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Performance Analysis and Enhancement of QoS Framework for Fixed WiMAX Networks

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PhD

Performance Analysis and Enhancement of QoS Framework for Fixed WiMAX Networks

Design, analysis and evaluation of 802.16 Point-to-Multipoint (PMP) Quality of Service Framework based on uplink scheduler and call admission control Analysis

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A thesis submitted for the degree of Doctor of Philosophy

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Performance Analysis and Enhancement of QoS Framework for Fixed WiMAX Networks, Elmabruk M. Laias, WiMAX, QoS, Scheduler, Connection Admission Control, OPNET

Abstract

Given the current developments and advances in the scientific and technological aspects of human knowledge and introducing new approaches in various fields of telecommunication technologies and industries, there has been an increasing growth in its players' plans and a positive change in their outlooks in order to achieve the target of "anywhere and anytime access". Recent developments of WiMAX (Worldwide interoperability for Microwave Access) networks, as a sign of increasing needs and demands for new telecommunication services and capabilities, have led to revolutions in global telecommunication which should be perceived properly in terms of the commercial and technical aspects in order to enjoy the new opportunities.

Most experts believe that WiMAX technology is a preliminary step to develop Fourth Generation networks known as 4G technologies. It has not only succeeded in the utilization of several of the latest telecommunication techniques in the form of unique practical standards, but also paved the way for the quantitative and qualitative developments of high-speed broadband access.

IEEE 802.16 Standard introduces several advantages, and one of them is the support for Quality of Services (QoS) at the Media Access Control (MAC) level. For these purposes, the standard defines several scheduling classes at MAC layer

Performance Analysis and Enhancement of QoS Framework for Fixed WiMAX Networks, Elmabruk M. Laias, WiMAX, QoS, Scheduler, Connection Admission Control, OPNET

to treat service flow in a different way, depending on QoS requirements. In this thesis, we have proposed a new QoS framework for Point-to-Multi Point (PMP) 802.16 systems operating in Time Division Duplexing (TDD) mode over a WirelessMAN-OFDM physical layer. The proposed framework consists of a Call Admission Control (CAC) module and a scheduling scheme for the uplink traffic as well as a simple frame allocation scheme. The proposed CAC module interacts with the uplink scheduler status and it makes its decision based on the scheduler queue status; on the other hand, the proposed scheduling scheme for the uplink traffic aims to support realtime flows and adapts the frame-by-frame allocations to the current needs of the connections, with respect to the grants boundaries fixed by the CAC module.

Extensive OPNET simulation demonstrates the effectiveness of the proposed architecture.

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Publications

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- Elmabruk Laias, Irfan Awan, Pauline M.L. Chan," Fair and Latency Aware Uplink Scheduler In IEEE 802.16 Using Customized Deficit Round Robin", in Proceedings of the IEEE 23rd International Conference on Advanced Information Networking and Applications, IEEE Computer Society, 2009.

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List of Abbreviations

AMC: Adaptive modulation and Coding

BE: Best Effort

BER: Bit Error Rate

BPSK: Binary Phase Shift Keying

BS: Base Station

CBR: Constant Bit Rate

CSI: Channel State Information

FDD: Frequency Division Duplex

FDMA: Frequency Division Multiple Access

FFT: fast Fourier transforms

FTP: File Transfer Protocol

HDR: High Data Rate

ICL: Integrated Cross-layer scheduling

APF: Integrated Proportional Fairness

LOS: Line Of Sight

MAC: Medium Access Control

MPEG: moving pictures experts group

NLOS: Non-Line Of Sight

nrtPS: non-real-time Polling Service

OFDM: Orthogonal Frequency Division Multiplexing

OFDMA: Orthogonal Frequency Division Multiple Access

PDU: Protocol Data Unit

PF: Proportional Fairness

PHY: Physical Layer

PMP: Point to Multi-Point

PS: Physical Slot

QAM: Quarter Amplitude Modulation

QoS: Quality of Service

QPSK: quaternary phase shift keying

RR: Round Robin

rtPS: real time Polling Service

SCa: Single Carrier

SDU: Service Data Units

SNR: Signal to Noise Ration

SS: Subscriber Station

TDD: Time Division Duplex

TDMA: Time Division Multiple Access

UGS: Unsolicited Grant Service

VBR: Variable Bit-Rate

VoIP: Voice over IP

WLAN: Wireless Local Area Networks

WiMAX: Worldwide interoperability for Microwave Access

Chapter 1

Introduction

1.1 Background

Broadband wireless sits at the confluence of two of the most remarkable growth stories of the telecommunications industry in recent years. Both wireless and broadband have on their own enjoyed rapid mass-market adoption. Wireless mobile services grew from 11 million subscribers worldwide in 1990 to more than 2 billion in 2005 [1]. During the same period, the Internet grew from being a curious academic tool to having about a billion users. This staggering growth of the Internet is driving demand for higher-speed Internet-access services, leading to a parallel growth in broadband adoption. In less than a decade, broadband subscription worldwide has grown from virtually zero to over 200 million [2]. Many industry observers believe combining the convenience of wireless with the rich performance of broadband will be the next frontier for growth in the industry and such a combination will be technically and commercially viable as well, as the wireless will deliver broadband applications and services that are of interest to the end-users.

The state of broadband access today can be classified into two categories, *Digital Subscriber Line* (DSL) technology, which delivers broadband over twisted-pair telephone wires, and *cable modem* technology, which delivers over coaxial cable from a TV plant, are the predominant mass-market broadband access technologies today. Both of these technologies typically provide up to a few megabits per second of data to each user, and continuing advances are making several tens of megabits per second possible. Since their initial deployment in the late 1990s, these services have enjoyed considerable growth. The United States has more than 50 million broadband subscribers, including more than half of home Internet users. Worldwide, this number is more than 200 million today and is projected to grow to more than 400 million by 2010 [2]. The availability of a wireless solution for broadband could potentially accelerate this growth.

Broadband users worldwide are finding that it dramatically changes how we share information, conduct business, and seek entertainment.

Broadband access not only provides faster Web surfing and quicker file downloads but also enables several multimedia applications, such as realtime audio and video streaming, multimedia conferencing, and interactive gaming. Broadband connections are also being used for voice telephony using voice-over-Internet Protocol (VoIP) technology. More advanced broadband access systems, such as fibre-to-the-home (FTTH) and very high data rate digital subscriber loop (VDSL) enable such applications as entertainment-quality video, including high-definition TV (HDTV) and video on demand (VoD). As the broadband market continues to grow, several new applications are likely to emerge, and it is difficult to predict which ones will succeed in the future.

So, broadband wireless is about bringing the broadband experience to a wireless context, which offers users certain unique benefits and convenience. There are two fundamentally different types of broadband wireless services. The first type attempts to provide a set of services similar to that of the traditional fixed-line broadband but using wireless as the medium of transmission. This type, called *fixed wireless broadband*, can be thought of as a competitive alternative to a DSL or a cable modem. The second type of broadband wireless, called *mobile broadband*, offers the additional functionality of portability, nomadic, and mobility.

Mobile broadband attempts to bring broadband applications to new user experience scenarios and hence can offer the end user a very different value proposition. WiMAX (Worldwide interoperability for Microwave Access) technology [3], the subject of this research, is designed to accommodate both fixed and mobile broadband applications.

Box 1. Confusion around the term "WiMAX"

WiMAX is not a technology, but rather a certification mark, or "stamp of approval" given to equipment that meets certain conformity and interoperability tests for the IEEE 802.16 family of standards. A similar confusion surrounds the term Wi-Fi (Wireless Fidelity), which like WiMAX, is a certification mark for equipment based on a different set of IEEE standards from the 802.11 working group for wireless local area networks (WLAN). Neither WiMAX, nor Wi-Fi is a technology but their names have been adopted in popular usage to denote the technologies behind them. This is likely due to the difficulty of using terms like "IEEE 802.16" in common speech and writing.

Using the terms "WiMAX" and "IEEE 802.16" interchangeably poses problems since it is feasible that equipment manufacturers could build products based on IEEE 802.16 standards that would not be labelled as WiMAX certified.



the term "WiMAX" refers to WiMAX-certified equipment that is based on the IEEE 802.16 set of standards. Any reference to WiMAX technologies implies the IEEE 802.16 set of standards that are the foundation of WiMAX certification.

The term *Nomadicity* implies the ability to connect to the network from different locations via different base stations; *mobility* implies the ability to keep ongoing connections active while moving at vehicular speeds.

In this chapter, we provide a brief overview of broadband wireless. The objective is to present the background and context necessary for understanding WiMAX. We review the history of broadband wireless, specify its applications, and discuss the business drivers and challenges.

1.2 Growth of Broadband Wireless

The history of broadband wireless as it relates to WiMAX can be traced back to the desire to find a competitive alternative to traditional wireline-access technologies. Spurred by the deregulation of the telecom industry and the rapid growth of the Internet, several competitive carriers were motivated to find a wireless solution to bypass incumbent service providers [1]. During the past decade or so, a number of wireless access systems have been developed, mostly by start-up companies motivated by the disruptive potential of wireless. These systems varied widely in their performance capabilities, protocols, frequency spectrum used, applications supported, and a host of other parameters. Some systems were commercially deployed only to be decommissioned later. Successful deployments have so far been limited to a few niche applications and markets. Clearly, broadband wireless has until now had a checkered record, in part because of the fragmentation of the industry due to the lack of a common standard. The

emergence of WiMAX as an industry standard is expected to change this situation.

Given the wide variety of solutions developed and deployed for broadband wireless in the past, a full historical survey of these is beyond the scope of this section. Instead, we provide a brief review of some of the broader patterns in this development. WiMAX technology has evolved through four stages, albeit not fully distinct or clearly sequential: (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, and (4) standards-based broadband wireless systems [52].

1.2.1 Second-Generation Broadband Systems

The second generation (2G) of mobile networks started to be deployed in the beginning of the 1990s. The main 2G mobile network and the most successful by far, is the Global System for Mobile communications (GSM) [4]. The first and unique service was voice, quickly joined by Short Message Service (SMS). The so-called second-and-half generation (2.5G or 2G+) such as General Packet Radio Service (GPRS) [5] and Enhanced Data Rates for GSM Evolution (EDGE) [6] added packet data services and higher data rate mainly for Internet-style access and e-mail. The theoretical maximum rate in the GPRS system is 115Kbps. The EDGE system provides a better theoretical maximum rate (up to 384Kbps).

Today, users need wireless high-speed Internet access. Moreover, users want to be able to access the Internet from a larger area. In the late 1990s, the third generation (3G) complemented the 2G system in many geographical areas. The

3G system can support multimedia, data, video, and other services including voice. The main 3G systems are the Universal Mobile Telecommunications System (UMTS) [7] and CDMA2000 [8]. The first deployment of CDMA2000 and UMTS took place in 2000–2001. Yet, the 3G systems are still in evolution. The first data rates were in the magnitude of 1Mbps. Nowadays, much higher data rates are expected in both uplink and downlink with the High Speed Downlink Packet Access (HSDPA) and the High Speed Uplink Packet Access (HSUPA) evolutions [9] (see, for example, Release 7 of UMTS). Apart from the displayed physical data rates, application-level data rates are smaller; for example, in 2007, the HSUPA could reach 1Mbps for a File Transfer Protocol (FTP) application [10].

More recent versions of HSUPA have higher figures. The next step after 3G is (evidently) 4G or what is also known as B3G (Beyond 3G). The main 4G system is currently Long Term Evolution (LTE). The official name of this technology is Evolved Packet System (EPS). According to presently displayed figures, the LTE network provides a downlink throughput of 100 Mbps for Single In Single Out (SISO) antennas and 173Mbps for 2×2 Multiple In Multiple Out (MIMO) antennas [11]. The third Generation Partnership Project (3GPP) is developing the LTE Advanced standard in order to have a 4G access technology running from 2010.

1.3 Emergence of 802.16

The standard IEEE 802.16 can fulfil the requirements of the quality of service for different types of applications including instantaneous traffic. The advantages for this standard bring it into competition with other wireless standards like IEEE 802.11 [12] and its amendments IEEE 802.11b [13] and IEEE 802.11g [14]. This network can be implemented in populated areas with much lower costs compared to cable technologies and this leads to higher demands for such services. Figure 1-1 shows Commercial WiMAX Deployments [56].



Figure 1-1 Commercial WiMAX Deployments

The architecture of WiMAX includes a Base Station (BS) and two or more Subscriber Stations (SS). Clients are connected to SSs or the SS itself can be a client.

Subscriber stations can only transmit on the specified time schedule granted to them. Decision-making for this scheduling is taken by BS. At the beginning of each transmitted frame to SS (in UL-MAP), such decisions are included. Although some bandwidth dedication methods and quality of service insurance are defined in the IEEE 802.16 standard, the details on scheduling methods and how to grant the bandwidth are not included in the standard.

Data transmission in uplink channels (from SS to BS) and/or downlink channel (from BS to SS) is done through the Time Division Multiple Access (TDMA) method. Time is divided between frames and there is a guard time between each frame. Each frame is then divided into two sub-frames as uplink and downlink sub-frames.

An uplink sub-frame is divided into 3 time intervals: Ranging Period, Bandwidth Contention Period, and Uplink Data Period.

Therefore, the base station should specify the time, the period, and the condition in which the SS should transmit. Key specifications such as delay, different flows, least reserved bandwidth, bandwidth request methods and bandwidth dedication are defined in the standard but when and where we can use them for having the maximum quality of service is not stated in the standard. The base station is responsible for scheduling the packets available or those coming from other stations. In the downlink, scheduling is easier as the BS knows the packets and is aware of their specifications and status but scheduling in the uplink is more complicated as specifications like the number of clients connected to the SS, delay

limitations, required bandwidth for each flow, transmission time, waiting period and packet status for BS must be specified in advance.

1.3.1 WiMAX versus 3G and Wi-Fi

The throughput capabilities of WiMAX depend on the channel bandwidth used. Unlike 3G systems which have a fixed channel bandwidth, WiMAX defines a selectable channel bandwidth from 1.25MHz to 20MHz, which allows for a very flexible deployment. When deployed using the more likely 10MHz TDD (time division duplexing) channel, assuming a 3:1 downlink-to-uplink split and 2:2 MIMO, WiMAX offers 46Mbps peak downlink throughput and 7Mbps uplink.

The reliance of Wi-Fi and WiMAX on OFDM modulation, as opposed to CDMA as in 3G, allows them to support very high peak rates. The need for spreading makes very high data rates more difficult in CDMA systems.

More important than peak data rate offered over an individual link, is the average throughput and overall system capacity when deployed in a multicellular environment.

The fact that WiMAX specifications accommodated multiple antennas right from the start gives it a boost in spectral efficiency. In 3G systems, on the other hand, multiple-antenna support is being added in the form of revisions. Furthermore, the OFDM physical layer used by WiMAX is more amenable to MIMO implementations than are CDMA systems from the standpoint of the required complexity for comparable gain. OFDM also makes it easier to exploit frequency diversity and multi-user diversity to improve capacity. Therefore, when compared to 3G, WiMAX offers higher peak data rates, greater flexibility, and higher average throughput and system capacity.

Another advantage of WiMAX is its ability to efficiently support more symmetric links useful for fixed applications, such as T1 replacement and support for flexible and dynamic adjustment of the downlink-to-uplink data rate ratios. Typically, 3G systems have a fixed asymmetric data rate ratio between downlink and uplink. in terms of supporting advanced IP applications, such as voice, video, and multimedia, and prioritizing traffic and controlling quality, The WiMAX media access control layer has been built from the ground up to support a variety of traffic mixes, including realtime and non-realtime constant bitrate and variable bitrate traffic, prioritized data, and best-effort data. Such 3G solutions as HSDPA and 1x EV-DO were also designed for a variety of QoS levels.

Perhaps the most important advantage for WiMAX may be the potential for lower cost, owing to its lightweight IP architecture. Using IP architecture simplifies the core network; on the other hand, 3G has a complex and separate core network for voice and data and reduces the capital and operating expenses. IP also puts WiMAX on a performance/price curve that is more in line with general-purpose processors (Moore's Law), thereby providing greater capital and operational efficiencies. IP also allows for easier integration with third-party application developers and makes convergence with other networks and applications easier. In summary, WiMAX occupies a somewhat middle ground between Wi-Fi and 3G technologies when compared in the key dimensions of data rate, coverage, QoS, mobility, and price.

1.4 Motivation

WiMAX is one of the most emerging technologies for Broadband Wireless Access (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 provides high data rate applications with a variety of Quality of Service (QoS) requirements.

We are reaching the goal of realizing a unique wireless network to cover a big area. In a large scale wireless network, the radio resource must be shared among multiple users.

The bandwidth allocation algorithms have been designed for the efficient utilization of the scarce radio resource. In addition, to support multimedia traffic, the Medium Access Control (MAC) protocols will co-ordinate the transmission of traffic flow. The channel characteristics of users and traffic flow requirements are largely diverse, motivating us to design efficient MAC layer protocols that can improve system performance due to the channel and traffic dynamics.

1.5 Research Challenges

Scheduling algorithms serve as an important component in any communication network to satisfy the QoS requirements. The design is especially challenged by

the limited capacity and dynamic channel status that are inherent in wireless communication systems.

Different scheduling mechanisms [15], [16], [17], [18] and [19] have been proposed in the literature; however, not all of them comply with the IEEE 802.16 standard. Moreover, most of them are based on scheduling policies, such as Weighted Fair Queuing, which are not so simple to implement.

To design an MAC layer protocol which can optimize system performance, the following features and criteria should be a concern:

• Bandwidth utilization.

Efficient bandwidth utilization is the most important part of the algorithm design. The algorithm must utilize the channel efficiently. This implies that the scheduler should not assign a transmission slot to a connection with a currently bad link.

• QoS requirements.

The proposed algorithm should support different applications to better exploit QoS. To support delay-sensitive applications, the algorithm provides the delay bound provisioning. The long-term throughput should be guaranteed for all connections when sufficient bandwidth is provided.

• Fairness.

The algorithm should assign available resource fairly across connections. The fairness should be provided for both the short-term and the long-term.

• Implementation complexity.

In a high-speed network, the scheduling decision-making process must be completed very rapidly, and the reconfiguration process in response to any network state variation. Therefore, the amount of time available to the scheduler is limited. A low-complexity algorithm is necessary.

• Scalability.

The algorithm should operate efficiently as the number of connections or users sharing the channel increases.

Our protocol design is desirable to fulfil all of the above features.

1.5.1 Contributions

- 1. The thesis focused on the dependencies across layers and the relationships between the Scheduler and CAC in 802.16 networks [57], [58], [59], [60], [61] and the outlined BS model to be used for simulation studies to investigate the effect of various strategies involving the Scheduler and CAC algorithms and their effect on network productivity in terms of frame throughput, provider return throughput, bandwidth use and other performance indices.
- 2. Analyzing different research directions, the thesis offers the definition of quality of services as a QoS parameter set, describing network capability in order to satisfy user requests.
- 3. The major objective of this thesis is to develop an effective yet simple QoS framework for fixed WiMax networks that can be deployed and implemented with reduced overhead.
- 4. The thesis includes the design and implementation of the proposed uplink scheduler, CAC and frame allocation models, as a QoS framework support model using an OPNET network simulator, which have shown that the proposed

algorithm can differentiate services in terms of the delay constraints over a largescale network.

1.6 Outline of the Thesis

Chapter 2 presents an overview of WiMAX. We briefly describe the transmission technologies supported by the WiMAX PHY layer. We consider only the Orthogonal Frequency Division Multiplexing (OFDM) layer. We describe the frame structure. A frame consists of a downlink subframe (for transmission from the Base Station) and an uplink subframe (for transmission for the Subscriber Station). Since the OFDM symbol represents the unit of allocation when using the OFDM PHY layer, we present the computations for the OFDM symbol duration and then the number of useful symbols per frame. The useful throughput can be computed when all users have the same radio channel characteristics. Since the radio channel is variable and each subscriber has its own characteristics, the network simulation can be used in order to estimate the WiMAX capacity. In the second part of this Chapter, we present briefly the different sublayers of the MAC layer. Then, we present the service flow management that consists of an addition of a new connection, a change of parameters of an existing connection, and a deletion of an existing connection. This management is based on the exchange of Dynamic Service management messages between the Base Station and the Subscriber Stations. We then describe the deferent QoS classes defined by the IEEE 802.16 standard. These QoS classes are useful for the determination of the QoS requirements of the connections. We also describe the link adaption since

WiMAX supports many Modulation and Coding Schemes (MCSs).

Chapter 3 is the core of the thesis and it talks about the present scheduling

algorithms in general. However, Modified Deficit Round Robin will be discussed

in detail, since it is the main objective of the thesis. In this chapter we also explore

the simulator tool used to be able to conduct this work.

Chapter 4. In this Chapter, we describe in detail the proposed uplink packet

scheduling (UPS) algorithm. Then we evaluate the proposed scheduler using an

OPNET WiMAX module and compare it with a MDRR scheduler and show the

impact of our proposed scheduler on the rtPS delay as well as throughput.

Chapter 5. The admission control policy is introduced in this chapter and we

present the simulations and discuss the outcomes. The main features of the

proposed solution are explained and we show how the algorithm is dependent in

respect to the scheduling policy used in the BS and that the algorithm is only

based on delay measurements. Simulation realized with an OPNET simulator

show the effectiveness of the proposed algorithm, in terms of providing a QoS

guarantee to rtPS flow admitted in the network, while a deterministic QoS

guarantee is provided to UGS and nrtPS flows.

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Chapter 1: Introduction

Chapter 6 has the proposed frame allocation scheme presented in detail in this

chapter and its effectiveness through the simulation has been shown compared

with a fixed allocation scheme.

Chapter 7 concludes the achieved work by presenting the main contributions and

suggests directions for future research.

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Chapter 2:

An Overview of WiMAX and QoS

2.1 Introduction

There are two types of architecture for WiMAX, which are Point-to-Multipoint (PMP) [20], [55] (Figure 2.1) and mesh (Figure 2.2). In PMP architecture, a (BS) base station serves all the (SS) subscriber stations within its range and is responsible for setting and managing the connections when a request is sent by an SS. Here, all the communications between SSs are done through the BS. In the mesh architecture, there are several hops which arrange all the connections and form a tree-shape network topology. In this mode, traffic can be routed directly among SSs without needing a central station.

Two different channels are used for transmission in PMP architecture, which are a downlink channel (from BS to SS) and an uplink channel (from SS to BS) and the traffic between these channels is directed by a scheduling algorithm which is implemented at the BS. A CAC (Call Admission Control) is also implemented at the BS [55] to ensure that the minimum QoS (Quality of Service) requirements for the SS can be satisfied and also the load supplied by the SSs can be handled by the network.

There are different network parameters for deciding QoS, such as jitter, latency, bit error rate, average data throughput and minimum throughput. In realtime applications

such as audio and video streaming, voice chat and video conferencing, delay and delay jitter are supposed as the most important QoS requirements. Realtime applications need to have reasonably stable delay jitter which is the inter-packet arrival time at the receiver. In non-realtime applications such as file transfer protocol (FTP), throughput is considered as the most important QoS requirement. There are other applications like web-browsing and email which do not have any QoS requirements. In a typical network, there might be different types of applications with diverse QoS requirements.

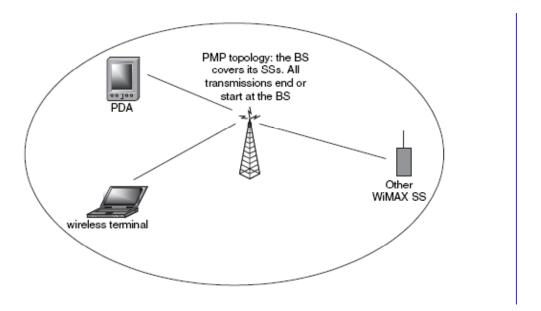


Figure 2-1 WiMAX PMP Network

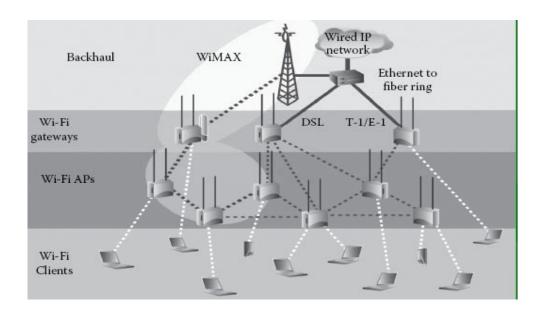


Figure 2-2 WiMAX Mesh Network

2.2 WiMAX Network Advantages

WiMAX with all its capabilities can provide higher bandwidth to areas lacking cable infrastructure and also deliver city-wide coverage in areas with limited access to buildings or those suburbs with a large distance to telecommunication centres or with poor infrastructure.

• Wide Coverage

WiMAX can cover a non line-of-sight range of 5Km. In the last mile solution, WiMAX can transfer 1.5Mbps and provide broadband services as a T1 line (any data circuit that runs at the original 1.544Mbit/s line rate).

WiMAX standard can deliver audio, video and information signals at the speed of about 70Mbps with a line-of-sight range of 50Km.

• Flexibility

802.16–2004 standards support a flexible frequency bandwidth (different frequencies) and to further increase the network capabilities, utilize frequency bands in different channels. This standard can work in frequency channels of 20, 25, and 28MHz.

• Cost Effectiveness

The wireless medium used by WiMAX help service providers to decrease network development costs, including time and installation costs.

Duplexing Method Support

Both FDD and TDD which are called Frequency Division and Time Division Duplexing are supported in 802.16–2004 standards.

• Wide Frequency Band

The ability to use Licensed and Unlicensed frequency bands is among WiMAX standard capabilities to deploy and implement such networks in the world.

• Security

To provide security in 802.16 standards, various methods and different levels like PKM (Privacy Key Management) and EAP (Extensible Authentication Protocol) are used and therefore it is more secure compared to Wi-Fi networks.

• Quality of Service

The quality of service has improved in the network in order to transmit audio and video.

According to the changes in OSI layers, this standard can provide different types of services and have a plan on the type of the services.

As WiMAX networks are used for transferring multimedia, audio, video and data, having an ensured quality of service for different types of services can be one of the challenges of WiMAX networks.

In the IEEE 802.16 standard, by having changes in the MAC layer and PHY layer, there are different solutions for ensuring quality of service, but where and when to use such mechanisms and methods would depend on service providers.

2.3 IEEE 802.16 Network Layer Model

The IEEE 802.16 standard comprises two layers (see Figure 2-3), namely MAC and PHY where mainly the wireless services are regulated. Details of these two layers are given in the following section:

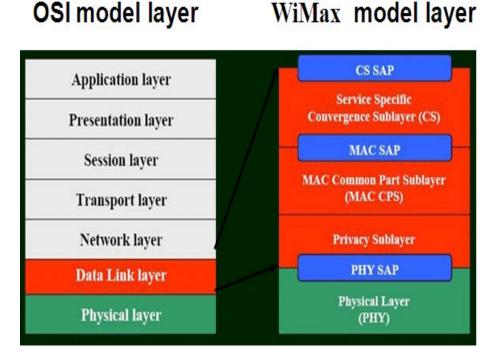


Figure 2-3 IEEE 802.16 Network Layer Model

2.3.1 IEEE 802.16 MAC Layer

The MAC layer of 802.16 is divided into three sub-layers: the convergence sub-layer, the common part sub-layer and the MAC Security sub-layer. Figure 2-4 is a basic illustration of the tasks and services that the MAC sub-

layers are responsible for. The convergence sub-layer maps the transport layer-specific traffic into the core MAC common part ub-layer.

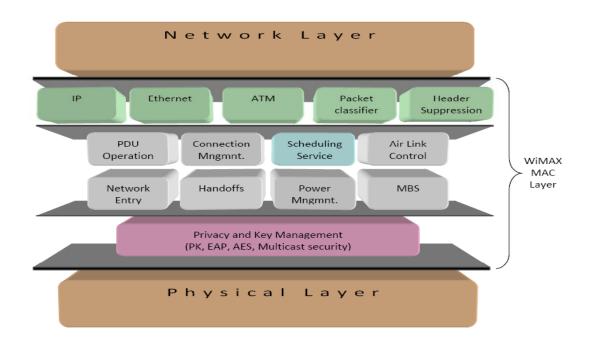


Figure 2-4 WiMAX MAC layer services

As the name implies, the convergence sub-layer handles the convergence of ATM cells and IP packets, so the MAC layer can support both ATM services and packet services, such as IPv4, IPv6, Ethernet, and VLAN services. The common part sub-layer is independent of the transport mechanism and is responsible for fragmentation and segmentation of the Service Data Units (SDUs) into MAC protocol data units (PDUs) as illustrated in Figure 2-5. It is also responsible for QoS control, scheduling and retransmission of MAC PDUs.

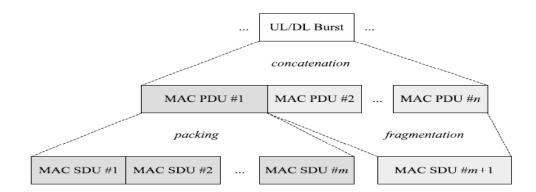


Figure 2-5 Fragmentation and Packing for MAC PDU

The convergence sub-layer classifies the incoming SDUs by their type of traffic (voice, web surfing, ATM CBR) and assigns them to a service flow using a 32-bit SFID. When the service flow is admitted or active, it is mapped to a MAC connection that can handle its QoS requirements using a unique 16-bit CID. A service flow is characterized by a QoS Parameter Set which describes its latency, jitter and throughput assurances. And with Adaptive Burst Profiling, each service flow is assigned a PHY layer configuration (i.e. Modulation scheme, Forward Error Correction scheme, etc.) to handle the service. Once the service flow is assigned a CID, it is forwarded to the appropriate queue. Uplink packet scheduling is done by the BS through signalling to the SS. At the SS, the packet scheduler will retrieve the packets from the queues and transmit them to the network in the appropriate time slots, as defined by the Uplink Map Message (UL-MAP) sent by the BS.

MAC PDUs can be concatenated into bursts having the same modulation and coding. The scheduling and re-transmission of MAC PDUs is done in this sub-layer. The common part sub-layer also performs QoS control. The control signalling for the bandwidth request and grant mechanisms are performed in this sub-layer.

In summary, 802.16 is a connection-oriented MAC in that it assigns traffic to a service flow and maps it to MAC connection using a CID. In this way, even connectionless protocols, such as IP and UDP, are transformed into connection-oriented service flows. The connection can represent an individual application or a group of applications sending with the same CID and the service classes defined in 802.16 are ATM-compatible, since Internet-working with ATM is important due to its role in telecom carrier infrastructure and its common use in DSL services.

2.3.2 IEEE 802.16 PHY layer

The 802.16 PHY layer of the 802.16 includes OFDM, FEC and Adaptive Modulation to improve QoS performance. And Adaptive Burst Profiles allow the modulation and coding schemes to be adaptively adjusted according to link conditions.

The PHY layer standard incorporates a number of mechanisms to provide QoS, such as Adaptive Modulation (QPSK to QAM 16 to QAM 64), Frequency Division Duplex (FDD), Time Division Duplex (TDD), Orthogonal Frequency Division Multiplexing (OFDM), Fast Fourier Transform (FFT), and Forward Error Correction (FEC). Every 802.16 implementation will use some combination of these mechanisms to achieve QoS. They are all implemented in the PHY layer and their parameters are based on the QoS requirements handed down by the higher layers. This is done through QoS provisioning. The QoS mechanisms described above are some of the general mechanisms that 802.16 use to ensure good QoS. These mechanisms are already well established in the wireless technology industry and they have been proven to reduce latency, jitter, and packet loss, which are all goals of QoS, and they are briefly defined as follows:

2.3.2.1 TDD

Can dynamically allocate uplink and downlink bandwidth, depending on their requirements; for example, when there is more uplink traffic, more bandwidth can be allocated to that, and when there is less uplink traffic it can be taken away. This is illustrated in Figure 2-6. Each 802.16 TDD frame is one downlink sub-frame and one uplink sub-frame, separated by a guard slot. 802.16 adaptively allocate the number of slots for each, depending on their bandwidth needs:

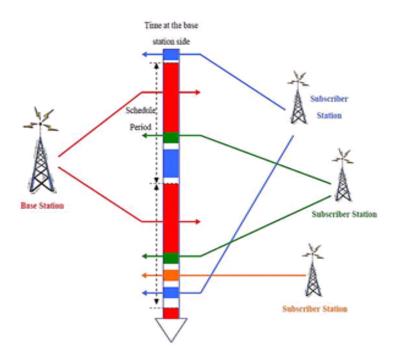


Figure 2-6 IEEE 802.16 TDD Frame Structure

2.3.2.2 FDD

Allows base stations to transmit on different sub-bands (see Figure 2-7), and thus do not interfere with each other. This also allows for even more bandwidth allocation flexibility.

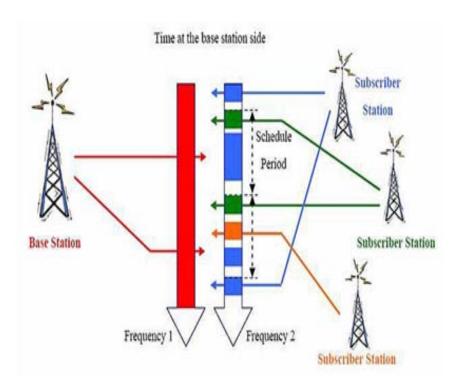


Figure 2-7 IEEE 802.16 FDD Frame Structure

2.3.2.3 OFDM

It is a mechanism that offers a greater spectral efficiency and lower interference with its tighter beam width and its dispersal of data across different frequencies.

There are a couple of QoS aspects that are specific to OFDM given in the following subsections.

2.3.2.4 FEC

FEC builds redundancy into the transmission by repeating some of the information bits, so bits that are missing or in error can be corrected at the receiving end. Without FEC, error correction would require whole frames to be retransmitted, resulting in latency and lower QoS. The other way OFDM helps with QoS is with interleaving. Since OFDM uses multiple subcarriers (see Figure 2-8), a portion of each information bit can be carried on a number of subcarriers, so that if any of the subcarriers is weakened, the information bit can still be received at the destination. And, interleaving means that bits

that were close together in time are transmitted on subcarriers that are spaced out in frequency. Thus, errors created on weakened subcarriers are broken up into small bursts and spread out. These small errors can more easily be corrected with FEC.

2.3.2.5 FFT

Which in mathematical terms, makes evaluating complex numbers more efficient by greatly reducing the number of arithmetical operations require in radio technology. Digital data signals in the form of square waves can be expressed as the sum of a series of sine waves in Fourier's Theorem. OFDM converts a single data stream into M streams and modulates them onto M subcarriers using FFT. In general, FFT can make the transmission of digital signals over the air link more efficient, which also helps in providing QoS.

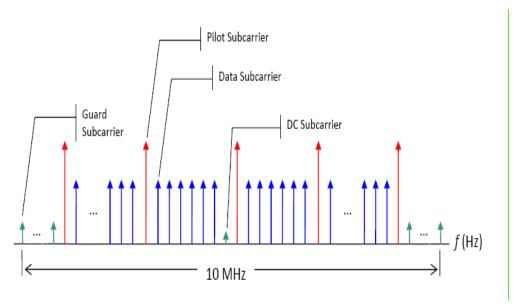


Figure 2-8 OFDM Subcarrier structure [21]

2.3.2.6 Modulation

The 802.16 standard provides adaptive modulation, which enables dynamic bandwidth allocation to match the current channel conditions. The three modulation schemes used in 802.16 are (from high- to low-modulation order): 64-QAM, 16-QAM, and QPSK. A higher order modulation scheme can deliver higher throughput, but a higher number of bits per symbol makes it more susceptible to interference and noise. There is a trade-off between throughput and range. The modulation order can be based on the distance from BS to SS (see Figure 2-9). With adaptive modulation, the BS can adaptively change the code if the distance and atmospheric conditions require it; for example, if the BS cannot establish a robust link to a distant SS using 64-QAM, the modulation order can be reduced to 16-QAM or QPSK. The greater the distance, the lower the QoS guarantee.

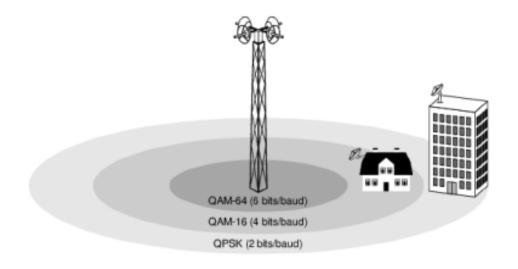


Figure 2-9 AMC example

2.3.2.7 Adaptive Burst Profiles

Another QoS mechanism provided in the PHY level is adaptive burst profiles. Both TDD and FDD configurations support adaptive burst profiling, in which the modulation

and coding schemes are specified in a burst profile, where they can be adjusted individually to each SS on a frame-by-frame basis. The burst file allows the modulation and coding schemes to be adaptively adjusted according to link conditions. Burst profiles describe the UL or DL transmission properties. For UL, the SS transmits in a given time slot. The different MCS supported are shown in Table 2.1. In that Table, we present the number of useful bits per OFDM symbol, depending on the MCS used.

MCS	Modulat ion	Coding rate(c)	Number of bits per modulation symbol(d)	Number of useful bits per OFDM symbol
BPSK ½	BPSK	1/2	1	192*1*1/2=96
QPSK ½	QPSK	1/2	2	192*2*1/2=192
QPSK ¾	QPSK	3/4	2	192*2*3/4=288
16-QAM1/2	16- QAM	1/2	4	192*4*1/2=384
16-QAM3/4	16- QAM	3/4	4	192*4*3/4=576
64-QAM2/3	64- QAM	2/3	6	192*6*2/3=768
64-QAM3/4	64- QAM	3/4	6	192*6*3/4=864

Table 2.1 The number of useful bits per OFDM symbol

2.4 Quality of Services in IEEE 802.16

The IEEE 802.16 QoS architecture can handle multiple levels of QoS through its classification, queuing, and control signalling mechanisms.

Packet header suppression is used to avoid the transmission of redundant information over the air line. This helps reduce packet delay, which is essential for maintaining an acceptable delay for applications like VoIP. Once the service flow is classified and the

CID is assigned to it, the non-changing header information (such as an ATM cell header or an IP header) is suppressed.

2.4.1 Bandwidth Requests and Grants

Allocation of bandwidth through request and grant mechanisms are available in the 802.16 standard. These mechanisms enable multiple types of service flows to support a wide range of applications.

2.4.1.1 Bandwidth Requests

A bandwidth request can be incremental or collective. An incremental bandwidth request means the SS asks for more bandwidth for a connection. A collective bandwidth request means the SS specifies how much total bandwidth is needed for a connection. Most requests are incremental, but collective requests are occasionally used so the BS can efficiently correct its perception of the SSs' needs.

Bandwidth requests are always per connection. Each connection in an SS requests bandwidth with a BW Request message, which can be sent as a stand-alone packet or piggybacked with another packet. For UGS service flows, the SS does not need to send bandwidth requests because the BS grants it unsolicited.

The SS can request bandwidth implicitly for UGS. In this case, it is negotiated at connection setup, so no actual messages are used. BW Request messages uses a BW Request header Requests up to 32 KB with a single message Incremental or aggregate, as indicated by the MAC header piggybacked request (for non-UGS services only). Presented in the GM sub-header and always incremental up to 32Kb per request for the connection. Poll-Me Bit Stations request that the BS poll them. Thus, requests can be done in a number of ways. The polling mechanism is detailed and flexible, but requires

some overhead. Realtime applications, such as VoIP or video streaming, require a realtime polling service that offers periodic dedicated request opportunities. Non-realtime applications, such as FTP, can use a non-realtime polling service that allows random transmit opportunities for bandwidth requests.

The standard allows the BS to poll stations individually or in groups. In total, there are three polling methods: Unicast polls, to check for inactive stations; Multicast and broadcast polls, when there is insufficient bandwidth to poll the stations individually; and Station initiated-polls, where stations request that the BS poll them (also called the Poll-Me Bit). A Best Effort (BE) service is also defined for applications not requiring QoS support. In this case, the SS issues its requests in a contention period.

2.4.1.2 Bandwidth Grants

Two models for developing bandwidth grants are defined in the 802.16 standard: Grant per Connection (GPC) and Grant per Subscriber Station (GPSS). Either of these models can be used for bandwidth by the BS.

Both GPC and GPSS use a self-correcting protocol, rather than an acknowledged protocol. All errors are handled in the same way. After a timeout, the SS simply requests again. This method eliminates the overhead of using acknowledgements, and it uses less bandwidth. Grants, which are given as durations, are carried in the UL-MAP messages.

GPC BS grants bandwidth explicitly for a connection SS and uses it only for that connection. GPSS BS grants bandwidth to an SS as an aggregate of grants in response to per connection requests from the SS. The SS may redistribute bandwidth among its connections, maintaining QoS and service-level agreements. GPC is more suitable for fewer users per subscriber station. It has higher overheads, but allows a simpler SS.

GPSS is more suitable for many connections per terminal. It is more scalable, and it reacts more quickly to QoS needs. It has low overheads, but it requires an intelligent SS. GPSS is mandatory for the 10–6 GHz PHY.

The decision to grant bandwidth is mainly based on the amount requested by the needs of the current service flows and the available network resources.

2.5 Scheduling Service

Scheduling services have represented the data handling mechanisms supported by the MAC scheduler for the data transport on a connection. To provide the service parameters respectively, traffic management is necessary. The IEEE 802.16 standard divides all services in four different classes. Each group corresponds to a single service class, which is associated with a set of QoS parameters for quantifying the aspects of its behaviour.

Here is an outline of these four services flows:

- 1) Unsolicited grant service (UGS): It supports the constant bitrate (CBR) or fixed throughput connections at periodic intervals, such as T1/E1 and voice over IP (VoIP) which needs to grant the constant bandwidth without any request. This service can guarantee the data throughput and the latency.
- 2) Realtime polling service (rtPS): It is a realtime data stream comprising variable bitrate (VBR) data packets which are issued at periodic intervals, such as the Moving Pictures Experts Group (MPEG) video. This application guarantees the minimum reserved rate and the latency, which are same as those of UGS. But the rtPS has to request transmission resources by polling, which means that the contention and the piggyback are not allowed.

- 3) Non-realtime polling service (nrtPS): This service is a delay-tolerant data stream consisting of variable-sized data packets, such as the file transfer protocol (FTP). The minimum data rate is required and the bandwidth request by polling is needed.
- 4) Best effort (BE): It does not provide any QoS guarantee, like the email or the short-length FTP. There is no minimum resource allocation granted, where the occurrence of dedicated opportunities is subject to the network load.

Scheduling services are determined by a set of parameters demonstrated in Table 2.2 below:

QOS Classes	Main QOS Parameter(s)	Piggyback grant request	<u>Unicast</u> polling	Contention based Polling	Example
UGS	Periodic ,fixed size, data grants	Allowed	Poll_me(pm) can be used	Not Allowed	T1/E1 circuit voice
ertPS	Periodic data grants	Extended Piggyback	Allowed	Allowed	VOIP
ctPS	Minimum data rate; Periodic unicast polling	Not Allowed	Allowed	Not Allowed	MPEG
nrtPS	Slightly better than BE	Not Allowed	Allowed	Allowed	FTP,HTTP
BE	Best Effort ,no unicast request polling obligation for the BS	Not Allowed	Allowed	Allowed	EMAIL,FAX

Table 2.2 Scheduling Services Parameters

2.6 Scheduling in WiMAX

The IEEE 802.16 defines the MAC and PHY layers, the types of scheduling service classes (or QoS classes), the QoS parameters requirements and the management

messages. However, it leaves the scheduling algorithm as an open issue. It is up to vendors and operators to choose the scheduling algorithm(s) to be used. We introduce scheduling for both the PMP and mesh modes.

We consider only the PMP mode in our thesis. Scheduling will be studied in more details in Chapter 3.

2.6.1 Scheduling in WiMAX in PMP mode

In the WiMAX PMP mode, the MAC architecture is centralized at the BS. The BS scheduler is responsible for the whole access control of the different wireless subscribers in the downlink and uplink directions. Therefore, scheduling has to be applied to the downlink and uplink directions in the Base Station (BS) (see Figure 2-10). In order to indicate the assignment of the downlink and uplink transmission intervals (or bursts) in each frame, the BS transmits the DL-MAP and UL-MAP MAC management messages, respectively.

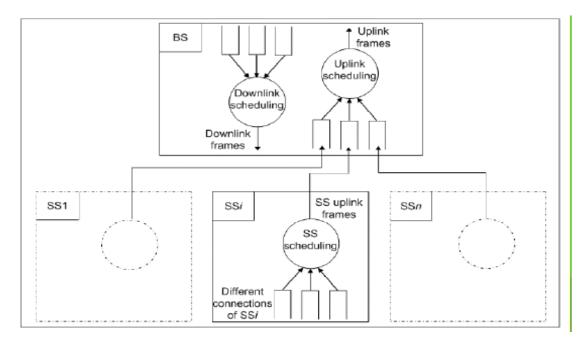


Figure 2-10 Packets Scheduling in BS and SS. The uplink scheduler may have different scheduling classes depending on the service type

These messages are transmitted at the beginning of the downlink sub-frame (see Figure 2-6). When it receives an UL-MAP management message, the SS determines if it can access to the uplink channel during the current frame. Since the SS may have several simultaneous connections, an uplink scheduler is required in each SS (see Figure 2-10). The scheduling algorithm determines the SSs that will receive data (in the downlink direction) as well as the SSs that will send data (in the uplink direction). Therefore, the length of the DLMAP and UL-MAP management messages and then the number of useful symbols depends on the scheduler used. Moreover, a preamble is added to each burst. So, the more SSs the BS serves per frame the less number of useful OFDM symbols there are. The length of the UL-MAP message also depends on the bandwidth requests sent by the different SSs. A bandwidth request can be sent using contention, like for nrtPS and BE users. In this case, these users use the bandwidth contention. As a consequence, the size of the bandwidth contention affects the number of useful OFDM symbols and the collision probability between the bandwidth requests. The number of useful symbols decreases when the bandwidth contention size increases, while the probability increases when the bandwidth contention size decreases. A bandwidth request can be sent using unicast request opportunities, like for rtPS users. These unicast request opportunities are sent periodically by the BS and the period of transmission is determined by the BS using the maximum latency of the connection.

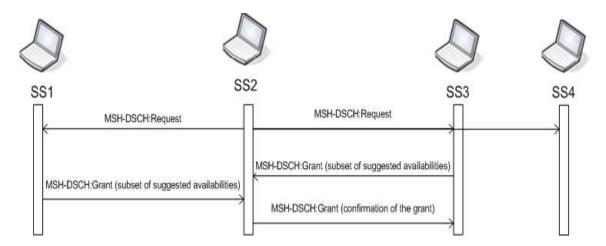


Figure 2-11 Resources Allocation in Mesh-distributed Scheduler

Finally, it is useless to send bandwidth requests by the UGS users, since the grant requested remains constant during all the connections. Therefore, the IEEE 802.16 standard specified that a UGS user announces its grant size once when he creates a new connection using the Dynamic Service Addition (DSA) messages. Moreover, UGS users are forbidden to send bandwidth requests using unicast request opportunities or bandwidth contention.

2.6.2 Scheduling in WiMAX in Mesh Mode

In the WiMAX mesh mode, either a distributed or centralized scheduler can be used:

- when using a distributed scheduler, the mesh BS and SSs shall co-ordinate their transmissions in their two-hop neighbourhood. The two-hop neighbourhood represents the set of all the extended neighbours of the neighbourhood. The neighbourhood contains all stations with which a node has direct links. The BS and SSs shall also broadcast their requests, available resources, and grants to all their neighbours. The allocation of resources is performed using a three-way handshake (see Figure 2-11):
- _ a station broadcasts its bandwidth request using a Mesh-distributed scheduling (MSH-DSCH) Request message;

_ when receiving an MSH-DSCH Request message, a station having available resources that fit with the request sends an MSH-DSCH Grant message including all the suggested availabilities;

_ the original requester sends an MSH-DSCH Grant message in order to confirm the Schedule;

when using a centralized scheduler, the mesh BS is responsible for the bandwidth allocation of a certain number of hop (h) neighbourhoods. The BS gathers the bandwidth requests from its h-hop neighbourhood. Then, it determines the granted resources for each downlink and uplink links. Finally, the BS informs all SSs belonging to its h-hop neighbourhood about its decision.

We note that the BS is solely responsible of the allocation of resources in the PMP mode and in the mesh mode when a centralized scheduler is used. When distributed scheduling is used in the mesh mode, the mesh BS and SSs have the same importance in the scheduling decision.

In our work, we consider only the PMP mode.

2.7 Summary

In this Chapter, we have introduced the PHY and MAC layers as well as scheduling in the PMP and mesh modes for the OFDM physical layer. In the rest of our work, our interest is only on scheduling in the PMP mode. The scheduling algorithm used directly affects the performance of the system, since the number of useful OFDM symbols depends on the scheduling decision. The system performance also depends on the channel characteristics of the different users, since the Modulation and Coding Scheme (MCS) used (and then the number of useful bits) depends on the Signal-to-Noise Ratio (SNR) of the subscribers. We can estimate the WiMAX capacity using computations but we have to assume that all subscribers use the same MCS and always have data to send. Otherwise, the WiMAX capacity depends on the channel characteristics. It also depends on the scheduling algorithm used, since the scheduler determines which subscribers will send and/or receive uplink and/or downlink bursts, respectively. Therefore, a more sophisticated alternative (other than simple computations) is needed in order to study the performance of scheduling algorithms and estimate the WiMAX capacity. In our thesis, we use for that the network simulation.

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Chapter 3

Related Work and Simulation

Environment

3.1 Introduction

There have been many attempts at solutions for QoS provisioning in WiMAX networks which are elaborated in the literature. Most of them focus on scheduling algorithms while only a few have addressed the Connection Admission Control problem. Among the existing scheduling algorithms presented in the literature, the majority of the work unrealistically assumes the presence of a simple CAC. Based on the fact that both CAC and scheduling jointly handle the QoS level, a suitable CAC algorithm is needed in order to guarantee the required QoS. A failure of QoS provision occurs when CAC and a scheduling algorithm operate under unbalanced and different criteria. This mostly leads to interference. Therefore, striving for a better scheduling algorithm, together with a dependent CAC algorithm, is believed to enhance the QoS management process.

Figure 3-1 shows an uplink scheduler operation in which at the BS, different scheduling services are assigned to different traffics. In WiMAX, as the scheduling algorithm is left to the Base Station designer, so it is the responsibility of a Designer

how efficient he can design a scheduling algorithm so that it can fulfil the QoS requirements. In the coming sections we will discuss some uplink traffic scheduling algorithms and we will evaluate the Modified Deficit Round Robin algorithms for the uplink traffic in a WiMAX network. We will check how this algorithm can schedule different traffic classes.

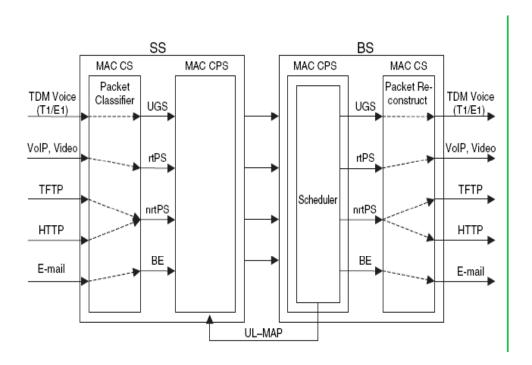


Figure 3-1 Uplink Scheduler Operation

3.2 Previous Works

Since The IEEE 802.16 standard is in the interest of researchers from the few years. There is not enough work available on Uplink Scheduling in 802.16–2004 standards. Some of the relevant literature is discussed. The literature studied here is divided on the basis of scheduling algorithms that show how different scheduling algorithms are used to fulfil the QoS requirements for multi-class traffic.

3.2.1 Earliest Deadline First Algorithm (EDF)

Earliest Deadline First Algorithm is used widely in realtime systems for realtime traffic. An EDF Algorithm places the SS packets in a priority queue by assigning a deadline to the packets. This queue will be then searched for the packet closest to its deadline; the one with the closest deadline will be served first.

An EDF algorithm is implemented in Broadband Wireless networks [22]. First, the deadline for every packet is calculated and then it is inserted in the queue. The packet with an earliest deadline is served first. One issue in using EDF is how to assign the deadline to the packet. In [22] the deadline to the packet is assigned based on the maximum latency requirement of the packet. The problem in using EDF for multi-class traffic in WiMAX is that as the rtPS and UGS class SS has strict delay requirements, the algorithm will first start scheduling their packets, leaving behind the packets from the other classes unless all the packets from these classes are scheduled. So, all other classes with no strict delay requirements like nrtPS and BE have to wait for a long time.

3.2.2 Weighted Fair Queuing Algorithm

A Weighted Fair Queuing Algorithm provides efficient priority to multi-class traffic, but doesn't offer strict priority for voice traffic, during high traffic rate periods. WFQ can offer a solution that provides a stable, fair response time, based on weights, to heavy and light traffic equally, without adding too much bandwidth.

WFQ is a practical implementation of the GPS algorithm [23]; according to a GPS algorithm, a packet in a queue can be divided into bits and scheduled separately. But in WFQ, weights are assigned to packets and then the packet with the higher weight is scheduled first. A Weighted Fair Queuing (WFQ) algorithm is evaluated in [24] for

multi-class traffic in WiMAX networks. It is found that WFQ algorithm performance for variable size packets is superior, compared to a WRR algorithm.

3.2.3 Round Robin (RR)

RoundRobin as a scheduling algorithm is considered the most basic and the least complex scheduling algorithm. It has a complexity value of O (1) [25].

Basically, the algorithm services the backlogged queues in a round robin fashion. Each t ime the scheduler pointer stops at a particular queue, one packet is dequeued from that q ueue and then the scheduler pointer goes to the next queue. This is shown in Figure 3-2:

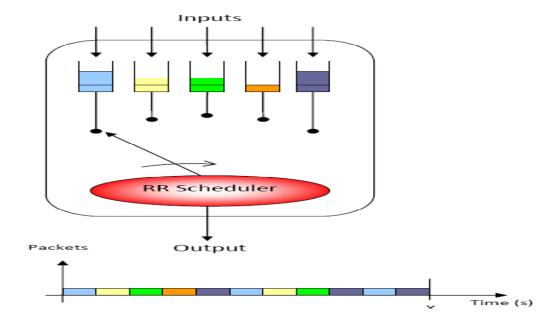


Figure 3-1 Round Robin Scheduler

Note that in this case all packets are of same length. However, for instance, an MPEG video application may have variable sized packet lengths. This case is shown in Figure 3-3:

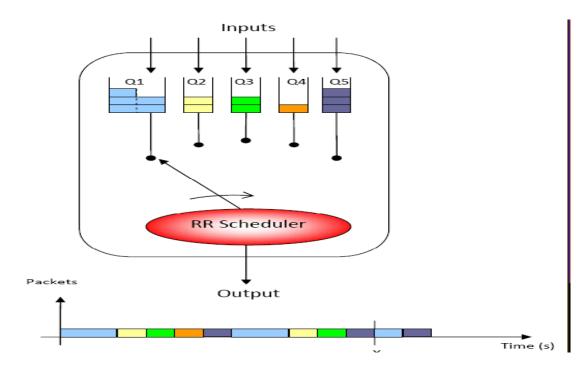


Figure 3-2 Round Robin Scheduler – Variable packet size

It is assumed that queues Q2-Q5 have a

constant packet size of 50 bytes and Q1 has a packet size of 100 bytes. Note that in Figure 3-3, unlike Figure 3-2, Q1 has superior throughput than the other queues.

Previously, Q1 was transmitting 3×50 bytes per X interval = 150 bytes/X interval.

• Now Q1 is transmitting 2×100 bytes per X interval = 200 bytes/X interval.

This was caused by transmitting longer packet lengths. Hence, we can deduce that the ro und robin scheduling algorithm does not convey fairness in systems with variable packet lengths, since RR tends to serve flows with longer packets more often.

3.2.4 Weighted Round Robin Algorithm

A Round Robin Algorithm is not considered an efficient algorithm for multi-class traffic because it doesn't give priority to any traffic class. A Weighted Round Robin [64] is an extension to the Round Robin Algorithm. A WRR assigns weight to the packets of different SSs, and the bandwidth is then allocated to the SS on the basis of

weight assigned to them. The algorithm originally is implemented in an ATM network in [25] for which it works efficiently. One issue in implementing the WRR is that for assigning weight to any packet, the mean packet size should be known. In an ATM network, because of the fixed packet size, it is not a problem to find the mean packet size, but in the wireless network due to the variable packet size, it is almost impossible and the algorithm may not work fairly among different SSs with different traffics.

A WRR algorithm is implemented in [26] all the contention slots and uplink data slots are distributed according to bandwidth requirements. Five priority queues are chosen and dynamic priority ratio parameters are assigned. How the ratio is assigned is not justified. WFQ scheduling is used for higher priority services (UGS), WRR is used for middle priority services and FIFO scheduling for lower priority services. The author in this work did not cleared what weights are used for WRR scheduling as well as BS downlink scheduling. Some traffic policing and traffic shaping methods to stop SSs using more than allocated bandwidth are also employed. In [26], no simulation or theoretical analysis results are presented in the study.

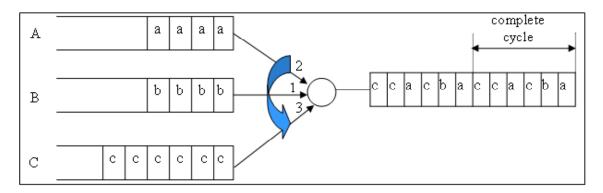


Figure 3-3 Packet queues for a Weighted Round Robin (WRR)Scheduling

Algorithm

An example of WRR algorithm execution is represented in Figure 3-4. In this example, there are three queues: A, B, and C. The weight of queues A, B, and C are

equal to 2, 1, and 3, respectively. In WiMAX, the connections have different QoS parameters and the subscribers use different MCS. Moreover, the subscribers do not generally have the same traffic. Therefore, the connections do not need the same resources. The use of the WRR scheduler can be suitable for WiMAX by assigning different values of weights to the queues.

3.2.5 Deficit Round Robin (DRR)

The DRR [27] scheduling algorithm was designed to overcome the unfairness characteristic of the previous RR and WRR algorithms. Besides, it retains the hereditary per packet complexity value of O (1) from the RR scheduling.

In DRR scheduling, every queue is accompanied by a deficit counter which is initially set to the quantum of the queue. A quantum is a configurable amount of credits (in bits/bytes) given to a queue whenever it is served. The quantum should represent the idle amount of bits/bytes a queue may require. Adding quantum is proportional to assigning weight to a queue [28], [29].

The deficit counter is increased by one quantum on every visit of the scheduler, except when the queue is empty; the deficit counter is deducted by the amount of information being served on each round of the scheduler to the queue. Queues are served only if the amount of quantum added to the remaining deficit counter amount from the previous round is greater than zero. Otherwise, the quantum is added only and that particular queue is held till it is served in the next round.

On the other hand, when packets of a backlog queue are completely served then any remaining credit in the deficit counter will be set to zero, as the accumulation of credit without being utilized will result in unfairness. [30]

The DRR scheduling algorithm is as shown in Figure 3-4:

```
Quant i = Quantum for Queue i

DC i = Deficit Counter for Queue i

For Queues i: 1 to n

If #Packets in Queue i > 0

DC i = DC i + Quant i

If DC i > 0

Do

[Serve Packet]

DC i = DC i - Packet Size

While (DC i >= 0 AND #Packets>0)

If DC i>= 0 AND #Packets=0 // for fairness issues

DC i = 0 // the DC is reset.
```

Figure 3-4 DRR Scheduling Algorithm

Usually the quantum is set to the maximum packet size. This is done in order to make s ure that at least one packet per flow per non-empty queue is served. For some traffic, like VoIP which needs both delay and bandwidth requirements, DRR may not be a good option, since the algorithm should know the exact size of the packet in order to work in the uplink direction, as the Base Station is only able to estimate the backlog amount of a connection; that is why some manufacturers use DRR in Subscriber Stations [26] as a downlink scheduler, without considering the WiMAX QoS parameters.

An illustration of a DRR algorithm execution is represented in Figure 3-6. There are three queues: A, B, and C. The deficit counter (DC) of queues A, B, C, are 350, 300, and 250, respectively. In Figure 3-6, the reference of the packet number k of queue A, B, and C are ak, bk, and ck, respectively. The packet length is L (.).

We note that packet a1 is immediately sent because its length (L(a1)=200) is lower than the deficit counter of queue A (DC(A)=350). However, packet b1 waits two rounds

before being sent. Indeed, its length (L(b1)=500) shall be lower than the deficit counter of queue B (2 * DC(B)=600).

The DDR scheduler requires a minimum rate to be reserved for each packet flow before being scheduled. This characteristic can be useful in WiMAX because some WiMAX QoS classes require a minimum reserved rate.

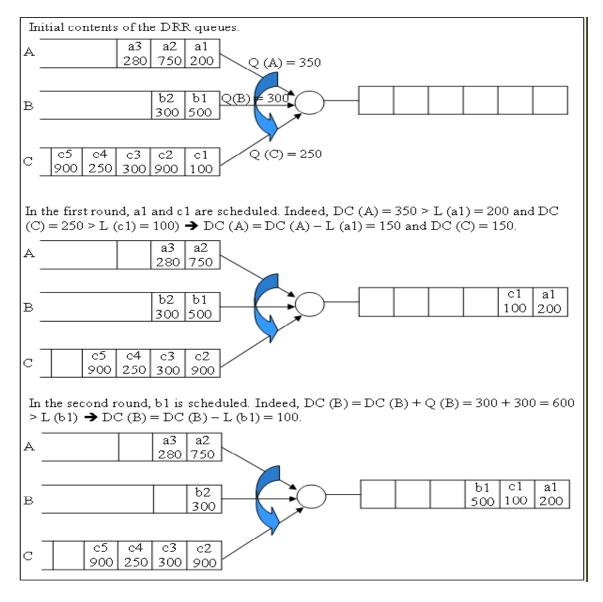


Figure 3.6 Packet Queues for a Deficit Round Robin (DRR) Scheduling Algorithm

3.2.6 Modified Deficit Round Robin (MDRR)

In this section a number of localized QoS routing algorithms will be discussed. The main aim of these algorithms is to enhance the performance of the network. This aim is achieved by avoiding the need for exchanging communication and process overheads.

3.2.7 Opportunistic Deficit Round Robin Scheduler

In [31], the Opportunistic Deficit Round Robin (O-DRR) Scheduler is used as a BS uplink scheduler in a WiMAX system. The O-DRR scheduler determines the SSs that can be scheduled as follows: the BS polls all subscribers periodically, every k frames. After each period, called a scheduling epoch, the BS determines the set of subscribers that are eligible to transmit packets as well as their bandwidth requirements. This set is called an eligible set. A subscriber is eligible to transmit when:

- > the subscriber has a non-empty queue; and,
- ➤ the signal-to-interference-plus-noise ratio (SINR) of its wireless link is above a minimum threshold, called SINRth.

A subscriber is scheduled in the current frame when:

- It is eligible at the start of the current scheduling epoch, and, it still has data to send.
- The scheduled set is changed dynamically. This change depends on the wireless link state of each eligible subscriber.

At the beginning of a new scheduling epoch, the BS resets the eligible and scheduled set and performs the above process again.

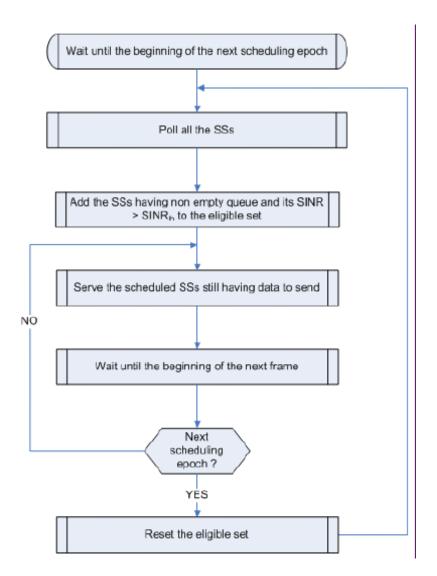


Figure 3-7 Main Steps of Determination of Scheduled SSs using the O-DRR Scheduler

The main steps of the determination of the scheduled SSs are represented in Figure 3-7. The assignment of the bandwidth using the O-DRR scheduler is performed as follows: each SS has a quantum Qi. If the SINR of the wireless link of the subscriber i is lower than the threshold SINRth, then:

- \clubsuit The quantum Qi of the subscriber i is distributed among the scheduled subscribers;
- \diamond The lead/lag counter of the subscriber *i* is incremented by Qi;

❖ The lead/lag counter of the scheduled subscriber j is decremented by the amount that the subscriber j receives above its quantum Qj.

The BS polls all subscribers every k frames. A low value of k causes a polling overhead. So, the efficiency will decrease. Furthermore, a high value of k causes unfair traffic and a non-satisfaction of QoS requirements. The authors in [31] propose that the BS objective is the minimization of the worst-case relative fairness in bandwidth and the normalized delay.

The results of the number of slots assigned, depending on the number of subscribers and the k value, show that the number of slots assignment increases when k increases. Indeed, when k increases, the SINR becomes more variable for the different subscribers and the lead/lag counter has more influence on the bandwidth assignment.

The results of the fairness in bandwidth using Jain's Fairness Index [32], depending on the number of subscribers and the k value, show that Jain's Fairness Index remains above 90%. Then the provider has more choice to choose an appropriate value of k at which the fairness and the bandwidth requirements are both satisfied.

3.2.8 Cross-layer Scheduling Algorithm with QoS Support

In [33], a novel cross-layer scheduling algorithm is proposed for wireless networks. This scheduler can support multiple connections with various QoS requirements and in various kinds of wireless networks. The main idea of the cross-layer scheduler is the affectation of priorities to the different connections. These priorities depend on the QoS requirements of the connections. This scheduler is applied to the UGS, rtPS, nrtPS, and BE WiMAX QoS classes.

For the UGS connections, the scheduler must guarantee a constant number of time slots allocated during the whole service time. For the rtPS and nrtPS connections, the

scheduler must guarantee the latency and the minimum reserved rate respectively. For the BE connections, there is no QoS guarantee but a Packet Error Rate (PER) should be maintained.

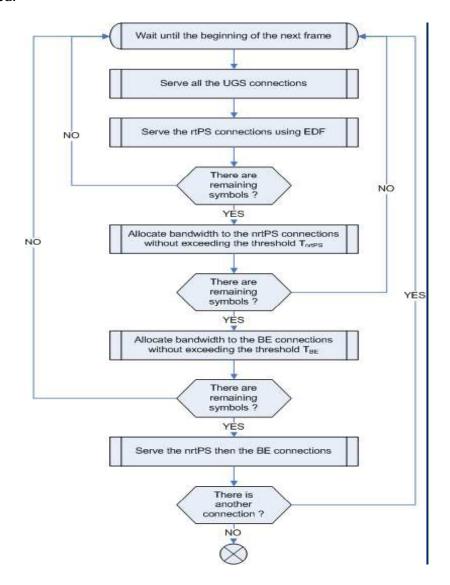


Figure 3-8 Main Steps of the Uplink Packet Scheduler with CAC

After serving all UGS connections, the scheduler allocates all the residual time slots to the rtPS, nrtPS, and then BE connections that have the maximum value of a defined Priority Function (PRF). The PRFs, for the rtPS, nrtPS, and BE connections consequently depend on the delay satisfaction indicator, the rate of the average

transmission rate over the minimum reserved rate, and the normalized channel quality, respectively.

The PRFs details are presented in [33].

When there is enough available bandwidth, the simulation results show that the delay outage probabilities of the rtPS connections are always below 5%. Therefore, the latency constraints are guaranteed. The results also show that the average reserved rate from each nrtPS connection is greater than its minimum reserved rate. However, the average transmission rates of the BE connections have large variations and sometimes are null. This behaviour is expected, since there are no guarantees for the BE connections.

When the number of the residual slots decreases, the performance of the BE connections (then the nrtPS connections) degrades. This is due to insufficient available bandwidth and the fact that the nrtPS connections have higher priority than the BE connections.

3.2.9 Combined Algorithms

Some manufacturers and researches are combining different types of algorithms for achieving QoS requirements for multi-class traffic, some of which are discussed below. EDF, WFQ and FIFO scheduling algorithms are combined in [34]. The approach used is that the bandwidth is allocated to higher priority SSs until they have no packets to send. The EDF scheduling algorithm is used for SSs of the rtPS class, WFQ is used for SSs of the nrtPS class and FIFO for SSs of the BE class. An admission control procedure and for controlling traffic, a traffic policing mechanism is also proposed. A drawback in the approach is that it is not specified that in the case of higher priority SSs, what that lower priority SSs will do – will they again starve?

In [35] the author used EDF for SSs of the rtPS class and WFQ for SSs of the nrtPS and BE classes. This approach is little different from the one in [34] because the WFQ algorithm is used for SSs of both nrtPS and BE classes and the overall bandwidth allocation is not done in a strict priority manner. The bandwidth is allocated among the classes in a fair manner, as SSs of the BE class do not have any QoS requirements, there is no need to use a complex algorithm, such as WFQ.

Both WRR and RR algorithms are studied in [36] for allocation of bandwidth. First, bandwidth is allocated on a strict priority basis to SSs of the rtPS and nrtPS, then the remaining bandwidth is distributed among the SSs of the BE class using the RR algorithm. The algorithm doesn't seem fair enough to all SSs, as it first selects the SSs with the most robust burst profiles, as it is using WRR. This algorithm will also starve lower priority SSs. In [18] a new complex scheduling scheme is introduced and used in IEEE 802.16. Bandwidth is first distributed on a fixed priority mechanism per flow and follows strict priority from highest to lowest (UGS, rtPS, nrtPS, BE). Bandwidth is allocated to the UGS as based on its fixed bandwidth requirement, EDF is used for rtPS, WFQ for nrtPS, and the remaining bandwidth is distributed between the BE. Traffic policing mechanisms are used on the BS to enforce the traffic, based on a connection traffic contract. The scheduling scheme provides comparatively a good bandwidth allocation and fairness among different SSs from multi-class traffic.

Thus, many scheduling schemes are proposed in the literature [15], [34], [37], and [38]. However, none of them consider the traffic data rate in realtime or the used queue size in the BS Uplink scheduler.

In [34], a two-layer scheduling structure of the bandwidth allocation was proposed to support all the existing types of service flows. In the first layer, the Deficit Fair Priority

Queue (DFPQ) was used to distribute total bandwidth among various flow services in different queues. In the second layer, scheduling packets within each of the six queues will be served according to a certain scheduling algorithm.

Although the DFPQ suits the scheduling for multi services, it presents a probability close to null for servicing due to the rtPS deadline of packets and an increase of the delay by an amount of at least the duration of one frame. Several packet scheduling algorithms for broadband wireless networks were published [39], [40]. In [40] authors introduced a scheduling scheme that considers the burst nature of realtime and non-realtime traffic. A hierarchal scheduling scheme is also proposed with two levels: interclass and intra-class. The first level provides service differentiation of rtPS and nrtPS-time classes. The second one decides the service priority of messages within the same class. This scheduler considers delay for rtPS traffic and prioritizes it over nrtPS traffic in the uplink direction only. UGS and BE traffic classes are not treated. This work could be considered as a special case of a scheduler that treats some classes while not taking into account the whole status of the WiMAX network.

In general they introduce complex scheduling schemes, composed of hierarchies of known schedulers, such as Earliest Deadline First (EDF) and Weighted Fair Queuing (WFQ). Simpler solutions are desirable, since the scheduler executes at every frame, which in OFDM-based systems can occur at a frequency of 400 frames per second [55]. The adaptive rtPS scheduler proposed in [41] is used only for the rtPS QoS class. It is based on the prediction of the rtPS packets arrival. As defined in the IEEE 802.16 standard [55], the BS allocates bandwidth for rtPS traffic after receiving a bandwidth request. When the request is granted by the BS, the subscriber may receive from upper layers new rtPS packets. These packets will wait for the next grant to be sent. Therefore,

these new packets may suffer from extra delay. The basic idea of the adaptive rtPS scheduler is to propose an rtPS bandwidth request process in which the subscriber requests time slots for the data present in the rtPS queue and also for the data which will arrive. The authors of [41] define a stochastic prediction algorithm in order to estimate the data arrival.

The adaptive rtPS scheduler is compared with the weighted flow scheduler. The simulation results show that the adaptive rtPS scheduler provides better average delay in low and medium load. This is because this scheduler considers the data generated between the sending time of the bandwidth request and the allocation time of the bandwidth. Moreover, the adaptive rtPS scheduler requires less buffer size for the rtPS data queue.

In high load, the adaptive rtPS and weighted flow scheduler have the same performance.

This is due to the saturation of the network.

[42] Studied the performance of different physical layer options that are founded in the IEEE 802.16 standard using various channel conditions. The researchers investigate the performance of the IEEE 80.2.16 downlink. They implement the DOCSIS model in OPNET to simulate the performance IEEE 802.16 MAC layer. However, they made a modification and replaced the bus link with the radio link [42]. They used OPNET's DOCSIS model because of their significant similarities. The similarities include:

- The scheduling services in IEEE 802.16 are similar to those defined in Data-Over-Cable Service Interface Specification (DOCSIS). The services include UGS, rtPS, nrtPS and BE;
- Both DOCSIS v 1.1 and IEEE 802.16 MAC uses DAMA-TDMA scheme;

• Furthermore, Quality of Service features in DOCSIS v 1.1 and IEEE 802.16 are the same.

The authors ignored features like interference and antenna gains while they compute the BER values in MATLAB. The topology they used was simple with two SSs and one Base Station. Moreover, the authors used a simple burst profile with no FEC codes instead of various FEC codes.

In [43], this paper proposes a novel adaptive scheduling algorithm for WiMAX, wherein a SS sends a request for extra bandwidth beforehand to BS by speculating the rtPS traffic patterns. As the arrival patterns and service time are random, it is complex to predict the futuristic needs of bandwidth at SS.

Moreover, the researcher proposed a hierarchical structure for bandwidth allocation to decide whether QoS for a particular connection can be satisfied at the BS. It is based on a simple connection admission control mechanism, as described in the following equation:

$$BR \le \beta - (B_{UGS} + B_{rtPS} + B_{nrtPS}) \qquad (3)$$

where B_{UGS} , B_{rtPS} and B_{nrtPS} are the rates reserved for connections already admitted of type UGS, rtPS, and nrtPS, respectively and BR is the rate requested by the new flow and β is the total link bandwidth.

This solution allows providing bandwidth guarantee to admit flows, but it cannot satisfy delay constraints for realtime application.

On the other hand, authors in [44] and [45] have considered either only realtime traffic or only best-effort TCP traffic.

[46] presented an admission control schema and analytical evaluations have been introduced for existing WiMAX networks. The author did not provide any constraints

on degrading the low-priority service flow whereby the proposed schema doesn't consider the scheduler which may lead to scheduler overload.

There are schedulers proposed for many WiMAX QoS classes. Some of them take into account only the deadline of the realtime applications and do not provide their minimum reserved rates like the cross-layer [33] and Hybrid (EDD+WFQ) [47] schedulers. The minimum reserved rates of nrtPS connections are also not taken into account by these schedulers. Some of them may block the non-realtime applications like the uplink scheduler with CAC mechanism and schedulers ensuring QoS requirements.

With respect to CAC optimization, previous study focuses on the optimal revenue policy only to consider the profit of service providers. As an enhancement, in this thesis we also take into account the requirement of WiMAX subscribers, and develop a policy with satisfying trade-offs between service providers and subscribers.

3.3 Evaluation Methodology

In accordance to [48], there are three main methods to evaluate a Scheduling Algorithm:

- 1. Deterministic modeling: Different algorithms are tested against a predetermined workload, and then the performance results are compared.
- 2. Queuing models: Random backlogs are studied analytically in a mathematical way.
- 3. Implementation/Simulation: The most versatile method of testing scheduling algorithms is to actually simulate the designed algorithm with real life data and conditions.

In this thesis, the third point of evaluation methodology will be considered.

3.3.1 OPNET MODELER®

Several WiMAX simulators have been implemented in analyzing and investigating WiMAX standard. They are open source tools and commercial tools. Examples of commercial tools are Qualnet and OPNET Modeler. The ns2 simulation tool is an open source tool. The OPNET and QualNET are the tools that provides *Graphical User Intrface*(GUI) for its users. However, QualNET is coded in JAVA and OPNET in C++ [66] Using simulation, the network engineers reduce costs because they test and analyse the design before production.

In this thesis for WiMAX system model simulation, OPNET Modeler was researched to be one of the best candidates, which provides more functions such as various QoS mechanism, various scheduling algorithm, Graphical User Interface and many more attractive features. Furthermore, OPNET Modeler provides documentation of the model together with the varieties case studies. OPNET Modeler is among many tools from the OPNET Technologies suit. The disadvantage of OPNET Modeler is that it is not Open Source software, but the model parameters can be modified [67]. However, [66] claims that OPNET Modeller cannot exactly evaluate the performance of real-life applications, therefore they are in need of some modification. In the following section, we present the history of OPNET Modeler.

3.3.1.1 History

OPNET technology is among the leading network model providers together with the simulation software. The OPNET Technology has been used and verified by different corporations, government, universities involved in research, defense agencies and network service providers. OPNET was introduced in 1987 and since that time, it has

been used in network troubleshooting, protocol improvement, network configuration auditing and application deployment planning. OPNET modeler was developed at MIT as the commercial network simulator [68]. It is fairly expensive when used commercially but there are some free licences offered for educational purposes. By 2007, it is estimated that OPNET technologies employ around 490 employees and the revenue was 95 Million USD [65].

3.3.1.2 Installing OPNET Modeller

OPNET modeller was developed at MIT in 1987. OPNET is commercial software. For an OPNET Modeler 14.5 to work, three modules have to be installed. These include:

- OPNET Modeler
- OPNET Model library and
- OPNET Model Documentation

It is recommended to install the compiler before the installation of the three modules.

OPNET is compatible with different Operating System such as Windows Vista, XP and
2000 together with Linux and other Linux based Operating system.

OPNET Modeler is made up of 4 main editors:

- 1. Project editor: This is where the wireless network is laid out. The network comprises of the network nodes and connections.
- 2. Node editor: Nodes can be edited with the node editor. Nodes are made up of Sub modules, which carry out the functions of the node. The functions are in the form of processes.
- 3. Process editor: Processes function as a Finite State Machine (FSM).
- 4. Code editor: Each state in the FSM is coded in either C or C++ programming

Language. The code is actually the tasks that the node does.

This hierarchy is shown for WiMax Module Structure as illustrated in Figure 3-9.

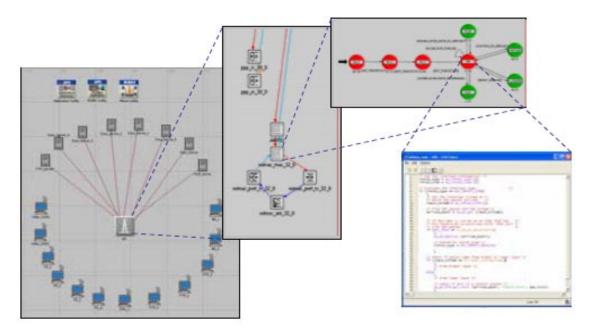


Figure 3-9 OPNET WiMax Module Structure

3.3.1.3 The OPNET WiMAX Specialized Model

OPNET Modeler® Wireless Suite supports the IEEE 802.16 standards. The OPNET Modeller 14.5 supports IEEE 802.16-2004 and IEEE 802.16e-2005. The OPNET WiMAX Specialized Model was developed by OPNET University with supervision from Motorola, Alcatel-Lucent, Samsung and France Telecom [70].

Telecommunication Service Providers, University researchers, Government and Defence organization uses the OPNET Simulation tool to design, study and evaluate WiMAX networks. The works include:

- Evaluating scheduling algorithms for Subscriber Stations (SSs) and Base
 Stations (BSs)
- Analysing the performance of IEEE 802.16 (WiMAX) network

Moreover, OPNET won 2008 WiMAX Distinction Award Winner [70]. The WiMAX licence is required for running the simulation. Furthermore, the licence is required for viewing WiMAX models.

The WiMAX Model features in OPNET Modeller includes varieties of IEEE 802.16 feature. The features include:

- MAC Messages
- Scheduling Service
- Automatic Retransmission Request (ARQ)
- Hybrid Automatic Retransmission Request
- Packet loss modelling
- Mobility
- Ranging
- AMC
- QoS and Physical layer modelling [69].

For OFDMA Physical layer, QPSK 1/2, QPSK 3/4, 16-QAM 1/2, 16-QAM 3/4, 64-QAM 1/2, 64 QAM 2/3, and 64 QAM 3/4 Modulation and Coding Schemes are supported.

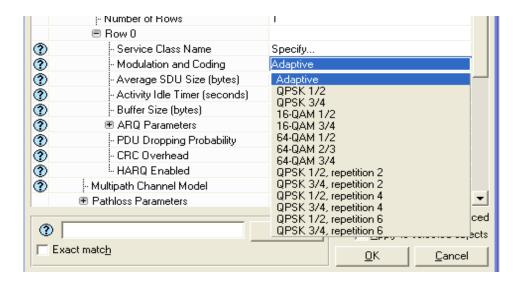


Figure 3.10 Modulation and coding schemes Supported in WiMAX Model

WiMAX Node Models are included in wimax and wimax_adv object palette.see Figure 3.11

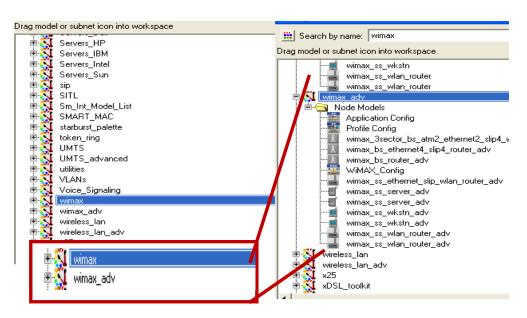


Figure 3.11 WiMAX object Palette

[69] outlined important steps to be used during WiMAX configuration. The steps include:

1- Creating the topology

To create a WiMAX network topology is similar to other network topology. The node can added to the network model manually by dragging and dropping the object from WiMAX object palette into a project editor workspace. However, a user can create the topology from the Wireless Network Wizard.

2- Adding Traffic to the Network Model.

Different application traffic such as FTP, Email and VOIP can be added to the WiMAX network topology. Different Applications are supported in the WiMAX Model. Figure 3.12 shows the applications supported in WiMAX model [70].

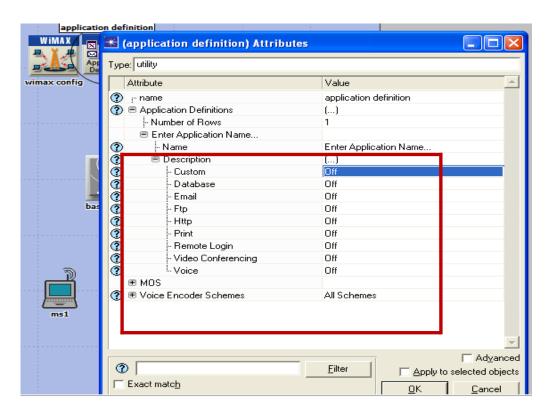


Figure 3.12 Applications supported in WiMAX Model.

3-Configuring WiMAX Parameters

In this stage, the user defines the service classes, configure physical layer profiles, and associate Subscriber Stations with a Base Station and assigning the service classes to the service flows. Figure 3.13 shows the attribute for the OFDM PHY [70].

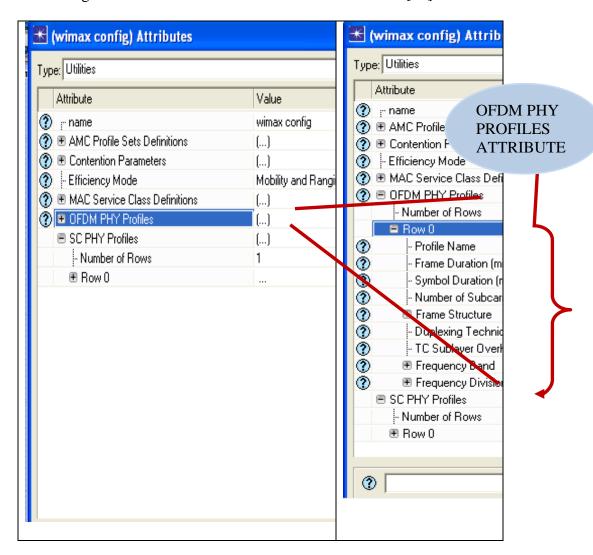


Figure 3.13 OFDM- PHY Profiles attributes.

Moreover, Subscriber Station parameter includes UL Service Flows attributes and DL Service Flows Attributes. Figure 3.14 shows the SS parameters exist in WiMAX Model. By default, the SS is connected to the nearest Base Station [69].

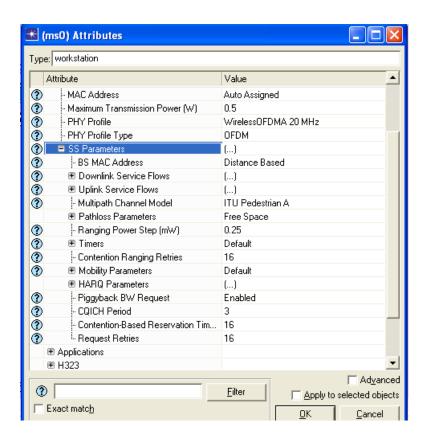


Figure 3.14 Subscriber Station parameters.

Additionally the Subscriber Stations architecture is given in Figure 3.15.

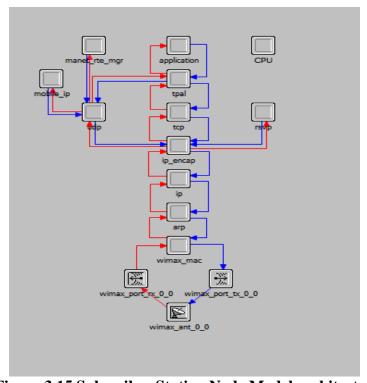


Figure 3.15 Subscriber Station Node Model architecture

Finally, Figure 3.16 depicts the wimax_mac process model. Moreover, the WiMAX supports two more additional process models. These are *wimax_bs_control* and *wimax_ss_controls*. However, in this thesis, the wimax_mac process model is used. The wimax_mac process model is the root process and is responsible for data forwarding, packet delivery, Encapsulation and decapsulation of Service Data Units (SDUs) [69].

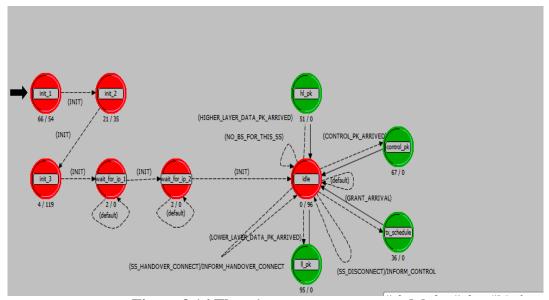


Figure 3.16 The wimax_mac process model

3.3.1.4 Analyzing WiMAX networks in OPNET Modeler 14.5

Several statistics are available to analyze the WiMAX performance. WiMAX statistics can be collected on a per-node basis or a per-connection basis [69]. Figure 3.17 shows WiMAX Node Statistics.

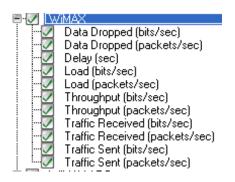


Figure 3.17 Statistic WiMAX traffic at the MAC layer.

3.3.1.5 OPNET Modeler Amendment

Several modifications has been added to the WiMAX model in order to implement the proposed uplink scheduler, such as a deadline checker function and the functions which are responsible for redistributing the amount of the deficient counter which resulted from moving deadline requests from rtPS queues to the introduced extra queue.

Moreover, the OPNET WiMAX model employs a bandwidth-based call admission control that checks the bandwidth availability before admitting a new flow. The WiMAX-BS-control child process implements the admission control function. At each start of the simulation, this process is to be realized even if a flow will start successively; furthermore, an admitted flow keeps the assigned bandwidth until the end of simulation. This policy becomes ineffective in a dynamic scenario where flows start and end in different instants. The bandwidth assigned to a flow that ends before the end of the simulation should be not assigned to a flow that will start later. A remedy to this problem of adjusting the unused bandwidth will be by modifying the admission control function taking action on WiMAX-MAC, BS-control and SS control processes.

In details a new WiMAX Mac process has been created, called "WiMAX-new-MAC" (see Figure 3-10), and amended WiMAX-BS-control and WiMAX-SS-control processes. In order to realize the proposed CAC, it was necessary to make possible:

- 1. The bandwidth release of an ending flow.
- 2. The Subscriber Station activation in every instant (₹), and not only at the start of the simulation.
- 3. A realtime invocation for the admission control function.

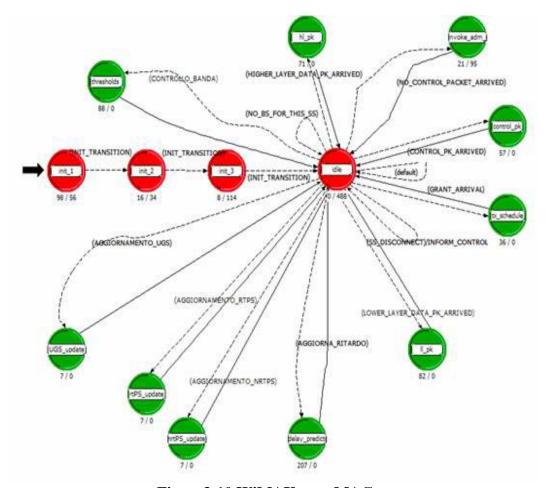


Figure 3-10 WiMAX-new-MAC process

3.4 Summary

Legacy scheduling algorithms such as EDF, WFQ and EDF+WFQ do not explicitly consider all required QoS parameters of the traffic classes in IEEE 802.16. This is not sufficient, since scheduling classes have multiple QoS parameters, such as rtPS requiring delay, packet loss, and throughput guarantee.

Although Cross-layer and queuing theory scheduling algorithms have some drawbacks such as implementation complexity (especially the queuing theory scheduling algorithm), they are more suitable, since they include the maximum latency, MRTR, and the channel quality in the priority functions.

In summary, we will focus on the dependencies across layers and the relationships between the Scheduler and CAC in 802.16 networks, and outlined BS models to be used for simulation studies to investigate the effect of various strategies involving the frame throughput, provider return throughput, bandwidth use, and other performance indices. Since 802.16 is new, the vendors do not know the answers yet and are very interested in this research. The work will be carried out by means of simulation using an OPNET simulator, described in the previous section.

Chapter 4:

Customized Deficit Round Robin Uplink Scheduler (CDRR)

4.1 Introduction

An enhancement of MDRR with Strict Priority algorithm [50], which is based on a DRR mechanism, is proposed in this section to be used as an uplink scheduler. Contrary to MDRR, the proposed scheme (CDRR) has the capability to minimize the delay and improve the management of handling different classes laid on top of a MDRR mechanism. The proposed scheme is based on a single queue for both UGS and unicast polling, and one queue for a BE. Moreover, a list of queues for both rtPS and nrtPS is provided. We should note that grouping multiple rtPS connections into a single queue under an EDF algorithm fails to guarantee the minimum reserved traffic rate of an individual rtPS connection; for such, this might lead to an unbalanced sharing of the available bandwidth, since one rtPS connection with a tight delay budget and an extra amount of traffic may consume the entire bandwidth and starve all the other rtPS connections in the same queue. In the proposed scheme, each queue in the list represents

a single connection, as seen in Figure 4-1. This list is updated for every frame by adding new queues and removing empty queues from the list.

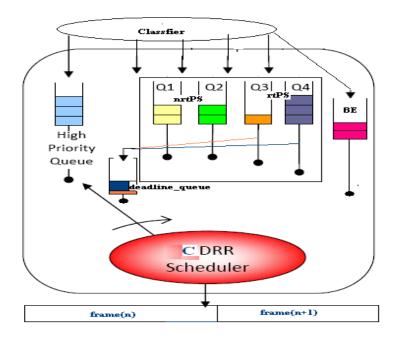


Figure 4-1 Proposed Scheduler Architecture

Bandwidth requirement can be measured by the maximum sustained traffic rate (γ_{max}) and the minimum reserved traffic rate (γ_{min}), depending on the service flow scheduling type. Each queue in the list is attached with a deficit counter variable to determine the number of requests to be served in the round and this is incremented in every round by a fixed value (*quantum*) and the quantum is computed as Equation (1).

In this scheme, an extra queue has been introduced to store a set of requests whose deadline is due to expire in the next frame. Every time the scheduler starts the scheduling cycle, this queue will be filled by all rtPS requests which are expected to miss their deadline in the next frame. An rtPS request is said to be subject to a deadline when the request connection is engaged but will probably fail to meet the expected deadline. In other words, we define a request packet as due-to-deadline in a certain

frame if its deadline expires before the next frame is totally served and at the same time, the remaining capacity of the current frame will not be enough to service this packet after the service flow currently being serviced or about to be serviced uses up its quantum.

More formally, an rtPS data grant G is said to be at its transmit time due-to-deadline if equations (4) and (5) are satisfied:

$$deadlineG < (frame_n + 1) \times frame_duration$$
(4)

$$sizeG > frame_{aval} - DC_i$$
 (5)

where frame_n is the current frame number, $\mathit{frame}_\mathit{avail}$ is the available capacity in the current frame, sizeG is the size of the current packet and DC_i is the deficit counter of the \vec{t}_{ti} service flow belonging to the rtPS queue which will be about to be serviced.

In the proposed scheme, it is assumed that the deadline of a request should be equal to the sum of the arrival time of the last request sent by the connection and its maximum delay requirement.

In the next scheduling cycle, the scheduler will first check if any request has been added to this extra queue. If the extra queue is not empty, the scheduler will serve this queue after the UGS and polling queue. Once the extra queue becomes empty and there are available BW in the UL-MAP, the scheduler will continue serving the polling services (PS) list, using DRR with quantum as expressed in equation (1). Note that, it is well known that lower-priority PS queues can actually be starved when an extra queue has packets to be served. Therefore, PS queues cannot be guaranteed a minimum service rate or a maximum latency unless constraints on the extra queue traffic are enforced. In this scheme, it is assumed that when the connection gets polling opportunity, more

requests are expected to be sent in the next uplink frame, so the scheduler will share the polling interval time and the sum of deficit left as a result of moving due-to-deadline requests from rtPS connections, in adding extra value to the deficit counter for the such connections to increase the number of requests to be served in this round under the following conditions:

The connection has just been polled in this frame;

The queue size of this connection is exceeding its maximum threshold:

queue
$$\max_{t}$$
 threshold = $r_{min} \times (frame_t]$ duration) (6)

For BE queues, the scheduler will assign the remaining bandwidth in FIFO method, since there are no QoS boundaries.

Next, we show the Pseudo code for the uplink scheduling algorithm which will act as a fundamental for the support of QoS requirements, and also allocates bandwidth to the SSs. The proposed scheme is fully standard-compliant and it can be easily implemented at the BS.

4.2 Proposed Uplink Scheduler Algorithm

```
Initialize: (Invoked when the scheduler is initialized)

1. Active_list = 0;

2. Extra_queue=0; exceed_deficit=0; No_nrtPS//number of nrtPS connections in the active list.

For (i=0; i<0; i++)

{
    Deficit_counter(i)=0;
    }

    Enqueue: (Invoked when a packet arrives)

3. Let J be Queue In Which Packet Arrives;

4. If (ExistsInList(J) == FALSE) then

{
```

```
AddQueueTo Active _List [CID]
5. Insert the UGS grants and unicast polling into their corresponding queue that must be scheduled in
this frame;
6. Insert the BW requests in rtPS, nrtPS, BE queues;
7. For each request i in rtPS queues
do
  if ((deadline[i] - current time)+ frame duration >0) && (Number of Request [CID] >
max_threshold[CID]) then
   {
// which rtPS requests must be sent in the next frame in order to satisfy the maximum latency;
  extra_queue = extra_queue + dequeue.rtPS[i];
 exceed_deficent=exceed_deficent+size_of (req[i]);
end do;
8. Schedule the requests in the UGS queue using First In First Out (FIFO);
9. if Available slots>0 && extra queue is empty=Flase
then
schedule the requests in the extra_queue using Early Deadline First (EDF);
10. For each connection CID of type nrtPS do
if Poll[CID].time== current time && rmin[CID] \leq granted BW[CID]&& available Slots>0;
 then
Deficit _counter (CID)== Deficit _counter (CID) + (exceed_deficit / No_nrtp);
exceed_deficit = exceed_ deficit - (exceed_ deficit / No_nrtps);
end do
11. if available slots >0
   then
Schedule the requests in the rtPS, nrtPS queues starting from the head of the queue;
12. if available slots >0 && rtPS,nrtPS queues are empty then
```

Schedule the requests in the BE queue starting from the head of the queue;

}

In Line 7, examining deadline requests, each individual step requires O(1) time and they are all executed for all the requests in the rtPS queues for r requests thus, the procedure requires O(r) time. The add extra Deficit procedure (line 10) takes O(n) time where n represent the connections which just polled in the last frame, since in the worst case the number of rtPS and nrtPS connections is equal to n. As DRR complexity equal O(1), so the time complexity of the proposed algorithm is O(1 + n + r).

4.3 Simulation Scenarios and Configuration

Simulations have been realized with the following configurations at MAC as well as the PHY layer; it makes use of Wireless MAN-OFDMA physical interface between BS and SSs, with the TDD duplexing technique and the NLOS configured for lower frequency at 5GHz and channel bandwidth of 20MHz and 2048 sub-carriers. The frame duration is 5ms and the OFDMA symbol duration of 102.86µsec. The modulation chosen for downlink and uplink direction is QPSK.

Different simulation scenarios have been conducted throughout the following section, and an analysis of the obtained results is described. An assumption is considered here for every scenario, as each SS can only transmit a single application to establish connection with the BS which will not impact the simulation results in anyway.

In the following simulation experiments, the number of SSs increased from 15 to 150 in steps of 10 units (one for each type of service). Each simulation ran ten times with different seeds. The mean and the 95% confidence interval are shown in some graphs.

Here, as depicted in Figure 4-2, a network consisting of one BS serving a number of SSs has been simulated with different traffic flows as shown in Table 4.1. For the incoming and outgoing video streams, details are given in [51].

Traffic Type	Scheduling Type	Traffic Model	Distribution	Traffic Rate(λ)
Voice	UGS	On/off	(On/:1.2s) (Off:1.8s)	66 bytes every 10ms
Video	rtPS	Video Conference	Exponential Distribution	10 frames/s
Web	nrtPS	Light browsing	Hybrid longnormal/ perto	Head (7247 bytes) Tail (10558 bytes)
FTP	BE	Medium Load	Exponential Distribution	512 Kbytes
Traffic Type	Scheduling Type	Traffic Model	Distribution	Traffic Rate(λ)
Voice	UGS	On/off	(On/:1.2s) (Off:1.8s)	66 bytes every 10ms
Video	rtPS	Video Conference	Exponential Distribution	10 frames/s
Web	nrtPS	Light browsing	Hybrid longnormal/ perto	Head (7247 bytes) Tail (10558 bytes)
FTP	BE	Medium Load	Exponential Distribution	512 Kbytes

Table 4-1 Traffic Flows

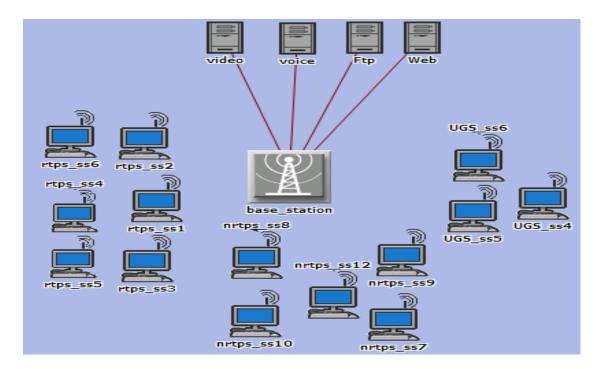


Figure 4-2 Network Topology

The interval between unicast request opportunities of the rtPS service is 20ms and the interval of the nrtPS service is 1sec. For rtPS service, the delay requirement is 100ms and each connection has its own maximum bandwidth requirement of 64Kbps.

The nrtPS service minimum bandwidth requirement is set to 64Kbps, and the BE service would not require for any QoS guarantee. The simulation compares the delays incurred in the proposed scheme with those incurred in the Modified Deficit Round Robin (MDRR) implemented in OPNET 14 WiMAX module [70].

Here are the Metrics used in the simulation analysis:

Delay: End-to-end delay of all packets received by the node's wireless LAN MAC and forwarded to the higher layer.

Load: Total number of bits received from the higher layer. Packets arriving from the higher layer are stored in the higher layer queue.

Throughput: Total number of bits sent to the higher layer from the MAC layer. The data packets received at the physical layer are sent to the higher layer if they are destined for this station.

4.3.1 Behaviour of the UGS with the CDRR Scheduler

In this section, we study the behaviour of our UGS scheduler. We have nine rtPS subscribers who generate a mean traffic rate equal to 80Kbps. We have also two BE SSs that generates FTP traffic.

Figure 4-3 represents the throughput of the UGS connections as a function of the UGS traffic load submitted in the network. In the rest of the document, existing MDRR references the scheduler implemented by OPNET. For a very low traffic load, our CDRR scheduler and MDRR provide the same UGS throughput, since all SSs are entirely served. We observe that the MDRR scheduler throttles the network traffic and the throughput cannot exceed 500Kbps. Indeed, the MDRR scheduler does not differentiate between the QoS classes. Since there are sixteen SSs and five of them use UGS connections, the MDRR scheduler always allocates five uplink subframes for each period of sixteen frames. Our scheduler works as defined in the standard.

All UGS subscribers must be entirely served. The curve of our UGS scheduler is linear and the coefficient is equal to 1.

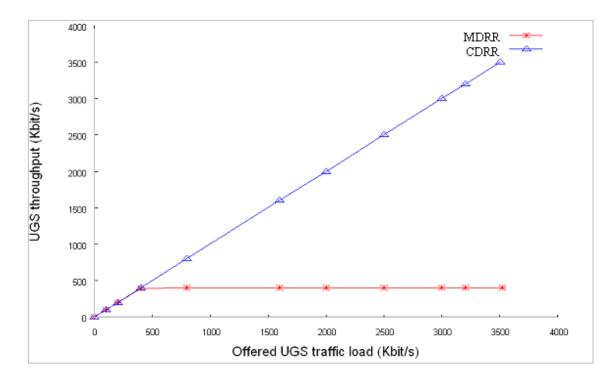


Figure 4-3 UGS Throughput versus Offered UGS Traffic Load

The delay of the UGS class is negligible because UGS has the lowest and constant delay due to its higher priority and stringent QoS requirements.

4.3.2 Behaviour of the rtPS Scheduler

In this section, we study the behaviour of the rtPS schedulers. We consider the scheduler of the existing module (MDRR) as well as one of our implemented schedulers: CDRR.

We have five UGS subscribers. Each UGS SS generates Constant Bitrate (CBR) traffic with a rate of 160Kbps. We have also two BE SSs that generate FTP traffic.

Figure 4-4 shows the throughput of the rtPS connections as a function of the rtPS traffic load submitted in the network. This figure shows the low efficiency of the MDRR scheduler.

Indeed, this scheduler allocates all the symbols to one SS, even if it has no data to send.

We note that the rtPS throughput of the MDRR scheduler is nearly nine times worse than that of our implemented rtPS scheduler.

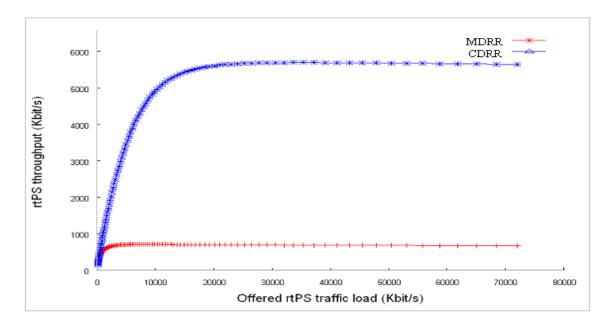


Figure 4-4. rtPS Throughput versus Offered rtPS Traffic Load

The video delay of rtPS is observed compared to the MDRR scheduler and this is shown in Figure 4-5.

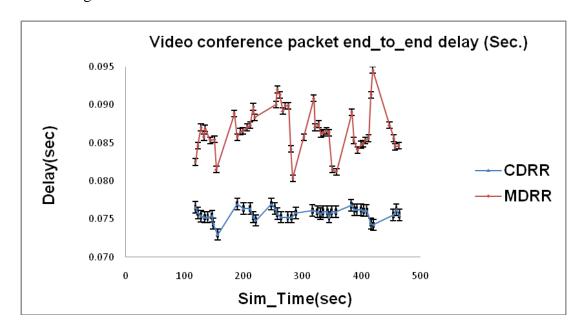


Figure 4-5 Delay of Video Packets in both MDRR and the Proposed Scheme

From the graph, it can be seen that video packets encounter a higher delay when using MDRR. On the contrary, with the proposed scheduling schema, the delays are lower. This is due to the fact that realtime requests closer to the deadline are given high priority. We also consider increasing the chance of the service for both rtPS requests and nrtPS requests whenever their connections get a polling chance. Since every queue in the PS List represents one connection, the queuing delay has been investigated and the result depicted in Figure 4-6; storing due-to-deadline requests in a separate queue can be seen as a solution leading to reduce the requests drop probability which in turn will improve rtPS queue delays.

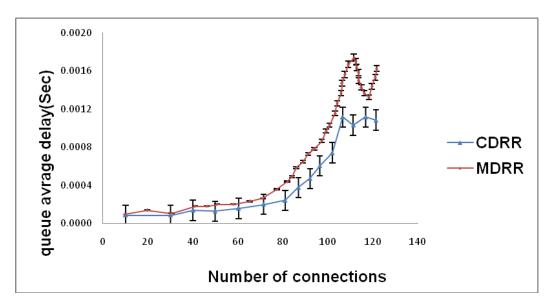


Figure 4-6 Average Delay for the Video Conference Queue

Figures 4-7 and 4-8 show the throughput for rtPS connection for both MDRR and CDRR respectively; the throughput is lower than the load in time when we use MDRR, since the rtPS connection is configured as 64Kbps, but it receives 96Kbps in load. The difference is made up by overhead between the application layer and the MAC layer.

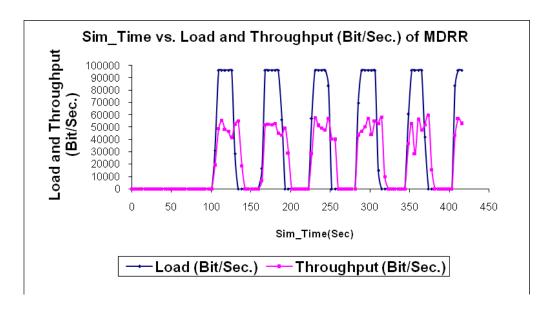


Figure 4-7 MDRR rtPS Load and Throughput vs. Time

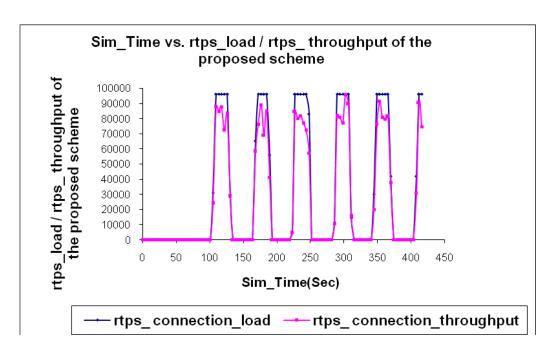


Figure 4-8 Proposed Scheme (CDRR) rtPS Load and Throughput vs. Time

The throughput of rtPS for both MDRR and CDRR algorithms is given by the following Equation [15]:

$$\mathbf{T}_{=} \sum_{i=1}^{j} \mathrm{Map}(i,j) \qquad (7)$$

Where \mathcal{J} is the total number of frames for a service flow $\overline{\mathbf{a}}$, and Map(i,j) is the size of the data serviced for the service $\overline{\mathbf{a}}$ in frame \mathcal{J} .

4.3.3 Behaviour of the BE Scheduler

In this section, we study the behaviour of our scheduler. Since we have rtPS and UGS Schedulers, we can vary the UGS or rtPS traffic load. We choose to study the relationship between the BE and UGS schedulers. In this scenario, we have nine rtPS subscribers who generate a mean traffic rate equal to 80Kbps. We have also two BE SSs that generates FTP traffic.

Figure 4-8 represents the throughput of the BE connections as a function of the UGS traffic load submitted in the network. This figure shows that the MDRR scheduler provides the same BE throughput independently of the offered traffic load. This is because the MDRR scheduler is applied to all the QoS classes. In our case, it periodically allocates two uplink subframes and the period is equal to the duration of sixteen frames.

The higher the offered traffic load, the lower is the BE throughput. This is because our scheduling implementation serves the UGS, then rtPS, and finally BE connections. So, the higher the number of the remaining symbols is, the higher is the BE throughput. This behaviour fits with the standard specification, as the BE connections have no QoS requirements.

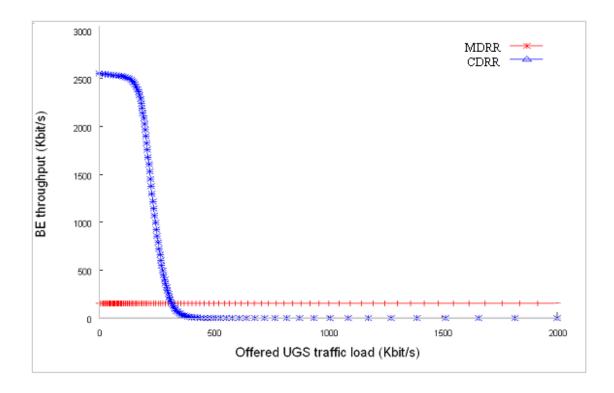


Figure 4-9 BE Throughput vs. Offered UGS Traffic Load

The graph in Figure 4-10 shows four curves that represent the throughput of the rtPS and BE services in both the MDRR algorithm and the CDRR algorithm. We chose to compare rtPS and BE services to show that the higher priority service (rtPS) will enhance its throughput using the CDRR algorithm; on the other hand, the BE services will experience a relatively decreased throughput using the CDRR rather than when the MDRR algorithm is applied. However, the decrease in the throughput BE service is relatively low, since it will remain bounded, and it is guaranteed that the lower priority queues will not experience starvation, and they will be eventually serviced.

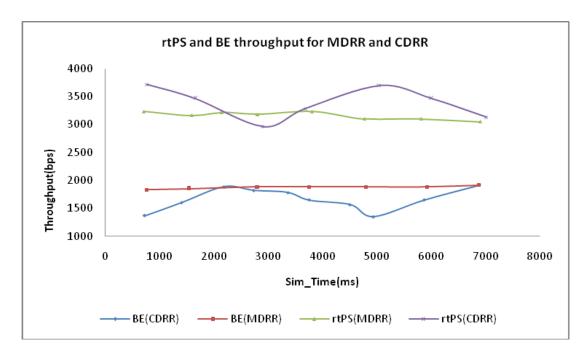


Figure 4-9 rtPS and BE Throughput for MDRR and CDRR

We prove the fairness performance of our scheme using the fairness definition described in [53].

$$Fairness = \left| \frac{T_{rtps}}{S_{rtps}} - \frac{T_{nrtps}}{S_{nrtps}} - \frac{T_{be}}{S_{be}} \right|$$
(8)

where $T_{\it rtPS}$, $T_{\it nrtPS}$ and $T_{\it BE}$ parameters represent the throughputs which were allocated to rtPS, nrtPS and BE flow services respectively, and $S_{\it rtPS}$, $S_{\it rtPS}$ and $S_{\it BE}$ parameters denote the total traffic of rtPS, nrtPS and BE services, respectively.

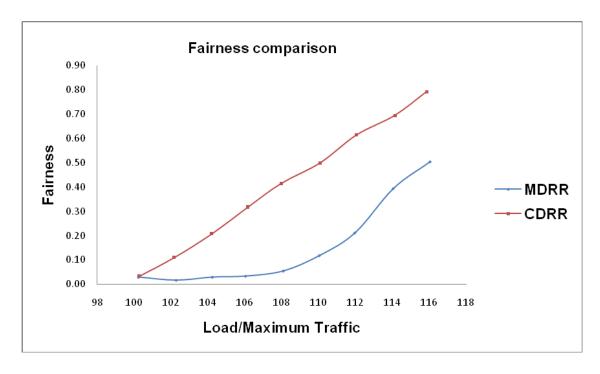


Figure 4-10 Fairness of the Two Schemes Vs. Increased Traffic Load

In Figure 4-11, since we study the long-term fairness, so the simulation results collected at load greater than 100Kbit/frame, the result demonstrates that the CDRR scheme is fairer from the lower load than MDRR, which mean that MDRR give more service to the higher priority flows when the load is low until the overall load is around 112Kbits/frame. When the overall load exceeds 112Kbits/frame, both schedulers are likely to have the same effect on fairness. This means throughput allocated to one flow will not exceed throughput allocated to the other flows of the same type.

4.4 Summary

Considering system complexity, the MDRR was especially chosen to be enhanced since it provides O (1) per packet complexity. Thus, from the point of view of implementation, this scheduler should not be complex or expensive.

Throughput was not affected by the weights that were assigned, since the polling process might have had the upper hand in controlling the mobile stations and the times for them to be polled, and thus affecting the throughput.

The delay values found from intensive simulation shows that the scheduler is capable of handling video traffic. However, further simulations must be done to assure that the scheduler is also able to provide the QoS constraints with a larger number of Subscriber Stations with respect to the QoS constraints that were achieved in this work.

Chapter 5:

Proposed Call Admission

Control Scheme

5.1 Introduction

The 802.16 standard provides a signalling function for dynamically establishing service flows and requesting QoS parameters. There are three types of control messages for service flows:

Dynamic Service Activate (DSA): Activate a service flow;

Dynamic Service Change (DSC): Change an existing service flow;

Dynamic Service Delete (DSD): Delete a service flow.

New connections may be established when a customer's needs change. This may be initiated by the BS. The BS sends a control message called a DSA-REQ, which can contain the SFID, CID, and a QoS parameter set. The SS then sends a DSA-RSP message to accept or reject the service flow. This mechanism allows an application to acquire more resources when required. Multiple service flows can

be allocated to the same application, so more service flows can be added if needed to provide good QoS.

Activation of a service flow proceeds in two phases: admit first, then activate. An Authorization Module in the BS provides this function. It approves or rejects a request regarding a service flow. The Authorization Module can activate a service flow immediately or defer activation to a later time.

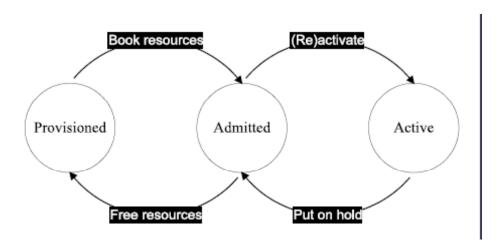


Figure 5-1 Service Flow Stat Diagram

Once the service flow has been admitted, both the BS and SS can reserve resources for it. Resources reserved by the BS and SS are not limited to bandwidth. They can include other resources, such as memory. Dynamic changes to the QoS parameters of an existing service flow are also approved by the Authorization Module.

QoS parameter changes are requested with Dynamic Service Flow messages sent between the BS and the SS. All requests are in the form described above (i.e. DSA, DSC, and DSD).

A QoS parameter set is associated with each service flow. The type of QoS parameter set distinguishes the status granted by the Authorization Module (admitted or active). Also, an external set of QoS parameters can be provisioned to the MAC without the Authorization Module, which means they are outside of the scope of the standard; for example, a network management system may provision the QoS parameter set altogether.

The method for determining which QoS parameters will be allowed depends on the authorization model and the 802.16 standard recognizes two authorization models:

Provisioned Authorization: QoS parameters are provided by the network management system upon setup, and remain static.

Dynamic Authorization: Changes to QoS parameters can be requested, and the Authorization Module issues its decisions.

Thus, the 802.16 standard provides some flexibility in its QoS provisioning. The two-phase activation allows service flows to be admitted before activation. QoS parameters can also be provisioned by a network management system for use at alater time, the standard recognizes two authorization models, which allows the vendors some flexibility in their design. This provides an efficient framework for dynamic resource allocation.

The QoS requirements are determined by the higher layer application. For example, a VoIP application may require a realtime service flow with fixed-size data grants, whereas an FTP application may use a non-realtime service flow with variable-sized data grants. If the application requires QoS, it can define the QoS parameter set, or it can imply a set of QoS parameters with a Service Class Name.

Depending on the available network resources, the network then decides if it can meet the QoS requirements of the application. If so, the QoS parameters are handed down through the MAC layer.

5.2 Proposed CAC Algorithm

In this work, a new CAC algorithm for a fixed WiMAX network (standard 802.16d) in PMP mode is proposed using GPSS (Grant per Subscriber Station) mode for bandwidth granting to SSs. The proposed CAC algorithm is suitable to be implemented in the BS, but requires measurement information about the delays of the flows crossing the WiMAX link beside the QoS requirements of the new flow, in terms of delay and bandwidth constraints.

The aim of proposing such an algorithm is to provide QoS guarantees for admitted flows in terms of bandwidth guarantee and delay. Hereafter in this work, the proposed CAC algorithm is referred to as "Interactive CAC".

Calling [Equation (3)], maximum traffic rate is the necessary bandwidth which must be satisfied for both UGS and rtPS connections in order to meet QoS requirements. On the other hand, due to the property of nrtPS flow, the required bandwidth of an nrtPS flow may vary within the range of $[b_{nrtps}^{\min}, b_{nrtps}^{\max}]$ where b_{nrtps}^{\min} , and b_{nrtps}^{\max} are the minimum and maximum bandwidth required for the nrtPS flow, respectively. If sufficient bandwidth is available (i.e. fewer connections), each nrtPS flow can be transmitted at a higher rate.

Since the number of connections increase, the existing nrtPS flows can give up some bandwidth to new connections in order to have more connections in the system.

An nrtPS connection said to be non-active if it has a connection queue size less than the fixed threshold, calculated using [Equation (6)].

We call this model an interactive model, in which α is the most possible amount of bandwidth which can be taken from all ongoing non-active nrtPS connections (Nrtps). Thus, the current reserved bandwidth for each non-active nrtPS connection is b_{nrtps}^{\max} .

In what follows, we describe our call admission control:

```
Accept = false; \\ DSA = new \ connection \ request; \\ b_{nrtps}^{\min} \\ b_{nrtps}^{\min} = Service \ Flow \ -> min\_rate \\ b_{nrtps}^{\max} = Service \ Flow \ -> max\_rate \\ if \ DSA. \ Type = BE \\ Accept = true; \\ if \ DSA. \ Type = rtPS \ AND \ BUGS < B \\ Accept = true; \\ // calculate \ the \ number \ of \ all \ ongoing \ non-active \ nrtPS \ connections. \\ i \ from \ 0 \ to \ number \ of \ nrtps \ connection \ in \ the \ active \ list \\ if \ CID[i]. \ Length < max \ begin{picture}(c) & Mintellet &
```

```
End for;
if DSA.Type = UGS AND BUGS < B
  do Accept = true;
else
  do check_scheduler_status (frame_number) // Function call
   if DSA. Type = UGS AND B_{UGS} < \mathcal{L} + \alpha AND Queues_delay = false
     do Accept = true;
   else
     do Accept = false;
if DSA.Type = rtPS AND B_{rtPS} < 1
  do Accept = true;
else
  do check_scheduler_status (frame_number) // Function call
   if DSA. Type = rtPS AND B_{rtPS} < \mathcal{L} + \alpha AND Queues_delay = false
     do\ Accept = true;
   else
     do\ Accept = false;
function check_scheduler_status (frame_number)
while (frame_number MOD 1000)=0
  do if extra_queue <threshold
     Queues_delay =false;
    else
     Queues_delay = true;
     Quite;
return Queues_delay;
```

Figure 5-2 CAC Algorithm

When the request for BE connection arrives at the BS, the request is always admitted, but BS will not set aside any bandwidth for such a connection. In the 802.16 MAC layer, the BS connections get the transmission opportunities only when other service connections do not transmit. Generally, BS connections do have long idle periods and data in each transmission is relatively small, especially in the uplink direction. Therefore, QoS of BE can be easily satisfied.

5.3 Simulation and Performance Results

Since there is no former CAC-bandwidth allocation scheme in GPC approach, no comparison to former research can be made. So, here we investigate the flow acceptance ratio. The main parameters of the simulation model are represented in Table 5.1. We consider five UGS, nine rtPS, and two BE subscribers. The subscribers can use the QPSK 1/2, QPSK 3/4, 16-QAM 1/2, 16-QAM 3/4, 64-QAM 2/3, and 64-QAM 3/4 MCSs.

Parameters	Value
bandwidth of the BS	10 (Mbps)
downlink / uplink ration	3:2
no. of OFDMA symbol per	49
frame	
no. of OFDMA symbol per	48 (data portion)
frame	
packet size of service flow	200 (byte)
service distribution of UGS	constant bit rate
service flow	
service distribution of rtPS	exponential
service flow	distribution
service distribution of nrtPS	normal distribution
service flow	
service distribution of BE	normal distribution
service flow	

Table 5-1 WiMAX Subscribers Station Parameters

Figure 5-3 shows the change in flow acceptance ratio as the average connection arrival rate changes. The flow acceptance ratio is almost 100% until the connection arrival rate is around 38. Thus, if one 802.16 network is to be deployed for voice only (UGS) traffic, then the network administrator should make sure that new connections arrive at a rate less than 38 connections per second.

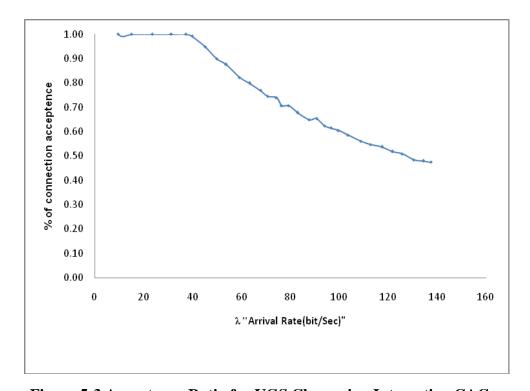


Figure 5-3 Acceptance Ratio for UGS Class using Interactive-CAC

According to the standard IEEE 802.16, UGS connections have a fixed resource reservation. The CAC module and the scheduler module act according to the standard and guarantee such resource for every VoIP connection. This simulation demonstrates that every UGS connection has a constant delay on the WiMAX link. Moreover, Figure 5-4 shows that the delay is constant during the whole simulation time, thus demonstrating that the acceptance of a new UGS flow does not impact on the delay of other already admitted UGS flows.

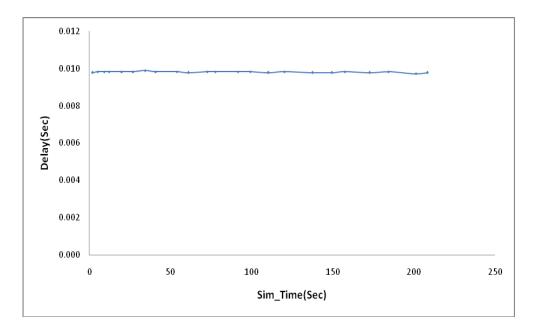


Figure 5-4 UGS Delay (sec)

In the second simulation scenario, only rtPS connections are considered with a maximum latency of 30ms.

As depicted in Figure 5-5, BW-CAC is not able to provide delay guarantees, because it accepts new flows until there is enough free capacity in the link. On the contrary, proposed CAC allows guaranteeing delay constraints by considering the number of the due-to-deadline requests in the scheduler using a delay check process after the bandwidth check. In the same plot, it is possible to see how the proposed algorithm allows respecting the limit of 30ms required by the application over the WiMAX link.

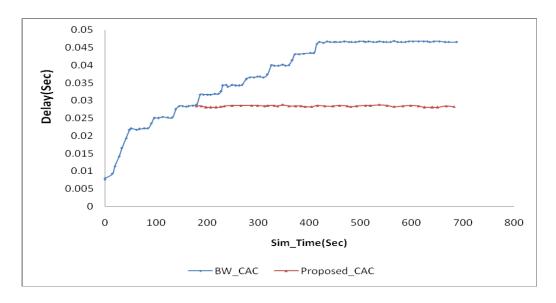


Figure 5-5 rtPS Delay (sec)

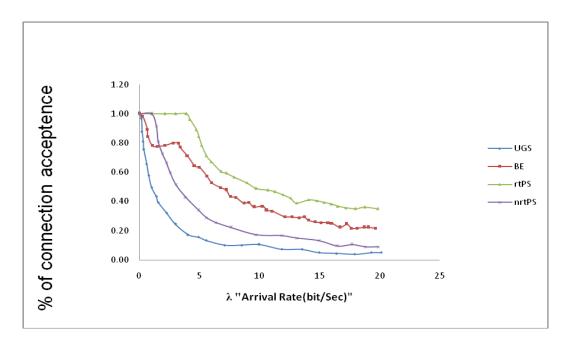


Figure 5-6 Acceptance Ratio for all Classes of Traffic Proposed-CAC

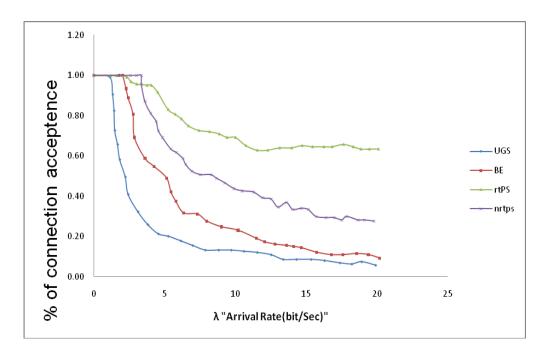


Figure 5-7 Acceptance Ratio for all Classes of Traffic using BW-CAC

Figure 5-6 shows the Flow-Acceptance ratio of each class of traffic when the proposed CAC is used. When this is compared with the case when allocation is done based on BW-CAC (see Figure 5-7), it can be noticed that Flow-Acceptance ratio improved for all classes of traffic, except nrtPS. Hence, nrtPS is similar to rtPS connections, except that the parameters have larger values (e.g. the min-rate and max-rate are larger than rtPS connections). Thus, slots (bandwidth) which were taken out using the degradation of nrtPS could not be used to admit more nrtPS connections because of their large bandwidth requirement.

For the other types of connections, because of their small parameter values, they were able to take up the saved slots and improve their acceptance ratio.

Although BW-CAC admits connections based solely on availability of bandwidth (slots), it will typically incur west of bandwidth. The proposed CAC, on the other

hand, will have better utilization, and will have less bandwidth west, since it admits connections only when delay of the connection can be met. Figure 5-8 compares the bandwidth utilization using both modes: the proposed CAC mode and the constant rate mode. When working in the constant rate mode, the nrtPS flows can only transmit at the maximum rate. Hence, we define a Utilization performance as defined below:

No-of-slots and total-slots represent the number of slots assigned to the connection i and total number of slots available, respectively.

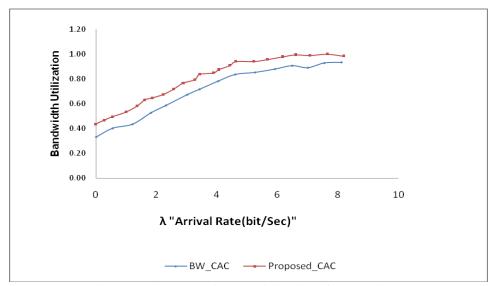


Figure 5-8 Bandwidth Utilization Comparison

Other simulation experiments, not presented here due to space limitation, indicate that the rtPS connections acceptance ratio can be increased by tuning the value of the time interval used to check the scheduler status.

5.4 Summary

In this chapter, an admission control scheme for services defined in the 802. I6 specification has been proposed. The proposed scheme gives the highest priority for UGS flows and maximizes the bandwidth utilization by bandwidth borrowing and degradation for the low service flow nrtPS. With the use of OPNET, the results shows that in order to satisfy the QoS requirements of different services, the admission control must work together with an appropriate granting control at the MAC layer, so that the actual bandwidth can be allocated when data unit is ready for transmission.

Chapter 6:

Proposed Frame Allocation

Scheme

6.1 Introduction

To integrate all features in WiMAX PHY and QoS service classes, a well-designed algorithm is demanded to satisfy the following metrics. First, service classes must be satisfied for the requirements of QoS parameters, such as minimum reserved rate, priority, and maximum latency. The maximum latency guarantee is most important for the realtime application in rtPS. Second, for fairness, the allocation algorithm should serve the service classes fairly to avoid the starvation of low-priority service classes. The problem statement leads to a dynamic downlink and uplink subframes bandwidth allocation in a WiMAX BS. A basic mechanism is designed in order to allow the uplink subframe to make use of resources from the DL subframe, if the number of the due-to-deadline requests in the uplink scheduler is high.

6.2 Proposed Frame Allocation Scheme Mechanism

The initial size of both subframes is set to 70%, and 30% for DL and UL subframes respectively, and it is used as a reference to reset the system when the DL subframe "needs" its resources back, giving the DL subframe a bigger size than the UL subframe, due to the fact that the BS wants to serve as much as possible of DL traffic to avoid congestion at the BS scheduler. Also, the load in the downlink is higher compared to the uplink, hence the downlink subframe is expected to have a longer duration. A threshold based on the number of deadline requests is used to reset the partitions to their initial settings.

Sum up the number of deadline requests as to reserve a bandwidth for those that must be served in this frame.

When a new frame starts, the required data/request size is firstly translated into a number of slots as: $Number of slot = \frac{Request_Size}{Capacity of Slot}$ (8)

Since a slot contains N number of data sub-carriers and the modulation decides

the number of bits carried in a sub-carrier, we can have:

$$Capacity_of_slot = \frac{(N * X * codeing_{rate})}{8}$$
 (9)

Where X represent the number of bits carried in a sub-carrier.

By summing up the number of reserved slots calculated from deadline requests and dividing them by the number of UL sub-channels in slot duration to obtain the amount of symbols to be reserved for the deadline requests.

If the amount of the symbols needed by the number of the deadline requests is greater than 30% of the frame size, then the initial size of both subframes is set to 50% for DL and UL sub frames, otherwise the amount of the remaining symbols is thus calculated by subtracting the number of reserved symbols from the total number of symbols in a frame by proportioning the remaining symbols for the DL and the UL according to their amount of bandwidth requested by data/requests. Letting Req-DL and Req-UL represent the above requested bandwidth for DL and UL, respectively, the proportion can be derived as:

$$\frac{Req_DL}{Req_UL} = \frac{Sym_{rem-(SympL \times Z)}}{Sym_{UL} \times Z}$$
(10)

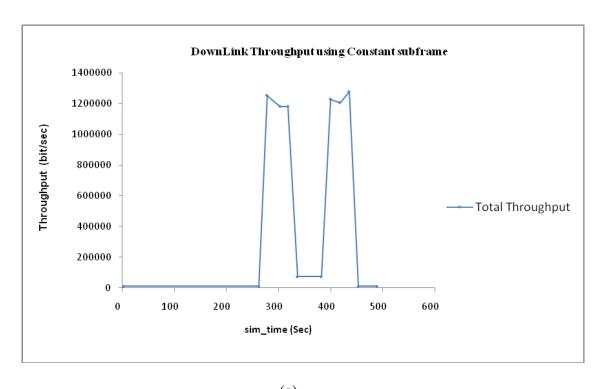
Where Sym_{rem} indicates the number of remaining symbols and Sym_{DL} and Sym_{DL} and Sym_{DL} means the number of symbols in a DL and UL slot duration, respectively and Sym_{DL} represents shows the average number of slot durations for both DL and UL. In short, the proposed scheme reserves symbols for the requests which must be served in this frame, then proportionate the remaining symbols by the data/requests to decide the DL/UL sub-frame size.

6.3 Frame Allocation Scheme Performance Analysis

In order to examine the frame allocation scheme a network composed of one WiMAX cell with four SS nodes with traffic configuration such that all SS nodes have an uplink application load of 250Kbps for a total of 1Mbps and at specific

times, the Server generates 600Kbps of application traffic directed to SS-0 and SS-1; this creates a total downlink application load of 1.2Mbps.

Here an OFDMA frame with 512 subcarriers and 5 milliseconds duration is used. The Uplink subframe is set to 12 symbol times and the Downlink subframe is assigned 34 symbol times as an initial setting; for QPSK ½, the capacity expected is Uplink: ~ 600Kbps and Downlink: ~2.5Mbps. The rest of the parameters used here can be found in Table 5.1.



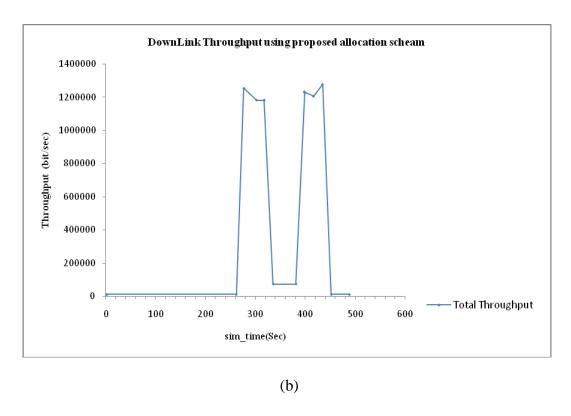


Figure 6-1 (a) Downlink Throughput using Constant subframe, (b) Downlink

Throughput using Proposed Allocation Schema.

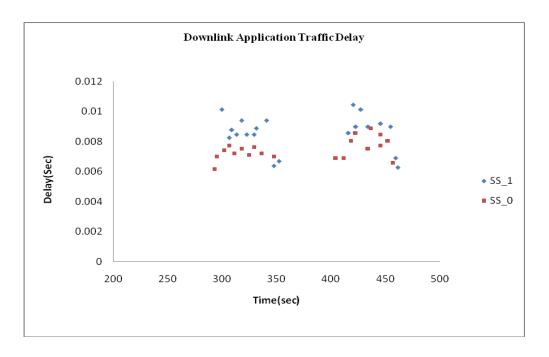
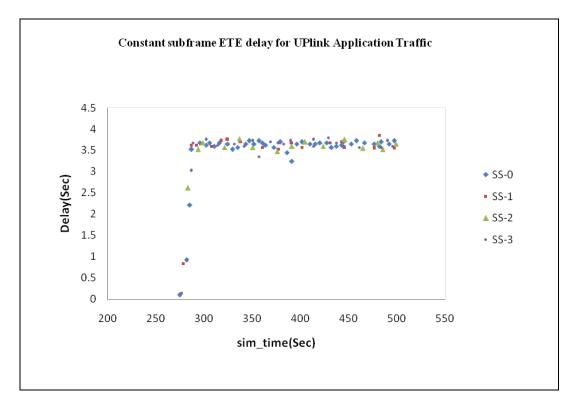
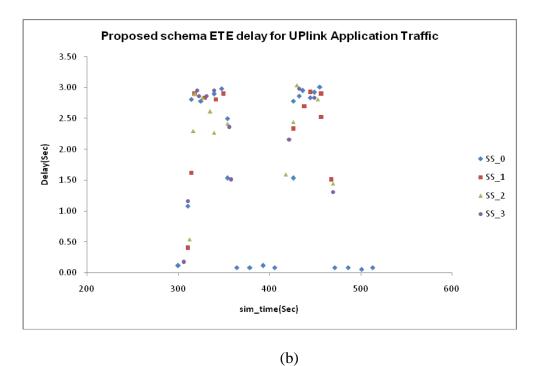


Figure 6-2 DL Application Delay using the Proposed Scheme

As shown in the first Figure 6-1 (a, b) above, comparing the downlink throughput using the proposed scheme, the downlink traffic performs the same as in the constant subframe cases, up to 1.2Mbps MAC throughput (e.g. no change in downlink throughput). Also, the application delay ~8 milliseconds (see Figure 6-2_ which explains that the downlink traffic remain unaffected by the new scheme.





UP LINK Throughput 1400000 1200000 1000000 Throughput (bit/sec) 800000 Proposed Schema 600000 Constants ubframe 400000 200000 0 100 400 500 sim_time(Sec) (c)

Figure 6-3 (a) Constant subframe ETE Delay for Uplink Application Traffic,
(b) Proposed Scheme ETE Delay for Uplink Application Traffic, (c) UL
Throughput for both Proposed and Constant Scheme

On the other hand, for the UL traffic in Figure 6-3 (a, b, c), the behaviour is different (compared to the DL traffic); notice here "the period of time (0–~230) is the time needed to exchange initial messages between BS and SSs", for uplink traffic can be seen. In the proposed subframe allocation scheme for time periods (230–320 seconds) and (400–440 seconds), the MAC throughput is ~700Kbps and delays are ~3 second; on the other hand, for time periods (320–400 seconds) and (440–500 seconds), the MAC throughput is ~1Mbps and delays are ~50 milliseconds, which in turn, compared with the constant subframe case, where throughput was ~560Kbps and delay was ~3.7 seconds (between 280–500 seconds). So, there is a big improvement in the uplink performance due to the reallocation of the subframe resources.

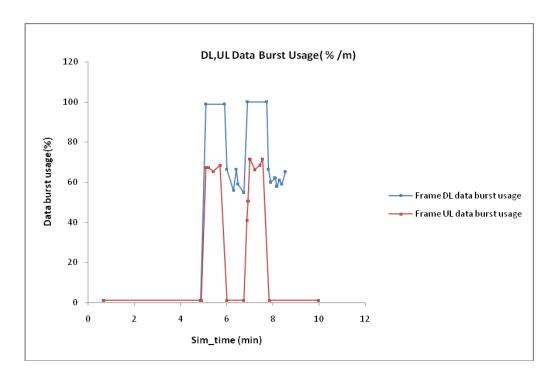


Figure 6-4 DL, UL Data Burst Usage (%/min)

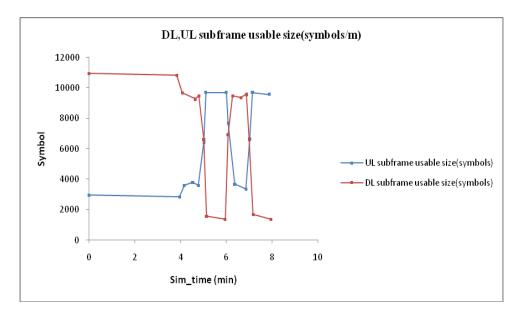


Figure 6-5 DL, UL subframe usable size (symbols/min)

Figures 6-4 and 6-5 show the consumption of both downlink (in red) and uplink (in blue) subframes, as well as their available symbols during the simulation.

It can be clearly seen how the mechanism is changing the subframe sizes (e.g. Subframe Usable Size). UL burst usage is high (100%) in the time (5–6 minutes) and (7–8 minutes), when it cannot increase its size too much because the deadline requests size is less than 30% (average). Although there is a small increase in the UL subframe, it is most likely due to DL subframes that are idle for very short periods of time.

For time periods (5–6 minutes) and (7–8 minutes), UL subframe size grows significantly and the corresponding utilization value increases. This is because the size needed by the deadline requests is over 30% during those periods.

6.4 Summary

In this chapter, the proposed mechanism kept the performance of downlink traffic unaffected by monitoring the number of due-to-deadline requests and returning the DL subframe to its original size if resources were required.

The mechanism has been tested in a controlled environment for correctness. To determine its effectiveness more simulations should be run, enhancing the framework to support the configuration of the various thresholds and parameters via attributes (instead of constant values). In this way parametric study can be conducted in order to characterize this specific algorithm.

Chapter 7:

Conclusions and Future Work

7.1 Summary and Conclusions

Being one of the hottest current research issues and as indicated by Samsung [54], designing a scheduler that is less complex, more efficient and provides a superior Quality of Service is of great importance to WiMAX systems.

Stemming from such an initiative, the IEEE standard of fixed 802.16 [55] networks has gained a lot of concern [62] [63] in recent years. However, how to effectively provide QoS guarantees to realtime video traffic is still under discussion.

In this thesis, a comprehensive, yet brief introduction was given for the IEEE 802.16 commercially known as WiMAX Systems. A Modified DRR scheduling algorithm has been studied in depth. After that, attempts were made to enhance the throughput of the system with regard to the number of deadline requests of the realtime connections while taking fairness into consideration.

Considering system complexity, the MDRR was especially chosen to be enhanced, since it provides O (1) per packet complexity. Thus, from the point of view of implementation this scheduler should not be complex or expensive.

Throughput was not affected by the weights that were assigned, since the polling process might have had the upper hand in controlling the subscriber stations and the times for them to be polled, and thus affecting the throughput.

The delay values found from intensive simulation shows that the scheduler is also capable of handling voice traffic.

A Connection Admission Control algorithm in a WiMAX network is presented in this thesis. The main features of the proposed solution are that the algorithms are dependent in respect to the scheduling policy used in the BS and that the algorithm is only based on delay measurements. Simulation realized with an OPNET simulator show the effectiveness of the proposed algorithm, as it allows providing a probabilistic QoS guarantee to rtPS flows admitted in the network, while deterministic QoS guarantee is provided to UGS and nrtPS flows.

However, further simulations must be done to assure that the scheduler is also able to provide the QoS constraints with a larger number of subscriber stations with respect to the QoS constraints that were achieved in this work.

Unfortunately, this could not be done here for this thesis, mainly because a normal Personal Computer (PC) was used for the purpose of simulating the proposed work. Nevertheless, attempts have been made to simulate a 19 cell in a fixed

environment but the simulation would take about 6 hours to finish, hence the simulation was aborted for the safety and incapability of the PC.

With regard to the proposed frame allocation scheme we can conclude with the following:

- The proposed mechanism helped to take advantage of an under-utilized downlink subframe, allowing the uplink subframe to acquire temporarily non-used resources.
- The mechanism also kept the performance of downlink traffic unaffected by monitoring the downlink utilization and returning the DL subframe to its original size if resources were required.
- This fairly simple implementation shows the advantages of open source models that together, with modular design, allow us to customize the model behaviour to implement and evaluate vendor-specific mechanisms and their impact on the system (for example, MAC and application performance).
- The mechanism has been tested in a controlled environment for correctness. To determine its effectiveness more simulations should be run, enhancing the framework to support the configuration of the various thresholds and parameters via attributes (instead of constant values). In this way parametric study can be conducted in order to characterize this specific algorithm.

7.2 Future Work

Other directions for future work might include the following:

- Another solution for enhancing throughput may be achieved by updating the values of the bandwidths given to individual stations as they change from one burst profile to another, thus, reducing the amount of bandwidth wastage caused by the AMC scheme. Furthermore, the proposed scheduler may be taken forward and applied to other different systems. This will test the versatility of the algorithm in different environments.
- Subframe partition size is a key system configuration parameter that directly determines the capacity balance of the cell between uplink and downlink segments. Whether the system requires a constant or a dynamic distribution of the resources, simulations are a powerful tool to determine either the optimal point for fixed systems or the best mechanism that could be used by adaptive systems.

Nowadays, WiMAX has taken another step forward and currently a newer standard in under development. The standard is IEEE 802.16m and aims for 1Gbps for nomadic and 100Mbps for mobile terminals. This is indeed a revolution in the field of mobile communications and thus further research on this standard would be very fruitful.

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