ACHIEVING QUALITY OF SERVICE IN GROUP SCHEDULING IN CELLULAR NETWORKS

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BY

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ABSTRACT

Cellular 3G/4G networks provide a wonderfully rich set of applications and social networking capabilities. From a QoS perspective, the traffic is basically divided into Real time and Non real time traffic which helps in scheduling priorities to the packets. With increase in need for QoS in the commercial networks, scheduling schemes such as MLWDF (Modified Largest Weighted Delay First) are playing a prominent role in deciding factors of packet selection. But most of these features are not available to public safety and emergency organizations where these organizations must use dedicated systems to obtain the reliability and protected performance that is needed.

This research work provides a brief survey of the regulatory and commercial issues involved. The research work then provides solutions to give real-time and non-real-time traffic scheduling priorities to balance different requirements. We introduce the concept of a queue indicator that uses queue awareness to decide which traffic type to transmit. Then we introduce the concept

of group scheduling that adds together scheduling metrics of different users within groups to decide which groups should transmit. These metrics are both opportunistic to take advantage of changing channel conditions and they are queue aware to adapt to traffic conditions. But the metrics are very simple so that scheduling mechanisms are practical and scalable for implementations. These are all evaluated through a detailed simulator (MATLAB-Simulator) that models long-term and short-term fading impacts. We find the best queue indicator values and then assess different cases where groups have various delay requirements.

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.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the School of Computing and Engineering have examined a thesis titled "Achieving Quality of Service in Group Scheduling in Cellular Networks", presented by Kula deep Bezawada Changalraya Naidu, candidate for the master of Electrical Engineering degree, and certify that in their opinion it is worthy of acceptance.

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CHAPTER 1

INTRODUCTION

There has been a growing interest in providing solutions to public safety and emergency groups utilizing commercially deployed structures in recent years. Currently, the majority of such bodies employ their own dedicated systems and spectrum. There are countless reasons why these groups should be using commercially available systems. Several of them would be greater bandwidth availability, access to latest smartphone hardware and capabilities, lower equipment, maintenance, operating cost and wider coverage. In particular, interoperability between different agencies is a very significant problem in today's public safety and emergency groups and the issues regarding this problem are faced quite often.

The multimedia capable devices for such groups will definitely enrich the communication compared to the ones capable of only voice. In addition, various types of technological deployments and further evolution of such technologies will provide an everlasting advantage to the public safety and emergency groups.

As mentioned above there are numerous advantages and features that commercial services would provide at the same there are reasonable concerns that are questionable. In general the public safety departments have rigid demands when compared to these commercial networks. Some common demands that these public safety departments raise are interoperability and security. Supporting these type of demands along with the current 3G/4G architecture is not an easy task.

Packet scheduling has been a very hot topic in wireless communication since the migration towards the packet-based networks. The uncertainty factor of the wireless channel brings another dimension and opportunity to the scheduling problem. There are many papers written on this topic utilizing unique approaches to meet QoS for users/packets such as throughput, delay and packet loss.

In this project, packets are defined with deadline values depending on the type of the traffic they belong to. This value essentially describes the time the packet can wait in the queue before it is no longer useful, in which case it simply should be dropped. The second possibility of dropping a packet arises from the fact that each item of user equipment (UE) has a finite-sized queue and packets are constantly arriving to be sent. The incoming number of packets per time slot depends on traffic load. If traffic load is on average higher than the rate at which packets are scheduled, the queues gradually fill until they are full.

In the context of public safety and emergency traffic, we define traffic based on groups (fire, police, EMS, etc.) and provide services based on sharing, fairness, and priorities between groups. The scheduler first chooses the group to which the current timeslot will be allocated. Then the group chooses which mobile gets service.

1.1 Objective of the Project

The objective of the thesis is to provide a structure and some preliminary solutions to the problem of Quality of Service at the packet level and accordingly managing the resources for public safety groups.

The work that has been done focuses on efficiency and operability. As mentioned before, current public safety and emergency agencies have their own dedicated resources, therefore they all enjoy pre-determined/pre-negotiated (nearly constant) QoS such as throughput, packet delay and packet drops. The bandwidth, however, is low. Our scheduling scheme defines groups (police, fire depts.) with heterogeneous traffic, namely, real time packets/traffic and non-real time packets/traffic. The work focuses on controlling packet dropping.

The goal of the thesis is to show that QoS can be implemented along with group scheduling at a whole group level as well as at user equipment level. The scheduling policy that is framed in this project, which will be explained in greater detail in the upcoming sections, is to minimize the total number of dropped packets over a certain time window. This can be thought of as a composite objective function with two different components, to minimize dropped packets due to expired deadlines and another to minimize drops due to full queues. The interaction of these two components is thoroughly studied. Utilizing a scheduling policy where one component is minimized comes with an expense of an increase in the other. The impact of the traffic load parameter on the total number of dropped packets is examined as well. We have produced group scheduling simulation results for various sets of requirements and show the impact that these requirements have on delay and packet loss.

CHAPTER 2

BACKGROUND

2.1 Cellular Networks

The first generation of wireless telephone technology, commonly abbreviated 1G, was introduced in the 1980's. These were analog telecommunication standards with data speeds in the range of 2.9Kbps to 5.6Kbps uplink. The efficiency of 1G technology was very low. Hence in order to increase the capacity and therefore the efficiency, new technologies were developed like GSM, TDMA and CDMA. These developments lead to 2G.

2G cellular telecommunications networks launched on the GSM standard in 1991. Here more calls were transmitted in the same amount of radio bandwidth. Data services were included in this technology. The speed was also increased up to 30Kbps to 40Kbps.

Further, 2.5G (GPRS) increased speeds up to 115Kbps. This is implemented on a packet switched domain. Next, the 2.75G (EDGE) was deployed in the beginning of 2003 with improved data transmission rates. More increase in the transmission rates lead to 3G. The first commercial 3G network was deployed in 2001 with transmission rates of at least 200Kbps. Many advanced features like video streaming, video conferencing and high speed packet data up to 1.5Mbps are provided by this technology.

Next is 4G. Mobile WiMAX and LTE are the two 4G systems that are deployed. WiMAX was deployed in 2008 and around since 2010 4G LTE has been deployed with up to 100 Mbps data transfer. Through the cellular network evolution, it is observed that data rate and data related services are given more importance.

2.2 Fading

Fading is considered as one of the most important signal factors affecting wireless networks. This is caused over a propagation media due to attenuation affecting the signal. The signal transmitted from the base station to a mobile user chooses different paths to travel that are caused due to diffraction, reflection and scattering. These signal components, called multi path components (MPC) travel in different directions, with different lengths and phases. Multi Path components are altered due the interference caused by the movement of mobile users. All MPC's are summed up at mobile user which can either lead to a raise or fall of the signal strength causing the fading effect.

Fading is categorized into two types.

1. Small Scale Fading
2. Large Scale Fading

In small scale fading, signal attenuation is considered over small distances. In this project, Rayleigh fading is used to model small scale fading. This is best suited to sub-urban and urban areas, because of no dominant line of sight propagation between base station and mobile user. The radio signal is reflected and scattered in many ways before it reaches the mobile user due to the presence of many objects in the environment.

In large scale fading, signal attenuation is considered over large distances. In this project, the Okamura-Hata model is used to determine large scale fading. This is used in rural areas i.e., small and medium sized cities. This model suits both point-to-point and broadcast transmissions. The coverage frequency ranges from 150MHz to 1.5GHz. This can predict the total path loss of a cellular communication.

The formula used to calculate the path loss using Okamura-Hata model is:

$$L_p = 69.55+26.16*\log(F_c)-13.82*\log(H_b)-a(H_m)+(44.96.55*\log(H_b))*\log(d) \quad (1)$$

Where

$$a = (1.1*\log(F_c)-0.7)*H_m-1.56*\log(F_c)-0.8 \quad (2)$$

L_p is the Path loss in dB

F_c is the frequency in MHz

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

H_m 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)

2.3 Scheduling or Packet Mobilization

Scheduling policy chooses the packets which are to be sent to users that are at various locations with changing instantaneous channel conditions during a timeslot. The general objectives of any scheduling policy would be the optimal usage of available resources, QoS guarantee, maximizing goodput and minimizing power consumption while ensuring feasible algorithm complexity and system scalability. An effective policy also considers location, mobility, fading and fairness concerns. In this project we mainly focused on QoS and optimized serving of packets depending upon the type of traffic.

Scheduling schemes are classified into two types.

1. Channel aware: They take channel conditions into consideration.

   Eg: MLWDF, Proportional Fairness

2. Channel unaware: They do not take channel conditions into consideration.

   Eg: Round Robin

In this thesis we mainly worked on channel aware schemes with constraints like QoS and delay requirements, and as a part of this we chose and modified MLWDF as our scheduling scheme. This scheduling scheme is explained and implemented in the later sections.

2.4 Public Safety Communications

Wireless communication systems have been built with standards for high reliability so that they will continue to operate in stressed conditions because lives are commonly at stake. Hence public safety communications came to exist. The Public Safety communication system is a wireless communications network used by emergency service organizations like police, fire, medical services etc. to prevent or respond to emergency situations.

Today, there are 45,000 licensed land mobile radio (LMR) systems and around 50,000 independent public safety organizations in the United States operating wireless communication systems [1][2]. The spectrum allocation for public safety applications has always been an important topic since the beginning of wireless communication. Federal legislation in 1912, 1927, and 1934 established rules across the United States by which local, county, state and regional public safety organizations built, maintained and updated their individual communications systems [3]. For many decades the exclusive service on such networks was voice. 34 MHz of spectrum was allocated to public safety purposes when the 700 MHz television channels were decommissioned. While everyone agreed that this was much needed, the FCC allocated 10 MHz of this spectrum to what was called the "D Block". In this block, the FCC considered the use of public-private or public-commercial partnerships for the use of the spectrum instead of just allocating the spectrum directly to individual public safety agencies, which was done with the other 24 MHz [4-11]. The reader can refer to [12] for the technological evolution of public safety and emergency systems.

In spite of numerous appealing features commercialized systems would provide as mentioned above, there are evident concerns. Public safety and emergency communication systems have more stringent demands than regular communication systems. These mission-critical networks are defined to possess elements/requirements such as interoperability, resiliency, security, efficiency, interdependence, operability, and reliability. Supporting such a system with all of these properties with the current 3G/4G networks is certainly is not an easy task. Any type of a failure or congestion in the network may lead to inoperability of the emergency communication system and lives can be at stake. There must be well-defined structures implemented on top of the regular systems in order to prevent such disasters.

Several requirements have been defined for public safety communications by the Public Safety and Homeland Security Bureau of the FCC, such as Operability, Interoperability, Reliability, Resiliency, Redundancy, Scalability, Security, Efficiency and Interdependence. This thesis addresses the issues of Operability and Efficiency. Public safety groups are self-governed. Once they are allocated resources they can distribute them according to their own operating procedures for command, control, resource efficiency, etc. Since the beginning of wireless communication, the allocation of spectrum for public safety applications has been of primary importance. With the arrival of data services, a wide spectrum of new capabilities is available to public safety groups. Most public safety communications have been confined to dedicated systems and spectrums. They also need coverage in hard-to-reach areas which could be important to emergency response, where a commercial system might not reach. Several technologies like EVDO, HSPA and LTE can be used in public safety communications. “In an envisioned future, public safety communications use the same technologies as the consumer market, allowing cost reductions and improved data service capabilities”[4].

There are several difficulties in today’s public safety and emergency groups like lack of interoperability between different agencies, small markets, expensive devices, etc. This project emphasizes more on the aspect of lack of interoperability. “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”[5]. The group scheduling scheme developed here deals with the problem of resource management without degrading the performance level using commercial systems. And also ensures that this is reliable under different conditions.

CHAPTER 3

SCHEDULER DESIGN AND RELATED WORK

3.1 Group Scheduling

In this project, a mechanism called Group Scheduling is implemented. Group Scheduling is channel aware downlink packet scheduling which maximizes the channel capacity and where the available spectrum is used efficiently between public safety groups. These groups include police, fire, and health services which are associated to public safety. Group scheduling policy in this project has low complexity making it suitable for implementation in practical systems. This is robust to emergency situations that commonly reduce system capacity and increase traffic demand. Thus assures performance to public safety groups while not sacrificing spectrum efficiency. Hence tradeoffs and utility function based optimizations are implemented. Such optimizations are the group requirements like throughput, number of timeslots etc.

The uncertainty factor of the wireless channel brings another dimension to the scheduling problem to opportunistically take advantage of channel fluctuations. There are an array of papers written on this topic utilizing unique approaches for users/packets to meet QoS requirements such as throughput, delay and packet loss.

Scheduling decisions are made between the groups to use the available timeslot. Group scheduling proposes two levels of decisions.

1. Decision to choose a group to use the timeslot
2. Decision to choose a node inside the group to use this timeslot.

Different metrics are employed in the Group Scheduling mechanism to perform the group decisions. The Modified-Largest Weighted Deadline First (MLWDF) scheduling scheme is being used to select between groups. To select a node inside the group, metrics we call the RT Metric and NRT Metric are used.

We designed a metric which is similar to Modified-Largest Weighted Deadline First (MLWDF) scheduling scheme where it chooses a node with the best metric. Here is how the metric works: QoS uses head of the line waiting time in the following scheduling metric for each user.

$$\frac{r_i}{\overline{r_i}} \times \frac{W_i}{D_i} \text{--- (1)}$$

Here r_i is the instantaneous channel rate for mobile i, $\overline{r_i}$ is the average rate mobile i has been achieving, W_i is the waiting time the packet has been in the queue and D_i is the deadline value (max time the packet can wait in a queue).

This concludes that MLWDF considers throughput, fairness and QoS as well. Hence MLWDF is implemented between the groups and also choosing a mobile inside a group to make sure all the groups have nearly equal chance to meet their QoS requirements and individual mobiles as well. Two different metrics named RT metric and NRT metric have been used to choose a user inside the group to use the timeslot.

3.2 Packet Scheduling

Packets are defined with deadline values depending on the type of the traffic they belong to. This value essentially describes the time the packet can wait in the queue before it is no longer useful, in which case it simply should be dropped. The second possibility of dropping a packet arises from the fact that each item of user equipment (UE) has a finite-sized queue and packets are constantly arriving to be sent. The incoming number of packets per time slot depends on traffic load. If traffic load is on average higher than the rate at which packets are scheduled, the queues gradually fill until they are full. New packets will have no available queue and will be dropped.

The goal of the scheduling policy, which will be explained in greater detail in the upcoming sections, is to minimize the total number of dropped packets over a certain time window. This can be thought of as a composite objective function with two different components, to minimize dropped packets due to expired deadlines and another to minimize drops due to full queues. The interaction of these two components is thoroughly studied. Utilizing a scheduling policy where one component is minimized comes with an expense of an increase in the other. The impact of the traffic load parameter on the total number of dropped packets is examined as well.

In the context of public safety and emergency traffic, we define traffic based on groups (fire, police, EMS, etc.) and provide services based on sharing, fairness, and priorities between groups. The scheduler first chooses the group to which the current timeslot will be allocated. Then the group chooses which mobile gets service. To date to the best of our knowledge, no work had been done to provide what we call this group scheduling service to groups of UEs.

The remainder of the work first discusses the scheduling approach. Then we investigate how to find the best balance of real-time and non-real-time traffic scheduling. After that we produce group scheduling simulation results for various sets of requirements and show the impact that these requirements have on delay and packet loss.

3.2.1 Scheduler Design

There have been numerous methods proposed describing scheduling schemes since the evolution of packet-based networks including well known fair queuing [21], virtual clock [22], self-clocked fair [23], earliest due date [24]. Packet scheduling has been a very hot topic in wireless communication since the migration towards the packet-based networks. The uncertainty factor of the wireless channel brings another dimension and opportunity to the scheduling problem. There are many papers written on this topic utilizing unique approaches to meet QoS for users/packets such as throughput, delay and packet loss.

The paper [21] reviews the well-known schemes such as Round Robin (RR), Maximum Carrier/Interference (Max C/I), Proportional Fair (PF), and Modified – Largest Weighted Deadline First (M-LWDF). There are also papers where the scheduling problem is formulated as an optimization problem associating a utility function for each user [25-32].

Packets are defined with deadline values depending on the type of the traffic they belong to. This value essentially describes the time the packet can wait in the queue before it is no longer useful, in which case simply should be dropped. The second possibility of dropping a packet arises from the fact that each item of user equipment (UE) has a finite-sized queue and packets are constantly arriving to be sent. The incoming number of packets per time slot depends on traffic load.

If traffic load is on average higher than the rate at which packets are scheduled, the queues gradually fill until they are full. The goal of the scheduling policy, which will be explained in greater detail in the upcoming sections, is to minimize the total number of dropped packets over a certain time window. This can be thought of as a composite objective function with two different components, to minimize dropped packets due to expired deadlines and another to minimize drops due to full queues. The interaction of these two components is thoroughly studied. Utilizing a scheduling policy where one component is minimized comes with an expense of an increase in the other. The impact of the traffic load parameter on the total number of dropped packets is examined as well.

In the context of public safety and emergency traffic, we define traffic based on groups (fire, police, EMS, etc.) and provide services based on sharing, fairness, and priorities between groups. The scheduler first chooses the group to which the current timeslot will be allocated. Then the group chooses which mobile gets service. To date to the best of our knowledge, no work had been done to provide what we call this *group scheduling* service to groups of UEs.

We have used a fully functional MATLAB simulator built in our laboratory for the simulations. It models large-scale and small-scale propagation characteristics that can potentially change every time slot, depending on the Doppler spreading. It implements the Okumura-Hata model, Rayleigh fading, and Stokes spectrum for Doppler spread (assumed 100 Hz).

In the simulator we have considered 24 mobiles and we have classified them as real-time (RT) and non-real-time (NRT) mobiles within the total 24 mobiles. We framed all the even numbered mobiles (ie., 2,4,6,8,….24) as RT traffic carrying mobiles and odd numbered mobiles (i.e., 1,3,5,7,…23) as NRT traffic carrying mobiles. We have divided them into four groups, that is each group has 6 mobiles, three RT and three NRT. In order to choose between RT and NRT traffic classes we created what we call a queue indicator that we now describe.

In our simulator design we considered that RT traffic has an upper hand (i.e., priority) over NRT traffic when it comes to choosing between them. In general cellular communication scenarios, RT traffic packets have less tolerance towards delay requirements when compared to NRT packets. We designed the scheduler in such a way that at each scheduled time slot, the scheduler makes sure that it checks the traffic class priority and queue indicator of each UE.

The scheduler first chooses RT or NRT traffic to transmit. Of course the lower priority is given to NRT traffic. Then within that same type of traffic it transmits the highest priority or most urgent packet. If there is no RT traffic with maximum delay tolerance available then by default the scheduler selects NRT traffic. Also while serving NRT traffic if there would arise a situation where there are no packets in any of the NRT queues then the scheduler shouldn't waste the time slot sending nothing. So for that reason the scheduler picks the best mobile from the RT queues instead of sending nothing.

In detail this is how the simulator works; we have set the queue size for each mobile to 10 packets, that is a mobile can have up to 10 packets in its queue.

When using the group scheduling concept, the scheduler must first choose the best group to get a chance to send. We discuss that process a little later. Then after the scheduler has chosen a best group among four groups, now inside the group it has to choose the best traffic class according to what has already been discussed.

When choosing between UEs of the same group to send packets, we have separate metrics for each traffic type. We have considered two traffic types for the simulation,

- Real Time traffic
- Non-Real Time traffic

The metrics for the above traffic types are explained in the following sections.

3.2.2 RT Traffic Metric

QoS or RT traffic uses head of the line waiting time in the following scheduling metric for each user.

$$\frac{r_i}{\overline{r_i}} \times \frac{W_i}{D_i} \text{ -- (2)}$$

Here r_i is the instantaneous channel rate for mobile i, $\overline{r_i}$ is the average rate mobile i has been achieving, W_i is the waiting time the packet has been in the queue and D_i is the deadline value (max time the packet can wait in a queue). The left side of this metric is the traditional Proportional Fair metric. The right side increases in value as waiting time W_i increases.

3.2.3 NRT Traffic Metric

For NRT traffic or BE (Best Effort) traffic types, there is no sense of meeting QoS delay requirements and therefore no need of monitoring delay requirements. NRT traffic is queue aware and uses current queue fill multiplied by channel conditions as a scheduling metric for each user.

$$\frac{r_i}{\bar{r}_i} \times \frac{Q_i}{Q_z} \text{ --- } (3)$$

Q_i is the current queue fill of the chosen mobile and Q_z is the standard queue size. This gives UEs with more packets in their queues a relatively stronger chance to transmit an NRT packet.

3.3 QoS and Delay Requirements Based on Queue Priorities

As mentioned above, we have created a queue indicator in order to choose the traffic type. Firstly the scheduler goes through all of the RT mobile queues and depending upon the queue indicator it decides whether to serve RT or NRT traffic. For instance if the queue indicator is set to 2, RT mobiles will be served if there is at least one RT mobile that has more than 2 packets sitting in the queue. Otherwise serve the NRT traffic. In this way we give more priority to the Real time traffic which is indeed necessary in the case there is also non-real time traffic.

We varied the queue indicator from 1 to 9 for a queue size of 10 packets and conducted several simulations. The best queue indicator is considered from the conducted simulations. For the results we have considered average delay, packet drops, user outage ratio and throughput as metrics to be investigated. We found 7 as the best queue indicator from the given parameters and simulations conducted. The results and the graphs are plotted in the results section.

Throughput, fairness and QOS requirements are the three major parameters every group requires, regardless of their channel conditions and demands from other groups. Here the groups will be provided throughput and QoS guarantees and so will be protected from the demands from other groups.

3.4 QoS and Delay Requirements Based on Packet Deadline

Now we consider group scheduling. We take the concepts just presented and then use them to first choose the best group in each timeslot to receive service. We use the metrics in (2) and (3) and find the sum of those metrics for each group. Then the group is chosen with the best sum-of-metrics. We again use the queue indicator concept to choose whether RT or NRT traffic is chosen. We found the best queue indicator in the above section as 7, so we use that queue indicator for further simulations. Here is the procedure.

1. Go through each group and sum the metrics using (2). Choose the group with the highest sum.

2. See if any mobile in the group has an RT queue that has more packets than the queue indicator. If so, choose to send RT packets.

3. The group then chooses the mobile in its group with the highest metric, either using (2) or (3) depending on the type of traffic to send.

To then compare simulation results to see the performance of each group, we vary the RT packet deadline values for each group. Those with tighter deadlines would of course be given relatively stronger priority because D_i is smaller and is in the denominator of (2).

We have considered the cases listed in the Results chapter in Table 1 by varying packet deadline value for RT traffic by groups with different cases.

CHAPTER 4

MATLAB CODE IMPLEMENTATION

4.1 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.

4.2 Assumptions

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

- users have traffic inflow at all times (greedy sources)
- scheduling is only limited to downlink
- this simulation model does not include the effect of shadowing
- the fading model used in this thesis 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.
- At the beginning of the simulation, one packet is placed in each queue.

4.3 Code Description

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

A total number of 24 users are divided into four groups.

Each group is given with same number of users for ideal conditions.

```
startindex=zeros(1,GA+1);
for i=1:GA
    startindex(i)=floor(N/GA*(i-1))+1;
end
startindex(GA+1)=N+1;
```

But for a separate simulation of practical conditions, each group is given different numbers of users.

For results with ideal conditions, each user is placed at the same distance from the base station.

```
distancefromBS=ones(1,N).*5;
```

where N is total number of mobiles considered for the simulation

For results with practical conditions, each user is placed at a certain distance (in km) from the base station.

```
distancefromBS=[8 5 4 9.2 2 6 7 9 7.5 9.9 5.5 2.3 3.4 8
9.5 4.5 7 5 6 9.8 3 3.5 9 6];
```

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

Okamura-Hata model has been used in this project to emulate large scale fading. Large scale fading is observed over long distances. The following is the code used for large scale fading:

```
for j=1:N
    Fc=950;    % Carrier frequency
    Hb=60;    % Base station antenna height
    Hm=5;     % Mobile station antenna height
    EIRP=30;
    Gm=0;     % Antenna gain of the mobile (in dB)
    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;  % Received power
    Pn = -174+10*log10(200e3);  % Thermal noise for 200 kHz
channel (in dB)
    % Pn = -174+10*log10(950e6);
    SNR = Pr-Pn;
    locationSNR(j)=SNR;
    stdshadow=2;
    % shadow=randn*stdshadow;  % this generates a normal
random variable with standard deviation stdshadow
    while (anglefromBS(j)>=360)
        anglefromBS(j) = anglefromBS(j) - 360;
    end
    while (anglefromBS(j)<0)
        anglefromBS(j) = anglefromBS(j) + 360;
    end
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 [3]

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
```

The following table is used to map SNR to throughput. Different modulation schemes can be used for different throughput. This table comes from WiMAX documents [4]

```
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];
```

4.3.1 Code for choosing a best group between groups

Now comes the next step to decide which one of the groups should be chosen from a given instantaneous time slot. Since this project is mainly focused on QoS and delay requirements, we decided to implement MLWDF in selecting a best group between the groups. Deadline metric for all the users is calculated for each time slot. The top user with best deadline metric in each group is chosen to get the final metric for each group. The group with the best final metric is given the time slot.

```
W1= (timestamp-(Mat-packetdeadline)); % Calculating the waiting time
deadlinemetric1=
(W1./packetdeadline).*actualthroughput./(pastthroughput/(i*timeslot));%
packet deadline has been declared already and how to get the 'W' value
 sortvect1=deadlinemetric1(startindex(Gindex):startindex(Gindex+1)-1);
             sortvect1=sort(sortvect1,'descend');
      % Find the sum of the largest "topnum" values in the group
              for iii=1:topnum
                    G(Gindex)=G(Gindex)+sortvect1(iii);

              end
```

If a group has no packets waiting, code is written such that it is not chosen. This will make sure that we are not choosing a group with no packets.

```
      % Make sure each group has packets to send, if not scale down
                      % its G by 1/1e10
              for Gindex=1:GA

                    Q(startindex(Gindex):startindex(Gindex+1)-1,1);
                      if min(Q(startindex(Gindex):startindex(Gindex+1)-
             1,1)) > 1e10
                                      G(Gindex)=G(Gindex)/Inf;
                      end
                  end

                            [Y,Gmaxindex] = max(G);
```

4.3.2 Code for choosing a mobile inside a chosen group

At this point we have chosen the group, and next is to choose the mobile inside a group according to QoS and Delay requirements. In this project two traffic types are developed and the corresponding code is explained below.

We have taken two types of traffic in to consideration for this project at mobile level.

(i) Real time traffic

(ii) Non-Real time traffic

Code for Serving Real time traffic:

Real time traffic is given priority over Non-Real traffic. And always keeping a queue indicator as a comparison and depending upon the queue indicator it decides whether to serve RT or NRT traffic

```
        Qgroup1=Q(startindex(Gmaxindex):startindex(Gmaxindex+1)-
        1,1)';
        A = Q;
        A(:,11) = sum(A~=Inf,2);
        Weight_requiredQueue=A(startindex(Gmaxindex):startindex(
        Gmaxindex+1)-1,11)';
        Actual_weight=(Weight_requiredQueue/Qsize);
        pick_RT_moblies=Actual_weight(2:2:end);
if (sum(pick_RT_moblies>0.7))>0 % check the RT mobiles if
their queues are filled more than half
        actualthroughput1=actualthroughput(startindex(Gmaxindex)
        :startindex(Gmaxindex+1)-1);
        actualthroughput1([1:2:end])=0; % Make throughput for
        NRT mobiles equal zero so they are not chosen.

        pastthroughput1=pastthroughput(startindex(Gmaxindex):sta
        rtindex(Gmaxindex+1)-1);

        W=(timestamp-(Qgroup1-
        packetdeadline(startindex(Gmaxindex):startindex(Gmaxinde
        x+1)-1)));

        deadlinemetric=(W./packetdeadline(startindex(Gmaxindex):
        startindex(Gmaxindex+1)-
        1)).*actualthroughput1./(pastthroughput1/(i*timeslot));
```

Once that Real Traffic is chosen to be served for a timeslot, then the best mobile among the Real time traffic mobiles is chosen with the following code.

```
[Y,II]=max(deadlinemetric);

deadlinevalue=Qgroup1(II);

II=II+startindex(Gmaxindex)-1;

mobile=II;
```

Also in serving the Real time traffic, the packets are constantly checked to ensure that they are within the deadline value. If they have reached the deadline value and still in the queue then they dropped. The following code is used for the logic.

```
if timestamp>deadlinevalue %& (RT=1)
                    % This packet should be dropped
                    droppacket=1;
     sendpacket=0;
     droppedpackets_delay(II)=droppedpackets_delay(II)+1;
                    tryagain=1;
else
     tryagain=0;
     if deadlinevalue > 1e10
         Q
         tryagain=0;
     end
     sendpacket=1;
     droppacket=0;
     thisdelay=timestamp-deadlinevalue+packetdeadline(II);
     avgdelay(II)=(avgdelay(II)*pastslots(II)+thisdelay)/(
     pastslots(II)+1);
end
```

Code for Serving Non-Real time traffic:

Only when the scheduler is learnt that there is no Real time traffic is needed to serve based on the urgency factor, the Non-Real time traffic is selected to serve.

```
pick_NRT_mobiles=Actual_weight(1:2:end);
NRT=0;

 if sum(pick_NRT_mobiles)==0
    Gmaxindex=Gmaxindex_2;
```

```
        Qgroup1=Q(startindex(Gmaxindex):startindex(Gmaxindex+1)-
        1,1)';

        Weight_requiredQueue=A(startindex(Gmaxindex):startindex(
        Gmaxindex+1)-1,11)';

        Actual_weight=(Weight_requiredQueue/Qsize);
         NRT=1;
     end


if (NRT)==1

 pick_NRT_mobiles_2=Actual_weight(1:2:end);

  if sum(pick_NRT_mobiles_2)==0
     Gmaxindex=Gmaxindex_3;

        Qgroup1=Q(startindex(Gmaxindex):startindex(Gmaxindex+1)-
        1,1)';

        Weight_requiredQueue=A(startindex(Gmaxindex):startindex(
        Gmaxindex+1)-1,11)';

        Actual_weight=(Weight_requiredQueue/Qsize);
                            % disp 'third highest'
                            NRT=2;
                      end
                end
```

QoS and Delay Requirements Based on Queue Priorities:

We varied the queue indicator from 1 to 9 for a queue size of 10 packets and conducted several simulations. The best queue indicator is considered from the conducted simulations. The following code is written to execute the Queue Indicator.

```
% Queue indicator = 1
   if(sum(pick_RT_moblies>0.1))>0
   actualthroughput1=actualthroughput(startindex(Gmaxindex):start
   index(Gmaxindex+1)-1);
   actualthroughput1([1:2:end])=0;

   pastthroughput1=pastthroughput(startindex(Gmaxindex):startinde
   x(Gmaxindex+1)-1);
```

```
        W=(timestamp-(Qgroup1-
       packetdeadline(startindex(Gmaxindex):startindex(Gmaxindex+1)-
       1)));

       deadlinemetric=(W./packetdeadline(startindex(Gmaxindex):starti
       ndex(Gmaxindex+1)-
       1)).*actualthroughput1./(pastthroughput1/(i*timeslot));
   end
  % Queue indicator = 2
   if (sum(pick_RT_moblies>0.2))>0

       actualthroughput1=actualthroughput(startindex(Gmaxindex):start
       index(Gmaxindex+1)-1);
       actualthroughput1([1:2:end])=0;

       pastthroughput1=pastthroughput(startindex(Gmaxindex):startinde
       x(Gmaxindex+1)-1);
        W=(timestamp-(Qgroup1-
       packetdeadline(startindex(Gmaxindex):startindex(Gmaxindex+1)-
       1)));

       deadlinemetric=(W./packetdeadline(startindex(Gmaxindex):starti
       ndex(Gmaxindex+1)-
       1)).*actualthroughput1./(pastthroughput1/(i*timeslot));
   end
```

Similarly the code is written for Queue Indicator = 3,4,5,6,7,8,9 and optimized queue indicator is chosen from the results.

QoS and Delay Requirements Based on Packet Deadline:

We have considered different packet deadline values for RT traffic by groups with different cases. To compare simulation results to see the performance of each group, we vary the RT packet deadline values for each group. To show how the deadline values impact the packet drops and throughput etc., we varied packet deadline values for each group.

We have considered different deadline values like Cases 1 through 4 vary two classes together. Groups 3 and 4 stay at 10 msec. while Groups 1 and 2 increase together from 20 to 50 msec.

Cases 5 through 8 vary three classes together by keeping Group 1 at 10 msec. and the other three groups have increasing values from 20 to 50 msec.

For the results we have considered average delay, packet drops and user outage ratio as performance parameters.

Finally, we calculate the throughput for each group. Various parameters like packet drops, user outage ratio and average delay are compared and their results are published in the following section. Also the total throughput, which is the addition of throughputs of all the groups, is calculated. Location SNR, actual SNR and past throughput are also computed and compared.

CHAPTER 5

RESULTS AND ANALYSIS

In this section a broad analysis of the performance of the various metrics are developed and compared. The first step here is to understand the basic behavior of the approach.

Let us consider the following simulation results.

Number of nodes, N = 24
Number of groups, G = 4
Number of Nodes per Group = 6

Based on the above consideration with a total number of mobiles as 24 and these are divided into 4 groups with 6 mobiles in each group. Simulations are done and results plotted according to the various parameters considered in this thesis.

5.1 QoS and Delay Requirements Based on Queue Priorities

As mentioned above, we have created a queue indicator in order to choose the traffic type. Firstly the scheduler goes through all of the RT mobile queues and depending upon the queue indicator it decides whether to serve RT or NRT traffic. For instance if the queue indicator is set to 2, RT mobiles will be served if there is at least one RT mobile that has more than 2 packets sitting in the queue. Otherwise serve the NRT traffic.

We varied the queue indicator from 1 to 9 for a queue size of 10 packets and conducted several simulations. The best queue indicator is considered from the conducted simulations. For the results we have considered average delay, packet drops, user outage ratio and throughput as metrics to be investigated. We found the value '7' (This depends on traffic load what is the load--- explain this)as the best queue indicator from the simulations conducted. The results and the graphs are plotted below.

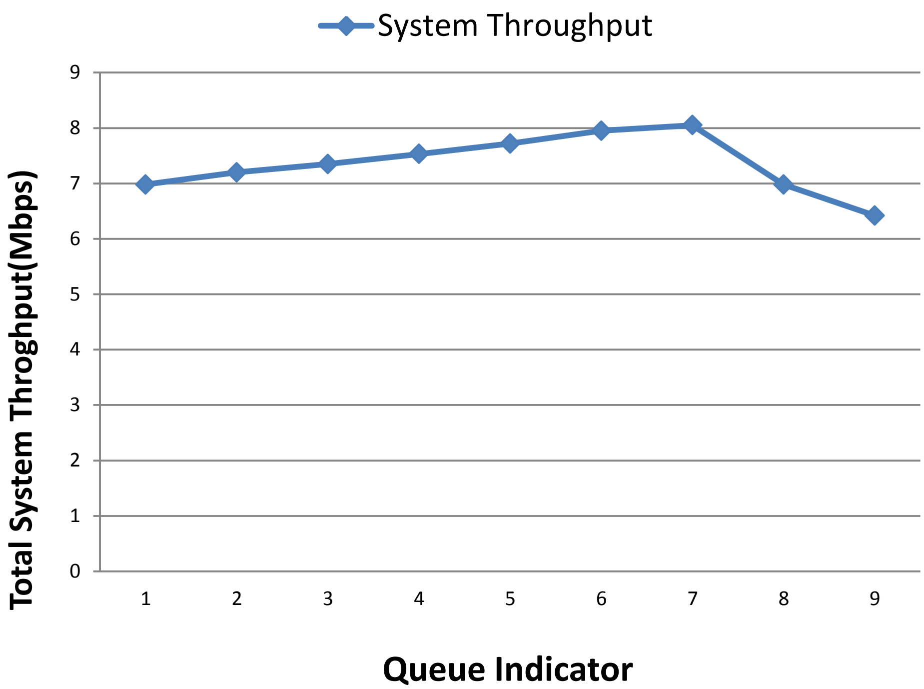

Fig 1. Throughput Comparison by varying Queue Indicator from 1 to 9

Fig. 1 shows why 7 is found to be the recommended value for the best queue indicator in our simulations. The plot is the result of total throughput by varying queue indicator from a 10% fill of packets in the queue to a 90% fill for a queue size of 10.

Initially with 10% of the RT queue filled, the overall system throughput was around 7.00 Mbps, that is 6.98 Mbps, which is considerable. But we found some interesting results as we varied the queue indicator. Throughput increased as we varied queue indicator from 10% to 70%. In the 80% case, the throughput showed a sharp decline when compared to previous cases and even worse in the case of 90% queue fill.

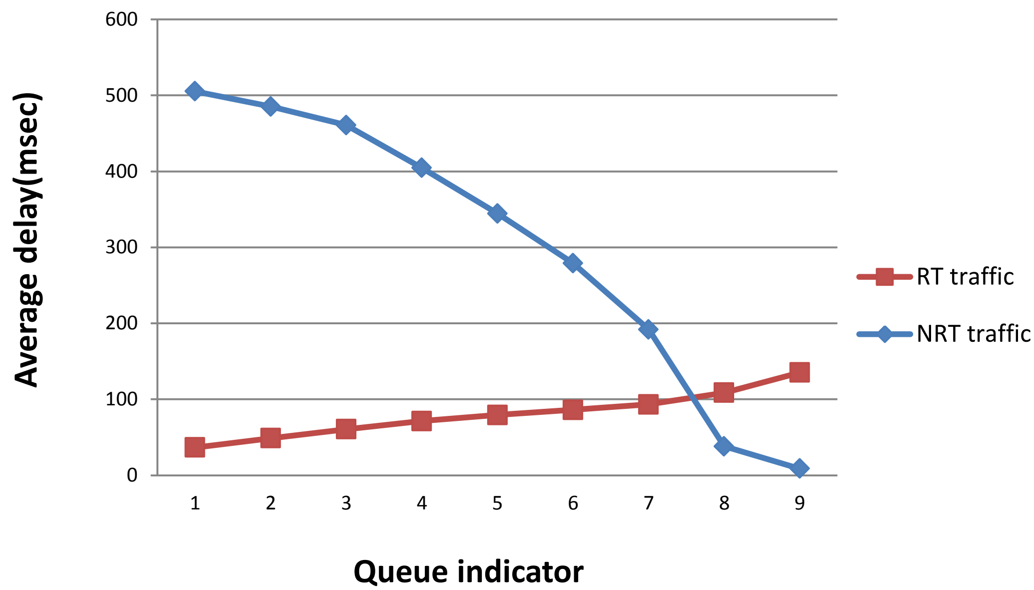

Fig 2. Average Delay Comparison varying Queue Indicator from 1 to 9

Fig. 2 is the result of average delay by varying the queue indicator from 10% fill of the packets in the queue to 90% fill. Initially with the 10% value, NRT mobiles show high average delay of 505.3 msec. which is worst. So it takes a long time for the NRT traffic to be scheduled. On the other hand in the same conditions, the RT mobiles have the best average delay with 36.7 msec. Considering the recommended best case scenario, when the queue indicator is 7, average delay for NRT mobiles is below 200 msec. that is 192 msec., and for RT mobiles the average delay is below 100 msec., that is 93.4 msec.

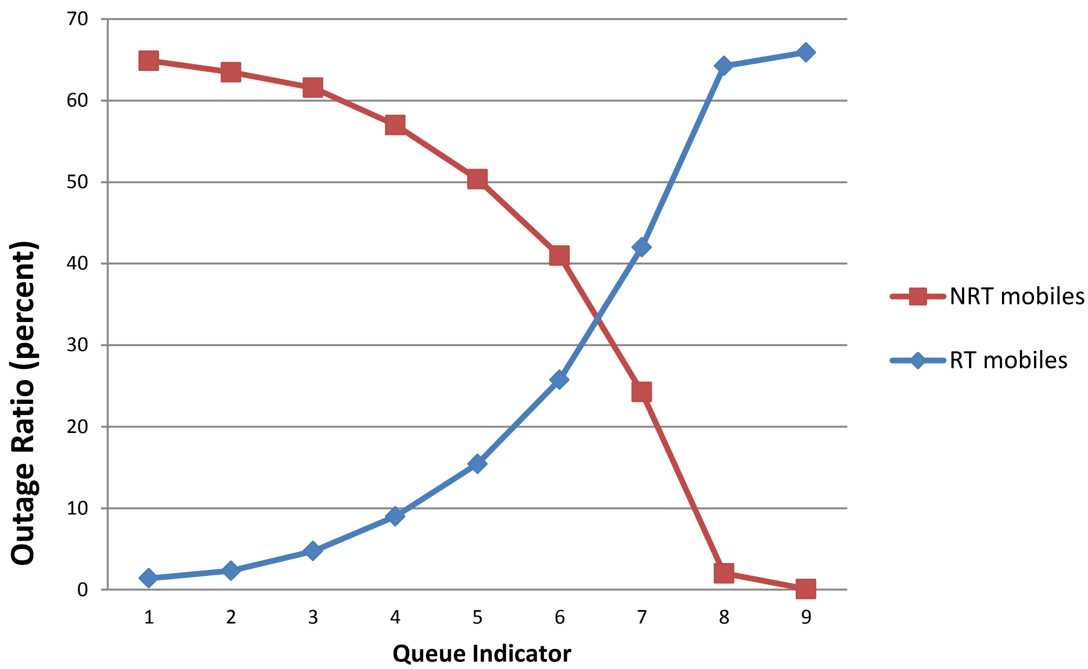

Fig 3. Outage ratio comparison by varying Queue Indicator from 1 to 9

Fig. 3 is the result of outage ratio, which we define as the total sum of packet drops (due to both delay violations and full queues) divided by the total number of packets simulated. Initially with 10% fill of the RT queue, NRT mobiles experience very high packet loss around 80% which is worst. On the other hand with same conditions, the RT mobiles experience very low packet loss, less than 5%. At a queue indicator with 60% queue fill, packet loss for NRT mobiles is below 50% and for RT mobiles the packet loss is around 30%.

Note that we have simulated with quite high load for comparison purposes. These loss rates should not be occurring in a normally operating system; QoS controls should be active to limit the traffic.

5.2 QoS and Delay Requirements Based on Packet Deadline

Now we consider group scheduling. We take the concepts just presented and then use them to first choose the best group in each timeslot to receive service. We use the metrics in (1) and (2) and find the sum of those metrics for each group. Then the group is chosen with the best sum-of-metrics. We again use the queue indicator concept to choose whether RT or NRT traffic is chosen. We found the best queue indicator in the above section as 7, so we use that queue indicator for further simulations. Here is the procedure.

- Go through each group and sum the metrics using (1). Choose the group with the highest sum.
- See if any mobile in the group has an RT queue that has more packets than the queue indicator. If so, choose to send RT packets.
- The group then chooses the mobile in its group with the highest metric, either using (2) or (3) depending on the type of traffic to send.

To then compare simulation results to see the performance of each group, we vary the RT packet deadline values for each group. Those with tighter deadlines would of course be given relatively stronger priority because D_i is in the denominator of (2).

We have considered the following cases listed in Table 1 by varying packet deadline value for RT traffic by groups with different cases.

Table 1.Simulation results for Deadline values per group

	Group 1	Group 2	Group 3	Group 4
Case 1	20 msec.	20 msec.	10 msec.	10 msec.
Case 2	30 msec.	30 msec.	10 msec.	10 msec.
Case 3	40 msec.	40 msec.	10 msec.	10 msec.
Case 4	50 msec.	50 msec.	10 msec.	10 msec.
Case 5	10 msec.	20 msec.	20 msec.	20 msec.
Case 6	10 msec.	30 msec.	30 msec.	30 msec.
Case 7	10 msec.	40 msec.	40 msec.	40 msec.
Case 8	10 msec.	50 msec.	50 msec.	50 msec.

Cases 1 through 4 vary two classes together. Groups 3 and 4 stay at 10 msec. while Groups 1 and 2 increase together from 20 to 50 msec. Cases 5 through 8 vary three classes together by keeping Group 1 at 10 msec. and the other three groups have increasing values from 20 to 50 msec. For the results we have considered average delay, packet drops and user outage ratio as performance parameters.

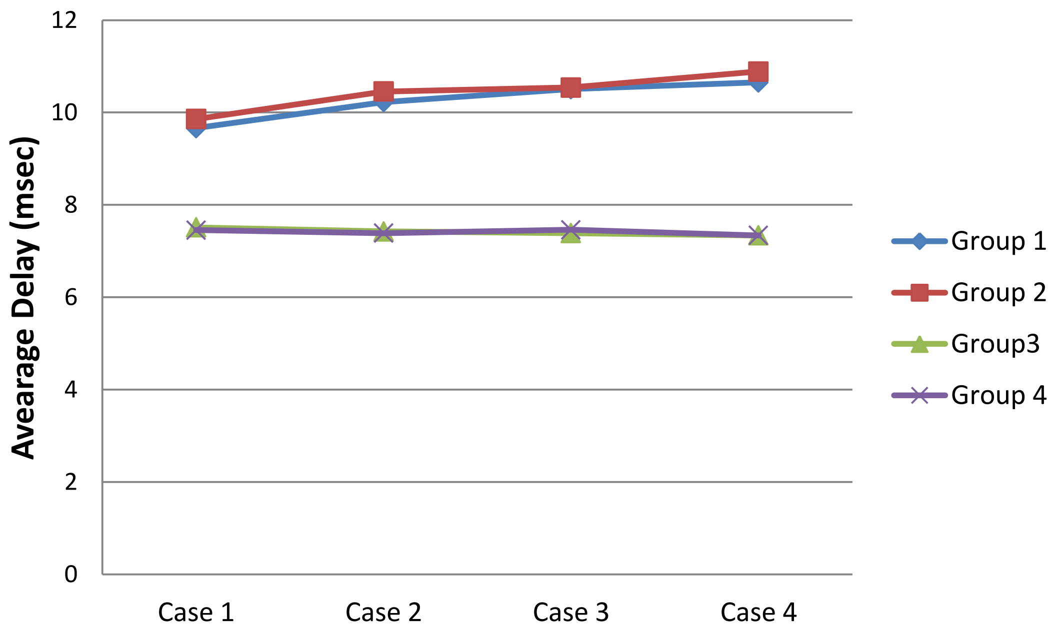

Fig 4. Average Delay Comparison for RT traffic by varying packet deadline value in Case 1 to Case 4

Fig. 4 is the result of average delay comparison for RT traffic by varying packet deadline value from Case 1 to Case 4. It clearly shows that Groups 1 and 2 have higher average delay when compared to Groups 3 and 4. And Groups 3 and 4 are not affected by changing deadlines for the other groups. As the delay requirements relax for Groups 1 and 2, the average delay increases somewhat.

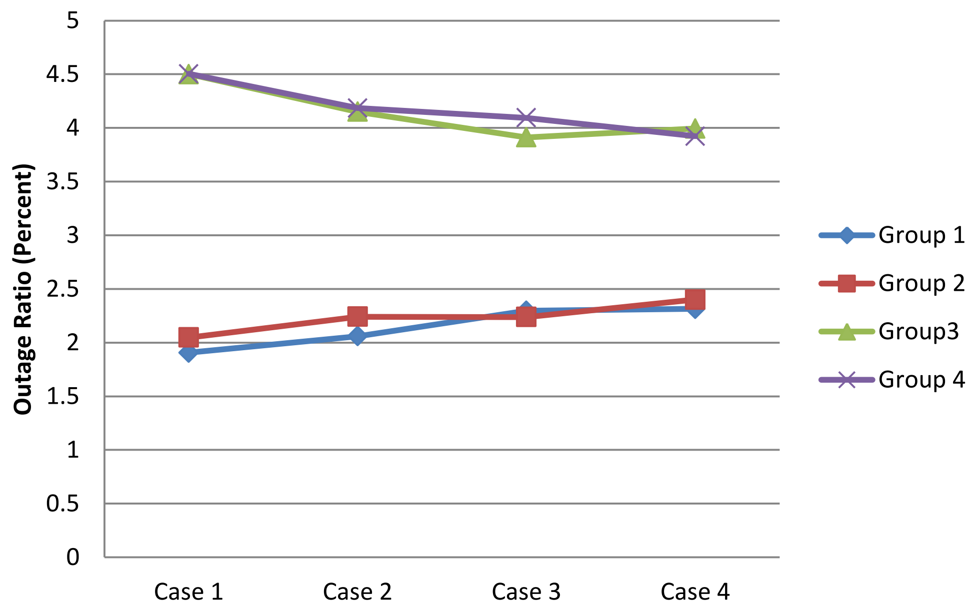

Fig 5. User Outage Ratio for RT traffic by varying packet deadline value in Case 1 to Case 4.

Fig. 5 shows user outage ratio; Groups 1 and 2 are better than Groups 3 and 4. Their looser delay bounds allow for more packets to be transmitted. Note the interesting result that increasing delay bounds help Groups 3 and 4 to have lower user outage ratios, but actually result in some increased outage ratio for Groups 1 and 2.

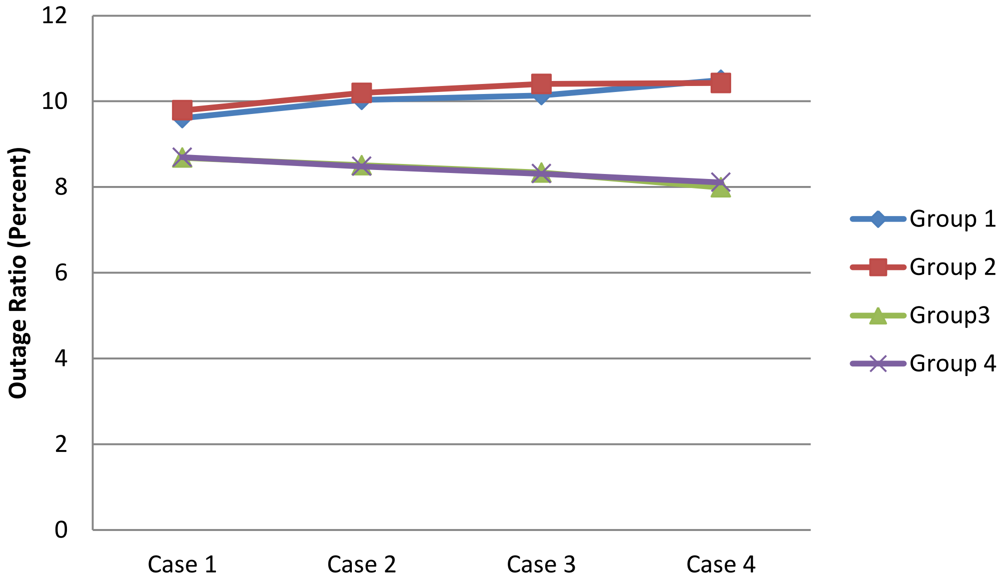

Fig 6. User Outage Ratio for NRT traffic by varying packet deadline value in Case 1 to Case 4.

Fig. 6 shows the result of user outage ratio comparison for the other traffic, the NRT traffic, by varying packet deadline values in Cases 1 to 4. Groups 3 and 4 show better results and their results get better as the delay abounds for Classes 1 and 2 increase. This means that the stricter delay bounds for the RT traffic also help the NRT traffic for the same classes.

The next plots show uneven number of groups (three versus 1) in Cases 5 to 8 that have the same packet deadline values, which go from 20 msec. to 50 msec.

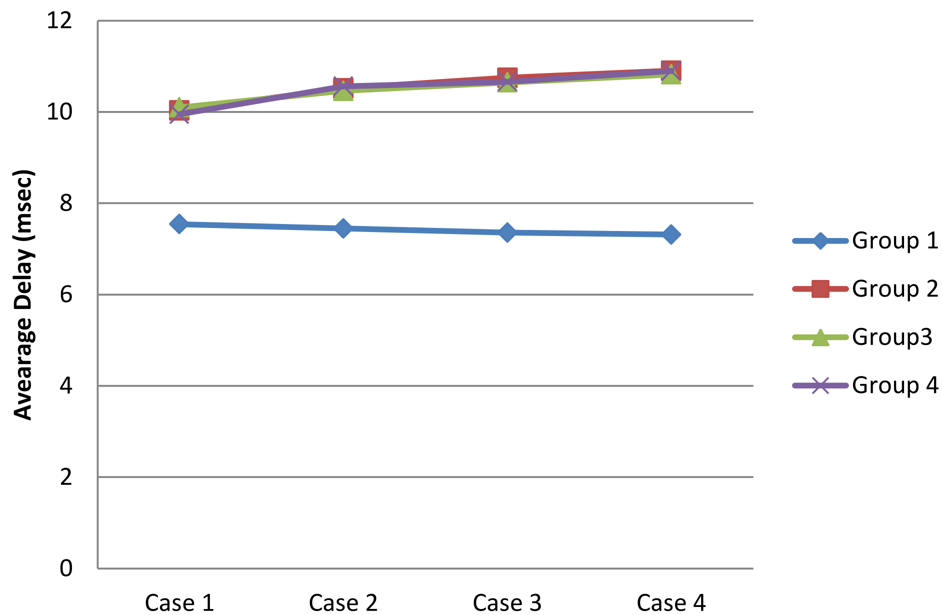

Fig 7. Average Delay Comparison for RT traffic by varying packet deadline value in Case 5 to Case 8

Fig. 7 is the result of average delay comparison for RT traffic. It clearly shows that Groups 2, 3, and 4 have higher average delay when compared to Group 1.

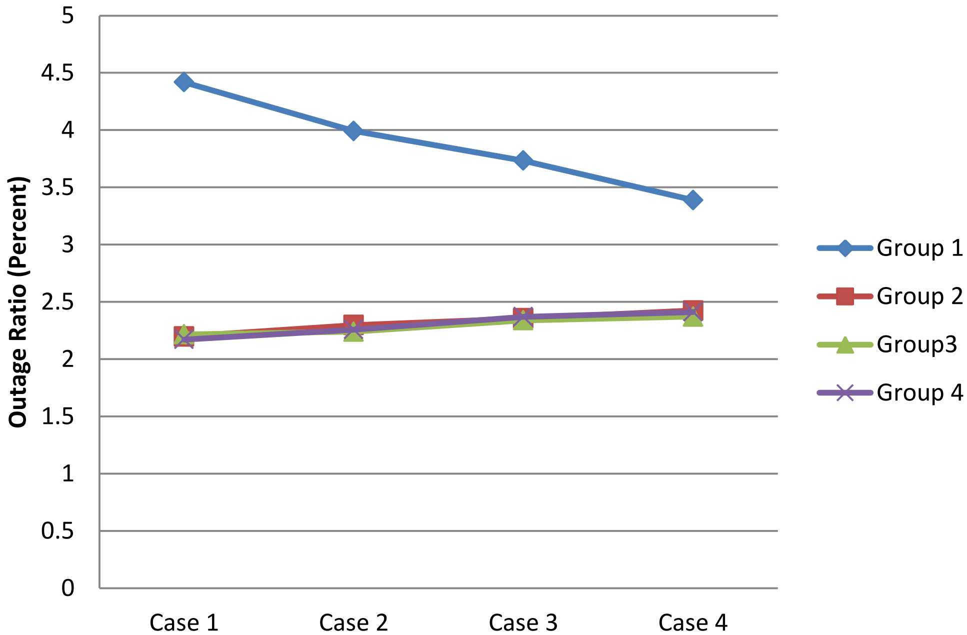

Fig 8. User Outage Ratio for RT traffic by varying packet deadline value in Case 5 to Case 8.

In terms of user outage ratio seen in Fig. 8, Group 1 has the worst performance when compared to other groups. But it improves strongly as the deadline values for Groups 2, 3, and 4 increase. This means that the relaxed requirements of the other classes give Class 1 more opportunity.

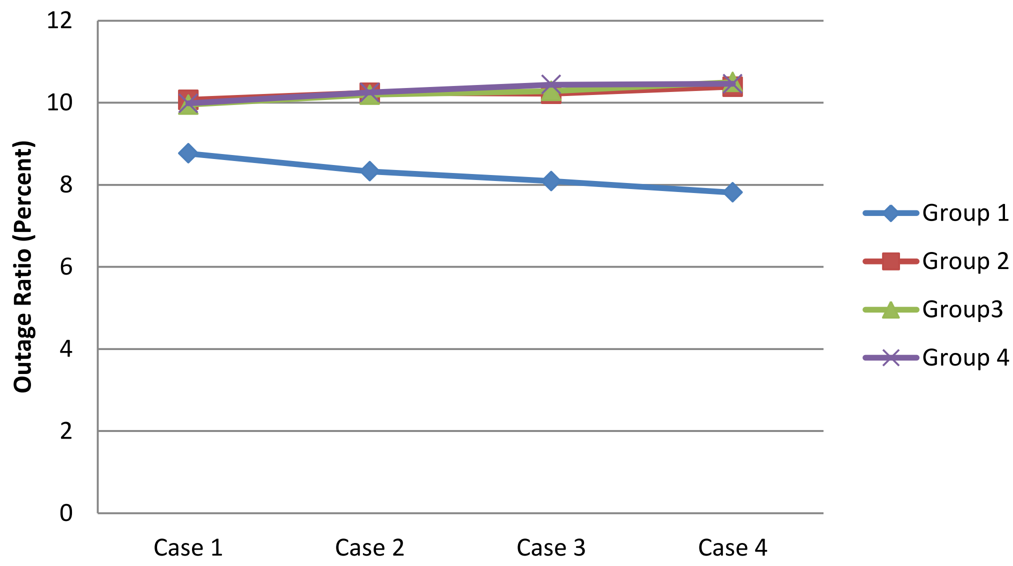

Fig 9. User Outage Ratio for NRT traffic by varying packet deadline value in Case 5 to Case 8.

Fig. 9 shows NRT traffic outage ratios, which are higher for the three classes, and it shows that the outage ratio improves for Group 1 as the deadlines for the other groups increase. The benefits of increasing deadlines are actually more obvious for Class 1.

From the above results it is seen that this scheme provides the groups in emergency condition with more bandwidth and also tries to meet the requirements of groups. The increase in emergency condition increases the bandwidth provided to emergency groups compromising the requirements of other groups.

All the above scenarios show that group scheduling scheme for public safety communications with proportional fairness between the groups works consistent under different conditions proving the reliability of the scheme. The metrics developed helps achieve guaranteed performance of the groups. And groups are given more bandwidth in emergency conditions making the scheme reliable and sensible for public safety communications.

CHAPTER 6

6.1 CONCLUSION

This thesis mainly focuses on QoS and delay requirements and presents the context of the problem of public safety communications in cellular networks and the concept of group scheduling to provide a scheduling of capacity in various ways to meet QoS requirements for RT and NRT traffic. This thesis introduced the concept of queue indicator to provide a means of selecting whether RT or NRT traffic should be transmitted in a timeslot. Then we introduced group scheduling, accomplished by using a sum of metrics (2) or (3) to find the best groups. Finally, our work presented simulation results to find the best queue indicator values and compared cases of different delay requirements between groups.

Much more work in this area is necessary to be accomplished for the public safety problem to be solved. Even more generally, QoS as a whole is not implemented very much at all in cellular systems [2]. Complexity and scalability issues are significant so simple algorithms and simple equations like (2) and (3) are necessary. Also, mathematical optimization frameworks based on utility formulations have been shown to be effective at these types of scheduling problems, as long as the complexity can be kept low by using utility functions whose derivatives involve simple mathematical operations. For example, equation

(1) here is a result of using a logarithmic utility function [18]. Also, the idea of simply adding per-node metrics may be more effectively replaced by other forms of aggregate group performance metrics.

6.2 Future Scope

Further enhancements would involve prioritizing between groups. For example when one public safety group is in an emergency situation, most extra bandwidth should go to that group. If bandwidth is limited, then the emergency group should have the first priority to have its requirements met. 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 for even more important functions like saving lives. This goal can be met.

The demands of the users such as high data rates, fairness and low latency are extremely difficult to achieve yet important. QoS as a whole is not implemented very much at all in cellular systems. There are a lot of technologies that can be used to meet these requirements, such as MIMO, adaptive modulation and coding. 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. The group scheduling scheme implemented here 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.

This project presented the context of the problem of public safety communications in cellular networks and the concept of group scheduling to provide a scheduling of capacity in various ways to meet timeslot and throughput requirements. Several metrics are formulated to achieve these requirements. Metrics that are being opportunistic which meets the requirements of at least some of the groups and metrics that are being fair which treats every group equally even if not meeting any of their requirements. Complexity and scalability issues are significant so simple algorithms are developed. This simulator allocated one timeslot to one user at a time, but could easily be extended to a multicarrier OFDMA solution.

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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 field of Telecommunications in the future.