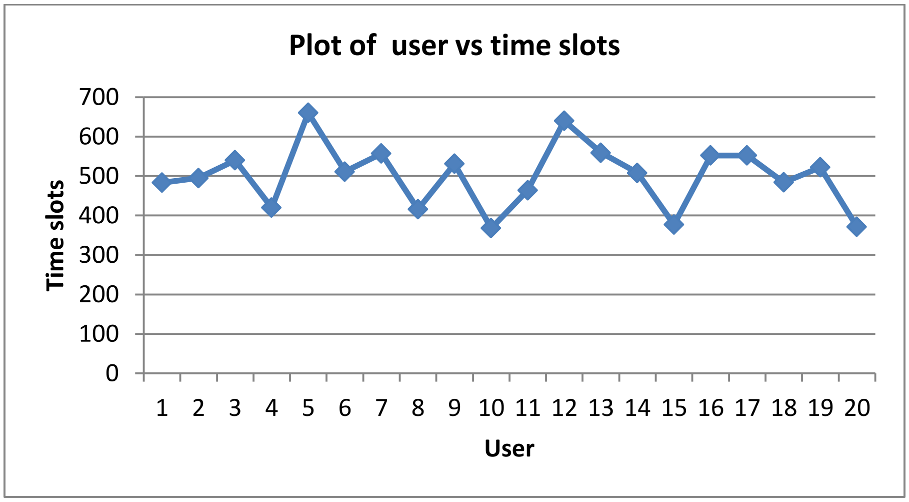


Figure 4.5 Plot for the time slots of each user with MLWDF

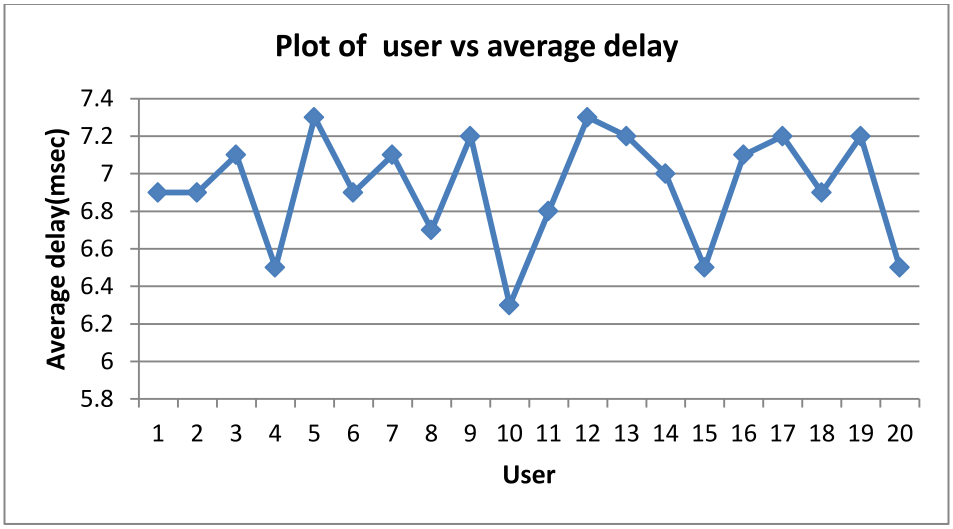


Figure 4.6 Plot for the average delay of each user with MLWDF

From the above figures, we can see that the average delay for each user is around 7ms with the given packet deadline of 10ms. All the users had the same packet deadline. Also, every user got a fair share of the time slots. The total throughput with MLWDF is 7.66Mbps which is slightly less than the PF scheme (7.66 compared to 7.88Mbps).

### 4.1.4 Round Robin Scheme

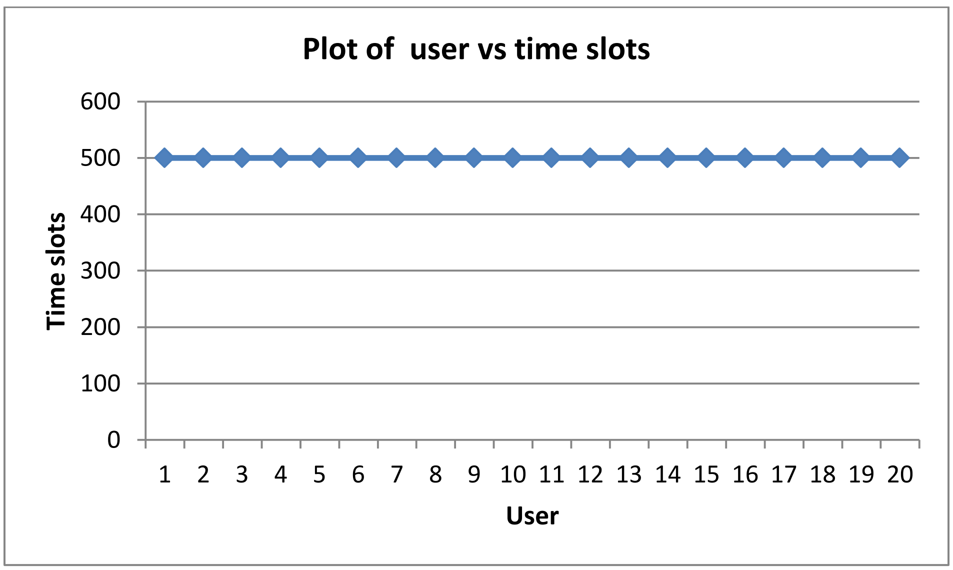


Figure 4.7 Plot for time slots of each user with Round Robin

From the figure above, it can be seen that with Round Robin all the users got equal number of time slots. The total throughput with this scheme is 3.75Mbps which is considerably low. When compared to the PF scheme, fairness is a bit better but the total throughput drops by close to 50% from 7.88 Mbps to 3.75 Mbps, which makes PF a much better choice.

4.2 Comparison of Group Scheduling with Round Robin and PF

The following figures present the results for 2 groups with 10 users each and using the Round Robin scheme and PF between the groups. Users 1 to 10 are in Group1 and users 11 to 20 are in Group2. Once the group has been chosen, all the four scheduling schemes have been implemented inside the group.

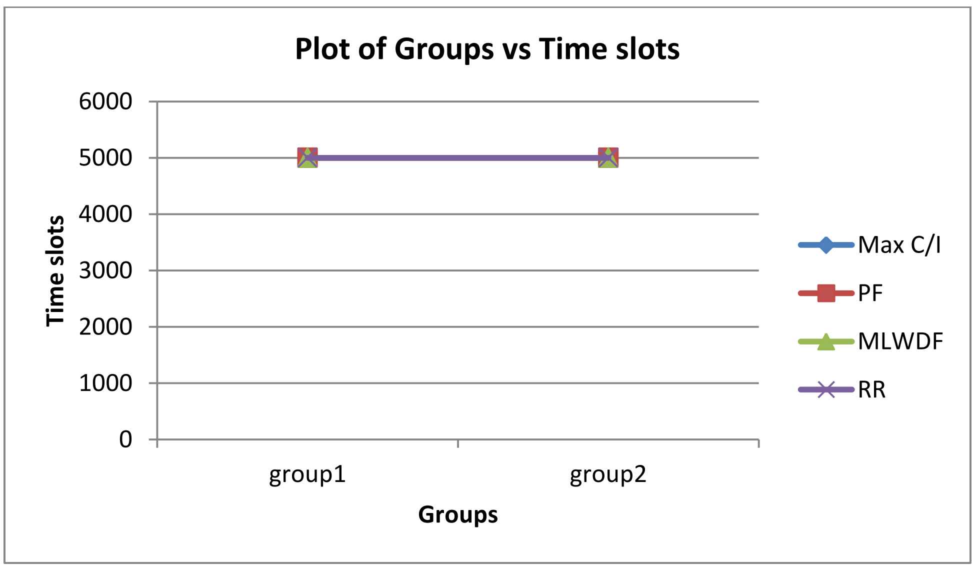


Figure 4.8 Plot for the time slots of each group with Round Robin

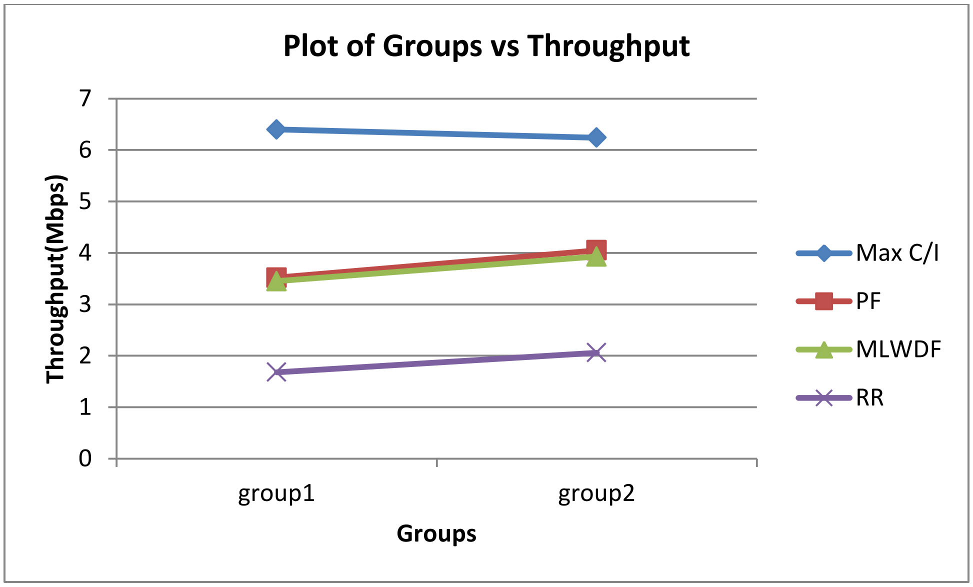

Figure 4.9 Plot for the throughput of each group with round robin

Below is the total throughput of the system with round robin between the groups

- with max C/I inside the group it is 12.64Mbps
- with round robin inside the group it is 3.74 Mbps
- with proportional fair inside the group it is 7.57 Mbps
- with MLWDF inside the group it is 7.37 Mbps

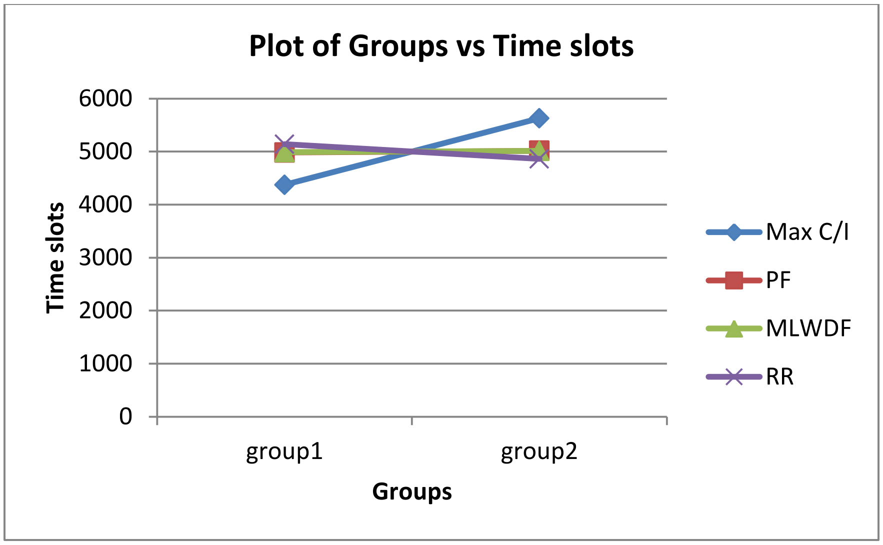


Figure 4.10 Plot for the time slots of each group with PF

Note how the scheduling scheme inside the group affects the choice of groups.

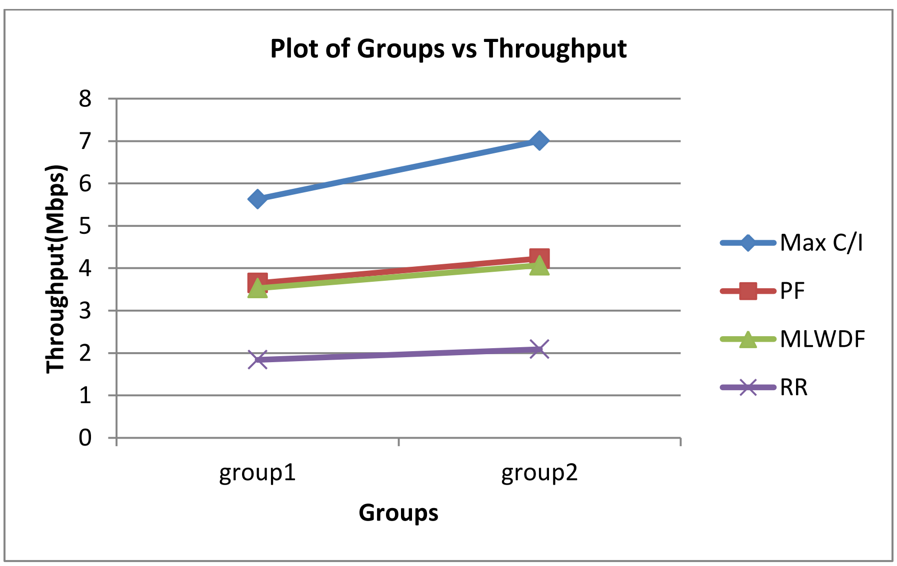


Figure 4.11 Plot for the throughput of each group with PF

Below is the total throughput of the system with PF between the groups

- with max C/I inside the group it is 12.64Mbps

- with round robin inside the group it is 3.93 Mbps
- with proportional fair inside the group it is 7.88 Mbps
- with MLWDF inside the group it is 7.6 Mbps

From the above numbers, it can be seen that there is an increase in throughput in each of the groups and also the total throughput when using Proportional Fairness scheme between the groups as compared to using Round Robin. Also, there is not much difference in the time slots for each of the groups using both the schemes. This implies that both the schemes are being fair to the groups. PF takes the channel conditions and round robin does not. Taking all these things into consideration, we come to a conclusion that using PF yields better results as compared to using round robin between the groups.

To summarize the group scheduling mechanism, proportional fairness will be used in the first stage to decide the group and in the second stage, all the four scheduling schemes discussed in the project are used to choose a particular user inside the group.

## 4.3 Reliability of the Group Scheduling Scheme

To prove the reliability of this group scheduling mechanism with PF between the groups, different conditions have been taken into considerations that include

- increase the number of Users

- have users in one group in better conditions as compared to the other group
- have groups with different sizes
- increase the number of Groups.

### 4.3.1 Increase the Number of Users

For this scenario, the number of users has been increased to 40 and they are split into two groups of 20 Users each. The following figures present the results for this test case.

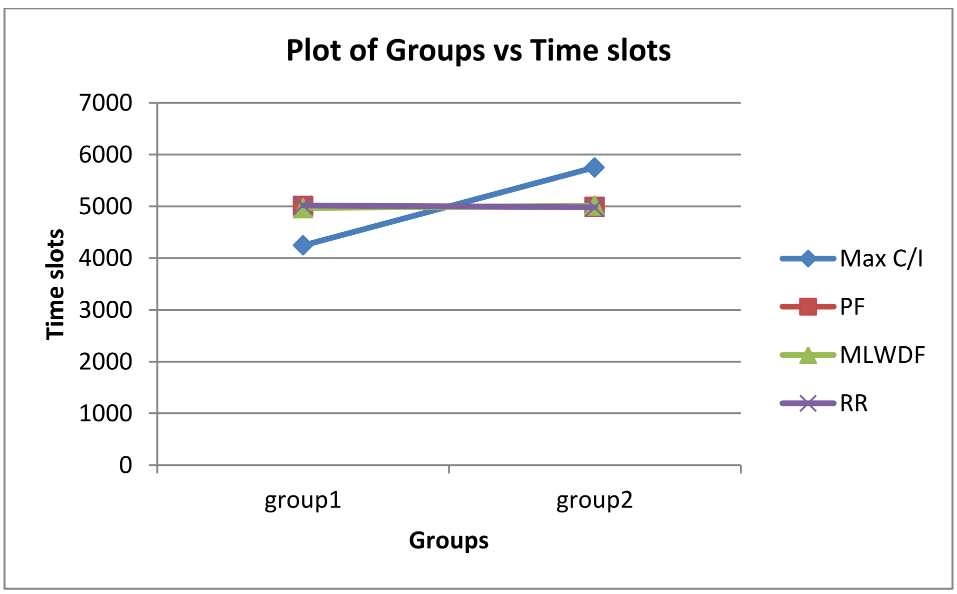


Figure 4.12 Plot for the times slots of each group of 20 users with PF

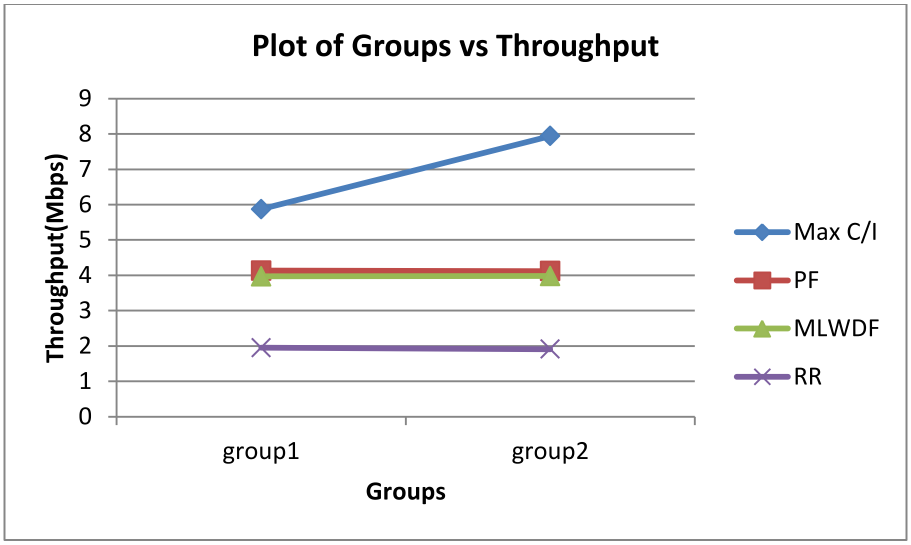


Figure 4.13 Plot for the Group Throughput with PF

Below are the total throughputs for this scenario

- with max C/I inside the group it is 13.81 Mbps
- with round robin inside the group it is 3.86 Mbps
- with proportional fair inside the group it is 8.25 Mbps
- with MLWDF inside the group it is 7.94 Mbps

From the above figures, it can be seen though the number of users has increased to 40, time slots assigned to both the groups has been very consistent. Also, there has been an increase in the total throughput with all the schemes as compared to having 20 users. Note also that Max C/I inside the group still causes unequal allocations.

4.3.2 Users of One Group in Good Channel Conditions Compared to the Other

For this condition, users in group 1 are located close to the base station which results in high location SNR as compared to the users in group 2 located far away which results in very poor location SNR. The following figures present the results on how the PF scheme performs for this particular scenario.

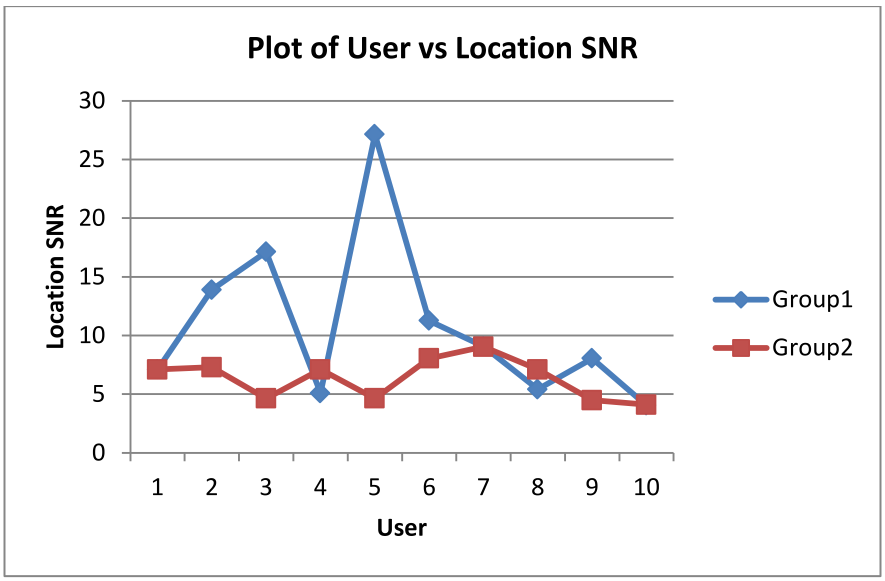


Figure 4.14 Plot for the location SNR of the users in both the groups

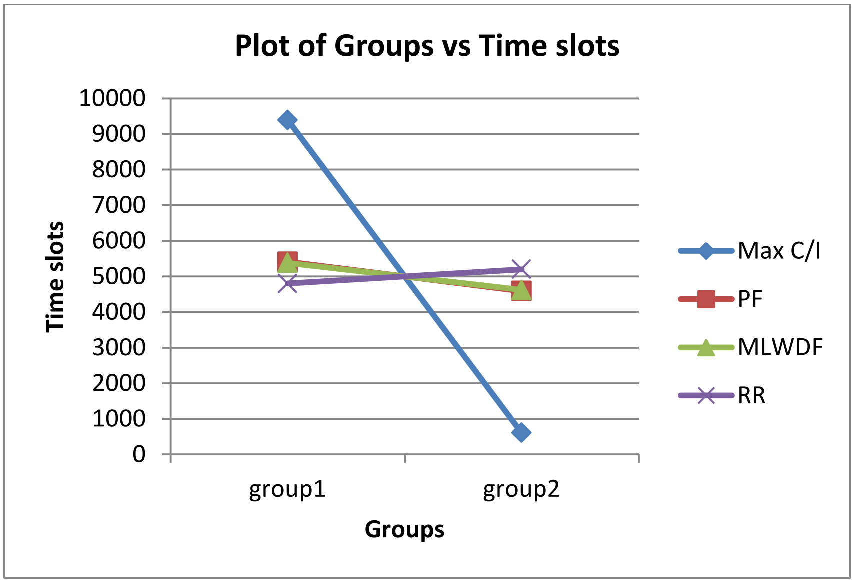


Figure 4.15 Plot for time slots of each group with different channel conditions

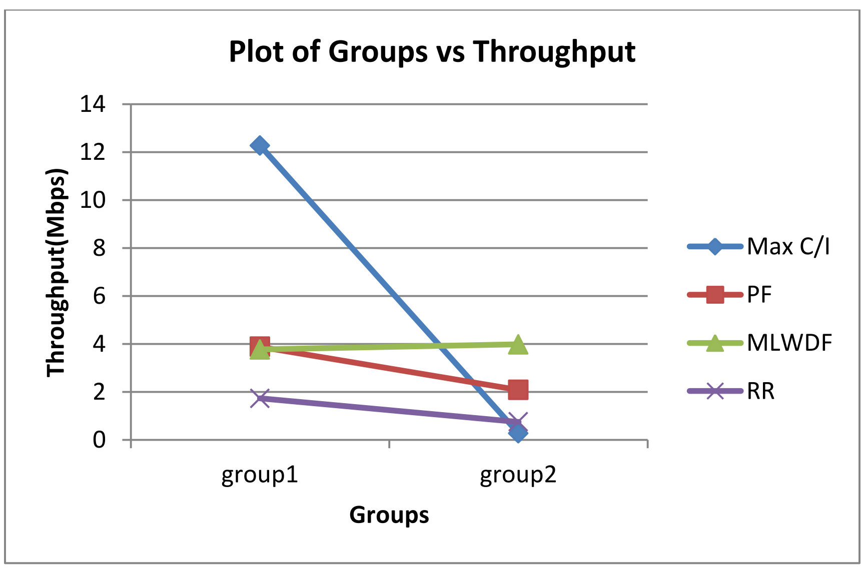


Figure 4.16 Plot for the group throughput with PF under different channel conditions

The main purpose of creating this scenario was to see if the PF scheme maintains the same level of consistency even when the users in one of the groups are all far away from the base station. From the above figures, it can be seen that despite of the users of both groups are in different channel conditions, the PF scheme performs consistently when it comes to sharing the time slots except with Max C/I inside groups. For instance, using PF between the groups and also inside the groups, a fair share of the time slots has been given to all the users. The minimum number of slots given to a user is 386 while the maximum is 658.

### 4.3.3 Groups of Different Size

For this scenario, two groups of different sizes are considered. Group 1 consists of 15 users and the rest 5 users form Group 2.

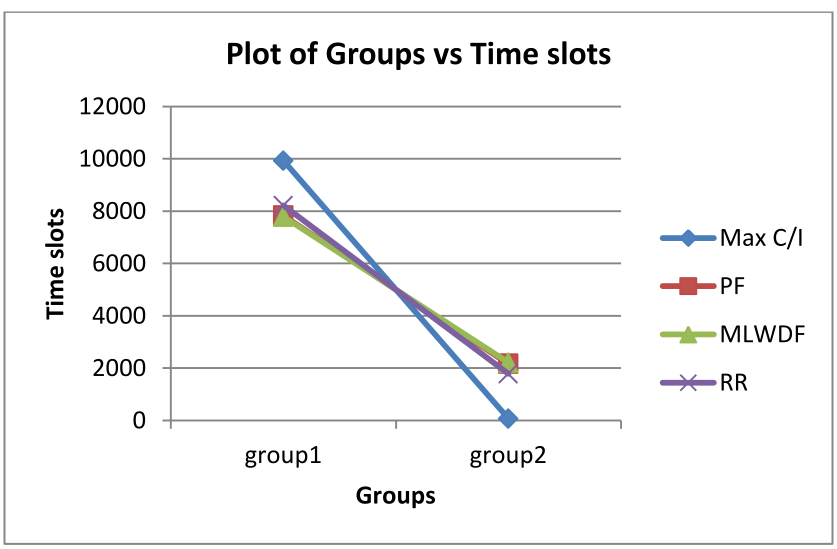


Figure 4.17 Plot for the time slots of each group with different number of users

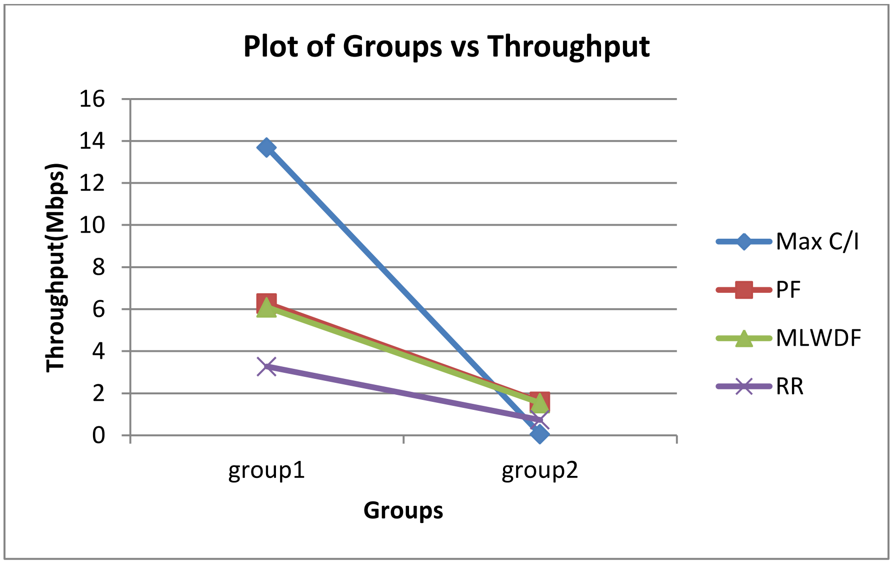


Figure 4.18 Plot for the group throughput with different number of users

This condition is studied to ensure that PF scheme performs consistently even when the group sizes are different. From the results above, it could be seen that the time slots assigned to each of the groups is consistent with the ratio of the number of users inside the groups. For instance, using PF scheme inside the group the number of slots for Group1 is 7831 and for Group2, it is 2169 which is consistent with what one would expect (7500 to 2500). This means that with more users, the proportion of time the top 3 PF metrics per group are proportional to the number of users.

### 4.3.4 Increase the Number of Groups

For this simulation, the number of groups has been increased from 2 to 4. So, each group has a total of 5 users.

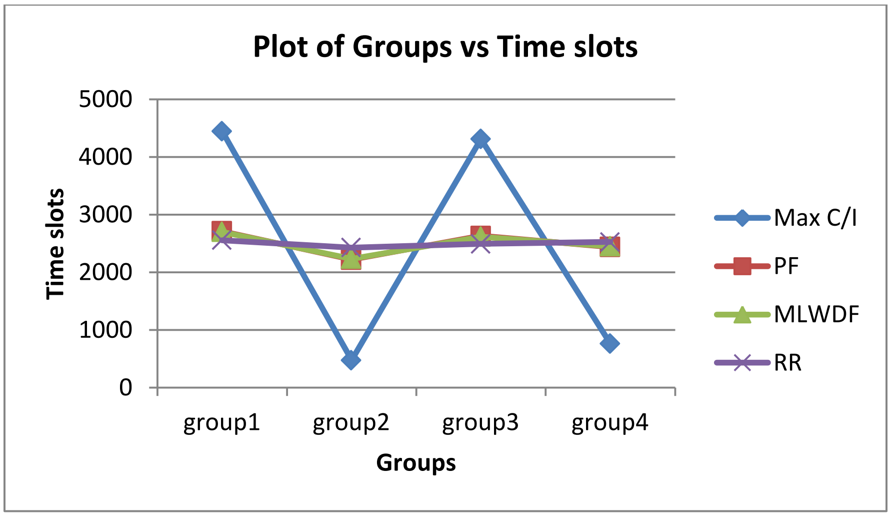


Figure 4.19 Plot for the time slots with increase in the number of groups

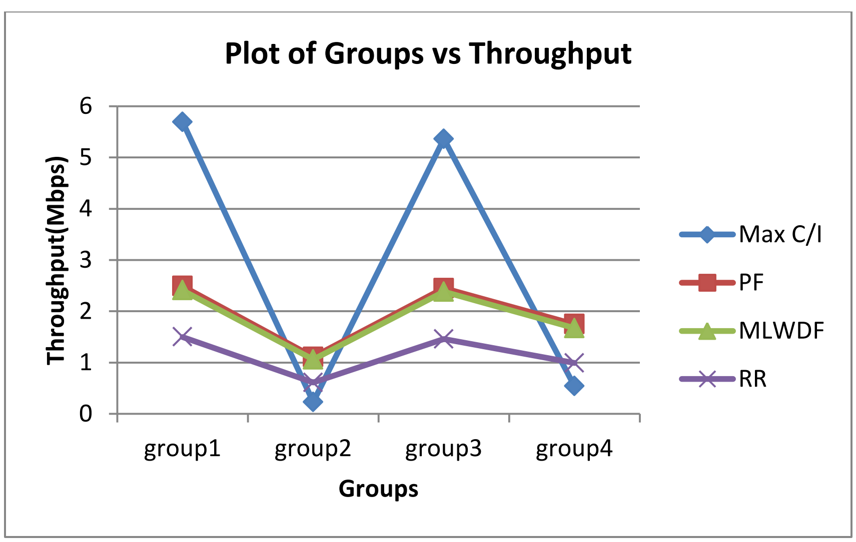


Figure 4.20 Plot for group throughput with increase in the number of groups

The number of time slots that each of the four groups is close to 2500 which is really good, except for Max C/I. These results prove that PF scheme works the same way even though the number of groups has been increased.

All the above scenarios show that group scheduling scheme with proportional fairness between the groups works consistent under different conditions proving the reliability of the scheme.

### 4.4 Tunable PF Metric

Tunable PF metric is a compromise between the Max C/I and the proportional fairness schemes. The metric used to decide the user in Max C/I only takes instantaneous data rate of the user into consideration where as in PF scheme, instantaneous data rate as well as the average throughput of the user are considered. Max C/I gives us the best throughput possible where as PF ensures fairness among the users in terms of resource allocation while taking channel conditions into account.

Metric used for Max C/I = Instantaneous data rate of the user

PF metric = Instantaneous data rate of the user/ Average throughput of the user

If we carefully analyze both the metrics, PF metric is the same as Max C/I divided by the average throughput. Tunable PF metric is a solution to find the right balance between Max C/I and PF such that the fairness among the users is still maintained while increasing the overall throughput of the system.

$$\text{Tunable PF Metric} = \frac{\text{Instantaneous data rate of the user}}{\text{X} + (1-\text{X}) * \text{ Average throughput of the user}}$$

Tunable PF Metric = Instantaneous data rate of the user/ {X + (1-X)* Average throughput of the user}

In the above equation, if X =0 it becomes PF metric and if X=1 makes it the metric for Max C/I. For this project, we have used tunable PF metric both between the groups and also inside the groups. Simulations have been done for different combinations of the tunable PF metric between and inside the group. The table below presents the results

Table 4.1 Simulation results for tunable PF metric

| Combination ID | Tunable PF metric inside the group | Tunable PF metric between the groups | Throughput( Mbps) | Group1 time slots | Worst case user Group1 | Worst case user Group2 |
|---|---|---|---|---|---|---|
| 1 | 1*AT | 1*AT | 7.86 | 4986 | 423 | 420 |
| 2 | 1*AT | 0.9*AT | 7.89 | 4926 | 401 | 406 |
| 3 | 1*AT | 0.8*AT | 7.92 | 4821 | 344 | 420 |
| 4 | 1*AT | 0.7*AT | 8 | 4786 | 322 | 379 |
| 5 | 1*AT | 0.6*AT | 8 | 4705 | 326 | 355 |
| 6 | 1*AT | 0.5*AT | 7.98 | 4580 | 297 | 320 |
| 7 | 0.95*AT | 1*AT | 8.08 | 4998 | 362 | 354 |
| 8 | 0.95*AT | 0.9*AT | 8.15 | 4887 | 351 | 374 |
| 9 | 0.95*AT | 0.8*AT | 8.22 | 4853 | 330 | 357 |
| 10 | 0.95*AT | 0.7*AT | 8.17 | 4750 | 307 | 381 |
| 11 | 0.95*AT | 0.6*AT | 8.18 | 4696 | 299 | 345 |
| 12 | 0.95*AT | 0.5*AT | 8.2 | 4562 | 290 | 343 |
| 13 | 0.9*AT | 1*AT | 8.3 | 5019 | 352 | 310 |
| 14 | 0.9*AT | 0.9*AT | 8.4 | 4893 | 319 | 310 |

| Combination ID | Tunable PF metric inside the group | Tunable PF metric between the groups | Throughput( Mbps) | Group1 time slots | Worst case user Group1 | Worst case user Group2 |
|---|---|---|---|---|---|---|
| 15 | 0.9*AT | 0.8*AT | 8.44 | 4851 | 315 | 310 |
| 16 | 0.9*AT | 0.7*AT | 8.45 | 4727 | 281 | 313 |
| 17 | 0.9*AT | 0.6*AT | 8.45 | 4593 | 266 | 327 |
| 18 | 0.9*AT | 0.5*AT | 8.44 | 4588 | 242 | 318 |
| 19 | 0.85*AT | 1*AT | 8.58 | 4983 | 288 | 235 |
| 20 | 0.85*AT | 0.9*AT | 8.60 | 4945 | 264 | 239 |
| 21 | 0.85*AT | 0.8*AT | 8.68 | 4842 | 260 | 247 |
| 22 | 0.85*AT | 0.7*AT | 8.78 | 4729 | 233 | 235 |
| 23 | 0.85*AT | 0.6*AT | 8.74 | 4659 | 237 | 262 |
| 24 | 0.85*AT | 0.5*AT | 8.78 | 4569 | 195 | 243 |
| 25 | 0.8*AT | 1*AT | 8.74 | 4918 | 211 | 232 |
| 26 | 0.8*AT | 0.9*AT | 8.86 | 4878 | 186 | 221 |
| 27 | 0.8*AT | 0.8*AT | 8.95 | 4815 | 176 | 182 |
| 28 | 0.8*AT | 0.7*AT | 9 | 4757 | 181 | 161 |
| 29 | 0.8*AT | 0.6*AT | 9.06 | 4644 | 175 | 192 |
| 30 | 0.8*AT | 0.5*AT | 9.08 | 4552 | 182 | 199 |
| 31 | 0.75*AT | 1*AT | 8.9 | 4962 | 213 | 226 |
| 32 | 0.75*AT | 0.9*AT | 9.11 | 4876 | 156 | 195 |
| 33 | 0.75*AT | 0.8*AT | 9.14 | 4735 | 149 | 187 |
| 34 | 0.75*AT | 0.7*AT | 9.26 | 4734 | 131 | 143 |
| 35 | 0.75*AT | 0.6*AT | 9.34 | 4604 | 98 | 143 |
| 36 | 0.75*AT | 0.5*AT | 9.33 | 4556 | 144 | 104 |
| 37 | 0.7*AT | 1*AT | 9.16 | 4949 | 189 | 154 |
| 38 | 0.7*AT | 0.9*AT | 9.25 | 4911 | 178 | 175 |
| 39 | 0.7*AT | 0.8*AT | 9.43 | 4727 | 102 | 174 |
| 40 | 0.7*AT | 0.7*AT | 9.5 | 4656 | 129 | 157 |
| 41 | 0.7*AT | 0.6*AT | 9.51 | 4604 | 111 | 149 |
| 42 | 0.7*AT | 0.5*AT | 9.58 | 4459 | 86 | 116 |

In the above table, AT stands for actual throughput and the tunable PF metric only shows the denominator portion of the actual metric.

1*AT is the same as the original PF metric and 0.95*AT is the same as 0.05 + 0.95*AT

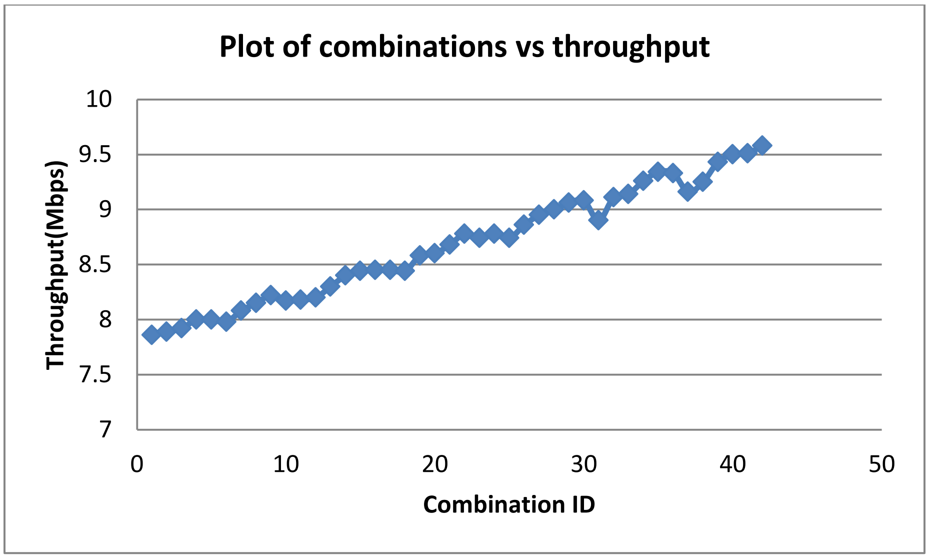


Figure 4.21 Plot for throughput for different combinations of the tunable PF metric

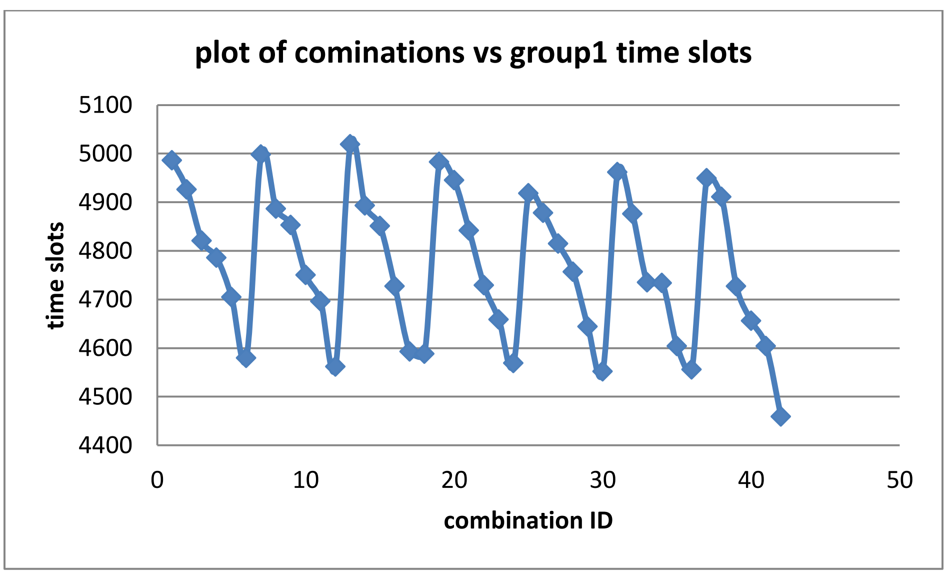


Figure 4.22 Plot for combination ID and group1 time slots

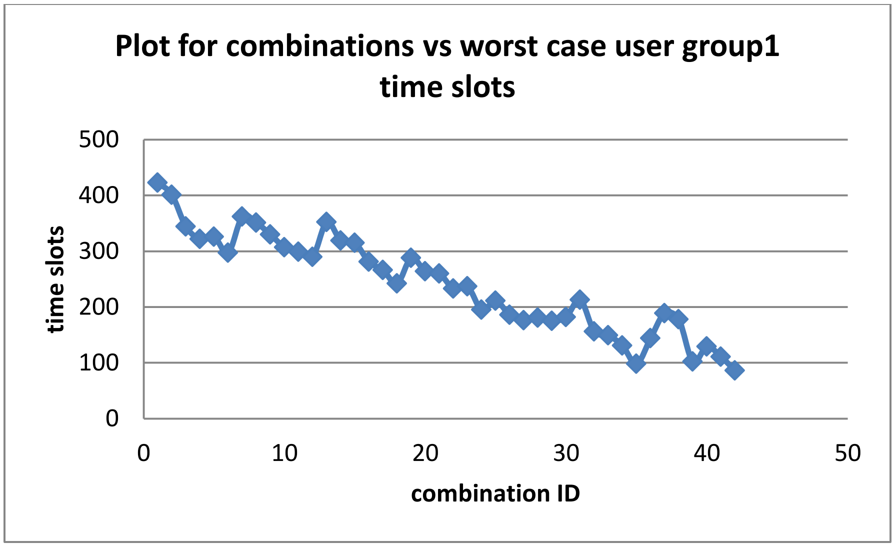


Figure 4.23 Plot for combination ID and the time slots for the worst case user in group1

For the above simulations, 2 groups with 10 users each have been used. From the above table and the figures, it could be seen that as we move from PF to Max C/I there is an increase in throughput. There is a 22% increase in throughput when using original PF metric both inside and between the groups (Throughput = 7.86) compared to when using 0.3+0.7*AT inside the group and 0.5+0.5*AT between the groups (Throughput = 9.58) which is a considerable increase. However the worst case in second case gets only 86 time slots.

The number of slots assigned to group1 goes down as we move from proportional fairness to Max C/I. Careful observation of the results show that as we move from PF scheme to Max C/I, the slots are taken from the users in poor channel conditions, who are far away from the Base station and given to the users who are in good conditions.

The best condition for the above results seems to be to use 0.15 + 0.85*AT inside the group and use 0.3 + 0.7*AT between the groups. This condition yields close to 12% increase in the total throughput, the slots assigned to Group1 is 4729 which is about only a 2.5% drop from ideal condition. Also, the slots assigned to the Worst case User is 233 in group1 and 235 in group2 which is still a fair amount of slots as compared to having nothing in case of Max C/I. Worst case user for these simulations means the user who has the least amount of time slots in a particular group.

# CHAPTER 5

# CONCLUSION AND FUTURE SCOPE

## 5.1 Conclusion

Meeting the demands of the users such as high data rates, fairness and low latency is important and extremely difficult to achieve. There are a lot of technologies such as MIMO, adaptive modulation and coding that can be used to meet this requirements and scheduling is one among them. To have a scheduling scheme that can make the best use of the available resources is vitally important for a cellular network.

Group scheduling adds a new dimension to the traditional scheduler by dividing the users into groups and meeting the QoS requirements such as throughput and fairness at the group level and also at the user level. Proportional fair has been chosen to decide between the groups and we have seen that it performs better than the round robin scheme. At the user level, different scheduling schemes have been used which meet different objectives. Max C/I achieves the maximum overall throughput while round robin is perfectly fair. The Proportional fair scheme finds a balance between throughput and fairness by taking into account user's past average throughput. Modified largest weighed delay first scheme accomplishes the user latency requirement. Results have been simulated to show the reliability of the group scheduling under different conditions. The Tunable PF metric has also been proposed in this project and results show that it could be used to increase the overall throughput of the system by maintaining the aspect of fairness.

To conclude, the proposed group scheduling scheme meets the requirements of the public safety groups by dividing the resources fairly and effectively between the groups and also inside the group at the user level.

## 5.2 Future Scope

Future work that can be done based on this project includes

- finding the optimal solution for the tunable PF metric
- adding the aspect of Multi user MIMO and beamforming
- design a group scheduling scheme that can guarantee a certain throughput across all the groups while maintaining fairness
- group scheduling in the uplink
- scheduling subcarriers for OFDMA in LTE.

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# VITA

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Upon the completion of the degree, he plans to work as a Network Engineer in the future.