In the Name of ALLAH the Merciful the Compassionate

Islamic University of Gaza
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ENHANCING SCHEDULING FOR IEEE 802.16 NETWORKS

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ABSTRACT

The IEEE 802.16 standard defines the specifications of the Worldwide Interoperability for Microwave Access (WiMAX) technology as a Broadband Wireless Access network. This type of networks supports multiservice traffic (data, voice and video) and guarantees the Quality of Service at the MAC layer level. However, the IEEE 802.16 standard specifies three QoS components that reside in the MAC layer such as scheduler and call admission control. Although, the IEEE 802.16 defined the function of each component but left the implementation open for vendors and operators.

In this thesis, we aim to design two new scheduling algorithms that guarantee QoS in WiMAX network. The new algorithms will consider application traffic requirements, channel condition states and compliant with the standard. The first algorithm is Deadline maximum Signal to Interference Ratio (DmSIR) scheduling algorithm and it is a modified version from maximum Signal to Interference Ratio (mSIR) scheduling algorithm. The DmSIR scheduling algorithm makes scheduling decision based on two factors: the packets deadline and signal to noise ratio. The second algorithm which we named the Priority based Deficit Round Robin (PbDRR) solves the problem of long delay for non real-time traffic with low signal to noise ratio as well as giving priority to real-time traffic that approach to deadline. The PbDRR scheduling algorithm makes scheduling decision based on three factors: packets deadline, signal to noise ratio and backlog traffic.

We used the NS2 network simulation to evaluate the performance of the new algorithms and three performance metrics are evaluated for this purpose. The simulation results for DmSIR shows enhancement in the performance compared to the mSIR scheduling algorithm but the non real-time traffic with low signal to noise ratio suffers from long delay. On the other hand, the simulation results for the PbDRR scheduling algorithm shows better performance than the DmSIR and Deficit Round Robin + Fragmentation (DRR+F) scheduling algorithms.

Keywords: IEEE 802.16, WiMAX, scheduling, Quality of Service, Signal to Noise Ratio and NS2 network simulation.

الملخص

تحسين الجدولة في شبكات 802.16

للباحث: م."ربيع مصطفى" علي أبوطير

قامت منظمة IEEE بوضع المعيار 802.16 الخاص بشبكات النطاق الواسع اللاسلكية (وايماكس) التي من طبيعتها دعم مختلف أنواع البيانات. كذلك تقدم شبكات وايماكس جودة الخدمة على مستوى طبقة ربط البيانات ولضمان ذلك قامت بتحديد ثلاث عناصر لهذه العملية. أحد أهم هذه العناصر هو المجدول حيث أن المعيار 802.16 قام بتعريف عمله لكن ترك تصميمه لمزودي الخدمة والمصنعين.

في هذه الرسالة نهدف إلى تصميم خوارزميات للجدولة تقوم بضمان جودة الخدمة في شبكات وايماكس بالإضافة إلى توافقها مع معيار 802.16. الخوارزمية الأولى تقوم بالجدولة بناءا على معيارين هما حالة القناة والزمن المتبقي للحزم. الخوارزمية الثانية هي نسخة مطورة عن الأولى وتقوم بعمل الجدولة بنفس المعاير بالإضافة إلى معيار ثالث هو البيانات المتراكمة.

لقد إستخدمنا محاكي الشبكات (NS2) لتقييم أداء الخوارزميتين بإستخدام ثلاث معايير أخذت من دراسات سابقة في نفس المجال. أثبتت نتائج محاكات الخوارزمية الأولى تحسن في الأداء مقارنة بخوارزمية (mSIR) ولكن حزم بيانات الوقت غير الحقيقي عانت من تأخر في الوصول. الخوارزمية الثانية قامت بحل هذه المشكلة وأثبتت نتائج المحاكاة تحسنا في الأداء مقارنة بالخوارزمية الأولى.

DEDICATION

TO MY BELOVED PARENTS …
TO MY WIFE AND SON…
TO MY BROTHERS …
TO MY FRIENDS …
TO WHOM I LOVE

ACKNOWLEDGMENTS

MY THANKS TO ALL THOSE WHO GENEROUSLY CONTRIBUTED THEIR FAVORITE RECIPES. WITHOUT THEIR HELP, THIS WORK WOULD HAVE NEVER BEEN POSSIBLE.

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LIST OF ABBREVIATIONS

ACK	ACKnowledgement
AMC	Adaptive Modulation And Coding Scheme
ARQ	Automatic Repeat Request
ATM	Asynchronous Transfer Mode
BE	Best Effort
BPSK	Binary Phase Shift Keying
CAC	Call Admission Control
CDRR	Customized Deficit Round Robin
CID	Connection IDentifier
CINR	Carrier to Interference-plus-Noise Ratio
CPS	Common Part Sublayer
CQI	Channel Quality Indicator
CS	Convergence Sublayer
DAPQ	Dynamically Allocating Priority Queue
DC	Deficit Counter
DL	DownLink
DL-BS	DownLink-Base station Scheduler
DL-MAP	DownLink-MAP
DmSIR	Deadline maximum Signal to Interference Ratio
DQ	Deadline Queue
DRR	Deficit Round Robin
DWRR	Deficit Weighted Round Robin
EDF	Earliest Deadline First
ERTPS	Extended Real-Time Polling Service
FCH	Frame Control Header
FDD	Frequency Division Duplexing
FFT	Fast Fourier transform
FIFO	First In First Out
FTP	File Transfer Protocol
HOL	Head-Of-Line
HTTP	Hypertext Transfer Protocol
IEEE	Institute of Electrical and Electronics Engineers
I-MDRR	Improvised Modified Deficit Round Robin

IP	Internet Protocol
IQ	Idle Queue
LOS	Line Of Site
MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MDRR	Modified Deficit Round Robin
ML	Maximum Latency
mmSIR	modified maximum Signal to Interference Radio
MPDU	MAC Protocol Data Units
MPEG	Moving Picture Experts Group
MRTR	Minimum Reserved Traffic Rate
MSDU	MAC Service Data Units
mSIR	maximum Signal to Interference Radio
MSTR	Maximum Sustained Traffic Rate
NRTPS	Non Real Time Polling Service
NS2	Network Simulator 2
O-DRR	Opportunistic Deficit Round Robin
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
OSI	Open Systems Interconnection
OTcL	Object oriented Tool command Language
PbDRR	Priority based Deficit Round Robin
PDU	Protocol Data Unit
PHS	Payload Header Suppression
PHY	Physical
PKM	Privacy Key Management
PUSC	Partial Usage of Subchannels
Q	Quantum
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RR	Round Robin
RRM	Radio Resources Management
RTPS	Real Time Polling Service
SDU	Service Data Unit
SFID	Service Flow IDentifier

SIR	Signal to Interference Ratio
SNR	Signal to Noise Ratio
SOFDMA	Scalable Orthogonal Frequency Division Multiplexing Access
SP	Strict Priority
TcL	Tool command Language
TcLCL	TcL Class Libraries
TDD	Time Division Duplex
TJ	Tolerated Jitter
UF-DRR	Uniformly-Fair Deficit Round Robin
UGS	Unsolicited Grant Service
UL	UpLink
UL-BS	UpLink –Base station Scheduler
UL-MAP	UpLink-MAP
UL-MS	UpLink –Mobile station Scheduler
VOIP	Voice Over IP
WDRR	Wireless Deficit Round Robin
WF2Q	Worst-case Fair Weighted Fair Queuing
WFQ	Weighted Fair Queue
WFQ	Weighted Fair Queue
WRR	Weighted Round Robin
VOIP	Voice Over IP

Chapter 1 Introduction

1.1 Overview

Due to the rapidly growing demand for internet access in suburban area where the last mile solution such as ADSL is not available, the broadband wireless access (BWA) has come out as promising solution that provides internet connection for data, voice and video service. However, BWA industry players have been slow and reluctant to implement a single common standard. Therefore, the IEEE has started a task group name 802.16 to design standard broadband wireless access for metropolitan area networks (MAN). After that a set of telecommunication industry constructs the worldwide interoperability of microwave access forum or for simplicity WiMAX forum which is nonprofit organization aims to design BWA solution.

The WiMAX forum produces WiMAX which is the implemented version from IEEE 802.16 standard. In literature, the WiMAX and IEEE 802.16 refer to the same thing and in thesis we use both keywords to refer to the same technology. The WiMAX architecture is designed to achieve a set of goals such as: easy to deploy, high speed data rate, large coverage area, efficient spectrum usage, multiservice (data, voice and video) and the support of Quality of Service (QoS) for different type of applications. The IEEE 802.16 standard constructs a new medium access control (MAC) and physical (PHY) layers and it keeps the rest layer without change. Also in its first release the operation band was from 10 to 66 GHZ frequency range but later changed from 2 to 11 GHZ frequency band. Although, the IEEE 802.16e is the most uses version so our thesis contribution is based on this version.

1.2 Problem Statement

The IEEE 802.16 standard specifies three QoS components that reside in the MAC layer and they are: classifier, scheduler and call admission control. Firstly, the classifier classifies packets to set of predefined classes and put them into queues. Secondly, the Scheduler plays a vital role that helps the addressing of QoS guarantee to the variant types of traffic. The main function of scheduler is serving the packets after the classification process with the considering of priority. Finally, the call admission control (CAC) is an important part of QoS components which contributes to admitting the new connections. Notice that, the standard specifies the function of the scheduler and call admission control but lefts the implementation open for vendors and operators to provide their own solution.

Actually, the scheduler is the main component at the MAC layer that impacts significantly on the performance by increasing throughout and decreasing delay. Although, it helps to provide service guarantee to heterogeneous traffic where there is variety in QoS requirements so the design of new scheduler will be investigated by the researcher.

1.3 Thesis Contribution

The aim of this thesis is to propose two new scheduling algorithms to guarantee QoS in WiMAX network, considering application traffic requirements and channel condition states. The first algorithm is easy to implement and fully compliant with standard but not fair for non real-time traffic with bad channel state. On the other hand, the second algorithm solves this problem and is fully compliant with the standard. We used the NS2 network simulation to evaluate the performance of the new algorithms and three performance metrics are used for this purpose.

1.4 Thesis Structure

In chapter 2, we describe the IEEE 802.16 Architecture, the medium access control, the physical layer, the modulation and coding scheme and the IEEE 802.16 QoS parameters.

In chapter 3, we describe the classification of scheduling algorithms, the channel-unaware scheduler, the intra-class scheduler, the inter-class scheduler, the channel-aware scheduler and several related algorithms.

In chapter 4, we present our proposed algorithms the Deadline maximum Signal to Interference Ratio (DmSIR) scheduling algorithm and Priority based Deficit Round Robin (PbDRR) scheduling algorithm.

In chapter 5, we present the NS2 network simulator, the channel model and link adaptation, the call admission control, the network topology, the simulation parameters, the traffic Model and the simulation results for both algorithms.

Finally, in chapter 6 we present conclusion and future works.

Chapter 2 IEEE 802.16 Overview

2.1 Introduction

Todays, users need high speed internet access in large coverage area and multiservice support. Users demand on wireless internet increased sharply because the spread of handheld devices (Laptop, Tablet…) and this increase is the main drive behind the continuous development in wireless broadband. The IEEE 802.16 is a wireless broadband access standard developed by the Institute of Electrical and Electronics Engineers (IEEE). The two main objectives of this standard are providing broadband access with high throughput and wide coverage.

The IEEE 802.16 work group was established in 1998 to develop air-interference standard for Broadband Wireless Access (BWA). The main task of this working group is addressing primarily applications of wireless technology to link commercial and residential buildings to high datarate core networks and thereby provide access to those networks and this link is known popularly as the "last mile". The WiMAX (Worldwide Interoperability for Microwave Access) is the commercial implementation of IEEE 802.16 and it contains a partial implementation of the standard but in literature both keywords are used interchangeably to refer to the same technology. Theoretically WIMAX offers several features such as long coverage area up to 48 km and high datarate up to 70Mbps [2].

The IEEE 802.16 standard has many versions and revisions and the most widely implemented versions are:

- The IEEE 802.16d-2004 (IEEE 802.16d) was first practical standard of IEEE 802.16. It was published in October 2004 and popularly called as fixed WiMAX. This standard integrated all the previous standards to improve performance for 802.16 especially in the uplink traffic.

- The IEEE 802.16 work group completed and approved IEEE 802.16e-2005(IEEE 802.16e) in December 2005. It is amendment to the IEEE 802.16-

2004 standard with mobility supports. The IEEE 802.16e-2005 provides solution for nomadic and mobile applications and is often referred as mobile WiMAX.

- In June 2009, the IEEE 802.16-2009 (IEEE 802.16j) was approved and the main contribution of this standard which has multihop relay capabilities. It enables operation of a wireless relay station in order to enhance coverage, throughput, and system capacity with interoperable relay stations.
- The IEEE 802.16m expected to be approved in this year and it will support advanced air interface with datarate of 100 Mbps for mobile node and 1 Gbps for fixed node and movement speed up to 360 kmps. The IEEE 802.16m known as mobile WiMAX release 2.

The IEEE 802.16 standard provides specification for both MAC and PHY layers. We will focus in this thesis on the IEEE 802.16e because it is basis for later IEEE 802.16 standards. Although, this standard includes details about the various flavors of PHY layers supported and the characteristics of the MAC layer such as bandwidth request mechanisms packets scheduling. Theoretically, the IEEE 802.16e base station (BS) can provide broadband wireless access in a range up to 50 km for fixed stations and from 5 to 15 km for mobile stations (MSs) with a maximum data rate of up to 70 Mbps and movement speed up to 120 kmps [2].

In General, there are two types of deployment for WiMAX networks: a point-to-multipoint (PMP) and mesh topology. In PMP all the mobile stations connect directly to the central WiMAX (BS) through the wireless link. Thus, connections are established between MSs and BS for data transmissions, and direct communications between MSs are not allowed. Although, in this mode any communications or data transmission between two MSs are routed through the WiMAX BS. However, in mesh topology, the existing MSs are not directly connected to the BS but MSs are acting as relay stations (RSs) and permit communications between MSs in order to achieve coverage extension of a BS without installation of another BS. In this thesis we will focus on PMP topology because it is the most common transmission mode in WiMAX [1,2].

2.2 IEEE 802.16 Architecture

The IEEE 802.16 network standard applies Open Systems Interconnection (OSI) network reference of the seven layers model and this model is very often used to describe the different aspects of a network technology. The OSI network model starts from the application layer (layer 7) on the top and ends with the physical (PHY) Layer (layer 1) on the bottom. The IEEE 802 standard splits the OSI Data Link Layer into two sublayers named Logical Link Control (LLC) and Media Access Control (MAC). The PHY layer creates the physical connection between the two communicating entities (the peer entities), while the MAC layer is responsible for the establishment and maintenance of the connection (multiple access, scheduling, etc...) [3].

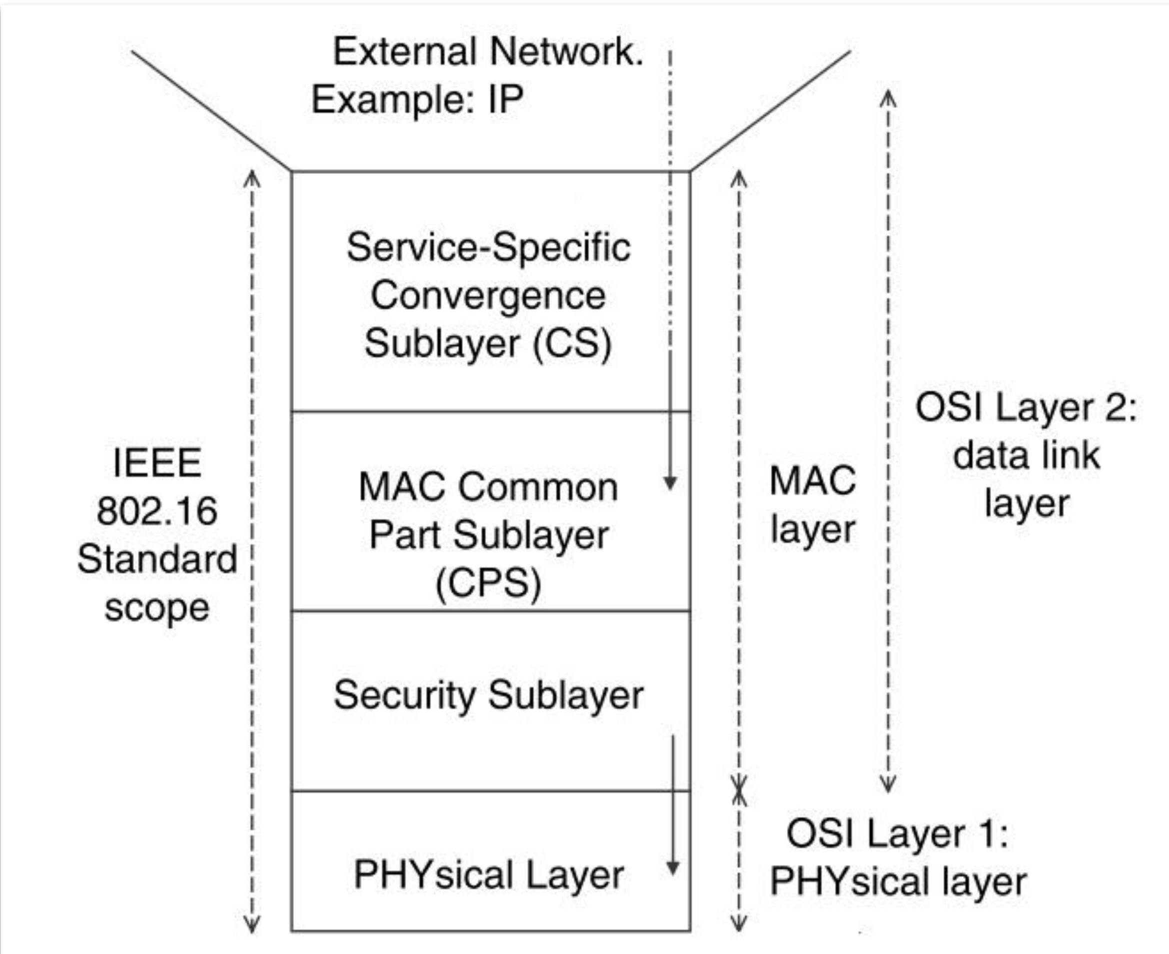

Figure2.1 : The layers stack for the IEEE 802.16 standard (adapted from WiMAX: Technology for Broadband Wireless Access [4]).

The protocol layers architecture defined in IEEE 802.16 standard is shown in figure 2.1 and as it is clear from the figure the 802.16 standard defines only the two lowest layers, (1) the Physical layer and (2) the MAC layer, which is the main part of the Data Link Layer. In the next sections we will describe both the PHY and MAC layer for the IEEE 802.16.

2.3 Physical Sublayer

The IEEE 802.16 standard defines within it scope four types of PHY layer interfaces that could be used with the MAC layer without any change. The PHY layers which are defined in IEEE 802.16 are:

- WirelessMAN-SC: a single carrier PHY layer intended for frequencies beyond 11GHZ and it requires a line of site (LOS) connection and supports point to point operations.

- WirelessMAN-SCa: a single carrier PHY layer for frequencies between 2GHZ and 11 GHZ and supports point to multipoint (PMP) operations.

- Wireless MAN-OFDM: use 256 point FFT based on orthogonal frequency-division multiplexing (OFDM) encoding for frequencies between 2GHZ and 11 GHZ and supports PMP operations. These specifications finalized in IEEE 802.16-2004 and accepted by WiMAX Forum for fixed WiMAX operations.

- Wireless MAN-OFDMA: use 2048 point FFT based on orthogonal frequency-division multiple accesses (OFDMA) encoding for frequencies between 2GHZ and 11 GHZ. This PHY layer modified to scalable OFDMA (SOFDMA) where the FFT size is variable and these modified specifications finalized in IEEE 802.16-2005 and accepted by WiMAX Forum for mobile WIMAX operations.

The IEEE 802.16e was designed to support high datarate, large coverage area and permits mobile operations scenarios. Towards this goal, the IEEE 802.16e use SOFDMA. However, in this technique the frequency is divided into subcarriers and the time is divided into symbols and only a subset of subcarriers is allocated to each user which is clear in figure 2.2.

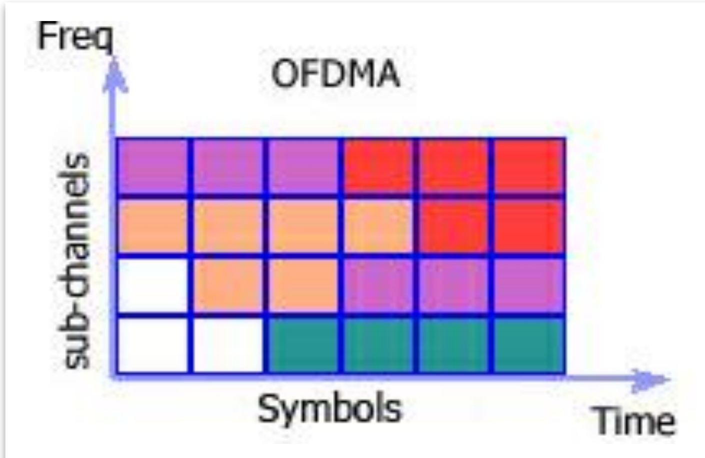

Figure 2.2: The OFDMA multiplexing technique (adapted from WiMAX: Technology for Broadband Wireless Access [4]).

The available subcarriers are grouped into subchannels and one or more subchannels are allocated to the transmitted data during a specific number of symbols. This technique called subchannelization and the standard specifies seven methods could be used. However, the partial usage of the subchannels (PUSC) is mandated by the IEEE 802.16e standard. The subchannelization process makes the bandwidth allocation mechanism more flexible because the allocation are performed based on time (OFDM symbols) and frequency (subchannels) using data allocation unit , called slot and the size of slot depends on subchannelization method.

The IEEE 802.16e uses time division duplex (TDD) and for that the frame is divided to uplink (UL) subframe and downlink (DL) subframe and the frame structure will be discussed in details in the next section. Figure 2.3 shows the DL and UL PUSC and as it clear in DL slot is organized using 2 blocks and each block contains 14 subcarriers over 2 symbols (24 for data, 4 for pilot). Therefore, the DL slot contains 28 subcarriers over 2 symbols. On the other hand, the UL slot is defined as 6 blocks where each block is composed of 4 subcarriers over 3 symbols (8 for data, 4 for pilot). Therefore, the UL slot contains 24 subcarriers over 3 symbols [3].

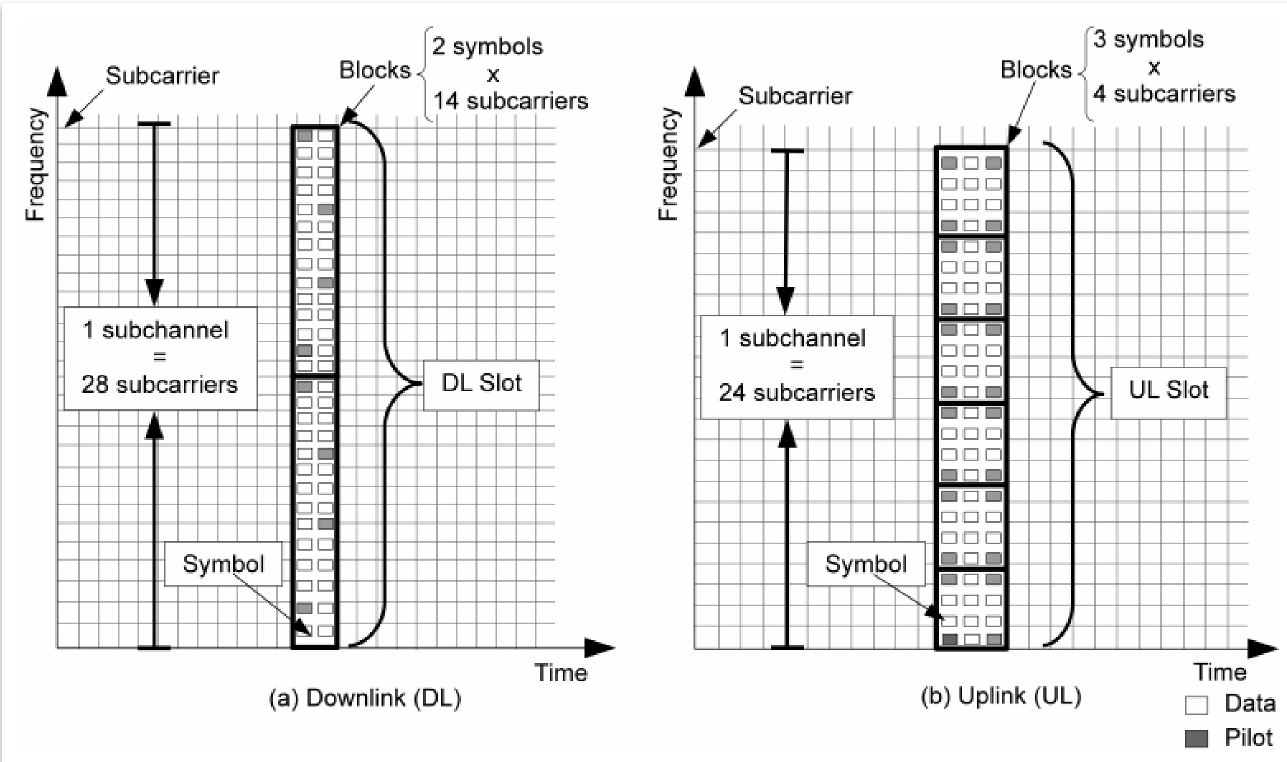

Figure 2.3: The Downlink and Uplink PUSC (adapted from WiMAX: Technology for Broadband Wireless Access [4]).

2.3.1 Modulation and Coding Scheme

In the IEEE 802.16 standard, the number of useful data bits is variable and depends on the used Modulation Coding Scheme (MCS). The choice of the appropriate MCS depends on the value of the receiver Signal-to-Noise Ratio (SNR). Although, four modulations techniques are supported by the IEEE 802.16 standard: Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), 16-Quadrature Amplitude Modulation (16-QAM) and 64-Quadrature Amplitude Modulation (64-QAM) [4].

In general, the mobile station switches to a more energy efficient MCS if the SNR is good. The MS can also switch to a more robust MCS if the SNR is poor. Once the MCS is defined, the number of bits per symbol, and then the useful number of bits per frame, can be computed. Therefore, the BS must take into account the link adaptation in its scheduling considerations. Table 2.1 shows the Modulation and coding rate, received signal to noise ratio, the received uplink and downlink data rate with frame duration of 5 ms, channel bandwidth 10 MHz and TDD mode. As shown in the table when SNR increases the uplink and downlink data rate increases and when the SNR decreases the uplink and downlink data rate decreases and this because of the changing of modulation technique.

MCS	bits / symbol	Receiver SNR (db)	Downlink Rate (Mbps)	Uplink Rate (Mbps)
QPSK 1/2	2	5	6.34	4.70
QPSK 3/4	2	8	9.50	7.06
16-QAM 1/2	4	10.5	12.67	9.41
16-QAM 3/4	4	14	19.01	14.11
64-QAM 1/2	6	16	19.01	14.11
64-QAM 2/3	6	18	25.34	18.82
64-QAM 3/4	6	20	28.51	21.17
64-QAM 5/6	6	22	31.68	23.52

Table2.1: The IEEE 802.16e MCS and SNR (adapted from WiMAX: Technology for Broadband Wireless Access [4]).

2.4 MAC Sublayer

The MAC layer of the IEEE 802.16 is designed to support multiple higher layer protocols including ATM, IP and other future protocols. Although it supports different duplex techniques such as TDD and FDD. As shown in the figure 2.1 WiMAX MAC layer is composed of three sublayers, namely, service specific convergence sublayer (CS), common part sublayer (CPS) and security sublayer. In the next subsections we will present further information about these sublayers [4].

2.4.1 Convergence Sublayer

The convergence sublayer serves as the main interface to higher-layer protocols and MAC layer. At the transmitter, the convergence sublayer accepts a data packet, called the SDU, from higher layer and performs some initial processing on it then passes it to the CPS for further processing and at the receiver, the reverse is performed. The convergence sublayer is also known as the service specific convergence sublayer in that its processing functions depend on which higher layer protocol.

At the transmitter, the convergence sublayer maps the original (higher layer) addresses used by the SDU to the system specific addresses used by MAC. For example, if the higher-layer protocol is IP, then the IP packet would have a source IP address and a destination IP address. Using these IP addresses and their host protocol, the convergence sublayer maps them to the addresses specifically used by MAC. Two addresses are important in this respect: the connection identifier (CID) and service flow identifier (SFID). Although, IEEE 802.16 is a connection oriented wireless network and if the connection is from the BS to the MS it is called downlink connection otherwise it is called uplink connection. Each connection it has CID which is used to identify it and CID is 16 bits long. A service flow, on the other hand, is a MAC transport service that provides unidirectional transport of packets on the uplink or on the downlink. In fact, there is one connection for each service flow and to identify a single service flow the system uses the SFID which is 32 bits long.

The MAC layer of IEEE 802.16 is integrated with Quality of Service (QoS) which refers to the ability of network to provide better service to selected network traffic over rest traffic. Each service flow is classified by a set of QoS parameters that contains details on the way that MS send bandwidth request messages. The three main QoS parameters of IEEE 802.16e are:

- **Maximum Sustained traffic Rate (MSTR):** this parameter defines the peak information rate of the service flow. The rate is expressed in bits per second and pertains to the SDUs from higher layer.

- **Minimum Reserved Traffic Rate (MRTR):** this parameter specifies the minimum rate reserved for the service flow. The rate is expressed in bits per second and presents the minimum amount of date to be transmitted on behalf of the service flow when averaged overtime. The BS should allocate the MRTR for the MS but if the requested bandwidth is less than MRTR the exceeding bandwidth should reallocated for other purpose.

- **Maximum Latency (ML):** the value of this parameter specifies the maximum time between the ingress of the packet to CS and forwarding of SDU to The PHY layer. the value of this parameter is expressed in milliseconds

The IEEE 802.16 networks offer powerful techniques to achieve different levels of QoS requirement for different classes of service flow and the standard defines five classes of service:

- **Unsolicited Grant Service (UGS):** designed to support real-time applications that generate fixed-size data packets (constant bit rate) on a periodic basis, such as Voice over IP without silence suppression.

- **Extended Real Time Polling Service (ertPS):** designed to support real-time service flows that generate variable size data packets on a periodic basis, such as Voice over IP services with silence suppression.

- **Real Time Polling Service (rtPS):** designed to support real-time service flows that generate variable size data packets (variable bit rate) on a periodic basis, such as Moving Pictures Experts Group (MPEG) video.

- **Non Real Time Polling Service (nrtPS):** designed to support delay-tolerant data streams consisting of variable sized data packets for which a minimum data rate is required, such as File Transfer Protocol (FTP).

- **Best Effort (BE):** designed for applications that do not have any specific delay requirements such as The Hypertext Transfer Protocol (HTTP).

Class of service	Application	QoS Parameter
UGS	VoIP without silence suppression	MSTR ML
rtPS	Streaming audio or video	MRTR MSTR ML
ertPS	VoIP with silence suppression	MRTR MSTR ML
nrtPS	FTP	MRTR MSTR
BE	HTTP	MSTR

Table2.2: The QoS parameters for each class of service flows (adapted from WiMAX: Technology for Broadband Wireless Access [4]).

The CS is responsible for the classification of the traffic flows to these classes according to the QoS parameters and the BS manages and distributes bandwidth among these classes. Each class of service flow has a set of QoS parameters that associated with it. Table 2.2 shows the QoS parameters that are mandatory for each class of service.

2.4.2 Common Part Sublayer

Common part sublayer is the second sublayer of MAC and it receives PDUs from CS. This sublayer provides core MAC functionality including packing, fragmentation, error control, QoS, bandwidth allocation, connection establishment and the maintenance of connections between MSs and BS.

Fragmentation is the process where MAC SDU (MSDU) is divided into two or more MAC PDUs (MPDU) and Packing is the process where two or more MSDUs combined into a single MPDU. On the other hand, reliable transfer of information is critical for IEEE 802.16 so the standard defines automatic repeat request (ARQ) mechanism which is responsible for the handling of error at MPDU. Since the MAC in IEEE 802.16e is a connection oriented, QoS is support on per-connection basis. Both BS and MS provide QoS according to the QoS parameters that was discussed in the previous subsection and further information about IEEE 802.16 QoS architecture will be discussed in the next section. Also the IEEE 802.16 standard defines a set of control messages that are exchanged between both BS and MSs before data transmissions. However, these messages are follow the OFDMA frame structure so the understanding of this structure is important topic and must be explained. The mobile WiMAX use both TDD duplex with OFDMA access for that the OFDMA frame could be presented as bi-dimensional matrix where x-axis represent time (OFDMA symbols) and y-axis represent frequency (subchannels). However, different subchannelization methods could be used in IEEE 802.16 but partial usage subchannelization (PUSC) is mandatory for IEEE 802.16e. Figure 2.4 show the OFDMA frame structure with PUSC where the frame is divided into downlink (DL) and uplink (UL) subframe.

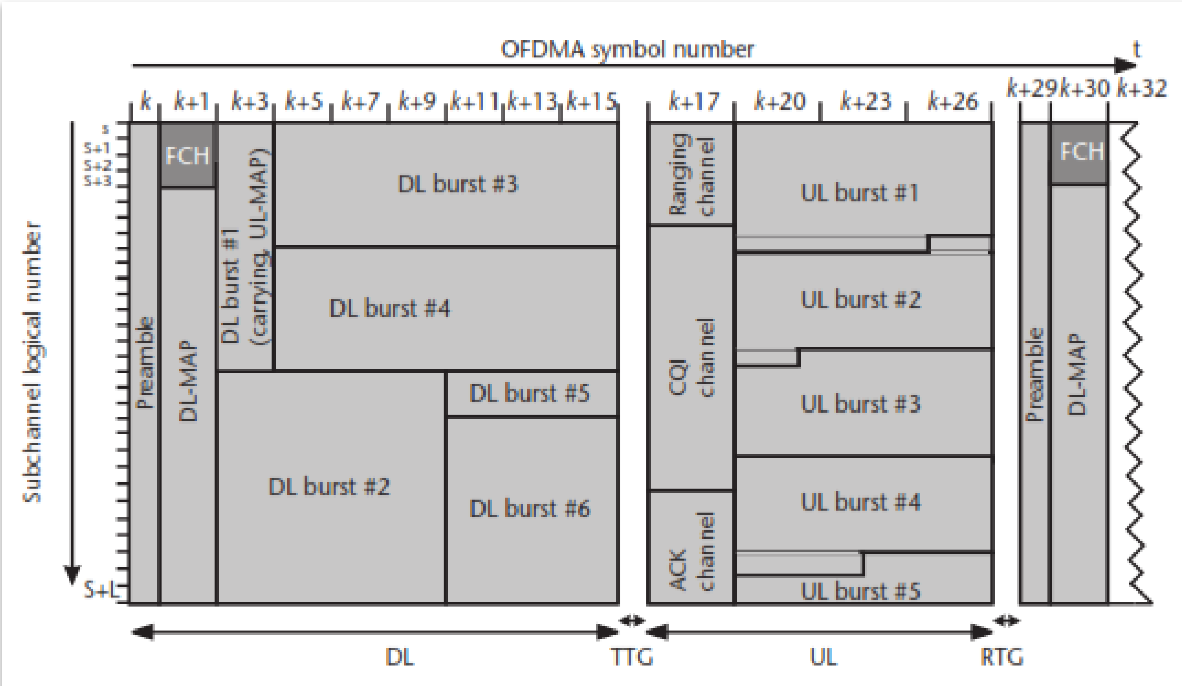

Figure 2.4: The OFDMA frame structure in TDD mode (adapted from WiMAX: Technology for Broadband Wireless Access [4]).

The DL subframe starts with preamble which used for synchronization and followed by frame control header (FCH) which contains burst profiles that define physical configurations for each active MSs. The next part is download map (DL-MAP) which defines start-time for bursts transmission. The rest of part of DL subframe contains the downlink bursts. The UL subframe contains ranging channel which is shared among all MSs and used for bandwidth requests. The channel quality indicator (CQI) is fast feedback channel used for measuring of the communication quality of wireless channels between MSs and BS. The acknowledgement (ACK) channel is allocated to provide feedback for fast retransmission in case the packet is in error.

2.4.3 Security Sublayer

The security sublayer is responsible for security functions such as authentication, encryption and key distributions. In WIMAX, connections between BS and MSs must be encrypted by applying the same protocol in both ways. This protocol must define a set of supported cryptography tools in both sides. The privacy and key management (PKM) protocol is used to provide authentication and key distributions between the BS and MSs. this protocol has many revision and it is out of the scope of this thesis.

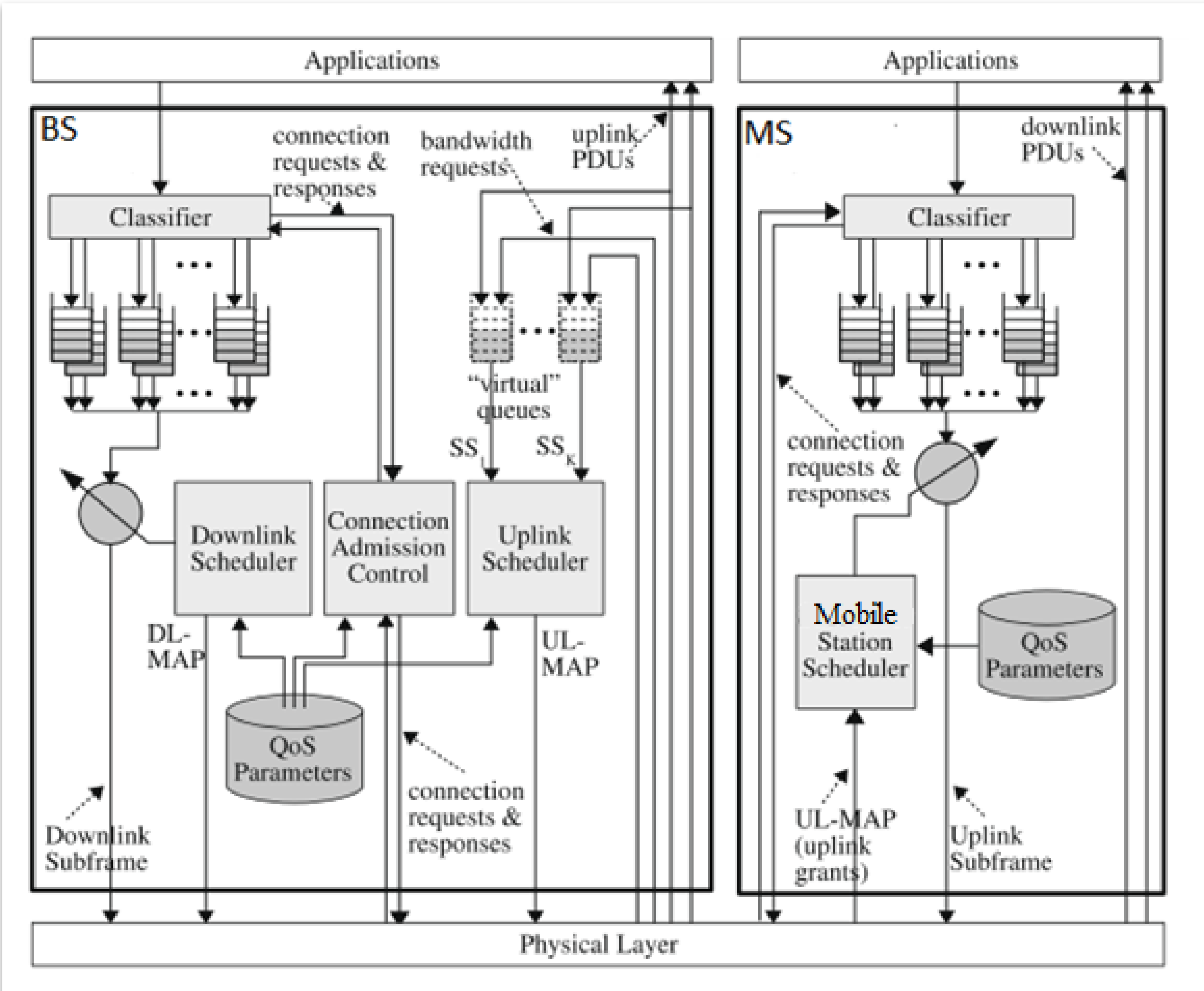

Figure 2.5: The Overall structure of 802.16 QoS architecture (adapted A Survey of MAC based QoS Implementations for WiMAX Networks [5]).

2.5 IEEE 802.16 QoS Architecture

The IEEE 802.16 standard defines a framework for the QoS management at MAC layer. It specifies a set of QoS components such as classifier, connection admission control (CAC) and scheduler. This components reside at both convergence sublayer and common part sublayer and integrated with PHY layer. However, the standard defines the function of each components and lefts the implementation details open for vendors and researchers to provide their solutions [5].

The IEEE 802.16e is centralized architecture where the BS has the responsibility of managing and maintaining the QoS for all packets. Figure 2.5 shows the IEEE 802.16 QoS architecture as defined by the standard.

Classifier

The classifier classifies PDUs form upper layer (applications) to the five classes of service flow and putting them in service flow queues. The classification process associates a MAC SDU with a connection, which also creates an association with the service flow characteristics of that connection. Classification mechanisms exist in the uplink and downlink. In the case of a downlink transmission, the classifier will be present in the BS and in the case of an uplink transmission it is present in the MS. A classifier is a set of matching criteria applied to each packet entering the MAC layer to classify packets to the five predefined classes of service flow.

Connection Admission Control

Connection Admission Control (CAC) is an important part of WIMAX QoS components which contributes to maintaining the QoS of new connections by preventing overload MSs Connections. Without an efficient CAC networks will not be able to maintain the QoS of time critical applications such as video and voice under increased load. The CAC resides in the BS and accepts or denies connection requests taking into the considerations network load. The classifier at MS sends connection request to BS and this request contains the QoS parameters for the service flows. However, the CAC components analyze the QoS parameter and network load then make decision to accept or deny this connection. Manay, CAC algorithms are proposed and the design of new CAC algorithms is outside the scope of this thesis. In this thesis we used the same CAC that proposed in [8].

Scheduler

Scheduler plays a vital role that helps the addressing of QoS guarantee to the variant types of service flow. The main function of scheduler is serving the packets queue after the classification process with the considering of priority, QoS parameters, service flow classes and channel state condition to increase the utilization of network resource under limited resource situation.

In the BS we need two types of scheduler an uplink and downlink scheduler. The downlink scheduler is responsible for the scheduling of packet queues in BS and the allocation of resources between them in the downlink subframe. Although, the downlink scheduler decides which queue to service and how many SDUs should be transmitted to each MS. On the other hand, the base station controls the access to the medium so the uplink scheduler makes the allocation decision based on the bandwidth requests from the mobile stations and the associated QoS parameters. Since the BS schedulers are responsible for the whole control access for the different MSs and when the uplink scheduler grants the bandwidth for each MS, the MS scheduler decides which queues should use that allocation. Recall that while the requests are per connection, the grants are per subscriber, and the subscriber is free to choose the appropriate queue to service. The MS scheduler needs a mechanism to allocate the bandwidth in an effcient way.

Generally, schedulers work as a distributor to allocate the resources among MSs or service flows. However, The IEEE 802.16 standard does not specify the scheduling algorithm to be used so vendors and operators have the choice among many existing scheduling techniques; they can also propose their own scheduling algorithms. In this thesis we focus on the design of new scheduling algorithms dedicated to WIMAX taking into account the QoS parameters and channel state condition. In the next chapter we will presents some related works and discuss the pros and cons for each one.

Chapter 3 Related Literature Reviews

3.1 Introduction

The IEEE 802.16 defines the MAC and PHY layers, the QoS classes and the QoS parameters requirement but the scheduling algorithm is left as an open issue to be implemented by vendors and operators. This thesis focuses on the development of new scheduling algorithms to enhance the overall performance by increasing throughput, decreasing delay and taking into account the QoS requirements. In chapter 2, we describe the function and types (uplink and downlink) of scheduler. In this chapter we will present and discuss a set of schedulers proposed for IEEE 802.16 networks.

Scheduler is the main component at the MAC layer that impacts significantly on the performance by increasing throughput, decreasing delay and enhancing QoS. Although, it helps to providing service guarantee to heterogeneous classes of traffic where there is variety in QoS requirements. In general, scheduler needs to be simple, efficient, fast, scalable and have low computational complexity. Actually, the scheduler works as radio resources allocator among the active connections. The allocated resources could be defined as the number of slots and these slots mapped into subchannels and symbols. The slot size depends on the subchannelization modes.

In IEEE 802.16, there are three distinct scheduling processes: two at the BS and one at MS. The scheduling process at the BS and MS are shown in figure 3.1. In the BS the classifier classifies packets from upper layer (Downlink Data) and put into different queues (Downlink Queues) based on service flow types. Then based on some criteria such as (QoS parameters, channel condition …) the Downlink scheduler (DL-BS) decides which queue to be served in the next DL-Subframe and the number of SDUs to be transmitted.

One of the main functions of BS is the control of access the medium where there exists many MSs so the BS needs new uplink scheduler (UL-BS) to makes allocation of radio resources between MSs in the UL-Subframe based on bandwidth requests from MSs.

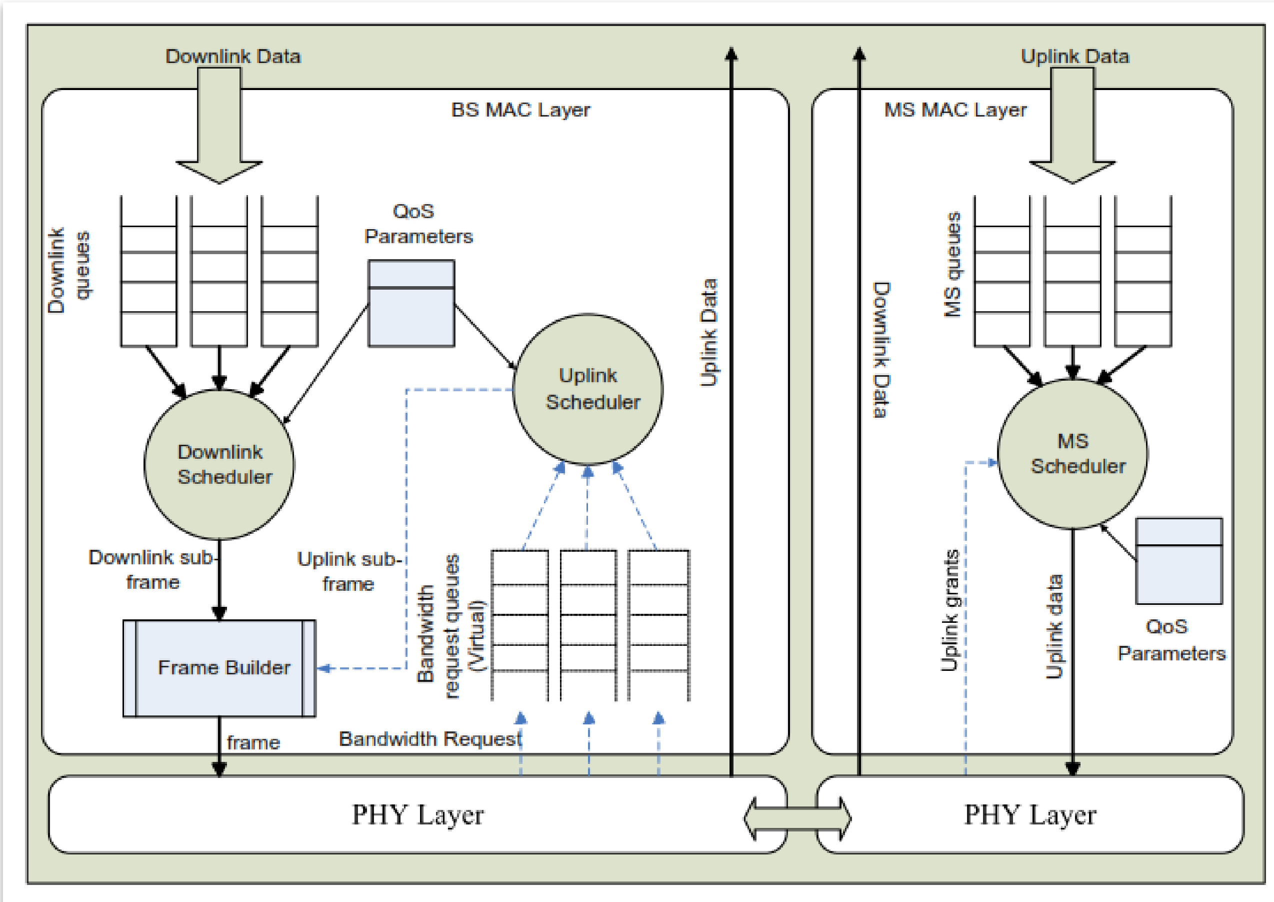

Figure 3.1: scheduling process at BS and MS (adapted from Highest Urgency First (HUF): A latency and modulation aware bandwidth allocation algorithm for WiMAX base stations [14]).

These bandwidth requests put on virtual queues (Bandwidth request queues) then based on some criteria such as (QoS parameters, channel condition …) the uplink scheduler decides which MSs to be served in the next UL-Subframe and the number of SDUs to be transmitted. The scheduling results from UL-BS and DL-BS are passed to the frame builder to generate the UL-MAP and DL-MAP and build the next frame then send it to the PHY layer to start the transmission and reception process. Finally, the third scheduler is at the MS and after the UL-BS grants the bandwidth for the MS, the MS scheduler decides which queues should use that allocation and therefore it needs a mechanism to allocate the bandwidth in an efficient way.

3.2 Scheduling algorithms classification

Many research proposals have been conducted for WiMAX scheduling and Most of these proposals give special attention for UL and DL schedulers at the BS. According to [15], the scheduling algorithms for WiMAX can be classified into two main categories: “channel-unaware schedulers” and “channel-aware schedulers”. Generally, channel-unaware scheduler doesn’t use information of channel state condition in making the scheduling decisions. On the other hand, the channel-aware scheduler uses the channel state condition in making the scheduling decision.

3.2.1 Channel-unaware scheduler

This type of scheduler doesn’t use any information about channel condition such as transmission power, signal to noise radio, error and loss rates. In this approach, it is assumed error-free channel condition and this scheduler could classify into: intra-class scheduler and inter-class scheduler

Intra-class scheduler: is used to allocate traffic within queues of the same class of service. In [15], three types of intra-class scheduler groups are proposed: (1) Round Robin (RR), (2) Weighted Fair Queue (WFQ) and (3) delay based. The first group is very simple to implement such as Deficit Round Robin (DRR) algorithm but this group cannot assure the QoS for different service classes. The second group is weighted based schedulers and the weight value could be used to adjust the throughput and delay requirement such as Deficit Weighted Round Robin (DWRR) algorithm. The last group is design for real-time application where delay bound is critical such as Earliest Deadline First (EDF) algorithm.

Inter-class scheduler: is used to define in which order queues of different service flows should be served. Although, to guarantee QoS for different classes of service a priority based algorithm should be used and the weight of radio resources to each class should be defined. The disadvantage of priority based algorithms is the occurrence of starvation for low priority connections and this drawback could reduce the overall throughput so innovative solutions must be introduced to solve this problem.

3.2.2 Channel-aware scheduler

In wireless networks, the characteristics of wireless link are variable and unpredictable due the nature of wireless medium and mobility of users. In wireless environment, there is high variability of radio link due to signal attenuation, fading, interference and noise. The channel awareness is very important and scheduler should take into account the channel state in order to makes optimal radio resources allocation.

Generally, the channel-aware scheduler allocates resources to MSs that have the best channel conditions for taking the advantages of multiuser diversity to increase the slot usage. When the scheduler uses the advantages of multiuser diversity the overall throughput and the number of supported users increase because it serves the MSs that have the best radio link which decrease the error rate and the number of dropped packets. According to [15], the channel-aware schedulers can be classified into four groups based on their objectives: (1) fairness, (2) QoS guarantee, (3) system throughput maximization and (4) power optimization. The first type guarantees the long term fairness but cannot guarantee delay, the second type aims to provide throughput and delay without fairness, the third type aims to maximize the overall throughput but cannot provide QoS requirements and the last type aims to minimize power consumption but cannot provide QoS requirements.

3.3 Scheduler Solutions

The choice of scheduling algorithm for WiMAX is an open issue for vendors and many scheduling algorithms are presented in literature. In the next subsections we will describe some selected algorithms related to our work and we will show pros and cons for each algorithm.

3.3.1 Related Channel-unaware scheduler

Many channel-unaware schedulers were proposed for WiMAX but one of the early algorithms is proposed in [16]. The proposed algorithm uses hybrid approach which means it uses a set of predefined algorithms work together. This algorithm focuses on uplink scheduler and forgets downlink scheduler and it works as follows: the UGS traffic is scheduled by First In First Out (FIFO) algorithm, the rtPS traffics are scheduled by Earliest Deadline First (EDF) algorithm, the nrtPS are scheduled by Weighted Fair Queue (WFQ), the BE traffics are scheduled by Round Robin (RR) algorithm and it is uses Strict Priority (SP) algorithm as inter-class scheduler.

However, the use of different scheduling algorithms increase the complexity of the system and using of strict priority algorithm cause starvation for low priority traffic classes. Although, this algorithm focuses only on uplink scheduler and forget both the ertPS traffic class and the QoS parameters.

A new Idea was proposed in [17, 18] the publisher selected DRR as the downlink scheduler and Weighted Round Robin (WRR) as the uplink scheduler. Both DRR and WRR are suitable for non real-time applications because they focus on throughput guarantee and ignore delay, priority and the QoS parameters. Also the proposed algorithm design for fixed WiMAX and forget ertPS traffic class.

In [19, 20], the authors introduce a new uplink scheduling algorithm for fixed WiMAX and they named it Customized Deficit Round Robin (CDRR) which is modified version of Modified Deficit Round Robin (MDRR) [21] with additional queue for real-time packets prior to deadline. Generally, the DRR is fast scheduling algorithm comparing to the other algorithms with O(1) complexity so it is favorable for computer networks but it is originally designed for wired networks. However, the CDRR algorithm show better results than MDRR in throughput, load, fairness index and latency but in wireless networks the channel state and link quality change rapidly so channel state must tacked into account to design robust scheduling algorithm.

Raj Jain et el [22], proposed a Deficit Round Robin with Fragmentation (DRRF) to solve a problem in DRR which is some space may be left unused in WiMAX frame since the next packet not fit in frame free space. The DRRF is similar to DRR but allow fragmentation for the purpose of achieving full frame utilization. However, the simulation results show increase in throughput and that due to the full frame utilization but the QoS parameters and link quality are ignored and that lead to bad performance in noisy channel or heavy load.

A new idea was proposed in [23], it is based on the using of three queues: low, intermediate and high priority queue and the scheduler serves these queues according to their level of priority. Service flows are distributed among these queues and could be migrated to high priority queue to guarantee their QoS requirements. The simulation results show that the proposed solution is able to provide QoS for different type of applications but this result could be changed in heavy load and noisy channel.

As we presented my research proposals for scheduling algorithm in WiMAX are based on the modification of DRR to be suitable for wireless networks. The authors in [24], proposed New MDRR scheduling algorithm for multimedia traffics in WiMAX and they defines the weight for the served queue as function based on MRTR and the slot size in the subframe. Although, this scheduler is designed for small packet size and delay sensitive applications but the channel variability is ignored and thus has negative aspects on the performance when channel is noisy.

The Radio Resource Management (RRM) for WiMAX is investigated by the authors in [25] and they proposed 2-Tires Ad-Hoc Scheduling Scheme (2-TAHSS) as scheduling algorithm. In the first tier of the algorithm the UGS traffics are scheduled by EDF algorithm , both rtPS and ertPS are scheduled by Weighted Fair Queue (WFQ) algorithm , the nrtPS traffics are scheduled Round Robin (RR) algorithm and the BE traffics are scheduled by FIFO algorithm. After finish the scheduling of traffics flows in the first tier the results will put in the second tier to schedule by Dynamically Allocating Priority Queue (DAPQ) algorithm and the DAPQ makes sure the allocated resource for real-time traffics are less than 40% and the UGS traffics are greater than 45% in each frame. However, using different scheduling algorithms may cause system inconsistency and ignoring the channel state between the BS and MSs decrease the overall throughput due the increasing of packet loss.

The same authors of [25], proposed a novel scheme for packet scheduling and bandwidth allocation for WiMAX [26, 27] and they used the same idea of two tier scheduler with changing in the percentage of allocation for traffic flows in the frame. The new algorithm dynamically changes the bandwidth allocation based on traffic characteristic but it suffers from the same problem of [25] which discussed above.

Kumar and V proposed Improvised Modified Deficit Round Robin (I-MDRR) [28] scheduling algorithm to enforce and guarantee the QoS requirements. The I-MDRR is based on combination of MDRR and EDF algorithm and the simulation results show higher throughput than DRR and EDF. Although, the authors write in the conclusion they will study the performance of I-MDRR by measuring the pack signal to noise ratio to increase the Quality of Service.

3.3.2 Related Channel-aware scheduler

In WiMAX networks radio links state between BS and MSs are changed rapidly and many researchers notice this issue and proposed scheduling algorithms that take the channel state as a factor for scheduling decisions [29]. In [30], the authors proposed Opportunistic Deficit Round Robin (O-DRR) as BS uplink scheduler and it works as follows: the BS use periodic polls to identify the SSs to be served and the decision for selected which

SSs for transmission is based on the channel state, link quality and Signal to Interference Ratio (SIR). However, this algorithm ignores the QoS requirements which lead to bad performance and increases drop rate for real-time application.

Lera et el [31] proposed a Channel-aware scheduler for QoS and fairness provisioning in the IEEE 802.16 networks. This scheduler is based on Worst-case Fair Weighted Fair Queuing (WF^2Q) and it supports the five types of service flows and the packet will be blocked from transmission when the Carrier to Interference-plus-Noise Ratio (CINR) not enough. The main disadvantages of this approach are the ignorance of QoS requirements and using virtual-time approach which is computationally complex.

In [32], the authors proposed a modified version from Wireless Deficit Round Robin (WDRR), called Uniformly-Fair Deficit Round Robin (UF-DRR). In WDRR, resources are allocated to MSs that have good channel state and the MSs with bad channel state are ignored and that cause unfairness. In UF-DRR, the surplus resources are distributed among all connections and it result fairness but this approach cannot prevent greedy connection from occupying the entire bandwidth and real-time applications will be suffered from the skipping of QoS requirements.

Belgith and Nyaymi [33] proposed maximum Signal to Interference Radio (mSIR) as scheduling algorithm and it works as follows: firstly, the BS sorts the SSs bandwidth requests in descending order according to the received SNR. Therefore, mSIR has the high throughput due the best usage of slots but it does not guarantee fairness for SSs that have small SNR. In addition, they proposed modified maximum Signal to Interference Radio (mmSIR) [34,35] as shown in the figure 3.2 the mmSIR sorts SSs in descending order according to the received SNR values and if the next SS to be served has unicast opportunity in the next frame the BS does not serve this SS and serves the next SS. The main drawback of mmSIR is the ignorance of QoS requirements like maximum latency so real-time and delay insensitive applications have the same priority which leads to bad performance and increase the drop rate for real-time application. Although, the same authors make review about scheduling algorithms that proposed for WiMAX [36] and they highlight on spectrum efficiency. The simulation results show that the channel-aware based schedulers have the highest spectrum efficiency.

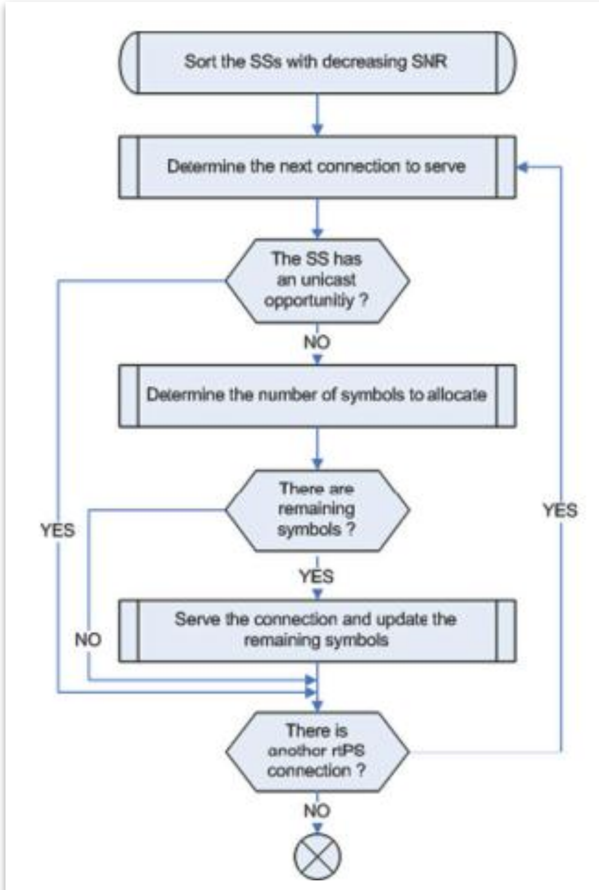

Figure 3.2: Main steps of the proposed mmSIR scheduler (adapted from Scheduling Techniques for WiMAX [35]).

Scheduling algorithms for wired networks are not suitable for IEEE 802.16 networks due the channel variability. The authors of [37,38] proposed an uplink cross layer scheduler which makes bandwidth allocation based on information about channel quality and QoS requirements for each connection. This algorithm is extended version from [23] by adding the SNR as decision factor which means any MS that has SNR less than the threshold value is prevented from transmission but one of the disadvantages of this algorithm is the computational complexity which increase the overall delay and effects on system performance.

Chapter 4 Proposed Algorithms

In this chapter, we present our proposed solutions for scheduling in IEEE 802.16 networks. We design two scheduling algorithms compliant with the IEEE 802.16 standard. The first algorithm aims to increase channel utilization and the second algorithm aims to increase both channel utilization along with fairness between different traffic classes. We test both algorithms under NS2 networks simulations and the results were phenomenal.

4.1 Overview

In wireless environment, when many users move independently, there is at any time probability that one of the users will have strong channel. Therefore, this user should be allowed to transmit and as a result for that the spectrum efficiency will be increased. This phenomenon called multiuser diversity. Figure 4.1 illustrates an example of multiuser diversity where the user with strong channel should schedule to transmit signals [41]. Mobile WiMAX networks use adaptive modulation and coding scheme (AMC) in order to take the advantages of fluctuation in channel. The idea of AMC is simple: which is transmitting at high datarate when channel is good and in low datarate when channel is poor. In WiMAX networks, the modulation and coding scheme changes based on channel quality (received signal to noise ratio) and that impacts on slot utilization and spectrum efficiency. In good channel condition the slot utilization increase and vice versa.

As a result, the scheduling algorithms for IEEE 802.16 networks must take into the account the channel state for making scheduling decision to increase spectrum efficiency. In real world, the BS uses the channel quality indicator (CQI) to provide channel state information from subscriber stations.

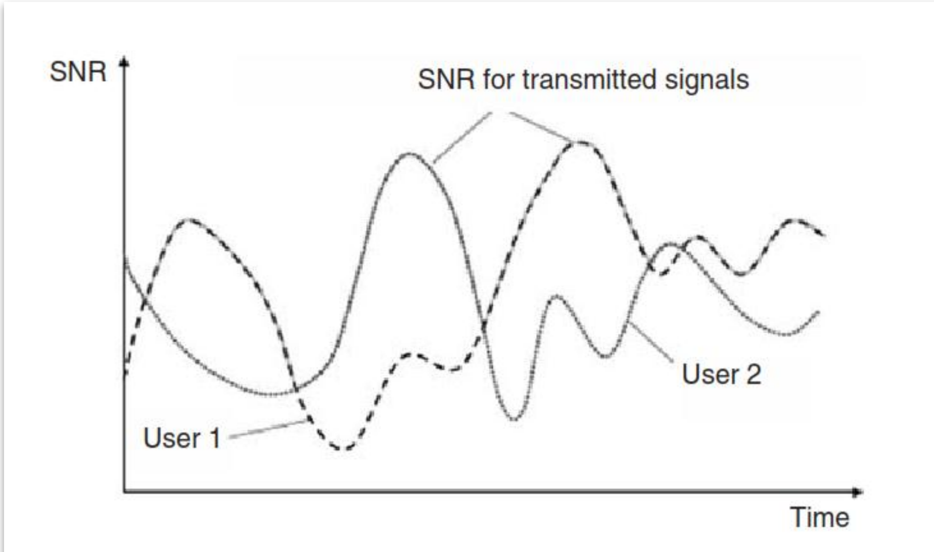

Figure 4.1: The multiuser diversity – for two user cases. (Adapted from WiMAX Security and Quality of Service: An End-To-End Perspective , page 249 [41]).

4.2 Deadline maximum Signal to Interference Ratio (DmSIR) scheduling algorithm

In this thesis, we aim to design new scheduling algorithms for WiMAX networks that provide both uplink and downlink resource allocation at the BS. These algorithms are aware with the changes of channel conditions, service flow requirements and compliant with the IEEE 802.16 standard. The first algorithm that we proposed is Deadline maximum Signal to Interference Ratio (DmSIR) which is derived from maximum Signal to Interference Ratio (mSIR) [33]. The main objectives of the DmSIR scheduling algorithm are increasing the spectrum efficiency, decreasing drop rate in packets that miss deadline next frame. The mSIR algorithm sorts MSs based on the received signal to noise ratio values and through this process the mSIR takes the benefits of multiuser diversity by serving MSs that have good channel conditions and that leads to increase the spectrum efficiency and bandwidth utilization. Thus occurs by using high modulation and coding scheme to increase slots utilization.

The mSIR algorithm excludes the QoS parameters for the service flows and treats all service flows in the same way. Notice that, the real-time service flows (UGS, ertPS and rtPS) have the maximum latency parameter and when real-time packets reach this value it must be dropped. Therefore, the mSIR algorithm has high drop rate in real-time packets and the next example will illustrates this problem in details:

Example 4.1:

Suppose that we have five MSs as shown in the figure 4.2:

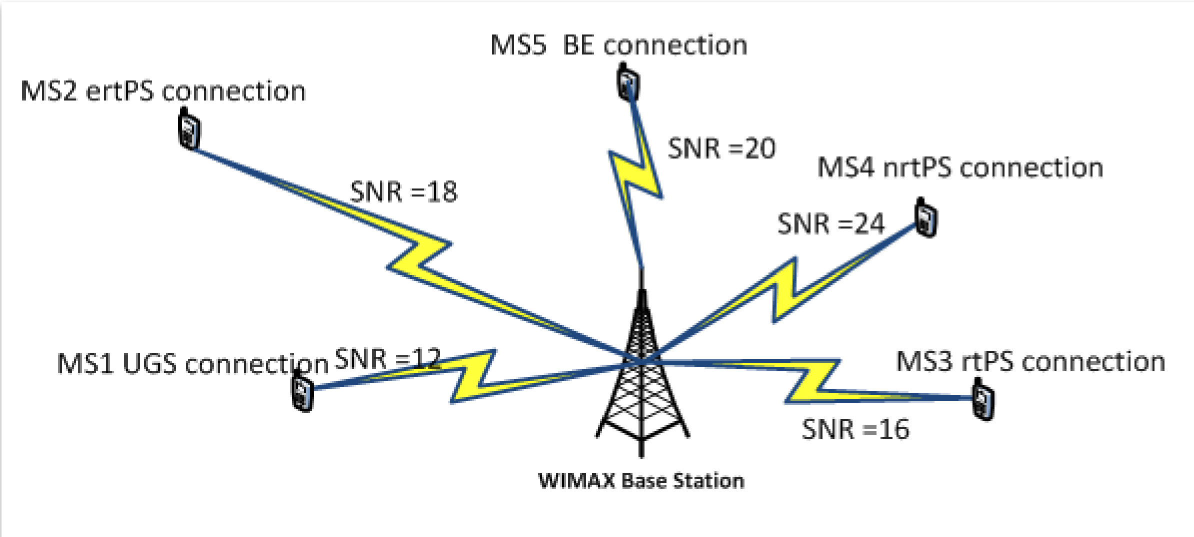

Figure 4.2: Example 4.1 network topology.

Each one of these MSs has one connection and the link between the MS and BS contains the signal to noise ratio value. Assume the frame duration is 20 ms and its capacity is 200 Kbpf. The maximum latency (ML) for UGS packets are 20 ms, for ertPS packets are 40 ms and for rtPS packets are 60 ms. the bandwidth requests from MS1 = 0.1Mb, MS2 = 0.2 Mb, MS3= 0.2 Mb, MS4 = 0.6 Mb and MS5 = 0.8Mb.

By using mSIR scheduling algorithm the MSs are ordered as follows:

- MS4 for 3 frames (3 x 20 ms = 60 ms).
- MS5 for 4 frames (4 x 20 ms = 80 ms).
- The real-time connections will be served in frame 8 but all real-time packets will be dropped due the miss of deadline.
- The packets drop rate in this example is equal to (0.5/1.8) =27 % and this value is large and unacceptable in wireless networks.

The DmSIR solves the previous problem by scheduling packets according based on two criteria: the link quality and packets deadline. The DmSIR algorithm uses two queues, the first queue is Idle Queue (IQ) and the second queue is Deadline Queue (DQ). Figure 4.3 shows the DmSIR scheduling algorithm components. After the classification of packets or bandwidth requests by the classifier the DmSIR algorithm starts bandwidth allocation procedure as follows:

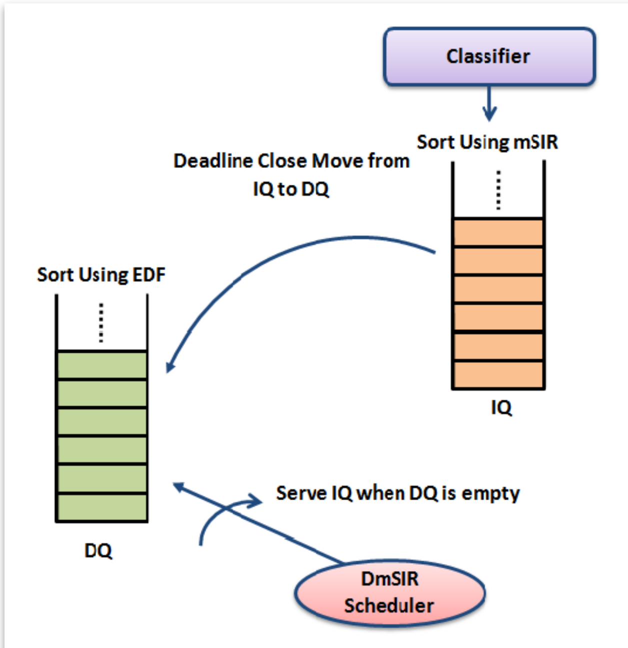

Figure 4.3: The DmSIR scheduling algorithm components.

Firstly, in downlink bandwidth allocation phase, the DmSIR algorithm sorts packets according to the last updated signal to noise ratio that captured by channel quality indicator and after that the DmSIR cheeks the packets deadline using this equation :

$$\text{deadline} = \left\lfloor \frac{\mathrm{L}}{\mathrm{F}} \right\rfloor \begin{cases} < 1 \; \textit{deadline expire must be dropped} \\ 1 \text{ meet deadline next frame} \\ > 1 \; \textit{still time to meet deadline} \end{cases} \qquad \dots\dots\dots (4.1)$$

Where L is means the maximum latency for the service flow and F represents the frame duration. After calculating the deadline of packets the procedure of bandwidth allocation starts as follows:

- Any packets has deadline less than 1 it will be dropped.
- Any packet have deadline equal to 1 must be moved from IQ to DQ to be served in the next frame.

- If DQ is not empty, then the packets in this queue must be served using EDF algorithm and if there a remaining slots then the IQ will be served until all slots are fill up.
- Otherwise, if DQ is empty the packets in IQ will be served.

Secondly, in uplink bandwidth allocation phase the DmSIR algorithm works in the same way of downlink bandwidth allocation phase. Notice that, the DmSIR algorithm uses the last updated value of SNR from CQI and after the bandwidth allocation phase the DL and UL MAP will be generated and sent to notify the MSs about the transmission and receiving opportunities which describe in section 2.4. The next example will illustrate the solutions of example 4.1 using DmSIR algorithm:

Example 4.2:

By using the same parameters of example 4.1 the DmSIR algorithm works as follows:

- Calculate deadline for each packet by equation 4.1.
- Deadline for UGS = 1, Deadline for ertPS = 2 , Deadline for rtPS = 3;
- In the first frame, UGS traffics should be moved to DQ and saved and the remaining slots for the rest traffic in IQ.
- In the second frame, ertPS traffic should be moved to DQ and saved and there are no remaining slots.
- In the third frame, rtPS traffic moved to DQ and saved and there are no remaining slots.
- In the rest frames, there is no real-time traffic so DQ is empty and the packets in IQ will be served.
- In this example there is no drop in packets.

Figure 4.4 shows the pseudo code of the DmSIR scheduling algorithm and as it clear the time complexity of it is O(n). Although, the simulation results of DmSIR scheduling algorithm will be discussed in the next chapter.

The DmSIR scheduling algorithm pseudo code

```
Begin initialize
While (queues are not empty)
    For i = 1 to n  // where n is the number of packets
        Sorts packets based on last update SNR in the IQ
        deadline_i = ⌊L/F⌋// calculated deadline using this
        equation
            If( deadline_i = 1)
                move Packet to Deadline Queue (DQ)
            Else If( deadline_i < 1)
                drop  Packet_i
            End_If
    End_For
    If (DQ is empty)
        Serve Packets on the ID
    Else
        Serve  Packets in the DQ using EDF algorithm
    End_If
End_While
End
```

Figure 4.4: The DmSIR scheduling algorithm pseudo code.

4.3 Priority based Deficit Round Robin (PbDRR) scheduling algorithm

In this section, we will present the second algorithm that we proposed for scheduling in WiMAX networks. We named the new algorithm Priority based Deficit Round Robin (PbDRR) which is based on Deficit Round Robin (DRR) and Earliest Deadline first (EDF) scheduling algorithms. The DmSIR algorithm works to increase the spectrum efficiency but non real-time traffics with low signal to noise ratio will suffer from starvation because the DmSIR algorithm makes scheduling decisions only based on signal to noise ratio and packets deadline but it ignores the backlog traffics for non real-real-time traffic.

The PbDRR algorithm solves this problem by making the scheduling decision based on the QoS parameters, backlog traffics and signal to noise ratio. In the next sub-section, we will describe the Deficit Round Robin and Earliest Deadline first algorithms then we will present the PbDRR scheduling algorithm for WiMAX networks.

4.3.1 Deficit Round Robin algorithm

The Deficit Round Robin algorithm [44] is a well-known algorithm designed for wired IP networks. It was a modified version from Weighted Round Robin (WRR) that handles variable packet sizes in fair manner. In DRR algorithm, a Deficit Counter (DC) is associated with each queue. This counter tracks the credits for each queue has the link scheduler. If the size of the Head-Of-Line (HOL) packet is smaller or equal to the DC, then the packet is served and the DC is decremented by the size of HOL packet.

The DRR serves packets in the queue as allowed by the DC. When the DC is too small for the HOL packet then the DRR moves to next queue…etc. After round finish, the DC for all queues add by fixed amount named quantum (Q) then the DRR starts scheduling again. Although, the DRR is very fast algorithm and it is computational complicity O (1). Therefore, is widely used in commercial solutions such as core internet router [21]. The next example will illustrate how the DRR algorithm works.

Example 4.3:

Suppose that we have 3 queues as shown in the next figure and each queue has a set of packets. The size of packet is shown inside the rectangle and the initial value of DC is 0 and the quantum is 100. The DRR algorithm will schedule the packets as follows:

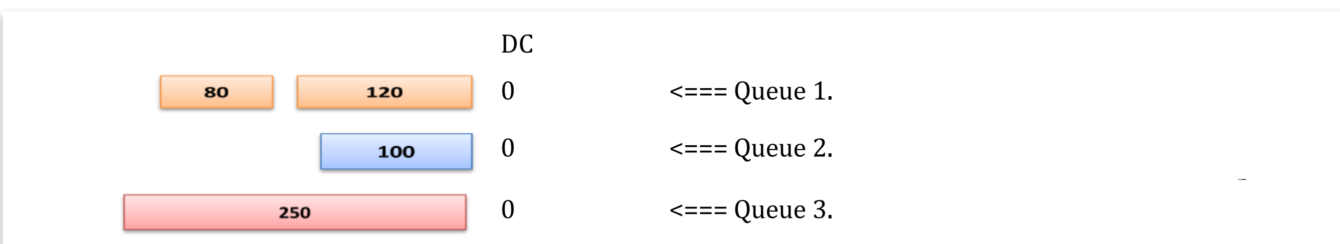

Figure 4.5: Example 4.3 diagram.

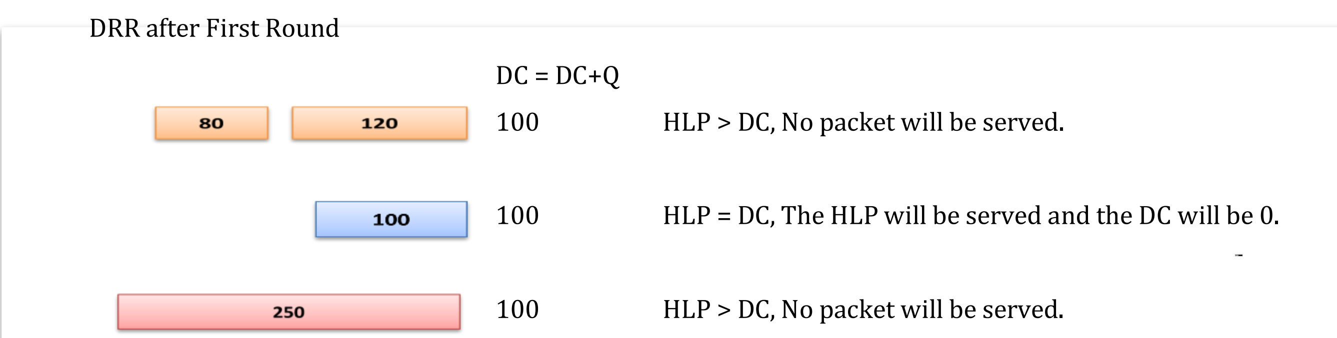

Figure 4.6: Example 4.3 diagram after First Round.

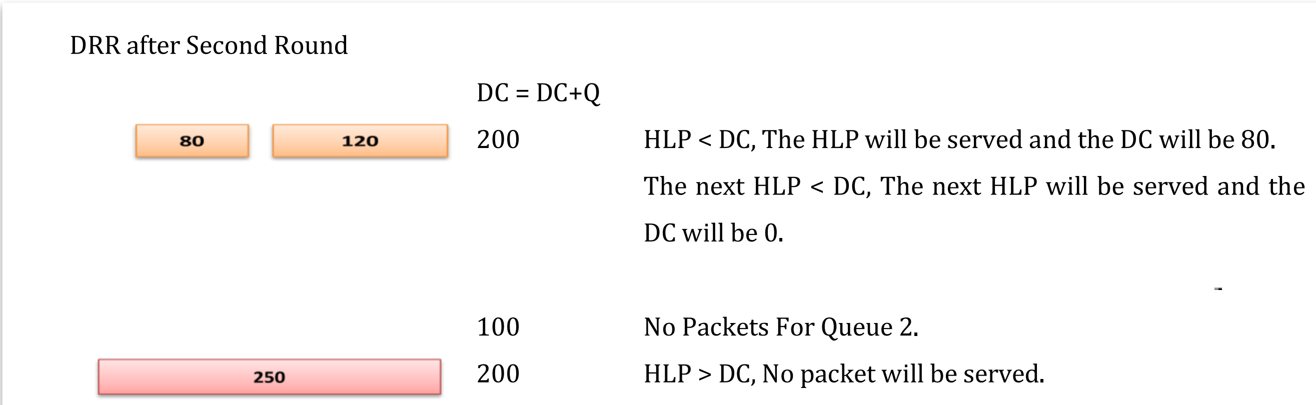

Figure 4.7: Example 4.3 diagram after Second Round.

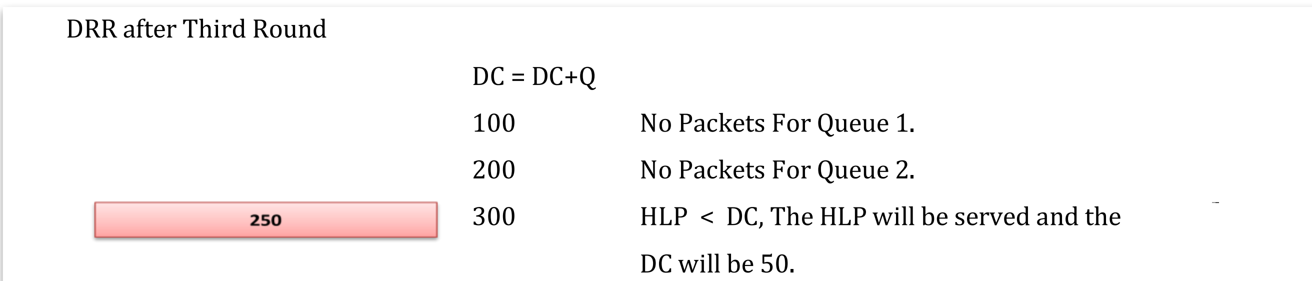

Figure 4.8: Example 4.3 diagram after Third Round.

From this example, it is clear that the DRR algorithm treats all packets in the same manner and doesn't give any priority to the traffic type. The DRR algorithm originally designed for wired networks so is incompatible with wireless networks. Therefore, many researchers have modified the DRR algorithm to be suitable for the instability state of wireless networks. Some modified versions from DRR were discussed in chapter 3 but these algorithms either ignore channel quality or QoS parameters so it is unsuitable for WiMAX networks.

4.3.2 Earliest Deadline First Algorithm

The Earliest Deadline First (EDF) is a simple algorithm that designed for real-time applications. Given a set of packets, the EDF algorithm sorts these packets based on earliest deadline constraint and served it in this manner. Although, the EDF algorithm is unsuitable for WiMAX networks because it ignores the channel quality and QoS parameters for service flow.

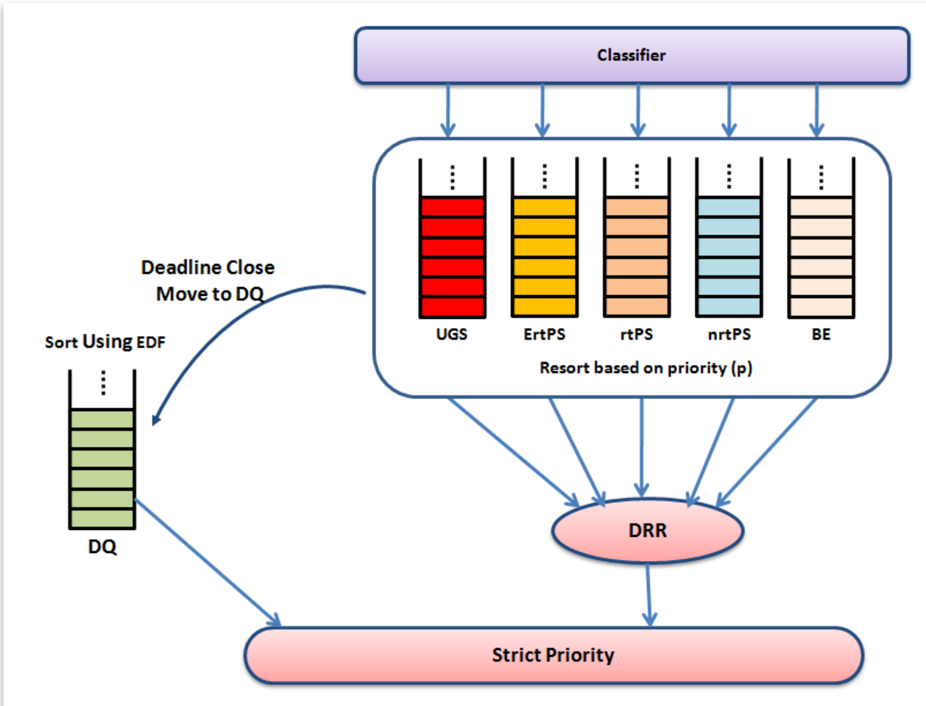

Figure 4.9: The PbDRR scheduling algorithm architecture.

4.3.3 The PbDRR scheduling algorithm for WiMAX networks

As we mention, the PbDRR algorithm is modified version from the DRR algorithm and it is compliant with the IEEE 802.16 standard. Although, the PbDRR algorithm treats the non real-time traffic in fair way so it doesn't suffer from starvation. After the classification of packets (or bandwidth requests in uplink phase) at the BS by the classifier the packets put in queues and the packets from the same type of service flow are putted in the same queue. After that, the bandwidth allocation procedure starts. Generally, the PbDRR algorithm has four main steps either in uplink or downlink bandwidth allocation and we will describe these steps in the next paragraphs. The PbDRR algorithm architecture is shown in the figure 4.9 and as it is clear from the figure the PbDRR has six queues, one for packets meat deadline next frame and we named it the Deadline Queue (DQ), five traffic queues each one for specific service flow.

Firstly, in downlink bandwidth allocation phase the PbDRR algorithm sorts packets in the queues based on the priority value (p) which is calculated based on the normalized value of the last updated signal to noise ratio of MS and the normalized backlog traffic form the MS in the same queue. The backlog traffic could be calculated by the summation of all packets size that has the same basic connection identifier (CID) in the same queue. The four steps of PbDRR for bandwidth allocations are:

Step1:

The PbDRR algorithm uses the equation (4.1) to calculate the deadline for all packets in all queues and any packet that meats deadline next frame will be moved from traffic queue to deadline queue.

Step2:

Next, The PbDRR algorithm calculates the priorities for all packets in the traffic queues and then sorts the packets in traffic queues according to the calculated priorities as follows:

1. The PbDRR algorithm calculated the backlog traffic for all MSs in all queues.
2. For each MS the backlog traffic is normalized to adjusting the value in common scale using the maximum standardization method as follows:
   a. Assume the maximum backlog traffic in the queue is bt^{max}.
   b. Then the normalized values of backlog traffic for each MS in the queue is ${bt_i}^*$ and calculated using this equation:

$$ {bt_i}^* = \frac{bt_i}{bt^{max}} \dots \dots \dots (4.2) $$

   Where 1≤ i ≤n and n is the number of MSs that have packets in the queue, bt_i is the backlog traffic for MS i.

3. For each MS the SNR is normalized to adjusting the values in common scale using the maximum standardization method as follows:
   a. Assume the maximum SNR in the queue is SNR^{max}.
   b. Then the normalized values of SNR for each MS in the queue is ${SNR_i}^*$ and calculated using this equation:

$$ {SNR_i}^* = \frac{SNR_i}{SNR^{max}} \dots \dots \dots (4.3) $$

   Where 1≤ i ≤n and n is the number of MSs that have packets in the queue, SNR_i is the SNR for MS i.

4. After applying equations 4.2 and 4.3 for all MSs then the priority (p) for the MS_i packets could be calculated by:

$$p_i = \alpha \times bt_i^{*} + (1-\alpha) \times SNR_i^{*} \quad \ldots\ldots\ldots (4.4)$$

α is penalty factor, when $\alpha > 0.5$ then the backlog traffic is control the priority of packet, when $\alpha < 0.5$ then SNR is control the priority of packet.

5. After applying equation 4.4 for all packets in all traffic queues, then all packets in the traffic queues are sorted based on packets priorities where the high values has the high priority and vice versa.

Step3:

For inter-class scheduling between the traffic queues, we use the DRR algorithm because is a fast algorithm and achieves fairness between different traffics classes. As we mention, the DRR use the quantum (Q) value to increase the deficit counter each round. We proposed a dynamic value for the quantum that changed based on the QoS parameters. The quantum for each traffics queue could be calculated as follow:

- Suppose that MRTR is the minimum reserved traffic rate. The packets in any traffic queue have the same QoS parameters because they belong to the same service flow class.
- Let $R_j = MRTR_j \times FD \quad \ldots\ldots\ldots (4.5)$

  Where R_j is the minimum required bandwidth for any MS in queue, $MRTR_j$ is the MRTR for queue j, FD is the frame duration (in the simulation FD = 5ms) and when $MRTR$ not available for service flow we use $MSTR$.
- In WiMAX networks, packets requests or traffic are converted to slots in the physical layer and as we described in chapter 2 there are a fixed amount of slots either for uplink or downlink subframe. The slots size is depends on the MCS that used by the MS and could be calculated by this equation which is adapted from [14]:

$$Slot\ Size = 48 \times MB \times CR \ \ldots\ldots\ldots (4.6)$$

  Where MB is the modulation bit, CR is the coding rate and both depend on the modulation and coding scheme.

- we proposed dynamic value for the quantum and it is the number of slots that required for guarantee the minimum required bandwidth for all MS that belong to the traffic queue j, the quantum value could be calculated by this equation :

$$Q_j = \sum_{i=1}^{m} \frac{R_j}{Slot\ Size_i} \quad \dots \dots \dots (4.7)$$

  Q_j is the number of slots that assigned as quantum for the traffic queue j , R_j the minimum required bandwidth for queue j and could be calculated by equation 4.5, $Slot\ Size_i$ is the slots size for MS i in the traffic queue j and m is the number of MSs either that have bandwidth requests in uplink or packets in downlink and could be calculated by equation 4.6.

- The PbDRR algorithm assigns slots as quantum value but there is chance that there is one of the packets cannot fits in the remaining sub-frame slots that assigned by the PbDRR so the fragmentation must be enabled. However, Fragmentation is the process by which a MAC SDU is divided in two or more MAC PDUs and this process allows efficient use of available slots. In the destination, the fragmented packets could be reconstructed easily as we describe in chapter 2.

Step4:

This is the last step of PbDRR algorithm in the downlink bandwidth allocation. If there is packets in the DQ the PbDRR algorithm served the packets in the DQ. Otherwise, the PbDRR served the packets in the traffic Queue using the DRR algorithm with the dynamic quantum value that calculated by equation 4.7 and if there is remaining in the downlink subframe after the first round then the PbDRR restarts again from step2 until all slots of the downlink subframe is fallen by data.

Secondly, in uplink bandwidth allocation phase the PbDRR algorithm works in the same way of downlink bandwidth allocation phase. Notice that, the PbDRR uses the last updated value of SNR from CQI and the backlog traffic is calculated every round. After the bandwidth allocation phase the DL and UL MAP will be generated and sent to notify the MSs about the transmission and receiving opportunity which describe in section 2.4. Figure 4.10 shows the pseudo code of the PbDRR scheduling algorithm and as it clear the time complexity of it is O(n). Although, the simulation results of PbDRR scheduling algorithm will be discussed in the next chapter.

The PbDRR scheduling algorithm pseudo code

```
Begin initialize
While (queues are not empty)
    #step 1:
    For all packets
        deadline_i = ⌊L/F⌋// calculated deadline using this equation
        If( deadline_i = 1)
            move Packet to Deadline Queue (DQ)
        Else If( deadline_i < 1)
            drop Packet_i
        End_If
    End_For
    #step2:
    For all packets
        Normalize the SNR
        Normalize the backlog traffic for the MS
        Calculate the packets priority (p)
    End_For
    Sorts all packets in traffic queues based on their priorities.
    #step3:
    For all traffic queues
        Calculate the quantum Q_i
    End_For
    #step 4:
    If (DQ is empty)
        Serve Packets in Traffic Queue using the DRR algorithm
    Else
        Serve Packets in DQ using EDF algorithm
    End_If

End_While
End
```

Figure 4.10: The PbDRR scheduling algorithm pseudo code.

Chapter 5 Simulation and Results

In this chapter, we present the evaluation of the new proposed algorithms for WiMAX networks under different type of traffic load. Although, we discuss the performance metrics that used for evaluation. We used the NS2 network simulator [45] and QoS-included WiMAX module [46] for this purpose.

5.1 NS2 Network Simulator

Network simulator (version 2), widely known as NS2 is a discrete event-driven simulation tool that has proofed in studying the nature of dynamic networks and could be used for studying wired and wireless networks. Therefore, it has gained constant popularity in network research community since it birth in 1989. Figure 5.1 shows the basic architecture of NS2 network simulator, the input script file and the output trace file. In NS2 simulator there exist executable command "ns" which takes and input argument the name of Tool command Language (TcL) script file which contains the network parameters, nodes specifications, networks scenario and simulation output format.

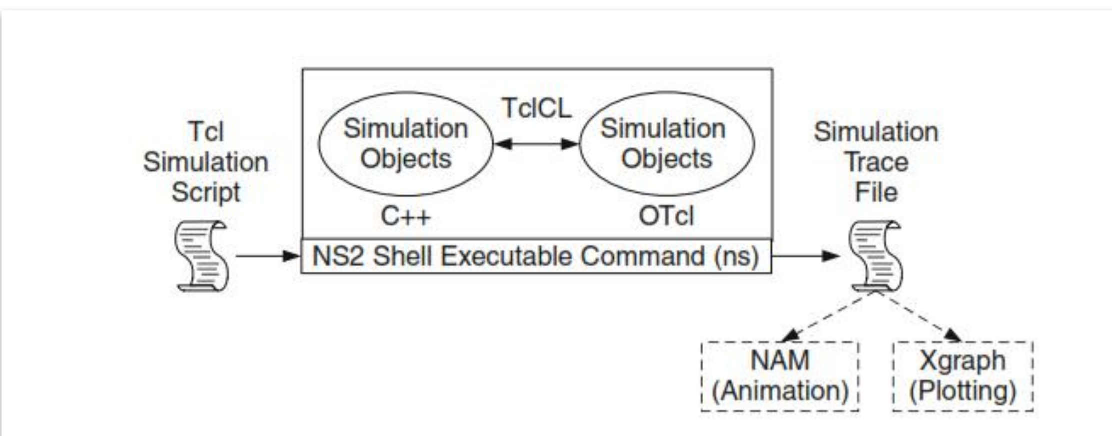

Figure 5.1: The basic architecture of NS2 network simulator (Adapted from Introduction to Network Simulator NS2, page 22 [47]).

After execute the TcL script file, the simulation trace file is created and is used to analysis the network performance, plot graphs and create animation for the scenario. Although, the NS2 simulation consists from two key languages files: C++ and Object oriented Tool command Language (OTcL). The C++ files define the internal mechanism of the simulation and the OTcL files schedule the discrete events and both files are linked together by TcL Class Libraries (TcLCL). The NS2 simulation provides a large number of built in C++ classes which is used to setup simulation via the TcL simulation script.

The NS2 simulator doesn't contain module for WiMAX networks so we used external module developed by aymen and lautfi [46]. The module name is QoS-included WiMAX and was developed from NIST implementation of WiMAX [48]. The QoS-included WiMAX module implements the OFDM PHY and TDD MAC layers but we extend the PHY layer to supports OFDMA which described in chapter 2.

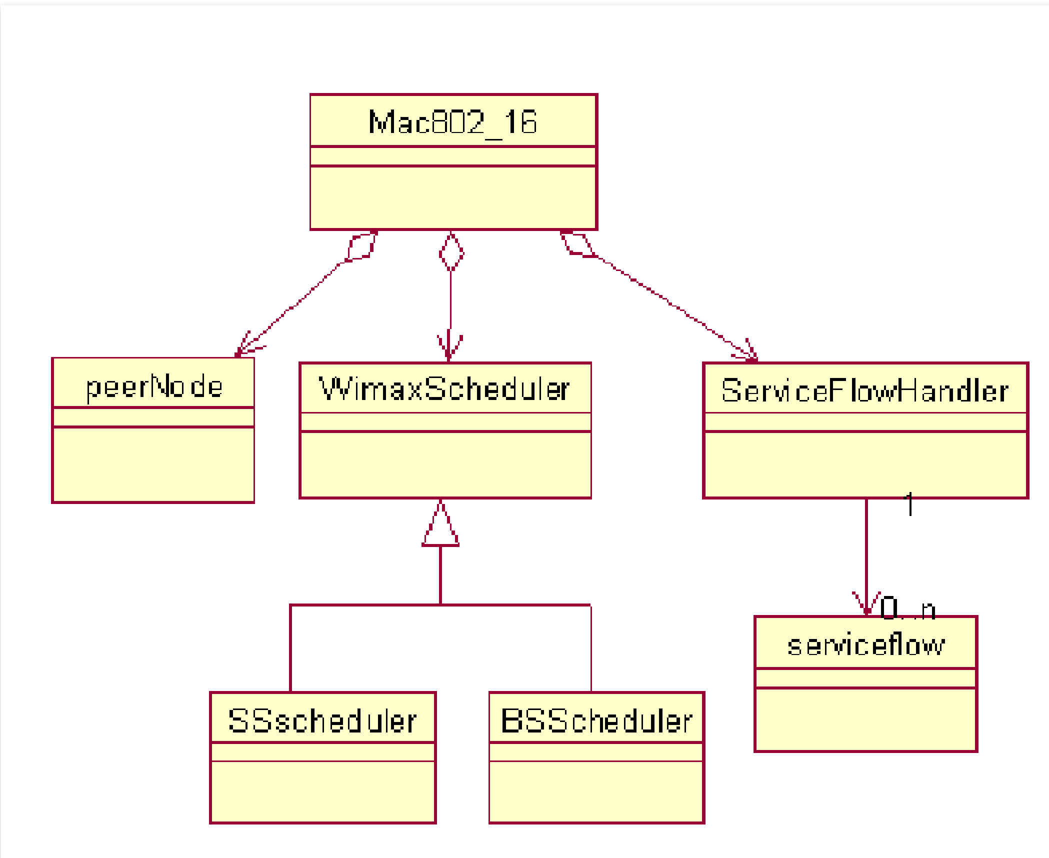

Figure 5.2: The MAC 802.16 class diagram (Adapted from Design and Implementation of a QoS-included WiMAX Module for NS-2 Simulator [46]).

The MAC class diagram is shown in the figure 5.2 and the MAC_802.16 class represents the MAC layer and it has relations with other classes: ServiceFlowHandler, peerNode, and WimaxScheduler. ServiceFlowHandler is responsible for the management of the downlink and uplink connections. Each connection has an association with a service flow that contains the QoS parameters. The QoS parameters of a service flow are set based on the connection requirements. The peerNode class contains information about the MSs or the BS. The WimaxScheduler class is responsible for the ranging and registration and performs scheduling algorithms. It includes two schedulers: one for the BS (BSScheduler) and one for the MSs (SSscheduler). However, we used Cost 231 – Hata channel model to evaluate the link adaptation between the MSs and the BS and calculate the SNR values which is used to detect the MCS for the MSs and it will be model is presented in the next section.

5.2 Channel Model and Link Adaptation

Channel model is used to represent channel quality between base station and mobile station in WiMAX networks. Therefore, the appropriate channel model has significance impacts on the simulation results. In WiMAX Literature, researcher introduce many channel models but we choose the same model from [34] where the authors introduce the signal to noise ratio as factor that represents the channel. When the signal to noise ratio (SNR) is high then the channel is good and vice versa.

In [42, 43], the authors used Cost 231 - Hata path loss model to evaluate the SNR as follows:

$$\mathrm{P_L} = 46.3 + 33.9\log_{10}(\mathrm{f}) - 13.82\log_{10}(\mathrm{h_B}) - \mathrm{A}(\mathrm{h_R})$$
$$+[44.9 - 6.55\log_{10}(\mathrm{h_B})]\log_{10}\mathrm{d} + \mathrm{C} \ldots\ldots\ldots (5.1)$$

Where P_L is the total path loss, C is a correction factor and equal to 3 for WiMAX networks, f is the frequency of transmission, $\mathrm{h_B}$ is the base station antenna effective height, d is the link distance, $\mathrm{h_R}$ is the subscriber station antenna effective height, $\mathrm{A}(\mathrm{h_R})$ is the mobile station Antenna height correction factor and is computed by this equation :

$$A(h_R) = (11\log_{10}\mathrm{f} - 0.7)h_R - 1.56\log_{10}\mathrm{f} - 0.8 \ldots\ldots\ldots (5.2)$$

After that the signal to noise ratio is computed by this equations:

$$\mathrm{SNR} = \mathrm{P_t} - \mathrm{P_L} - \mathrm{N_{noise}} \quad \ldots\ldots\ldots (5.3)$$

$$\mathrm{P_t} = 43 + \mathrm{G_t} + \mathrm{G_r} \ \ldots\ldots\ldots (5.4)$$

$$\mathrm{N_{noise}} = -174 + 10\log_{10}(\mathrm{BW}) + \mathrm{NF} \ \ldots\ldots\ldots (5.5)$$

Where P_t is transmitted power, P_L is the COST-231 Hata path loss, G_t is transmitter antenna gain, G_r is receiver antenna gain, BW is the system bandwidth and NF is the noise figure. After calculating the SNR values for the MSs, the simulation uses the table 2.1 to evaluate the MCS between the BS and MSs.

5.3 Call Admission Control

Call Admission Control (CAC) is a part from the QoS architecture for WiMAX networks and it is responsible for accepts or denies new connection at the BS. Although, it is responsible for preventing network overload by extra traffic. Figure 5.3 shows the QoS architecture for IEEE 802.16 networks and as shown in the figure the MS needs admission from the BS before it sends bandwidth request. Notice that, the CAC admits or denies this connection based on the traffic load.

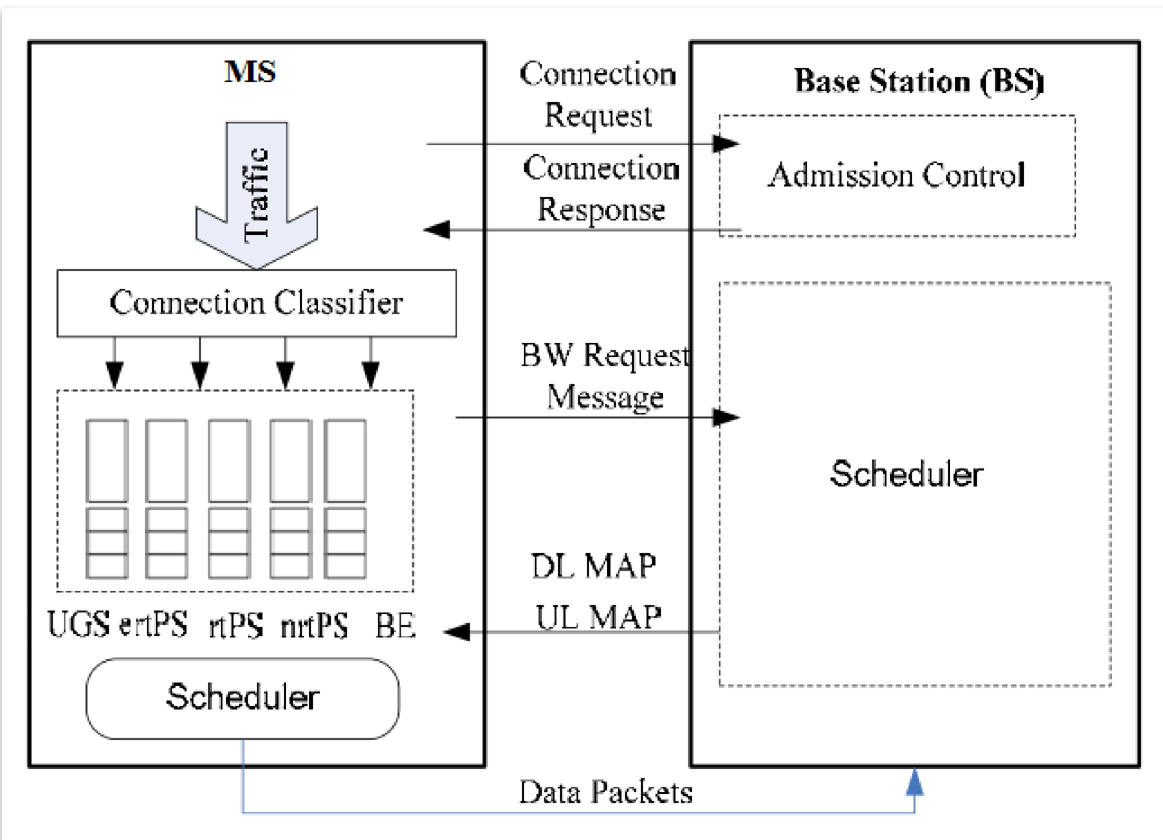

Figure 5.3: The IEEE 802.16 QoS architecture (Adapted from New Scheduling Architecture for IEEE 802.16 Wireless Metropolitan Area Network [8]).

On the literature, many CAC architectures were proposed but we use the same one that proposed in [8] where the new connection is admitted only if the available bandwidth is greater than the MRTR of the new connection.

5.4 Performance Metrics

One of the main objectives of this thesis is to evaluate the performance of the new proposed scheduling algorithms. Therefore, we used several metrics to assess the performance of our new algorithms and these metrics are[35]:

1. **Throughput:** is the overall amount of net data carried out by the system in the unit of time and it can be evaluated by this equation:

$$\mathrm{Th} = \frac{\sum_{i=1}^{n} \mathrm{PacketSize}_i}{\mathrm{PacketArival}_n - \mathrm{PacketStart}_1} \;\ldots\ldots\ldots (5.6)$$

   Where Th is the throughput, n is the total number of packets, $\mathrm{PacketSize}_i$ is the size of Packet_i, $\mathrm{PacketArival}_n$ is the time when last packet reach destination node and $\mathrm{PacketStart}_1$ is the time when first packet left source node.

2. **Average end to end delay:** is the mean value between the values that represent the time difference between the instant of the reception of the final bit in the packet and the instant of the sending of the first bit in the packet by the sender and it can be evaluated by this equation:

$$\mathrm{AD} = \frac{\sum_{i=1}^{n} (\mathrm{PR}_i - \mathrm{PS}_i)}{n} \;\ldots\ldots\ldots (5.7)$$

   Where AD is the average end to end delay, PR is the packet reception time, PS is the packet sending time and n is the total number of packets.

3. **Frame utilization:** is the arithmetic mean of MSs per frame and it can be evaluate by this equation:

$$\mathrm{Fu} = \frac{1}{q} \times \sum_{j=1}^{q} z_i \;\ldots\ldots\ldots (5.8)$$

Where Fu is the frame utilization, z_i is the number of served MSs per frame, q is the total number of frames.

5.5 Network Topology and Simulation Parameters

The simulation scenario is consists from single BS and 36 MSs move using random waypoint mobility model. These MSs establish nine UGS, nine ertPS, nine rtPS, five nrtPS and four BE traffic flows. The MSs are randomly deployed with random coordinates in the coverage area of the BS. Although, the BS connected with gateway (Sink Node) through 100 Mbps full duplex link. Figure 5.4 shows the network topology of the simulation scenario where MSs are distributed randomly in the coverage of the BS.

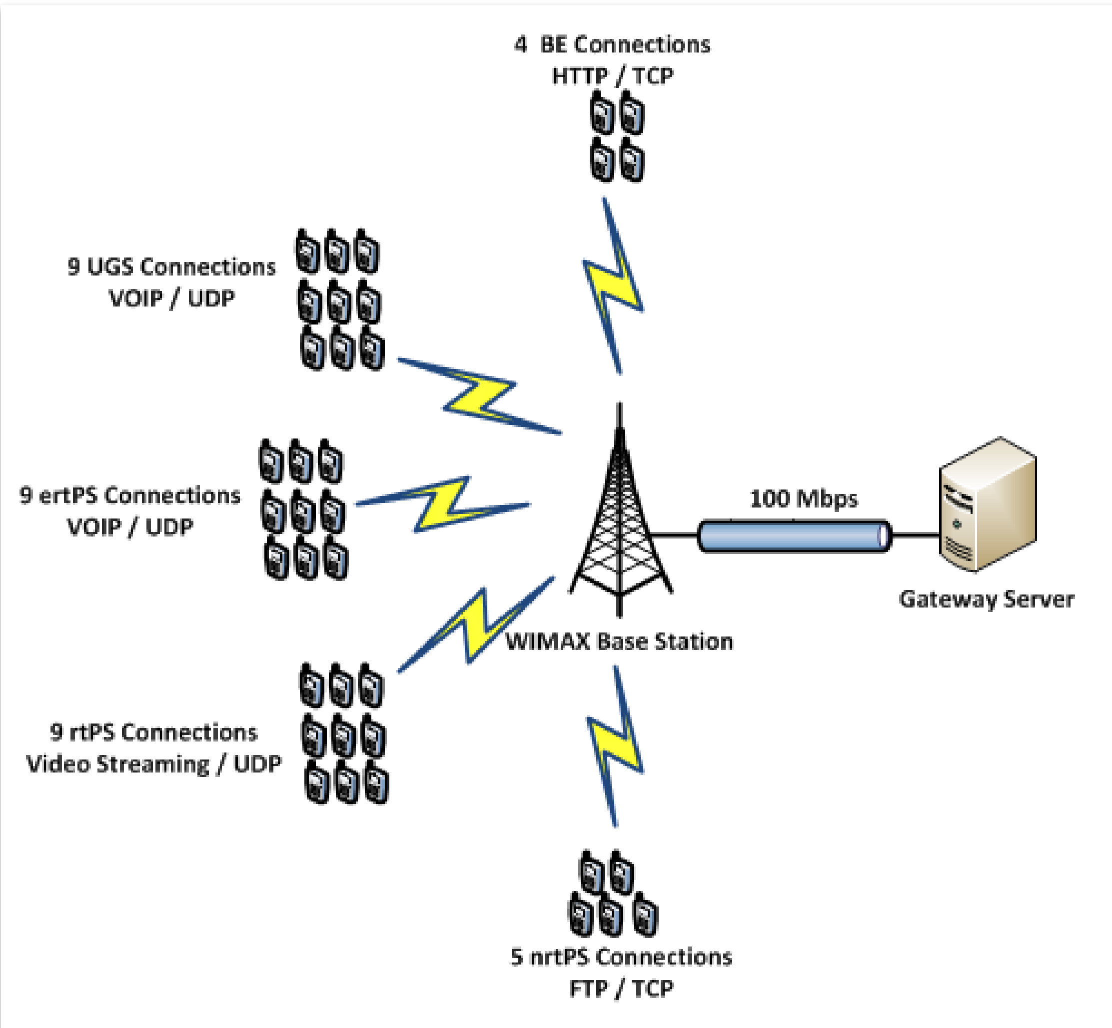

Figure 5.4: The network topology of the simulation scenario.

The IEEE 802.16 has a set of QoS parameters such as The Minimum Reserved Traffic Rate (MRTR), Maximum Sustained Traffic Rate (MSTR), Maximum latency (ML) and maximum Packet Size in bytes (mPS).These QoS parameters are vary according to the service flow types, Table 5.1 shows the QoS parameters that used in the simulation.

Parameter	UGS	ertPS	rtPS	nrtPS	BE
MRTR (kbps)	-	8	512	512	-
MSTR (kbps)	64	64	1024	1024	1024
ML (ms)	50	100	150	1000	1500
mPS (bytes)	40	80	300	1500	1500

Table 5.1: The QoS parameters for different service flows (Adapted from towards a common benchmark in WiMAX environment and a performance study of uplink scheduling algorithms in point-to-multipoint WiMAX networks [48, 49]).

Each MS had one uplink flow and one downlink flow, where both of them mapped to the same service flow type. Although, Different type of traffic and connection request models are developed to associate with the service class. These models are based on WiMAX forum documents [6] and they describe the behavior of the traffic:

1. **VOIP traffic Model:**

   The VOIP without silence suppression traffic was associated with UGS service flow and the VOIP with silence suppression traffic was associated with ertPS service flow. However, the VOIP application behaves like ON/OFF source model where the PDUs are transmitted during the ON period and only comfort noise is sent during OFF period. The ON/OFF model follow as exponential probability distribution where both the ON and OFF periods associated with 1.2 and 1.8 mean values and during the ON periods 66 bytes of data was generated [50].

2. **Video traffic Model:**

   The video streaming traffic was associated with rtPS service flow and the values that suggested by the WiMAX Forum are considered. Although, the Video traffic was generated by real MPEG traces extracted from “Transporter 2” movie in high definition format [51, 52].

3. FTP traffic Model:

The File Transfer Protocol (FTP) traffic was associated with nrtPS service flow and it traffic was generated using an exponential distribution [8].

4. HTTP (Web) traffic Model:

The Hypertext Transfer Protocol (HTTP) traffic was associated with BE service flow and it is modeled using typical sessions of web browsing. In this context, each web page consists of a number of objects, such as a main page and embedded objects. The body of the distribution is a lognormal distribution [53].

Parameter	Values
Topology	Single BS with 36 MSs
Spectrum	2.5 GHz
Physical Layer	OFDMA - TDD
System Bandwidth	10 MHz
Sampling factor	28/25
FFT size (NFFT)	1024
Propagation model	COST-231 Hata Model
BS Antenna Height (h_B)	32 meters
SS Antenna Height (h_R)	1.5 meters
BS Antenna Gain (G_t)	16 dBi
MS Antenna Gain (G_r)	0 dBi
BS Maximum Power Amplifier	43 dBm
MS Maximum Power Amplifier	23 dBm
BS Noise Figure (NF)	5 dB
SS Noise Figure (NF)	7 dB
Frame duration	5 ms
Downlink: Uplink symbols	26:21
TTG+RTG	1.6 symbol
Permutation	PUSC
Antenna model	Omni antenna
Link adaptation	Enabled
No. of OFDMA symbols /frame	47 + 1 Preamble
OFDMA Symbol Duration	102.9 us
Simulation duration	100 s

Table 5.2: The simulation parameters.

The WiMAX parameters value that used in the simulation are based on the WiMAX Forum Mobile System profile and is presented in Table 5.2. The main features are: the PHY layer is OFDMA with TDD, system bandwidth is 10 MHZ, the propagation bath loss is COST 231 Hata model, PUSC Permutation and the simulation duration is 100s.

5.6 The DmSIR Scheduling Algorithm Simulation Results

We simulate the DmSIR scheduling algorithm within the QoS-included WiMAX module and we compare it with both the mSIR and the mmSIR scheduling algorithms. In this section, we will discuss and analyze the simulation results for these algorithms. However, a single simulation run is usually incredible and produces inaccurate results so we do multiple simulation runs to provide credibility and insight [61]. We used the central limit theorem to determine the number of simulation runs and to insure the validity of results. First we do several independent runs then we calculate the mean (x) and the standard deviation (s) for the results. Then we could evaluate the number of runs by using this equation:

$$N = [(100 \times z \times s)/(r \times x)]^2 \quad \dots\dots\dots (5.9)$$

Where N is the number of runs, z is the normal variant for 90 percent confidence interval which is 1.645 and r is the precision level and we suppose it 5. The duration of each simulation run was 100 seconds and at the end of each simulation run a trace file will be generated. Although, the three performance metrics will be extracted from each trace file and the mean value of each metric from all runs will be obtained. The results were presented in three graphs as follow:

Figure 5.5 shows the throughput as a function of the simulation time submitted by the network scenario. As shown in the figure, the mSIR and the mmSIR scheduling algorithm had low throughput due the ignorance of maximum latency (delay) for packets so many packets were dropped. Although, we observe the mmSIR scheduling algorithm perform better than the mSIR scheduling algorithm because the mmSIR served MSs that have the highest SIR without a unicast request opportunities and therefore gives better opportunity to rest MSs to take radio resources.

On the other hand, the DmSIR scheduling algorithm has better throughput than the mSIR and the mmSIR scheduling algorithm because it gives the radio resources to the MSs that have the highest SIR until one or more packets meet their deadline, in this case they will be served first and by this technique it reduces the number of dropped packets which leads to increase throughput and decrease packets retransmission. Although, one of the main objectives of this thesis is to improve scheduling for real-time packets and the DmSIR scheduling algorithm achieves that by taking the maximum latency for the real-time packets into account to make the scheduling decision. The DmSIR scheduling algorithm increases network throughput about 33% than the mSIR scheduling algorithm and 15.3% than the mmSIR scheduling algorithm.

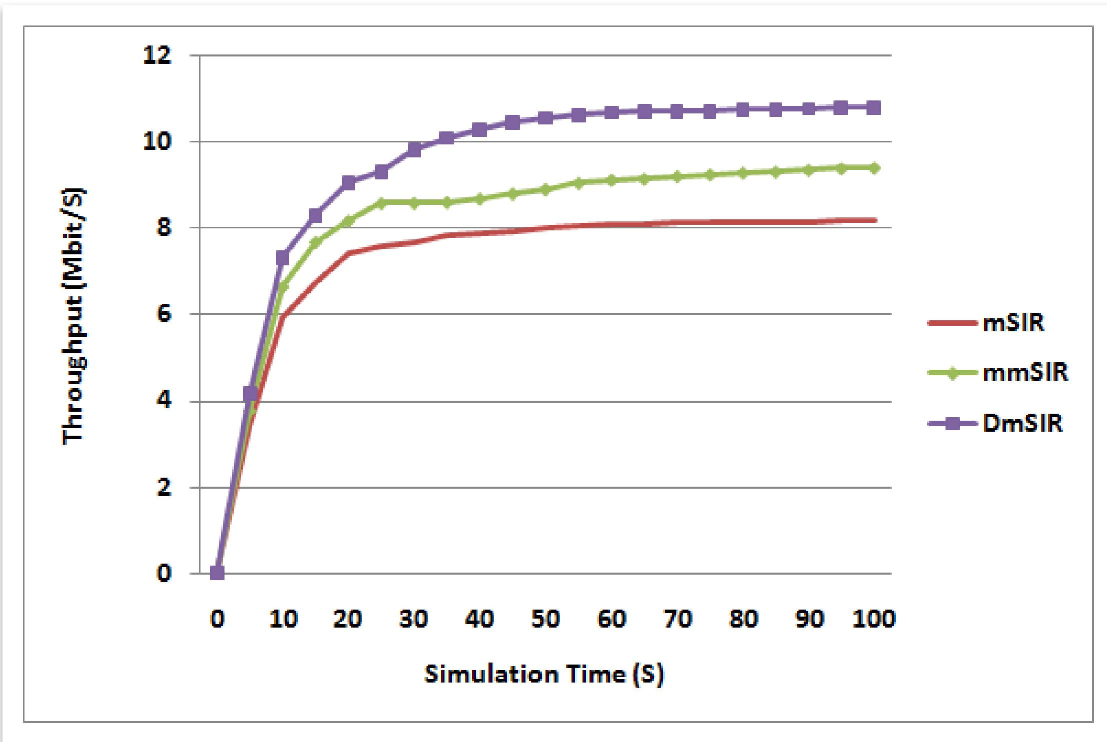

Figure 5.5: The network throughput versus simulation time for (DmSIR, mmSIR and mSIR) scheduling algorithms.

Figure 5.6, shows the average end to end delay as a function of the simulation time submitted by the network scenario for the three scheduling algorithms. As shown in the figure the mSIR scheduling algorithm has the greatest end to end delay value and that because it depends on SNR only for making scheduling decisions and that leads to long delay (starvation) for packets that belongs to MSs with low SNR values.

On the other hand, the mmSIR scheduling algorithm has low average end to end delay values than the mSIR scheduling algorithm because it served MSs that have the highest SIR without a unicast request opportunities and therefore gives better opportunity to rest MSs. However, the DmSIR scheduling algorithm has the lowest end to end delay value and that because it uses the delay and the SNR values for making scheduling decisions and that decreases the probability of long delay for packets and packets retransmission due to packets drop. The DmSIR scheduling algorithm decreases the end to end delay about 57% than the mSIR scheduling algorithm and 25% than the mmSIR scheduling algorithm.

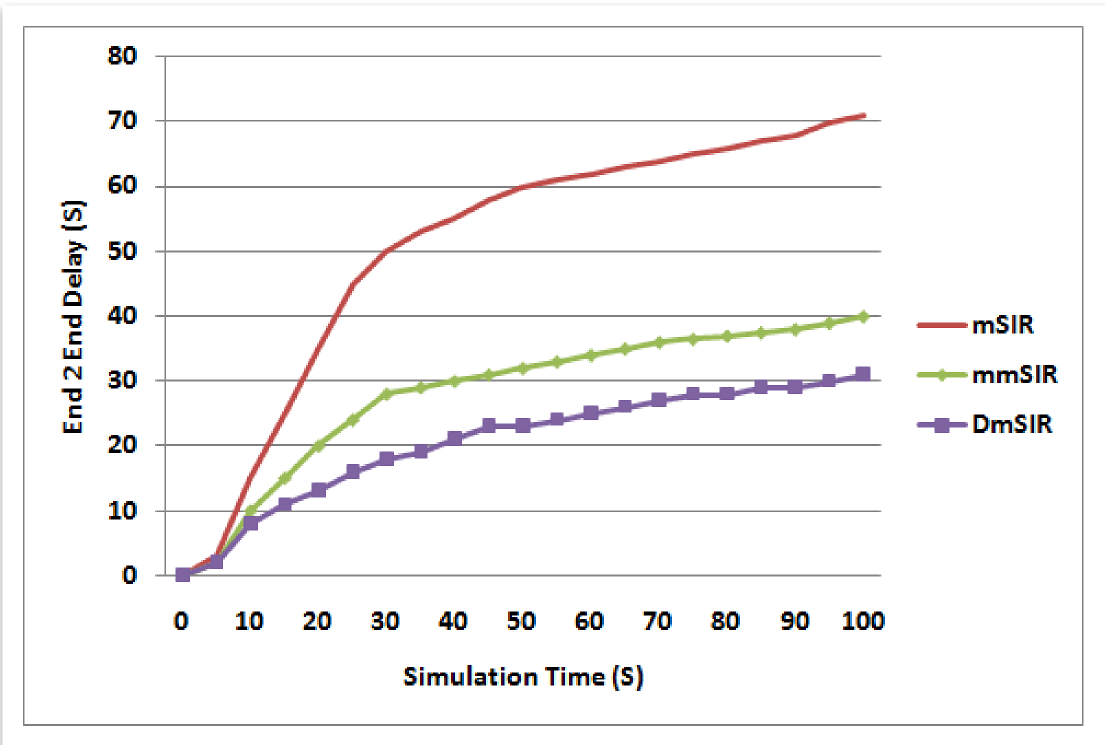

Figure 5.6: The Average end to end delay versus simulation time for (DmSIR, mmSIR and mSIR) scheduling algorithms.

Figure 5.7 shows the frame utilization as a function of the simulation time submitted by network scenario. As it is clear from the figure the DmSIR scheduling algorithm served more MSs per frame and that because it gives priority to packets meet deadline next frame and these packets have small size because it is belongs to real-time traffic. Therefore, the DmSIR served more packets per frame and that increase the possibility to serve more MSs per frame. On the other hand, the mSIR and mmSIR scheduling algorithm have low frame utilization because both algorithm seek to serve packets belong to MSs that have high SNR and usually they belong to the same MS.

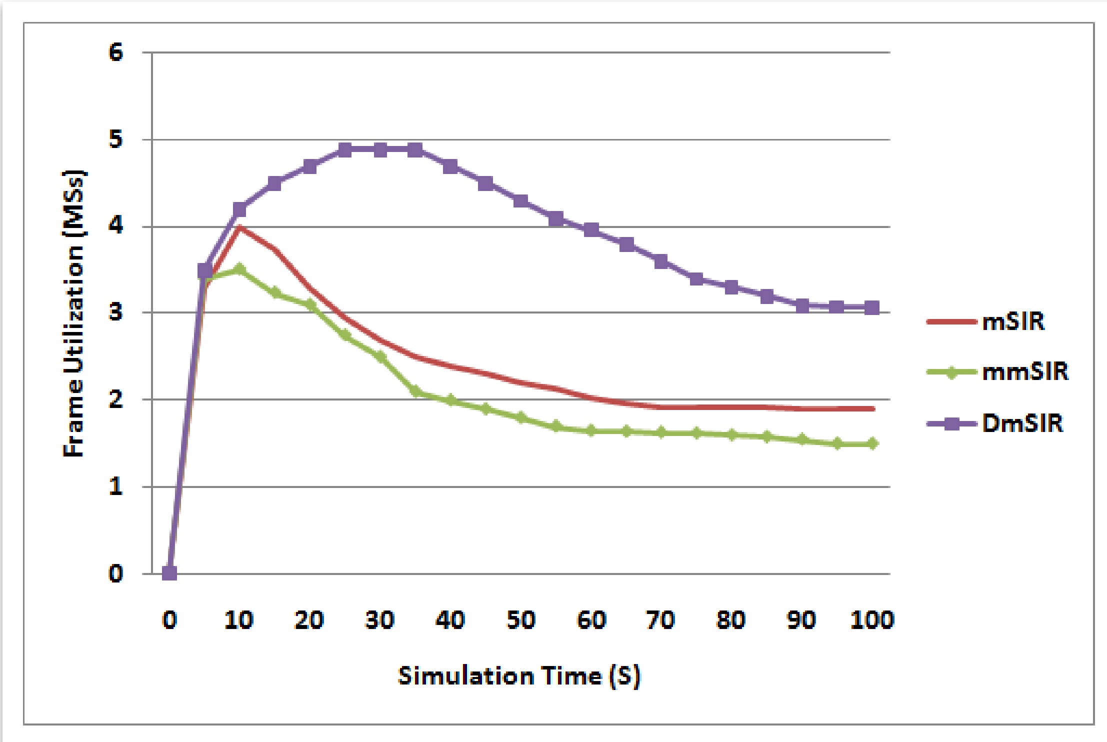

Figure 5.7: The Frame utilization versus simulation time for (DmSIR, mmSIR and mSIR) scheduling algorithms.

5.7 The PbDRR Scheduling Algorithm Simulation Results

In this section we will present and discuss the simulation results of our second proposed scheduling algorithm. We use the same simulation parameters that discussed in section 5.2 and we compare it with the DmSIR and DRR with fragmentation [22] scheduling algorithm. The fragmentation operation at the MAC layer is not enabled when we evaluate the performance of the DmSIR scheduling algorithm because it is not used. However, when we evaluate the PbDRR and DRR scheduling algorithms we enable this option to make sure that there is no waste slots. Notice that, for PbDRR the value of α that used in the simulation scenario is equal to 0.5. Although, we used the same technique to evaluate the number of simulation runs that discuss in previous section. The three performance metrics will be extracted from each trace file and the mean value of each metric from all runs will be obtained. The results were presented in three graphs as follow:

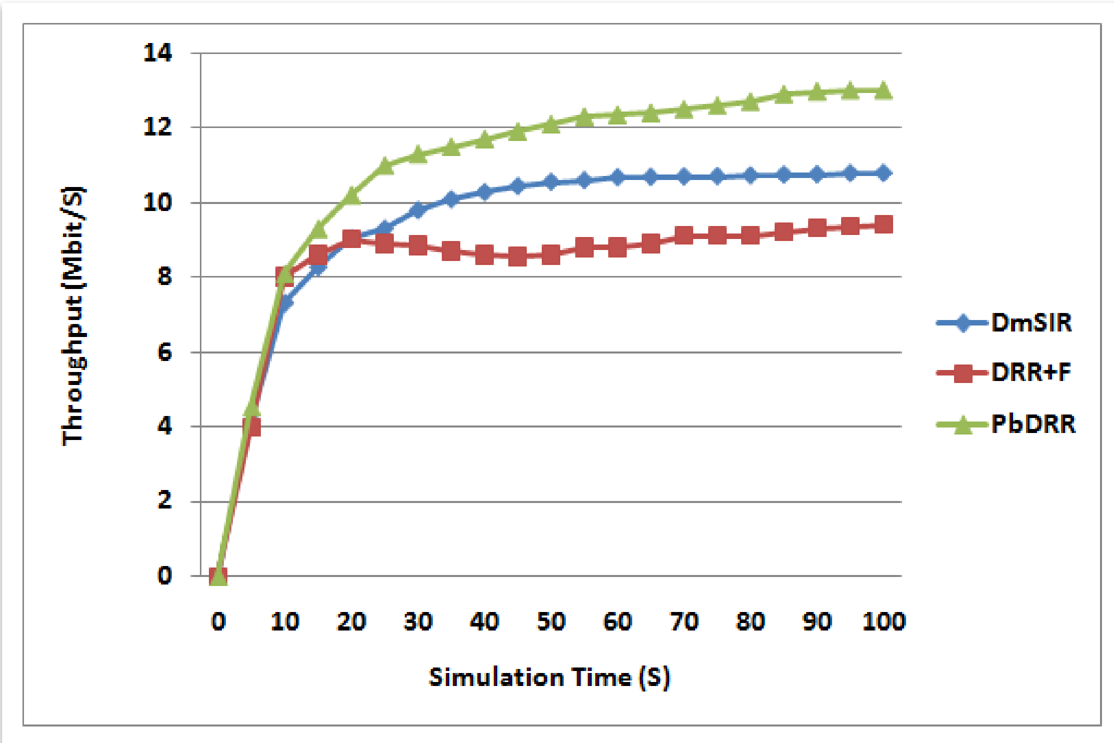

Figure 5.8: The network throughput versus simulation time for (DmSIR, DRR+F and PbDRR) scheduling algorithms.

Figure 5.8 shows throughput as a function of time for the three scheduling algorithms that submitted by the simulation scenario. As shown in the figure the DRR+F scheduling algorithm has low throughput compared to the rest algorithms and that because it ignores the QoS parameters for service flow so many packets will be dropped because their latency expired. On the other hand, the DmSIR scheduling algorithm has better throughput compared to DRR+F scheduling algorithm because it served packets that approach to deadline first and that decrease number of drooped packets. The PbDRR algorithm has better throughput compared to DmSIR algorithm because it makes scheduling decision based on many factors (SNR, backlog traffic and deadline) and that gives chance to non-real time packets to be scheduled which leads to decrease number of dropped packets and packets retransmission. Notice that, the PbDRR scheduling algorithm improves resource allocation for real-time packets as well as prevents starvation for non real-time packets. The PbDRR scheduling algorithm increases network throughput about 38% than the DRR+F scheduling algorithm and 19.3% than the DmSIR scheduling algorithm.

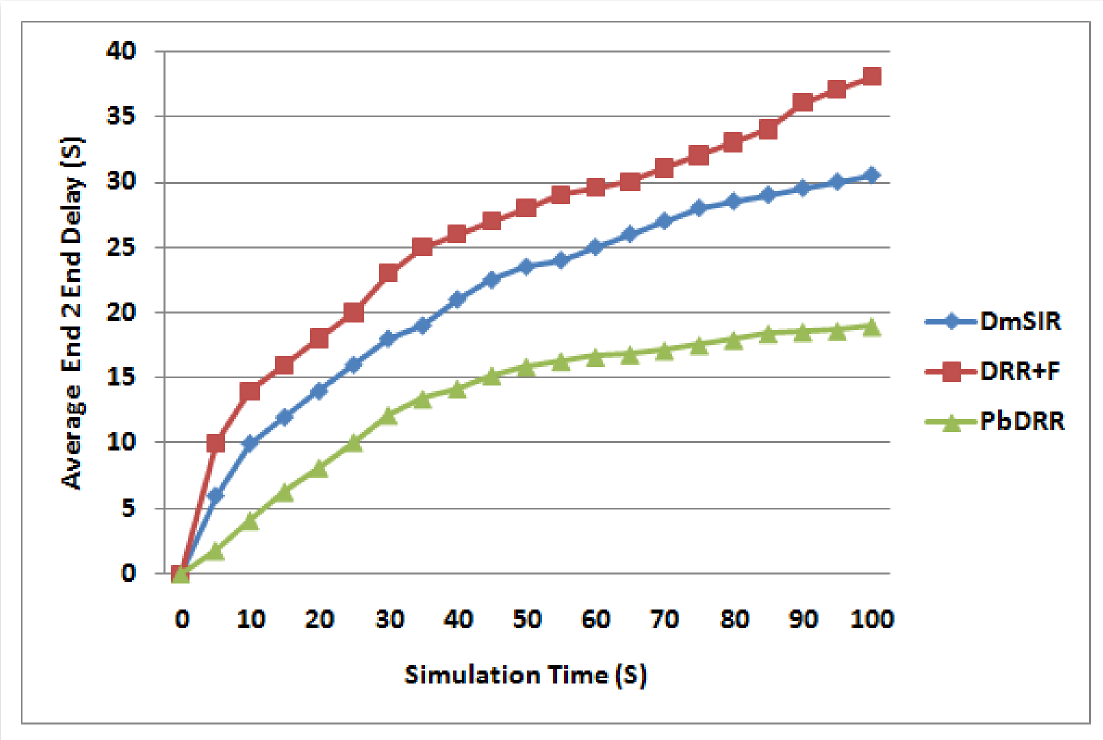

Figure 5.9: The average end to end delay versus simulation time for (DmSIR, DRR+F and PbDRR) scheduling algorithms.

Figure 5.9 shows the average end to end delay as function of time for the three simulated algorithms. As it clear from the figure the new proposed algorithm (PbDRR) has the lowest end to end delay values due the wisdom in scheduling decision. The PbDRR scheduling algorithm makes resource allocation based different factors leads to give priority to real-time packets approach to deadline as well as prevents non real-time packets from starvation. On the other hand, the DmSIR scheduling algorithm makes scheduling based on two factors only (deadline and signal to noise ratio) and that leads to long delay for non real-time packets that have low SNR values and that increase the average end to end delay. Unlike the PbDRR and DmSIR scheduling algorithms, the DRR+F scheduling algorithms ignores service flow QoS parameters which leads to packets dropping, packets retransmission and traffic congestions. Therefore, the average end to end delay for the DRR+F scheduling algorithm is greater than the rest algorithms. The PbDRR scheduling algorithm decreases the end to end delay about 36% than the DmSIR scheduling algorithm and 52% than the mmSIR scheduling algorithm.

Figure 5.10 presents the frame utilization as a function of time for (DmSIR, DRR+F and PbDRR) scheduling algorithms. As it is clear from the figure the DRR+F have the lowest frame utilization values because it served queue in round robin manner and always the frame slots consumed by two or three MSs packets. On the other hand, the PbDRR have the heights frame utilization values because it gives priority to packets meet deadline next frame and that increase the possibility to serve more MSs per frame like the DmSIR scheduling algorithm. Although, it served packets based on the backlog traffic and signal to noise ratio and also that increase the possibility to serve more MSs per frame.

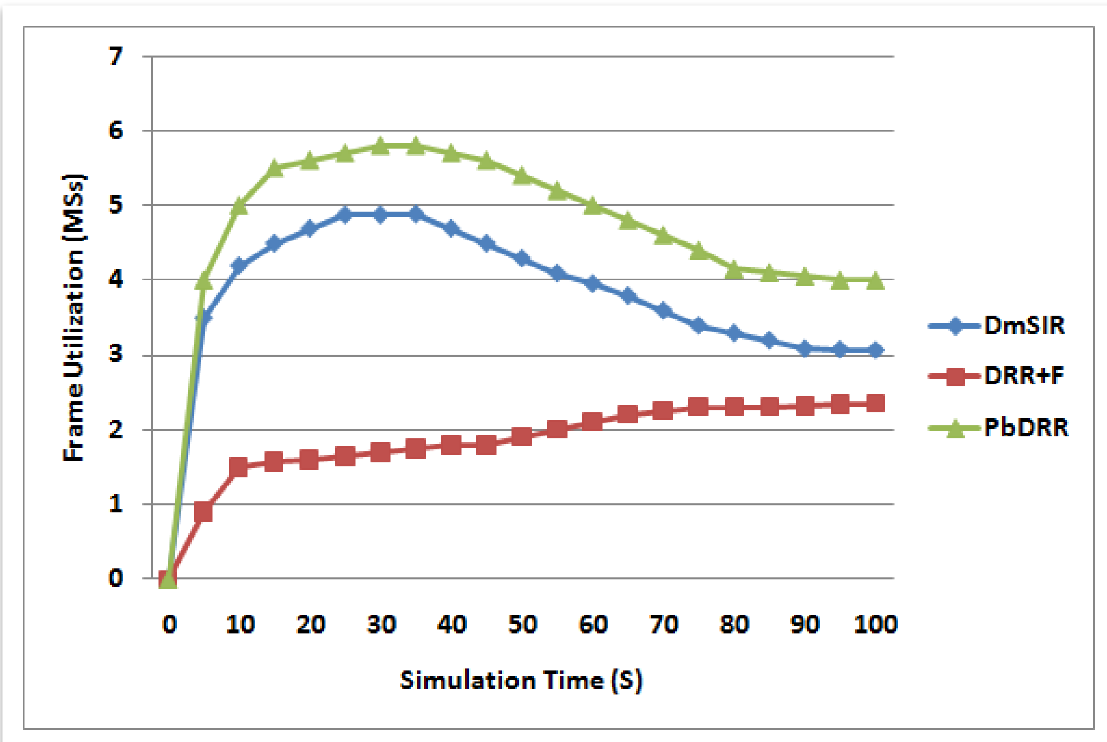

Figure 5.10: The frame utilization versus simulation time for (DmSIR, DRR+F and PbDRR) scheduling algorithms.

Chapter 6 Conclusion and Future Works

In this thesis, we have introduced two new scheduling algorithms for WiMAX networks. The two proposed algorithms are fully compliant with the standard. The first algorithm is Deadline maximum Signal to Interference Ratio (DmSIR) scheduling algorithm. It is a modified version from maximum Signal to Interference Ratio (mSIR) scheduling algorithm. In the DmSIR scheduling algorithm, scheduling decision based on two factors: the packets deadline and signal to noise ratio. The simulation results for DmSIR shows enhancement in the performance compared to the mSIR scheduling algorithm but the non real-time traffic with low signal to noise ratio suffers from long delay.

On the other hand, our second algorithm which we named the Priority based Deficit Round Robin (PbDRR) solves the problem of long delay for non real-time traffic with low signal to noise ratio as well as giving priority to real-time traffic that approach to deadline. In the PbDRR scheduling algorithm, scheduling decision based on three factors: packets deadline, signal to noise ratio and backlog traffic. Although, the simulation results for the PbDRR scheduling algorithm shows better performance than the DmSIR and Deficit Round Robin + Fragmentation (DRR+F) scheduling algorithm.

Comparison Factors	*DmSIR*	*PbDRR*
Fairness between service flows	No	Yes
Hardware implementation	Easy	Complex
Channel awareness	Yes	Yes
Intra-class scheduling	No	Yes
Inter-class scheduling	Yes	Yes
Good handling for real-time traffic	Yes	Yes
Good handling Backlog traffic	No	Yes

Table 6.1: A comparison between the DmSIR and PbDRR scheduling algorithms.

Actually, both algorithms have their pros and cons that make them candidate for using by vendors and operators. Table 6.1 shows comparisons between the two algorithms in many design factors. As it is clear from the table, the DmSIR scheduling algorithm is easy to implement but it isn't fair for all service flow especially non real-time traffic with low signal to noise ratio. The PbDRR scheduling algorithm is more complex to implement and it needs more hardware but it achieves fairness between all service flows.

The major goals of this thesis is enhancing the scheduling for IEEE 802.16 networks to provide better QoS for multiservice traffic but there is other factor could be used to satisfy this goal such as robust call admission control component. In future works we will study the design of new call admission control component that fully compliant with the proposed algorithms. Although, we will upgrade both algorithms to take more factors in making scheduling decision such as traffic jitter. The last idea in our mind about this thesis is to apply both algorithms for mobile WiMAX 2.0 and analyze the results.

References

[1] IEEE 802.16-2004, "IEEE standard for Local and Metropolitan Area Networks – Part 16: Air interface for Fixed Broadband Wireless Access systems," October 2004.

[2] IEEE 802.16e-2005, "IEEE Standard for Local and Metropolitan Area Networks – Part 16: Air interface for Fixed Broadband Wireless Access systems – Amendment 2: Physical and Medium Access Control layers for combined fixed and mobile operation in licensed bands and Corrigendum 1," February 2006.

[3] Y. A. Şekercioğlua, M. Ivanovicha, and A. Yeğin, "A Survey of MAC based QoS Implementations for WiMAX Networks," Computer Networks (Elsevier), Vol. 53, no. 14, pp. 2517-2536, Sept. 2009.

[4] Nuaymi L., "WiMAX: Technology for Broadband Wireless Access," John Wiley & Sons, 2007.

[5] WiMAX Forum, "Mobile WiMAX: A technical overview and performance evaluation," June 2006.

[6] WiMAX Forum, "WiMAX System Evaluation Methodology V2.1," Jul. 2008

[7] Z. Abate, "WiMax RF systems engineering", ARTECH HOUSE, Boston, 2009, pp.68–73.

[8] Safa Haidar, Artail Hassan, Karam Marcel, Soudah Rawan, Khayat Samar; "New Scheduling Architecture for IEEE 802.16 Wireless Metropolitan Area Network," IEEE/ACS International Conference on Computer Systems and Applications, 2007, Page(s): 203-210, 13-16 May 2007.

[9] Zakhia Abichar, Yanlin Peng, and J. Morris Chang, "WiMAX: The Emergence of Wireless Broadband", IT Pro magazine IEEE computer society, July-Aug. 2006, pp. 44-48.

[10] Y. Zhang and H. Chen, "Mobile WiMAX: Toward Broadband Wireless Metropolitan Area Networks", edited, New York: CRC Press, 2008.

[11] Sassan Ahmadi,"Mobile WiMAX A Systems Approach to Understanding IEEE 802.16m Radio Access Technology", elsevier publisher, 2011.

[12] Ramjee Prasad and Fernando J. Velez,' WiMAX Networks Techno Economic Vision and Challenges', Springer Science and Business Media B.V, 2010.

[13] S. Shakkottai and R. Srikant, "Scheduling real-time traffic with deadlines over a wireless channel," ACM/Baltzer Wireless Networks., vol. 8, pp.13-26, Jan. 2002.

[14] Y.-N. Lin, Y.-D. Lin, Y.-C. Lai, and Che-Wen, "Highest urgency first (HUF): A latency and modulation aware bandwidth allocation algorithm for wimax base stations," Computer Communications, vol. 32, pp. 332 – 342, Nov 2008.

[15] C. So-In, R. Jain, and A.-K. Tamimi, "Scheduling in IEEE 802.16e mobile WiMAX networks: key issues and a survey," IEEE Journal on Selected Areas in Communications, vol. 27, no. 2, pp. 156–171, 2009.

[16] K. Wongthavarawat and A. Ganz, "Packet scheduling for QoS support in IEEE 802.16 broadband wireless access systems," International Journal of Communication Systems., vol. 16, pp. 81-96, Feb. 2003.

[17] C. Cicconetti et al., "Quality of Service Support in IEEE 802.16 Networks," IEEE Network, vol. 20, no. 2, pp. 50–55, Mar.2006.

[18] C. Cicconetti, A. Erta, L. Lenzini, and E. Mingozzi, "Performance evaluation of the IEEE 802.16 MAC for QoS support," IEEE Transaction on Mobile Computing., vol. 6, no. 1, pp. 26–38, Jan. 2007.

[19] E. Laias, I. Awan, and P. M. L. Chan, "Fair and Latency Aware Uplink Scheduler in IEEE 802.16 Using Customized Deficit Round Robin," Advanced Information Networking and Applications Workshops, pp.425-432, May 2009.

[20] E. Laias, I. Awan, and P. M. L. Chan, "An interactive QoS framework for fixed WiMAX networks," Simulation Modelling Practice and Theory journal 18, pp.291-303, Jan 2010.

[21] "Understanding and Confguring MDRR/WRED on the Cisco 12000 Series Internet Router", doc. ID 18841, http://www.cisco.com/en/US/products/hw/routers/ps167/products_tech_note09186a0080094c00.shtml, last visit 11/09/2012.

[22] C. So-In, R. Jain, and A.-K. Tamimi, “A deficit round robin with fragmentation scheduler for IEEE 802.16e mobile WiMAX,” in Proceedings of IEEE Sarnoff Symposium (SARNOFF '09), pp. 1–7, Princeton, NJ, USA, March-April 200

[23] J. F. Borin and N. L. S. Da Fonseca, “Uplink scheduler and admission control for the IEEE 802.16 standard,” Globecom, 2009.

[24] German D. Castellanos and Jamil Y. Khan, “Performance of WiMAX Packet Schedulers for Multi-Class Traffic,” in Communications (LATINCOM), 2010 IEEE Latin-American Conference, pp. 1–6, Bogota, Colombia, Sept 2010.

[25] Amir Esmailpour and Nidal Nasser ,"Packet Scheduling Scheme with Quality of ServiceSupport for Mobile WiMAX Networks",The 9th IEEE International Workshop on Wireless Local Networks (WLN 2009) Zürich, Switzerland; 20-23 October 2009.

[26] Amir Esmailpour and Nidal Nasser “Dynamic QoS-Based Bandwidth Allocation Framework for Broadband Wireless Networks”, IEEE Transactions on Vehicular Technology, 60(6), 2690-2700, 2011.

[27] Amir Esmailpour and Nidal Nasser, “A Novel Scheme for Packet Scheduling and Bandwidth Allocation in WiMAX Networks”, IEEE International Conference on Communications (ICC), p.p 1-5 ,2011.

[28] Dhananjay kumar and Priyameenal V, “Adaptive Packet Scheduling Algorithm for Real-Time Services in Wi-MAX Networks”, IEEE International Conference on Recent Trends in Information Technology , p.p 1-6 ,2011.

[29] Cristiano, B.B., Eliane, G.C, “Analysis of WiMAX bandwidth allocation mechanism considering physical conditions”, IEEE ISWCS, p.p 643-647, 2008.

[30] H. K. Rath, A. Bhorkar, and V. Sharma. “An opportunistic drr (o-drr) uplink scheduling scheme for IEEE 802.16-based broadband wireless networks,” International Conference on Next Generation Networks, February 2006.

[31] A. Iera, A. Molinaro, S. Pizzi, and R. Calabria, “Channel-Aware Scheduling for QoS and Fairness Provisioning in IEEE 802.16/WiMAX Broadband Wireless Access Systems,” IEEE Network, vol. 21, pp. 34-41, Oct. 2007.

[32] V. Sharma and N. Vamaney, ”The Uniformly-Fair Deficit Round Robin (UF-DRR) Scheduler for Improved QoS Guarantees in IEEE 802.16 WiMAX Networks,” IEEE International Military Communications Conference, p.p 1-7, 2007.

[33] A. Belghith and L. Nuaymi,”WiMAX capacity estimations and simulation results”, IEEE 67th Vehicular Technology Conference, VTC2008-Spring, Marina Bay, Singapore, May 2008.

[34] A. Belghith and L. Nuaymi, ”Comparison of WiMAX scheduling algorithms and proposals for the rtPS QoS class”, 14th European Wireless 2008, EW2008, Prague, Czech Republic, June 2008.

[35] A. Belghith and L. Nuaymi (2009). Scheduling Techniques for WiMAX. In: Maode Ma. Current Technology Developments of WiMAX Systems. Springer. Pages 61-84.

[36] A. Belghith and L. Nuaymi,” WiMAX spectrum efficiency: considerations and simulation results”, 5th European International Symposium on Wireless Pervasive Computing (ISWPC), p.p 1-8, June 2010.

[37] F. A. Kubota, J. F. Borin, and N. L. S. Da Fonseca, “Cross-layer Uplink Scheduler for the IEEE 802.16 standard,” in Proceedings of the IEEE Globecom, p.p 1-6, 2010.

[38] F. A. Kubota, J. F. Borin, and N. L. S. Da Fonseca, “Opportunistic Cross-layer Uplink Scheduler for the IEEE 802.16 standard,” in IEEE Communications Society ICC 2011, p.p 1-5, 2011.

[39] B. Rong, Y. Qian, K. Lu, H. H.Chen, and M. Guizani, “Call admission control optimization in WiMAX networks,”IEEE Transactions on Vehicular Technology, vol. 57, Jul. 2008.

[40] Po-Chun Ting, Chia-Yu Yu, and Naveen Chilamkurti, “A Proposed RED-based Scheduling Scheme for QoS in WiMAX Networks,” IEEE International Symposium on Wireless Pervasive Computing (ISWPC), February 2009.

[41] Seok Yee Tang, Peter Muller, Hamid R.Sharif “WiMAX Security and Quality of Service an End-to-End Perspective”, Wiley 2010.

[42] M. Ismail, G. Piro, L. Grieco, and T. Turletti, “An improved IEEE 802.16 WiMAX module for the NS-3 simulator,” in Proceedings of the 3rd International ICST Conference on Simulation Tools and Techniques, 2010.

[43] Peng Wu,Tsung Tsa,Yung-Cheng Kao,Jenq-Neng Hwang, and Chung-Nan Lee, "An NS2 Simulation Module for Multicast and OFDMA of IEEE 802.16e Mobile WiMAX," unpublished.

[44] M. Shreedhar and George Varghese. Efficient fair queuing using deficit round robin. IEEE/ACM Transactions on Networking, 4, 1996.

[45] www.isi.edu/nsnam/ns/.

[46] A. Belghith and L. Nuaymi, "Design and Implementation of a QoS-included WiMAX Module for ns-2 Simulator", In 2nd International Conference on Simulation Tools and Techniques (SIMUTools'09), March 2008.

[47] Teerawat Issariyakul and Ekram Hossain , "Introduction to Network Simulator NS2" Springer publisher, 2012.

[48] L. Chrost and A. Brachman, "Towards a common benchmark in wimax environment," in Wireless Communication, Vehicular Technology, Information Theory and Aerospace Electronic Systems Technology, 2009. Wireless VITAE 2009. 1st International Conference on, may 2009.

[49] Dhrona, P., Abu, A., Hassanein, H., "A performance study of scheduling algorithms in Point-to-Multipoint WiMAX networks", Computer Communications, vol. 32 . pp. 511-521, February 2009.

[50] P. Brady,"A model for generating on–off speech patterns in two-way conversations", Bell System Technical Journal 48, 1969.

[51] P. Seeling, M. Reisslein, B. Kulapala, "Network performance evaluation using frame size and quality traces of single-layer and two-layer video: a tutorial", IEEE Communications Surveys and Tutorials 6, 2004.

[52] http://trace.eas.asu.edu/tracemain.html.

[53] P. Barford et al., "Changes in web client access patterns: characteristics and caching implications", Technical Report 1998-023, Boston University, 1998.

[54] R. Jain, The Art of Computer Systems Performance Analysis, John Wiley & Sons Inc., 1991.

[55] R. Jain, D. Chiu, W. Hawe, “A quantitative measure of fairness and discrimination for resource allocation in shared computer systems,” DEC Research Report TR-301, September 1984.

[56] X. Xie, H. Chen, H. Wu, “Simulation studies of a Fair and Effective Queueing algorithm for WiMAX resource allocation,” in Proc. ChinaCom, pp.281 - 285, Aug. 2008.

[57] L. Tassiulas and S. Sarkar, “Maxmin fair scheduling in wireless networks,” in Proc. IEEE Computer Communication Conf., pp. 763-772, 2002.

[58] P. Bhagwat, P. Bhattacharya, A. Krishna, and S. K. Tripathi, “Enhancing throughput over Wireless LANs using channel state dependent packet scheduling,” in Proc. IEEE Computer Communication Conf., San Francisco, CA, 1996.

[59] C. Chuah and R. H. Katz, “Characterizing Packet Audio Streams from Internet Multimedia Applications,” in Proc. of Int. Commun. Conf. (ICC), New York, NY, Apr. 2002.

[60] J.-G. Choi and S. Bahk, “Cell-throughput analysis of the proportional fair scheduler in the single-cell environment,” IEEE Trans. Veh. Technol., vol. 56, no. 2, pp. 766 –778, Mar. 2007.

[61] T. Andel, A.Yasinsac, “On the Credibility of Manet Simulations,” Proc. IEEE for Computer Society, July 2006.

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