# PERFORMANCE EVALUATION OF WIMAX NETWORK IN ASPECT OF MODULATION AND CODING SCHEMES AND HAND-OFF USING OPNET

**DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT FOR**

**THE DEGREE OF**

**MASTER OF TECHNOLOGY IN DISTRIBUTED AND MOBILE COMPUTING**

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## FACULTY OF ENGINEERING AND TECHNOLOGY
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# Acknowledgement

In the first place I would like to record my gratitude to Prof. Iti Saha Misra for her supervision, advice and valuable guidance from the very early stage of this project as well as giving me extraordinary experiences throughout the work. Above all and the most needed, she provided me unflinching encouragement and support in various ways. Her truly scientific intuition has made her a constant oasis of ideas and passions in science, which exceptionally inspire and enrich my growth as a student, a researcher and a scientist want to be.

I gratefully acknowledge Prof. Salil K. Sanyal of Department of Electronics & Telecommunication Engineering, Jadavpur University for his advice, supervision and crucial contribution, which made him a backbone of this research and so to this thesis.

I convey special acknowledgement to Budhaditya Bhattacharyya, Anindita Kundu, Atri Mukhopadhyay, Tamal Chakraborty, Ranjan Maji and Prasun Chowdhury for their generous assistance in writing the thesis.

I also deeply acknowledge the support from DST, Govt. of India for this work in the form of FIST Project on "Broadband Wireless Communication" in the Department of ETCE, Jadavpur University.

I would like to thank the entire School of Mobile Computing and Communication and all the people, who directly and indirectly helped me to achieve one of the major goals of my life.

Last but not the least, I deeply express my gratitude to my parents and my grand parents who had struggled a lot in life right from my childhood to bring me to the position what I am now. I dedicate this thesis to them.

**Place: Kolkata**
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# Abstract

WiMAX-the Worldwide Interoperability for Microwave Access is a future promising technology for offering high speed data, video and multimedia services over mobile platform evolving towards all IP networks. The increasing demand of WiMAX for VoIP and high speed multimedia is due the simplicity of installation and cost reduction compared to traditional wired DSL cable. The challenges to service providers lie with Quality of Service (QoS) under varied fading environment at the same time maximizing for resource utilization. In this thesis comprehensive performance studies for mobile WiMAX have been made with respect to adaptive modulation and coding techniques when the speed of the mobile, path-loss parameters, scheduling services and application type change and compared with the fixed type of modulations. To do this, we use the OPNET 14.5.A modeler for WiMAX platform in which adaptation is realized at the physical layer of the transmission in WiMAX OFDMA structure. Observation reveals that dynamic adaptation based on multiple thresholds on channel attenuation in various modulations and coding techniques enables better QoS while consuming low overall bandwidth of the system.

We also extended our work for WiMAX handoff management, which is a crucial factor in QoS aware broadband wireless networks. The hierarchical WiMAX network model gives low hand-off latency but requires centralized control approach which introduces system overhead and increased packet end-to-end delay. The flat architecture model reduces system overhead and packet end to end delay at the cost of higher hand-off latency. Hence, a scheme to reduce hand off latency in flat architecture model is proposed. The proposed scheme utilizes information provided by the Medium Access Control (MAC) layer regarding hand-off in order to minimize network layer hand off delay. With the help of simulation using OPNET 15.0.A Modeler, it is shown that the new scheme decreases the hand-off latency while causing no extra overhead to the WiMAX network.

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Chapter 1

# INTRODUCTION

*"The Internet will break down international borders and lead to world peace… children are not going know what nationalism is."*

- Nicholas Negroponte, MIT, 1997

*"It (the rise of wireless data) is going to be disruptive to the people who don't take advantage of it. Entire vertical industries like construction and retail are going to be changed by broadband wireless."*

-Sean Maloney, Intel

Beginning with the Telegraph in the 1840s, electronic data communication are greatly speeded up the transmission rate of information what took days or weeks to transmit during the ancient age could be transmitted in minutes or hours by the 1900. Today telecommunication network transmit huge quantities of information in a fraction of seconds. The communication landscape is changing dramatically under the increasing pressure of rapid technological development and intensifying competition. The effects of this revolution have been felt in almost every sector including banking, investment, health care, real estate, education, trading, manufacturing, governance and law. In the last few decades, distinction among telephone, broadcast, cable, satellite, wireless, and information services have all disappeared as broadband wireless internet technologies subsume all models of data, voice, and multimedia transmission.

Starting with the Advanced Mobile Telephone System (AMPS), cellular communication has evolved through Global System for Mobile Communications (GSM), Personal Access Communication System (PACS), High Speed Circuit Switched Data (HSCSD), Code Division Multiple Access (CDMA), General Packet Radio Services (GPRS), Wide-band CDMA (WCDMA), Enhanced Data rate For GSM Evolution (EDGE), Universal Mobile Telecommunication System (UMTS) etc., cellular wireless communication has gained strong ground in the communication network over the fixed and Wired network. The Worldwide Interoperability for Microwave Access technology, under its trade name of WiMAX has been in the talk of the world in the wireless communication industry for the past ten years. It is a technology that aims to provide wireless long distance broadband access for a variety of applications.

WiMAX is a next step on the road to a broadband as well as a wireless world, extending broadband wireless access over longer distance as well as significantly reducing the cost of bringing broadband to new areas. It offers better range and bandwidth than the other available or soon to be available broadband wireless access technologies such as Wireless Fidelity (Wi-Fi) and ultra-wide-band (UWB) family of standards and provides a wireless alternative to wired back haul and last mile deployments that use Data Over Cable Services Interface Specification (DOCSIS) cable models, Digital Subscriber Line Technologies (xDSL), T-carrier and E-carrier (Tx/Ex) systems, and optical carrier level (OC-X) technologies[1].

Conventional high-speed broadband solutions are based on wired Digital Subscriber Line (DSL). This type of solution is not suitable in remote places and also mobility of the users is not supported. With the ever increasing demand for high data rate services such as multimedia applications for mobile users, wireless communications are expanding their field of action for low cost solution comparable to cabled solution with easy deployment. The IEEE 802.16 family of standards [2][3] supported by WiMAX commercial consortium is the outcome of continuous research in wireless communication to address the problem of Broadband Wireless Access (BWA). It specifies the physical (PHY) and Medium Access Control (MAC) layers for BWA communication protocol. The IEEE 802.16 / WiMAX is a promising technology for broadband Wireless Metropolitan area networks (WMANs). WiMAX supports both packet oriented data transmission and standard mobile telephony over a large coverage with better performance than traditional wireless communication standards especially for applications that require high and stable throughput. It can be used to deliver backhaul services, enterprise campus and to Wi-Fi (local area) hot-spots. The original WiMAX was meant for fixed and nomadic users and reviewed to address the mobility in the IEEE 802.16e standard, known as mobile WiMAX [2]. Very soon it becomes the competitor to 3G cellular communication systems for delivery high speed data applications [4]. Due to the ease of deployment and integration with other existing networks, mobile WiMAX will evolve towards the all-IP networks for broadband wireless access.

The WiMAX physical layer is based on orthogonal Frequency Division Multiplexing (OFDM). OFDM is the transmission technology to enable high-speed data, video and multimedia communications and is used by a variety of commercial broadband system including DSL, Wi-Fi besides WiMAX. OFDM is also an efficient technique for high rate data transmission in a Non-Line-of Sight (NLOS) or multi-path radio environment [5]. OFDM can mitigate the adverse effects of frequency selective multi-path fading and efficiently can contrast the inter-symbol and inter carrier interferences. The multi carrier nature of OFDM transmission is helpful in adaptation of modulation and coding technique for more efficient realization of bit error rate and throughput. This adaptation is fully based on the dynamic channel condition in a fading environment. The PHY features of IEEE 802.16e includes scalable Orthogonal Frequency Division Multiple Access (OFDMA) to carry data supporting channel bandwidth between 1.25 MHz to 20 MHz with up to 2048 sub-carrier [3].

The performance of WiMAX systems is sensible to the speed of Subscriber Station (SS) [6] as the channel condition in terms of attenuation change with respect to speed. Here lies the requirement of adaptation techniques. Recently there are some works based on performance studies on mobile WiMAX. In [4], capacity study of OFDM based WiMAX is done considering AMC and Inter Cell interference. While [6] examines the performance with changing physical layer parameters under single cell environment.

In this thesis, in depth performance evaluation for mobile WiMAX is carried out using adaptive modulation and coding in the real-like simulation environment like OPNET. OPNET provides the comprehensive development of network models including all the necessary parameters that need to be reflected in the design procedure of PHY and/or MAC layers. Series of simulation scenarios under OPNET 14.5.A PL8 for broadband wireless communication are developed.

The different types of data services with QoS requirements that are supported by mobile WiMAX are suitably configured in the OPNET for performance evaluation. We evaluate the performance parameters for MOS (Mean Opinion Score), Upload data burst usage, and data dropped, Throughput etc. By varying speed of the mobile and different path-loss model under both AMC and fixed types of modulation techniques. Two sets of AMC schemes, AMC-1 and AMC-2 are considered. Each AMC is basically characterized by two threshold parameters, one is mandatory and other is minimum entry threshold for different modulation schemes. The determination of the threshold is a challenging problem because their value strongly interfere the behaviour of the adaptation algorithm in the performance measurement. Two determining techniques for these thresholds are given in [8]. The first one is the target Block Error Rate (BLER) for which the error rate under a target limit is maintained for certain QoS and the second one is the Maximum Throughput algorithm that maximize the total link throughput for a certain SINR value. We have taken the set of threshold values as given in [9].

## 1.1 Objective of this Thesis

The objective of the thesis is to study the various performances over mobile WiMAX network extensively using the fixed and adaptive modulation and coding techniques. In wireless communication, the nodes with high mobility experiences random fluctuation of received signal due to different fading occur in the multi-path propagation. Adaptive Modulation and Coding (AMC) allows WiMAX system to select the most appropriate modulation and coding scheme depending on the communication channel condition. As for example for high data rate transmission, a higher order modulation scheme with low coding redundancy is required in good propagation condition on the contrary in a fading environment, a modulation scheme and coding of lower order is needed to maintain quality of link connection without increasing signal power. By varying the modulation scheme, the amount of data transferred per signal varies. To enhance the throughput, therefore AMC has become a standard approach in WiMAX PHY layer [7][8]. Again the performance is also varied in different path-loss condition in contrast to free space path-loss model in idealistic situation. With the larger number of consumers of QoS enabled high data rate services, it is required to have knowledge of performance parameters over mobile WiMAX networks under fixed type of modulation and coding along with the adaptation to select the best combination. In this thesis, in depth performance evaluation for mobile WiMAX is carried out using adaptive modulation and coding in the real-like simulation environment like OPNET.

The flat model of WiMAX network architecture offers low network latency as number of nodes between SS and IP core network is reduced to one and provides high scalability as there is no centralized bottleneck. Thus, single point failure may not affect greatly. Where as, in case of hierarchical architecture, failure of centralized controller may disrupt large area. Most significant challenge for flat architecture is hand off latency. Hierarchical network gives fast hand-off through only layer 2 hand-off but flat architecture requires network layer mobility which causes significant delay and thereby affecting real time application. Hence, flat model though advantageous lies behind mainly due to poor handoff performance. In this thesis we propose a scheme that reduces the handoff latency without any extra overhead on WiMAX network.

## 1.2 Related Work

Paper [7] and [8] shows that AMC has become a standard approach in WiMAX PHY layer design for enhancing system throughput. Paper [6] examines the performance with changing physical layer parameters under single cell environment. Papers [9][10] and [11] gives performance analysis of WiMAX network with respect to AMC in fixed and single cell environment. The detail explanation of the related work is provided in chapter 2 and 3. In [12] efficient AMC techniques for WiMAX OFDMA are given. Two techniques have been proposed by taking into consideration of channel behaviours in terms of user's mobility. The first technique keeps the error rate within a limit and then employs suitable modulation and coding scheme (MCS). The second method aims to maximize the system throughput with MCS among the available ones for each Signal to Interference and Noise Ratio (SINR). Both techniques show advantageous in respect of AMC. Paper [8] provides performance evolution of WiMAX physical layer under AMC and channels with different types, such as

AWGN, Rayleigh and Rician. The effect of the forward error correction on different channels is evaluated in term of BER. It is observed that Reed-Solomon with ⅔ rated Convolutional Coding (CCC) under BPSK modulation technique provides satisfactory performance with different channels.

A survey on hand-off performance for mobile network is given in [13]. [14] [15] reveals that most of the research works have concentrated on enhancing MAC layer to reduce hand-off latency. Paper [15] suggests a way to decrease the hand-off latency using fast-MIP. This paper intends to change overall structure of WiMAX network whereas our proposed model makes changes only at the SS node.

## 1.3 Outline of the Thesis

The Thesis is organized as follows:

- Chapter 2 briefly discuss about the architecture of IEEE 802.16 Broadband Wireless Access Network. The PHY, MAC and Network layers and the Mobility management are discussed in brief.
- Chapter 3 discuss the concept of adaptive modulation & coding and different physical parameters for performance evaluation which affect the system performance such as speed of mobile node, path-loss parameter of the wireless channel, application type and scheduling services.
- Chapter 4 discuss about the simulation setup and results obtained for performance evaluation.
- Chapter 5 discuss about the hand-off management of flat architecture. A scheme to reduce the hand-off latency is proposed. Sufficient simulation result is provided to reveal that the scheme is beneficial in terms of hand-off latency.
- Chapter 6 discuss about the procedure to set OPNET simulation scenarios and generate new model development.
- Chapter 7 concludes the thesis and also discuss about the future work.

Chapter 2

# About WiMAX

## 2.1 Introduction:

The IEEE 802.16 group was formed in 1998 to develop an air interface standard for wireless broadband. The resulting standard – the original 802.16 standard, completed in December 2001 – was based on a single-carrier physical layer with a burst time division multiplexed MAC layer. This group subsequently produced 802.16a, an amendment to the standard, to include NLOS application in 2-11 GHz band, using orthogonal frequency division multiplexing (OFDM) based physical layer. Further revision resulted in a new standard in 2004, called 802.16-2004 [2], which replaced all prior versions and formed the basis for the first WiMAX solution. In December 2005, the IEEE group completed and approved a IEEE 802.16e-2005, an amendment to IEEE 802.16-2004 standard that added mobility support, forming the basis for the WiMAX solution for nomadic and mobile application and is often referred to as mobile WiMAX [3].

A system profile defines the subset of mandatory and optional physical and MAC layer features selected by the WiMAX forum [16] from the IEEE 802.16 standards. Currently, the WiMAX forum has two different system profiles, one based on IEEE 802.16-2004, OFDM PHY called the fixed system profile; the other one based on 802.16e-2005 scalable OFDMA PHY, called the mobility system profile. A certification profile is defined as the particular instantiation of a system profile where the operating frequency, channel bandwidth, and duplexing mode are also specified. WiMAX forum has further defined five fixed and fourteen mobility certification profiles [1].

For the remainder of this chapter we focus solely on mobile WiMAX and therefore discuss only the aspects of IEEE 802.16e standard.

## 2.2 WiMAX Network Architecture

In this section, we focus on the end-to-end network system architecture of WiMAX. Simply specifying the PHY and MAC of the radio link alone is not sufficient to build an interoperable broadband wireless network. Rather, an interoperable network architecture framework that deals with the end-to-end service aspects such as IP connectivity and session management, security, QoS, and mobility management is needed. The WiMAX forum's Network Working Group (NWG) has developed and standardized these end-to-end networking aspects that are beyond the scope of the IEEE 802.16e-2005 standard.

The network architecture supports network sharing and a variety of business models. The architecture allows a logical separation between (1) the network access provider (NAP) - The entity that owns and operates the access network, (2) the network service provider (NSP) - the entity that owns the subscriber and provides the broadband access service, and (3) the application service provider (ASP). The architecture supports the concept of virtual network operator and not precludes the access networks being shared by multiple NSPs or NSPs using access networks from multiple NAPs [1]. The architecture supports the discovery and selection of one or more accessible NSPs by a subscriber.

***Network Reference Model***

Fig.2.1 shows the WiMAX network reference model (NRM) [4][17], which is a logical representation of the network architecture. The NRM identifies the functional entities in the architecture and the reference points between functional entities over which interoperability is achieved. The NRM divides the end-to-end system into three logical parts: (1) mobile stations used by the subscriber to access the network; (2) the access service network (ASN) which is owned by a NAP and comprises one or more base stations and one or more ASN gateway that form the radio access network; and (3) the connectivity service network (CSN), which is owned by an NSP, and provides IP connectivity and all the IP core network functions. The subscriber is served from the CSN belonging to the visited NSP; the home NSP is where the subscriber belongs. In the non roaming case, the visited and home NSPs are one and the same.

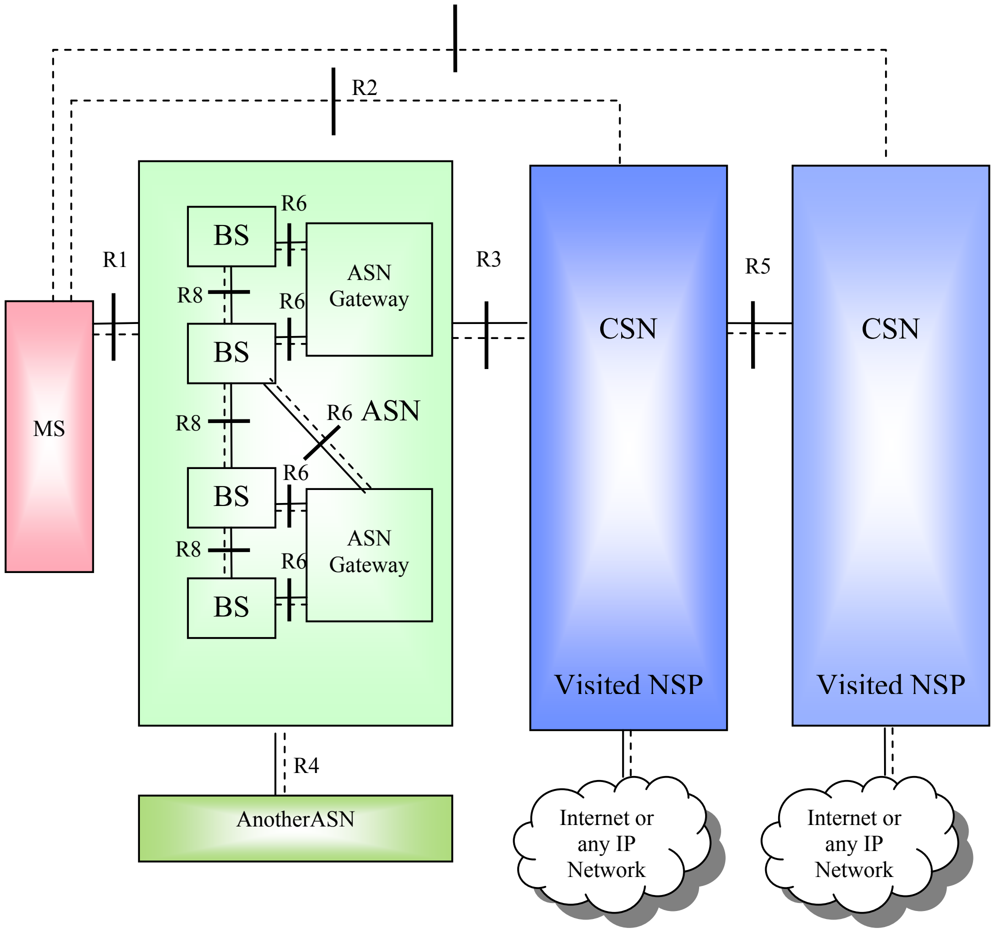


Figure 2.1. WiMAX Network Reference Model

**Access Service Network (ASN):**

The ASN performs the following functions [1] [4]:

- IEEE 802.16e-based layer 2 connectivity with the MS
- Network discovery and selection of the subscriber's preferred CSN/NSP.
- AAA proxy: transfer of device, user and service credentials to selected NSP AAA and temporary storage of user's profile.
- Relay functionality for establishing IP connectivity between the MS and the CSN.
- Radio Resource Management (RRM) and allocation based on the QoS policy and/or request from the NSP or the ASP.
- Mobility-related functions, such as handover, location management, and paging with the ASN, including support for mobile IP with foreign agent functionality.

The ASN may be decomposed into one or more base stations (BSs) and one or more ASN Gateway (ASN-GW) as shown in Fig. 2.1. The BS is defined as representing one sector frequency assignment implementing the IEEE 802.16e interface to the MS. Additional functions handled by the BS include scheduling for the uplink and downlink, traffic classification, and service flow management (SFM) by acting as the QoS policy enforcement point (PEP) for traffic via the interface, providing terminal activity (active, idle) status, supporting tunneling protocol towards the ASN-GW, providing DHCP proxy functionality, relaying authentication message between the MS and the ASN-GW. The WiMAX NRM defines multiple profiles for the ASN: profile A, B and C [1]. Profile B has both the BS and ASN-GW as an integrated unit. Profile A and C are quite similar with the following exception : In profile A, ASN-GW handles the handover operation while in profile C, BS take the responsibility of handover with ASN-GW performing only the handover relay function. Also, in profile A, the radio resource controller (RRC) is located in the ASN-GW, allowing for Radio Resource Management (RRM) across multiple BSs while in profile C, RRM is fully contained and distributed within the BSs. ASN-GW may optionally be decomposed into two groups of functions: decision point (DP) (include non-bearer plane control functions) and enforce point (EP) function (include bearer plane functions).

**Connectivity Service Network (CSN):**

The CSN provides the following functions [1][4][17]:

- IP address allocation to the MS for user sessions.
- Providing authentication, authorization and accounting (AAA) services.
- Policy and QoS management based on SLA contract with the user.
- Subscriber billing and interoperator settlement.
- Inter-CSN tunneling to support roaming between NSPs.
- Inter ASN mobility management and mobile IP home agent (HA) functionality.
- Connectivity infrastructure and policy control for such services as internet access.

**Reference Point:**

In the WiMAX NRM, each reference point is a logical interface aggregating the functional protocols between different functional entities on either side of it. Different protocols associated with a Reference Point may originate at and/or terminate in different functional entities on either side of it. Different protocols associated with a RP may originate at and/or terminate in different functional entities across that Reference Point .The WiMAX NRM defines the following Reference Points [1][4] [17]:

Table 2.1. WiMAX Reference Points

| Reference Point | End Points | Descriptions |
|---|---|---|
| R1 | MS and ASN | This includes the IEEE 802.16 standard specified PHY and MAC layers as well as L3 protocols and procedures related to control and management plane interactions and any bearer plane traffic terminating at the ASN |
| R2 | MS and CSN | Mainly associated with Authentication, Services Authorization and IP Host Configuration management. The authentication part of R2 runs between the MS and CSN in the home NSP, while the ASN and CSN in the visited NSP may partially support in the process. The IP Host Configuration management runs between the MS and the CSN(in either home or visited NSP). |
| R3 | ASN and CSN | This RP supports AAA, policy enforcement and mobility management capabilities as well as necessary tunneling to transfer user data between the ASN and the CSN. |
| R4 | ASN and ASN | Control and Bearer plane procedures between ASNs such as RRM,MS mobility across ASNs and idle mode/paging. The various protocols used over R4 may originate at and/or terminate in different functional entities of the communicating ASNs. R4 serves as the interoperability RP across any pair of ASNs regardless of their internal configuration profiles. |
| R5 | CSN and CSN | Control and Bearer plane protocols needed to support roaming between CSN operated by a home NSP and that operated by a visited NSP |
| R6 | BS and ASN-GW | Includes all control and bearer plane protocols between the BS and the associated ASN-GW. The control plane consists of QoS, security and mobility-related protocols such as paging and data path establishment/release and it may include radio resource management. The bearer plane represents the intra-ASN data path between the BS and ASN-GW. |
| R7 | ASN-GW-DP and ASN-GW-EP | Optional reference point separating decision and execution functions within a decomposed ASN-GW. If supported, R7 consists of an optional set of control plane protocols within an ASN/GW for AAA and Policy coordination as well as the coordination between the group of functions involved over R6. |
| R8 | BS and BS | Optional reference point between Base Stations to ensure fast and seamless handover through direct and fast transfer of MAC context and data between Base Stations involved in handover of a certain MS. If supported, the handover context and related control plane messages on R8 should be consistent with protocols defined in IEEE 802.16-2005 and 802.16g. |

## 2.3 WiMAX Protocol Stack:

Schematic diagram of WiMAX protocol stack is given in Fig. 2.2 which is formed with the help of [1][4] [17] [18].

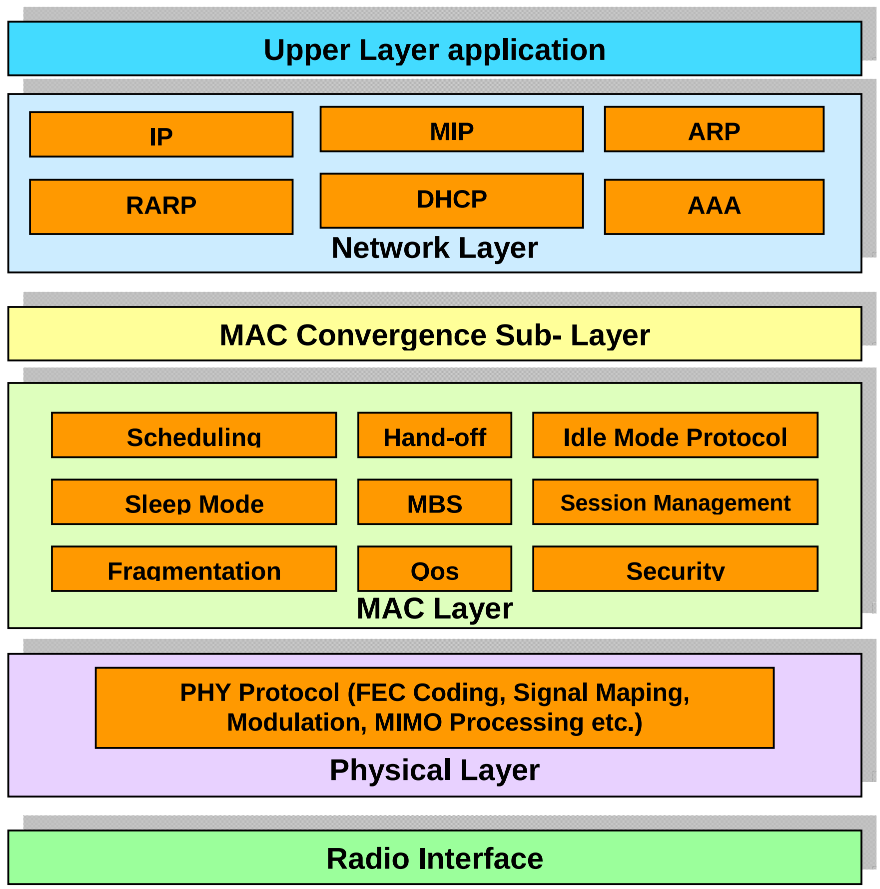


Figure 2.2. WiMAX Protocol Stack Reference Model

### 2.3.1 WiMAX PHY Layer:

The physical layer (PHY) of WiMAX is based on the IEEE 802.16 standards [2][3] and was designed with much influence from Wi-Fi, especially IEEE 802.11a [4]. Although many aspects of two technologies are different due to their purpose and application, some of their basic constructions are very similar. Although like Wi-Fi, WiMAX uses orthogonal frequency division multiplexing(OFDM) as multiplexing technique, in WiMAX the various parameters pertaining to physical layer, such as number of subcarriers, pilots, guard bands and so on, are quite different from Wi-Fi, since the two technologies are expected to function in very different environment. The standard defines within its scope four PHY layers, any of which can be used with the media access control (MAC) layer to develop broadband wireless system. Among these four standards we have used Wireless-MAN OFDMA, a 2,048-point FFT-based OFDMA PHY for point-to-multipoint operations in NLOS conditions at frequencies between 2GHz and 11GHz. In the IEEE 802.16e-2005 specifications, this PHY layer has been modified to SOFDMA (scalable OFDMA), where the FFT size is variable and can take any one of the following values: 128, 512, 1,024 and 2,408 [1]. The variable FFT size allows for optimum operation/implementation of the system over a wide range of channel bandwidths and radio conditions. This PHY layer has been accepted by WiMAX for mobile and portable operations and is also referred to as mobile WiMAX. Fig.2.3 shows the various functional stages of a WiMAX PHY layer.

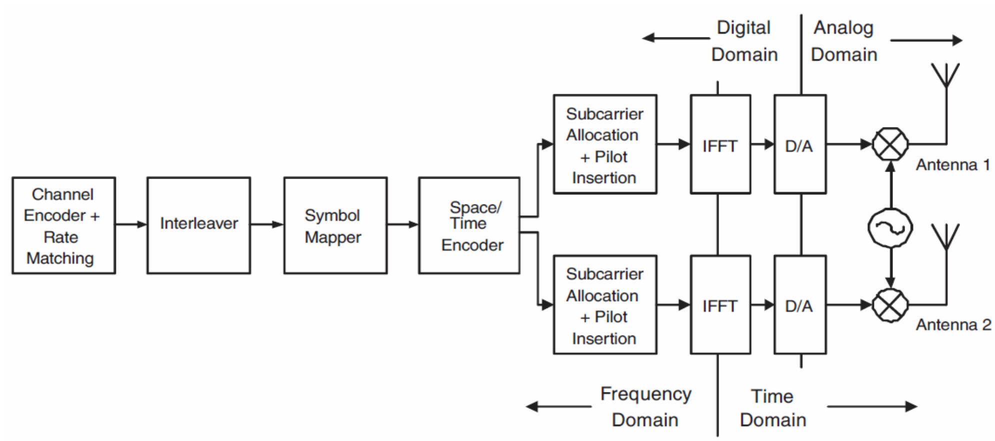


Figure 2.3. Functional stages of WiMAX PHY [1]

***Channel coding:***

In IEEE 802.16e-2005, the channel coding stage consists of the following steps: (1) data randomization, (2) channel coding, (3) rate matching, (4) HARQ, if used, (5) interleaving. Data randomization is performed in the uplink and the downlink, using the output of a maximum length shift-register sequence that is initiated at the beginning of every FEC block. Channel coding is performed on each FEC block, which consists of an integer number of subchannels, which comprises of several data and pilot subcarriers. The mandatory channel coding is based on binary non-recursive convolution coding (CC). The output of the data randomizer is encoded using this constituent encoder. In downlink of the OFDM mode, where the subchannelization is not used, the output of the data randomizer is first encoded using an outer systematic Reed Solomon (RS) code and then encoded using an inner rate ½ binary convolutional encoder [1]. The RS code is derived from a systematic (N=255, K=239, T=8) code using Galois Field (GF $2^8$). Other channel coding schemes such as block turbo codes, low density parity check (LDPC) and convolutional turbo code (CTC) have been defined in WiMAX as optional channel coding schemes.

***Interleaving:***

After channel coding, the encoded bits are interleaved using two step process. The first step ensures the adjacent bits are mapped onto the non adjacent subcarrier, which provides frequency diversity and improves the performance of the decoder. The second step ensures that adjacent bits are alternately mapped to less and more significant bits of the modulation constellation. The separation of the subcarriers to which two adjacent bits are mapped onto, depends on subcarrier permutation schemes used.

***Symbol Mapping:***

During this stage, the sequence of binary bits is converted to a sequence of complex valued symbols. The mandatory constellations are QPSK, 16 QAM and 64 QAM. The symbols are further multiplied by a pseudo random code to provide additional layer 1 encryption.

***OFDM Symbol Structure:***

Theoretically, the main purpose of an OFDM system is to split sequence of symbols having high data rate into multiple parallel low data rate sequence. Each of the subcarriers is uncorrelated and hence orthogonal [4]. During transmission of these multiple parallel low data rate sequences, the orthogonality between the subcarriers are to be maintained by combating effect of radio medium. Inter carrier interference, happens to be a loss associated when two consecutive subcarriers overlap. In the frequency domain, each OFDM symbol is created by mapping the sequence of symbols on the subcarriers. WiMAX has 3 classes of subcarriers: (1) **Data subcarriers** which carry data symbol, (2) **Pilot subcarrier**, used for channel estimation and channel tracking and (3) **Null (DC) subcarrier**. For a typical scenario in an OFDM symbol structure among 256 subcarriers, 200 data subcarriers, 8 pilot subcarriers and one null subcarrier and the rest are the guard intervals [19]. Fig.2.4 indicates a typical frequency domain representation of OFDM symbol [4].

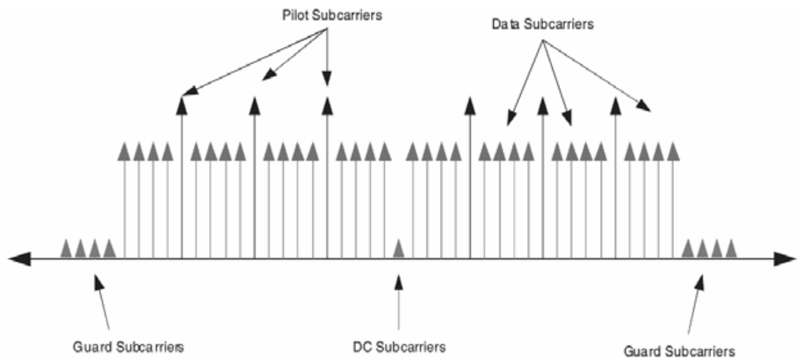


Figure 2.4 Frequeny domain representation of OFDM symbol

### 2.3.2 WiMAX MAC Layer

The Medium Access Control (MAC) layer, which resides above PHY layer, is responsible for controlling and multiplexing various links over the same physical medium. Some important functions of the MAC layer in WiMAX are [1][4][20]:

- Segment or concatenate the service data units (SDUs) received from higher layer into the MAC PDU (protocol data units), the basic building block of MAC-layer payload.
- Select the appropriate burst profile and power level to be used for the transmission of MAC PDUs
- Retransmission of MAC PDUs.
- Retransmission of MAC PDUs that were received erroneously by the receiver when automated repeat request (ARQ) is used.
- Provide QoS control and priority handling of MAC PDUs belonging to different data and signaling bearers.
- Schedule MAC PDUs over the PHY resources.
- Provide support to the higher layers for mobility management.
- Provide security and key management.
- Provide power-saving mode and idle-mode operation.

The 802.16e MAC layer is connection oriented and all data communication is associated to a connection. A connection together with QoS parameters make up a service flow which is a fundamental term in the standard.

***Framing:***

The MAC layer has support for both TDD and FDD framing where TDD separates uplink and downlink in time domain and FDD separates them in the frequency domain. The frame size can be varied in accordance to different physical profiles. The partition of the frame between uplink and downlink can also be adjusted [33].

- The **downlink (DL)** consists of several physical burst of different modulation and coding where the burst are sent in decreasing robustness. These bursts are addressed to different connections through Connection Identifiers (CID). This burst contains important control messages like the DL-MAP, UL-MAP, UCD and DCD messages. The DL-MAP, if scheduled for transmission in the frame, is always first and this describes the content of the downlink. This is to allow the MS to through the DL-MAP identify which bursts it should listen to and how it should set its radio so it can decode them.
- The **uplink (UL)** is shared by the subscriber stations, where each subscriber station uses their own modulation and encoding to transmit to the base station. The IEs in the UL-MAP sent on the downlink indicates who each burst is addressed to and what type of burst it is. The part of the uplink is reserved for contention based initial ranging, used when subscriber stations need to perform ranging with a base station to achieve synchronization and appropriate signal strengths for further communication.

***MAC PDUs:***

802.16e [3] has a wide array of management messages. These management messages and upper layer data packets can be packaged and sent using different methods. The standard makes use of Type/Length/Value (TLV), a formatting scheme that enables more dynamic contents in messages. Parameters are sent using this scheme which enables parsing of a predefined type, length and value. Messages can thus contain variable number of parameters, which can be detected using this scheme. PDUs can either be concatenated to fill an allocated burst, or fragmented. Fragmentation can allow for more efficient use of allocated bandwidth with regards to QoS requirements. There is also support for the Automatic Repeat Request (ARQ) protocol for handling retransmission of erroneous messages. This can be enabled for individual connections. Automatic Repeat Request is an error detection and correction technique. The receiver detects errors but cannot correct them and instead sends a retransmission request to the transmitter which then repeats the transmission. Fig 2.5 shows the MAC PDU format. Each PDU consists of a fixed length MAC header. The payload contains zero or more sub-headers and zero or more SDUs or fragments thereof. The size of a MAC PDU varies based on the contents of the payload. The PDU may optionally contain a Cyclic Redundancy Check (CRC) at the end.

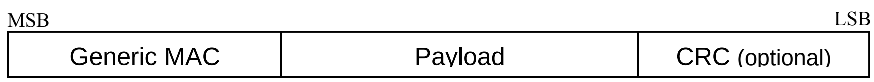


Figure 2.5. MAC PDU Format [2]

***<u>Connection:</u>***

Each SS has a 48-bit universal MAC address, much like the MAC address of regular network interfaces. It is used when first identifying an SS towards a BS or in the authentication process. As a subscriber station enters a BS cell and performs the steps necessary to begin data communication it is granted two mandatory and one optional management connections. These three connections are associated to a QoS level, which differentiates management into three priorities. The **Basic Connection** is used for time critical, short MAC management messages, while the **Primary Management** connection delivers longer more delay tolerant MAC messages. The **Secondary Management** connection is used for standards based protocols like DHCP, TFTP etc.

***<u>Scheduling Services:</u>***

The WiMAX MAC layer uses a scheduling service to deliver and handle SDUs and MAC PDUs with different QoS requirements. A scheduling service uniquely determines the mechanisms that network use to allocate UL and DL transmission opportunities for the PDUs. WiMAX define five scheduling services as given in table 2.2.

Table 2.2 WiMAX Scheduling Service Classes.

| QoS Category | Applications | QoS Specifications |
|---|---|---|
| UGS<br>Unsolicited Grant Service | VoIP | • Maximum Sustained Rate<br>• Maximum Latency tolerance<br>• Jitter Tolerance |
| rtPS<br>Real-Time Polling Service | Streaming Audio or Video | • Minimum Reserved Rate<br>• Maximum Sustained Rate<br>• Maximum Latency tolerance<br>• Traffic Priority |
| ertPS<br>Extended Real-Time Polling Service | Voice with Activity Detection (VoIP) | • Minimum Reserved Rate<br>• Maximum Sustained Rate<br>• Maximum Latency tolerance<br>• Jitter tolerance<br>• Traffic Priority |
| nrtPS<br>Non-Real-Time Polling Service | File Transfer Protocol (FTP) | • Minimum Reserved Rate<br>• Maximum Sustained Rate<br>• Traffic Priority |
| BE<br>Best-Effort Service | Data Transfer, Web Browsing, etc. | • Maximum Sustained Rate<br>• Traffic Priority |

***Bandwidth Requests:***

An SS may request bandwidth either by sending a Bandwidth Request message or through an optional Piggyback Request in a Grant Management sub-header. These requests can be sent in any uplink burst, except during an initial ranging interval. The requests are either incremental or aggregate, where an incremental request adds the requested bandwidth to the amount already allocated by the BS. An aggregate request replaces the current value with the value in the request. Piggyback requests can only be incremental since they have no field to indicate the type of the request and requests done during bursts where collisions can occur should be aggregate.

***Network Entry and Handover:***

The process of associating a mobile subscriber with a base station is similar to that of the mandatory handover process, stated in the 802.16e draft [3]. Fig. 2.8 shows initial network entry, followed by a handover to another BS. The process of network entry contains steps such as acquiring physical (bit) and MAC (frame) synchronization, ranging to adjust suitable transmission power, setup of management connections, authentication and retrieval of provisioned services and higher layer protocol interaction such as IP-connectivity through DHCP. In the case of handover the MS can during certain intervals perform ranging to synchronize and obtain information about neighboring BSs that could serve as candidates for handover. It can also receive this information from its current BS through a certain broadcast message, MOB NBR-ADV. This message contains channel information provided by neighboring BSs DCD/UCD messages. This information is distributed to the BSs through the backbone and saves the MS the trouble of scheduling intervals to perform the scanning process. There are different methods for scanning neighboring base stations where the MS can associate itself with a possible new anchor BS. Depending on how much information is exchanged during this scanning process, the actual handover can be shortened since required information already is available.

***Sleep Mode:***

A MS can enter sleep mode to save power or to decrease the usage of BS resources. The BS manages Power Saving Classes for each MS [20]. Each MS connection is associated to a particular Power Saving Class and there are three different classes. These three different classes are suitable for different service flows, as each flow has different requirements and methods for requesting bandwidth and sending data.

***Idle Mode:***

Idle mode is a mechanism used to allow a MS to move around a larger geographical area and possibly many cell boundaries without having to perform handover or send other management traffic. This is primarily intended for MS that are inactive and through this mechanism they can still be reached on the downlink without being registered to a specific BS.

### 2.3.3 Convergence Sub-layer

The Convergence Sub-layer (CS) performs the following two main tasks [2][3] :

***Packet Classification***

The process of Packet Classification is where the CS receives a higher layer packet and maps this packet to a service flow. Since each service flow is associated with specific QoS parameters, the classification of a packet to a flow leads to the delivery of that packet with appropriate QoS constraints. The classification is made based on different criterion, such as destination or source IP-adders. If a packet matches a criteria it is delivered to a MAC connection that has been matched to that criteria, i.e. the classification results in an appropriate Connection Identifier (CID) of a connection. Several classifiers may exist for the same service flow, and since they can overlap they are explicitly ordered.

***Payload Header Suppression :***

The capability of Payload Header Suppression (PHS) is optional and is used to remove repetitive or redundant information from higher layer packets headers. When a packet is classified it can also be mapped to a Package Header Suppression Rule. The information in the packet header is compared with a Package Header Suppression Field (PHSF). If the header bits match the PHSF, some of these bits can be masked. Such bits desirable to mask can be higher layer static fields, such as IP-adders.

After passing through the CS, the packet delivered to the appropriate service flow in the MAC-layer has the format shown in Figure 2.6. The standard calls this a MAC SDU, and it contains the PHSI (So that the receiver can select the appropriate PHSF for unmasking the header) and the higher layer PDU. The MAC SDU is now in the hands of the MAC-layer which is responsible for delivering the packet to the receiver over the air interface.

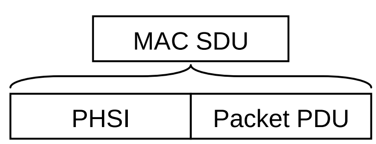

Figure 2.6. MAC SDU Format [3]

### 2.3.4 WiMAX Network Layer

The specification of Network layer is beyond the scope of IEEE 802.16 standard [2][4]. The WiMAX Forum [16] manages the global adaptation and interoperability of WiMAX systems. For delivering high speed data flow in wireless broadband system, WiMAX systems are tending towards all-IP network where every node are denoted by separate IP address unlikely to the conventional cellular system. The main function of Network layer is to communicate between core network and the wireless radio interface. The main functionalities are discussed briefly:

***IP Address Assignment:***

The Dynamic Host Configuration Protocol (DHCP) is used as the primary mechanism to allocate a dynamic point-of-attachment (PoA) IP address to the MS. Alternatively, the home CSN may allocate IP address to an ASN via AAA, which in turn is delivered to the MS via DHCP. In this case, the ASN will have a DHCP proxy function as opposed to a DHCP relay function. When an MS in IP gateway or host, the standard requires that a PoA IP address may be allocated to the gateway or the host, respectively. If the MS acts a layer 2 bridge (ETH-CS), IP addresses may be allocated to the host behind the MS. For fixed access, the IP address must be allocated from the CSN address space of the home NSP and may be either static or dynamic. For nomadic, portable, and mobile access dynamic allocation from either the home or the visited CSN is allowed, depending on roaming agreements and the user subscription profile and policy.

***Authentication and Security Architecture:***

The WiMAX authentication and security architecture is designed to support all the IEEE 802.16e security services, using an IETF EAP-based AAA framework. In addition to authentication, the AAA framework is used for service flow authentication, QoS policy control, and secure mobility management. Some of the WiMAX Forum specified requirements that the AAA framework should meet are as follows:

- Support for device, user, and manual authentication between MS/SS and the NSP, based on Privacy Key Management Version 2 (PKMv2) as defined in IEEE 802.16e-2005.
- Support for authentication mechanisms, using a variety of credentials, including shared secrets, subscriber identity module (SIM) cards, universal SIM (USIM), universal integrated circuit card (UICC), removable user identity module (RUIM), and X.509 certificate, as long as they are suitable for EAP methods satisfying RFC 4017.

- Support for global roaming between home and visited NSPs in a mobile scenario, including support for credential reuse and consistent use of authorization and accounting through the use of RADIUS in the ASN and the CSN. The AAA framework shall also allow the home CSN to obtain information, such as visited network identity, from the ASN or the visited CSN that may be needed during AAA.
- Accommodation of the mobile IPv4 and IPv6 security associations (SA) management.
- Support for policy provisioning at the ASN or the CSN by allowing for transfer of policy related information from the AAA server to the ASN or the CSN.

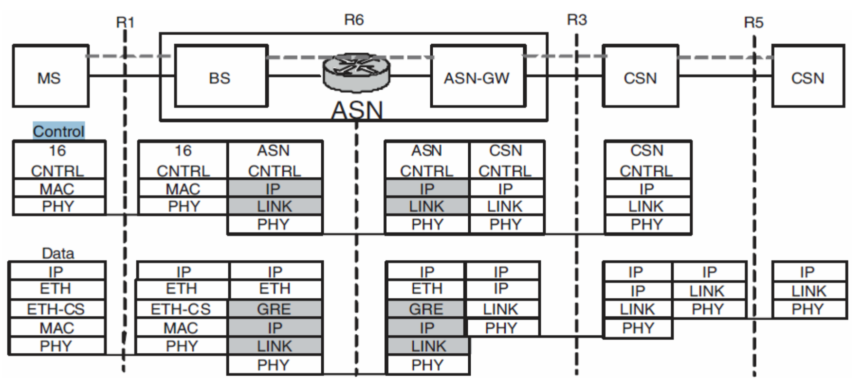


Figure 2.7. Protocol Stack for IP Convergence sub-layer with routed ASN [1]

## 2.4 Mobility Management

In WiMAX, the handoff procedure requires support from layers 1, 2 and 3. Although the ultimate decision for handoff is determined by layer 3, the MAC and PHY layer play a crucial role by providing information and triggers required by layer 3 to execute the handoff.

In order to be aware of its dynamic radio frequency environment, the BS allocates time for each MS to monitor and measure the radio condition of the neighbour BS. These process is called scanning and the time allocated to each MS is called scanning interval. During scanning interval, the MS measures the received signal strength indicator (RSSI) and the signal-to-interference-plus-noise ratio (SINR) of the neighboring BS and can optionally associate with some or all the

BSs in the neighbor list. In WiMAX, the handoff process is defined as the set of procedures and decisions that enable an MS to migrate from the air interface of one BS to the air interface of another BS. It consists of the following steps: -

1. **Cell Reselection:** MS performs scanning and association with one or more neighboring BSs to determine their suitability as a handoff target.
2. **Handoff decision:** Decision for the handoff can be taken by the MS, BS or some other external entity in the WiMAX network depending on the implementation. When the handoff decision is taken by the MS, it sends a MOB_MSHO-REQ message to the BS, indicating one or more BS as the handoff targets. The BS then sends a MOB_BSHO-RSP message the target BS to be used for this handoff. The MS sends a MOB_MSHO-IND indicating which of the BS indicated in MOB_BSHO-RSP will be used for handoff.
3. **Synchronization to the target BS:** Once the target BS is determined, the MS synchronizes with its DL transmission. The MS begins by processing the DL frame preamble of the target BS which provides the time and frequency synchronization. The MS then decode the DL-MAP, UL-MAP, DCD, and UCD messages to get information about the ranging channel.
4. **Ranging with target BS:** The MS uses the ranging channel to perform the initial ranging process to synchronize its UL transmission with the BS and get information about initial timing advance and power level.
5. **Termination of context with previous BS:** After establishing connection with target BS, the MS sends MOB_HO-IND message to the BS. On receipt of this message, BS starts resource retain timer and keeps all MAC state machines and buffered MAC PDUs associated with the MS until the expiry of this timer. After the retain timer expires, the BS discards all the MAC state machines and MAC PDUs belonging to the MS and handoff procedure is assumed to be completed.

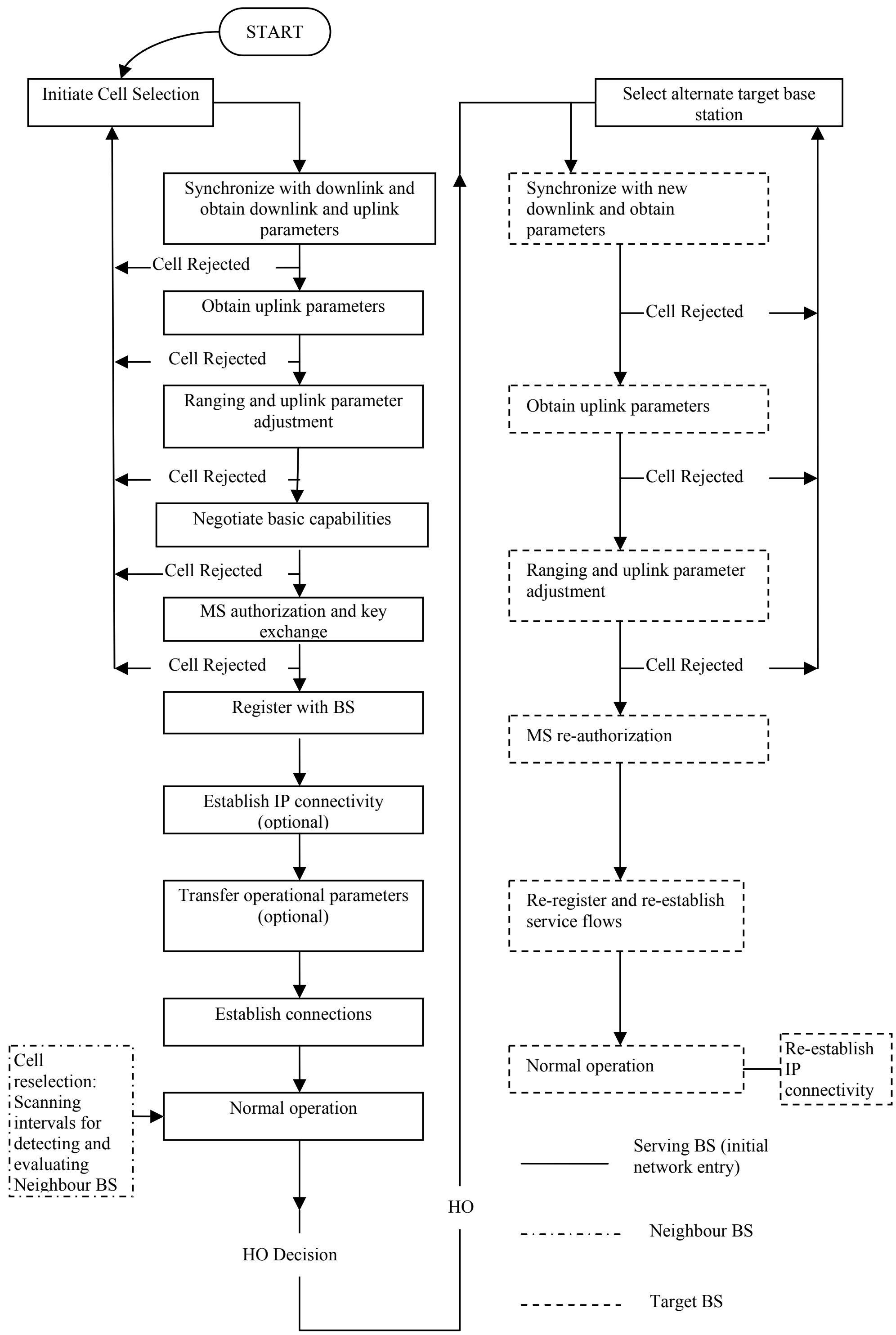


Figure 2.8. Handover and initial network entry [1]

Chapter 3

# Performance Evaluation in Aspect of Modulation and Coding

## 3.1 WiMAX Channel Coding:

The schematic representation of WiMAX PHY layer as shown in Fig. 3.1 is formed with the help of [21]-[23]. The diagram has basically 3 blocks which are transmitter, receiver and the channel. The transmitter consists of channel encoding, digital modulation, Serial to parallel conversion block followed by an OFDM modulation block, and a parallel to serial conversion block has been shown that has the specific purpose of serializing the data bits. The channel encoding block has “block encoder”, “convolutional encoder” and “puncture vector block” associated with it. The redundancy added to the data sequence is the sole purpose of the encoder block. Depending on channel conditions, WiMAX supports a variety of modulation and coding schemes and allows for the scheme to change on a burst-by-burst basis per link. Using the channel-quality feedback indicator (CFI), the mobile can provide the base station with feedback on the downlink channel quality. For the uplink, the base station can estimate the channel quality, based on the received signal quality. In the downlink, BPSK, QPSK, 16-QAM, and 64-QAM are mandatory for both fixed and mobile WiMAX; 64 QAM is optional in the uplink. These modulation techniques can be used in the PHY layer design [2]. WiMAX PHY uses Adaptive Modulation and Coding (AMC) which takes into account the channel SINR to dynamically select the proper modulation technique appropriate for that channel condition to deliver the maximum throughput. Serial to parallel conversion of the incoming bit becomes the critical set of operation that determines the parallel transmission of data bits. OFDM modulation being the key multiplexing technique in WiMAX helps the transmission of data bits at a very high rate at a negligible amount of Inter Symbol Interference (ISI) with minimal amount of packet loss and bit error. The data transmitted through wireless channel reaches the receiver. The channel which might be Additive Gaussian White Noise (AWGN), Rayleigh or Rician, determines the effective channel impairment introduced in the receiver. The receiver section does exactly the opposite to the transmitter.

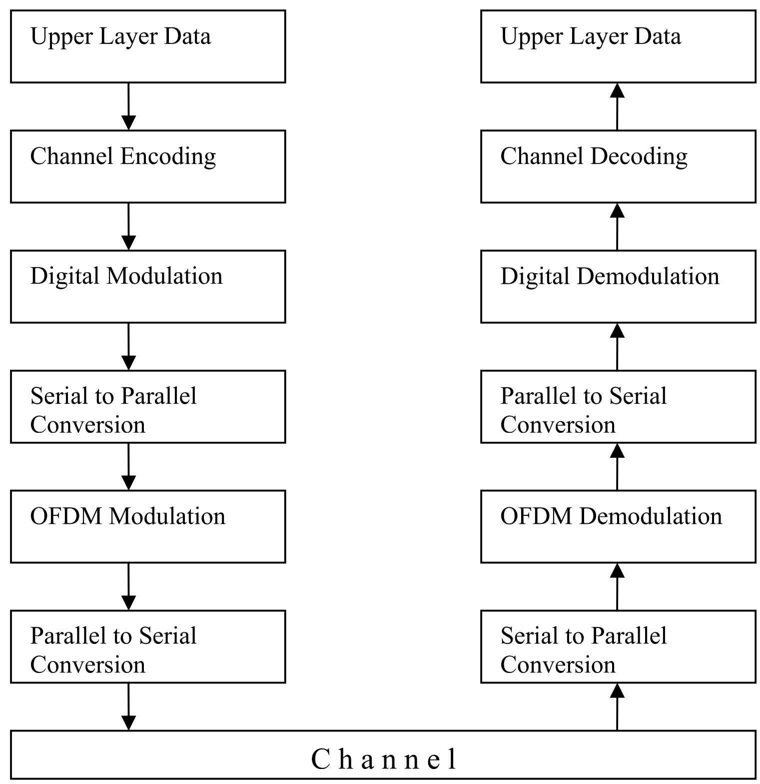


Figure 3.1. Block Diagram for WiMAX channel encoding

The channel encoding setup is shown in Fig. 3.1. Forward Error Correcting Code (FEC) typically uses error correcting codes that can detect with high probability of error locations. The improvement of the bit error rate by adding redundant bits, in a transmitted bit stream is done by these channel codes. A reduction in transmitted signal power for a given bit error rate is achieved at the expense of reduced data throughput and additional overhead. IEEE 802.16 uses an outer Reed-Solomon (RS) block code concatenated with an inner Convolutional

Code (CC). A RS block (255, 239, 8) code based on the Galois Field ($2^8$) with a symbol size of 8 bits is chosen for processing of 239 symbols [24]. However, it can correct up to 8 symbol errors. The CC block also maintains a specific code rate. If the input to CC is k bits/sec and the output is n bits/sec the rate of coding is k/n, where n is equal to ½ and ⅔. Constraint length m, similar to the memory in the system can be depicted as preceding k bits used in the encoding process. Constraint length m is usually selected as 3 and 5. Before these convolutionally encoded bits are converted into either of 4 complex modulations BPSK, QPSK, 16-QAM and 64-QAM they are further interleaved. Table-I gives the peak uplink and downlink data rates for Mobile WiMAX with different Information bits/symbol [17]. In our case we have studied the performance under mobile WiMAX scenario in OPNET simulator for QPSK and QAM with different coding rates. BPSK has been excluded from our discussion since OPNET does not support the specific coding. Changes are made in OPNET to achieve proper modulation for evaluation purpose. PHY Data Rate = (Data sub-carriers/Symbol period)*(information bits per symbol).

Table 3.1. Mobile WiMAX-PHY data rates for 5 MHz channel

| **Modulation Scheme** | **Information bits/ symbol** | **Downlink Rate (Mbps)** | **Uplink Rate (Mbps)** |
|---|---|---|---|
| QPSK 1/2 | 1 | 3.17 | 2.28 |
| QPSK 3/4 | 1.5 | 4.75 | 3.43 |
| 16QAM 1/2 | 2 | 6.34 | 4.57 |
| 16QAM 3/4 | 3 | 9.50 | 6.85 |
| 64QAM 1/2 | 3 | 9.50 | 6.85 |
| 64QAM 2/3 | 4 | 12.6 | 9.14 |
| 64QAM 3/4 | 4.5 | 14.26 | 10.28 |

Communication systems have two main resources such as transmission power and channel bandwidth. Bit rate determines the channel bandwidth efficiency. If two or more bits are combined, the signaling rate would reduce. Accordingly the frequency of the carrier is reduced as well. The channel bandwidth reduces with the reduction in frequency of the carrier. This specific scheme of two successive bits grouped together to form a data sequence in order to reduce the bandwidth of channel is called as Quadrature Phase Shift Keying (QPSK). The combination of two bits forms 4 distinct symbols. When the symbol is changed to next symbol, 45˚ ($\pi/4$ radian) phase shift occurs [25].

Signal compression can be avoided if the linear region of a power amplifier is selected as the point of operation. Quadrature Amplitude Modulation (QAM) fits exactly to this requirement. For this very reason as per as QAM signaling scheme is concern the waveform designers critically examines power efficiency for the total channel bandwidth. For M-array-QAM (M=4, 16, 64) the number of grouped bits varies from 2, 4 and 6 respectively. The 64-QAM has a higher data rate compared to 16-QAM. However outside interference or imperfections such as phase noise, I/Q (Inphase / Quadrature) imbalance etc have an adverse effect on QAM [26]. Figure 2 shows the different modulation scheme used depending on the location of the mobile from the WiMAX base station. The key feature of adaptive modulation is that it increases the range that a higher modulation scheme can be used over, since the system can flex to the actual fading conditions, as opposed to having a fixed scheme that is budgeted for the worst case conditions [5].

WiMAX is expected to provide support to mobile users with very high mobility. Paper [6] shows that increase in mobile speed, decreases performance of the WiMAX network substantially. The WiMAX forum sets requirement guidelines for the several applications that can be run over WiMAX [17]. Mobile WiMAX can support varied data services and application with stringent QoS requirements, high system throughput, symmetric Up-Link (UL), Down-Link (DL) capacity and flexible resource allocation as summarized in Table II [3]. WiMAX QoS is specified for each service flow. The connection oriented QoS thereby provides strong control over the air interface. It can effectively enable the QoS control by overcoming the bottleneck situation of air interface. MAC layer manages the service flow parameters and thereby accommodate the dynamic service demand. Same control mechanism is provided in both UL and DL so that QoS improves greatly in both directions. Thus the BS scheduler controls both the UL and DL.

## 3.2 Adaptive Modulation and Coding

WiMAX system uses Adaptive Modulation and Coding (AMC) in order to reduce the effect of fluctuation in channel condition. The basic idea is to transmit the highest possible data rate with respect to the channel condition and ensuring very less amount of dropped packet [1]. During symbol mapping stage, sequences of binary bits are converted into complex valued symbols. The mandatory constellations are QPSK, 16-QAM and 64-QAM. The higher data rates are achieved with large constellation such as 64-QAM and less robust error correcting codes (e.g. ¾ convolutional, turbo or LDPC codes). A block diagram of an AMC is shown in Fig. 3.3. Adaptive modulation allows the WiMAX system to adjust the signal modulation scheme depending on the SINR condition of the radio link. When the radio link is high in quality, the highest modulation scheme is used, giving the system more capacity. During a signal fading, the WiMAX system can shift to a lower modulation scheme to maintain the connection quality and link stability.

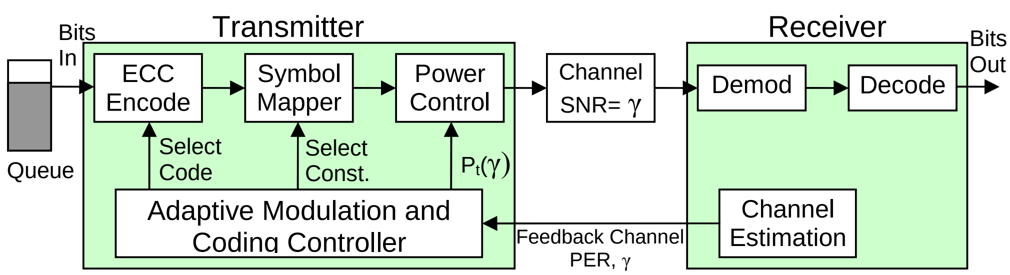


Figure 3.2. Adaptive modulation and coding block diagram [1]

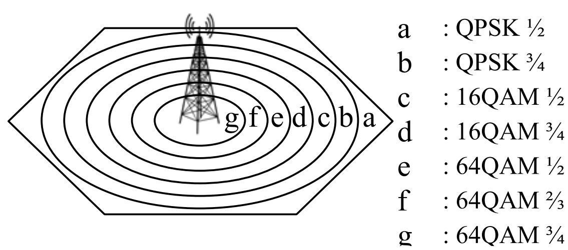


Figure 3.3. Annuls area which can be served by different modulation scheme.

## 3.3 Scheduling Services

WiMAX was developed from the outset to meet the stringent requirements for the delivery of broadband services. The WiMAX QoS is specified for each service flow. The connection-oriented QoS therefore, can provide accurate control over the air interface. Since the air interface is usually the bottleneck, the connection-oriented QoS can effectively enable the end-to-end QoS control. The service flow parameters can be dynamically managed through MAC messages to accommodate the dynamic service demand. Service flows provide the same control mechanism in both the DL and UL to improve QoS in both directions. Furthermore, since the sub-channels are orthogonal, there is no intra-cell interference in either DL or UL. Therefore, the DL and UL link quality and QoS can be easily controlled by the base station scheduler. The high system throughput also allows efficient multiplexing and low data latency. Therefore, with fast air link, high system throughput, symmetric downlink/uplink capacity, fine resource granularity and flexible resource allocation Mobile WiMAX can support a wide range of data services and applications with varied QoS requirements as summarized below:

1. ***The unsolicited service (UGS)*** is designed to support real-time service flows that generate fixed-size data packets on a periodic basis, such as T1/E1 and VoIP. UGS offers fixed-size grants on a real-time periodic and does not need the SS to explicitly request bandwidth, thus eliminating the overhead and latency associated with bandwidth request.
2. ***The real-time polling service (rtPS)*** is designed to support real-time services that generate variable-size data packets on a periodic basis, such as MPEG (Motion Pictures Experts Group) video. In this service class, the BS provides unicast polling opportunities for the MS to request bandwidth. The unicast polling opportunities are frequent enough to ensure that latency requirements of real-time services are met. This service requires more request overhead than UGS does but is more efficient for service that generates variable-size data packets or has a duty cycle less than 100 percent.
3. ***The non-real-time polling services (nrtPS)*** is very similar to rtPS except that the M<S can also use condition-based polling in the uplink to request bandwidth. In rtPS, it is allowable to have unicast polling opportunities, but the average duration between two such opportunities is in order of few seconds, which is large compared to rtPS. All the MSs belonging to the group can also request during the contention-based polling opportunity, which can often in collisions and additional attempts.
4. ***The best-effort service (BE)*** provides very little QoS support and is applicable only for services that do not have strict QoS requirements. Data is sent whenever resources are available and not required by any other scheduling-

service classes. The MS uses only the contention-based polling opportunity to request bandwidth.

5. ***The extended real-time polling service (ertPS)***, a new scheduling service introduces with the IEEE 802.16e standard, builds on the efficiencies of UGS and rtPS. In this case, periodic UL allocations provided for a particular MS can be used either for data transmission or for requesting additional bandwidth. This feature allows ertPS to accommodate data services whose bandwidth requirements change with time. Note that in this case of UGS, unlike ertPS, the MS is allowed to request additional bandwidth during the UL allocations for only non-UGS-related connections.

## 3.4 MOS:

In voice and video communication, quality usually means whether the hearing experience is good or bad. Besides this qualitative description, there is also a numerical method of representation for voice and video quality. The term is known as Mean Opinion Score (MOS). MOS gives the numerical representation of the perceived quality of the medium of transmission and eventually compressed using codec. MOS ranges from 1 (unacceptable) to 5 (excellent). The MOS values need not to be a whole number. A value of 4 to 4.5 is referred as satisfactory value normally used in public telephone services. MOS is inversely proportional to delay and packet dropped by the network. The E-model is an analytical model defined in ITU-T recommendation, provides a framework for an objective on-line quality estimation based on network performance measurements like delay and loss and application level factors like low bit rate codec. The result of the E-model is the calculation of the R-factor [27] (best case 100 worst case 0)

$$R = R_0 - I_s - I_d - I_e + A \qquad (1)$$

Where $R_0$ groups the effects of noise, $I_s$ includes the effects of the other impairments related to the quantisation of the voice signal, $I_d$ represents the impairment caused due to delay, $I_e$ covers the impairments caused by the low bit rate codec and packet losses. The advantage factor A compensates for the above impairments under various user conditions. $A$ is 10 for mobile telephony but for

VoIP $A$ is 0. The value of $R_0$ is considered to be 94.77 and the value of $I_s$ considered to be 1.43 in OPNET. The relation between MOS and R-factor is given as follows [27]:

$$MOS = 1 + 0.035R + 7R(R-60)(100-R)\times 10^{-6} \tag{2}$$

For VoIP operations MOS is used to judge the VoIP services from the network provider. Within a certain environment MOS value asses the work of codec used for compression for saving the bandwidth utilization.

## 3.5 Path-loss Models:

In wireless communication systems information is transmitted between the transmitter and the receiver antenna by electromagnetic waves. During propagation, electromagnetic waves interact with environment what causes reduction of signal strength. In a communication system, path-loss (sometimes called path attenuation) means the attenuation undergone by an electromagnetic wave in transit between a transmitter and a receiver [28]. WiMAX system can operate in NLOS condition. In this regard receiver exploits reflected, diffracted and scattered components of the transmitted signal which reach the receiving antenna through multi-path propagation. For the purpose of wireless network planning, propagation models are used for the electric field strength calculation [29]. These models require detailed geometric information on terrain profile, location and dimensions of buildings, and so on. Empirical models are based on measurements and predict mean path loss as a function of various parameters, e.g. antenna heights, distance, frequency, etc. Path-loss varies with the propagation model.

The common propagation models namely free Space, Suburban Fixed (Erceg), Outdoor to Indoor and Pedestrian Environment and Vehicular Environment are discussed in briefly that are used in mobile WiMAX performance evaluation.

### 3.5.1 Free Space Propagation model:

Free space model is a mathematical model which is hardly applicable in real-life scenario. It does not consider the fading effect due multi-path propagation. The model is expressed mathematically as [30]:

$$P_{rx}(r) = \frac{P_{tx} G_{tx} G_{rx} \lambda^2}{(4\pi)^2 r^2 L} \quad (3)$$

Where, $P_{rx}$ is received power in watts and is a function of distance between transmitter and receiver, $P_{tx}$ is the transmitted power in watts, $G_{rx}$ and $G_{tx}$ are the gain of the receiving and transmitting antennas respectively, $L$ is the system-loss factor and is not related to propagation. It is usually greater than 1 and $\lambda$ is the wavelength in meters.

### 3.5.2 Erceg's Suburban Fixed Model:

The Erceg model is based on extensive experimental data collected at 1.9 GHz in 95 macro cells of suburban areas across the United States [31]. This model is a slope intercept model given by:

$$PL = H + 10\gamma \log_{10}\left(\tfrac{d}{d_0}\right) + X_f + X_h + s \qquad \text{For } d > d_0 \quad (4)$$

Where $PL$ is the instantaneous attenuation, $H$ is the intercept and is given by free space path loss at the desired frequency over a distance of $d_0$ = 100 meters:

$$H = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right)$$

Where, $\lambda$ is the wavelength and $\gamma$ is a Gaussian random variable over the population of macro cells within each terrain category. It can be written as [31] [32].

$$\gamma = \left(e - gh_b + k/h_b\right) + x\sigma_\gamma$$

Where $h_b$ is the height of the base station antenna in meters, $\sigma_\gamma$ is the standard deviation of $\gamma$, $x$ is a zero-mean Gaussian variable of unity standard deviation N[0, 1]. $e$, $g$, $k$ and $\sigma_\gamma$ are all data-derived constants for each terrain category. The default value of $e$ is 4.6, $g$ is 0.0075/m, $k$ is 12.6m and $\sigma_\gamma$ is 0.57 [18]. The shadow fading components varies randomly from one terminal location to another within any given macro-cell. It is a zero-mean Gaussian variable and can be expressed as:

$$s = y\sigma \text{ and } \sigma = \mu + z$$

where $y$ and $z$ are the zero-mean Gaussian variables of unit standard deviation N[0, 1], $\sigma$ is the standard deviation of $s$, $\mu_\sigma$ is the mean of $\sigma$, and $\sigma_\sigma$ is the standard deviation of $\sigma$. $\mu_\sigma$ and $\sigma_\sigma$ are both data-derived constants for each terrain category. The default values of $\mu_\sigma$ and $\sigma_\sigma$ are 10.6 and 2.3 respectively [32]. The correlation factors of the model for the operating frequency and for the MS antenna height are [32].

$$X_f = 6.01\log_{10}\left(\frac{f}{2000}\right), \text{ and } X_h = -10.8\log_{10}\left(\frac{h_r}{2}\right)$$

Where $f$ is the frequency in MHz and $h_r$ is the height is the MS antenna above ground in meters. [29] gives comparison of the different propagation models in suburban region.

### 3.5.3 Outdoor-to-Indoor and pedestrian path-loss environment

This environment is characterized by small cells and low transmission power. Base stations with low antenna heights are located outdoors; pedestrian users are located on streets and inside buildings and residences [33].

$$PL = 40\log_{10} R + 30\log_{10} f + 49 \tag{5}$$

The above equation describes the path loss in dB where $R$ is the distance between the base station and the mobile station in kilometers and $f$ is the carrier frequency of 2000 MHz for IMT-2000 band application.

### 3.5.4 Vehicular environment:

This environment is characterized by larger cells and higher transmits power [34][35]. The path loss in vehicular environment in dB is given by:

$$PL = 40\left(1 - 4\times10^{-3} \times \Delta h_b\right)\log_{10} R - 18\log_{10}\Delta h_b - 21\log_{10} f + 80\,dB \tag{6}$$

Where $R$ is the distance between the base station and the mobile station, and $f$ is the 2000 MHz carrier frequency and $\Delta h_b$ is the base station antenna height in meters measured from the average roof top level.

Chapter 4

# SIMULATION SETUP & RESULTS

## 4.1 Simulation Setup

For simulation purpose, scenarios are deployed with 7-Hexagonal celled WiMAX using omni directional antenna (depicted in Fig. 4.1). We have used 2 Subscriber Station (SS) nodes with varying speed. These 2 nodes (mobile_2_1 and mobile_2_2) are moving along the trajectories indicated by green and blue lines respectively. The common attributes for simulation used are given in Table-4.1. Although WIMAX standard [3] claims that WiMAX would support very large coverage area, [1] shows that Mobile WiMAX typically support cell radius of approximately 3 km. So we have taken 3 km cell radius cell for our simulation.

Table 4.1. Common attributes for simulation

| **Attributes** | **Values** |
|---|---|
| Cell Radious | 3 km |
| Base Station Model | wimax_bs_router |
| Subscriber Station Model | wimax_ss_wkstn |
| Link model | PPP_DS3 |
| IP Backhaul model | Router_slip64_dc |

The objective of this thesis is to study the various performances over mobile WiMAX network extensively using the fixed and adaptive modulation and coding techniques. We have constructed various scenarios by varying speed, path-loss models, application type and scheduling services. As discussed in introduction, we use two sets of AMCs as given in Table 4.2. QPSK ½ is a conservative MCS which reduces block error rate at the cost of Bandwidth consumption [9]. Papers [9] [10] and [11] gives performance analysis of WiMAX network with respect to AMC in fixed and single cell environment. It shows that more aggressive AMC (i.e. using higher order modulation scheme at low SINR value) scheme gives less bandwidth consumption at the expense of increased BLER. We have used the same AMC profile as [9] and [10] for our simulation as given in Table 4.2. Here AMC-2 is conservative AMC as it is using lower order MCS most of the time. The mandatory exit threshold is the SINR at or below where this burst profile can no longer be used and where a change to a more robust (but also less frequency-use efficient) burst profile is required and minimum entry threshold is the minimum SINR required to start using this burst profile when changing from a more robust burst profile [36].

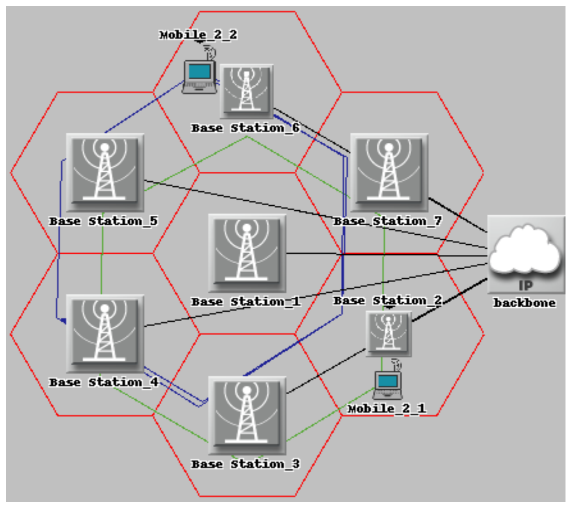


Figure 4.1. WiMAX network used for simulation

Table 4.2. AMC profile selected for simulation

| **Modulation and Coding** | **AMC-1** | | **AMC-2** | |
|---|---|---|---|---|
| | ***Mandatory Exit Threshold (dB)*** | ***Minimum Entry Threshold (dB)*** | ***Mandatory Exit Threshold (dB)*** | ***Minimum Entry Threshold (dB)*** |
| QPSK 1/2 | -20 | 2.0 | -20 | 2.0 |
| QPSK 3/4 | 5.0 | 5.9 | 11 | 11.9 |
| 16QAM 1/2 | 8.0 | 8.9 | 14 | 14.9 |
| 16QAM 3/4 | 11 | 11.9 | 17 | 17.9 |
| 64QAM 1/2 | 14 | 14.9 | 20 | 20.9 |
| 64QAM 2/3 | 17 | 17.9 | 23 | 23.9 |
| 64QAM 3/4 | 19 | 19.9 | 25 | 25.9 |

Four sets of simulation scenarios are considered: first for varying speed of the mobile, second for varying path loss models, third for different types of services with constant bit rate (CBR) traffic, and fourth one is similar to third scenario except it uses non-CBR traffic. For each set again types of modulation is chosen one by one to take the simulation results for a particular output parameter.

We implement the necessary configurations require for all scenarios in OPNET simulator. The outcome of the simulation is looking for MOS value, Throughput, Data dropped and the UL data burst usage at every instance of time. We get the values with respect to simulation time. We consider the average of the statistics obtained over the period of the simulation time for performance studies in different scenarios.

## 4.2 Scenario 1 (Varying Speed)

**In this scenario we consider the performance behaviour of different modulation and coding schemes with respect to mobility of SS considering speed as the parameter.**

We have considered the scenario keeping path-loss model, application and scheduling service constant. Path loss model is chosen as Free Space, application as CBR traffic of load 96 kbps, service class as ertPS. We provide the speed of the mobile in kmph. The performance parameters for this scenario are data drop; MOS value of the voice call, throughput of the mobile node and uplink data burst usage (%) for BS which is a measure of the utilization of uplink Bandwidth (BW) of a particular WiMAX BS.

Fig. 4.2 gives the throughput of Mobile_2_1 during the simulation time. As it moves from one cell to another cell it faces different SINR value depending upon its current distance from the BS of that cell. As it moves towards the cell boundary, the SINR gradually decreases which results in decreasing the throughput. As we can see from the graph, that when using QPSK-½ as MCS, the node experiences maximum throughput throughout the entire path. For, higher order MCS such as 64 QAM-¾, as the SS node moves towards cell boundary, the throughput fall drastically. AMC profile adopts the suitable MCS dynamically according to the received SINR value so it is keeping approximately constant throughput throughout its trajectory.

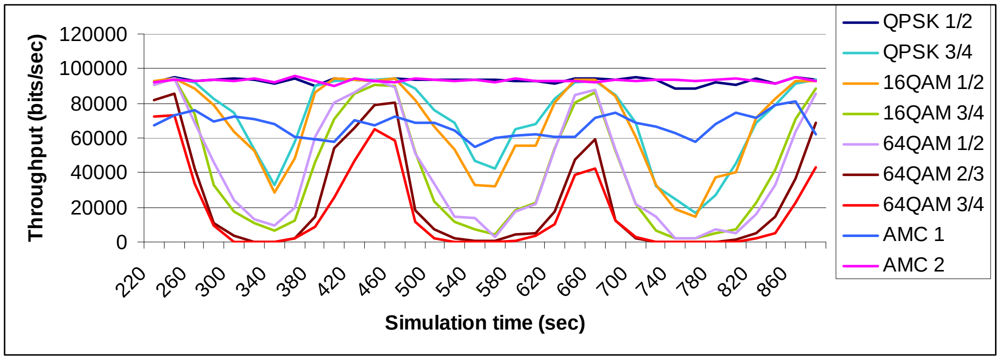


Figure 4.2. Throughput of SS node during simulation

Fig. 4.3 represents the average data dropped, Fig. 4.4 is for throughput and Fig. 4.5 is for MOS value. Fig. 4.6 is for UL data burst usage for the mobile node with fixed and adaptive modulations. As the speed of SS increases, the hand-off frequency increases which results in increased packet loss (data dropped) and thereby decreased throughput and MOS value. As can be viewed from Fig. 4.3 the average data drop is significantly high when SS moves with a greater speed (50 m/sec). The effect of data drop naturally decreases the average WiMAX throughput as shown in Fig. 4.4.

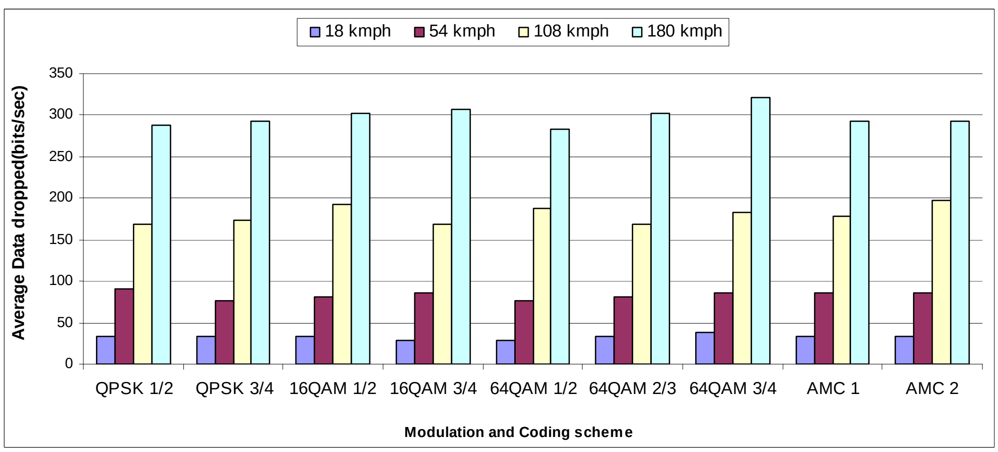


Figure 4.3. Average Data dropped for SS node.

From Fig. 4.3 it is observed that data dropped is almost constant for every modulation schemes and varies with speed. We know that higher order modulation scheme is more sensible to SINR [25]. As the SS is moving through the cell, it faces different SINR value depending upon the distance from the BS and the propagation environment. With increasing distance, the SINR decreases and the higher order MCS gives more BLER than the lower order MCS for same SINR value.

The average throughput is taken as a measure which will give the average of observed throughput throughout the simulation. So, as the order of MCS increases the average throughput will decrease which is observed from Fig. 4.4. For example, a 64-QAM ¾ has an average throughput of just 12 kbps compared to 90 kbps in case of QPSK ½ under the SS speed of 18 kmph. AMC-1 is an aggressive AMC i.e. SS node tends to use higher order of MCS compared to what AMC-2 uses at same value of SINR. So, it gives comparably lower value of average throughput than AMC-2.

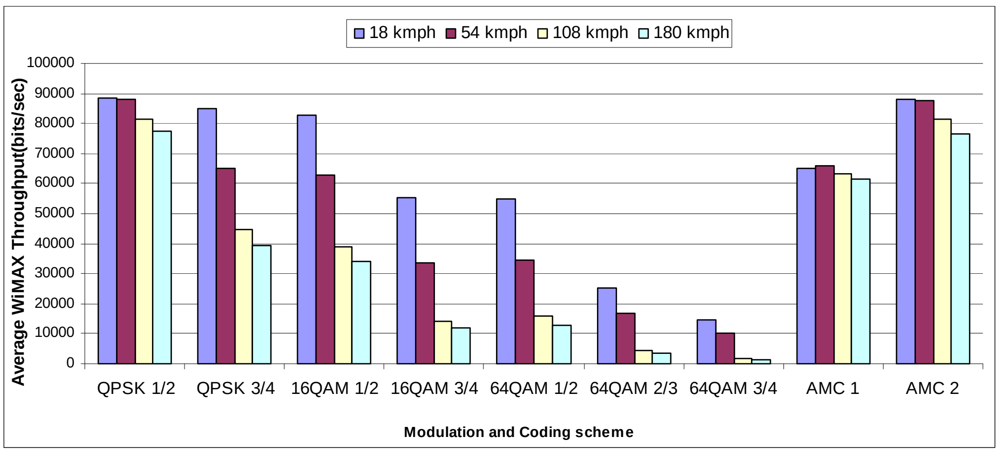


Figure 4.4. Average WiMAX Throughput of SS node

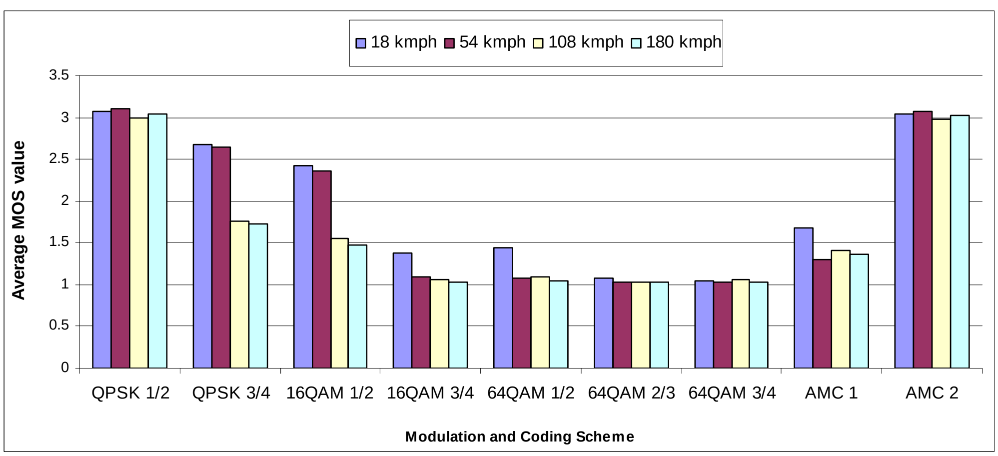


Figure 4.5. Average MOS value for voice application

Bit error probability of QPSK is less in noisy environment at the cost of high bandwidth usage. Voice is retrieved efficiently in noisy environment if QPSK is used. This is reflected in the graph shown in Fig. 4.5.

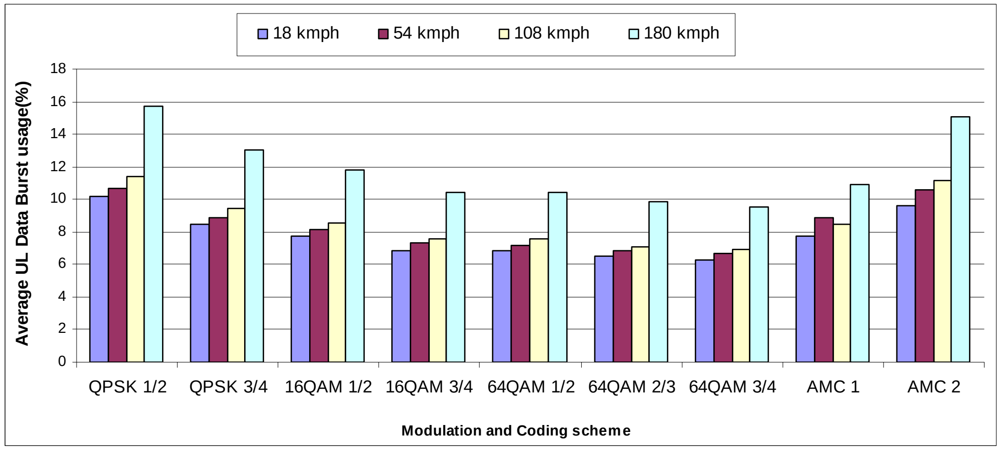


Figure 4.6. Average UL Data Burst usage of WiMAX BS.

From the results (Fig 4.3-4.6) it is observed that, WiMAX using QPSK as modulation technique shows better performance (i.e. high throughput and greater MOS value.) compared to QAM. This indicates increase in number of bits per symbol decreases the QoS. But when we see the UL data burst usage, it implies, increase in information bits per symbol decreases the data burst usage, thereby, increasing the system capacity. System capacity is always compromised with system quality.

The average MOS value (Fig. 4.5), indicates that a very poor performance is obtained for higher rate Coding schemes such as 16QAM ¾ and 64 QAM. Voice quality with MOS above 3 is considered to be of acceptable quality [26]. Hence, only QPSK ½ seems to satisfy the user demand of the voice quality, thereby giving a better performance. From Fig. 4.6 we observe that increase in information bits per symbol decreases the average UL data burst usage which implies less bandwidth consumption.

Considering the AMC profile in each of the cases, shows substantial better performance compared to the conventional fixed coding schemes. As we see the AMC-2 gives similar performance for average throughput and MOS value but the UL data burst usage is less. This implies AMC implementation minimizes the overall system BW usage irrespective of system performance and QoS.

From these results we can conclude that conservative AMC scheme i.e. AMC-2 improves performance of the WiMAX network over the aggressive AMC scheme i.e. AMC-1 in expense of system capacity i.e. using higher bandwidth. The application performance for AMC-2 and QPSK-½ is almost same but the average

UL data burst usage for AMC-2 is a bit less than QPSK ½, implying more system capacity. The results show that we gain an acceptable MOS value for AMC-2 keeping the bandwidth usage less than that of the QPSK ½.

## 4.3 Scenario 2: (varying path-loss model)

**In this scenario we consider the performance behaviour of different modulation and coding schemes with respect to various path loss models.**

We have considered the scenario keeping speed of SS, application and scheduling service constant. Speed of SS is chosen as 54 kmph, application as CBR traffic of load 96 kbps, service class as ertPS. In this scenario the performance of WiMAX network is observed for various modulation and coding schemes with respect to various path-loss models. We know that Outdoor to indoor and pedestrian path loss model is designed for Small and micro cell WiMAX network. However, for our study we have considered fixed radius WiMAX network for all the path loss models. For outdoor to indoor and pedestrian propagation model, as SS node moves away from BS it will encounter significant drop in SINR and as the higher order MCS (such as 64-QAM ¾) requires high value of SINR to give a good throughput, higher order MCS will face very large amount of data drop as can be revealed from Fig. 4.7.

Path loss for free space is lowest so reduction of SINR with the distance from BS is less which leads to better throughput. Again, as the reduction of SINR with distance from BS is less, the SS have to change its modulation scheme less frequently which results in very high throughput for AMC as shown in Fig. 4.8.

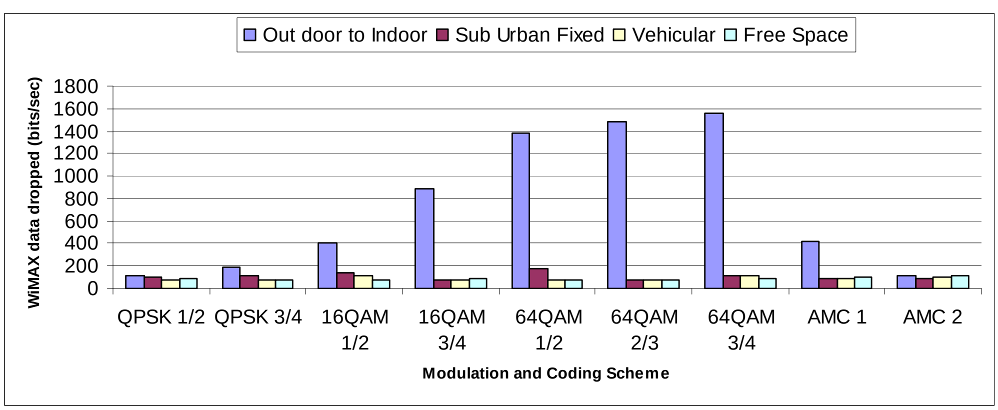


Figure 4.7. Average Data dropped for SS node.

In free space propagation model we do not consider fading and multi-path propagation phenomenon. So, path-loss would be very nominal and the received SINR would be ideal as we can see from Fig. 4.8 that the throughput for free space propagation model is highest for all MCS. As outdoor to indoor and pedestrian propagation model experiences very high packet drop compared to the others, it is giving the lowest throughput compared to other propagation model as can be observed from Fig. 4.8. For free space propagation model, QPSK ½ and AMC-2 are giving almost same throughput, but for other propagation models, AMC-2 performs better which implies that in idealistic condition AMC-2 performs as good as fixed coding but in noisy area and considering fading environment, AMC-2 performs better than the fixed type of coding scheme.

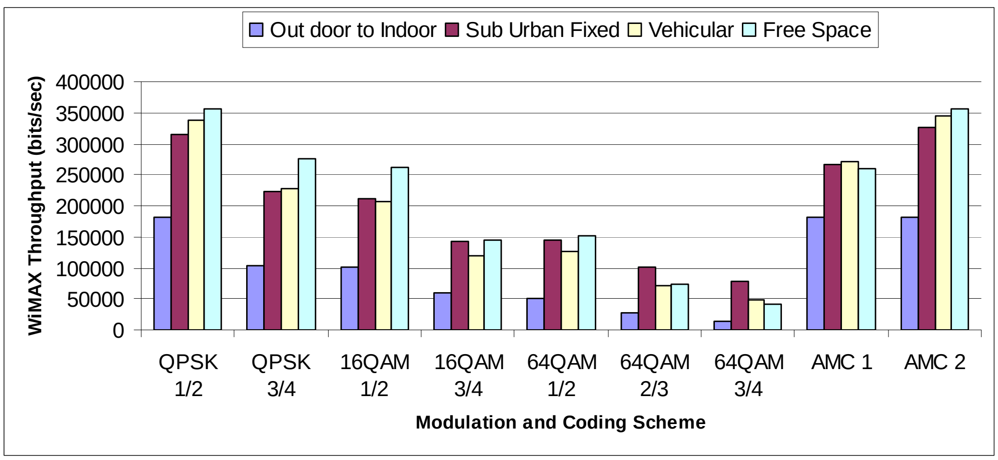


Figure 4.8. Average WiMAX Throughput of SS node

From Fig. 4.9 we can see that only QPSK ½ and AMC-2 provide satisfactory results (i.e. MOS>2) but other MCSs are giving very poor performance as MOS value of 1 is considered to be the worst condition.

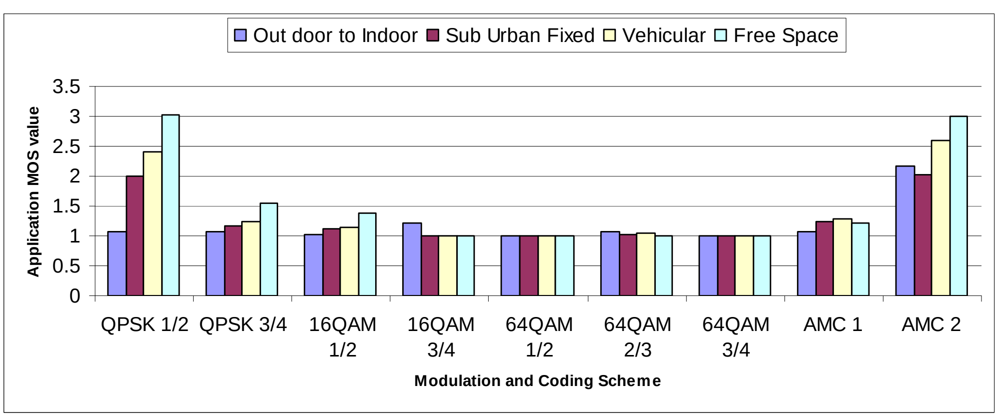


Figure 4.9. Average MOS value for voice application.

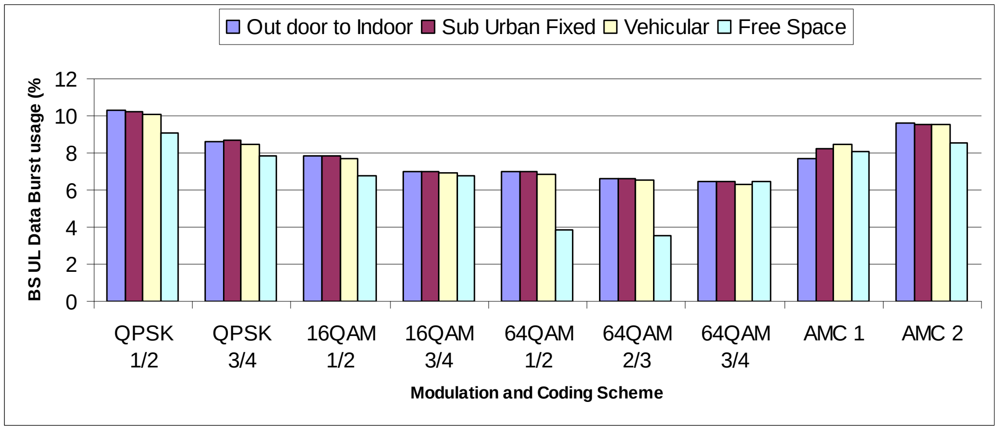


Figure 4.10. Average UL Data Burst usage of WiMAX BS

We can see from Fig. 4.10 that for all the path loss models, AMC-1 consumes less bandwidth than QPSK ½ where as AMC-1 gives almost same throughput as QPSK ½. So, we can conclude by comparing Fig. 4.8 and Fig. 4.10 that AMC improves system performance while consumes less BW as frequent changes of the scheme is not required.

## 4.4 Scenario 3 :( varying scheduling services with CBR traffic)

**In this scenario we consider the performance behaviour of different modulation and coding schemes with respect to various service types in WiMAX with CBR traffic.**

Though different scheduling types are designed to support different types of traffic, in this work we configure a Constant Bit Rate (CBR) traffic between the two SS nodes for comparing the performance of different scheduling types for CBR.We only take the results for throughput, BS UL data burst usage and data drop as the performance matrix.

As for UGS, a fixed amount of bandwidth on the periodic basis is requested at the setup phase of uplink. Then bandwidth is never requested explicitly [11]. Thus, UGS gives best result (good throughput and less consumed bandwidth) for CBR traffic which is revealed from Fig. 4.11 and Fig. 4.12.

ertPS is designed to Support real-time applications generating variable bit rate traffic periodically [37][38]. It offers periodic opportunities to request bandwidth consuming comparably high bandwidth for CBR traffic as shown in Fig. 4.12. For QPSK-½ and AMC-2, all scheduling types perform same result which reveals that for lower order of MCS and good SINR, all service classes give equal throughput but as the order of MCS increases, throughput fall drastically while consuming nearly same bandwidth.

nrtPS and BE gives comparatively same throughput for almost every coding scheme as these two service classes are designed to handle delay tolerant data packets i.e. data packets arriving aperiodically. So, these service classes will consume higher bandwidth than the UGS use to give same throughput which can be seen in Fig. 4.12. For fixed coding scheme there is hardly any difference in the bandwidth utilization however using the AMC the nrtPS consumes less bandwidth compared to BE. This is because the BE allocates the requested bandwidth for every arrived data packet where as nrtPS is designed for services that require variable size data grant burst type on a regular basis [11]. As we have used constant bit rate (CBR) application, the overall bandwidth consumption of nrtPS is lower. From Fig. 4.11 we see that ertPS provides greater throughput than nrtPS, UGS and BE. The simple reason behind this is ertPS is designed for VoIP application where CBR traffic is used.

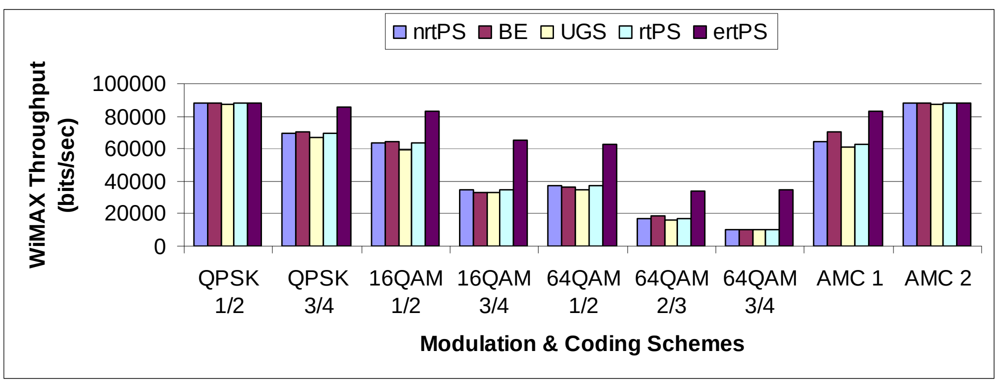


Figure 4.11. Average WiMAX Throughput of SS node.

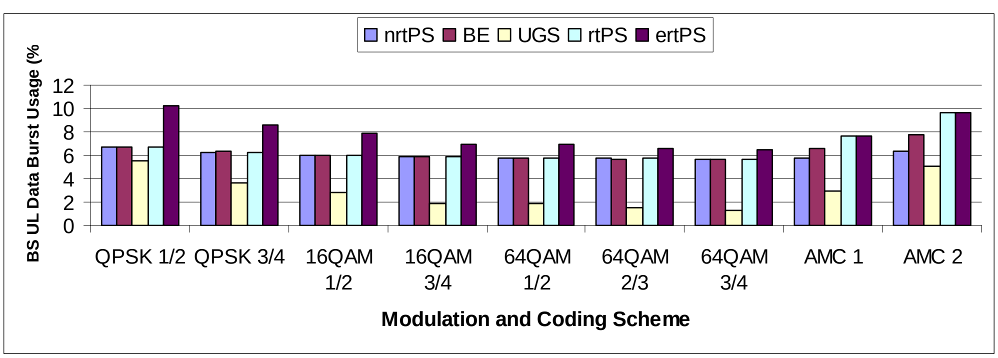


Figure 4.12. Average UL Data Burst usage of WiMAX BS

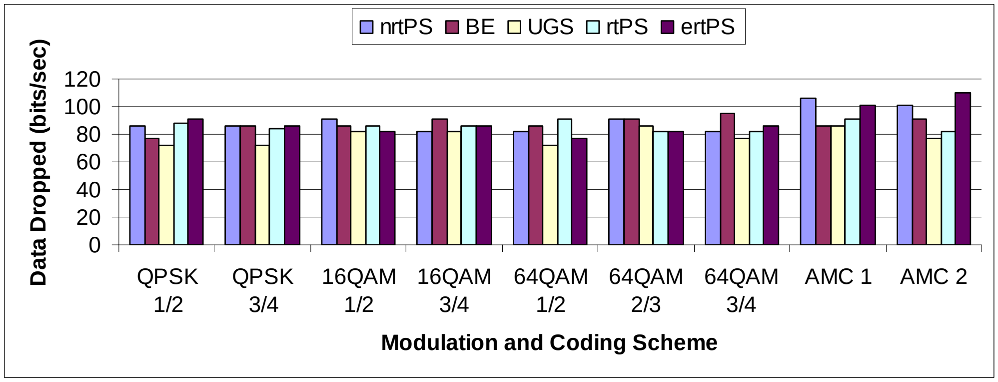


Figure 4.13. Average Data dropped for SS node

## 4.5 Scenario 4: (varying scheduling services with non- CBR traffic)

**In this scenario we consider the performance behaviour of different modulation and coding schemes with respect to various service types in WiMAX with non CBR traffic.**

In this scenario we have configured Voice traffic with silence suppression traffic between the SS nodes. Voice traffic with silence suppression means, the node will not send traffic while the user is silent i.e. it is sensing the user's voice amplitude all time and sending traffic according to it. The simulator uses a default value of Silence period of 65%. But when the user would be silent it is unknown to the user and data packet can arrive at any time. So it is not CBR traffic. We simulated this scenario with every scheduling type to compare the results.

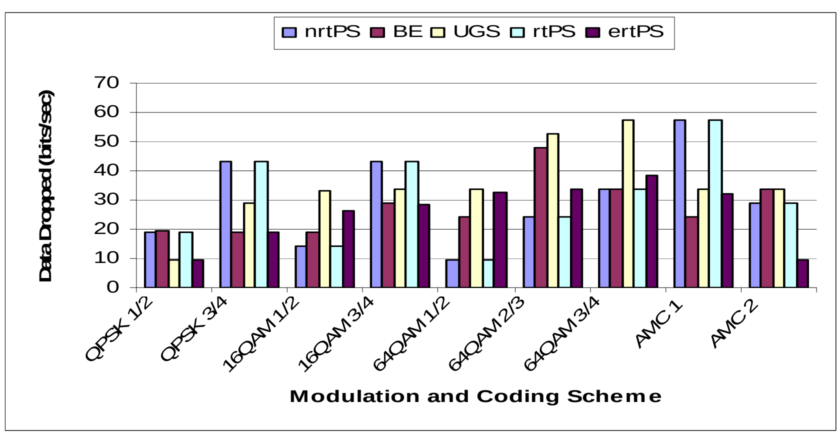


Figure 4.14. Average Data dropped for SS node.

As we can see, from Fig 4.15, that UGS gives best throughput irrespective of MCS but from Fig. 4.17 we see that it consumes very high bandwidth this is because UGS uses fixed slots for Voice call so it is giving good performance at the cost of high bandwidth. On the other hand ertPS is designed for VoIP service with activity detection, so it is giving comparatively better throughput than nrtPS, BE and rtPS while consuming slightly greater bandwidth than these schemes. rtPS and ertPS are consuming nearly same bandwidth but ertPS is giving very good performance (in terms of MOS and throughput). So, ertPS is enhancing system capacity. nrtPS and BE are used for non real-time traffic hence, their performance is poor compared to the others.

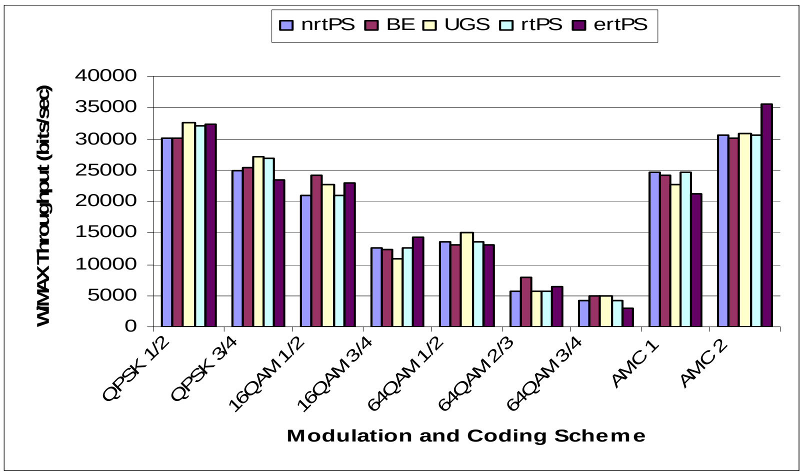


Figure 4.15. Average WiMAX Throughput of SS node

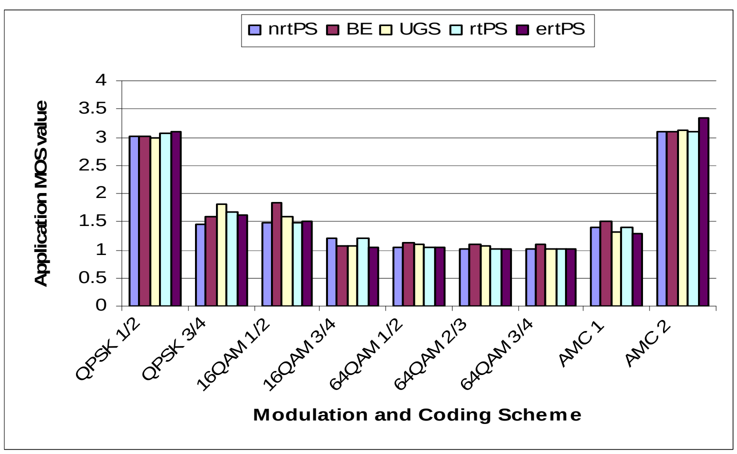


Figure 4.16. Average MOS value for voice application.

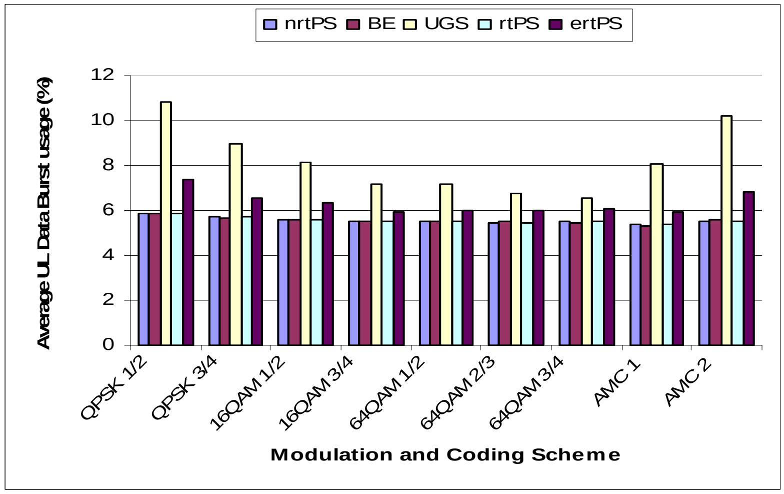


Figure 4.17. Average UL Data Burst usage of WiMAX BS

## 4.6 Conclusion

The adaptive modulation and coding issue related to WiMAX OFDMA system have been critically examined in great details in this paper. Several scenarios are simulated using the OPNET modeler for mobile WiMAX with multicellular arrangement. The simulation results reveal the effect of speed of mobile nodes, path-loss parameter of wireless channel, the type of application used and MAC scheduling services on the various system performance measures such as throughput, data drop, MOS value etc. We have also taken into account the system capacity in terms of UL data burst usage of a mobile node. A specific highlight has been given on the impact of adaptive modulation and coding scheme to show that the proper implementation of adaptive modulation and coding can highly enhance the system performance and quality consuming less system bandwidth. However conservative AMC gives best performance consuming higher system bandwidth. However the increase in velocity of a mobile station can decrease system quality. A key observation shows ertPS scheduling service class gives best performance for VOIP application, and among the feasible path loss models, vehicular model gives best result. The simulation result confirms that outdoor to indoor and pedestrian model can only be applicable to small and micro-cell WiMAX network. The results in this paper conclude that we have to compromise between system performance quality and system capacity while designing the AMC.

# Chapter 5

# REDUCING HAND-OFF LATENCY

## 5.1 Introduction

The IEEE 802.16e Standard [3] (WiMAX) network consists of the access services network (ASN) and connectivity services network (CSN). The core elements in the ASN are the base station (BS) and ASN gateway (ASN-GW) connected over an IP cloud (Fig. 5.1). In Hierarchical model of WiMAX network [39] the BSs are connected to the CSN through centralized node called as ASN-GW. Similar to the traditional network, the hierarchical architecture enables tight resource coupling where centralized controller (ASN-GW) manages all contexts regarding the Subscriber Stations (SS) attached to the BS under its supervision. Due to lack of scalability and high cost, the central controller can become a performance bottleneck [40]. As the centralized node is involved in processing and initiating a call, call set up time is very high ranging from several seconds to tens of second [41]. This is not crucial for Voice over Internet Protocol (VoIP) as in that case, call set up is invoked at beginning of a call but very crucial for other data traffic (e.g. Internet application like FTP, HTTP etc) where call set up is done very frequently[41].

On the other hand flat architecture [41][42] means a network in which all BS can be reached without going through another centralized node. Here, the functionalities of the ASN-GW and the BS are merged together in a single node which can act as an independent router and these integrated elements are directly connected to the IP core network. Flat architecture use Mobile IP [43] for mobility management [41] where resource management is distributed and no centralized node is involved in call set up procedure hence reduction in call set up time. Thus flat architecture is better in terms of dealing with data traffic where call set up is done very frequently. When a Mobile Subscriber Station (SS) node roams from one Base Station (BS) to another, since there is no coordination at the link layer between BSs, a layer 3 handoff is triggered only after the serving link is dropped. Service is further regained by the slow Mobile IP protocol which leads to large hand off latency. In this thesis, we propose a scheme that reduces the hand off latency without any extra overhead on the network.

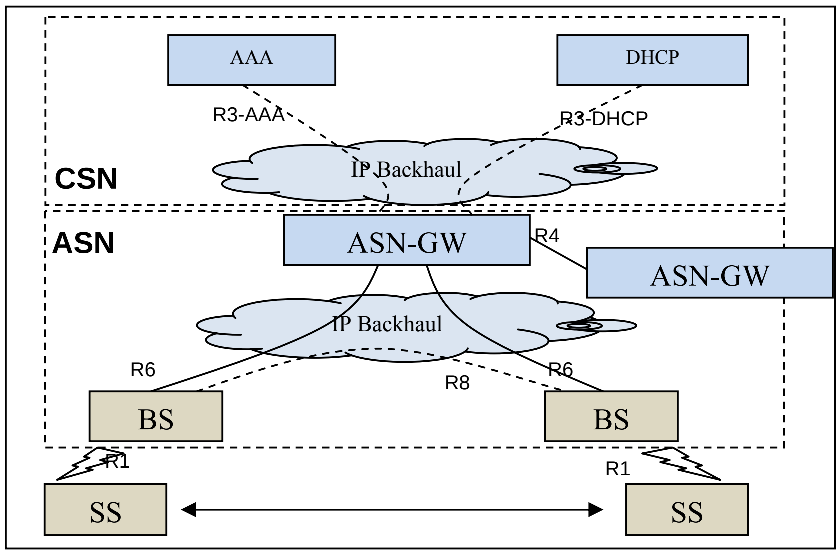


Figure 5.1. Mobile WiMAX network architecture.

The rest of this chapter is organized as follows. In section 2 essential background material needed for handover procedure in hierarchical and flat architecture are provided. In section 3 we present our proposed scheme to reduce hand off latency in flat architecture. Then in section 4 we present performance analysis results of various models including our proposed scheme with help of OPNET Modeler 15.0. Finally section 5 concludes this chapter.

## 5.2 WiMAX Hierarchical Network Architecture

Currently deployed WiMAX networks adopt the traditional hierarchical architecture [40] [44] where multiple BSs are connected to Core network(CSN) through ASN-GW (Depicted in fig. 5.2 below) which facilitates resource management and mobility support in highly efficient manner. All signaling and traffic have to flow through the central controller node (ASN-GW). It is highly scalable in terms of system capacity and geographical coverage. Hierarchical network is well suited for high speed mobility network.

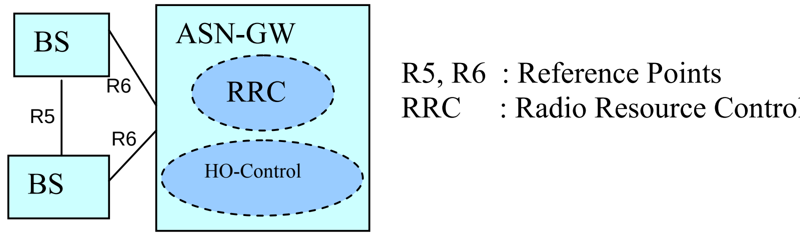


Figure 5.2. WiMAX Hierarchical Network Architecture

In this architecture a bidirectional Generic Routing Encapsulation (GRE) Tunnel is established between the ASN-GW and each BS to exchange traffic between them through the IP Backhaul [1][45]. The entire data packet received by the WiMAX interface in the BS must be forwarded to the ASN and ASN will decide which tunnel should be taken to forward the packet thereby selecting the correct WiMAX interface. So the complexity and the system over head are very high at the ASN-GW.

IEEE 802.16e Standard [3] defines various Handover procedures to support Data Link layer mobility in WiMAX network. Fig. 5.3 shows the message flow during handover in hierarchical network. The SS node is initially connected to Old BS. When the SS node moves from the coverage of Old BS to Target BS, it sends a HO_REQ (Handoff Request) message to the ASN-GW indicating need of handoff to Target BS. The ASN-GW checks the resources available at the Target BS by sending RES_REQ (Resource Request) and the Target BS confirms with RES_RSP (Resource Response).

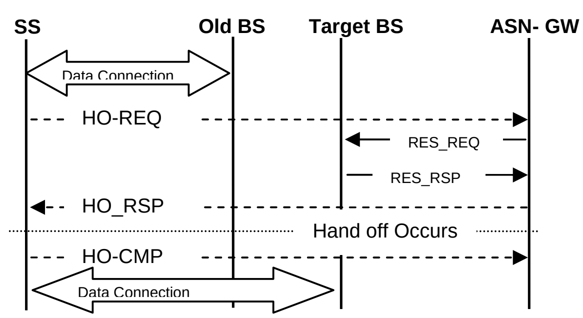


Figure 5.3. Message flow during hand-off in hierarchical architecture

Now the ASN-GW initiates a session transfer process between the Old and the Target BS. Once session transfer is done, the ASN-GW sends HO_RSP (Handoff Response) to confirm Handoff. Now the SS node replies HO_CMP (Handoff Complete) to ASN-GW indicating completion of handoff. In the hierarchical model, fast handover is achieved by Intra ASN (layer 2) mobility. Inter ASN handover is done by a Layer 3 handover with the help CSN and the Mobile IP [39] which leads to very high latency.

## 5.3 WiMAX Flat Network Architecture

Flat model of WiMAX architecture [41][42] consolidate the functionality of ASN-GW and BS in one node (depicted in Fig. 5.4) is sometimes called Base Station Router(BSR) [42]. These nodes are directly connected to IP core network to give seamless mobility through Network layer handover. Here the SS nodes must complete layer 2 and layer 3 hand-off to have uninterrupted data flow.

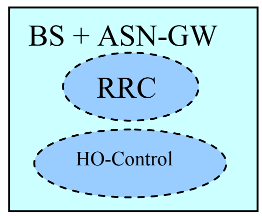


Figure 5.4. WiMAX Flat Network Architecture

The message flow during hand-off is given in the Fig. 5.5. The layer 2 handoff is same as the previous one. After the layer 2 handover is complete i.e. SS is now attached to Target BS and it must receive the Mobile IP (MIP) [43] Agent Advertisement (Agent Adv) message (broadcasted over the newly connected radio link) from the Foreign Agent (FA) situated at target BS. Upon receiving this Agent Adv, the SS node checks its Binding Catch whether the new Agent's address is same as previous agent's address or not. If this address is different, then the SS node sends a Registration Request (Reg_Req) to FA which relays the message to SS node's HA. HA updates its mobility binding table and send a Registration Reply (Reg_Rep) to the FA which update its visitor list table and forward the message to SS node. Now HA forward all the traffic intended to SS through Newly connected Target BS's FA.

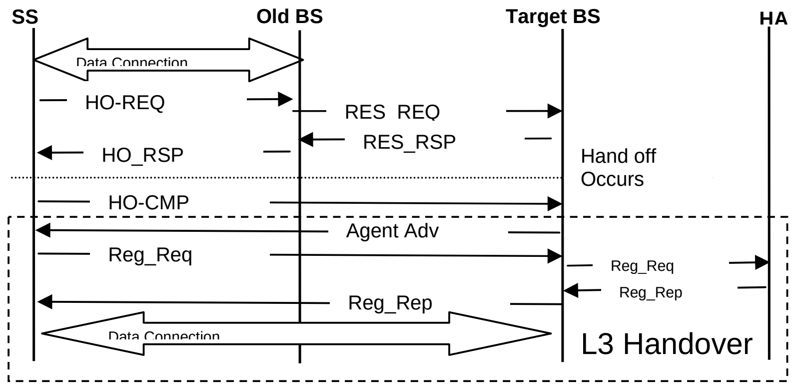


Figure 5.5. Message flow during hand-off in flat Architecture

## 5.4 Benefits & Drawbacks of Flat Architecture

A survey on handover performance for mobile network is given in [40]. The flat model of WiMAX offers low Network latency (End to End delay) as number of nodes between SS and IP core network is reduced to one, and avoids costly and complex inter-node interfaces (e.g. R6, R8 etc). It also provides high scalability as there is no centralized bottleneck. Thus, single point failure may not affect large number of radio access nodes. Whereas, in case of hierarchical architecture, failure in centralized controller causes disruption in large area.

Performance improvement may actually come with some challenges in flat architecture. Most significant challenge for flat network is hand off latency. In hierarchical architecture, fast handover is achieved through layer 2 mobility but in flat architecture, network layer mobility is needed which cause significant delay, which is too high for real time application like Voice over IP (VoIP) and Streaming video application (e.g. video conference). In hierarchical architecture, resource management is centralized, where as in flat architecture resource management is done in distributive way. It requires extra effort to share radio resource information and Authentication, Authorization, and Accounting (AAA) information among the BSs during the handoff.

So, we can see that, the flat model gives many advantages but lay behind mainly due to poor handoff performance. Most of the research works have concentrated on enhancing MAC layer to reduce handoff latency [14]. In this thesis we propose a scheme that reduces the handoff latency without any extra overhead on WiMAX network part. Proposed scheme uses IEEE 802.16 MAC layer handover information to reduce layer-3 handoff latency. Details are given in the subsequent section.

## 5.5 Proposed Handover Scheme

In flat architecture, network layer handoff is initiated after finishing the data link layer handoff causing slow hand-off. The network layer is unaware of the data link layer handoff. MIP handoff begins only when the mobile node receives Agent Advertisement message over the newly connected radio link. To overcome this shortcoming we have modified the WiMAX MAC and MIP protocol in the SS node. After completing the layer-2 hand-off procedure, mobile nodes start periodic ranging. At this time SS node is connected to Target BS over the newly connected WiMAX radio link. In our proposed scheme, at this stage, mobile node agent sends an Agent Solicitation message broadcast over the newly connected radio link. The FA at the Target BS replies Agent Advertisement message with its own address to the SS node. Receiving the Agent Advertisement, the SS node registers with the FA at the new BS. Thus the SS node does not need to wait for Agent Adv as in normal procedure. Fig 2 shows the schematic representation of proposed hand-off process. To implement our proposed model, we have modified WiMAX-MAC and MIP process models of the SS node (wimax_ss_wkstn) in OPNET. Here MAC layer sends an interrupt to the MIP Mobile Node Agent situated at the SS node itself giving information about completion of layer 2 hand-off. This interrupt triggers the MIP agent to send the Agent Solicitation message.

The interrupt processing is internal so it will take negligible time (of the order of micro second). Time delay for message transfer is usually in the range of microsecond while average time to get the Agent Advertisement is in range of second. By default, MIP Agent Advertisement is sent with an interval of 5 secs [45]. An SS node may receive Agent Advertisement just after entering the new cell or after 5secs. On an average it will get the message after 2.5secs. The Layer 2 handoff latency (98ms as per our simulation) is in the order of ms where as waiting time for getting Agent Advertisement is in the order of second. In our proposed scheme, after completing the L2 hand off, then SS node need not wait for the agent advertisement from target BS to initiate the L3 handoff, instead it sends Agent Solicitation message to trigger L3 handoff. Thus the waiting time is eliminated which reduces the handoff latency greatly.

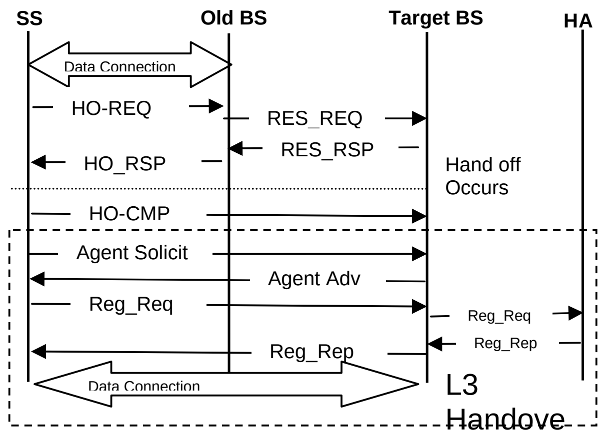


Figure 5.6. Message flow during handover in proposed scheme

### 5.5.1 Latency Analysis:

To analyze the delay performance, we defined some parameters as:

$T_{L2} =$ Average latency of Layer-2 handover procedure.

$T_{waiting} =$ Average time to wait for receiving Agent Advertisement after layer 2 handover is complete.

$T_{propagation} =$ Average propagation time of messages interchanged between SS and BS.

$T_{processing} =$ Average time required to process the registration request at the BS end. This include transmission delay for sending Reg_Req to HA, receiving Reg_Rep from HA and processing delay at the HA.

We can calculate the total handoff latency for conventional and proposed network using Fig. 5.5 and Fig. 5.6.

$$D_{conventional} = T_{L2} + T_{waiting} + 2 \times T_{propagation} + T_{processing}$$

$$D_{proposed} = T_{L2} + 4 \times T_{propagation} + T_{processing}$$

Now, $T_{propagation}$ is very small (in range of micro second) compared to Handover latency. So, eliminating this the equations become

$$D_{conventional} = T_{L2} + T_{waiting} + T_{processing}$$

$$D_{proposed} = T_{L2} + T_{processing}$$

This means,

$$D_{conventional} = D_{proposed} + T_{waiting}$$

Now, by default, MIP Agent Advertisement is send with an interval of 5 seconds [39]. An SS node may receive Agent Advertisement just after entering the new cell or after 5s. In average it will get the message after 2.5s. That means $T_{waiting}$=2.5.

The Layer 2 handoff latency, $T_{L2}$ (which is measured from our simulation as 98ms) and $T_{processing}$ are in the order of ms where as $T_{waiting}$ is in the order of second. So, by eliminating this $T_{waiting}$ we can improve the handoff performance greatly.

## 5.6 Simulation:

We have used OPNET modeler 15.0 for simulation to compare the Handoff delay and overall QoS between the conventional models and our proposed scheme. We built our proposed SS node model using 'wimax_ss_wkstn' node model present in the simulator. To simulate the 3 models we have constructed 3 simulation scenarios separately. The common things in all these scenarios are given in the Table 5.1.

Table 5.1. Common attributes for simulation

| Attributes | Values |
|---|---|
| Base Station Model | wimax_bs_router |
| Subscriber Station Model | wimax_ss_wkstn |
| Link model | PPP_DS3 |
| IP Backhaul model | Router_slip64_dc |
| Application traffic demand | 96Kbps (100 packets/s) |
| OFDM PHY Profile | Wireless OFDMA 20 MHz |
| Scheduling type | ertPS |

***Hierarchical Architecture:***

The network architecture, shown in fig. 5.7 is used for simulating the hierarchical model. Here we concentrate on Mobile_1_1 which is moving along the path marked by white line. Base Stations are connected to IP Backhaul using Point to Point link. 3 GRE tunnels (denoted by green lines) are configured among the BSs and the ASN-GW. All traffic arriving at WiMAX interface of the Base Station are forwarded to ASN-GW through these tunnels. The ASN-GW decides interface to forward the data to SS and route the traffic to desired WiMAX interface through tunnels.

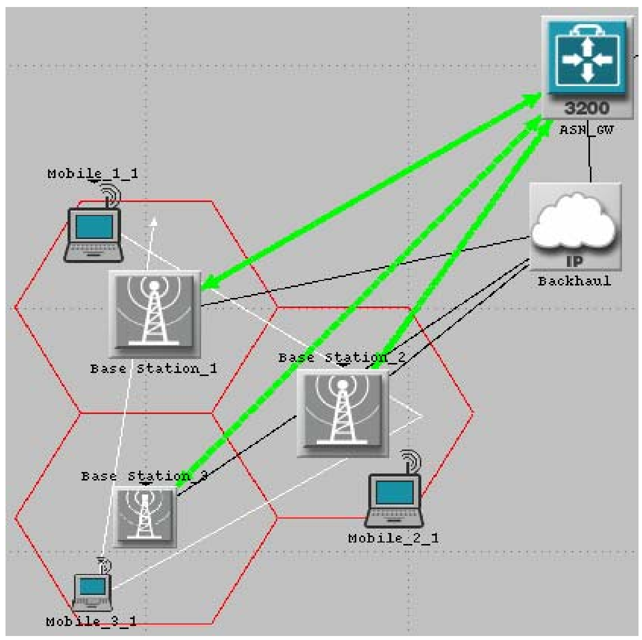


Figure 5.7. Network architecture for simulation of hierarchical model

***Conventional flat architecture***

The network architecture is shown in fig. 5.8. Here the WiMAX interface of Base Station_1 is configured as HA for Mobile_1_1 and other 2 Base Stations as Foreign Agent. All other configuration is same as previous one.

Minimum MIP Agent Advertisement Interval = 5s.

***Proposed flat architecture***

Here all configuration are same as the conventional flat architecture scenario except mobile node model, whose WiMAX-MAC and MIP process models are modified (in process models wimax_ss_control, ip_dispatch, mobile_ip_mgr, mobile_ip_mn). In our enhanced scheme we configured an interrupt at wimax_ss_control at the end of transaction from “Initial ranging” state to “Connected” state. The interrupt would be forwarded by ip_dispatch (IP process model) and mobile_ip_mgr to trigger mobile_ip_mn (MIP agent) for sending Agent Solicitation. The interrupt processing is internal so it will take negligible time (in order of micro second) to process the interrupt.

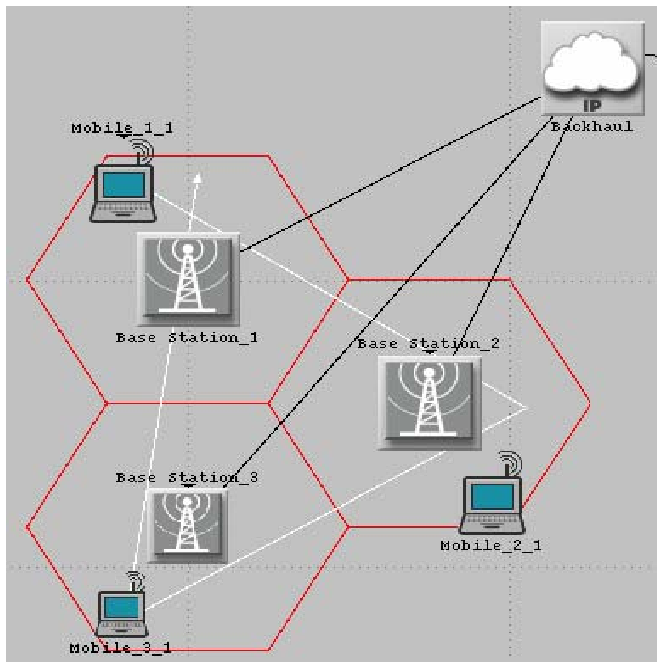


Figure 5.8. Network architecture for simulation of flat model

The application traffic End to End delay is plotted in Fig. 5.9. It is clear from the figure that flat architecture gives good performance in terms of delay. Our proposed scheme gives the same result as Conventional flat model.

Fig. 5.10 gives the Throughput (plotted vs. simulation time) during the Handoff of Mobile_1_1 from Base Station_1 to Base Station_2. As we can see, hierarchical architecture gives very fast handoff, so Packet drop is negligible compared to flat models. Our proposed scheme gives better handoff performance and packet drop is minimal compared to the conventional flat architecture.

Fig. 5.11 gives the average throughput of Mobile_1_1 for the 3 scheme. Average throughput is less in case of conventional flat architecture because during handoff its throughput is zero which affects average throughput. From this figure, we found average throughput of conventional flat architecture is 78225 and for proposed scheme it is 85775.

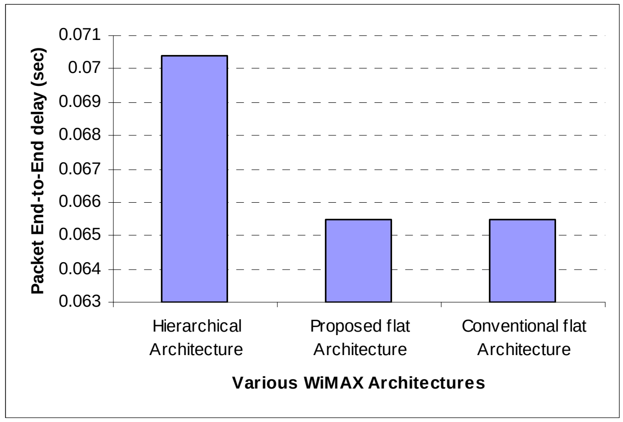


Figure 5.9. End to End delay comparison

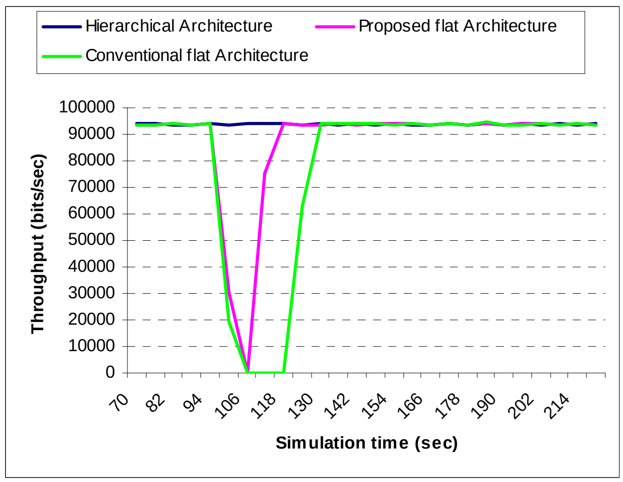


Figure 5.10. Throughput comparison with respect to simulation time

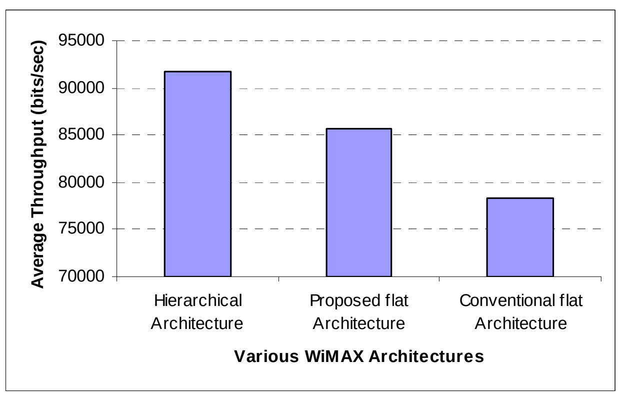


Figure 5.11. Average throughput comparison

## 5.7 Conclusion:

In this paper, the benefits and challenges of flat architecture network model over Hierarchical model have been discussed. Flat architecture network model is a promising option for next generation all-IP networks, but costs more hand-off latency which is also very crucial for QoS aware data communication. In this paper, we present a scheme to reduce the hand-off latency for flat architecture. The simulation model based on OPNET modeler confirms that our proposed scheme exploits the benefits of hierarchical network with reduced handoff delay maintaining the less signal overhead and end-to-end delay features of flat network without any network overhead.

Chapter 6

# SIMULATION SET UP IN OPNET

## 6.1 Introduction

OPNET (Optimized Network Engineering Tool) [46] provides comprehensive development environment supporting the modeling of communication networks and distributed systems. Both behavior and performance of the modeled systems can be analyzed by discrete event simulation. Tool for all phases of our study including model design, simulation, data collection and data analysis are incorporated in OPNET environment. Various constructs pertaining to communication and information processing are provided by OPNET. Thus it provides high leverage for modeling and distributed systems. Graphical specifications of a model are provided by OPNET most of the times. It provides a graphical editor to enter the network and model details. These editors provide an intuitive mapping from the modeled system to the OPNET model specification. OPNET provides 4 such type of editors namely the network editor, the node editor, the process editor and parameterized editor organized in a hierarchical way. It supports model level reuse i.e. models developed at one layer can be used by another model at a higher layer. All OPNET simulations automatically include support for analysis by a sophisticated interactive debugger. Technology developers leverage advanced simulation capabilities and rich protocol model suites to design and optimize proprietary wireless protocols.

In this thesis we take the advantages of OPNET Wireless modeler suites particularly the WiMAX platform for our performance study. We have performed a series of simulation with help of the WiMAX model of PL8 which provides very reliable results for Broadband Wireless communication.

## 6.2 OPNET Modeler Architecture:

OPNET Modeler provides a comprehensive development environment for modeling and performance evaluation of communication network and distributed systems. The package consists of a number of tools, each one focusing on particular aspects of the modeling tasks. These tools fall into three major categories that correspond to the three phases of modeling and simulation project:

- Model specification and modeling communications with packets.
- Data Collection & Simulation
- Analysis

These phases are necessarily performed in sequence. They generally perform a cycle, with a return to specification following analysis as illustrated in the Fig.6.1.

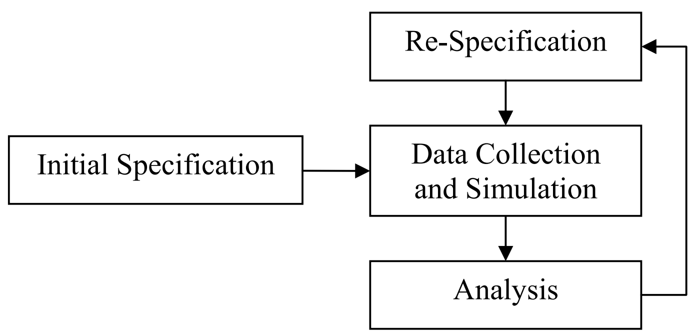


Figure 6.1. Simulation Project Cycle

## 6.3 Modeling Domains

The Network Domain role is to define the topology of a communication network. The communicating entities are called nodes and the specific capabilities of each node are defined by designating their model. Nodes are instances of node models, developed using the Node Editor. Network models consist of nodes and links which can be deployed within a geographical context. OPNET provides fixed nodes, point-to-point and bus links. The Radio version in addition provides mobile and satellite nodes.

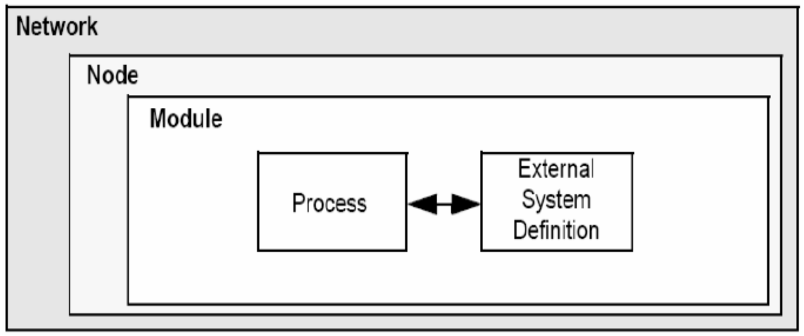


Figure 6.2. Relationship of Hierarchical Levels in OPNET Models

### 6.3.1 Network Domain

The Network Domains role is to define the topology of a communication network. The communicating entities are called nodes and the specific capabilities of each node are defined by designating their model. Node models are developed using the Node Editor. Within one network model, there may be many nodes that are based on the same node model. The Project Editor can provide a geographic context for network model development. Most nodes require the ability to communicate with other nodes to do their function in a network model. Several different types of communication link architectures are provided to interconnect nodes that communicate with each other. OPNET provides simplex (unidirectional) and duplex (bidirectional) point-to-point links to connect nodes in pairs and a bus link to allow broadcast communication for arbitrarily large sets of fixed nodes.

### 6.3.2 Node Domain

The Node Domain provides for the modeling of communication devices that can be deployed and interconnected at the network level. In OPNET terms, these devices are called nodes, and in the real world they may correspond to various types of computing and communicating equipment such as routers, bridges, workstations, terminals, mainframe computers, file servers, fast packet switches, satellites, and so on. Node models are developed in the Node Editor and are expressed in terms of smaller building blocks called modules. Some modules offer capability that is substantially predefined and can only be configured through a set of built-in parameters. These include various transmitters and receivers allowing a node to be attached to communication links in the network domain. Other modules, called processors, queues, and external systems, are highly programmable, their behavior being prescribed by an assigned process model. Three types of connections are provided to support interaction between modules. These are packet streams, statistic wires and logical associations.

### 6.3.3 Process Domain

Processes in OPNET are based on process models that are defined in the Process Editor. Each process that executes in a queue, processor module is an instance of a particular process model. When a simulation begins, each module has only one process, termed the root process. This process can later create new processes which can in turn create others as well, etc. When a process creates another one, it is termed the new process parent; the new process is called the child of the process that created it. OPNET's Process Editor expresses process models in a language called Proto-C. Proto-C is based on a combination of state transition diagrams (STDs), a library of high level commands known as Kernel Procedures, and the general facilities of the C or C++ programming language. A process model's STD defines a set of primary modes or states that the process can enter and, for each state, the conditions that would cause the process to move to another state. The condition needed for a particular change in state to occur and the associated destination states are called a transition. We can also declare state variables to the STD's.

## 6.4 Development of WiMAX scenario

For simulating WiMAX scenarios we have to perform few steps:

1. We create 7 cell WiMAX network using wireless network deployment wizard(Topology>deploy wireless network).The specifications we use are given below:

| Attributes | Value |
|---|---|
| Subscriber Transmission Power(W) | 0.5 |
| Base Station Transmission Power(W) | 10 |

| | |
|---|---|
| Path loss and multipath model | Vehicular |
| Cell Structure | Hexagon |
| Number of Cells | 7 |
| Cell Radius(km) | 3 |
| Base Station Node Model | Wimax_bs_router |
| Subscriber Station Model | Wimax_ss_wkstn |

2. Then we define the application to be run in the nodes. For this purpose we use two nodes namely *application config* and *profile config* to define the application and specifying the period of application respectively. Then we deploy this application and profile to the nodes which is desired to run this application.

3. We setup a required MAC service classifier definition class to run the specific application through 1 service class. For this purpose, right-click on wimax_config node that is created during WiMAX network deployment and select and *edit attribute*. In the attributes table we edit MAC service class definitions for fixing the required service class and the maximum tolerable latency that could be used by the specific type of application.

4. For changing the modulation and coding type we right-click on any *Subscriber station* node and select edit attributes. Then expand wimax parameter >SS parameter >uplink service flow. Then add a row and select the proper modulation and coding scheme for that particular service class. This can be viewed in Fig. 6.3.

5. To select the path loss model we select the *wimax parameter> ss parameter* >path loss parameter and select the required path-loss model.

6. For giving the mobility in the SS node, we have to define the trajectory (Topology>Define Trajectory) through which the node will move. At this stage, we can specify the speed of the mobile nodes.

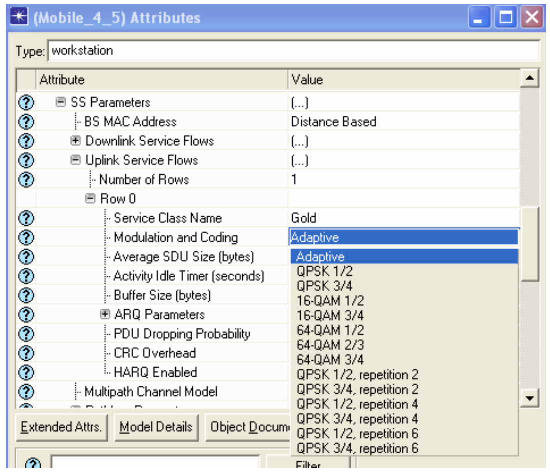


Figure 6.3. Screenshot of WiMAX ss node attributes

# 6.5 Modifying the WiMAX node

For our study we modify some part of the wimax_ss_wkstn node model. The node model of this node is depicted in Fig.6.4.Now we have configured a interrupt at the *wimax_mac* module that will trigger the *ip* module to send a mobile-IP agent solicitation message. For this purpose, we have modified the process models accordingly.

## 6.5.1 wimax_ss_control

This process model is a root process of *wimax_mac*, the root process of *wimax_mac* module of *wimax_ss_wkstn node*. When a mobile node finishes a hand-off, it is in the transition of "*rng_success*" state to "*idle*" state. So we have to write down the code in *function block* at wimax_ss_control_periodic_rng_start() function which defines the necessary task to do at this transaction.

If the variable '*ho_ranging_f*' is set to true that implies that the node has finished a handoff. After performing the necessary operation as a result of handoff we reset the variable at the end of this function, and we have to put our necessary code before this variable is reset. So we can write the code for sending interrupt at the line number 5995 as:

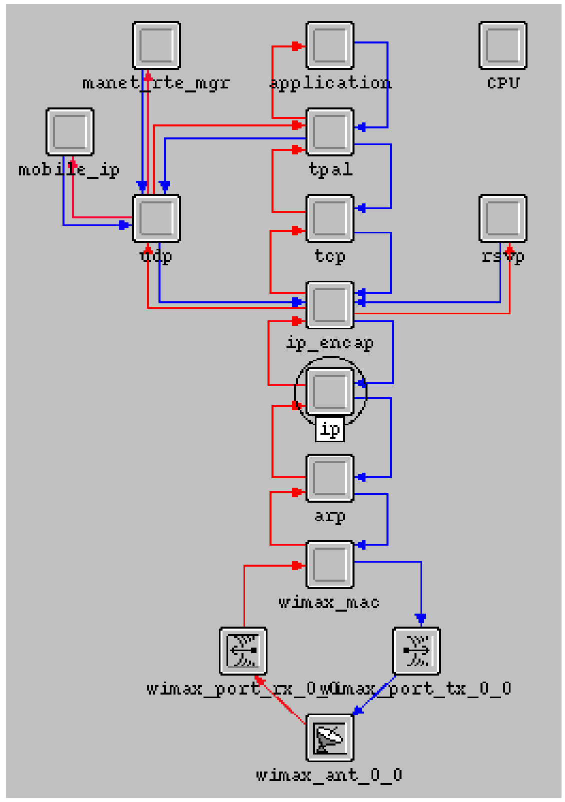


Figure 6.4. wimax_ss_wkstn node model

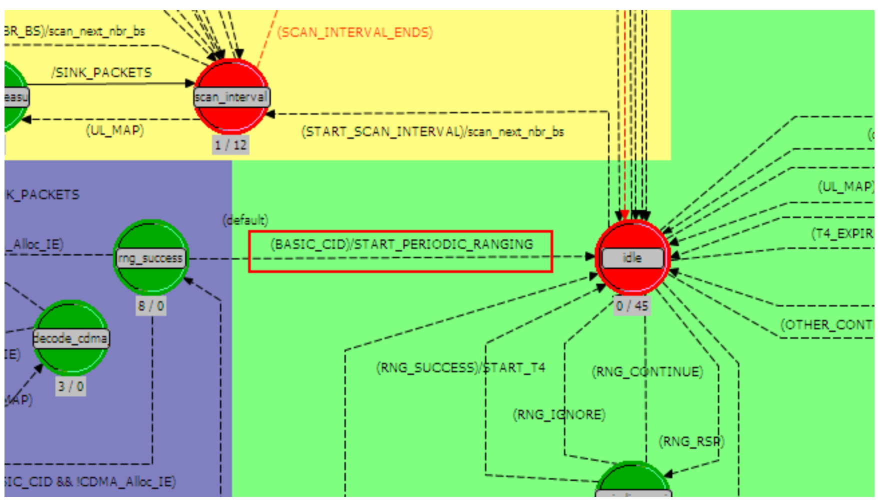


Figure.6.5. wimax_ss_control process model

```
/*Check whether the node has undergone a hand-off */
if(ho_ranging_f)
{
  /* Get the object ID of the local module. */
  loc_mod_objid = op_id_self ();

  /* Get the object ID of the local node. */
  own_node_objid = op_topo_parent (loc_mod_objid);

  /* Get the object ID of the ip module */
```

```
ip_module_objid = op_id_from_name (own_node_objid,
OPC_OBJTYPE_PROC, "ip");

/* Generate an interrupt for the ip module */
op_intrpt_schedule_remote (op_sim_time (), 8146,
ip_module_objid);
}
```

This will cause an interrupt at the *ip* module of the nodemodel. This remote interrupt will invoke the process model *ip_dispatch* process model.

### 6.5.2 ip_dispatch

This is the root process model if *ip* node module of *wimax_ss_wkstn* node model. This process model is unaware of layer 2 hand-off and execution is at *idle* state. So we have to modify this state to forward the interrupt to the required child process. First of all we have to change all those macros used in the *idle* state to prevent unwanted transaction. The macros are modified as :

```
#define MCAST_RSVP_VPN ((invoke_mode ==OPC_PROINV_DIRECT)
  && (intrpt_type == OPC_INTRPT_REMOTE) && (intrpt_code
  >=0)&&(!((op_intrpt_type()==OPC_INTRPT_REMOTE)&&(op_int
  rpt_code ()==8146))))

#define CHILD_INVOCATION ((invoke_mode ==
  OPC_PROINV_INDIRECT)&&(!((op_intrpt_type()==OPC_INTRPT_
  REMOTE)&&(op_intrpt_code ()==8146))))

#define DYN_ASSIGNMENT ((intrpt_type == PC_INTRPT_REMOTE)
  && (intrpt_code ==IPC_DYNAMIC_ASSIGNMENTS_INTRPT_CODE))

#define STRM_INTRPT ((intrpt_type == OPC_INTRPT_STRM) &&
  (invoke_mode == OPC_PROINV_DIRECT)&&(!((op_intrpt_type
  ()==OPC_INTRPT_REMOTE)&&(op_intrpt_code ()==8146))))

#define FAIL_REC ((invoke_mode == OPC_PROINV_DIRECT) &&
  (intrpt_code < IPC_OBSERVER_INTRPT_LIMIT) &&
  (intrpt_code > IPC_OBSERVER_INTRPT_LOWER_LIMIT) &&
  (!((op_intrpt_type)=OPC_INTRPT_REMOTE)&&(op_intrpt_code
  ()==8146))))

#define MANET_GRP ((invoke_mode == OPC_PROINV_DIRECT) &&
  (intrpt_type == OPC_INTRPT_REMOTE) && (intrpt_code >=
  IPC_OBSERVER_INTRPT_LIMIT) && (intrpt_code <
  0)&&(!((op_intrpt_type()==OPC_INTRPT_REMOTE)&&(op_intrp
  t_code ()==8146))))
```

Now, we have to add an extra transaction starting and ending both at the ‘idle’ state whose attributes would be:

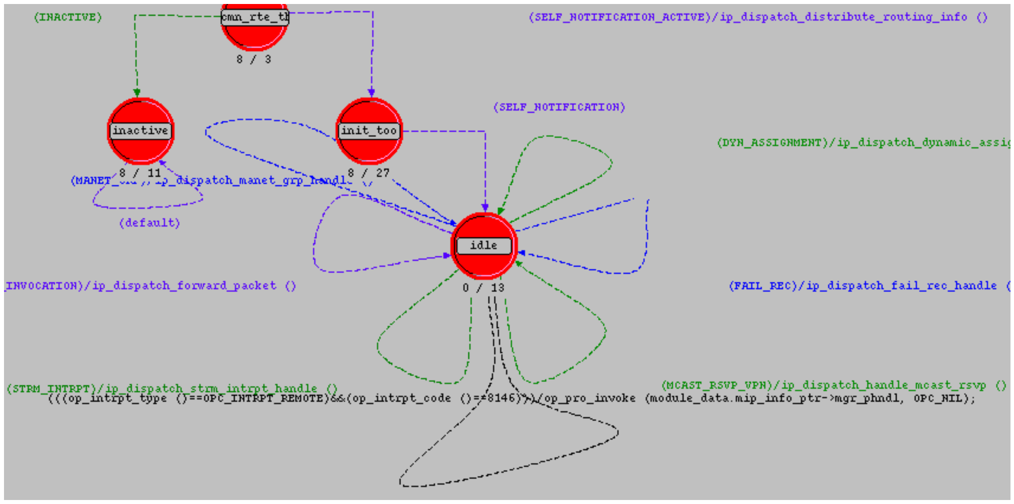


Figure 6.6. ip_dispatch process model

Condition: `((op_intpt_type()==OPC_INTRPT_REMOTE)`
`&&(op_intrpt_code()==8146))`
Executive: `op_invoke(module_data.mip_info_ptr->mgr_phndl,OPC_NIL)`

This will forward the interrupt to the *mobile_ip_mgr* process model.

### 6.5.3 mobile_ip_mgr

This process model is the root process of *ip_dispatch*. It will pass the interrupt received from *ip_dispatch* to the process model *mobile_ip_mn*. Here, the execution is at the idle state. We have to find the required process handle for *mobile_ip_mn* process. For this reason we write down the required code at *function block* line number 44 as:

```
/* Now contact registration manager process. */
proc_record_handle_lptr = op_prg_list_create ();
oms_pr_process_discover (OPC_OBJID_INVALID,
  proc_record_handle_lptr,"node objid", OMSC_PR_OBJID,
  module_data->node_id, "process name", OMSC_PR_STRING,
  "mobile_ip_reg_mgr", OPC_NIL);

/* Get the process record handle for the mobile ip reg
  manager process model */

process_record_handle=(OmsT_Pr_Handle) op_prg_list_remove
  (proc_record_handle_lptr, OPC_LISTPOS_HEAD);
op_prg_mem_free (proc_record_handle_lptr);

/* Obtain the process handle for the reg manager. */
oms_pr_attr_get (process_record_handle, "process handle",
  OMSC_PR_PROHANDLE, &reg_mgr_phndl);
```

Then we have to write down the required code at the *exit* executive of *Idle* state to response the incoming interrupt. At first we have to check whether the code is generated for sending agent solicitation or not. So we write the code at line no 3:

```
/*Check whether the interrupt is remotely generated and
  if interrupt code is 8146 */

if((op_intrpt_type()==OPC_INTRPT_REMOTE)&&(op_intrpt_code
  ()==8146))
{
/*Get the Interface configuration structure from local
  list */
tmp_proc_info_struct_ptr = (MipT_Proc_Info*)
  op_prg_list_access (mip_proc_lptr, list_index);

/* Invoke the mobile_ip_mn process */
op_pro_invoke (tmp_proc_info_struct_ptr->pro_hndl,
  OPC_NIL);
}

else{
        #existing code
    }
```

### 6.5.4 mobile_ip_mn

mobile_ip_mn is unaware of handoff right now. So it must be in '*At home*' or '*Away*' state right now. For both the cases, we can write down the code at their exit executive in line number 3 as:

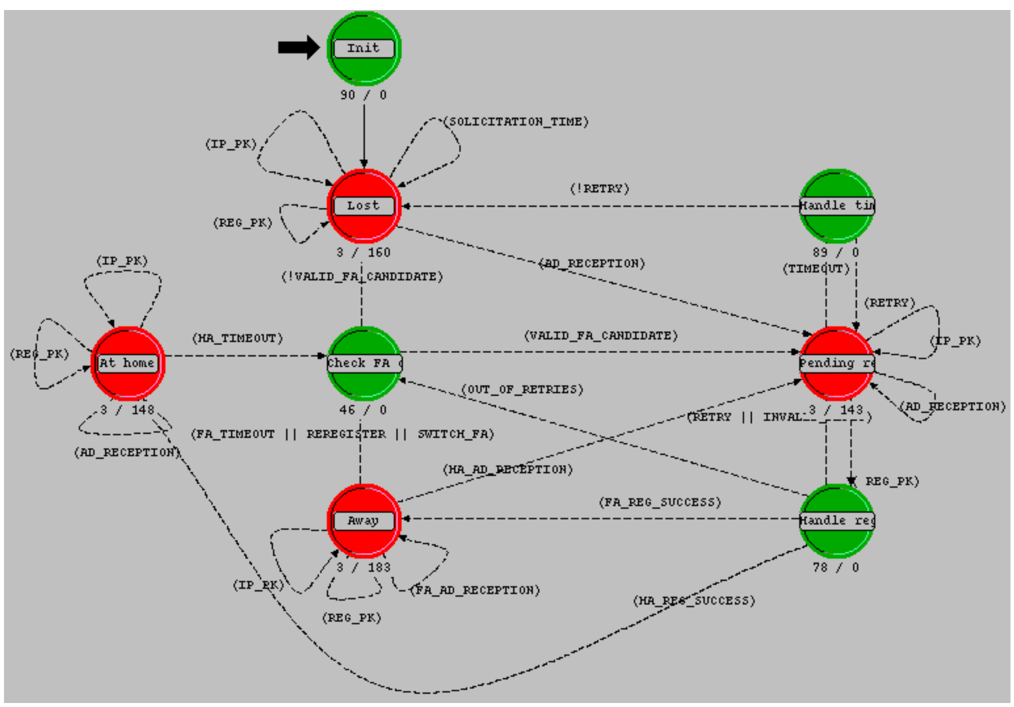


Figure. 6.7. mobile_ip_mn process model

```
/*Check whether the interrupt is remotely generated and
  if interrupt code is 8146 */
if((op_intrpt_type()==OPC_INTRPT_REMOTE)&&(op_intrpt_code
  ()==8146))
  {
/* Send the agent solicitation packet */
mip_mn_agent_solicit_pk_send ();
  }
  else{
       #existing code
       }
```

Now as this agent solicitation message is sent, the FA/HA at the BS will reply to it with the agent advertisement message.

Chapter 7

# Conclusion and Future Scope of Work

## 7.1 Conclusion

WiMAX is a promising technology, to offer high speed wireless internet access for data, voice and real time video. This technology provides a cost effective solution for last mile deployment problem, generally encountered by internet service providers. In this thesis work a main focus is given on the performance evaluation of mobile WiMAX system in light of adaptive modulation and coding (AMC) scheme. Specific interest is given on the effect of speed variation of mobile node, different path-loss models, scheduling services and type of application. The work has been extended by introducing a proposal for handoff management in WiMAX flat network. The work can be summarized as follows:

- The exhaustive simulation results using OPNET 14.5.A show that adaptive modulation and coding gives better performance than fixed modulation and coding scheme while consuming comparatively less system bandwidth, irrespective of other system parameters. A major compromise has to be taken into account, between system capacity and system performance quality while implementing the AMC scheme for WiMAX network. A comprehensive study shows that, conservative AMC utilizes higher system bandwidth to achieve a greater throughput, compared to aggressive AMC. A thorough inspection implies, vehicular path-loss model provides an excellent performance compared to the other physically realizable path-loss models. However, ertPS behaves best under VoIP application for the same system.

- The flat architecture of mobile WiMAX is a promising aspect for next generation all-IP network, with some limitation. It lags behind mainly due to greater hand-off latency compared to hierarchical architecture. A novel proposal of reducing the hand-off latency in WiMAX flat architecture has been highlighted in this thesis work. Simulation model based on OPNET 15.0.A modeler confirms that the proposed scheme combines the benefits of hierarchical network i.e. less hand-off latency maintaining minimum signal overhead and less end-to-end delay feature of flat network architecture. A significant improvement is adjudicated in the reduction of hand-off latency with a considerably less significant overhead on the WiMAX network.

## 7.2 Scope of Future Work

Although we have extensively studied the performance of mobile WIMAX network in aspect of adaptive modulation and coding scheme, we have not concentrated on developing new adaptive modulation and coding table. We have not studied the distance from the BS for which the AMC would change its modulation and coding scheme. So, this could be studied in details. We have not studied other parameters such as HARQ, Coding technique etc. and how they affect the WiMAX system performance.

We have proposed an efficient scheme to reduce handoff latency in WiMAX hierarchical architecture, modifying both the WiMAX MAC and MIP protocol. Proper design can be made to minimize hand-off latency by guessing the next target BS and sending the control signal accordingly to the currently attached BS. This could be done by optimization of MAC and network layer protocol. Due to the lack of time we could not implement the cross layer optimization. Hand-off management can be scaled using hierarchical mobile-IP and advantage of HMIP can be used in WiMAX network also. But, we could not implement the HMIP due to shortcomings and bugs in OPNET. Some of these bugs have been overcome in the OPNET 16.0.A and it is expected that HMIP can be built on the top of that modeler.

Chapter 8

# Abbreviations and Acronyms

| | |
|---|---|
| AAA | Authentication, Authorization and Accounting |
| AMC | Adaptive Modulation and Coding |
| ARP | Address Resolution Protocol |
| ARQ | Automatic Repeat Request |
| ASN | Access Service Network |
| ASN-GW | ASN Gateway |
| ASP | Application Service Provider |
| AWGN | Additive White Gaussian Noise |
| BE | Best Effort |
| BLER | Block Error Rate |
| BPSK | Binary Phase Shift Keying |
| BS | Base Station |
| BSR | Base Station Router |
| CBR | Constant Bit Rate |
| CC | Convolutional Coding |
| CFI | Channel-quality Feedback Indicator |
| CID | Connection Identifier |
| CRC | Cyclic Redundancy Check |
| CS | Convergence Sublayer |
| CSN | Connectivity Service Network |
| CTC | Convolutional Turbo Code |
| DCD | Downlink Channel Descriptor |
| DHCP | Dynamic Host Configuration Protocol |
| DIUC | Downlink Interval Usage Code |
| DL | Downlink |
| DP | Decision Point |
| DSL | Digital Subscriber Line |
| EAP | Extensible Authentication Protocol |
| EP | Enforce Point |
| ertPS | extended real time Polling Service |

| | |
|---|---|
| FA | Foreign Agent |
| FDD | Frequency Division Duplex |
| FEC | Forward Error Correction |
| FTP | File Transfer Protocol |
| | |
| GPRS | General Packet Radio Service |
| GRE | Generic Routing Encapsulation |
| GSM | Global System for Mobile Communications |
| | |
| HA | Home Agent |
| HARQ | Hybrid Automatic Repeat Request |
| | |
| IEEE | Institute of Electrical and Electronics Engineers |
| IETF | Internet Engineering Task Force |
| IP | Internet Protocol |
| ISI | Inter Symbol Interference |
| | |
| L2 | Layer 2, MAC Layer |
| L3 | Layer 3, Network Layer |
| LDPC | Low Density Parity Check |
| | |
| MAC | Medium Access Control |
| MAN | Metropolitan Area Network |
| MIMO | Multiple Input Multiple Output |
| MIP | Mobile IP |
| MOS | Mean Opinion Score |
| MS | Mobile Station |
| | |
| NAP | Network Access Provider |
| NLOS | Non Line of Sight |
| nrtPS | Non Real Time Polling Services |
| NRM | Network Reference Model |
| NSP | Network Service Provider |
| NWG | Network Working Group |
| | |
| OFDM | Orthogonal Frequency Division Multiplexing |
| OFDMA | Orthogonal Frequency Division Multiple Access |
| OPNET | Optimized Network Engineering Tool |
| | |
| PDU | Packet Data Unit |
| PEP | Policy Enforcement Point |
| PHS | Package Header Suppression |
| PHSF | PHS Field |
| PHSI | PHS Index |
| PHY | Physical |
| PoA | Point of Attachment |
| | |
| QAM | Quadrature Amplitude Modulation |
| QPSK | Quadrature Phase Shift Keying |
| QoS | Quality of Service |

| | |
|---|---|
| RNC | Radio Network Controller |
| RRC | Radio Resource Controller |
| RRM | Radio Resource Management |
| RTG | Receive/transmit Transition Gap |
| RS | Reed-Solomon |
| rtPS | Real Time Polling Service |
| RSSI | Received Signal Strength Indicator |
| RUIM | Removable User Identity Module |
| | |
| SA | Service Association |
| SDU | Service Data Unit |
| SFM | Service Flow Management |
| SIM | Subscriber Identity Module |
| SINR | Signal To Interference plus Noise Ratio |
| SLA | Service Level Agreement |
| SNR | Signal to Noise Ratio |
| SOFDMA | Scalable OFDMA |
| SS | Subscriber Station |
| | |
| TDD | Time Division Duplex |
| TFTP | Trivial File Transfer Protocol |
| TLV | Type/Length/Value |
| | |
| UCD | Uplink Channel Descriptor |
| UGS | Unsolicited Grant Service |
| UIUC | Uplink Interval Usage Code |
| UICC | Universal Integrated Circuit Card |
| UL | Uplink |
| USIM | Universal Subscriber Identity Module |
| | |
| VoIP | Voice over IP |
| | |
| Wi-Fi | Wireless Fidelity |
| WiMAX | Worldwide Interoperability for Microwave Access |
| WLAN | Wireless Local Area Network |

# Chapter 9

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Chapter 10

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