Sudan University of Science and Technology

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Performance Evaluation of Adaptive Modulation for WiMAX Broadband Network

تقويم الأداء التضمين التكيفي لشبكه نطاق الحزمة العريضة واي ماكس

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الآية

بِسْمِ اللهِ الرَّحْمنِ الرَّحِيمِ

قال تعالي:

(قَالُواْ سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ)

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صدق الله العظيم

الإهداء :

إلى من تعهداني بالتربية في الصغر ، وكانا لي نبراساً يضيء فكري

بالنصح ، و التوجيه في الكبر أمي ، وأبي

حفظهما الله

إلى من شملوني بالعطف ، وأمدوني بالعون ، وحفزوني للتقدم ، إخوتي ،

وأخواتي

رعاهما الله

إلى كل من علمني حرفاً ، وأخذ بيدي في سبيل تحصيل العلم ،

والمعرفة .

إليهم جميعاً أهدي ثمرة جهدي ، ونتاج بحثي المتواضع .

شكر وتقدير :

ومن حق النعمة الذكر، وأقل جزاء للمعروف الشكر

فبعد شكر المولى عز وجل ، المتفضل بجليل النعم ، وعظيم الجزاء ...

يجدر بي أن أتقدم ببالغ الامتنان ، وجزيل العرفان إلى كل من وجهني ، وعلمني ، وأخذ بيدي في سبيل إنجاز هذا البحث .. وأخص بذلك مشرفي ، الأستاذ الدكتور: محمد حسين ، الذي قوم ، وتابع ، وصوب ، بحسن إرشاده لي في كل مراحل البحث ، والذي وجدت في توجيهاته حرص المعلم ، التي تؤتي ثمارها الطيبة بإذن الله

Abstract

The main objective of this research to implement, and analysis of WiMAX model with different modulation and coding schemes to be compared with each other and with the Adaptive Modulation and Coding (AMC) using OPNET network modeler. By expressing the different types of modulation and coding method that actually used in wireless broadband network like WiFi, WiMAX. And more complex modulation methods that can guarantee higher data rates and require less interference and good line of sight (LOS) to the access points. In addition this research helps in understanding the concept of link adaptation which holds the view of adaptive MCS and other channel adaption attributes. And implementing of an adaptive modulation and coding scheme using AMC profiles to evaluate the performance according to spectral efficiency.

المستخلص

الهدف الرئيسي من هذا البحث هو تنفيذ وتحليل نموذج واي ماكس مع أنواع مختلفة للتضمين ومخططات الترميز ليتم مقارنتها مع بعضها البعض ومع التكيف التحويل والترميز (أي ام سي) باستخدام أوبنت شبكة صانع التماثيل. عن طريق استعراض أنواع مختلفة من التضمين والترميز التي استخدمت فعلا في الشبكة ذات النطاق العريض اللاسلكية مثل واي فاي، وواي ماكس. و طرق تضمين أكثر تعقيدا التي يمكن أن تضمن معدلات أعلى للبيانات وتتطلب كميات أقل من التدخل و توصيل مباشر جيد إلى نقاط الوصول. وبالإضافة إلى ذلك يساعد هذا البحث في فهم مفهوم تكيف الوصلة وغيرها من الصفات قناة التكيف. وتنفيذ التضمين على التكيف ونظام الترميز باستخدام ملفات (أي ام سي)لتقييم الأداء وفقا للكفاءة الطيفية.

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Abbreviation

AMC	Adaptive Modulation and Coding
ASN	Access Service Network
AWGN	Additive White Gaussian Noise
ASN-GW	Access Service Network Gateway
BS	Base Station
CC	Convolution Coding
CSN	Connectivity Service Network
DIUC	Downlink Interval Usage Code
ertPS	Extended Real Time Polling Service
FFT	Fast Fourier Transform
GUI	Graphical User Interface
ISI	InterSymbol Interference
LOS	Line of Sight
LTE	Long Term Evolution
MAC	Media Access Control
MAN	Metropolitan Area Network
MS	Mobile Subscriber
MCS	Modulation and Coding Scheme
nrtPS	Non-Real-Time Polling Service
NLOS	Non Line of Sight
OFDMA	Orthogonal Frequency Division Multiple Access
OPENT	Optimized Network Modeler Software
OFDM	Orthogonal Frequency Division Multiplexing
PRB	Physical Resource Block
PAPR	Peak to Average Power Ratio
PSTN	Public Switched Telephone Network

PDU	Protocol Data Units
rtPS	Real-Time Polling Service
RS	Relay Station
RTVR	Real Time Variable Rate
SINR	Signal to Interference plus Noise Ratio
ST	Subscriber Terminal
WiMAX	Worldwide Interoperability for Microwave Access
WiFi	Wireless Fidelity

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

1.1 Background

The development of wireless communication system had become a major issue in telecommunication engineering, and its development is depending on developing new algorithms and methods for better network performance and spectral efficiency increase.

Hence, Spectrum efficiency is the optimized use of spectrum or bandwidth to maximize the amount of data been transmitted with the fewest transmission errors. Modulation methods and coding techniques are one of the main network criteria that play a big role in maximization the network performance and spectral efficiency.

A modulator encodes a sequence of bits onto the carrier signal by adjusting the parameters that describe it to be used in the reverse process of decoding this sequence again by the demodulator. In WiMAX, different kinds of modulations are used according to the different channels in both uplink and downlink which are classified by radio transmission and reception technical specifications. Coding can refer to different meaning in a communication system, but the familiar concept of coding is meant to error control management by encoding a signal so that error occurred can be detected and possibly corrected, and that makes it very related to modulation mechanism.

OPNET Modeler provides a comprehensive development environment supporting the modeling of communication networks and distributed systems. Both behavior and performance of modeled systems can be analyzed by performing discrete event simulations. The OPNET Modeler environment incorporates tools for all phases of a study, including model design, simulation, data collection, and data analysis [1].

Worldwide Interoperability for Microwave Access (WiMAX) is under IEEE 802.16e standard supporting high-speed (up to 75 Mb/s) wireless Internet technology over wide area (up to 50 km) [2]. Although it covers broad area, it is a fixed system, which is not suitable for use of Internet service in a moving vehicle.

Mobile WiMAX and fixed WiMAX are both under Metropolitan Area Network (MAN) range that covers up to 50 km from base station (BS). However, only Mobile WiMAX guarantees connection from migration between two hotspots. Since BS control hotspots, Quality of Service (QoS) has to be implemented efficiently. Under Mobile WiMAX QoS classes, Real-Time Variable Rate (RTVR) suits flawlessly for this project. It supports real-time applications with variable-size data packet bursts, providing better throughput by “bursting” more than one packet at a time to reduce wait time duration. An example application of RT-VR is video and audio streaming. To ensure connection between a mobile subscriber (MS) and a BS, they must “form a unidirectional connection between their respective Media Access Control (MAC) layers” sharing same QoS parameters.

The use of modulation method is very old and usual strategy in communication engineering, amplitude, frequency, and phase modulations are the basic principle of modulation in radio transmission and reception. The development of these modulation methods has become an important manner to conveniently satisfy the requirement of the wireless networks reliability and the optimal spectral efficiency employment.

The actual implementation of the technology will be different between the downlink (i.e. from base station to mobile) and the uplink (i.e. mobile to the base station) as a result of the different requirements between the two directions and the equipment at either end. However OFDM was chosen as the signal bearer format because it is very resilient to interference. Also in recent years a considerable level of experience has been gained in its use from the various forms of broadcasting that use it along with Wi-Fi and WiMAX.

In modern wireless broadband networks modulation and coding are combined together in the concept of modulation and coding scheme (MCS), in WiMAX the MCS index value summarizes the modulation type and the coding rate that is used in a given physical resource block (PRB). Typically, a higher MCS index offers a higher spectral efficiency (which translates to a higher potential data rate) but requires a higher SNR to support it.

In WiMAX, link adaptation is based on the Adaptive Modulation and Coding (AMC) profiles to provide different service flow corresponds to specific feedback and conditions. AMC profile can adapt modulation scheme and code rate using operator specific profiles or the default way as the following procedure:

Modulation scheme: if the (Signal-to-Interference plus Noise Ratio) SINR is sufficiently high, higher-order modulation schemes with higher spectral efficiency (hence with higher bit rates) like 64QAM are used. In the case of poor SINR a lower-order modulation scheme like QPSK, which is more robust against transmission errors but has a lower spectral efficiency, is used.

Code rate: for a given modulation scheme, an appropriate code rate can be chosen depending on the channel quality. The better the channel quality, the higher the code rate is used and of course the higher the data rate [2].

OPNET Modeller is a C/C++ language based discrete-event simulation with Graphical User Interface (GUI) [13]. Simulations with GUI can be easily interpreted, hence convenient to develop networks. For that reason, 3 different scenarios of mobile WiMAX are simulated in OPNET version 14.5 for the project.

1.2 Related work

Orthogonal Frequency Division Multiplexing (OFDM) [3] is a special form of multi-carrier transmission technique in which a single high rate data stream is divided into multiple low rate data streams. In this way the symbol rate on each sub channel is greatly reduced, and hence the effect of InterSymbol Interference (ISI) due to channel dispersion in time caused by multipath delay spread is reduced. The use of adaptive modulation and coding (AMC) schemes in wireless communication systems is a topic widely considered and investigated in the recent literature [4]-[5]. In [6] the idea of combining the OFDM technique with adaptive modulation and coding is presented by showing the advantages in terms of overall throughput. Received signal-to-noise ratio (SNR) is applied to measure of the sub-channel state to choose a suitable code-rate for every subcarrier. Transmit power and modulation for each subcarrier is determined for reduction of the adaptive algorithm.

In addition, OFDMA is capable of managing the resource scheduling based on the frequency responses and channel time, which eventually allow allocation of different subcarriers to the individual users based on the channel condition. This technique is often known as multiuser diversity [7]. WiMAX offers very high spectral efficiency, particularly when using higher-order MIMO solutions [8].

1.3 Problem statement

In wireless broadband networks, noise and interference lead to errors in a wireless communication receiver especially in mobility and ranging scenarios. These are bad enough during voice calls, but are even more damaging to important information such as web pages and emails.

1.4 Objective

The main objective of this project is to explore more complex modulation methods that can guarantee higher data rates and require less interference and good line of sight (LOS) to the access points.

Implementing an adaptive modulation and coding scheme using AMC profiles to evaluate the performance according to spectral efficiency.

Create WiMAX network project with one scenario includes eight cells with eight users one in each cell, each of the seven users supports different modulation and coding scheme and the last one supported with the AMC.

Create traffic flow with IPv4 manually configured between the users and the server through the cloud routing node. Configure user's mobility scenario with star trajectory to evaluate the effects in the cell edges for each modulation and coding scheme of users.

Create another scenario with the same simulation parameter but all users will use the same MCS which the AMC in order to perform another comparison between the network using AMC and the previous scenario of network with multiple fixed MCSs

1.5 Methodology

Implement, and analyses of WiMAX model with different modulation and coding schemes to be compare with the AMC using OPNET network modeler.

Running the simulation for 20 minutes as the user's trajectory time in order to simulate the full trajectory length, and finally apply an analysis study to the simulation result individual statistics gathered by the simulator to summarize the effect of modulation and coding schemes with AMC profile.

Evaluate the performance metrics of each user which corresponds to the modulation and coding schemes it using in uplink and downlink, the chosen performance metrics are the end to end delay, jitter, and traffic sent and received for the IP traffic flows in the network.

1.6 Research outline

In this research, the modulation and coding techniques in wireless broadband network and the relation with spectral efficiency in WiMAX network are considered and will be explained. In the 1st chapter the study concerns and their relatives are introduce. In the 2nd chapter the literature of topics related to the project is reviewed, and link adaptation concept and its implementation in OFDMA transceiver are summarized .In the 3rd chapter, the proposed methodology that is used for modulation and coding schemes and the characteristics of its implementation in WiMAX network are introduced as mandated by IEEE 802.16e; which is the only version supported by OPNET modeller. In chapter 4, an OPNET network model of WiMAX is deployed and executed to establish the analysis study of the chosen individual statistics and will be discussed. Finally, in the 5th chapter the conclusion and recommendations for future studies are summarized.

CHAPTER TOW

LITEARUTRE OVERVIEW

CHAPTER TWO

2.1 Literature review

WIMAX stands for Worldwide Interoperability for Microwave Access; WiMAX refers to broadband wireless networks that are based on the IEEE 802.16 standard, which ensures compatibility and interoperability between broadband wireless access equipment. WiMAX is a wireless communications standard designed for creating metropolitan area networks (MANs). It is similar to the Wi-Fi standard, but supports a far greater range of coverage. While a Wi-Fi signal can cover a radius of several hundred feet, a fixed WiMAX station can cover a range of up to 30 miles. Mobile WiMAX stations can broadcast up to 10 miles. as show in figure (2.1), is primarily aimed at making broadband network access widely available without the expense of stringing wires (as in cable-access broadband) or the distance limitations of Digital Subscriber Line.

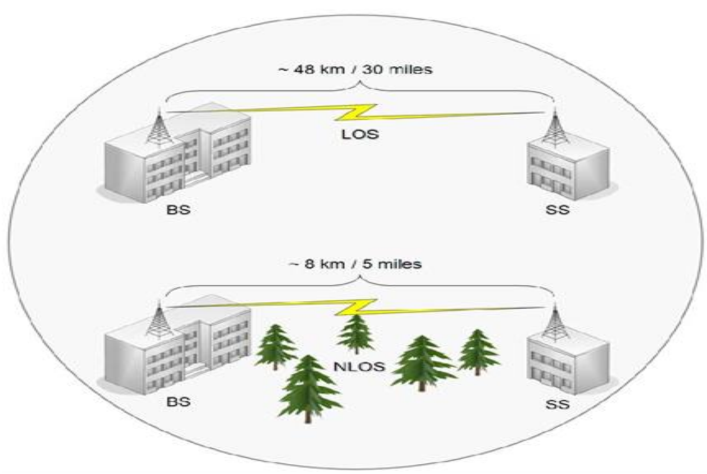

Figure **(2.1):** WiMAX coverage for Line of sight and NLOS environments

2.2 WiMAX evolution and development

802.xx family of IEEE standards dealing with local area networks and metropolitan area networks. The services and protocols specified in IEEE 802 map to the lower two layers (Data Link and Physical) of the seven-layer OSI networking reference model. These standards deal with Ethernet, Token Ring, Bridging & Virtual bridged LANs, WLAN, Wireless Personal Area Network (WPAN): Bluetooth, ZigBee, in or around a body, and so on [16].

It's obvious that WiMAX will replace all usual broadband access networks as promised, figure (2.2) illustrates the rabid developing of the IEEE 802.16 standard of WiMAX until the release 802.16g.

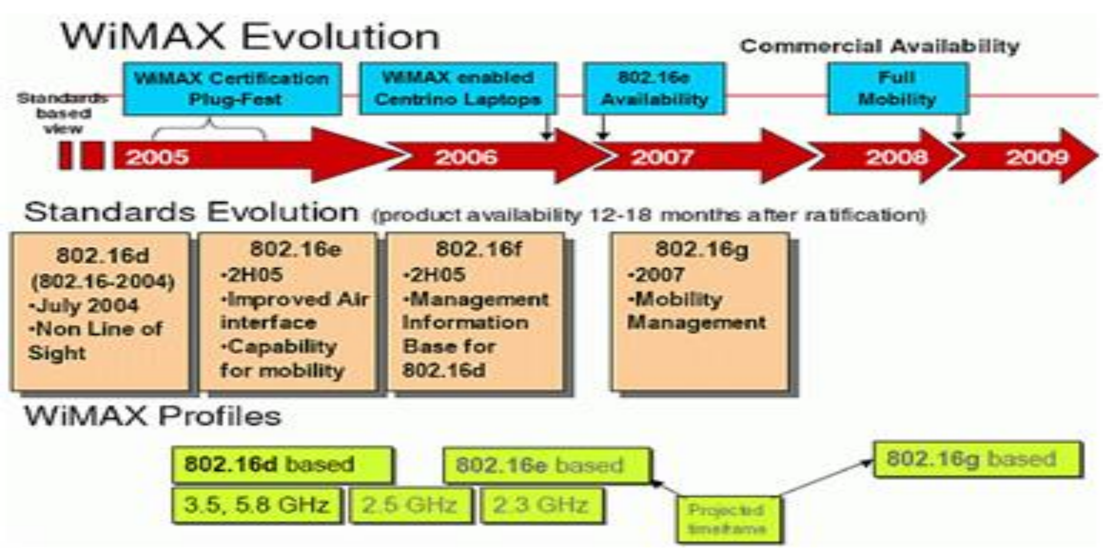

Figure **(2.2):** IEEE 802.16 Wimax standard development

During the development of IEEE 802.16 standard for fixed WiMAX, it was decided that mounting mobility support should also be considered.

Thereafter, Mobile WiMAX is developed under IEEE 802.16e standard with Orthogonal Frequency Division Multiple Access (OFDMA) as its physical layer [2]. Mobile WiMAX guarantees smooth and decent data transfer speed (10 Mb/s) for a moving vehicle (up to 120 km/h) from one BS to another with regional region service. Furthermore, the technology can be accessed through portable Universal Serial Bus (USB) that converts BS signal into Wireless Fidelity (WiFi) signal. To make it handy, the system can be preinstalled inside devices [3].

In the first phase WiMAX technology (based on IEEE 802.16-2004) provides fixed wireless connections, In the second phase WiMAX will be available as a cheap and self-installing Subscriber Terminal (ST), linked to PC and to antenna, The third phase enables portability, thus WiMAX (based on IEEE 802.16e) will be integrated into commercial laptops. In the last phase introduces better enhancement for mobility, neighboring, ranging, and handoff management.The IEEE 802.16e-2005 standard provides the air interface for WiMAX but does not define the full end-to-end WiMAX network. The WiMAX Forum's Network Working Group (NWG) is responsible for developing the end-to-end network requirements, architecture, and protocols for WiMAX, using IEEE 802.16e-2005 as the air interface. The WiMAX NWG has developed a network reference model to serve as an architecture framework for WiMAX deployments and to ensure interoperability among various WiMAX equipment and operators.

The following development of IEEE 802.16 standard is summarized in the table (2.1) which include new features and enhancement of WiMAX.

Table (2.1): WiMAX developing enhancement summarized

Standard	Description	Status
802.16-2001	Fixed Broadband Wireless Access (10–63 GHz)	Superseded

802.16a-2003	**Physical layer and MAC definitions for 2–11 GHz**	**Superseded**
802.16.2-2004	Recommended practice for coexistence	Superseded
802.16e-2005	Mobile Broadband Wireless Access System	Superseded
802.16g-2007	Management Plane Procedures and Services	Superseded
802.16j-2009	Multi-hop relay	Superseded
802.16h-2010	Improved Coexistence Mechanisms for License-Exempt Operation	Current
802.16m-2011	Advanced Air Interface with data rates of 100 Mbit/s mobile and 1 Gbit/s fixed. Also known as *Mobile WiMAX* or *Wireless MAN-Advanced*.	Current
802.16n	Higher Reliability Networks	Current
802.16p	Enhancements to Support Machine-to-Machine Applications	In Progress

WIMAX deployment is accomplished and it provides reasonable coverage in well-populated areas. WiMAX may initially be relegated to college campuses and larger corporate campuses where people are less mobile and costs containment is important.

2.3 WiMAX applications

The bandwidth and range of WiMAX make it suitable for the following potential applications:

- Providing a wireless alternative to cable and DSL for "last mile” broadband access.
- Providing data and telecommunications services.
- Providing a source of Internet connectivity as part of a business continuity plan.

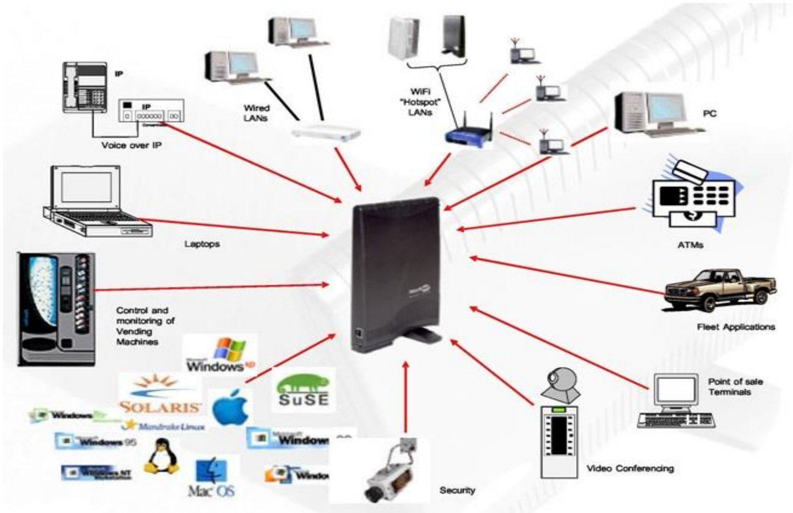

Figure **(2.3):** WiMAX various applications

Familiar WiMAX capable applications are Broadband Internet Access, VoIP, IPTV services, and also Cellular Phones.

2.4 WiMax Quality of Service (QoS)

Quality of Service (QoS) has to be implemented efficiently. Under Mobile WiMAX QoS classes, Real-Time Variable Rate (RTVR) suits flawlessly for this project. It supports real-time applications with variable-size data packet bursts, providing better throughput by “bursting” more than one packet at a time to reduce wait time duration. An example application of RT-VR is video and audio streaming. To ensure connection between a mobile subscriber (MS) and a BS, they must “form a unidirectional connection between their respective Media Access Control (MAC) layers” sharing same QoS parameters [8].

Excellent Quality Of service management appears from variety of WiMAX features. Just as on a Wi-Fi network, WiMAX users share a data and QoS can degrade as more users are added to the network. Using the QoS features of WiMAX service providers can guarantee certain users specific bandwidth amounts by limiting the bandwidth consumption of other users [6].

2.5 OFDM

OFDM stands for Orthogonal Frequency Division Multiplexing; it's a technology that provides the operator to beat the challenges of Non-Line-of-Sight (NLOS) transmission in the more efficient manner. OFDM waveform put forward the advantage of functioning with the larger delay spread of the NLOS background.

Typically, OFDM is a method of encoding digital data on multiple carrier frequencies .It has developed into a popular scheme for wide band digital communication, used in applications such as digital television and audio broadcasting, DSL Internet access, wireless networks, power line networks, and 4G mobile communications [7].

Also OFDM is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method. A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

In practical when the data is transmitted at high bit rates, over mobile radio channels, the channel impulse response can extend over many symbol periods, which lead to intersymbol interference (ISI). Orthogonal Frequency Division Multiplexing (OFDM) is one of the promising can did to mitigate the ISI. In an OFDM signal the bandwidth is divided into many narrowband channels. Each sub channel is typically chosen narrow enough to eliminate the effect of delay spread [4].Equipment vendors are coming together to speed the adoption of OFDM. Orthogonal Frequency Division Multiplexing

OFDM is a multicarrier transmission technique, many carriers, each one being modulated by a low rate data stream share the transmission bandwidth [9].

With the excellent quality of OFDM functionality, time and use of a cyclic prefix and it also removes the Inter Symbol Interference (ISI) complications of adaptive equalization. Multiple narrowband orthogonal carriers are composed because of OFDM waveform, localizing selective fading to a subset of carriers that are comparatively simple to equalize [7].

A comparison between an OFDM signal and a single carrier signal, with the information being sent in parallel for OFDM and in series for single carrier are shown in Figure (2.4).

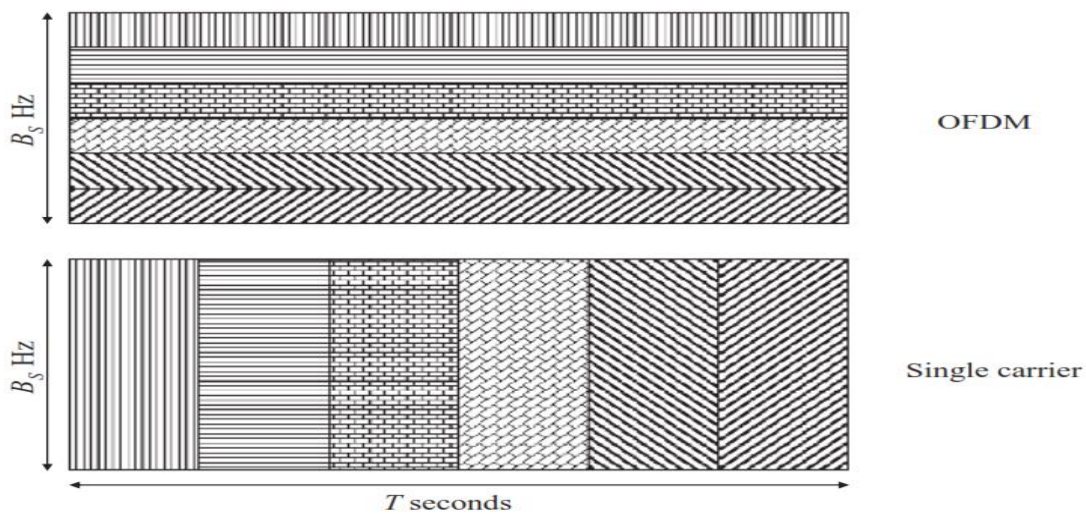

Figure **(2.4):** SC-FDM and OFDM

The facility to remove delay spread, Inter Symbol Interference (ISI) and multi-path in a proficient manner allows for higher data rate throughput. It is simpler to equalize the individual OFDM carriers than to equalize the broader single carrier signal. For these entire reasons modern international standards such as those set by IEEE 802.16, have created OFDM as the ideal technology [4].

The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly modulated narrowband signals rather than one rapidly modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to eliminate intersymbol interference (ISI) and utilize echoes and time spreading (on analogue TV these are visible as ghosting and blurring, respectively) to achieve a diversity gain, i.e. a signal-to-noise ratio improvement. This mechanism also facilitates the design of single frequency networks (SFNs), where several adjacent transmitters send the same signal simultaneously at the same frequency, as the signals from multiple distant transmitters may be combined constructively, rather than interfering as would typically occur in a traditional single-carrier system[7].

2.5.1 OFDM advantages

OFDM has high spectral efficiency as compared to other double sideband modulation schemes, spread spectrum .It can easily adapt to severe channel conditions without complex time-domain equalization.

It has robust against narrow-band co-channel interference, and ha Robust against inter-symbol interference (ISI) and fading caused by multipath propagation. Furthermore it is efficient in implementation using Fast Fourier Transform (FFT).As well it has low sensitivity to time synchronization errors.

2.5.2 OFDM Disadvantages

OFDM is sensitive to Doppler shift. It is as well sensitive to frequency synchronization problems. Also it has high peak-to-average-power ratio (PAPR), requiring linear transmitter circuitry, which suffers from poor power efficiency. It has also Loss of efficiency [7].

2.6 OFDMA

Orthogonal Frequency-Division Multiple Access (OFDMA) is a multi-user version of the popular orthogonal frequency-division multiplexing (OFDM) digital modulation scheme. Multiple access is achieved in OFDMA by assigning subsets of subcarriers to individual users as shown in the illustration below. This allows simultaneous low data rate transmission from several users. OFDMA is introduced by WiMAX in the release of IEEE802.16e development standard. Figure2.5 shows how OFDM differs from OFDMA.

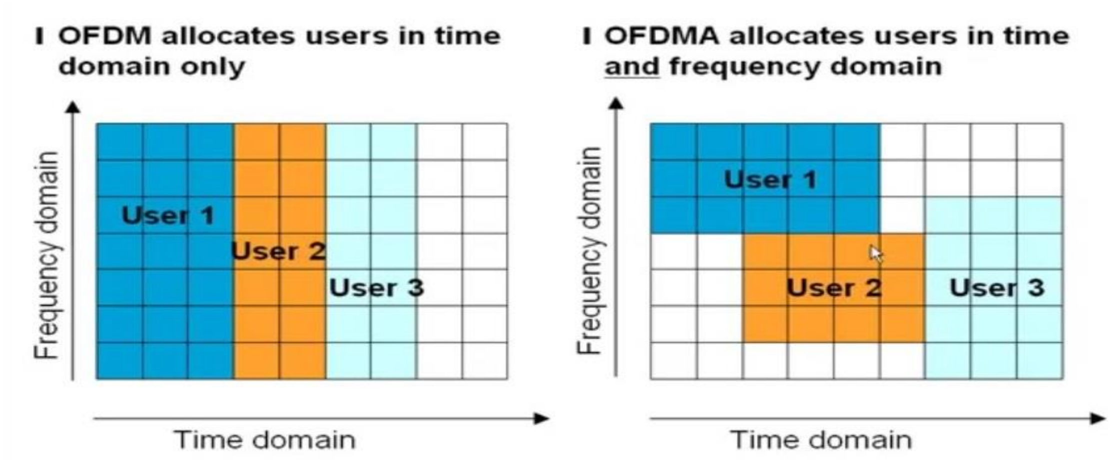

Figure2.5: OFDM & OFDMA allocations

2.7 WiMAX physical layer

The IEEE 802.16 PHY system operates in the range of 10 to 66 GHz. Line-of-sight propagation paths are a practical necessity in such systems. The standard specifies single carrier modulation schemes with FEC. The air interface supports both FDD and TDD operation modes.

The standard supports three different modulation schemes. It supports higher order 16-QAM and 64-QAM schemes to maximise link throughput and also supports QPSK for robustness and reliability. While both

QPSK and 16-QAM are mandatory on the downlink, the uplink need support only QPSK. Figure (2.6) shows WiMAX physical layer block diagram process.

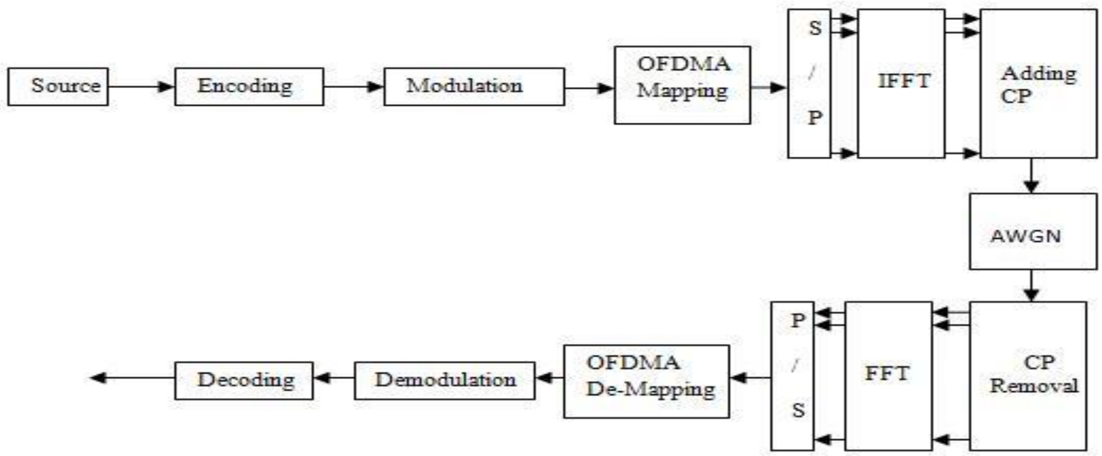

Figure2.6: WiMAX physical layer block diagram

The OFDMA parameters that mandated by the WiMAX forum are shown in the table (2.2) from [18]

Table (2.2) OFDMA parameters

Parameter	**Value**
Channel bandwidth (MHZ)	1.25 / 5 / 10 / 20
FFT size (N fft)	128 / 512 / 1024 / 2048
OFDMA symbol duration (Ts=Tb+Tg)	102.9 μs
CP time (Tg=Tb/8)	11.4μs

2.8 Radio Link Control

In addition to performing the traditional functions, such as power control and ranging, the RLC is responsible for transitioning from one PHY scheme to another. Combinations of PHY modulation and FEC schemes used between the BS and SSs are termed as downlink or uplink burst profiles depending on the direction of flow. In IEEE 802.16, burst profiles are identified using Downlink Interval Usage Code (DIUC) and Uplink Interval Usage Code (UIUC). The RLC is capable of switching between different PHY burst profiles on aper-frame and per-SS basis. The SSs use pre-set downlink burst profiles during connection setup. Thereafter, the BS and the SSs continuously negotiate uplink and downlink burst profiles in an effort to optimise network performance. These burst profiles defines the type of modulation and coding and link characteristics.

2.9 Medium Access Control

The primary task of the WiMAX MAC layer [15, 16] is to provide an interface between the higher transport layers and the physical layer. The MAC layer takes packets from the upper layer that is called MAC service data units (SDU) and organizes them into MAC protocol data units (PDU) for transmission over the air. For received transmissions, the MAC layer does the reverse. The IEEE 802.16-2004 and IEEE 802.16e-2005 MAC design includes a convergence sub layer that can interface with a variety of higher layer protocols, such as ATM, Ethernet, IP, and adaptable for future protocol. The WiMAX MAC uses a variable length PDU and offers a lot of flexibility to allow for their efficient transmission. For example, multiple PDUs of same or different lengths may be aggregated into a single burst to save PHY overhead. Similarly, multiple SDUs from the higher layer service may be concatenated into a single PDU to save MAC header overhead. Conversely, large SDUs may be fragmented into smaller PDUs and sent across multiple frames.

2.10 WiMAX system minimum requirement

WiMAX system minimum requirements consist of a WiMAX tower, similar in concept to a cell-phone tower – A single WiMAX tower can provide coverage to a very large area as big as 3,000 square miles (~8,000 square km). And aWiMAX receiver the receiver and antenna could be a small box or

Personal Computer Memory card, or they could be built into a laptop the way WiFi access is today.

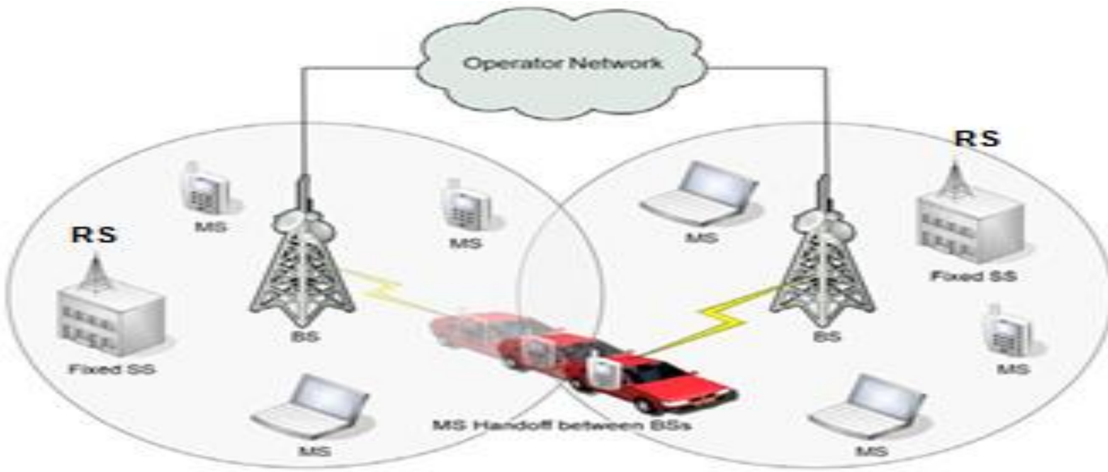

Figure2.7: principle of WiMAX broadband access network

The Base Station (BS) is the node that logically connects wireless subscriber devices to operator networks. The BS maintains communications with subscriber devices and governs access to the operator networks.

The Subscriber Station (SS) is a stationary WiMAX-capable radio system that communicates with a base station, although it may also connect to a relay station in multi-hop relay network operations.

The Mobile Station (MS) is an SS that is intended to be used while in motion at up to vehicular speeds. Compared with fixed (stationary) SSs, MSs typically are battery operated and therefore employ enhanced power management.

The Relay Station (RS) is a SS configured to forward traffic to other RSs or SSs in a multi-hop Security Zone The RS may be in a fixed location (e.g., attached toa building) or mobile (e.g., placed in an automobile). The air interface between an RS and an SS is identical to the air interface between a BS and an SS.

The operator network encompasses infrastructure network functions that provide radio access and IP connectivity services to WiMAX subscribers. These functions are defined in WiMAX Forum technical specifications as the access service network (radio access) and the connectivity service network (IP connectivity). WiMAX devices communicate using two wireless message types: management messages and data messages. Data messages transport data across the WiMAX network. Management messages are used to maintain communications between an SS/MS and BS, e.g., establishing communication parameters, exchanging security settings, and performing system registration events (initial network entry, handoffs, etc.)

2.11 Reference WiMAX Network Architecture

The WiMAX Forum's Network Working Group (NWG), is responsible for developing the end-to-end network requirements, architecture, and protocols for WiMAX, using IEEE 802.16e-2005 as the air interface [10].

The WiMAX NWG has developed a network reference model to serve as an architecture framework for WiMAX deployments and to ensure interoperability among various WiMAX equipment and operators. Figure (2.4) shows a simplified illustration of IP-based WiMAX network architecture. The overall network may be logically divided into three parts [11]:

- Mobile stations used by the end user to access the network.
- The access service network (ASN), which comprises one or more base stations and one or more ASN gateways that form the radio access network at the edge.
- The connectivity service network (CSN), which provides IP connectivity and all the IP core network functions.

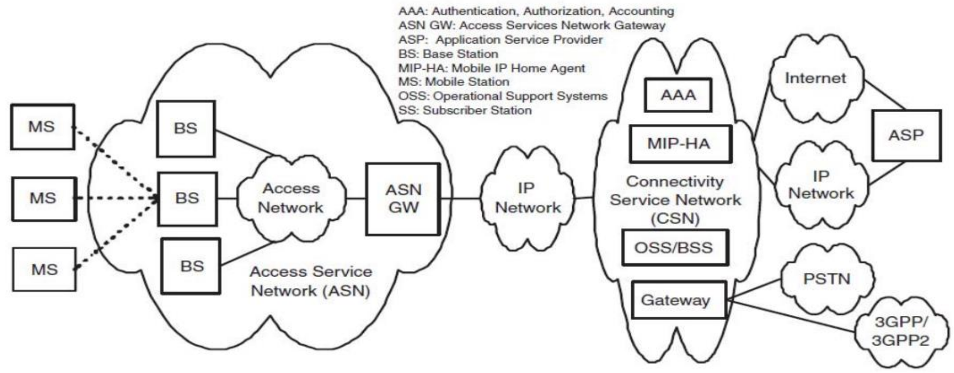

Figure2.8: IP-based WiMAX network architecture.

The network reference model developed by the WiMAX Forum NWG defines a number of functional entities and interfaces between those entities. Figure (2.8) shows some of the more important functional entities.

Typically the BS is responsible for providing the air interface to the MS. Additional functions that may be part of the BS are micro mobility management functions, such as handover triggering and tunnel establishment, radio resource management, QoS policy enforcement, DHCP (Dynamic Host Control Protocol) proxy, key management, session management, and multicast group management [11].

Access service network gateway (ASN-GW) typically acts as a layer 2 traffic aggregation point within an ASN. Additional functions that may be part of the ASN gateway include intra-ASN location management and paging, radio resource management and admission control, caching of subscriber profiles and encryption keys, AAA client functionality, establishment and management of mobility tunnel with base stations, foreign agent functionality for mobile IP, and routing to the selected CSN.

Connectivity service network (CSN) provides connectivity to the Internet, ASP, other public networks, and corporate networks. The CSN is owned by the network service provider and includes AAA servers that support authentication for the devices, users, and specific services. The CSN also provides per user policy management of QoS and security. The CSN is also responsible for IP address management, support for roaming between different NSPs, location management between ASNs, and mobility and roaming between ASNs. Further, CSN can also provide gateways and interworking with other networks, such as public switched telephone network (PSTN), 3GPP, and 3GPP2 [12].

In addition to functional entities, the reference architecture defines interfaces, called reference points, between function entities. The interfaces carry control and management protocols in support of several functions, such as mobility, security, and QoS, and so on.

The WiMAX network reference model defines reference points between:

- MS and the ASN, called R1, which in addition to the air interface includes protocols in the management.
- MS and CSN, called R2, which provides authentication, service authorization, IP configuration, and mobility management.
- ASN and CSN, called R3, to support policy enforcement and mobility management.
- ASN and ASN, called R4, to support inter-ASN mobility.
- CSN and CSN, called R5, to support roaming across multiple NSPs.
- BS and ASN-GW, called R6, which consists of intra-ASN bearer paths and IP tunnels for mobility events.
- BS to BS, called R7, to facilitate fast, seamless handover.

2.12 Link Adaptation

Link adaptation deals with how to set the transmission parameters of a radio link to handle diversities of the radio-link quality. Power or rate dynamical controls are the main mechanisms behind the link adaptation concept.

2.12.1-Dynamic transmit-power control

Dynamic transmit-power control dynamically adjusts the radio-link transmit power to compensate for diversities and differences in the immediate channel conditions. The aim of these adjustments is to maintain a (near) constant E_b/N_0 at the receiver to successfully transmit data without the error probability becoming too high. In principle, transmit-power control increases the power at the transmitter when the radio link experiences poor radio conditions (and vice versa). Thus, the transmit power is in essence inversely proportional to the channel quality, as illustrated in Figure (2.9a). This results in a basically constant data rate, regardless of the channel diversities. For services such as circuit-switched voice, this is a desirable property. Transmit-power control can be seen as one type of link adaptation that is, the adjustment of transmission parameters, in this case the transmit power to adapt to differences and diversities in the immediate channel conditions to maintain the received E_b/N_0 at a desired level.

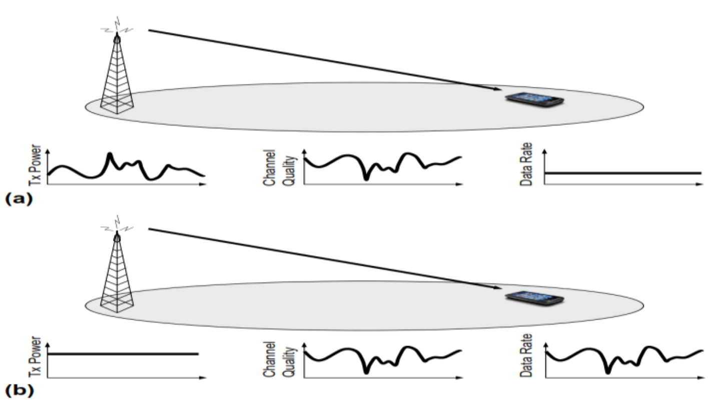

Figure **(2.9)** **(a)** Power control and **(b)** rate control

2.12.2-Dynamic rate control

An alternative to transmit-power control is link adaptation by means of dynamic rate control. Rate control does not aim at keeping the immediate radio-link data rate constant, in any case of the immediate channel conditions. In state, with rate control, the data rate is dynamically adjusted to recover for the varying channel conditions. In situations with useful channel conditions, the data rate is increased, and vice versa. So, rate control maintains the $E_b/N_0 \sim P/R$ at the desired level, not by adjusting the transmission power P, but rather by adjusting the data rate R. This is illustrated in Figure (2.9b).

It can be shown that rate control is more efficient than power control. Rate control in principle means that the power amplifier is always transmitting at full power and therefore efficiently exercised.

In practice, the radio-link data rate is controlled by adjusting the modulation scheme and/or the channel coding rate. In the case of advantageous radio-link conditions, the Eb/N0 at the receiver is high and the main limitation of the data rate is the bandwidth of the radio link.

2.13 Link adaptation in WiMAX

In WiMAX link adaptation monitors the uplink and downlink quality using the signal to noise ratio (SNR) and adaptively selects the best modulation and coding scheme (MCS) for overcoming time-selective signal fading and maximizing air-link capacity and coverage. Modulation schemes include QPSK, 16-QAM, and 64-QAM, where 64-QAM is optional on the uplink. Channel coding schemes are used to help reduce the SNR requirements by recovering corrupted packets that may have been lost due to burst errors or frequency selecting fading. These schemes generate redundancy bits to accompany information bits when transmitting over a channel. Coding schemes include convolution coding (CC) at various coding rates (1/2, 2/3 and 3/4) as well as Convolution turbo codes (CTC) at various coding rates (1/2, 2/3, 3/4, and 5/6). The coding rate is the ratio of the encoded block size to the coded block size. For example, a code rate of 1/2 indicates that a block of 12 bytes would be encoded as a block of 24 bytes. Ultimately, the link performance is a trade-off between efficiency and robustness.

Table (3.1) MCS vs SNR in AMC

Modulation	**Bits/Baud**	**FEC rate**	**Spectral efficiency**	**Receiver SNR (dB)**
QPSK	2	1/2	1	5
		3/4	1.5	8
16-QAM	4	1/2	2	10.5
		3/4	3	14
64-QAM	5	1/2	3	16
		2/3	4	18
		3/4	4.5	20
		5/6	5	22

As channel conditions degrade, the MCS is adaptively downgraded to a more robust, lower order modulation scheme to maintain connection quality and link stability. Similarly, as channel conditions improve, the MCS is adaptively upgraded to a higher, more efficient MCS. The spectral efficiency and minimum receiver SNR for a given MCS are shown in Table (3.1). Note that SNR values were derived assuming the additive white Gaussian noise (AWGN) environment using tail-biting CC [19].

CHAPTER THREE

DESIGN AND IMPLEMENTATION

CHAPTER THREE

3.1 System Model

Here the simulation setup will be discussed as the simulation parameters that configured in OPNET for the WiMAX network scenarios, also some information about the MCS burst profiles and the AMC default profiles will be expressed.

Network model performance analysis is accomplished by using the standalone discrete event simulation from the Optimized Network modeler software (OPNET) of version 14.5, which offers an exclusive set of tools for planning, configuring, and analyzing wireless networks projects.

IP traffic flow allows specifying the type of service and the traffic rate whatever the type of the application in this traffic, a randomly segments just generated and transmitted from the source to the destination as addressed by the traffic flow lines.

3.2 Simulation description

The network model consist of eight cells each cell includes a WiMAX base station (BS) and a mobile subscriber station (SS), in order to evaluate the performance of modulation and coding for different users the mobility and ranging should be enabled, which defined by the trajectory that users follow, the trajectory enables the evaluation of the user mobility inside the cell and at the cell edges as represented by the brown star-like shape in the network model figure 3.1.

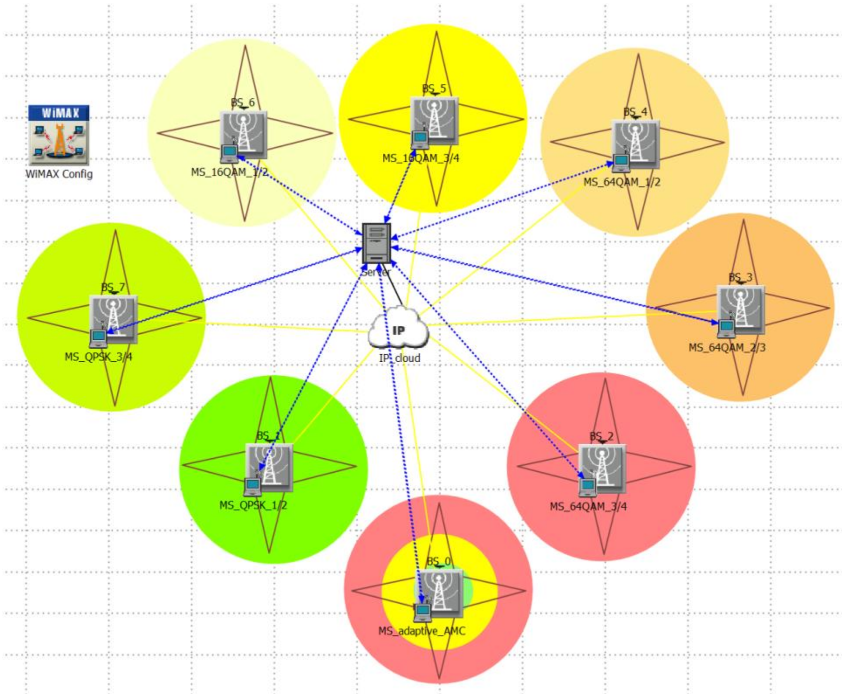

Figure 3.1 System network model

The blue lines represent the IP traffic flow between the users and the server, the yellow lines represents the physical interfaces that connects the users to the server through the IP cloud node which meant to introduce the internet routing mechanism.

Mainly, there are two scenarios created for the WiMAX network model, the first scenario each user uses different modulation and coding scheme including the adaptive modulation and coding. Second scenario constructs adaptive modulation and coding for all users to help us in evaluating the performance of the network in case of different fixed MCS and in case of AMC.

The first scenario is for evaluating the performance of each type of modulation and coding schemes in different distances from the base station while the user moving from and to the cell edges.

Simulation attributes are the same in the two scenarios represented by the simulation parameters in table 3.1 in simulation parameters.

3.3 Simulation parameters

The general configuration parameter of WiMAX network is set as in the table 3.1, these parameter are used in the both scenarios to establish a fairly compression. Time Domain Duplexing and OFDMA techniques are used as an exclusive features introduced in IEEE-802.11e standard.

Table 3.2 Simulation parameters

General configuration	
Attributes	**value**
Efficiency mode	Mobility and ranging enabled
Physical profile	OFDM
OFDM physical profile	Wireless-OFDMA 5 MHz
Duplexing technique	TDD
Frame duration	5 millisecond
Symbol duration	100.8 millisecond
Number of subcarriers	512
Supported service classes	Bronze, Silver, Gold, and Platinum
Traffic type	IP traffic flow
Traffic rate	64 Kb/s = 10 packets
Traffic Type of service	Excellent effort
IP traffic addressing	Manually , IPv4
Base station configuration	
Antenna gain	15 dBi
Maximum transmission power	2 W
Physical profile	OFDM
Supported service profiles	Silver and platinum
IP traffic interface	IF32
Internet traffic interface	IF24
Mobile station configuration	
Antenna gain	-1 dBi
Maximum transmission power	0.5 W

Physical profile	OFDM
Supported service class	Silver
Buffer size	64 Kb
MCS	QPSK-1/2, QPSK-3/4, 16QAM-1/2, 16QAM-3/4, 64QAM-1/2, 64QAM-2/3, 64QAM-3/4, and AMC

Table 3.3 AMC profiles configuration

Adaptive Modulation and Coding Profiles		
MCS	**CINR Mandatory exit threshold (dB)**	**CINR Minimum Entry threshold (dB)**
QPSK-1/2	-20	2
QPSK-3/4	5	5.9
16QAM-1/2	8	8.9
16QAM-3/4	11	11.9
64QAM-1/2	14	14.9
64QAM-2/3	17	17.9
64QAM-3/4	19	19.9

Table 3.4 Service classes' characteristics

Service classes		
Service class name	**Scheduling type**	**Traffic rate**
Bronze	Best effort	384 Kbps
Silver	rtPS	0.5 Mbps
Gold	ertPS	1 Mbps
Platinum	UGS	1.5 Mbps

A traffic type give the user with the specific type of traffic a priority upon other users, so as mentioned before that all users use the same traffic with one type of service, all the users will have the same priority in the network.

The service class specifies the scheduling mechanism and the data rate for the user with the supported service class, so as all the users use the same service class which is the (Silver) service class, then will all have the same scheduling and data rate characteristics. Silver service class defines the Real-Time Polling Service (rtPS) which ensures that the users get periodic bandwidth request opportunities. The users can then request bandwidth from the base station. This service permits the users to transmit without contending for the uplink channel and is ideal for applications that periodically generate variable sized packets. It targets applications such as voice over Internet Protocol (VoIP), streaming audio and streaming video.

The mobility track of the user is set to 20 minutes time long as the simulation running time, to allow tracking and gathering the results while the user complete its full trajectory.

3.4 Performance metrics

Two types of results are collected in discussed in the next chapter, physical statistics and traffic statistics, physical statistics are the Delay, Load, and Throughput in the physical layer. Traffic statistics are the Packet End to End Delay, Jitter, and traffic sent and received. The equations used by OPNET behind those results will be mentioned in this section.

3.4.1 End to End delay

Delay or latency could be defined as the time taken by the packets to reach from source to destination. The main sources of delay can be categorized into: propagation delay, source processing delay, network delay and destination processing delay.

Here we have calculated end to end delay which is a measure of elapsed time taken during modulation of the signal and the time taken by the packets to reach from source to destination. Here the packet losses some energy as well in the form of noise which is also taken into consideration. End to end delay could be measured as the difference of Packet arrival and packet start time [25]. Equation (3.1) shows the calculation of average end to end delay:

$$Delay = \sum Packet \text{ Arrival Time} - \ Packet\ Start \text{ Time} \tag{3.1}$$

3.4.2 Jitter or Packet Delay variance

Jitter could be termed as the variation in delay or packet delay variation. The value of jitter is calculated from the end to end delay. Measuring jitter is critical element to determining the performance of network and the QoS the network offers. It is the variation in the time between packets arriving. Jitter is commonly used as an indicator of consistency and stability of a network. Equation (3.2) shows how to calculate jitter.

$$Jitter = \frac{\sum_{i=0}^{n}\left(Delay_i - \overline{Delay}\right)^2}{N} \tag{3.2}$$

3.4.3 Throughput

Throughput is measure of number of packets successfully delivered in a network. It is measured in terms of packets/second[25]. The value of throughput should be high or else it affects every service class defined in WiMAX. Equation (3.3) shows how to calculate throughput.

$$\boldsymbol{Throughput} = \frac{\sum_i \textbf{Packets } \boldsymbol{Delivered}}{\sum_i \boldsymbol{Packet\ Arrival - Packet\ start\ time_i}} \tag{3.3}$$

CHAPTER FOUR

RESULTS AND DISCUSSION

CHAPTER FOUR

Result and Discussion

4.1 Introduction

By establishing this chapter the network model simulation is executed and here we will figure and discuss the graphs of the results gather from the discrete event simulation of our model according to each scenario in order, and the comparison of the two scenarios.

The chosen individual discrete event simulation statistics are: WiMAX physical statistics: Throughput, Load, and delay. Traffic statistics: End to end delay, Jitter, traffic sent and received.

WiMAX physical layer statistics is used to measure the performance between the two scenarios in case of the other scenario uses AMC for all users. The results collected and shown below are for the uplink and downlink connection or the connection from the mobile stations to the base stations. The performance metrics equations used by OPNET to calculate those results here are mentioned before in chapter 3.

Because of the mobility trajectory of the user the results seems to be distorted and discrete so in some figures we will use the average results for better visualization.

4.2 Case Number One

As mentioned before in chapter 3, the first scenario will execute the model with different types of MCS in to see the performance of each MCS and compare it with the other according to traffic statistics metrics.

In figure 4.1 the traffic End to end delay is shown, and it’s obvious that there are some lines are discrete or disconnected that where the user in the cell edges and hard handover is processed and reconnected to the base station, higher delays shown with the low order MCS like QPSK-1/2, QPSK-3/4, and 16QAM-1/2. Higher order MCS like 64QAM shows the minimum delays but with longer disconnects in the cell edges. The AMC and the 16QAM-3/4 show an average delay values with minimum disconnection intervals.

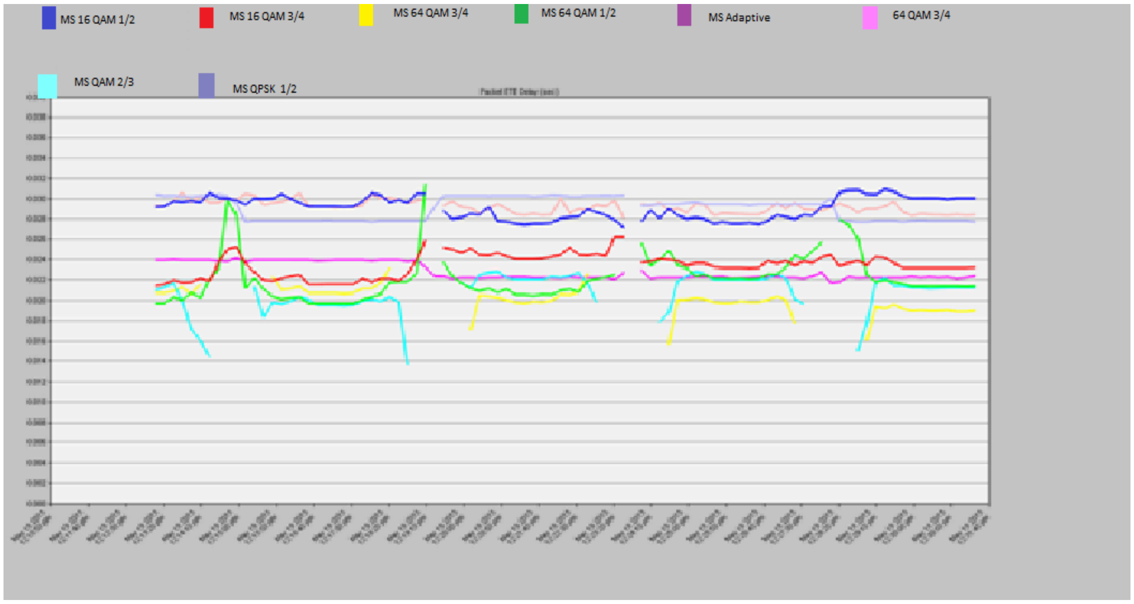

Figure 4.1 Uplink packet End to End delays in traffic

The jitter statistics are shown by the average values in the figure 4.2 below, the AMC and QPSK-1/2 low order MCS introduce the minimum jitter value and continuously connection.

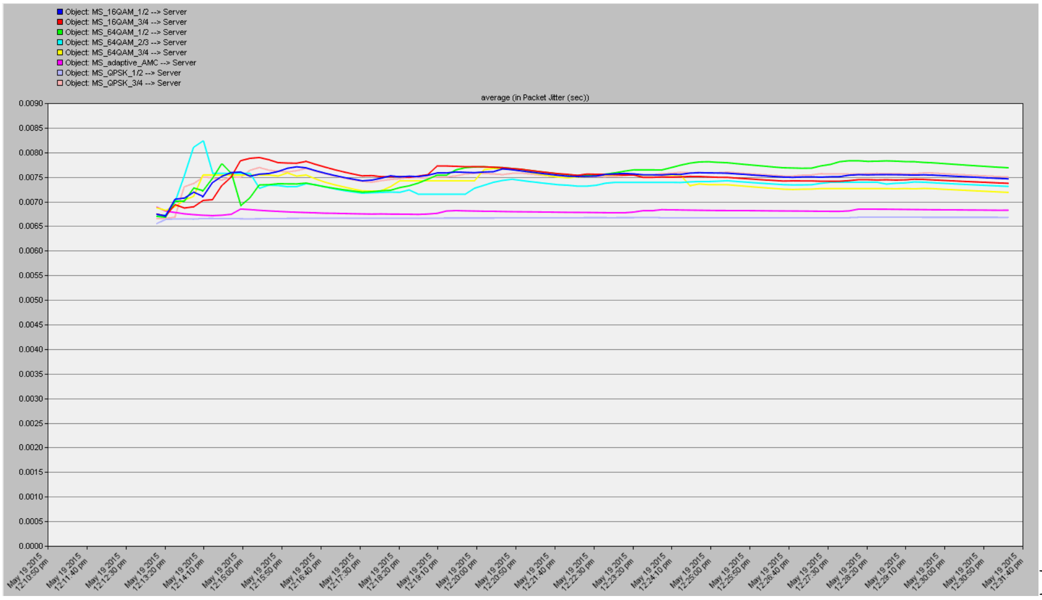

Figure 4.2 Uplink packet Jitter in traffic

From 4.2, the higher order MCS shows higher jitter, the disconnections not show because the figure is taken average values of the statistics.

The traffic sent is constant to 10 packets per sec from all users as specified in the simulation parameters; the traffic received is shown in figure 4.3, which reflect the realization from previous results, that the low order MCS like QPSK and 16QAM-1/2 and the AMC has the better performance in of traffic received and the disconnection intervals, while the higher order MCS has higher disconnection intervals which lowers the traffic received amount also.

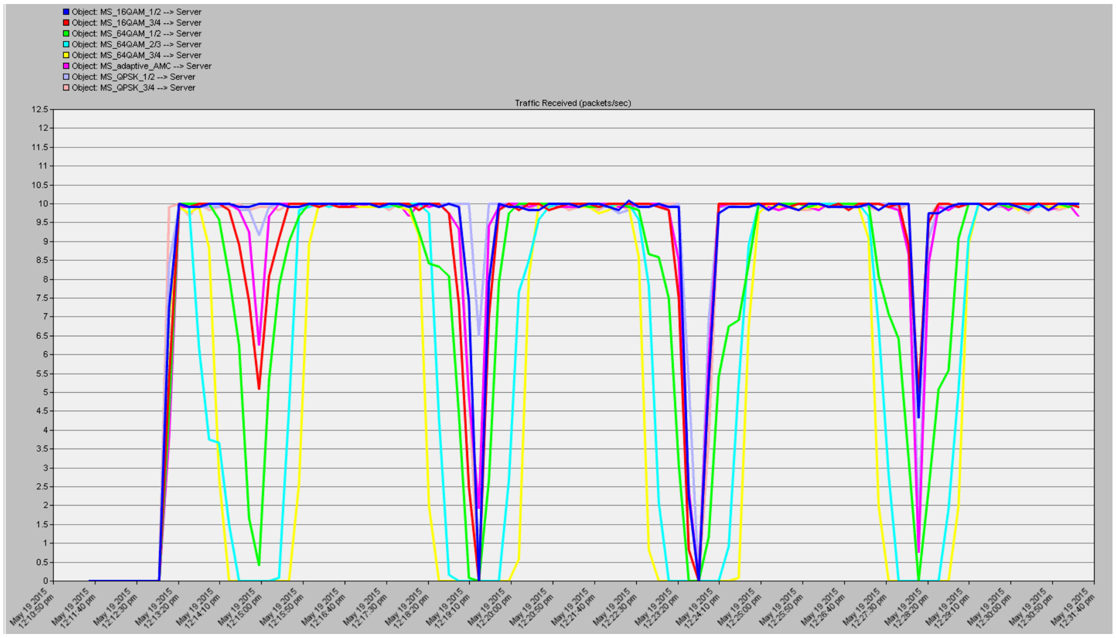

Figure 4.3 Uplink Traffic received

For the downlink traffic from the server to the users, the end to end delay is shown in the figures 4.4, as we can see the AMC user shows unusual activity in the earlier time of simulation this because the adaptation mechanism process, also the AMC user has little variations in the packet end to end delay while in other user it’s constant, this because the adaptation of link while the user moving in the track.

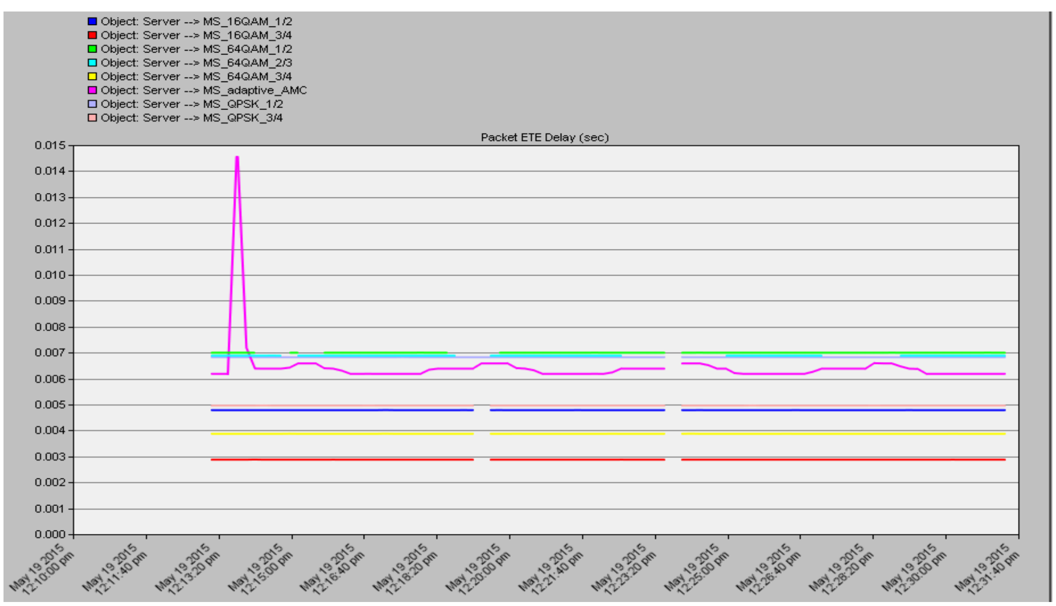

Figure 4.4 Downlink packet End to End delays in traffic

Here the downlink packet jitter values is very meager than in the uplink, and also there is an unusual high jitter from the AMC user in the beginning of the simulation, this is shown in figure 4.5.

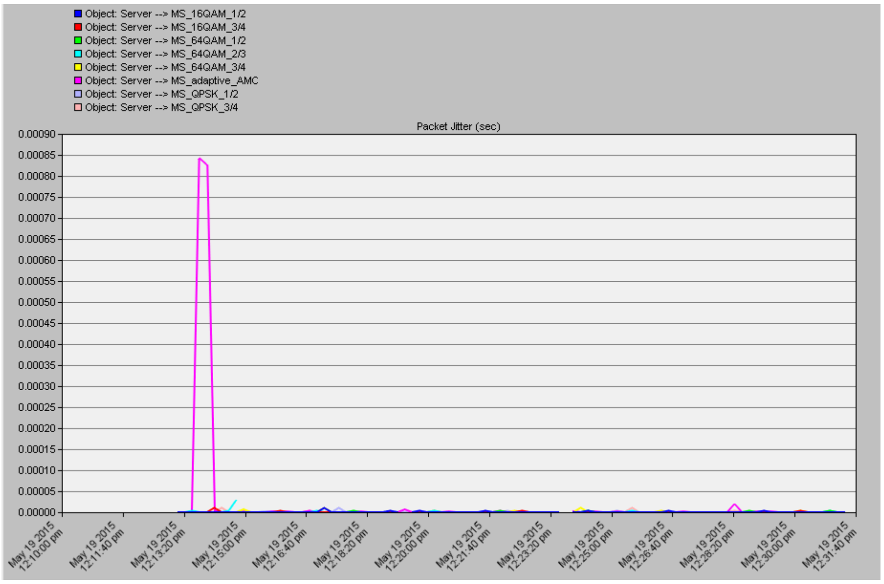

Figure 4.5 Downlink packets Jitter in traffic

As in the uplink the traffic sent is constant to 10 packets per second, while the traffic received is approximately identical to the uplink with a little variation in the beginning, the higher order MCS shows the maximum disconnection intervals specially the 64QAM-3/4, the AMC has the most stable statistics as in the other low order MCS, this is noted from the figure 4.6.

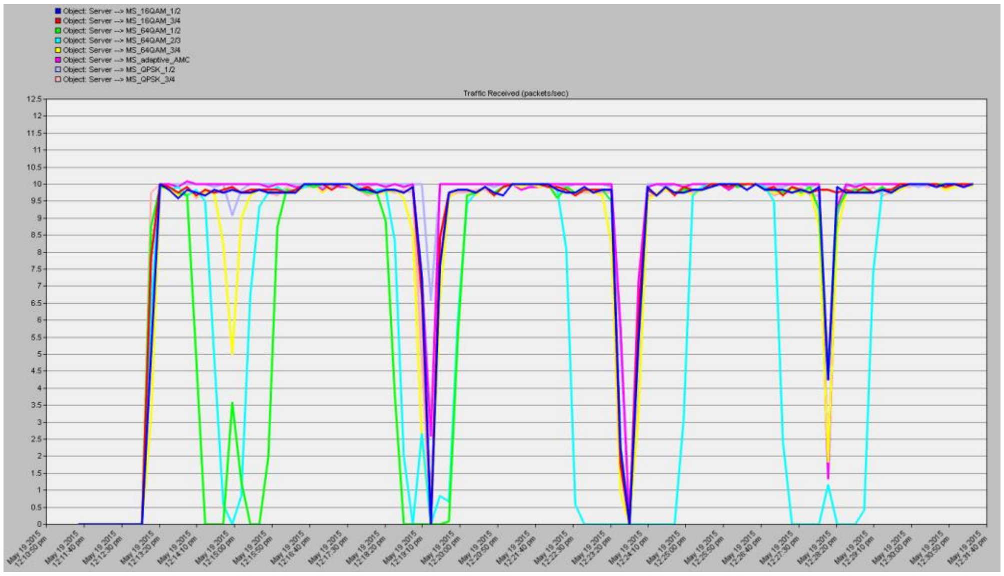

Figure 4.6 Downlink Traffic received

4.3 Case Number Two

The second part of this study is to compare the first network which each user uses a different MCS and the second network which all user's uses AMC, the performance metrics here is the WiMAX physical layer statistics.

In the figure 4.7 the blue line represent the AMC network and the red line represent the fixed MCS network, as we can see the delay is higher in the fixed MCS network because with different types MCS the network takes more time in processing and initializing the physical layer components, but with the AMC in all users the network will adapt after a while then the performance will be stable.

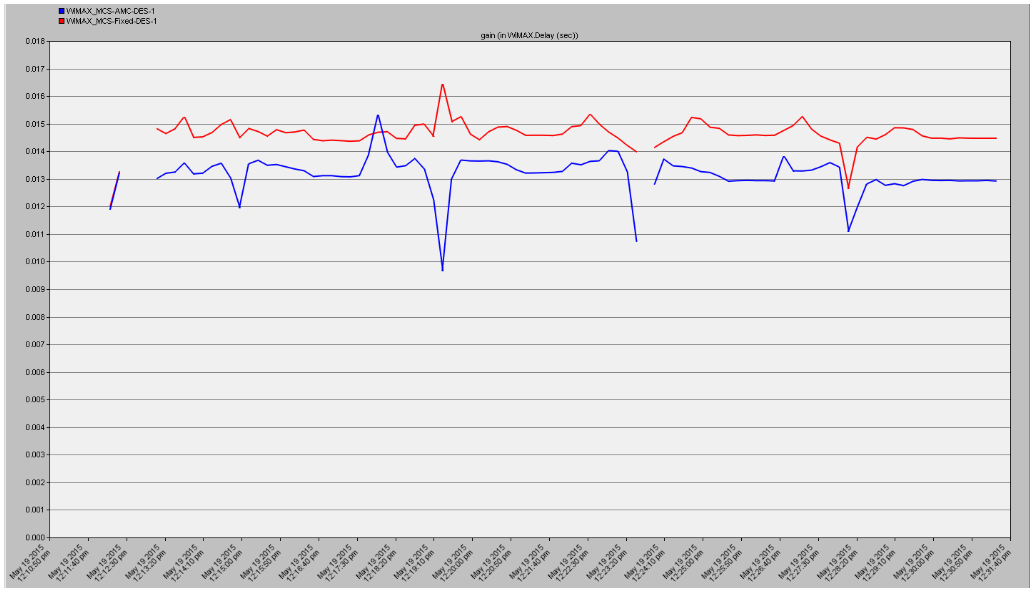

Figure 4.7 WiMAX physical layer delay

The load in the two networks is constant as the traffic sent and received which were 10 packets per second for each of the eight users, that's make the load in the network is constant to 160 packets per second. Then the throughput should be around the load value as in the figure 4.8.

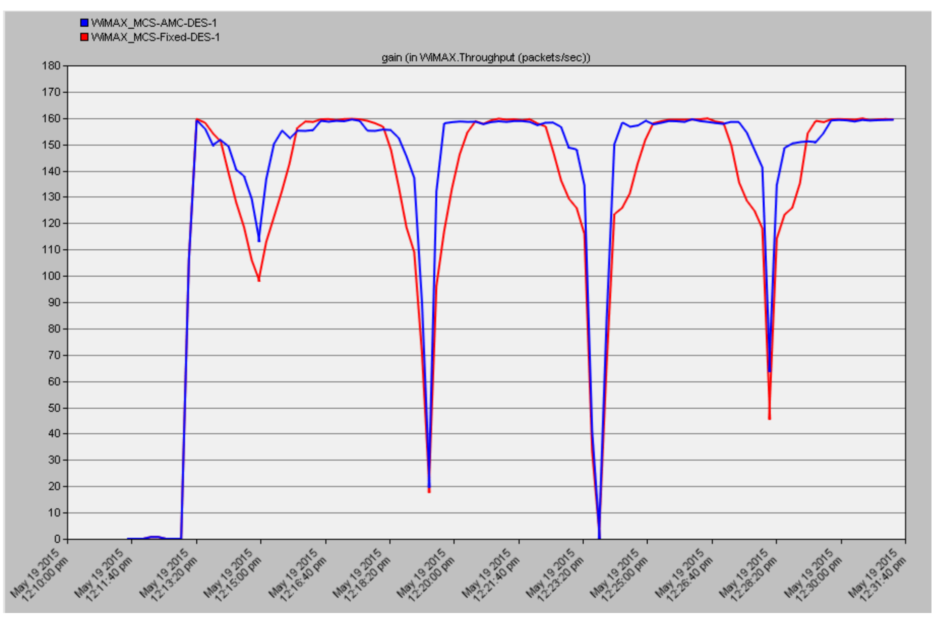

Figure 4.8 WiMAX physical layer throughputs (packets/sec)

From figure 4.8 it's obvious that the throughput in the AMC network is better and more stable than in the different fixed MCS network.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

CHAPTER FIVE

5.1 Conclusion and Recommendation

Here the results gathered from the chosen individual statistics are discussed and summarized in this chapter with some recommendations and future work.

WiMAX offers multiple modulations and coding schemes (MCS) with the adaptive modulation and coding (AMC), the AMC is dependable when the link adaptation is required; the AMC is depending on the value of the carrier to interference and noise ratio (CINR) which indicates the quality of the channel between the user and its serving base station.

Practically, the link adaptation technique uses the AMC to adapt transmission parameters for modulation scheme and code rate dynamically to the channel. The higher channel quality, the higher modulation order and code rate is used. Channel quality in downlink is measured in UE using the reference symbols. Upon this measurement, so-called CQIs, which are channel quality indicators are generated and sent to eNodeB. Each CQI value corresponds to a specific modulation scheme and a specific code rate, which are selected by eNodeB for the downlink transmission.

The QPSK represent the minimum ordered modulation which is equivalent to 4QAM, which make it the best when combined with coding in MCS, but it’s only efficient when connection reliability is not required as in the edges of the cell.

Generally low order MCS are not efficient in case of communication integrity and reliability but its efficiency occurs in low CINR conditions, the higher order MCS are granted for reliable and compact communication in higher CINR conditions.

From the results in chapter 4 the adaptive modulation and coding introduce has the advantage over fixed modulation and coding scheme when considering demand higher spectral efficiency

Enforceable QoS is an essential foundation for widespread acceptance of broadband wireless by using AMC, since it allows for more efficient sharing of the operator’s infrastructure, as demand for capacity increases with subscriber take-up and better coverage.

By the end of this study many issues has become understood and opens the mind by asking a question, which is; what is the next? And the answer is already known, which is; the next is now. As we can see the growth of the broadband wireless networks as in the 4G technologies there are more techniques and features which makes it possible and already implemented in the real world. So as an improvement of this work Recommended using the same methodology of this study to evaluate the spectral efficiency with 4G networks such as Long Term Evolution LTE. Also implement an Adaptive Modulation and Coding (AMC) features of the WiMAX PHY in MATLAB and analyze the performance of the system in different channel conditions (Rayleigh and Rician fading channel) with channel estimation and blind equalization.

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