# Hybrid scheduling For QoS in WiMAX

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Submitted By:

**Sushil Kumar**

**(Roll No. 80731024)**

Under the supervision of:

**Mr. Ajay Kumar**
**Mrs. Sunita Garhwal**


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COMPUTER SCIENCE AND ENGINEERING DEPARTMENT
THAPAR UNIVERSITY
PATIALA – 147004

# Certificate

I hereby certify that the work which is being presented in the thesis entitled, **"Hybrid Scheduling for QoS in WiMAX"**, in partial fulfillment of the requirements for the award of degree of Master of Engineering in Software Engineering submitted in Computer Science and Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Mr. Ajay Kumar, Mrs. Sunita Garhwal and refers other researcher's works which are duly listed in the reference section.

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

**(Sushil Kumar)**

This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

**Mr. Ajay Kumar**
Lecturer
CSED
Thapar University, Patiala

**Mrs Sunita Garhwal**
Lecturer
SMCA
Thapar University, Patiala

**Countersigned by:**

**(RAJESH BHATIA)**
Assistant Professor & Head
Computer Science & Engineering. Department
Thapar University
Patiala.

**(R.K.SHARMA)**
Dean (Academic Affairs)
Thapar University,
Patiala

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**Sushil Kumar**

**80731024**

# Abstract

WiMAX (IEEE 802.16) is one of the most emerging broadband wireless technologies and is viable alternative to traditional wired broadband techniques due to its cost efficiency. WiMAX supports various multimedia applications such as voice over Internet protocol (VoIP), video conferencing and online gaming. These applications are diverse in nature and they have diverse requirement to be satisfied. To satisfy these types of requirements it is necessary to take into consideration Quality of Service (QoS). The QoS, an accepted criteria for measuring the performance of a network is provided through both classification and scheduling of the four different types of traffic classes defined by the standard. Each class has it own bandwidth requirements as well as its level of QoS, which has to be maintained. Many traffic scheduling algorithms are available for wireless networks, e.g. Round Robin, Proportional Fairness (PF) scheme and Cross-layer scheduling. Among these conventional schemes, some cannot differentiate services, while some can fulfill the service differentiation with a high-complexity implementation. Therefore, an effective scheduling is a must for WiMAX.

In the presented work, an analysis of various available scheduling algorithms based on QoS criteria is carried out. Based upon the analysis, a new algorithm is proposed, by implying some credits to the Round Robin algorithm and is termed as - **"Credit Base Round Robin Algorithm". Our simulation results show that t**he proposed algorithm overcomes the limitations inherent in a single scheduling algorithm thus resulting in an efficient utilization of resources for better QoS.



**Key Words: Scheduling** algorithm, IEEE 802.16, QoS, WiMAX

# LIST OF ABBREVIATIONS

AMC: Adaptive Modulation and coding

ASN: Access Service Network

BE: Best Effort

BER: Bit Error Rate

BS: Base station

CBR: Constant Bit Rate

CPE: Customer Premise Equipment

DSL: Digital Subscriber Line

FDD: Frequency Division

FTP: File Transfer Protocol

HDR: High Data Rate

LOS: Line Of Sight

MAC: Medium Access Control

MPDU: MAC Protocol Data Units

MSDU: MAC Service Data Units

MPEG: Moving Pictures Expert Group

MS: Mobile Station

NLOS: Non Line Of Sight

nrtPS: Non Real Time Polling Service

NWG: Network Working Group

OFDM: Orthogonal Frequency Division Multiplexing

OFDMA: Orthogonal Frequency Division Multiple Access

PDA: Personal Digital Assistant

PER: Packet Error Rate

PF: Proportionate Fairness

PHY: Physical Layer

PMP: Point To Multi-Point

QAM: Quarter Amplitude Modulation

QoS: Quality of Services

RR: Round Robin

rtPS: Real Time Polling Service

SDU: Service Data Units

SNR: Signal to Noise Ratio

SSs: Subscriber Stations

TDD: Time Division Duplex

TDM: Time Division Multiplexing

TDMA: Time Division Multiple Access

TM: Transmission Mode

UGS: Unsolicited

VBR: Variable Bit Rate

VoIP: Voice Over IP

VPN: Virtual Private Network

WFQ: Wireless Fair Queuing

WLAN: Wireless Local Area Network

WMAN: Wireless Metropolitan Area Network

WiBro: Wireless Broadband

WiMAX: Worldwide interoperability for Microwave Access

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# Chapter 1

# Introduction

## 1.1 Network

A network is a series of points or nodes interconnected by communication paths. Networks can interconnect with other networks and contain sub networks. A network consists of two or more computers that are linked in order to share resources (such as printers and CD-ROMs), exchange files, or allow electronic communications. The computers on a network may be linked through cables, telephone lines, radio waves, satellites, or infrared light beams [1][2].

Network can also be characterized by the type of data transmission technology used by it, whether it carries voice, data, or both kinds of signals; by who can use the network (public or private); by the usual nature of its connections (dial-up or switched, dedicated or non switched, or virtual connections); and by the types of physical links (for example, optical fiber, coaxial cable, and Unshielded Twisted Pair). On the basis of transmission network can be divided in wired and wireless network [2].

### 1.1.1 Wired Network

In a wired network communication machine are connected physically. In order to facilitate communication there are three type of media used.

1 Twisted-Pair
2 Coaxial Cable
3 Fiber-Optic Cable

**1 Twisted-Pair:** A Twisted pair consists of two insulated copper wires, typically 1mm thick. The wires are twisted together in a helical form, the purpose of twisting is to reduce cross talk interference between several pairs. Twisted Pair is much cheaper than coaxial cable but it is susceptible to noise and electromagnetic interference and attenuation is large. Twisted Pair can be further classified in unshielded twisted pair and Shielded twisted pair.

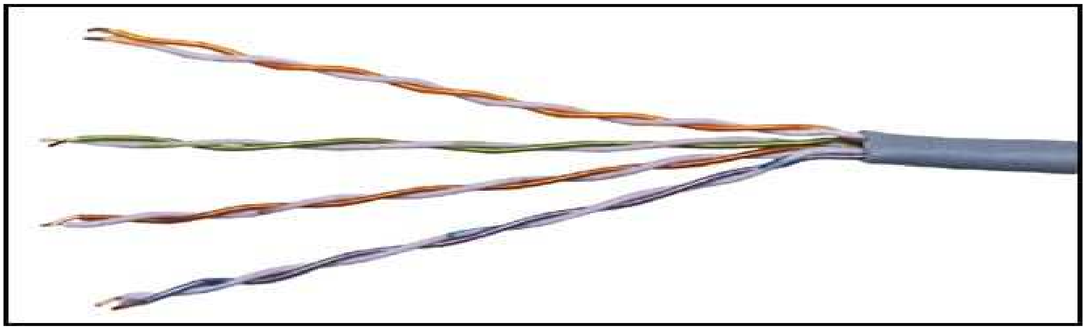

**Fig. 1.1: Twisted Pair Cable [4]**

**2 Coaxial Cable:** Coaxial cable consists of an inner conductor and an outer conductor which are separated by an insulator. The inner conductor is usually copper. A plastic jacket covers the outer conductor. It is named coaxial because the two conductors are coaxial. Typical diameter of coaxial cable lies between 0.4 inch to 1 inch. Application of coaxial cable is cable T.V. The coaxial cable has high bandwidth, with less attenuation.

**3 Optical Fiber:** In optical fiber, light is used to send the data. In general terms presence of light is taken as bit 1 and its absence as bit 0. The inner core of optical fiber consists of either glass or plastic. Core is surrounded by cladding of the same material but of different refractive index and cladding is surrounded by a plastic jacket which prevents optical fiber from electromagnetic interference and harshy environments. It uses the principle of total internal reflection to transfer data over optical fibers. Optical fiber is much better in bandwidth as compared to copper wire, since there is hardly any attenuation or electromagnetic interference in optical wires. Hence there are fewer requirements to improve quality of signal in long distance transmission. Disadvantage of optical fiber is that end points are fairly expensive. (e.g. switches).

### 1.1.2 Wireless Network

A wireless network allows us to connect our machine to a network using radio waves instead of wires. As long as you are within range of a wireless access point, you can move your computer or machine from place to place while maintaining un-ethered access to networked resources. This can make networking extremely portable. Unlike its predecessor, Ethernet that uses wires, wireless networking uses the air as the medium to transport data. As long as you have a wireless network card for your laptop and configure your laptop correctly, you're free to roam about the network with the same functionality as conventional Ethernet with a reduced speed [3].

Wireless standards are IEEE 802.11 and IEEE 802.16. IEEE 802.11 referred as Wi-Fi and IEEE 802.16 as a WiMAX. In 1997, the IEEE adopted the first standard for WLANs and revised in 1999. IEEE defines a MAC sublayer, MAC management protocols and services, and three physical (PHY) layers. The goals of IEEE 802.11 were to deliver services previously found only in wired networks and these services were high throughput, highly reliable data delivery and continuous network connection [20].

To transport the data on a wireless network radio frequency, microwave and infrared are used as a transportation media [4].

1 **Radio frequency (RF)**

RF refers to frequencies of radio waves. RF is part of electromagnetic spectrum that ranges from 3 Hz - 300 GHz. Radio wave is radiated by an antenna and produced by alternating currents fed to the antenna. RF was long been used for radio and TV broadcasting, wireless local loop, mobile communications, and amateur radio.

2 **Microwave**

Microwave is the upper part of RF spectrum having frequencies above 1 GHz. Because of the availability of larger bandwidth in microwave spectrum, microwave is used in many applications such as wireless PAN (Bluetooth), Wi-Fi, broadband wireless access (BWA) or wireless MAN (WiMAX), wireless WAN

(2G/3G cellular networks), satellite communications and radar. But it became very famous in houses because of its use in microwave oven.

## 3 Infrared

Infrared light is part of electromagnetic spectrum that is shorter than radio waves but longer than visible light. Its frequency range is between 300 GHz and 400 THz that corresponds to wavelength from 1mm to 750 nm. Night vision equipment and TV remote control is using infrared from a long time. Infrared is also one of the physical media in the original wireless LAN standard, that's IEEE 802.11. Infrared use in communication and networking, defined by the IrDA (Infrared Data Association). Using IrDA specifications, infrared can be used in a wide range of applications, e.g. file transfer, synchronization, dial-up networking, and payment. However, IrDA is limited in range (up to about 1 meter). It also requires the communicating devices to be in LOS (Line of Sight) and within its 30-degree beam-cone.

# Chapter 2

# WiMAX

## 2.1 WiMAX

WiMAX (Worldwide interoperability for Microwave Access) is one of the most emerging technologies for BWA in metropolitan areas by providing an exciting addition to the current broadband techniques for the last-mile access. It is demonstrated that WiMAX is a viable alternative to the cable modem and DSL technologies due to its high resource utilization, easy implementation and low cost. Furthermore, WiMAX not only enhances the existing features of the competitive cabled access networks, but also provides high data rate applications with a variety of Quality of Service (QoS) requirements. Companies like Motorola and Samsung are already developing WiMAX phones and portable digital assistant (PDAs) and they are already in use in Korea, with WiMAX cousin technology, WiBro (Wireless Broadband) [5]. To support multimedia traffics, the Medium Access Control (MAC) protocols will co-ordinate the transmission of traffic flows. The channel characteristics of users and traffic flow requirements are largely diverse, motivating us to design an efficient MAC layer protocols that can improve the system performance due to the channel and traffic dynamics. The bandwidth allocation algorithms have been designed for the efficient utilization of the scarce radio resources

The technologies and standards behind WiMAX are those developed by the IEEE 802.16 Working Group dealing with broadband wireless access. The group began developing technologies for wireless metropolitan networks in 2000, publishing its first standard in April 2002 for equipment operating in the 10-66 GHz frequency band. The group then extended the standard (IEEE 802.16a) for use in the lower frequency range of 2-11 GHz. This new frequency range allows for non line of sight (NLOS) connectivity and should be popular given certain license-exempt bands in that range.

Wireless MAN technology took a big step forward in February 2006 with the publication of the 802.16e amendment, Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands. This mouthful may well announce the imminent arrival of Ethernet's tanks on the front lawns of the 3G operators, as it extends the industry's best-bet heavyweight metro broadband fixed-wireless access standard to nomadic and fully mobile terminals. And it does it with an extensive range of quality of service (QOS) capabilities [10].

After years of development and uncertainty, a standards-based interoperable solution is emerging for wireless broadband. A broad industry consortium, the WiMAX Forum [7] has begun certifying broadband wireless products for interoperability and compliance with a standard. WiMAX is based on Wireless Metropolitan Area Networking (WMAN) standards developed by the IEEE 802.16 group and adopted by both IEEE and the ETSI HIPERMAN group. As described above the IEEE 802.16 group was formed in 1998 to develop an air interface standard for wireless broadband. 802.16a standard developed by this group covers NLOS applications in the 2GHz–11GHz band, using an Orthogonal Frequency Division Multiplexing (OFDM)-based physical layer. Further revisions resulted in a new standard in 2004, called IEEE 802.16-2004, which replaced all prior versions and formed the basis for the first WiMAX solution. These early WiMAX solutions based on IEEE 802.16-2004 targeted fixed applications, and we will refer to these as fixed WiMAX [8]. The IEEE 802.16e-2005 forms the basis for the WiMAX solution for nomadic and mobile applications and is often referred to as mobile WiMAX [9].

**Table 2.1 Basic Data on IEEE 802.16 Standards [10]**

| Parameters | 802.16 | 802.16-2004 | 802.16e-2005 |
|---|---|---|---|
| Status | Completed December 2001 | Completed June 2004 | Completed December 2005 |
| Frequency band | 10GHz–66GHz | 2GHz–11GHz | 2GHz–11GHz for fixed; 2GHz–6GHz for mobile applications |
| Application | Fixed LOS | Fixed NLOS | Fixed and mobile NLOS |
| MAC architecture | Point-to multipoint, mesh | Point-to-multipoint, mesh | Point-to-multipoint, mesh |
| Transmission scheme | Single carrier only | Single carrier, 256 OFDM or 2,048 OFDM | Single carrier, 256 OFDM or scalable OFDM with 128, 512, 1,024, or 2,048 subcarriers |
| Modulation | QPSK, 16 QAM, 64 QAM | QPSK, 16 QAM, 64 QAM | QPSK, 16 QAM, 64 QAM |
| Gross data rate | 32Mbps–134.4Mbps | 1Mbps–75Mbps | 1Mbps–75Mbps |
| Multiplexing | Burst TDM/TDMA | Burst TDM/TDMA/OFDMA | Burst TDM/TDMA/OFDMA |
| Duplexing | TDD and FDD | TDD and FDD | TDD and FDD |
| Channel bandwidths | 20MHz, 25MHz, 28MHz | 1.75MHz, 3.5MHz, 7MHz, 14MHz, 1.25MHz, 5MHz, 10MHz, 15MHz, 8.75MHz | 1.75MHz, 3.5MHz, 7MHz, 14MHz, 1.25MHz, 5MHz, 10MHz, 15MHz, 8.75MHz |
| Air-interface designation | WirelessMAN-SC | WirelessMAN-SCa WirelessMAN-OFDM WirelessMAN-OFDMA WirelessHUMAN[a] | WirelessMAN-SCa WirelessMAN-OFDM WirelessMAN-OFDMA WirelessHUMAN [a] |
| WiMAX implementation | None | 256 - OFDM as Fixed WiMAX | Scalable OFDMA as Mobile WiMAX |

a. WirelessHUMAN (Wireless high-speed unlicensed MAN) is similar to OFDMPHY (physical layer) but mandates dynamic frequency selection for license exempt bands.

For practical reasons of interoperability, the scope of the standard needs to be reduced, and a smaller set of design choices for implementation need to be defined. The WiMAX Forum does this by defining a limited number of system profiles and certification profiles. A system profile defines the subset of mandatory and optional physical and MAC layer features selected by the WiMAX Forum from the IEEE 802.16-2004 or IEEE 802.16e-2005 standard. It should be noted that the mandatory and optional status of a particular feature within a WiMAX system profile might be different from what it is in the original IEEE standard. Currently, the WiMAX Forum has two different system profiles [11]. One based on IEEE 802.16-2004, OFDM PHY, called the fixed system profile and the other one based on IEEE 802.16e-2005 scalable OFDMA PHY, called the mobility system profile. A certification profile is defined as a particular instantiation of a system profile where the operating frequency, channel bandwidth, and duplexing mode are also specified. WiMAX equipments are certified for interoperability against a particular certification profile.

The WiMAX Forum defined five fixed certification profiles and fourteen mobility certification profiles. Till date there are two fixed WiMAX profiles against which equipment have been certified. These are 3.5GHz systems operating over a 3.5MHz channel, using the fixed system profile based on the IEEE 802.16-2004 OFDM physical layer with a point-to-multipoint MAC. One of the profiles uses FDD and the other use TDD.

## 2.2 Evolution of WiMAX

WiMAX technology has evolved through four stages, although not fully distinct or clearly sequential: [12]

1 Narrowband wireless local-loop systems

2 First-generation Line of Sight (LOS) broadband systems

3 Second-generation Non Line of Sight (NLOS) broadband systems
4 Standards-based broadband wireless systems.

## 1 Narrowband Wireless Local-Loop Systems

The first application of a wireless alternative was developed and deployed was voice telephony. These systems are called Wireless Local-Loop (WLL), were quite successful in developing countries such as China, India, Indonesia Brazil, and Russia, whose high demand for basic telephone services could not be served using existing infrastructure. In fact, WLL systems based on the Digital-Enhanced Cordless Telephony (DECT) and Code Division Multiple Access (CDMA) standards continue to be deployed in these markets.

## 2 First-generation Line-of-Sight (LOS) broadband systems

As DSL and cable modems began to be deployed, wireless systems had to evolve to support much higher speeds to be competitive. Systems began to be developed for higher frequencies, such as the 2.5GHz and 3.5GHz bands. In the late 1990s, one of the more important deployments of wireless broadband happened, called Multichannel Multipoint Distribution Services (MMDS) band at 2.5GHz. The MMDS band was historically used to provide wireless cable broadcast video services, especially in rural areas where cable TV services were not available.

The first generation of these fixed broadband wireless solutions was deployed using the same towers that served wireless cable subscribers. These towers were typically several hundred feet tall and enabled LOS coverage to distances up to 35 miles, using high power transmitters. First-generation MMDS systems required that subscribers should install antennas at their premises. Outdoor antennas should be high enough and pointed toward the tower for a clear LOS transmission path.

## 3 Second-Generation Non Line of Sight (NLOS) Broadband Systems

Second-generation broadband wireless systems were able to overcome the LOS issue and provide more capacity. This was done through the use of a cellular architecture and implementation of advanced-signal processing techniques to improve the link and system performance under multipath conditions. By using techniques such as Orthogonal Frequency Division Multiplexing (OFDM), Code Division Multiple Access (CDMA), and multiantenna processing solved NLOS problem.

## 4 Emergence of Standards-Based Technology

In 1998, the Institute of Electrical and Electronics Engineers (IEEE) formed a group called 802.16 to develop a standard called wireless metropolitan area network, or wireless MAN. Originally, this group focused on developing solutions for delivering high-speed connections to businesses that could not bear the fiber link. The IEEE 802.16 group produced a standard that was approved in December 2001. This standard, Wireless MAN-SC, specified a physical layer that used single-carrier modulation techniques and a Media Access Control (MAC) layer with a burst Time Division Multiplexing (TDM) structure that supported both Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD). After completing this standard, the group started work on extending and modifying it to work in both licensed and license-exempt frequencies in the 2GHz to 11GHz range, which would enable NLOS deployments. This amendment, IEEE 802.16a, was completed in 2003, with OFDM schemes added as part of the physical layer for supporting deployment in multipath environments. By this time, OFDM had established itself as a method of choice for dealing with multipath for broadband and was already part of the revised IEEE 802.11 standards. Besides the OFDM physical layers, 802.16a also specified additional MAC-layer options, including support for Orthogonal Frequency Division Multiple Access (OFDMA).

## 2.3 WiMAX Architecture Issues

There are various architectural issues involved with WiMAX like-Point to Point (P2P), Point to Multipoint (PMP), LOS, NLOS along with wireless radio ant antennas are discussed in the following section:

### 2.3.1 P2P Vs PMP

**Point to Point (P2P)**

In a P2P architecture there is one transmitter and one receiver. As a backhaul in WiMAX this architecture is used, in which a base station acts as a base station and other as a receiver. Due to this architecture connective as far away as 30 miles becomes possible. P2P makes it possible to cover a large geographical area [13] [14].

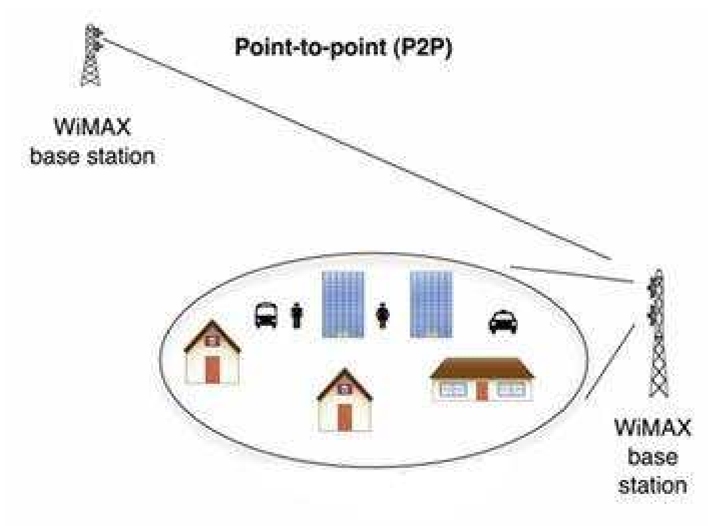


**Fig. 2.1: Point to Point Configuration [14]**

**Point to Multipoint (PMP)**

This architecture is based upon IEEE 802.16.2004 standard. In PMP architecture there are one transmitter and several receivers. One base station can support several receivers whether there are similar and dissimilar [13] [15].

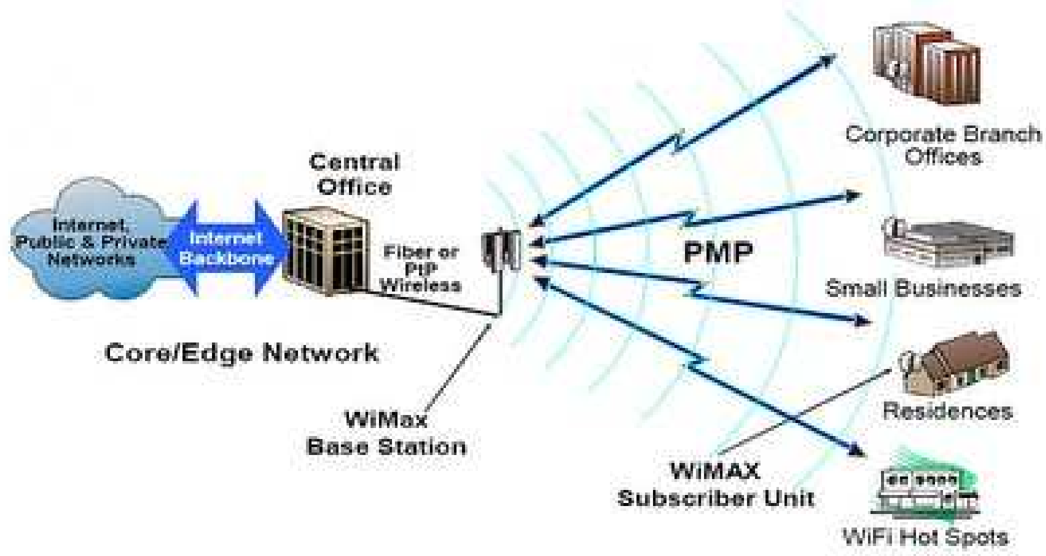


**Fig. 2.2: Point to Multipoint Configuration [14]**

### 2.3.2 LOS Vs NLOS

Earlier wireless technologies (LMDS, MMDS for example) were unsuccessful in the mass market because they could not deliver services in non-line-of-sight scenarios. This limited the number of subscribers they could reach and due to high cost of base stations and customer premisis equipment (CPE), those business plans failed. WiMAX functions best in line of sight situations and, unlike those earlier technologies which offers acceptable range and throughput to subscribers but do not support line of sight to the base station. Buildings between the base station and the subscriber diminish the range and throughput, but in an urban environment, the signal will still be strong enough to deliver adequate service.Due to WiMAX's ability to deliver services non-line-of-sight, the WiMAX service provider can reach many customers in high-rise office buildings to achieve a low cost per subscriber because so many subscribers can be reached from one base station.

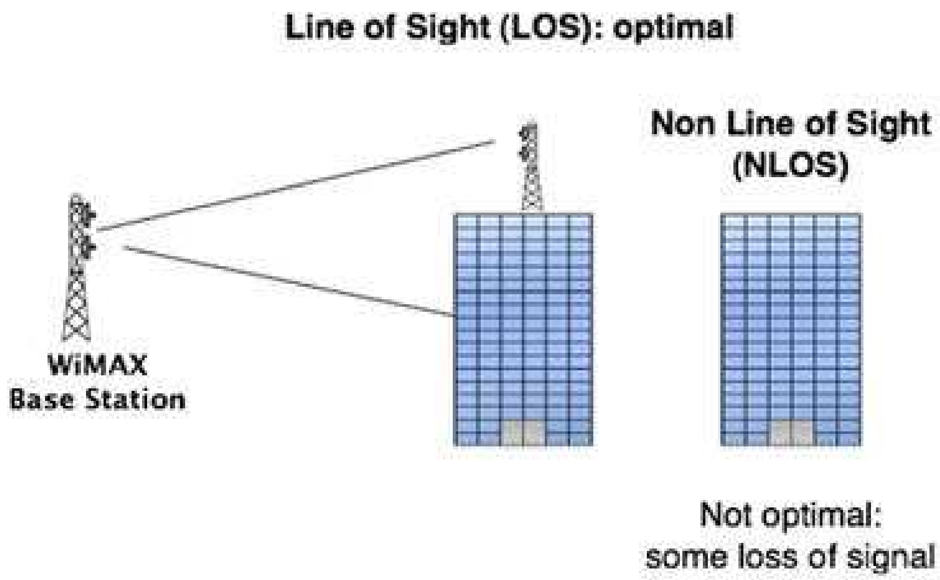


**Fig. 2.3: Difference between LOS and NLOS [14]**

### 2.3.3 WiMAX Radios & Antennas

WiMAX radio is the core of WiMAX. A radio contains both transmitter and receiver. It generates electrical oscillations at a frequency known as the carrier frequency (in WiMAX that is usually between 2 and 11 GHz). A radio might be thought of as a networking device similar to a router or a bridge, it is managed by software and is composed of circuit boards containing very complex chip sets. WiMAX architecture is built upon two components: radios and antennas. Most WiMAX products offer a base station radio separate from the antenna. Conversely, many CPE devices are also two-piece solutions with an antenna on the outside of the building and subscriber station inside of the building, as illustrated in fig. 2.4.

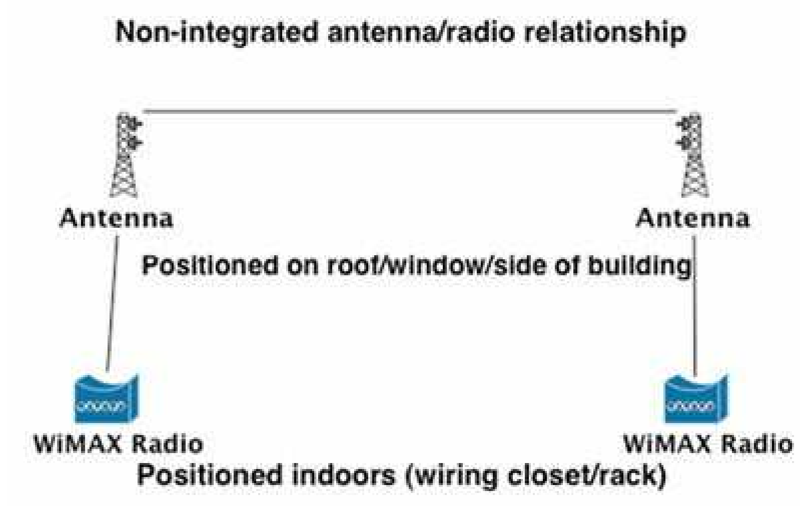


**Fig.2.4: WiMAX Radio and Antennas [24]**

The advantage is that the radio is protected from extremes of heat cold and humidity all of which reduce the performance and durability of radio. In addition, having the antenna outdoors optimizes the link budget (performance of the wireless connection) between transmitter and receiver especially in line of sight scenarios. The antenna is connected to WiMAX radio via a cable known as a "pigtail". One simple rule for wireless installations: keep the pigtail as short as possible so as to reduce the signal loss. For example popular LMR-400 cable will lose about 1 dB for every 10 feet of cable.

### 2.3.4 WiMAX Antennas

WiMAX antennas are just like the antennas for car radio, cell phone, FM radio, or TV, are designed to optimize performance for a given application. Fig. 2.5 illustrates the three main types of antennas used in WiMAX deployments. From top to bottom is an omni directional, sector and panel antenna each has a specific function.

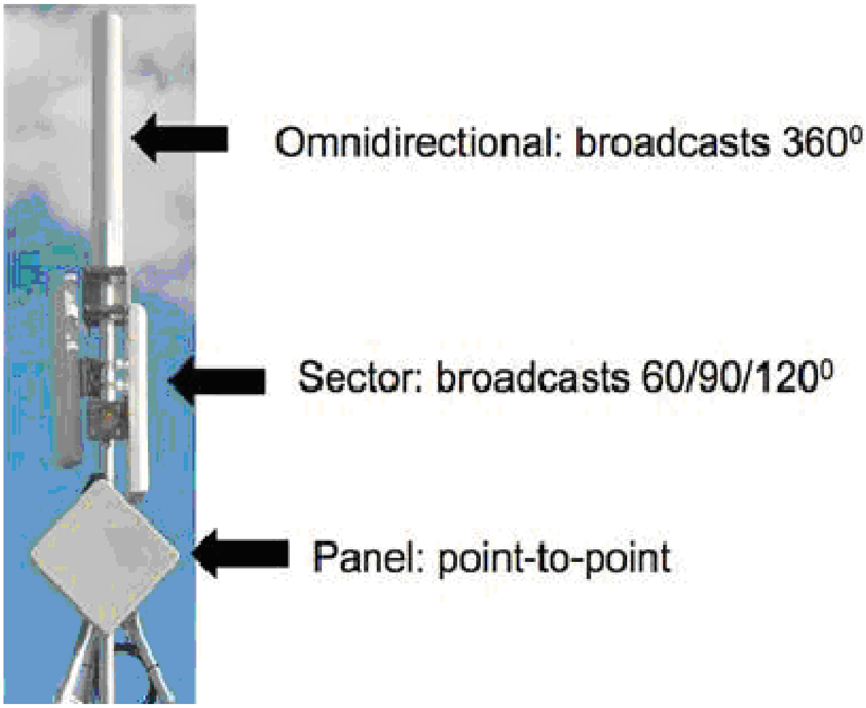


**Fig.2.5: Different types of Antennas for different applications [25]**

### 2.3.5 Subscriber Stations

The technical term for CPE is subscriber station. The generally accepted marketing terms now focus on either "indoor CPE" or "outdoor CPE". There are advantages and disadvantages to both deployment schemes as described below.

**Fig.2.6: An outdoor CPE device (Subscriber Station) [24]**

An outdoor CPE offers somewhat better performance over indoor CPE, given that WiMAX reception is not impeded by walls of concrete or brick, RF blocking glass or steel in the building's walls. Subscriber can install indoor CPE and service provider need not provide installation for it. Thus, it reduces waiting time needed for installation by service provider. Fig 2.7 shows typical Indoor CPE.

**Fig.2.7: Indoor WiMAX CPE [24]**

## 2.4 Quality of Services in WiMAX

Quality of Services (QoS) refers to different parameters in the network that determine the types of traffic that can be supported, and the type of experience a user will have. For each application and for each customer, a different set of QOS are required. To support a wide variety of applications, WiMAX defines five scheduling services that should be supported by the base station.

When we choose any scheduling algorithm then we also decide priority parameters for scheduling algorithm. Every QoS service class in WiMAX has different parameter. On the basis of these parameter and the application supported by service class we can priorities the service classes [16].

### 2.4.1 Requirement of QoS

IEEE 802.16 standard was designed for different types of traffic. WiMAX has to handle the requirements of very high data rate applications, such as VoIP and video or audio streaming, as well as low-data-rate applications, such as web surfing, handle extremely bursty traffic over the Internet and WiMAX may need to handle all of these traffic at the same time. Some applications simply can't work without quality of service. Some delay may be acceptable, but too much can make the application unusable. For example, the IEEE 802.16 group determined that an acceptable delay for VoIP is 120 ms, and over 150 ms delay results in noticeably impaired voice quality. Humans are intolerant of speech delays of over 200-ms. Scheduling algorithms in WiMAX have been designed to accommodate hundreds of connections per channel and allow a variety of QoS requirements. Applications of end user may be varied in their bandwidth and latency requirements, so 802.16 must be flexible and efficient over a range of different traffic models [16].

### 2.4.2 Service classes supported in WiMAX

**1 Unsolicited grant service (UGS)**

UGS supports real-time constant bit rate (CBR) applications that generate fixed size data packets on a periodic basis. The base station (BS) assigns them unsolicited fixed bandwidth grants at periodic intervals, based on their maximum sustained traffic rate, therefore scheduling is not required. It supports real time connection with fixed length, like voice over Internet protocol (VoIP) [17].

**2 Real-time polling service (rtPS)**

rtPS is appropriate to real-time applications that produce variable-size data packets on a periodic basis like Moving Picture Experts Group (MPEG). The BS provides subscriber stations (SSs) the possibility to issue bandwidth requests on a periodic basis by means of a polling Mechanism [17] [18].

**3 Extended real-time polling service (ertPS)**

ertPS is similar in nature to rtPS service, but the BS can ensure for ertPS a default bandwidth (corresponding to the maximum sustained traffic rate as for UGS) and dynamically provide additional resources, therefore scheduling is not required [17] [18].

**4 Non-real-time polling service (nrtPS)**

nrtPS is appropriate for delay tolerant applications that generate variable size data packets and require a minimum data rate. nrtPS flows can use contention slots to ask for bandwidth grants, but typically the BS polls them for issuing bandwidth requests on a regular basis (if possible). The polling interval is not guaranteed but may depend on network traffic load. nrtPS supports non real-time connection, like File Transfer Protocol (FTP) [18].

**5 Best effort (BE)**

BE is appropriate for traffic with weak QoS requirements. Flows of this class can only use contention slots to deliver their bandwidth requests [6]. BE class providing services for best effort traffic like Hypertext Transfer Protocol (HTTP) [17].

### 2.4.3 QOS specification for different service classes

**1 Latency**

The end-to-end packet transmission time is caused by the granularity of the physical-layer chain, and is typically almost 5ms in 802.16 systems. Latency is also affected by how packet queuing, various QOS protocols, and user characterizations. Maximum Latency is defined as the upper bound of latency between reception of a data packet from the network interface at transmitter side and forwarding of it to the RF (Radio Frequency) interface.

**2 Jitter**

Jitter is caused when packets arrive at different times due to different queuing times or due to the different routes taken by the communications. Jitter is typically addressed through a memory buffer that stores early arriving packets, concatenates later arriving packets, and thus smoothes the voice arriving at the receiver. Tolerated Jitter defines the maximum delay variation for the connection.

**3 Maximum Sustained traffic Rate**

Maximum Sustained Traffic Rate defines the peak information rate of the service [9]. For UGS, the Maximum Sustained Traffic Rate is also the minimum rate reserved for the service flow. Therefore this parameter, with the fixed grant size, determines the intervals at which BS issues periodic data grant. The grant size shall be large enough to contain the fixed length data carried by the service flow.

**Table 2.2: Service classes supported in WiMAX for prioritizing traffic**

| **Service Class** | **Applications** | **QoS Specifications** |
|---|---|---|
| Unsolicited Grant Service (UGS) | VoIP | Jitter Tolerance<br>Maximum Latency Tolerance<br>Maximum Sustained Rate |
| Real-time Polling Service (rtPS) | Streaming audio or video | Traffic Priority<br>Maximum Latency Tolerance<br>Maximum Reserved Rate<br>Maximum Sustained Rate |
| Extended real time Polling Services (ErtPS) | VoIP (Voice with Activity Detection) | Traffic Priority<br>Maximum Latency Tolerance<br>Jitter Tolerance<br>Maximum Reserved Rate<br>Maximum Sustained Rate |
| Non-real time polling services (nrtPS) | FTP | Traffic Priority<br>Maximum Reserved Rate<br>Maximum Sustained Rate |
| Best Effort (BE) | Data Transfer, Web surfing | Traffic Priority |

## 2.5 MAC Layer in IEEE 802.16

The MAC layer of IEEE 802.16 is designed to serve distributed stations with high data rates, where the SSs are not required to listen to the other stations like the MAC in IEEE 802.11. The BS schedules the transmissions of the corresponding SSs in advance. The MAC of WiMAX is reservation based and contention- ree. The SSs need to contend only when they access the channel for the first time at the connection admission control stage. The reservation based resource allocation allows the WiMAX BS to serve a large number of SSs as well as to guarantee of QoS in the connection level for both uplink and downlink traffic. In a contention based resource reservation scheme, QoS could hardly be considered in the early standard until the advent of 802.11e. However, most WLAN networks deployed now a day do not employ any QoS mechanism [19].

The main purpose of the MAC protocol is to share radio channel resources among multiple accesses of different users. In IEEE 802.16, the MAC layer is divided into three sublayers: the service specific convergence, common part sublayer, and security sublayer. The primary task of service specific convergence sublayer is to classify external service data units (SDU) and associate each of them with a proper MAC service flow identifier and connection identifier. The MAC layer protocol is flexible and efficient over different traffic types. The common part sublayer is independent of the transport mechanism, which is the kernel bearing all the MAC characteristics. It is responsible for fragmentation and segmentation of each MAC SDU into MAC protocol data units (PDUs), system access, bandwidth allocation, connection maintenance, QoS control, and scheduling transmission etc. The MAC also contains a separate security sublayer handling authentication, secure key exchange, and encryption.

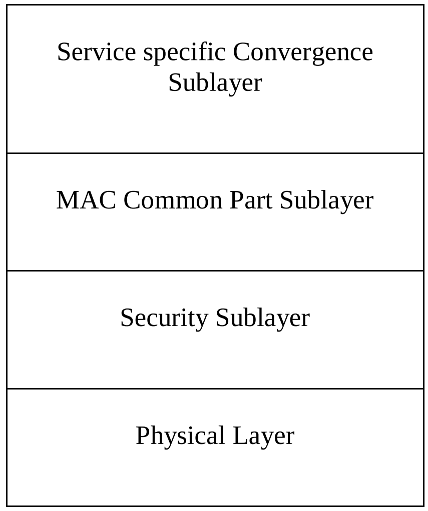


**Fig. 2.3: IEEE 802.16 protocol layering**

### 2.5.1 MAC Support of Physical Layer (PHY)

The basic distinction of MAC protocol is the duplexing techniques of uplink and downlink. The choice of duplexing techniques may affect PHY parameters as well as impact the features that can be supported. There are two approaches to implement it.

1. **Frequency Division Duplex (FDD)**

   In an FDD system, the uplink and downlink channels use separate subcarriers, which allows the terminals to transmit and receive simultaneously. The adoption of fixed duration frames in both uplink and downlink simplifies the design of bandwidth allocation algorithms.

2. **Time Division Duplex (TDD)**

   TDD framing is illustrated in Fig.2.4. The uplink and downlink transmissions share the same frequency while being allocated in each TDD frame according to an adaptive threshold. One TDD frame contains one downlink and one uplink subframe. The downlink subframe comes first because it contains the bandwidth requests and transmission information directly sent from SSs to the BS, which forms a map for scheduling the uplink resources among all the SSs.

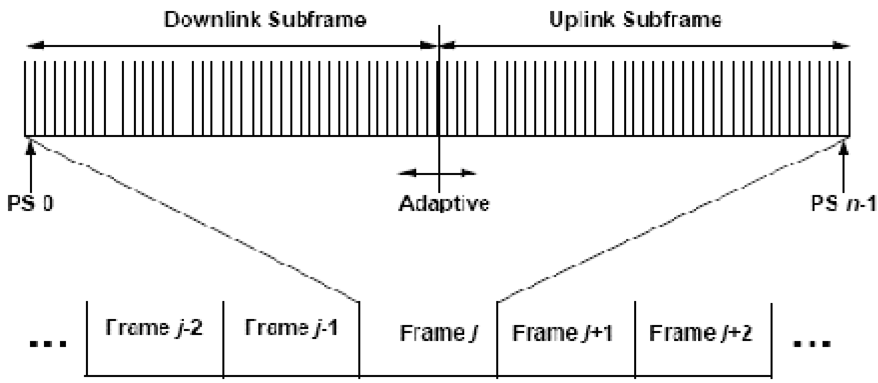


**Fig.2.4: The TDD frame structure in IEEE 802.16 [8]**

**Fig. 2.5 The TDD downlink subframe structure in IEEE 802.16. [8]**

The structure of the downlink subframe using TDD mode is illustrated in Fig.2.5 [8] [19]. The downlink subframe begins with a frame start preamble used by the PHY layer for synchronization and equalization. The preamble is followed by the frame control section, containing DL-MAP and UL-MAP stating the resource allocation of the downlink and uplink. The DL-MAP specifies when the PHY layer transition occurs within the downlink subframe. The following portion carries the data, which are transmitted to each SS using a negotiated burst profile. Due to the dynamics of the bandwidth demand for the varieties of services, the burst profiles vary dynamically from frame to frame. Thus the system can support different levels of the data transmission. In the case of TDD, a time gap separates the downlink subframe and the uplink subframe.

## Advantages of broadband wireless access through IEEE 802.16

There are various advantages by using WiMAX. With the help of WiMAX we can transfer data rapidly across a wide area. Due to the standardization of WiMAX, cost of CPE, antennas and radios are going down. In the following section we are going to describe all these advantages.

### Last Mile connectivity

For many home and business customers, broadband access via DSL or cable infrastructure is still not available. Many customers are outside the range of DSL's reaches are not served by broadband capable cable infrastructure. Practical limitations prevent cable and DSL technologies from reaching many potential broadband customers. Traditional DSL can only reach about 18,000 feet (3 miles) from the central office switch, and this limitation means that many urban and suburban locations may not be served by DSL connections. But with wireless broadband these problems can be solved. Because of its wireless nature, it can be faster to deploy, easier to scale and more flexible, thereby giving it the potential to serve customers not served or not satisfied by their wired broadband alternatives. It is especially important for developing countries like India with very low broadband connectivity and here 802.16 standards help to solve the last mile problems. Last-mile broadband wireless access can help to accelerate the deployment of 802.11 hotspots and home/small office wireless LANs.

### 2.6.2 Driving down costs

There are over 2000 wireless operators in the U.S alone. But they use expensive proprietary equipment that's not interoperable with equipment from other vendors. A lack of standards has also limited the usefulness of the technology and made it hard for wireless broadband access providers to be competitive and profitable. To combat these issues the 802.16 standard was developed. By enabling standards-based products with fewer variants and larger volume production, it is driving the cost of equipment down, and having standardized equipment will also encourage competition, making it possible to buy from many sources.

### 2.6.3 Roaming between networks

802.16e enables "handoff" procedure that allows a mobile device to switch the connection from one base station to another, from one 802 network type to another (such as from 802.11b to 802.16), and even from wired to 802.11 or 802.16 connections. Today, 802.11 users can move around a building or a hotspot and stay connected, but if they leave, they lose their connection. With 802.16e, users will be able to stay "best connected" connected by 802.11 when they're within a hot spot, and then connected to 802.16 when they leave the hot spot but are within a WiMAX service area. 802.16e capabilities embedded in a PDA or notebook (or added through an 802.16e-enabled card) will enable a user to remain connected within an entire metropolitan area. For example, a notebook could connect via Ethernet or 802.11, and stay connected with 802.16 when roaming the city.

### 2.6.4 Flexibility

802.16 standard will also provide an important flexibility advantage to new businesses that move their operations frequently, like a construction company with offices at different building site. Instead of waiting weeks for a T1 or DSL line, wireless broadband access can be quickly and easily set up at new and temporary sites.

### 2.6.5 Scalability

The 802.16 standard is scalable. To accommodate easy cell planning in both licensed and license-exempt spectrum worldwide, 802.16 supports flexible channel bandwidths. For example, if an operator is assigned 20 MHz of spectrum, that operator could divide it into two sectors of 10 MHz each, or 4 sectors of 5 MHz each. By focusing power on increasingly narrow sectors, the operator can increase the number of users while maintaining good range and throughput. With wireless broadband access, it's easy to ramp up service at a location for a short period of time, sometime wired broadband access service providers can't do.

# Chapter 3

# Literature Survey

## 3.1 Scheduling Algorithms for QoS Support in WiMAX

Scheduling for UGS, rtPS, nrtPS, ertPS and BE services is not defined in 802.16 standard, there are various approaches described to address this issue. Some of them consider modifying scheduling algorithms defined for wired networks. But this approach does not give accurate results for wireless networks because wireless channel is going to fade over time and so channel quality does not remain same. So, we have to take it in consideration during modification of any scheduling algorithm. Beside this, different scheduling algorithms works on a specific approach e.g. some algorithm are just priority based which schedules all connection by just one centralized scheduling. Some algorithm works by selecting different algorithm for each different class. To be more specific in this approach some algorithms are also developed which address one class. Here we are going to discuss these algorithms, which represent these different approaches.

## 3.2 Description of Various Scheduling Algorithms

In the following text we are going to describe about various scheduling algorithm and we will analyze how good they are in the perspective of supporting QoS.

### 3.2.1 Round Robin Scheduling Algorithm

This is a one of the simplest scheduling algorithm. In this algorithm a time quantum is defined, only in that time quantum packet will be served. Round Robin is used for fair allocation of resources. This algorithm works in the form of rounds, in each round every connection is served only once in there time quantum. However, the RR scheduler has the same bandwidth efficiency as a random scheduler. Also, it cannot guarantee different QoS requirements for each queue.

In a typical WDRR algorithm, the following procedure is followed [24]:

Each connection is assigned a quantum. This quantum is a function of the rate desired for the connection. When a grant is received, starting from the highest priority connection:

1 High priority connection are allocated their requested grant, if credits are remaining then low priority connection will be allocated their desired bandwidth.
2 The connection is served till than the size of packet is smaller then the allocated credit.

Fair allocation of resources is not possible in this algorithm. Waiting time for some of the connection could be less but some low priority connection can face the starvation

.

### 3.2.2 Proportionate Fair Scheduling

Qualcomm Company proposed proportionate Fair Scheduling (PF). This algorithm was proposed to avoid conflicts between full use and fairness in allocation of resources. PF is used to maintain trade off between throughput and starvation.
PF is based on one priority function [20] [21]

.

Ui(t) = ri(t) / Ri(t)

Where ri(t) is the current data rate and Ri(t) is an exponentially smoothing average of the service rate received by SS from i to slot t. Queue having highest value of Ui(t) is served at time slot t. For updating average throughput of the queue following function is used:

Ri(t+1)= (1-1/Tc)*Ri(t) + (1/Tc)Ri(t) if connection i is served at time-slot t
Ri(t+1)= (1-1/Tc)*Ri(t) if connection i is not served at time-slot t

Where Tc is a time constant to find out moving average, which is generally taken 1000 slots in CDMA-HDR system. By adjusting this Tc parameter we can make perceived throughput less sensitive to short-term starvation on the queue. So scheduler waits for long time for a particular connection for improvement of its channel quality. Also, when large number of users co-exists in system we can leverage from feature called multi-user diversity gain in which we can schedule connection having highest data rate at particular time slot. Thus PF algorithm is simple and efficient but it fails to deliver QoS parameter requirements for a particular connection as mentioned for various parameters e.g. delay, throughput etc.

### 3.2.3 Novel Scheduling Algorithm

Novel Scheduling Algorithm proposed different scheduling algorithm for different service classes [22]. For rtPS service, WFQ (Wireless Fair Queuing) policy is selected which adjust the priority of connections according to the connection weight. Dynamic Round Robin scheduling is adopted for nrtPS service class. FIFO is used for Best Effort (BE) service class because there is no QoS needed for BE service class. Before choosing any scheduling algorithm it should be take in to consideration about requirement of real time service, complexity of scheduling algorithm and fairness. But this algorithm did not show how could we integrate all these different algorithms for providing centralized control from one BS. Also, detail about DRR strategy for nrtPS is not mentioned.

### 3.2.4 Cross- Layer Scheduling Algorithm

Cross-Layer Scheduling algorithm proposed a scheduler which works on the bases of priority. To support QoS requirements this algorithm proposed various metrics defined for the different service classes [23]. Thus the connection having highest priority will be served first.

At the MAC, each connection belongs to a single service class and is associated with a set of QoS parameters that quantify its characteristics. The MAC in the IEEE 802.16 standard provides four QoS classes [23].

Following are different metrics for every service class:

**1 UGS**

Packet Error Rate (PER) and service rate is QoS parameter in UGS.

**2 rtPS**

PER and Maximum delay is QoS parameter in rtPS.

**3 nrtPS**

PER and minimum reserved rate is the QoS parameter in nrtPS.

**4 BE**

PER should be maintained in BE.

So, based on these metrics and channel condition priority of a particular connection is calculated. But this priority calculated for only three of service flow mentioned above. For UGS connection, there is no such any priority is calculated but certain fix number of slots are allocated to it. After that remaining slots are allocated to connection having highest priority. For calculating priority various parameters like channel condition, delay requirement (for rtPS) and average data rate (for nrtPS) are considered and priority is calculated.

### 3.2.5 TCP-Aware Uplink Scheduling Algorithm [26]

This algorithm works only BE service class. As this class has not any specific QoS requirement it is not advantageous to use bandwidth request mechanism for this class and to waste that bandwidth. Also, it is not advisable to equally allocate remaining bandwidth to all remaining BE connections because all connections can't utilize all bandwidth allocate to them and some may have more requirements than allocated. So, this algorithm works by calculating bandwidth for a particular connection according to sending rate of that connection. Also as sending rate

is going to change dynamically, it is not proper to allocate fix amount of bandwidth to a particular connection. For properly allocating bandwidth this algorithm works as follows:

Step1: Compute the sending rate.

Step2: If sending rate< allocated bandwidth

    Then demand=sending rate

Step3: if sending rate=allocate bandwidth

    Then demand=Increment allocated bandwidth in fix proportion

Step4: If Sending rate>allocated bandwidth

Then increase bandwidth until sending rate becomes stable.

The main strategy of this algorithm is to allocate bandwidth somewhat higher than actual sending rate of connection so that we can safely estimate the sending rate at any given time. To detect changes in sending rate its max & min. values are maintained over a period of time and are changed according to rate change. Whenever these values are to be changed above algorithm is used for demand estimation. After estimating demand for each connection, it uses max-min fair scheduling for allocating total bandwidth among all connections.

# Chapter 4

# Problem Formation and Methodologies

## 4.1 Research Challenges

As we have discussed in the beginning, in chapter-1st, wireless has become the most emerging technology. The market of Broadband wireless is increasing day by day. But as the market becoming broader there are also other issues are coming regarding the quality of the services providing by the vendors to users. Users are also demanding:

1 Lower maintenance cost
2 Easy configuration,
3 Scalability,
4 Rapid deployment and
5 User friendly

But there are also other alternatives that are giving best services to user so now it is very important to concentrate on QoS parameter of scheduling services.

WiMAX is one of such slandered who defines general QoS architecture and the most important part of this architecture is that scheduling algorithm is not defined and left upon vendors, to implement as per there needs. Scheduling algorithm plays a very important role to support QoS in WiMAX. Limited channel capacity, maximum number of users, limited no of available resources makes scheduling algorithm very much important in WiMAX. So it is very important to give proper attention to scheduling algorithm.

## 4.2 Problem Statement

From the literature survey carried out, we hereby propose a hybrid-scheduling algorithm, which can take the advantage of two different scheduling algorithms instead of considering them independently. So we decide to propose a system comprising of Round Robin with priority.

This algorithm takes the advantage of round robin that any service connection have not wait for a long time and by including priority parameter we are making it sure that connection having highest priority should be serve first. When only Round Robin algorithm is used, it gives equal weightage to every connection, so it is unable to satisfy QoS parameters, due to the different requirement of user if we provide QoS only by priority it may result in starvation, as in the case with all non-preemptive scheduling algorithms. So we propose an algorithm that combines the attribute of both and overcomes their individual limitations.

## 4.3 Methodology

We are proposing **"Credit Based Round Robin"** algorithm. In this algorithm we decide the credit on the basis of available Bandwidth. These credits are divided in to different service connection on the basis of the there priority. And here we decide priority on the basis of QoS parameter, jitter.

Following section is describing the steps of algorithm:

Begin

1: Decide the credit, which are based on bandwidth.

2: Calculate the priority of service class:

- Jitter, Latency will be accepted from the user for each service class.
- Service class having lowest value of jitter will be allocated highest priority and packets of that service class will be served first and in this way priority for every service class will be decided.

*Repeat steps 3 to 5 until packet list is empty*

3: Distribution of Credit:

- Number of packets and size of packet will be accepted from the user.
- Credits allocation will be start from the service class having highest priority.

- Initially for the service class having highest priority, allocated credit will be equal to size of packet.
- After allocating the credits to first service class we will go to next service class here we will check:

  If (remaining credits = > packet size)

  {

  Allocate the credit to the service class

  Calculate the remaining credits

  }

  else

  go to the next service class and check the same condition and allocate the credit if available.

4: Releasing the credit

- After completion of 3rd step every service class will release the allocated credit.

5: Reassignment of priority

- Find out the service class, which is not served in previous round.
- Check out for these left service class which one having the lowest value of jitter, will be allocated highest priority, in this way priority for these connection will be decided.
- Remaining connections, which have been served in previous round, will be served after serving the unserved connection in the same sequence in this round.

6: Step $3^{rd}$ to $5^{th}$ will be repeated till then the last packet of every connection will be Served.

7: Calculation of waiting time will be depending upon latency time.

End

# Chapter 5

# Results and Discussion

We have analyzed performance of our proposed algorithm via simulation. Scheduling algorithm is developed in C. We have performed simulation in various scenarios. Depending upon the scenario or input values we just calculate the waiting time to serve total no of incoming packets of every service class.

## 5.1 Simulation for different connection

We have performed different simulation for different connections. Here we take two sets of values to perform our simulation. And every set of values has seven different values. For first set of values we are considering some of the values will remain same.

### 5.1.1 Experiment-I

Table 5.1 shows different parameters that are kept constant during seven simulation scenarios.

**Table 5.1: Constant Parameters**

| Name of Service class | Size of Packets (kb) | Jitter (ms) | Latency (ms) |
|---|---|---|---|
| BE | 75 | 3 | 4 |
| nrtPS | 100 | 7 | 3 |
| rtPS | 90 | 5 | 2 |
| UGS | 70 | 2 | 5 |

Following table shows different values of number of Packets, considered during the seven simulation scenario**.**

**Table 5.2: Number of Packets**

| Name of Service Class | Scenario1 | Scenario2 | Scenario3 | Scenario4 | Scenario5 | Scenario6 | Scenario7 |
|---|---|---|---|---|---|---|---|
| **BE** | 2 | 8 | 13 | 17 | 18 | 27 | 30 |
| **nrtPS** | 6 | 6 | 9 | 15 | 18 | 23 | 26 |
| **rtPS** | 7 | 9 | 13 | 18 | 20 | 27 | 30 |
| **UGS** | 4 | 6 | 10 | 15 | 20 | 25 | 28 |

### 5.1.2 Result

Following table shows the calculated waiting time after simulation of first set of values for seven different scenarios.

**Table 5.3: Waiting Time (ms) against different scenario for 1st experiment**

| Name of Service Class | Scenario1 | Scenario2 | Scenario3 | Scenario4 | Scenario5 | Scenario6 | Scenario7 |
|---|---|---|---|---|---|---|---|
| **BE** | 14 | 50 | 50 | 79 | 113 | 124 | 177 |
| **nrtPS** | 35 | 35 | 9 | 56 | 98 | 119 | 154 |
| **rtPS** | 40 | 50 | 13 | 76 | 113 | 129 | 174 |
| **UGS** | 28 | 40 | 10 | 66 | 103 | 131 | 169 |

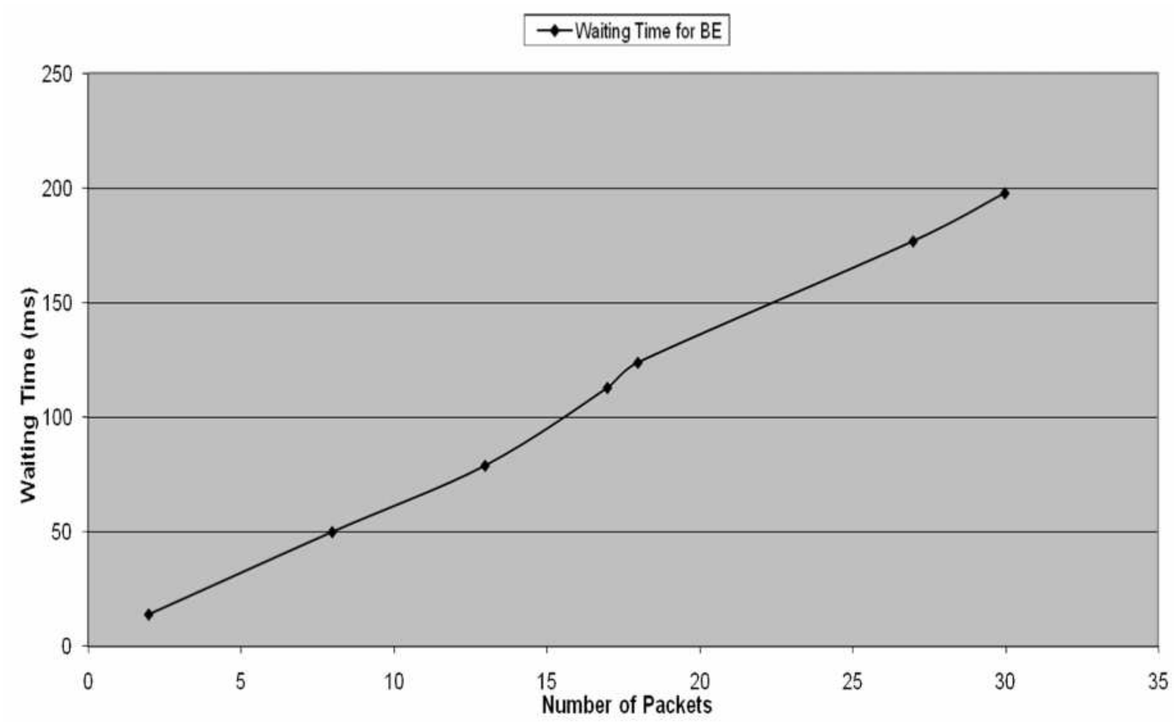


**Figure 5.1: Waiting time for BE**

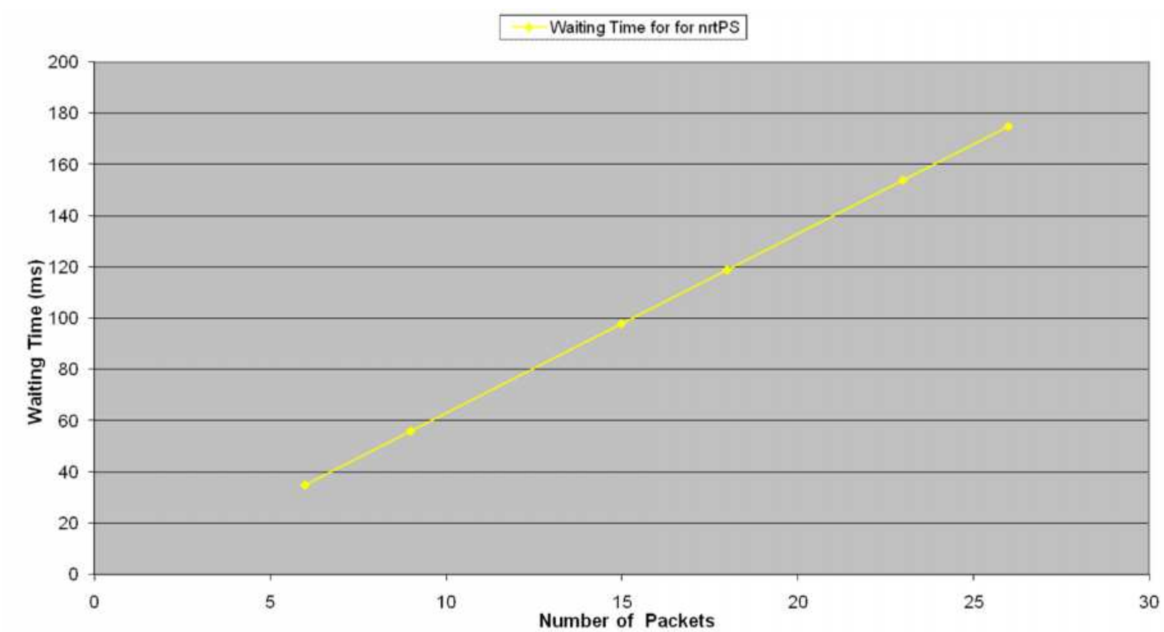


**Figure 5.2: Waiting time for nrtPS**

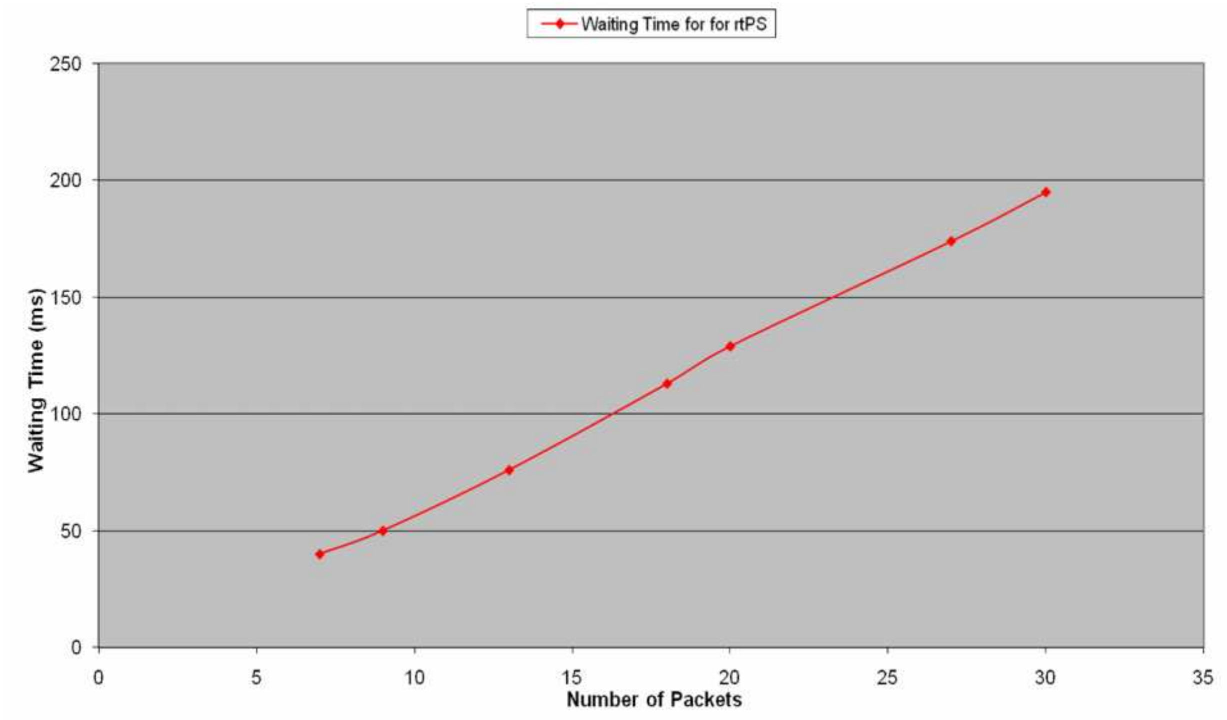


**Figure 5.3: Waiting time for rtPS**

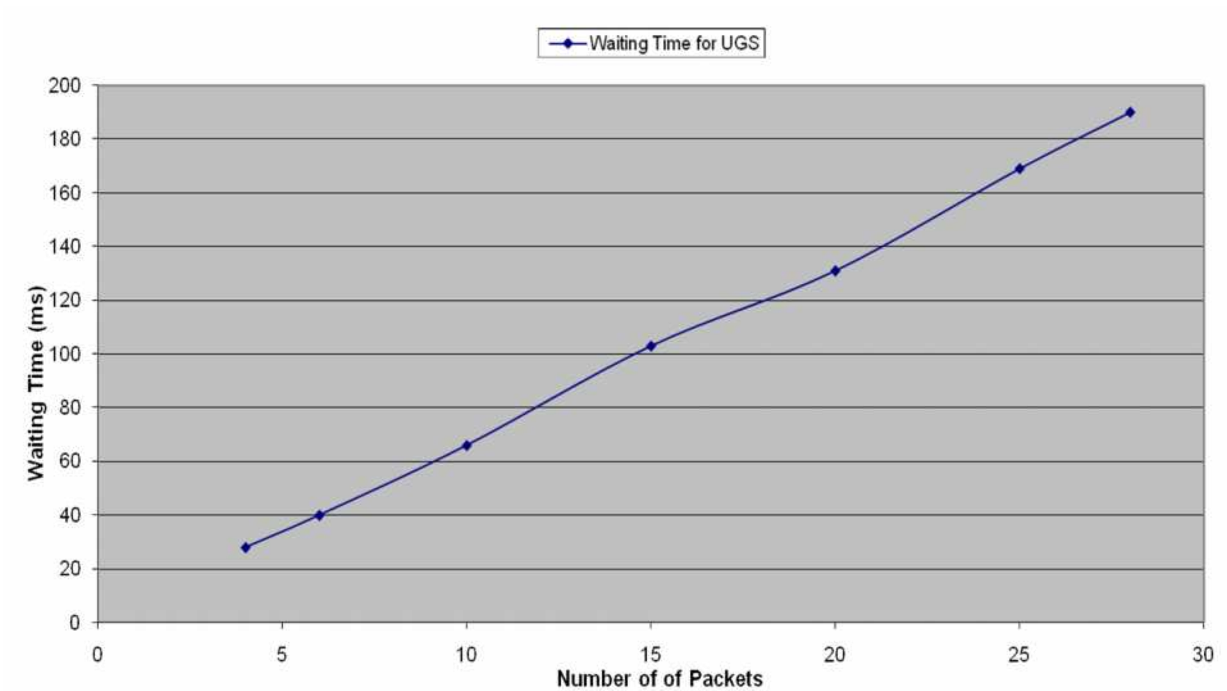


**Figure 5.4: Waiting time for UGS**

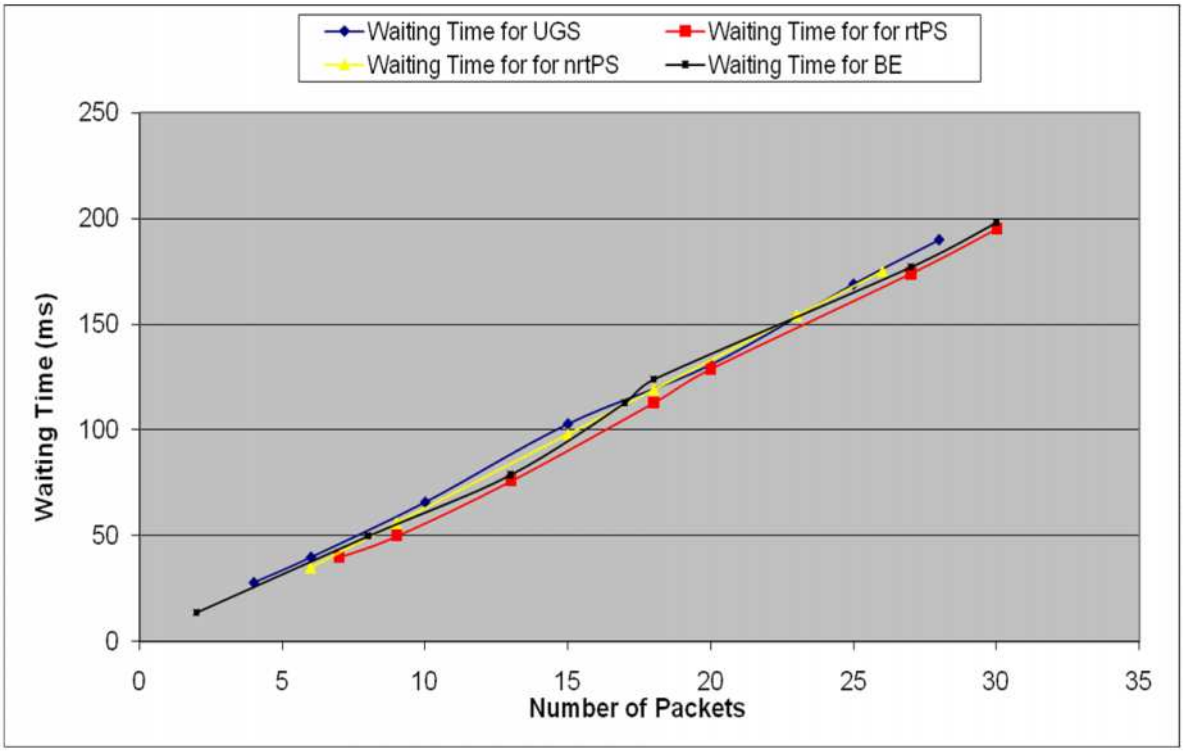


**Figure 5.5: Comparison of Waiting time for different Service classes**

**Discussion:**

We have generated a good number of simulation scenario (seven, in total), varying over a wide range of values. These scenarios represent the different possible number of combination of the number of packets. In scenario 1$^{st}$, we have considered very small size of packets and we slowly increase the number of packets so that we can study the effect of increase in number of packet on the waiting time and thus its effect on QoS. Further, in order to have an in depth comparison, another simulation scenario has been generated in which the values of number of packets are considered in a random order. The results of the simulation scenario are as shown below.

### 5.1.3 Experiment II

Table 5.4 shows different parameters that are kept constant during seven simulation scenarios.

**Table 5.4: Constant Parameters**

| Name of Service class | Size of Packets (kb) | Jitter (ms) | Latency (ms) |
|---|---|---|---|
| BE | 75 | 6 | 6 |
| nrtPS | 70 | 2 | 4 |
| rtPS | 80 | 3 | 5 |
| UGS | 50 | 5 | 8 |

Following table shows different values of number of Packets, considered during the seven simulation scenario**.**

**Table 5.5: Number of Packets**

| Name of Service Class | Scenario1 | Scenario2 | Scenario3 | Scenario4 | Scenario5 | Scenario6 | Scenario7 |
|---|---|---|---|---|---|---|---|
| **BE** | 7 | 10 | 8 | 3 | 16 | 11 | 22 |
| **nrtPS** | 6 | 5 | 4 | 4 | 13 | 15 | 18 |
| **rtPS** | 4 | 4 | 5 | 6 | 15 | 13 | 20 |
| **UGS** | 3 | 8 | 10 | 7 | 11 | 16 | 24 |

### 5.1.3 Result

Following table shows the calculated waiting time after simulation of first set of values for seven different scenarios.

**Table 5.6: Waiting Time (ms) against different scenario for 2nd experiment**

| Name of Service Class | Scenario1 | Scenario2 | Scenario3 | Scenario4 | Scenario5 | Scenario6 | Scenario7 |
|---|---|---|---|---|---|---|---|
| **BE** | 46 | 76 | 64 | 24 | 116 | 88 | 176 |
| **nrtPS** | 34 | 32 | 24 | 24 | 92 | 112 | 136 |
| **rtPS** | 22 | 24 | 32 | 40 | 104 | 96 | 152 |
| **UGS** | 16 | 56 | 72 | 48 | 80 | 120 | 184 |

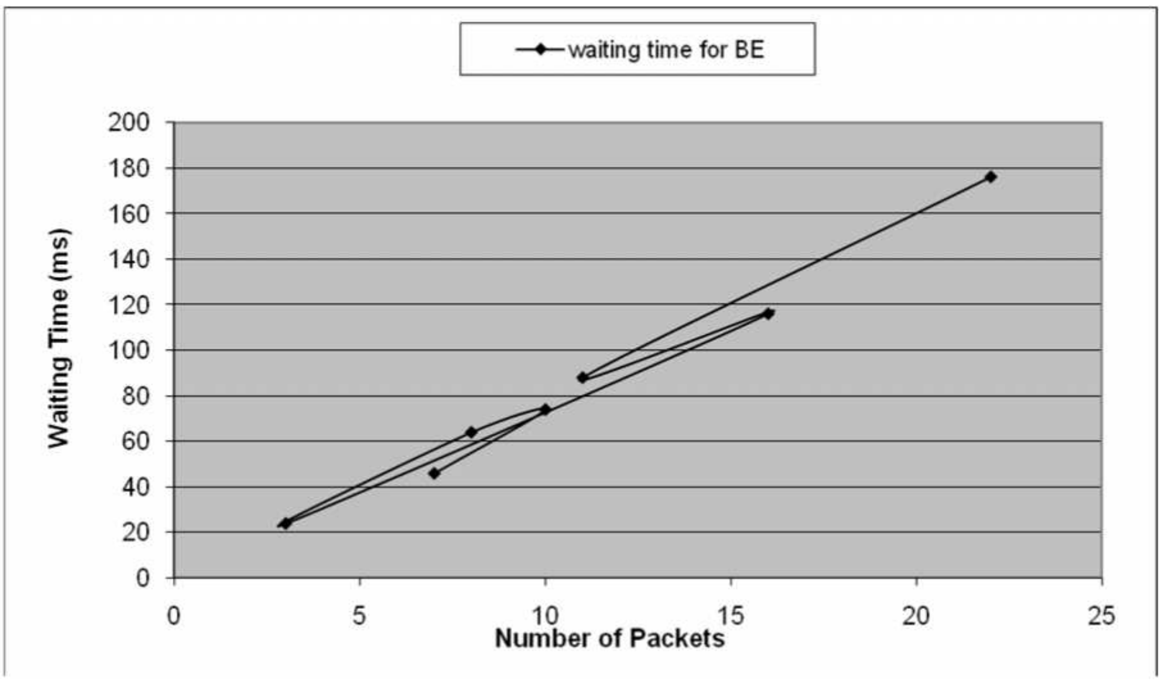


**Figure 5.6: Waiting time for BE**

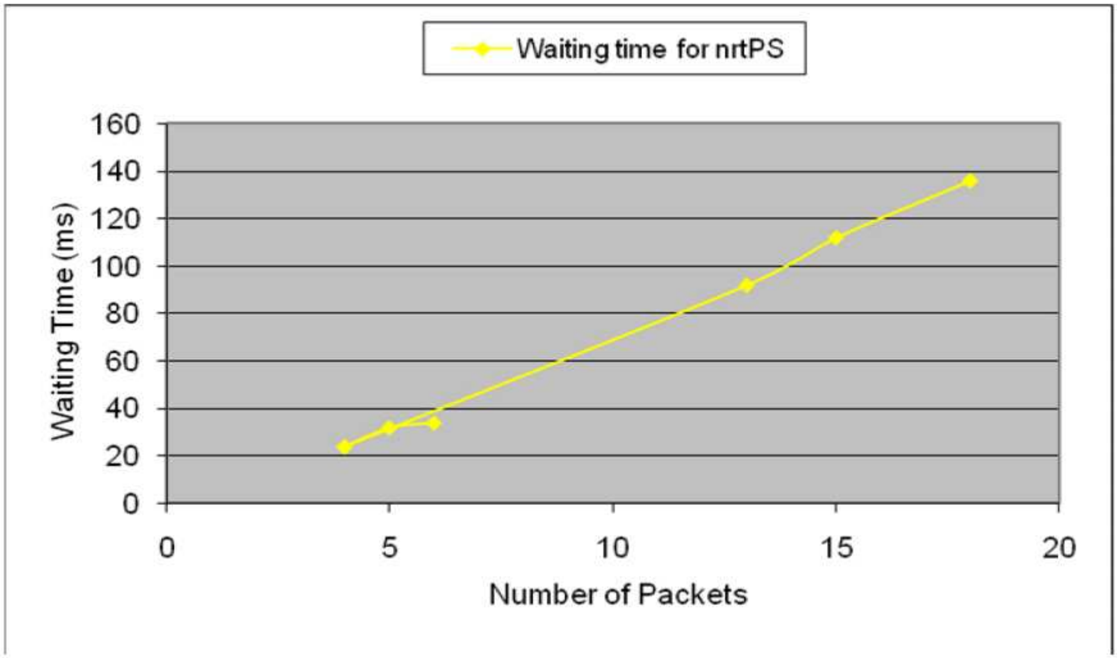


**Figure 5.7: Waiting time for nrPS**

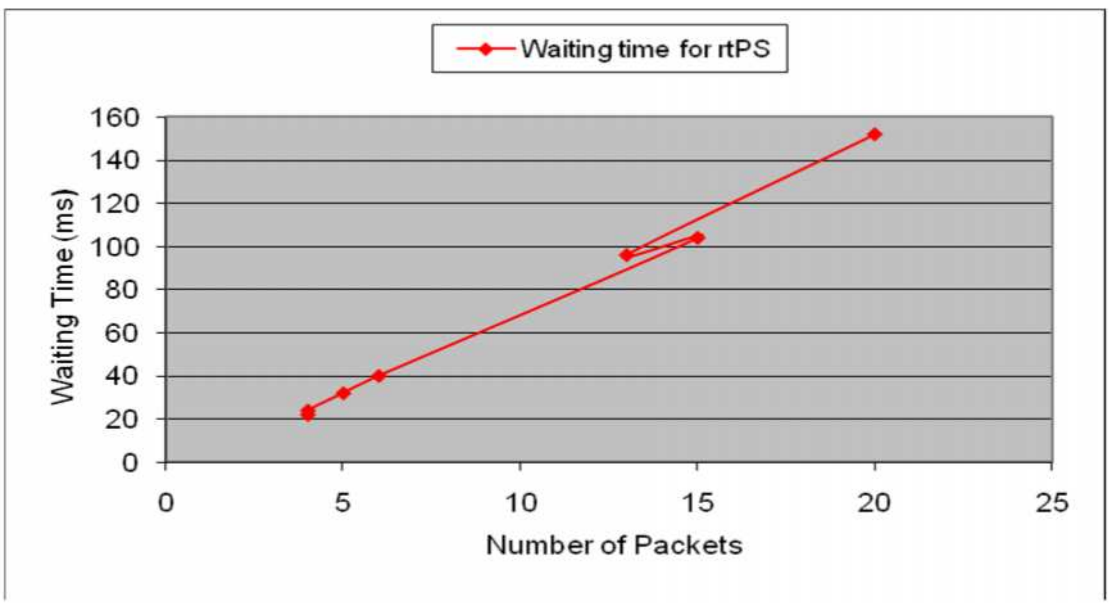


**Figure 5.8: Waiting time for nrPS**

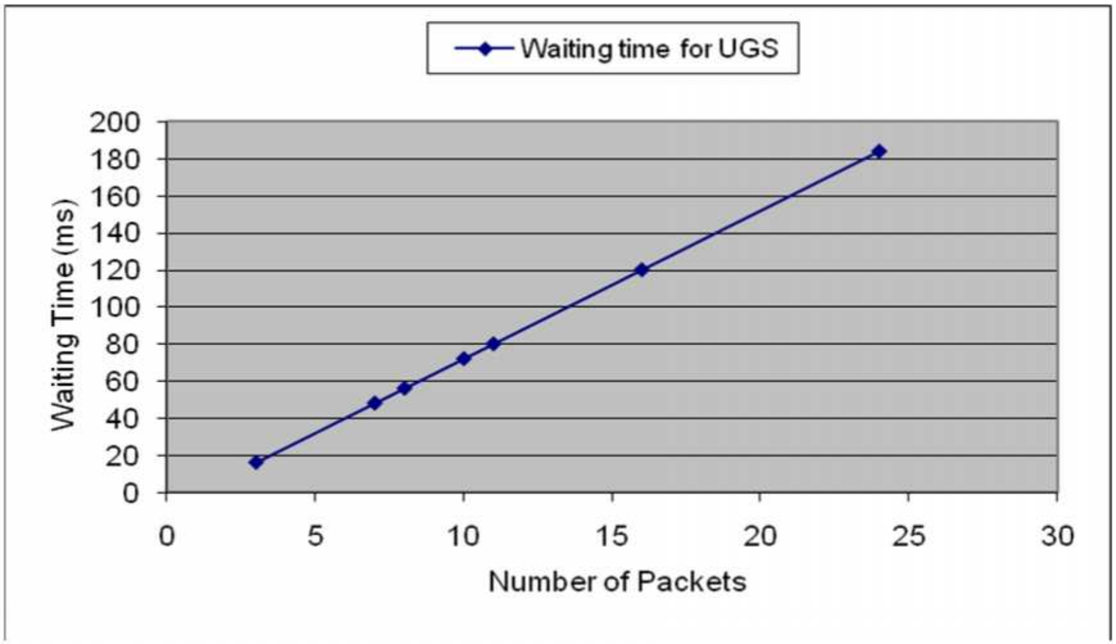


**Figure 5.9: Waiting time for UGS**

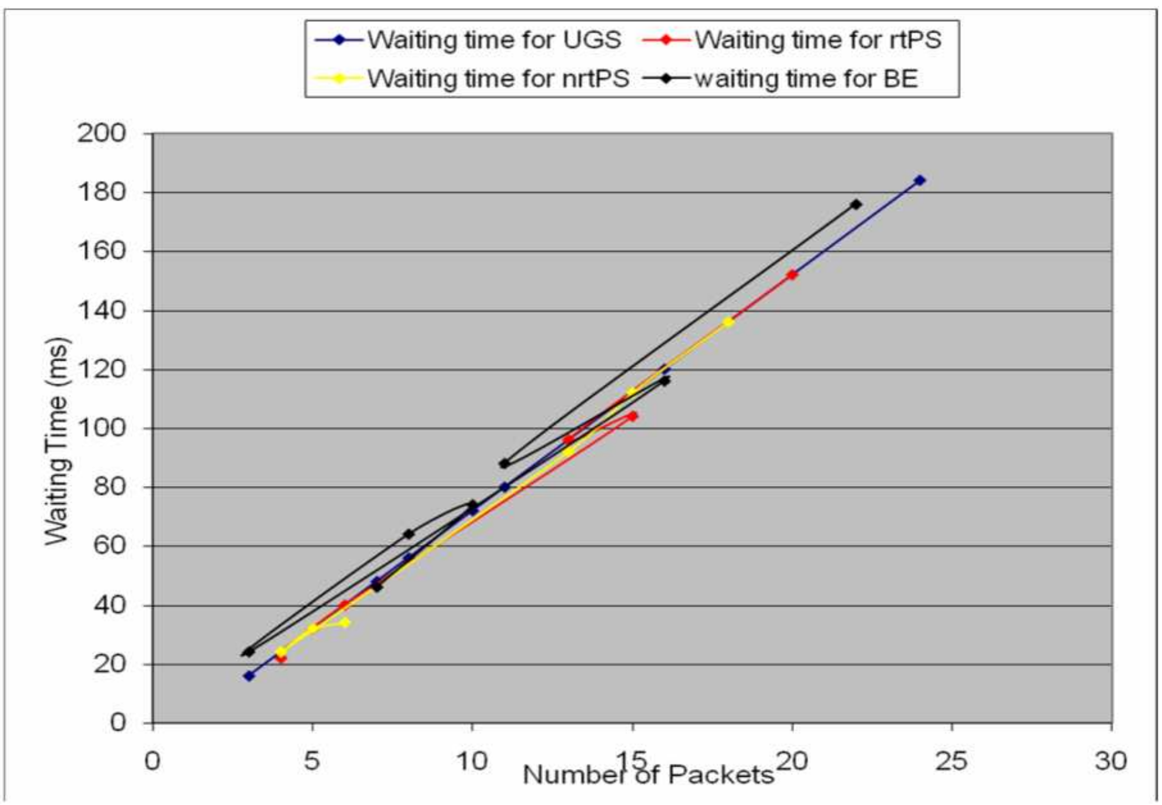


**Figure 5.10: Comparison of Waiting time for different Service classes**

**Discussion:**

The input values have been varied and the scenario represents the different possible number of combination of the number of packets. The numbers of packets are considered in a random order, which is different from the first set of values, considering an incremental value. The effect of these random values is that the waiting time also increases/decreases as per the packet size.

# Chapter 6

# Conclusion and Future Scope

## 6.1 Conclusion

Two different set of experimental values were taken, in the first set we generated seven different scenarios, varying numbers of packets and packet size in incremental order keeping the other parameters such as Jitter, Latency and packet size constant.

In the first set we increase the number of packets uniformly and observe that waiting time is also increasing uniformly. In the second set number of packets varied randomly and as such we observed that the waiting time is also varies randomly in proportionate with the number of packets. So, if we used the credit based scheduling algorithm, we have a smaller waiting time as compared to any preemptive scheduling algorithm (such as Round- Robin) or non preemptive scheduling algorithm (such as Priority Scheduling). So, our results encourage us that the proposed scheduling algorithm can be used in any of the service class of WiMAX. Thus enhancing QoS in such type of wireless networks using WiMAX.

## 6.2 Future Scope

This is an initial work in dealing with the scheduling aspects of various service classes in WiMAX, there are four different service classes Best Effort (BE), nor real time polling services (nrtPS), real time polling services (rtPS) and unsolicited grant services (UGS). However, this work can further be extended be taking some more simulation scenario(s) and exploiting this algorithm on a real time test bed. Further, the effect of this algorithm can also be studied by varying the size of packets, Jitter, Latency and other parameters.

# References


[1]. http://fcit.usf.edu/NETWORK/chap1/chap1.htm

[2]. http://searchnetworking.techtarget.com/sDefinition/0,,sid7_gci212644,00.html

[3]. http://nislab.bu.edu/nislab/education/sc441/one/intro.htm

[4]. http://www.conniq.com/Networking_Media5.htm

[5]. Mark C. Wood, “An Analysis of the Design and Implementation of QoS over IEEE 802.16”

[6]. http://www.wi-lan.com/library/LibraMX-ds.pdf.

[7]. www.wimaxforum.org/technology

[8]. IEEE. Standard 802.16-2004. Part16: Air interface for fixed broadband wireless access systems. October 2004.

[9]. IEEE. Standard 802.16e-2005. Part16: Air interface for fixed and mobile broadband wireless access systems—Amendment for physical and medium access control layers for combined fixed and mobile operation in licensed band. December 2005.

[10]. Jeffrey G. Andrews, Arunabha Ghosh, Rias Muhamed, “Fundamentals of WiMAX: Understanding Broadband Wireless Networking”, Prentice Hall

[11]. WiMAX Forum. WiMAX Forum Mobile System Profile. 2006–07

[12]. http://www.wimax.com/commentary/wimax_weekly

[13]. http://abhi.taralekar.googlepages.com/architecture

[14]. http://www.wimax.com/education/wimax/wireless_architectures

[15]. http://www.alvarion.com/

[16]. Sushil Kumar, Anil Kumar Verma, Ajay Kumar “Quality of Services in WiMAX- A Review”

[17]. Sahar Ghazal, Lynda Mokdad, Jalel Ben-Othman “Performance Analysis of UGS, rtPS, nrtPS Admission Control in WiMAX Networks”

[18]. Antonio Iera, Antonella Molinaro, and Sara Pizzi “Channel-Aware Scheduling for QoS and Fairness Provisioning in IEEE 802.16/WiMAX Broadband Wireless Access Systems”

[19]. Cicconetti, C., Lenzini, L., Mingozzi, E., Eklund, C., “Quality of service support in IEEE 802.16 networks,” Network IEEE, vol. 20, Issue 2, pp.50-55, Mar. Apr. 2006. [20] Mustafa Ergen, Department of Electrical Engineering and Computer Science University of California Berkeley “Tutorial of IEEE 802.11”.

[20]. Ashish Jain and Anil K. Verma “Comparative Study of Scheduling Algorithms for WiMAX”

[21]. A.Jalali, R. Padovani, and R. Pankaj, “Data throughput of CDMA-HDR a high efficiency-high data rate personal communication wireless system,” Proc. IEEEE VTC pp. 1854-1858, 2000, Tokyo, Japan.

[22]. Cao Y, Li VOK. ”Scheduling algorithms in broadband wireless network” Proceeding of the IEEE 2001 Volume 89, Issue 1, Jan. 2001 Page(s): 76 – 87

[23]. Q.Liu, S.Zhou, and G.B.Giannakis, “A Cross-layer scheduling Algorithm with QoS support in wireless networks,” IEEE Transactions on vehicular Technology, vol.55, No.3, May.2006.

[24]. Frank Ohrtman, “WIMAX in 50 Pages: A Simple Explanation To A Complex Subject”

[25]. http://www.wimax.com/education/wimax/antennas

[26]. Seungwoon Kim and Ikjun Yeom, “TCP-aware Uplimk scheduling for IEEE 802.16”. IEEE Communication Letter, Feb 2007.

[27]. S. Keshav, “An Engineering Approach to Computer Networking", Addison Wesley Longman, Inc., 1997.

[28]. Efficient QoS-based Uplink Scheduling in IEEE 802.16e Mobile Stations.

# List of Publications

1. Sushil Kumar, A.K. Verma, Ajay Kumar "Quality of Services in WiMAX- A Review", National Conference on "Advances in Computer Networks & Information Technology" organized by Department of Computer science & Engineering, Guru Jambheshwar University of Science & Technology, Hisar, March 24-25 march, 2009.