ANALYSIS OF THROUGHPUT AND FAIRNESS IN WIMAX NETWORK

By

Muhammad Yasir

(Registration No: 2009-NUST-MS-CSE(S)-03)

Supervisor

Dr. Adnan K Kiani
(SEECS-NUST)

School of Electrical Engineering and Computer Science

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A Thesis submitted in partial fulfillment of the requirements for the degree of

Master's in Communication Systems Engineering

School of Electrical Engineering and Computer Science

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NUST School of Electrical Engineering and Computer Sciences

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Advisor: ____________________________

Name: Dr Adnan K Kiani

Committee Member1: __________________

Name: Dr Adeel Baig

Committee Member2: ___________________

Name: Dr Zawar Hussain Shah

Committee Member3: ___________________

Name: Mr Farooq Cheema

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Author Name: Muhammad Yasir

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ACKNOWLEDGEMENT

First of all, I thank to Allah for giving me strength and ability to complete this project.
Secondly, my utmost gratitude to Dr. Adnan K Kiani, whose sincerity and encouragement I will never forget. His invaluable help of constructive comments and suggestions throughout the experimental and thesis works have contributed to the success of this research. Thanks are also extended to my committee members Dr Adeel,Dr Zawar and Mr Farooq for their guidance and support.
My deepest gratitude goes to my beloved parents,family and friends for their endless love, prayers and encouragement.
Last but not least, I wish to express my sincere thanks to all those who have one way or another helped me in making this project a success.

Contents

List of Abbreviation

WiMAX: Worldwide Interoperability for Microwave Access abbreviated

QoS: Quality of Service

NWG: Network Working Group

ASN: Access Service Network

CSN: Connectivity Services Network

AMC: Adaptive Modulation and Coding

MAP: Medium Access Protocol

MAN: Metropolitan Area Network

OFDMA: Orthogonal Frequency Division Multiple Access

ISI: Inter Symbol Interference

MIMO: Multiple Input Multiple Output

PDU: Protocol Data Unit

SDU: Service Data Unit

CID: Connection Identifier

CS: Convergence Sublayer

CPS: Common Part Sublayer

HARQ: Hybrid Automatic Repeat Request

FCH: Frame Control Header

OHHO: Optimized Hard Handover

EAP: Extensible Authentication Protocol

WFQ: Weighted Fair Queuing

TDD: Time Division Duplexing

FDD: Frequency Division Duplexing

FS: Fair Share

CINR: Carrier to Interference and Noise Ratio

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ABSTRACT

IEEE 802.16 based Worldwide Interoperability for Microwave Access networks (WiMAX) are increasingly being deployed for last hop broadband wireless access. In order to provide the high speed access to information resources broadband technology like WiMAX is needed. In this research we compared different uplink scheduling algorithms of WiMAX mainly maximum carrier to interference and noise (Max C/I) algorithm and fair share (FS) algorithm. Max C/I algorithm is a throughput maximizing algorithm but if throughput of the network is maximized without fairness, the SS with low CINR should be ignored and will experience starvation. Fair share (FS) scheme provides equal number of time slots to every SS irrespective of their CINR. If fairness is considered, providing fair share to low CINR users will require a lot of resources which will result into low throughput of the network although it can solve the problem of starvation.

In this research we propose a new scheme to optimize WiMAX network based on a compromise between Max C/I and FS algorithms. We propose a new optimum scheme which reserves some time slots for the users which are at the edges of a WiMAX cell and these users will share equal slots among them from reserve slots. The remaining slots are provided to other users according to Max C/I scheme. Hence this scheme optimizes between Throughput and Fairness in WiMAX Network We also compared different reservations schemes i.e. 30%, 40% and 50% reservation of time slots and compare network throughput in different reservation schemes. We also analyze the behavior of edge SS's in different reservation schemes.

The above scheme works fine if users are distributed uniformly in WiMAX cell but however if users are not distributed uniformly then this reserve slot percentage should be dynamic according to edge user's percentage. For this purpose we make this decision dynamic i.e. BS will decide this reservation percentage on a basis of users which are at the edges of a WiMAX cell or having low CINR value (lower modulation

Chapter 1

Introduction

1.1 Background

Worldwide Interoperability for Microwave Access abbreviated as WiMAX is a technology which is based on wireless and IP also called a broadband access technology whose working is similar to other wireless technology like WIFI but it provides coverage and QoS (Quality of Service) which is of cellular networks. This technology is described by the Institute of Electrical and Electronics Engineers Inc. as the IEEE 802.16 standard and is being deployed for last hop broadband wireless access. Typically, a WiMAX consists of a group of base stations, established at strategic locations, providing coverage over a certain geographic area. Each base station (BS) communicates with multiple subscriber stations (SS) within its coverage area in a point to multipoint fashion. The range of this broadband technology is 30 miles (50km) for fixed stations but if we consider mobility then it can provide up to range of 3-10 miles (5-15 km) for mobile stations.

WiMAX system consists of two parts:

- WiMAX BS: (Base Station) which can give coverage typically up to 10 Km radius
- WiMAX Receiver: It can be a stand-alone box (external) or PC card.

A number of base stations can be linked with one another through backhaul microwave links. It can be done in two ways:

- Wired-line backhauling
- Point-to-point microwave connection

1.2 Overview of WiMAX Technology

Earlier WiMAX products and certifications are intended to conform to the IEEE 802.16 air interface specifications. Later on, WiMAX Forum develops the specifications for WiMAX products in the network section. These specifications include network

interoperability specifications and end to end networking specifications. A group named NWG (Network Working Group) is formed within WiMAX Forum which specify the network specifications interoperating with other technologies and several services such as Multi-cast and Broadcast Service (MCBCS) and Location Based Service LBS).
The WiMAX system profile consists of five sub-profiles namely Physical, MAC, Radio, Duplexing Mode and Power Classes. According to different regional frequency spectrum regulations, different arrangements of center frequencies and channel bandwidth, all WiMAX products have the same physical layer and MAC layer features.

1.3 WiMAX Forum

A non-profit industry body known as WiMAX forum which was formed for the encouragement and implementation of WiMAX technology. It also ensures compatibility of different vendor's products and their interoperability.
Certified from WiMAX Forum means that a ISP can buy the products or equipment from different manufacturers being ensured that everything works together with compatibility. WiMAX Forum does this job by building up conformance and interoperability test plans and initiating different certification processes.
WiMAX is anticipated to offer fixed, nomadic, portable and eventually mobile wireless broadband connectivity without having the need for direct line of sight (LOS) connection with the base station.
Systems Certified from WiMAX Forum are likely to exceed data rate of about 40 Mbps per channel for portable and fixed access applications with a cell radius of about three to ten kilometers. It should provide a data rate of 15 Mbps in a cell radius of about 3km in case of mobile network.

1.4 Difference between WiMAX and the Predecessor Technology WiFi

In WiFi, maximum data rate under optimal conditions is up to 54 Mbps. Its range is about 100 feet (30 m). WiFi can use the frequency spectrum up to maximum 5 GHz.
WiMAX can handle date rate up to 70 Mbps. WiMAX can give wireless coverage in a cell of radius 30km to 50km depending upon the frequencies used and the power of the transmitter. WiMAX use 10-66 GHz frequency spectrum.

1.5 Salient Features of WiMAX

The air interface of WiMAX technology stands on the IEEE 802.16 standards. IEEE 802.16e specifies the Orthogonal Frequency Division Multiple Access (OFDMA) and supports mobility. IEEE 802.16-2004 standards is for fixed WiMAX (also referred to as

802.16d) which was later amended in December 2006 as 802.16e to provide support for mobile WiMAX stations.

1.5.1 Scalability

SOFDMA (Scalable Orthogonal Frequency Division Multiple Access is used in Mobile WiMAX which enables it to function in different bandwidths scalable from 1.25 to 20 MHz conforming to the different frequency allocations worldwide.

1.5.2 Security

WiMAX technology includes many advanced security features which ensures the safe use of this technology. These features include Extensible Authentication Protocol (EAP) based authentication, Advanced Encryption Standard (AES) based authenticated encryption. Control message protection schemes include Hashed Message Authentication Code (HMAC) and Cipher-based Message Authentication Code (CMAC).

1.5.3 High Data Rates

WiMAX technology can provide maximum downlink speed (DL) of 128 Mbps per sector and maximum speed for uplink case is 56 Mbps per sector in maximum 20 MHz bandwidth. These higher data rates are achievable due to adaptive modulation and flexible sub-channelization schemes used in WiMAX, coding and the use of MIMO (Multiple-input multiple-output) antennas.

1.5.4 Mobility

The seamless handovers in Wimax become a reality by introducing mobility in it . Latencies fewer than 50ms were achieved to ensure that application which require real time bandwidth like VoIP (Voice over IP) were achievable without degrading service quality

Security features make sure the security of the data during hand over

1.5.5 Quality of Service (QoS)

MAC architecture in WiMAX ensures QoS. Prioritizing the time sensitive traffic such as VoIP or video is a major solution in offering good QoS. Mobile WiMAX has five categories for prioritization of traffic while fixed WiMAX has four. MAC provides service flows, MAP (Medium Access Protocol) base signaling schemes, scheduling for optimized uplink and downlink, frequency and physical resources over the air interface on a frame by frame basis.

1.6 WiMAX Applications

The implemented of WiMAX in large public areas such as airports, university campuses is very successful and across cities through a range of devices to get mobile broadband connectivity. WiMAX can be adopted by large number of small and medium sized business for lower cost. WiMAX can be used to achieve high speed internet in such areas where wired connectivity is not feasible. An important reason to design WiMAX is to provide connectivity inline with DSL and cable. Also it is intended to interconnect WiFi hotspots into a Metropolitan Area Network (MAN). Its last mile connectivity option used by most of the companies will result in better priced services to customers. WiMAX can provide data, voice (VoIP) and IPTV (Triple Play) services.

Chapter 2

Literature Survey

2.1 802.16(WiMAX)

An overview of WiMAX 802.16 standard is presented in the following section. It reflects various aspects of Physical and Mac layers.

2.1.1 Physical Layer

WiMAX is operated in different frequency ranges depending on whether it is in LOS condition or not. In LOS condition its spectrum is from 10 to 66 GHz. In non LOS condition it can operate from 2 to 11 GHz so WiMAX can support both licensed and unlicensed bands. IEEE 802.16 e WiMAX standard can support mobility. Hence WiMAX can be used in fixed as well as in mobile environment.

The physical layer of WiMAX mainly consist of adaptive modulation and coding schemes (AMC), multi carrier modulation and multiple antennas techniques. WiMAX makes use of orthogonal frequency division multiple access (OFDMA). In this case data is transmitted on different carries which are orthogonal to each other as shown in Figure 2.1 Hence it can also mitigate the effect of inter symbol interference (ISI)

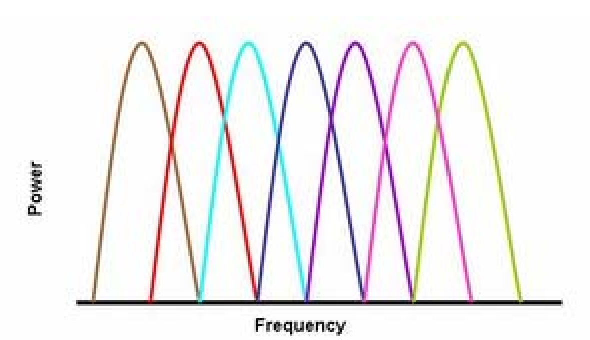

Figure 2.1 Orthogonal carriers

In WiMAX different modulation and coding options are available and SS has to select according to the circumstances. A number of modulation techniques such as 64 QAM, 16 QAM, QPSK and BPSK are available similarly different coding schemes are also

available as WiMAX uses convolutional turbo codes (CTC) as a channel coding technique so SS may select ½ CTC or 5/6 CTC etc. This AMC enables a SS to achieve high spectral efficiency.
WiMAX also uses multiple input multiple output (MIMO) technique. Transmit diversity and spatial multiplexing can b used to mitigate interference hence WiMAX supports multiple antennas at transmitter as well as at receiver as figure 2.2 show illustrate.

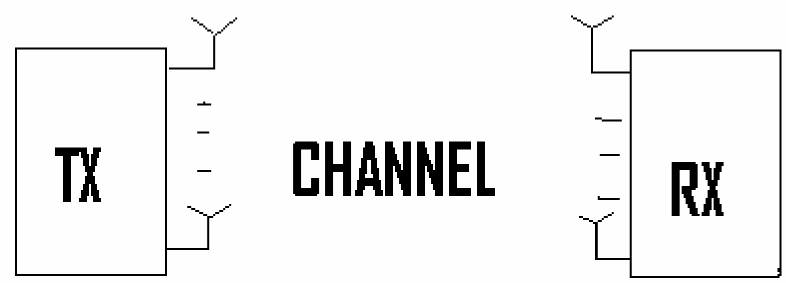

Figure 2.2 MIMO

WiMAX uses Time Division Duplexing (TDD). In latest WiMAX standard 802.16 m both TDD and Frequency Division Duplexing (FDD) can be used. In WiMAX frequency reuse factor is 3 in IEEE 802.16 e and in IEEE 802.16 m frequency reuse factor is 1 and 3.
Following are some key PHY features.

1. **Advanced Antenna Techniques (MIMO and BF)**

   WiMAX technology uses several sophisticated antenna techniques to provide higher throughputs and better range in a cell and from user's perspective as well. WiMAX technology is the first commercial cellular technology which got benefited by MIMO systems assured by the academic world for the years. MIMO uplink and downlink features allow operators as well as the end-users to get data rate doubled to that of SISO (Single Input Single Output System). So as a result we can get significant higher uplink and downlink throughput 10 Mbps and 37 Mbps respectively by utilizing channel bandwidth of 10 MHz with TDD.
   Inherent beam forming (BF) techniques in mobile WiMAX increases the cell area subjected to coverage. Together with TDD operation, powerful Beam Forming system enables BS to precisely make such a beam that matches the channel to an end terminal so that terminals lying at the boundary can reach up to downlink and uplink signals, expanding the cell coverage area effectively.

2. **Frequency Reuse**

   In communication, frequency spectrum is just like gold. So it is always costly for the operators to reserve a greater spectrum. Frequency reuse comes into play in this situation. WiMAX system provides flexible frequency reuse for real time applications e.g., terminals lying near the centre of the cell use frequency reuse one and a part of frequency is used for the terminals at the edge of the cell. This obviously reduces significant co-channel interference. In WiMAX frequency reuse factor is 3 in IEEE 802.16 e and in IEEE 802.16 m frequency reuse factor is 1 and 3.

3. TDD (Time Division Duplex)

We have different amount of internet traffic in uplink and downlink. Downlink traffic exceeds the uplink traffic. So normal frequency division duplex having equal bandwidth for uplink and downlink channel is not a choice for the best utilization of the resources. Operators using TDD are able to adjust uplink and downlink ratios based upon the needs of the services. TDD is inherently more suitable than FDD to advanced antenna techniques e.g., AAS (Adaptive Antenna System) and Beam-forming (BF) because of separate uplink and downlink.

4. Mobility

Designs of a suitable pilot as well as HARQ (Hybrid Automatic Repeat Request) diminish the fast channel effect and interference fluctuation in case of car on highway speed. The WiMAX system is capable of automatically toggling between various kinds of resource blocks known as sub channels after detecting the speed of the mobile entity to give favorable help to moving station. Errors arising due to link adaptation in fast fading channels are overcome by HARQ which also raise the overall system output.

5. Scalable OFDMA

OFDM is a special case of multi-carrier transmission. It uses overlapped orthogonal frequency carriers to provide a high efficient multicarrier transmission scheme. Each underlying sub-carrier is orthogonal to each other. OFDM is adopted in modern wireless broadband technologies with its higher performance in NLOS (Non-Line of Sight) multipath environment. It has relatively simpler transceiver structure and due to frequency and time sub-channelization, available spectrum resources are better managed. Sophisticated antenna systems as MIMO can be applied easily due to simpler structure of OFDMA transmitter and receiver.

OFDM gives a good way to handle mulitpath and it is robust against narrowband interference. Using OFDM, capacity can be enhanced by adapting the data rate of per sub-carrier related to SNR of the specific subcarrier.

In OFDM, FFT size: 256=192 data subcarriers + 8 pilot subcarriers + 56 guard subcarrriers. Guard intervals are ¼, 1/8, 1/16, 1/32. Adaptive modulation is used such as BPSK, QPSK, 16QAM, 64QAM. Downlink multi-access is only based on TDMA and uplink is a combination of FDMA + TDMA. Channel bandwidth is from 1.75 to 20 MHz. Frequency sub channels are made of multiple and non-adjacent carriers.

In scalable OFDMA, FFT size is variable for different channel bandwidth from 1.25 to 20 MHz by keeping a fixed sub carrier spacing.
In OFDM, separate sub-channels are used for multiple access by several simultaneous users. OFDM guarantees many features like enhanced scheduling, better capacity, lesser interference (no intra-cell interference), improved link margin and QoS support.

2.1.2 Mac Layer

Generally MAC layer is responsible for providing reliable data delivery, error detection, framing and access mediation. The main task of MAC layer is scheduling data over physical resources. Besides this it will also perform power and mobility management. Security features are also there is WiMAX MAC layer. It will convert service data unit (SDU) to MAC protocol data unit (PDU) hence data packet at MAC layer is called PDU. PDU’s are of two types one is Generic MAC PDU and second is Bandwidth Request PDU. Bandwidth Request PDU is only used when a SS wants to request BS for bandwidth while for signaling and carrying data, the generic MAC PDU comes into play. Generic MAC PDU is shown in Figure 2.3. Cyclic redundancy check (CRC) is used to detect any errors i.e. error detection is performed via CRC. Payload contains data whereas sub header field is used to provide additional information like in case of mesh networking, mesh sub header is used and if SDU is fragmented over PDU then fragmentation sub header is used etc.

Figure 2.3 Generic MAC PDU

Generic header is shown in Figure 2.4. HT shows header type and EC is encryption control key. Type field indicated whether one or sub header is present or not. Extended sub header field (ESF) presence is shown by ESF bit. Length shows the entire length of PDU. Connection identifier (CID) identifies the connection between MAC/PHY entities.

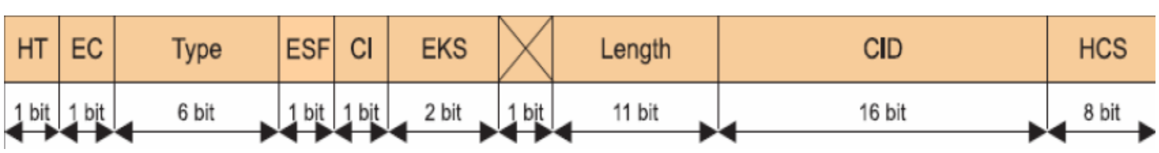

Figure 2.4 Generic Header

One of the three layers provided by WiMax MAC is convergence sub-layer (CS). Another layer which is the second one is common part sub-layer (CPS) and the last third layer is security sub-layer (SS). The main task of MAC layer is performed by CPS whereas SS is used to provide authentication and encryption and CS is used to provide interface to higher layers and to perform SDU suppression. Encryption is performed by SS to provide integrity and confidentiality to WiMAX network and authentication is used so that only valid SS can become a part of WiMAX network.

Access mediation is performed by CPS. MAC PDU is created by CPS. It is also responsible for mobility and connection management and reliable data delivery. For reliable data delivery it uses automatic repeat request (ARQ) which is optional or Hybrid ARQ (HARQ) as shown in figure 2.5 [2].

Figure 2.5 HARQ [2]

Quality of Service (QoS) is also very important MAC layer function which is performed by CPS in MAC layer of WiMAX. QoS is needed to support the applications like multimedia applications which require guaranteed bandwidth, less delay etc. QoS at MAC layer is actually defining different traffic categories (TC) and by setting priorities. These priorities settings depend on type of data i.e. data handed to MAC layer by upper layers so MAC layer tag a MAC frame i.e. adjusting its priority according to its QoS requirement. WiMAX support different scheduling services. A particular scheduling service depends on QoS requirement.

WiMAX uses TDD. WiMAX frame structure is shown in Figure 2.6

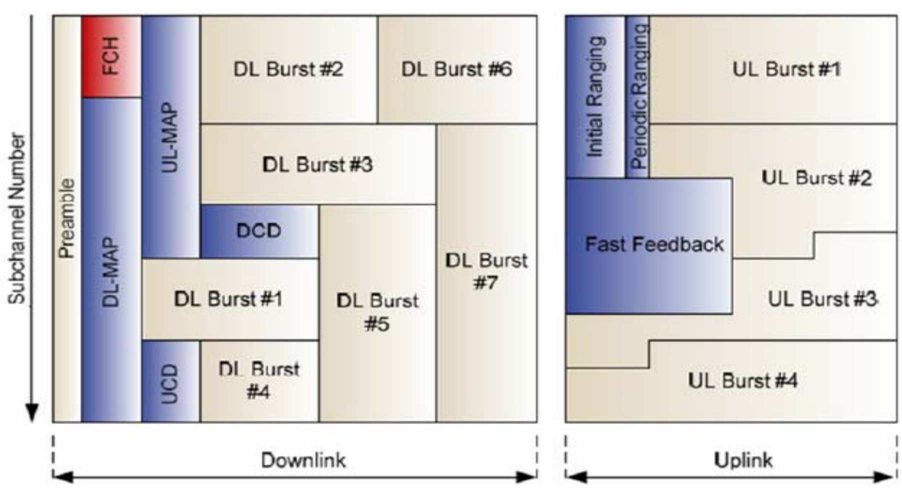

Figure 2.6 WiMAX Frame Structures

Preamble is sequence of bits that are used so that SS would identify the BS. Frame control header (FCH) contains information about DL-MAP length and sub Channel. UL MAP and DL MAP have bandwidth distribution and control information for the users. They also contain CID, symbols of OFDMA being used and number of sub channels. Downlink and uplink channel descriptor (DCD/UCD) contains physical layer parameters which may be type of modulation scheme and a type of coding scheme. SSs transmit ranging request at initialization and periodically at the request of the BS to determine power and burst profile changes. Fast feed back uses HAQR technique.
Following are some key MAC features.

1. <u>MAC Overhead Reduction</u>

Header compression technologies like IP Header Compression (ROHC) and general Purpose Header Suppression (PHS) are provided by the MAC layer of WiMAX. ROHC is a strong IETF standard which deals with header compression and is supported by WiMAX MAC layer. Header Suppression like PHS can be implemented over Ethernet regardless of the packet format (IPv4 or IPv6). This scheme is advantageous especially in case of IP and Ethernet destination addresses if significant portion of the traffic has same headers. The portion of the header which is recurring is replaced with a short identifier related to context. Therefore the overhead caused by the headers is reduced in this way.

2. <u>Handover</u>

WiMAX MAC layer support mobility feature that include a number of optimized handover procedures. In order to lessen the time consumption in finding the centre frequency and getting other parameters relating to the neighboring BS, the terminal moving device scans the wireless media of the neighboring base station while it is getting at a distance from the serving BS. Scanning results such as centre frequencies and other parameters of the neighboring base stations required for handover are then used in actual handover. Scanning can be done without interrupting the service. Serving base station ensures this by advertising the centre frequency of the neighboring BSs after a certain interval of time.
The time which is required for a mobile device to register itself with the new base station in a new cell can be cut down if the network has the ability to transfer the context related with moving end device from the present BS to new BS. Under ideal conditions, service interruption duration is as short as 5 ms during handover. Handover schemes used in a specific handover depend upon the situation and information available to mobile. These handover methods include FBSS (Fast BS Switching), Macro Diversity Handover, OHH (Optimized Hard Handover). WiMAX MAC supports mobile initiated, BS initiated and network initiated handover. Three way handshake for authentication ensures the security during handover and key validation. And in case of FBSS, security during handover is ensured by TEK sharing.

3. Security

Extensible Authentication Protocol (EAP) is provided by the security sub-layer of WiMAX MAC. The data blocks which are to be transmitted over the air are firmly encrypted by EAP to prevent and protect the data being transferred from unauthorized access. An authenticated key management protocol is deployed as client-server architecture under security sub-layer which makes BSs capable of allocation of keys and related parameters to mobile stations. This key management protocol also contains some components that enhance the security such as the verification and authentication of the mobile user through digital certificate provided by a trusted source. During fast handovers, pre-authentication with a particular target base station is used to help quick re-entry.

4. Power Saving

Power saving mechanisms is provided in the MAC layer of WiMAX under different circumstances. MS can switch to Idle Mode if it is not transmitting and receiving any traffic. In this mode it is no longer registered to any BS. The network can initiate a paging process to restart communication between the MS and the network.

The main method to save power is the use of Sleep Mode. For exponentially increasing specific time intervals, the MS stays away from BS in Sleep Mode. Unlike in idle mode, the mobile station remains registered with BS during these intervals however, it can turn down some circuits to save power consumption.

5. Connection-Oriented Data Transmission and QoS per Connection

WiMAX gives connection-oriented services. The type of traffic related to a connection is specified by certain classification rules for each service. For instance, it may be TCP/IP traffic to some destination internet address. MAC layer defines specific QoS parameters for each connection such as maximum sustained rate and minimum reserved rate. Different types of scheduling for diverse type of services such as real time services e.g., live broadcast, VOIP are opted according to that specific application needs. For instance, for voice over IP (IP Telephony), a certain type of scheduling mechanism is used named as ertPS which has the characteristics of silence suppression and adaptive codec's.

6. Flexible Bandwidth Allocation Mechanism

WiMAX MAC layer features dynamic bandwidth allocation to users in a cell with optimized procedures. Without making channels of the link, it makes best possible utilization of spectrum resources. End terminals having established connections make real time requests for bandwidth as required by them for bandwidth allocation. These bandwidth requests made at real time are attached with the data messages. In contention based scenario, these requests are not sent as attached with the data messages but separately. BS then performs resource allocations by analyzing these bandwidth demands along with QoS parameters of the connection.

Usually subscribers station request bandwidth incrementally when new bandwidth request is made, the requested bandwidth is included and added to the total apparent bandwith of requester subscriber station.

WiMAX MAC layer defines two classes of subscriber stations for handling different bandwidth allocations. In Grant Per Connection mode (GPC) the first set of subscriber station allows bandwidth awards for every connection. While in 2nd class of subscriber stations, all MS's bandwidth requests are granted and this class is termed as GPSS (Grant per Subscriber Station mode).

After analyzing status of queues at BS and MS, connections relating to specific service classes and QoS of connection, bandwidth scheduler determine the bandwidth requirements. BS monitors its own queues to calculate it bandwidth requirement at downlink and makes a decision to approve the bandwidth request or not.

7. Multicast and Broadcast Service

Multicast and Broadcast Services are provided by MAC layer of fixed and mobile WiMAX . Without any uplink transmission, mobile end stations can obtain data that is multicast and they can do even remaining in idle mode. TV broadcasting to mobile terminals is the most common instance of this feature. MS associates itself to broadcast region by forming paging groups. Downlink transmission is received but no uplink transmission is made.

2.2 Scheduling Algorithms

The subscriber stations request the bandwidth both in uplink as well as downlink direction on per frame basis using MAC layer messaging. Note that the demand of each SS may vary in both directions. Before the start of each physical layer frame transmission, depending upon the SS requests and QoS requirements, the scheduler at the BS decides the amount of data to be served to each SS both in uplink and downlink direction. The BS allocates the frequency-time resources within that frame for the SSs, both in uplink and downlink direction; such that the data demand of requesting SS can be served. No scheduling and resource allocation algorithm has been specified in IEEE 802.16 standard. Vendors of WiMAX hardware may use any scheduling and resource allocation algorithm to achieve specific performance.

In WiMAX networks, scheduling and resource allocation are closely related. In general, the scheduler cannot schedule the amount of data in one frame for which the resource allocator cannot allocate resources within the same physical frame. Although it is possible to schedule the data for multiple frames simultaneously, such a scheduling decision may not be able to provide tight time guarantees and may lead to short term starvation for some subscribers. Such events can also lead to disconnection of SS.

WiMAX base station has two schedulers running at MAC layer. Downlink data scheduler which schedules the data for downlink frame. Uplink grants scheduler which schedules

for the uplink frame. The scheduler mapping is based on Connection Identifier (CID). Which is a temporary and logical address assigned by the BS that identifies a connection between the peer MAC/PHY entities.
Figure 2.7 shows the mapping of CID's for base station downlink data scheduler.

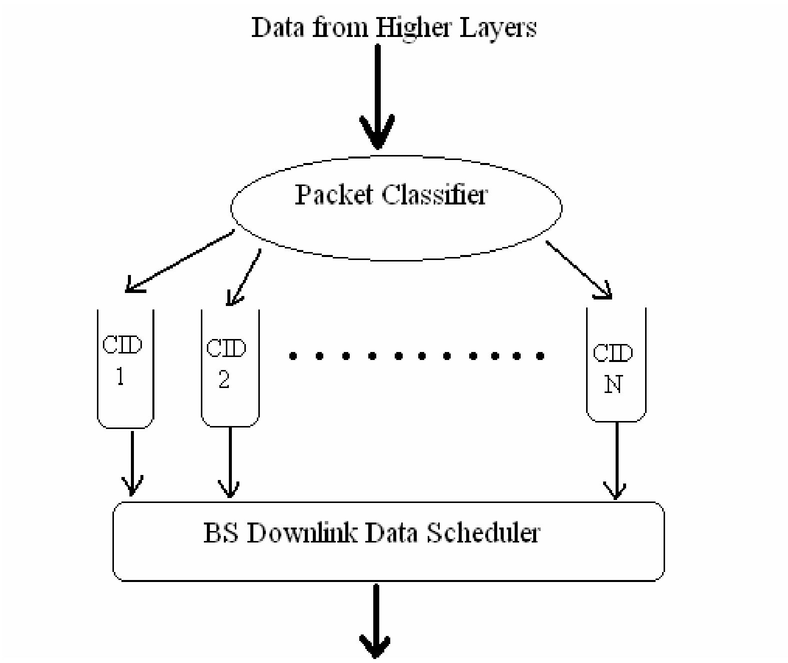

Figure 2.7 Mapping for Downlink Data scheduler

Figure 2.8 shows the mapping of CID's for base station uplink grant scheduler.

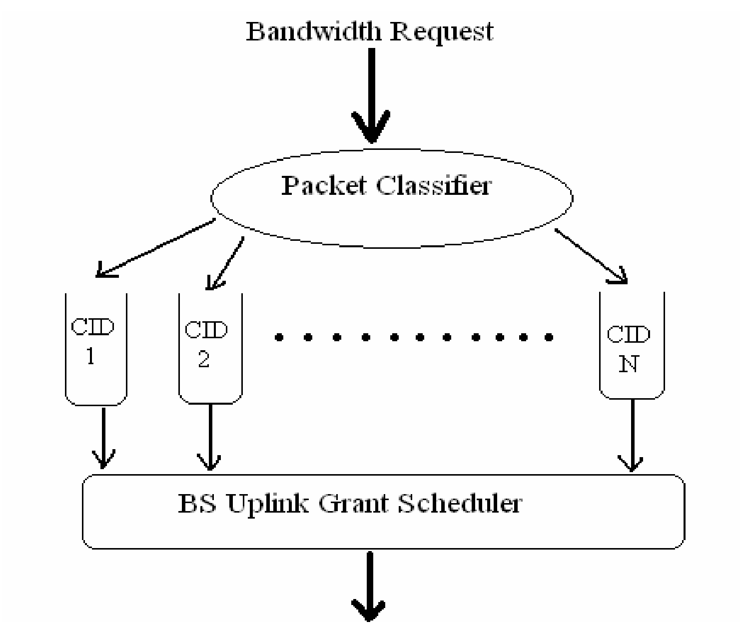

Figure 2.8 Mapping for Uplink Grant scheduler

A variety of algorithms perform scheduling in WiMax MAC layer, some of the famous are Max CIR (Carrier to Interference Ratio), Round Robin and Proportional Fair.[4, 5, 6].

2.2.1 Max Carrier to Interference Ratio Scheme.

In Max Carrier to Interference Ratio (Max C/I) Scheme, max resources are allocated to SS having Max CINR so it schedules the maximum amount of data for it. The received signal power (RSP) is inversely proportional to distance between BS and SS as shown in Figure 2.9. Different SSs may receive different carrier to interference and-noise-ratio (CINR) depending upon their distance from BS and interference in their neighborhood. BS selects the most suitable modulation and coding scheme (MCS) for each SS to ensure robust transmission. This dynamic selection of modulation and coding scheme (MCS) is known as Adaptive MCS (AMC).

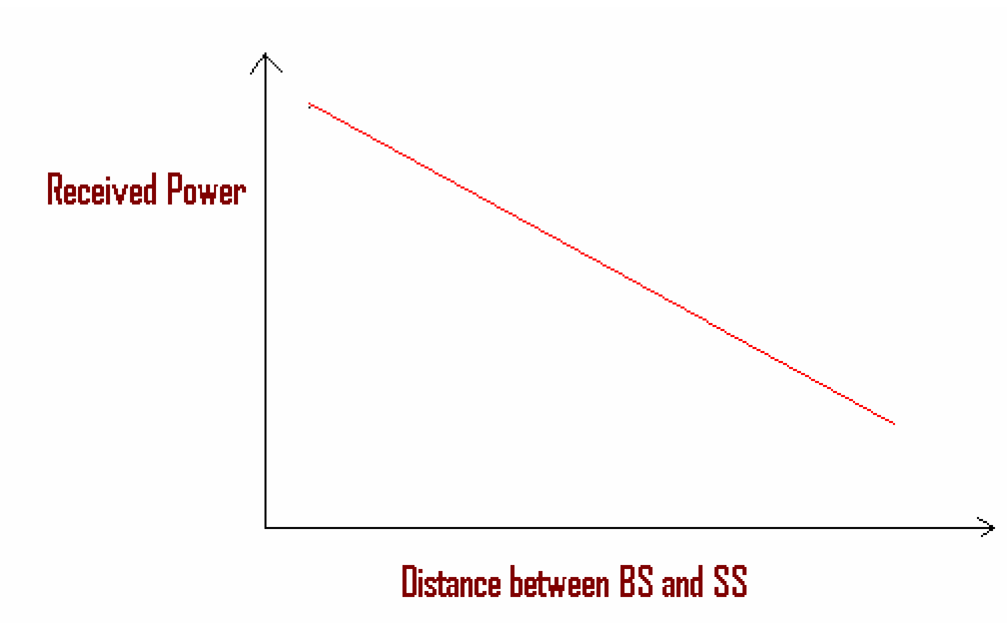

Figure 2.9 Received power as a function of distance

Because of the AMC, throughput from a unit PHY layer resource (sub-channel time slot) can vary significantly depending upon the CINR of the SS. A single SS with bandwidth request of a unit data using QPSK with 1/2 CTC (due to low CINR) may require more PHY layer resources compared to multiple SS each demanding unit data using 64-QAM with 5/6 CTC. Therefore, AMC has direct impact on the resource allocation. If throughput of the network is maximized without fairness, the SS with low CINR should be ignored and will experience starvation. On the other hand, if fairness is considered, providing fair share to low CINR users will require a lot of resources which will result into low throughput of the network.

Consider a WiMAX network with a BS and 5 SS's. SS1 and SS2 are far away from BS so both have low CINR. Higher modulation scheme can also be used for SS's having more CINR so the use of this modulation scheme can cause significant improvement in some individual SS's throughput but does not give overall enhancement of the throughput as subscriber stations bearing low CINR cannot opt to use higher modulation and coding techniques. If throughput is maximized, SS1 and SS2 will get less number of slots because of their low CINR thus affecting their data requirements and may result in their starvation as shown in Figure 2.10.

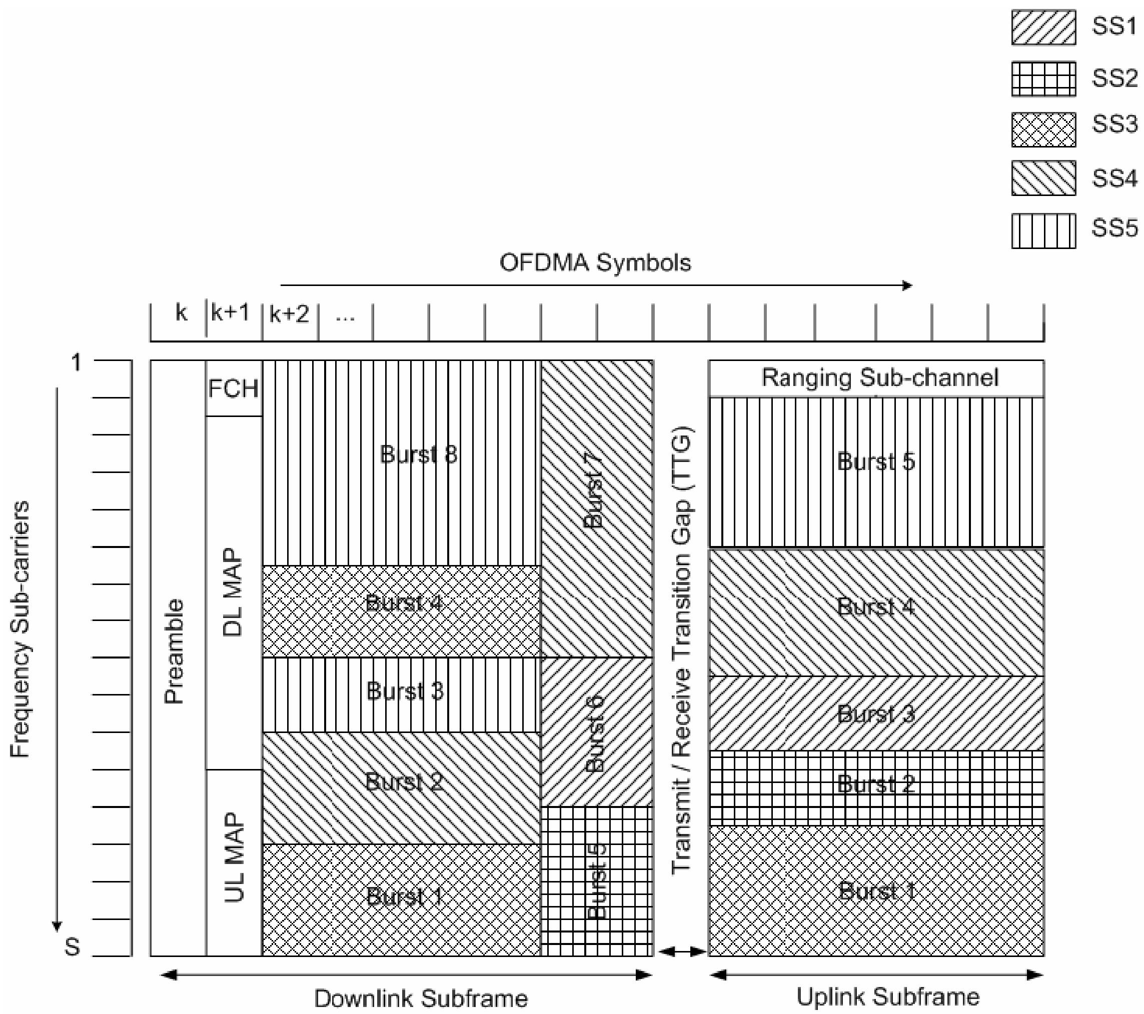

Figure 2.10 Throughput maximizing scheme

2.2.2 Fair Share Scheme.

Fair share (FS) scheme provides equal number of time slots to every SS irrespective of their CINR. Hence in a case of 5 SS's where SS1 and SS2 has low CINR value but they get equal number of time slots, as all the subscribers share same number of slots per frame. As a consequence, throughput of the network is low as SS1 and SS2 require more sub channel time slots for completing their transmissions because of their low CINR and MCS. Figure 2.11 shows FS scheme in which every SS shares equal number of time slots.

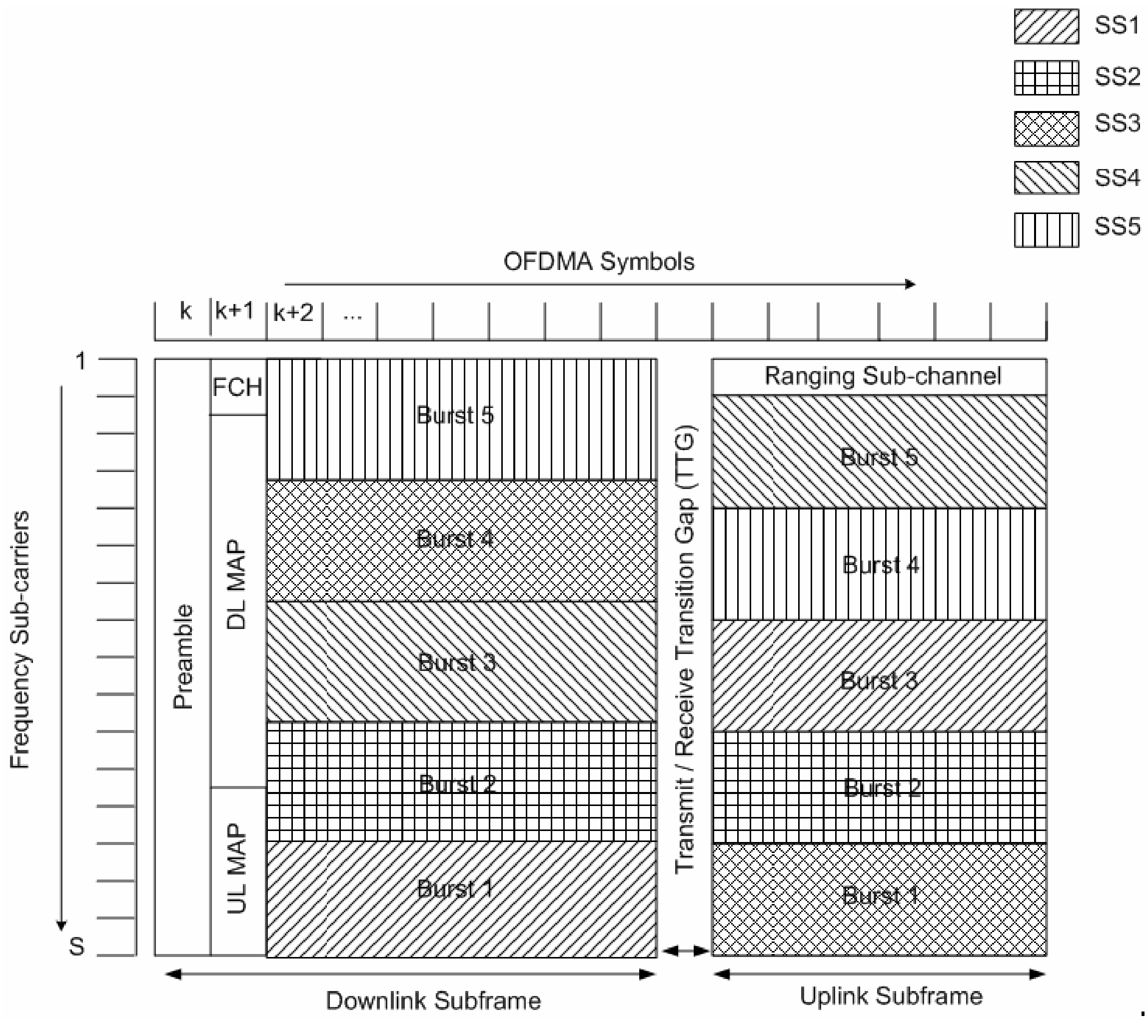

Figure 2.11 Fair Share scheme

2.2.2.1 Round Robin Scheme.

Round Robin (RR) is simplest scheduling scheme which gives equal time slots one by one to each traffic flow and for resource allocation of different SS's it provides every user one after the another a time slot of certain amount of time for each of them one by one and repeat the same process in a cycle. Hence in a case of 5 SS's each SS has all time slots in one particular time. Although this scheme will provide fairness among different SS's in a sense that all get equal time slots but it was shown in [7] that RR scheme does not provide fairness among traffic flows if data packets size is variable. The advantage of this scheme is that it is starvation free as SS which is far away from BS and have low

CINR requires more time slots to complete its transmission so in this case it will not face starvation.
There is one disadvantage that there is no Quality of Service (QoS) mechanism in this scheme as all user can get equal amount of time irrespective of their demand.

2.2.3 Proportional Fair Scheme.

Proportional fair is a scheme that tries to give minimum level of service to all users. This scheme basically assign priorities to each flow hence this scheme can also provide QoS There are different priority classes which are assigned to traffic flow. Weighted Fair Queuing (WFQ) is one of the methods to implement proportional fair. In WFQ each flow has assign a priority which is inversely proportional to resource consumption for instant priority for data flow i is

$$P_i = 1/R_i$$

Where R_i is the resource consumption of flow i. There are different ways to assign priority functions to each flow. Proportional fair is a scheme that compromises between maximum throughput and fairness.

2.2.3.1 Weighted Fair Queuing (WFQ).

WFQ is selected as scheduling scheme for traffic both in uplink and downlink in IEEE WiMAX MAC 802.16 standard. Flows classified in UGS, rtPS, nrtPS and BE are mapped using WFQ. These different classes are then assigned different weights according to their minimum bandwidth requirement.
Weighted Fair Queuing is defined as a hashing algorithm which sets different flows of data into separate queues and the numbers of packets which are to be processed simultaneously are determined by the weights of the queues. The method of determining weights is arbitrary. WFQ functions as if it has many windows. As soon as a packet is received, the classifier classifies it and places it on one of the window. Diverse windows have different weights awarded by different kinds of applications based on their QoS requirements. The window serves as an entry point to the queue.
Different traffic classes are scheduled by MPFQ (Multi Class Priority Fair Queue) scheduler. Every traffic class is scheduled conforming to different CIDs (Connection Identifiers). Transmit order is formed by assigning weight to each queue by WFQ.

2.3 Problem Statement

The problem of achieving an optimal operation point where throughput is maximized while ensuring fairness among a selected group of subscribers while providing maximum residual resources for remaining subscribers has not been explored.

The objective of proposed research study is to maximize the throughput of WiMAX networks through efficient scheduling and resource allocation While a certain level of fairness must be ensured for most of the SS connected to a BS, the group of SS that are capable of achieving very low data rates because of MCS may only be offered best effort service where only residual resources are allocated to such subscribers.

Chapter 3

Optimum Scheduling Scheme

3.1 Proposed Scheduling Scheme

We propose a new scheme to optimize WiMAX network based on a compromise between Max C/I and FS algorithms. In this scheme we reserve some time slots for the users which are at the edges of a WiMAX cell. Edges SS's will share equal slots among them from reserve slots. The remaining slots are provided to other users according to Max C/I scheme. SS's which are at the edges of a cell used timeslots from the reserved time slots hence enough time slots are available to them which can solve starvation problem. The remaining time slots (which are not reserved) are available to users which are near to BS and they will use these slots according to throughput maximizing scheme. Hence this scheme tries to maintain network throughput.

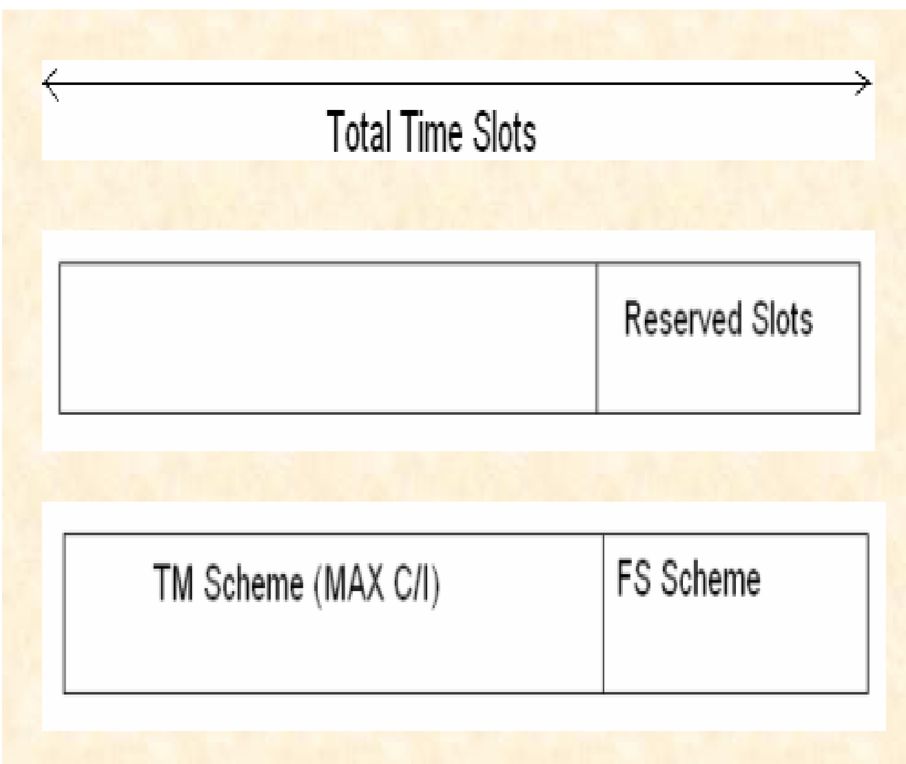

Figure 3.1 Optimum Algorithm

Initially we test this algorithm by reserving 30% 40% and 50% of the total time slots as shown in figure 3.2 and compare the results with Max C/I scheme and fair share scheme.

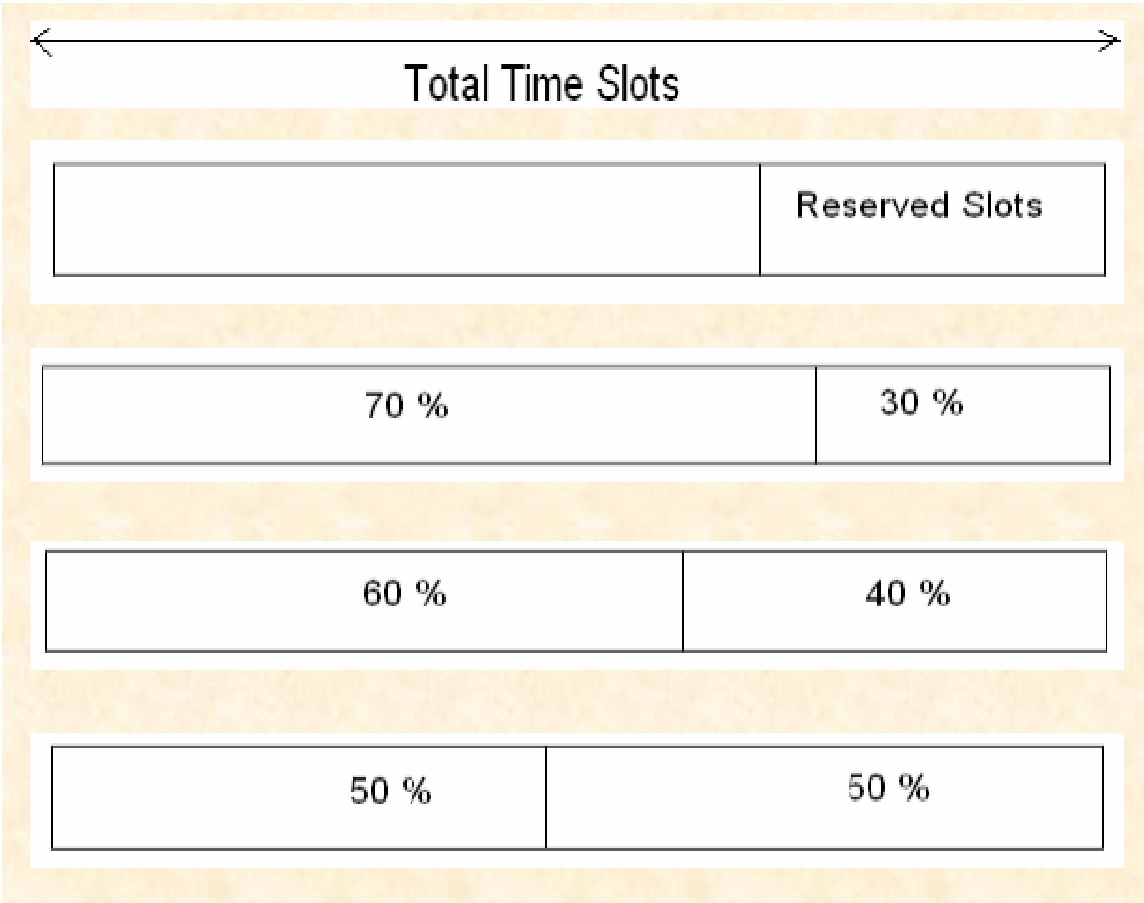

Figure 3.2 Different Reservation Percentages

If users are not distributed uniformly in WiMAX cell e.g. if there is a case that if more then 80% users are at edges of a cell (or having less CINR / Lower modulation scheme) then this reserve slot percentage should be dynamic according to edge user's percentage. For this purpose we make this decision dynamic i.e. BS will decide this reservation percentage on a basis of users which are at the edges of a WiMAX cell or having low CINR value (lower modulation) i.e. if 80% of users are at edges of a cell than BS will reserves 80% slots for them. Flow chart of the algorithm is shown in figure 3.3

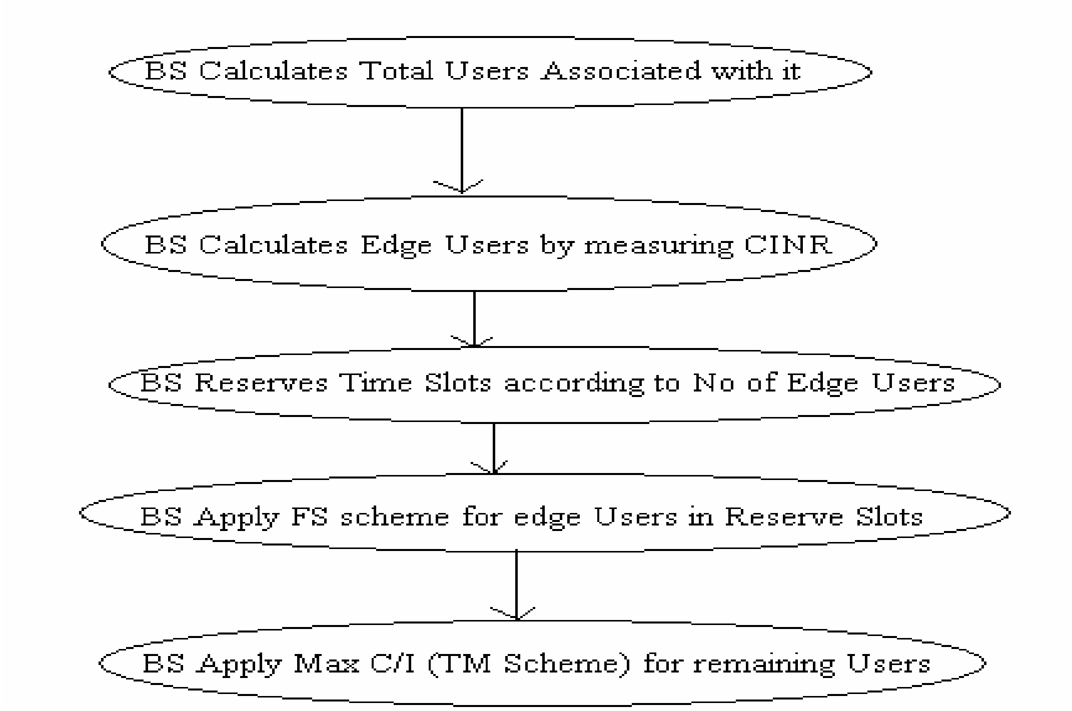

Figure 3.3 Flow Chart of Algorithm

Chapter 4

Simulation Setup

4.1 Simulation Setup

We use network simulator NS-2.31 and NIST (National Institute of Standards and Technology) WiMAX patch. NIST WiMAX patch support the following features

- Wireless OFDM
- Time Division Duplexing (TDD)
- Network entry messages
- Fragmentation and reassembly of frames
- Scanning and handovers

4.2 Scenario

Figure 4.1 shows the scenario of simulation setup. In this figure there is one WiMAX base station, one sink node and multiple WiMAX nodes distributed randomly around BS.

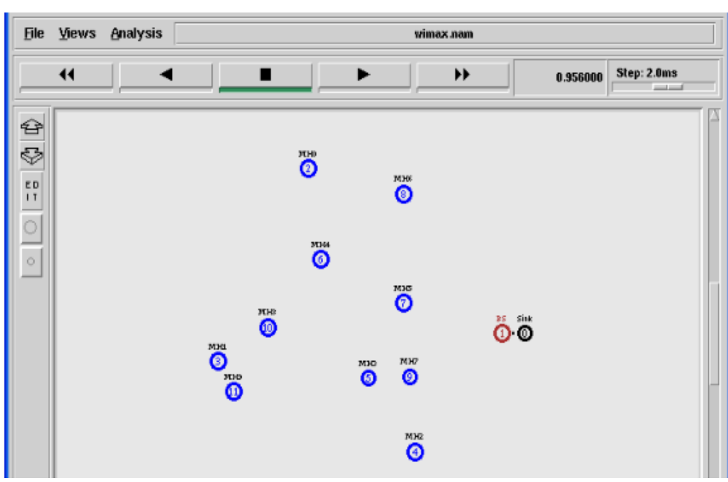

Figure 4.1 Simulation Scenario

Other parameters of simulation scenario are as following

- **Channel type:** Wireless
- **Radio Propagation model:** Two Ray Ground
- **Physical profile:** OFDM
- **MAC type:** MAC/802_16
- **No of nodes:** 4-40
- **Packet size:** 1500 bytes
- **Frame duration:** 0 .004
- **Modulation:** Adaptive
- **Interface queue size:** 50 packets
- **Maximum data rate of a link between BS and Sink:** 100 Mbps
- **Delay:** 3.42 msec

Chapter 5

Results and Discussions

5.1 Max C/I and FS Scheme

Consider a simulation scenario as shown in figure 5.1.

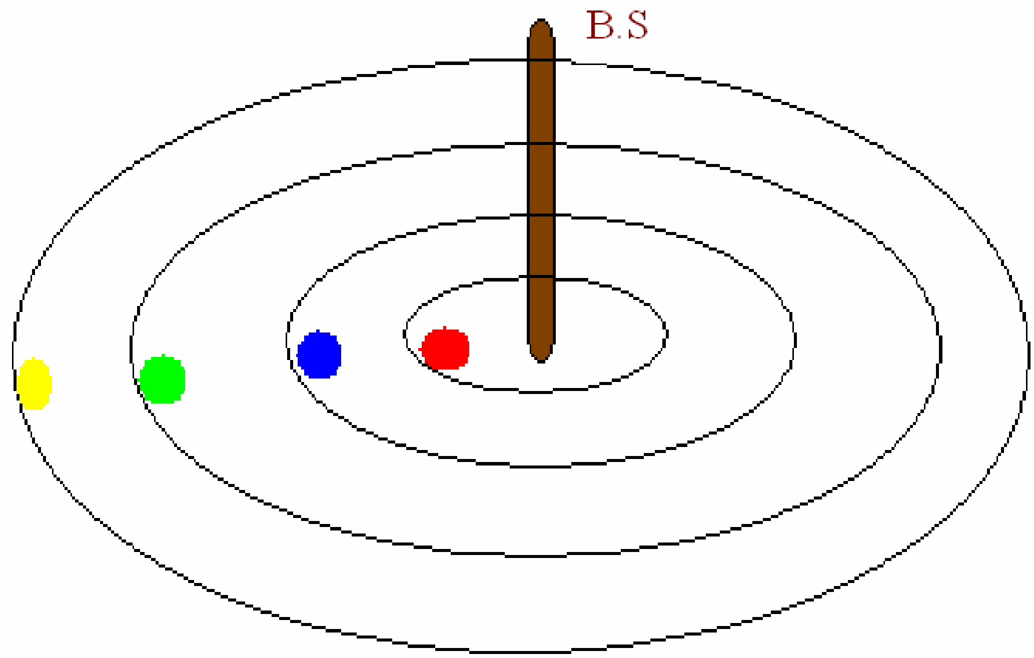

Figure 5.1 Simulation Scenario

Figure 5.2 shows the average throughput of Max C/I scheme having four SS's. Because of the AMC, throughput from a unit PHY layer resource (sub-channel time slot) can vary significantly depending upon the CINR of the SS. A single SS using QPSK (due to low CINR) may require more PHY layer resources compared to multiple SS each using 64-QAM.If throughput of the network is maximized without fairness, the SS with low CINR should be ignored (as they required more physical resources) and will experience starvation. SS_3 which is at the edge of WiMAX cell will face starvation as shown in figure.

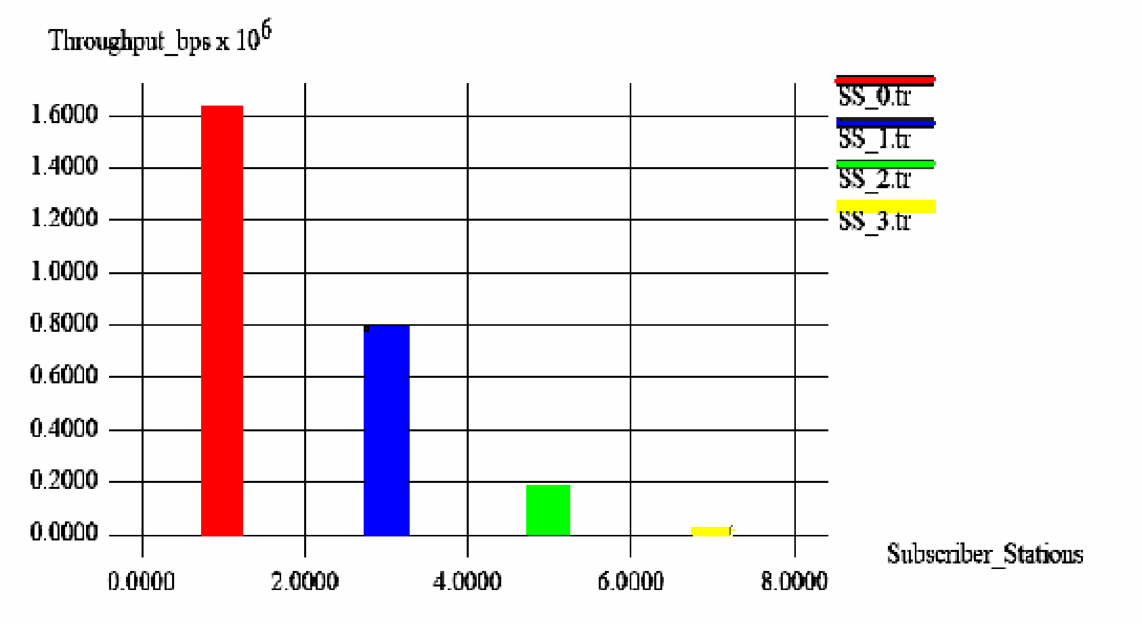

Figure 5.2 Average Individual Throughputs (Max C/I)

Figure 5.3 shows the average throughput of four SS's in case of FS scheduling scheme. As in FS all SS's shares same number of slots per frame hence SS_3 which is at the edge of a cell faces starvation in case of Max C/I scheme will not starve in FS scheme due to enough slots available as shown in figure bellow. The difference in throughput is due to adaptive modulation in WiMAX.

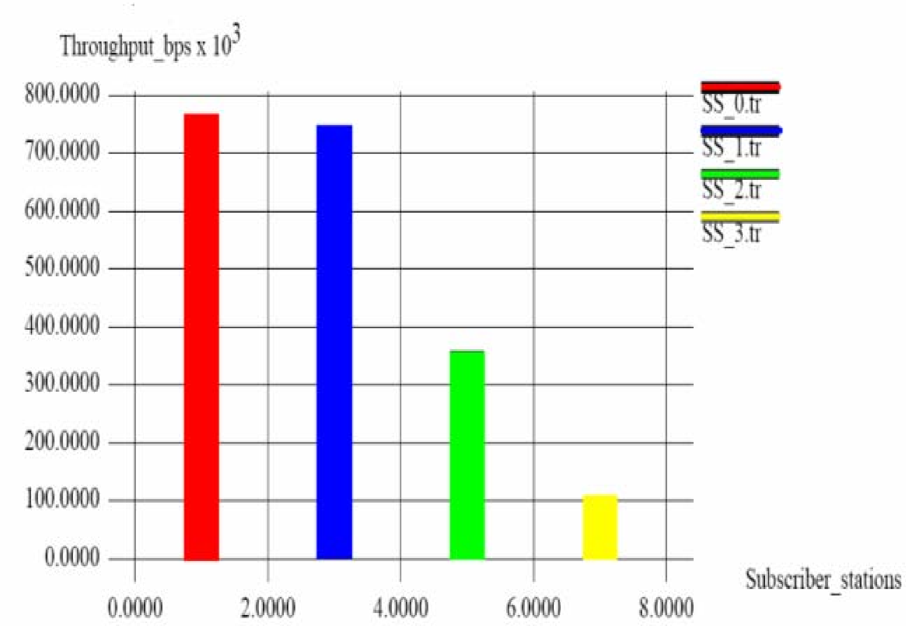

Figure 5.3 Average Individual Throughputs (Fair Share)

Table 5.1 shows the average individual throughput of four SS's in Max C/I and FS schemes.

Table 5.1 Individual Throughputs Comparison (Max C/I and FS)

Nodes	**Max C/I**	**F.S**
SS_0	1.6 Mbps	780 Kbps
SS_1	800 Kbps	750 Kbps
SS_2	200 Kbps	350 Kbps
SS_3	30 Kbps	110 Kbps

FS solves the problem of starvation as in FS all the subscribers share same number of slots per frame. As a consequence, throughput of the network is low as some SS require more sub channel time slots for completing their transmissions because of their low CINR and MCS. Average network throughput comparison of FS and Max C/I are shown in figure 5.4.

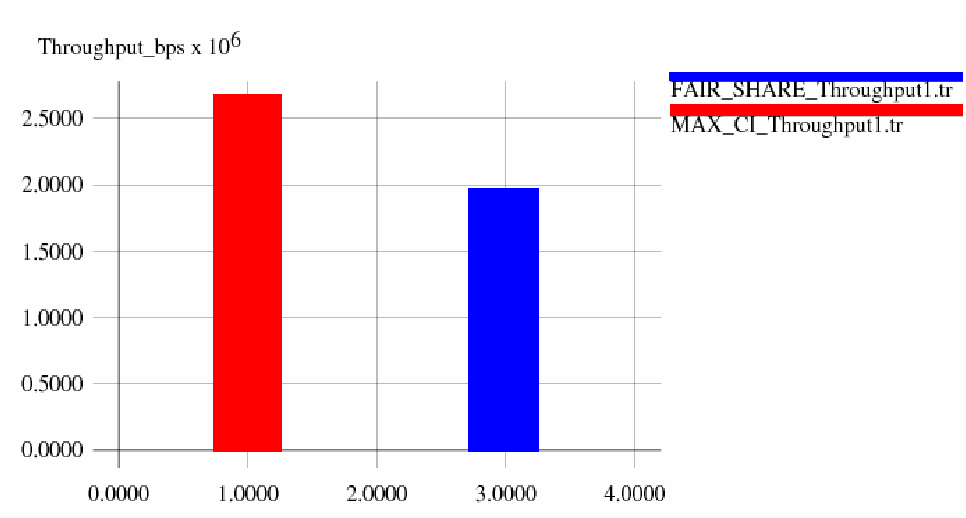

Figure 5.4 Network Throughputs Comparison

5.2 Optimum Scheme

Average individual's throughput of all SS's using optimum scheduling scheme is shown in figure 5.5.

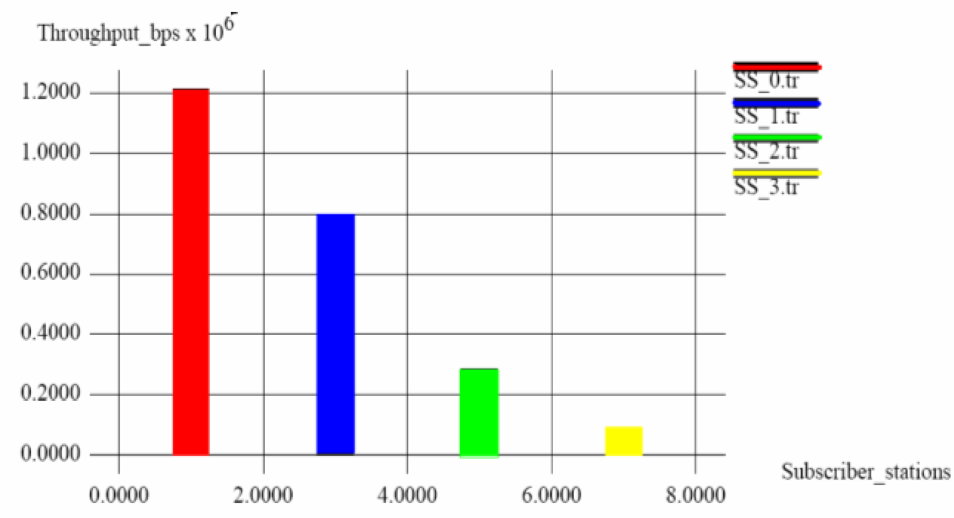

Figure 5.5 Average Individual Throughputs (Optimum)

Table 5.2 shows the average individual throughput of four SS's in Max C/I, FS and Optimum schemes.

Table 5.2 Individual Throughputs Comparison (Max C/I, FS and Optimum)

Nodes	**Max C/I**	**F.S**	**Optimum**
SS_0	1.6 Mbps	780 Kbps	1.2 Mbps
SS_1	800 Kbps	750 Kbps	800 Kbps
SS_2	200 Kbps	350 Kbps	300 Kbps
SS_3	30 Kbps	110 Kbps	90 Kbps

Optimum algorithm solves the problem of starvation. It also increases the network throughput. Individual throughput of SS_3 is compared in all scheduling schemes and results shows that there is no starvation except for Max C/I scheme as shown in figure 5.6.

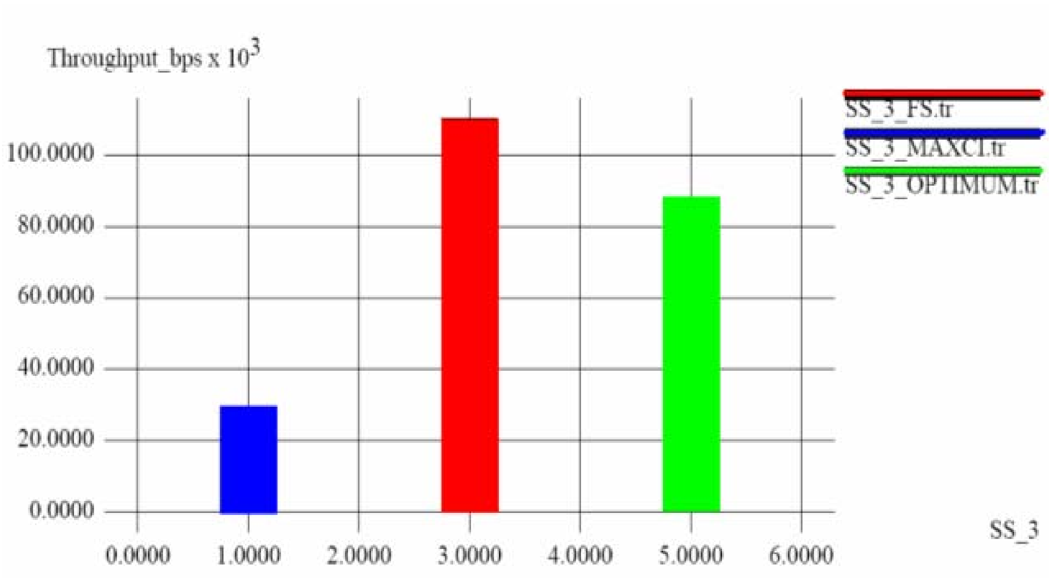

Figure 5.6 Edge SS Throughputs

Network throughput of optimum algorithm is also compared with all scheduling algorithms and results show that optimum scheme tries to maintain the throughput of the network as shown in figure 5.7.

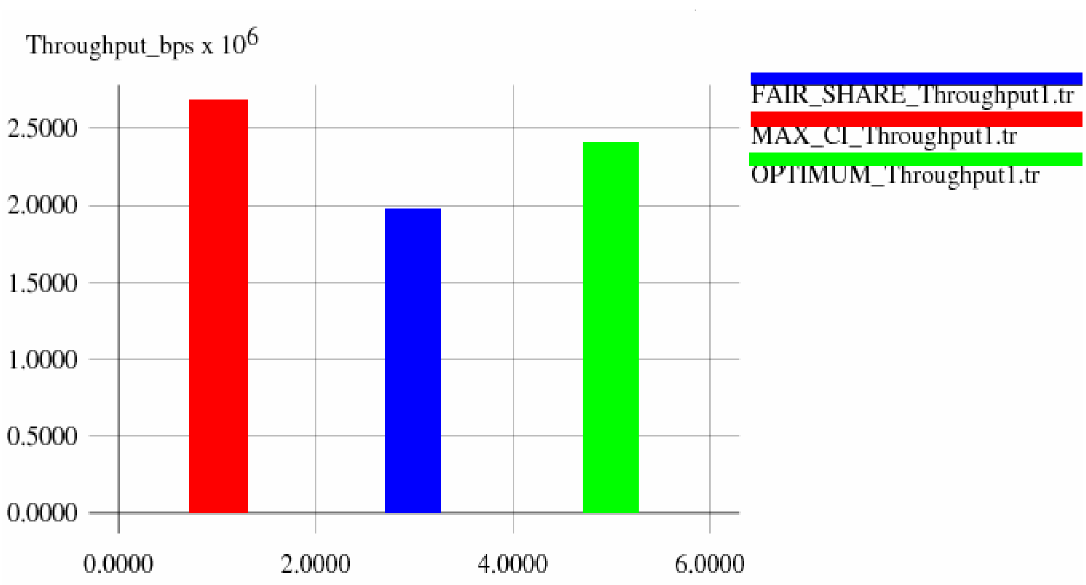

Figure 5.7 Network Throughputs Comparison

Table 5.3 shows the summary of network throughput and edge SS throughput in Max C/I, FS and Optimum schemes.

Table 5.3 Throughputs Comparison (Max C/I, FS and Optimum)

Scheduling Schemes	**Network Throughput**	**Edge SS Throughput**
Max C/I	2.7 Mbps	30 Kbps
F.S	1.9 Mbps	110 Kbps
Optimum	2.4 Mbps	90 Kbps

Consider a WiMAX cell with a BS and multiple SS's. If we divide the cell in two regions one is for SS's near to BS and second region is for edges SS's as shown in figure 5.8.

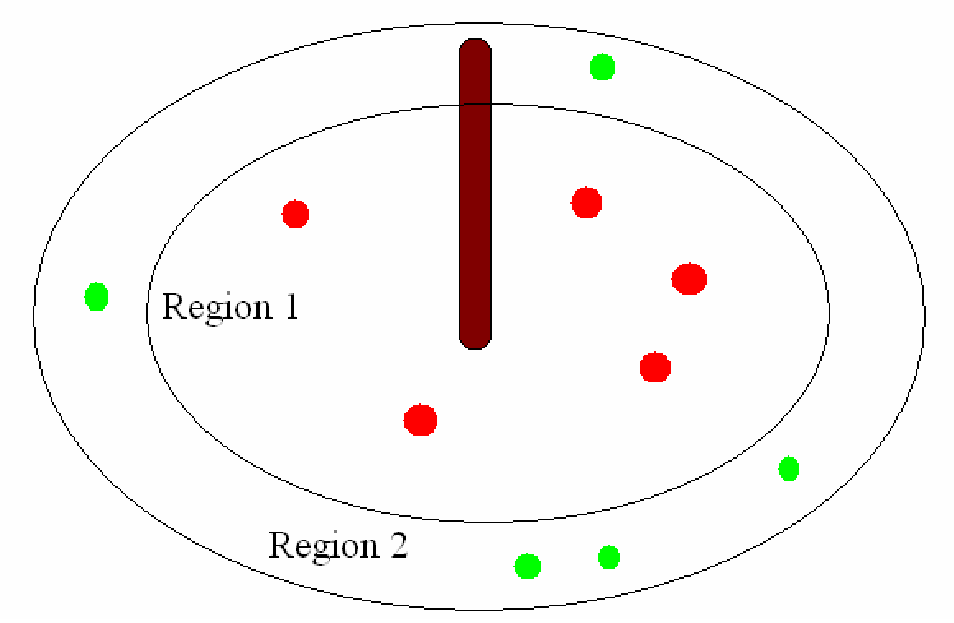

Figure 5.8 WiMAX Cell with two regions

Table 5.4 shows the average throughput per user in two different regions in case of Max C/I, FS and Optimum schemes.

Table 5.4 Average Throughput per User

Scheduling Schemes	**Average Throughput Per User**	
	Region 1	**Region 2**
Max C/I (T.M)	866.6 Kbps	30 Kbps
F.S	626.6 Kbps	110 Kbps
Optimum	766.6 Kbps	90 Kbps

Figure 5.9 shows individual throughput of a SS w.r.t distance. Figure shows that in case of Max C/I scheme SS has more throughput in the beginning but it decreases rapidly if SS moves towards the edge of a WiMAX cell. In case of FS scheme SS will not starve at the edge of a cell but it has lower throughput in the beginning. Optimum Scheme tries to compromise between Max C/I and FS as shown.

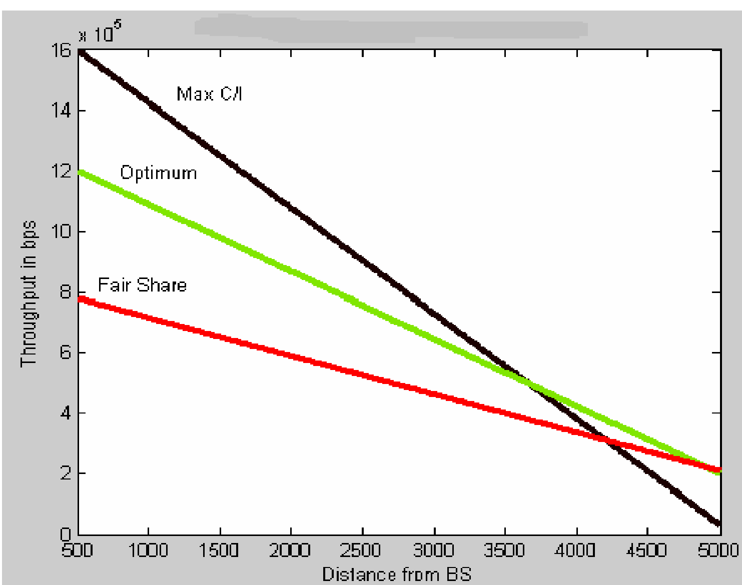

Figure 5.9 Throughputs Comparison w.r.t distance

Packet loss of a SS w.r.t distance is also calculated as shown in figure 5.10.Figure shows that packet drop is more in case of Max C/I at the edge of a cell but packet loss is less in case of Optimum algorithm.

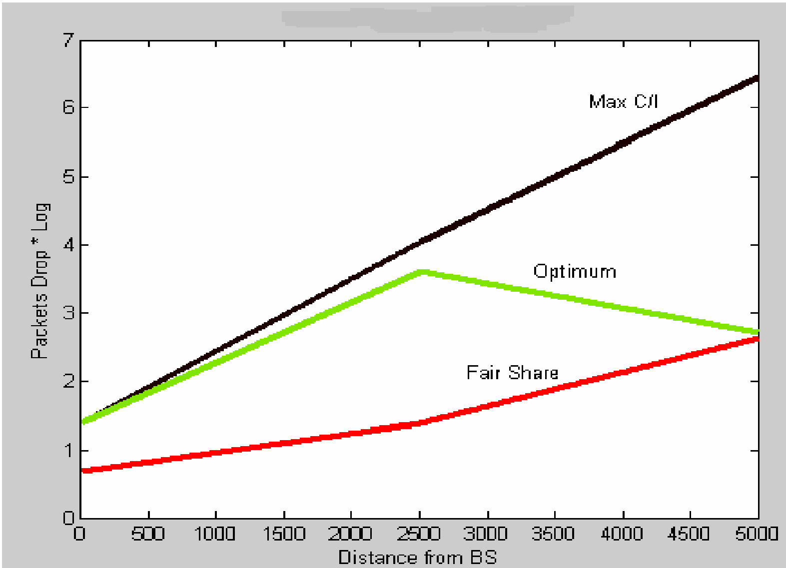

Figure 5.10 Packet Loss of a SS w.r.t Distance

We also compared different reservation schemes i.e. 30% 40% and 50% reservation of time slots and results are shown in figure 5.11. Result shows that by increasing the reservation slot percentage affects the network throughput i.e. network throughput decreases as FS scheme is applied in reserved slots.

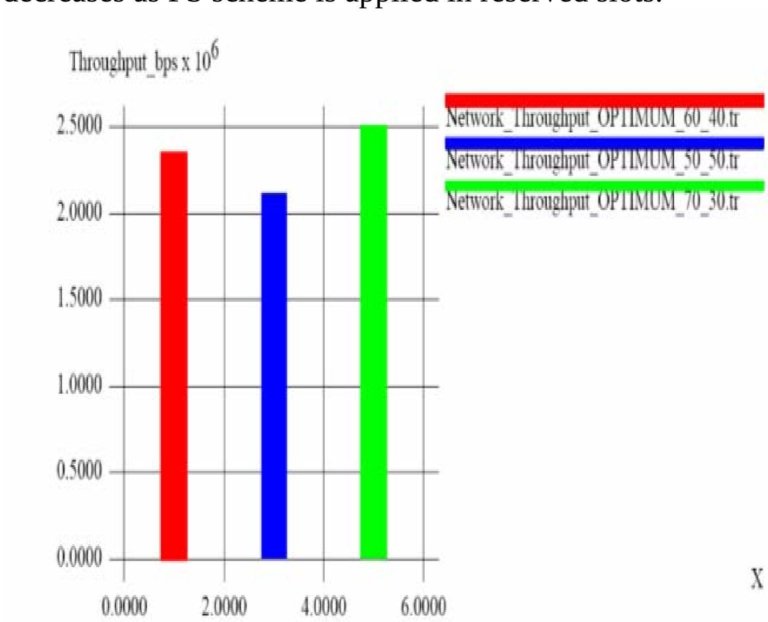

Figure 5.11 Throughput Comparison in different Reservations Schemes

Network throughput decreases as FS scheme is applied in reserved slots but on the other hand individual throughputs of edge SS's increases as enough slots are being provided to them as show in figure. Hence SS_3 which is at the edge of a cell has maximum throughput incase of 50% reservation and minimum throughput in case of 30% reservation although it will not face starvation whether 50% reservation scheme will used or 30% as shown in figure 5.12.

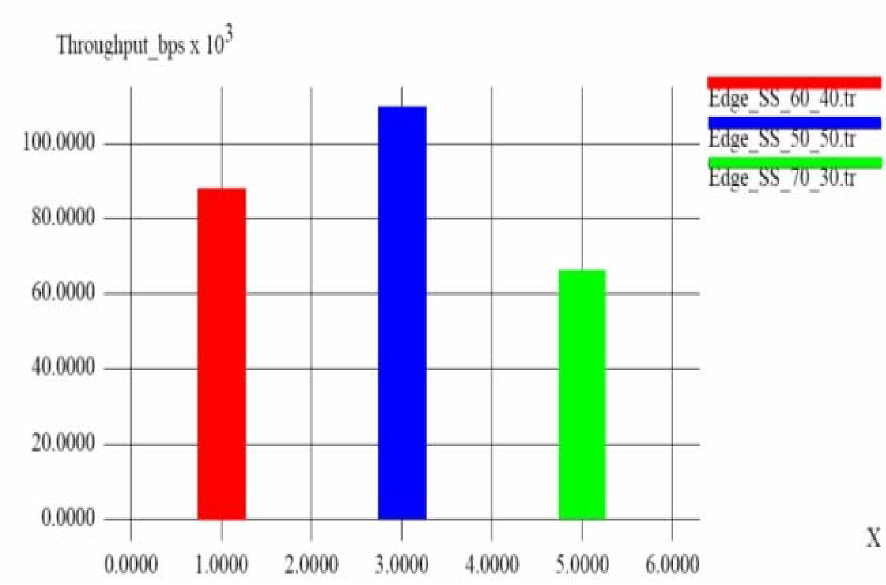

Figure 5.12 Edge SS Throughputs

We also apply four different combinations of throughput maximizing (TM) scheme and fair share (FS) scheme in time slots as shown in figure 5.13.

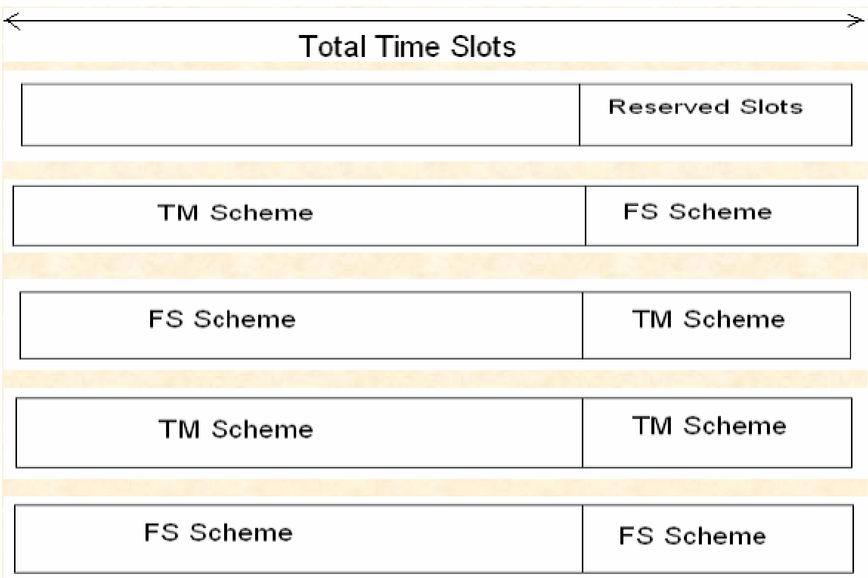

Figure 5.13 Different ways of applying Scheduling Schemes

Network throughput comparisons by applying four different combinations in time slots are shown in figure 5.14. It shows that network throughput is good if we apply TM scheme for the users near to BS but if we apply TM scheme in reserved slots then throughput deceases.

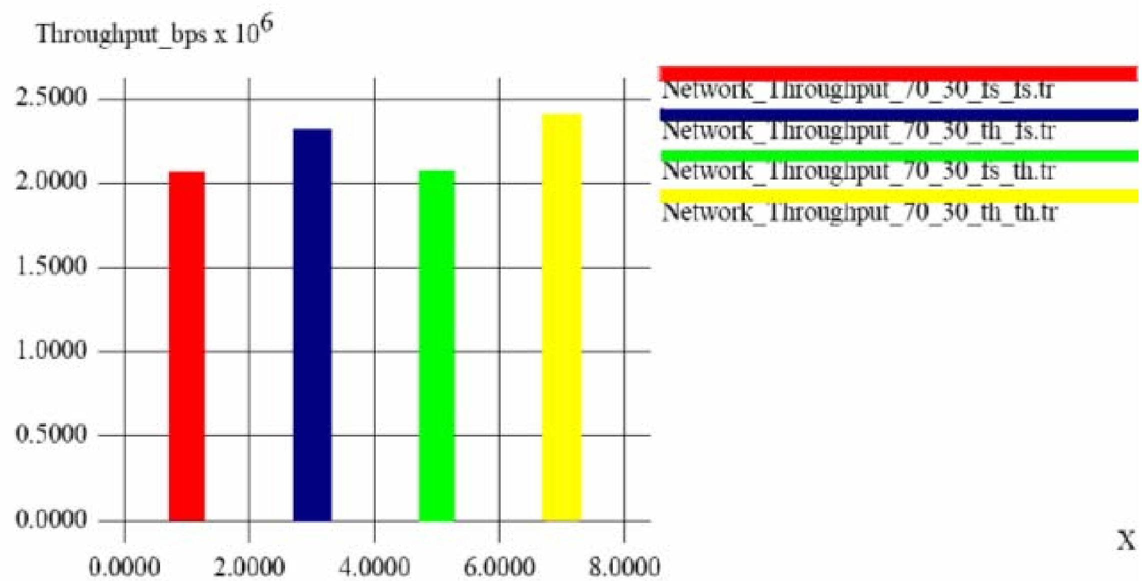

Figure 5.14 Network Throughput Comparisons

Figure 5.15 shows the individual throughput of edge SS. It is clear from the figure that TM scheme cannot be applied in reserved time slots as edge SS's will face starvation if we apply TM scheme in reserve time slots.

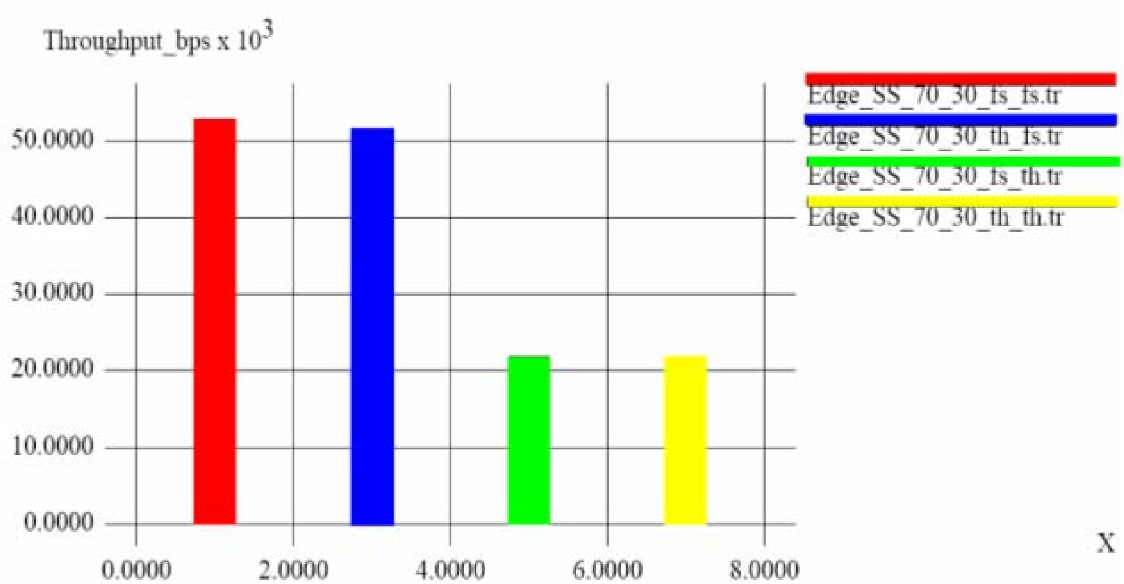

Figure 5.15 Edge SS Throughputs

5.3 Dynamic Decision of Reservation Slots Percentage

If users are not uniformly distributed then this reserve slot percentage should be dynamic according to edge user's percentage. BS will decide this reservation percentage on a basis of users which are at the edges of a WiMAX cell or having low CINR value (lower modulation).We consider two extreme case one in which 20% SS's are at edges (20% slots will reserved for edge SS's) and in another 80% SS's are at edges (80% slots will reserved for edge SS's).
Figure 5.16 shows the average individual throughputs in case 20% SS's are at edges.

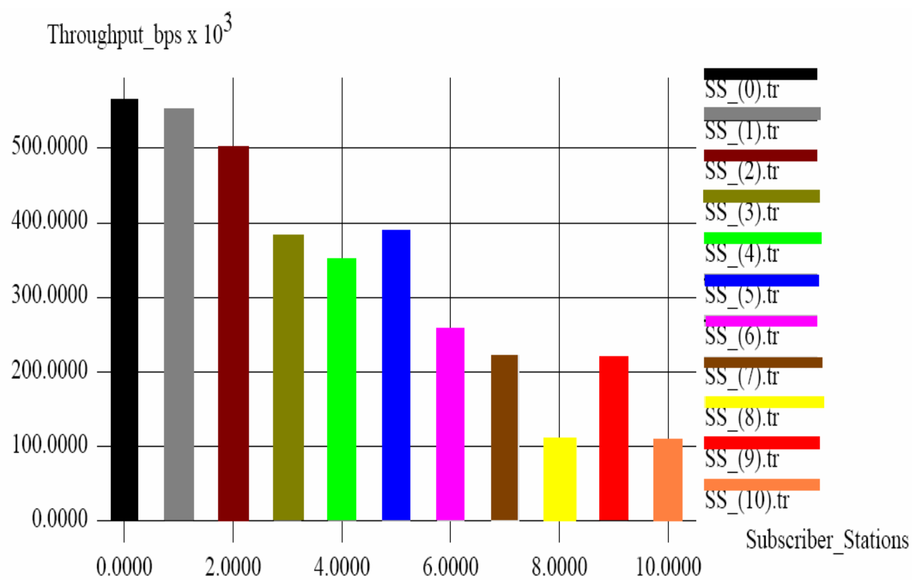

Figure 5.16 Average Individual Throughputs (20%)

Figure 5.17 shows the average individual throughputs in case 80% SS's are at edges.

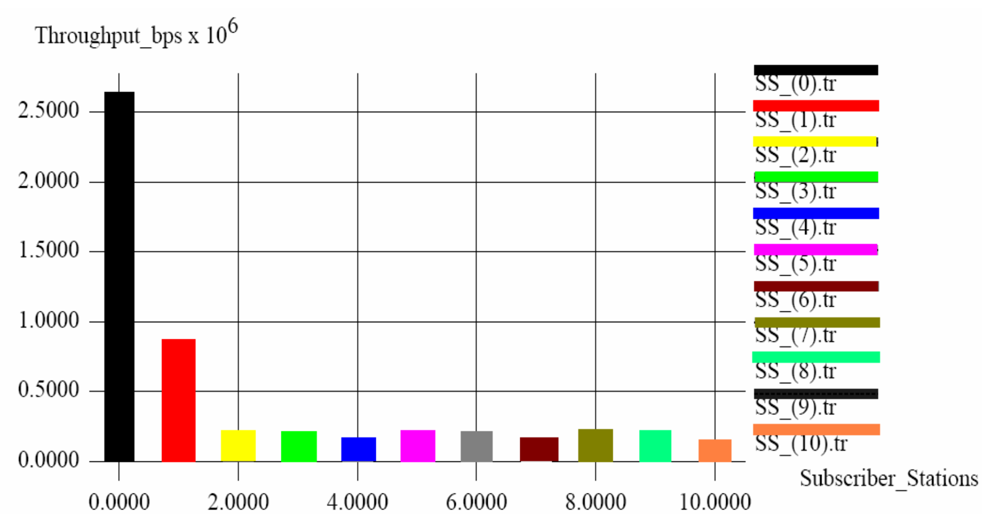

Figure 5.17 Average Individual Throughputs (80%)

Network Throughputs in case of 20% and 80% reservation is shown in Figure 5.18. Since in case of 20% reservation Fs scheme will apply in these reserve slots and Max C/I scheme will apply in remaining 80% of the slots hence network throughput is more in case of 20% reservation..

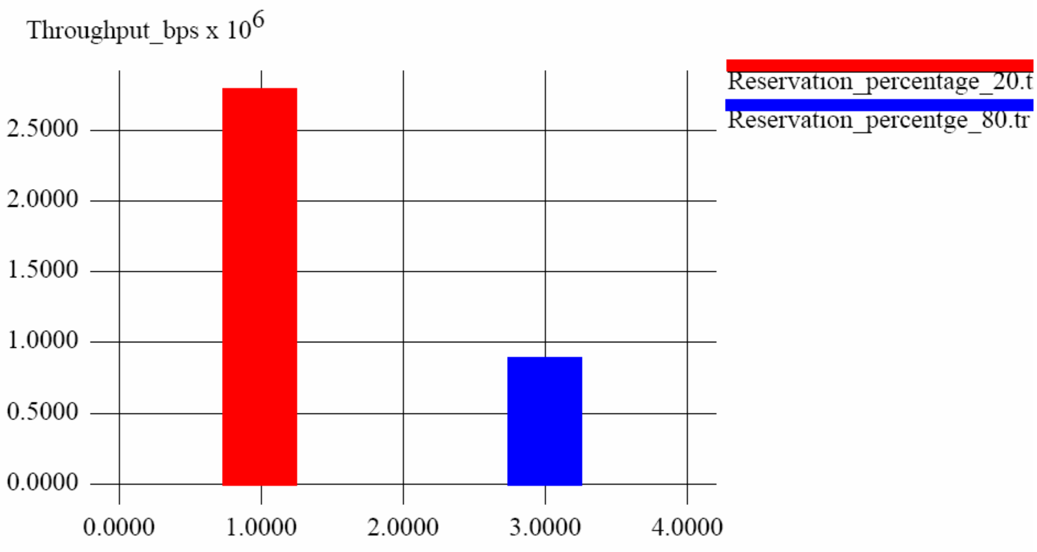

Figure 5.18 Network Throughput Comparisons

Figure 5.19 shows Network Throughputs with increase of SS's in the network. As newer SS's will use slots among the tot al slots of the uplink and downlink frame hence network throughput decreases with increase of SS's in the network.

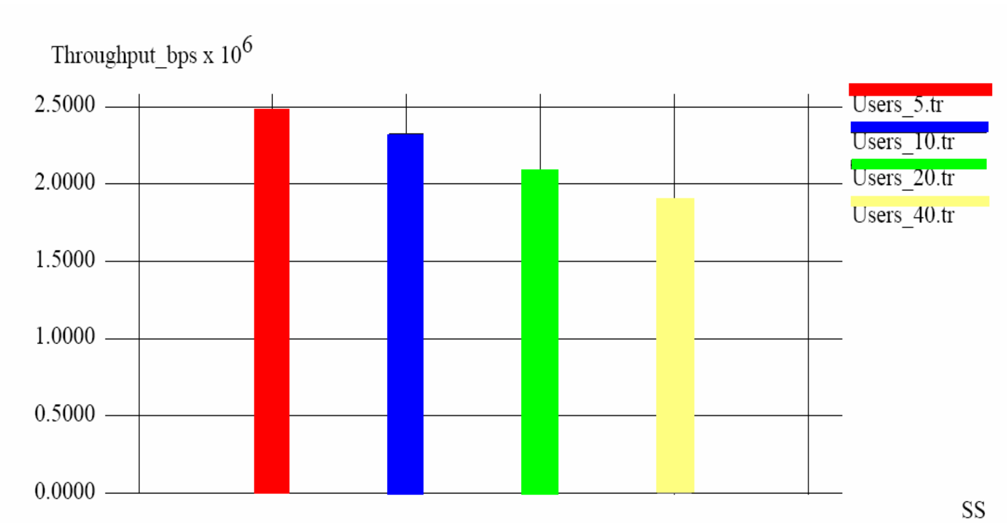

Figure 5.19 Network Throughput

Chapter 6

Conclusion

6.1 Conclusion

We compared Scheduling algorithms (Max C/I and Fair Share) that can be used in a WiMAX network. We also discussed advantages and disadvantages of Max C/I and FS scheduling algorithm and conclude that Max C/I is a throughput maximizing algorithm i.e. it increases the network throughput but it has one main disadvantage that is specifically for WiMAX network due to AMC is that SS's that are at the edges of a cell may starve. This Problem is catering in FS scheme but the disadvantage of the FS scheme is that it reduces the network throughput.

We also develop and test our own scheduling algorithm to optimize between the throughput and fairness in WiMAX network and results shows that this optimum algorithm not only solves the problem of starvation but it also increases the throughput of the WiMAX network.

Following are the key points of conclusion.

- Throughput of a network is optimized using optimum scheduling scheme.
- SS's which are at the edges of a cell will not starve.
- Fairness will be among SS's i.e. enough slots are available to every SS.
- This scheme will provide at least minimum level of service to SS's.
- Network throughput reduces by increasing reservation slots percentage but it increases the individual throughput of the SS's which are at the edges.
- Throughput maximizing scheme cannot be applied in reserve time slots (starvation). Only FS can apply.
- The best way of assigning slots is that edges users will share equal slots among them from reserve slots and remaining slots are provided to other users according to Max C/I scheme
- BS should decide reservation percentage on a basis of users which are at the edges of a WiMAX cell or having low CINR value (lower modulation)

6.2 Future Work

We proposed an optimum scheduling scheme which is based on a compromise between throughput maximizing scheme and fair share scheme. Reservation percentage is dynamic in our case i.e. base station calculate the number of SS's associated with it in start and reserve slots according to edges SS's. It will not vary reservation percentage with movement of SS's hence we consider static SS's throughout our simulations. We can extend this work by considering the moving SS's in which BS can dynamically vary reservation percentage depending upon the movement of SS's i.e. if SS's moves from edges towards BS then reservation percentage should also reduce accordingly.

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