QoS support in 4G networks

Arul Prasath Gurusamy

2009

Arul, P. G. (2009). QoS support in 4G networks. Master's thesis, Nanyang Technological University, Singapore.

<https://hdl.handle.net/10356/47477>

<https://doi.org/10.32657/10356/47477>

Nanyang Technological University

Downloaded on 26 Apr 2023 19:55:24 SGT

QoS Support in 4G Networks

ARUL PRASATH GURUSAMY

A thesis is submitted to Nanyang Technological University
in fulfillment of the requirement for the degree of

Master of Engineering

SCHOOL OF COMPUTER ENGINEERING

2009

Acknowledgement

First and foremost, I would like to thank my beloved supervisor **Dr. Franklin Cheng Peng Fu** for his continuous guidance, valuable commitment and time spent on my research. He has made my post-graduate study experience affluent and rewarding. I would like to express my heartily gratitude to **Dr. Maode Ma** for his generous help and critical suggestions during my research. I would also like to thank him for sharing his personal and professional experience towards my research work.

I like to express my appreciation to Ms. Linda and the members of “4G Research Laboratory” for providing me an ideal research environment. I would like to thank Ms. Yap Liy Mui Molly and Mr. Alan of graduate office for their help and approval in providing the necessary facilities to carry out my research. My earnest acknowledgement goes to the School of Computer Engineering and Nanyang Technological University.

Special appreciation goes to my dear parents and family members for their unconditional support and love throughout my post-graduate studies. Without them it would not have been possible to complete my research work.

Last but not least I would like to thank all my friends and well wishers for their valuable suggestions and encouragement in every way.

Abstract

IEEE 802.11 is the WLAN standard for providing short range data communication at a moderate to high speed generally within a building. IEEE 802.16 (WiMAX) is the standard for broadband WMANs which provide Internet access over long ranges in outdoor environments. Inside the building, however, it is susceptible to fading. By integrating WLAN and WiMAX, we would be able to acquire the best of both these technologies. Ultimately, WiMAX based wireless networks would bestow backhaul support for WLAN mobile hotspots. Therefore, the service availability for mobile Internet users will expand through the extended coverage range of WLAN. In our thesis, an integration model is proposed by introducing an Integration Management Entity (IME) which maps the different traffic categories at the Customer Premises Equipments (CPEs). We also discuss the diverse QoS requirements for various application flows in WiMAX and WLANs. The necessary parameters that could stipulate the QoS requirements for an application are identified and the mapping of various parameters for different kinds of flows is specified. Moreover, we propose a Base Station (BS) assisted scheduling mechanism to be implemented at the CPE which would make sure that an application ultimately receives the QoS it requested. The efficiency of the proposed algorithm is revealed through extensive simulations using the QualNet simulator. It is shown that QoS can be provided for both real-time and non-real-time traffic over the broadband integrated network.

Group mobility with centralized control is widely prevalent in military networks and vehicular networks. Providing QoS in such scenarios is often complex since the wireless channel is subject to fading and erasures. The IEEE 802.16e wireless broadband network standard provides a robust PHY and MAC specifications for high data rate mobile communication. These WiMAX PHY and MAC specifications can be utilized to establish a Point to Multi Point (PMP) mobile network topology with QoS provisioning. However, the issue of group mobility in mobile WiMAX networks has not been explored so far. Nevertheless, as the mobile nodes move away from the BS, their channel condition degrades and they are provided with lesser bandwidth due to the inherent modulation and coding schemes (MCS) provided by the IEEE 802.16e MAC layer. This bandwidth throttling might starve the bandwidth of real-time traffic and cause packet dropping. In our thesis, we adapt the IEEE 802.16e standard with modifications to provide robust communication among a group of mobile nodes centrally controlled by a mobile Base Station (BS). We also analyze group mobility scenarios and propose an adaptive QoS scheduling algorithm to provide QoS for real-time traffic flow.

Contents

Acknowledgement..... i

Abstract ii

Table of Contents..... iv

List of Figures ix

List of Tables..... xii

Abbreviations..... xiii

Chapter 1 1

 1.1 Introduction 1

 1.1.1 Drawbacks in 3G Networks and the Motivation for
 4G Research2

 1.1.2 4G Networks.....3

 1.1.3 Challenges in 4G Networks.....5

 1.1.3.1 4G Architecture5

 1.1.3.2 Quality of Service (QoS) in 4G Network6

1.1.3.3	Mobility in 4G Networks.....	7
1.2	Motivation	8
1.2.1	Integration of WLAN and WiMAX.....	8
1.2.2	Group Mobility	9
1.3	Objective	10
1.3.1	Integration of WLAN and WiMAX.....	11
1.3.2	Group Mobility	11
1.4	Report Structure	12
Chapter 2 Literature Review.....		14
2.1	IEEE 802.11 WLAN.....	14
2.1.1	Basic Architecture of IEEE 802.11	15
2.1.2	IEEE 802.11 MAC Frame.....	18
2.1.3	MAC Super Frame of 802.11.....	19
2.1.4	QoS in IEEE 802.11	21
2.2	IEEE 802.16 (WiMAX)	23
2.2.1	Basic Architecture of WiMAX	24
2.2.2	WiMAX MAC Protocol.....	27
2.2.3	WiMAX MAC Layer Services.....	29

2.3 Literature Review on Integration of WLAN and WiMAX.....	31
2.3.1 Literature Review on Integration	31
2.3.1.1 Integration Model for WLAN and WiMAX	32
2.3.1.2 Mobility Management in Next Generation Networks	34
2.3.1.3 Ethernet-Based Integration	34
2.3.1.4 Integration at Access Point	35
2.3.2 Literature Review on Providing QoS in WLAN-WiMAX	
Integrated Network	36
2.3.2.1 Feedback Based Bandwidth Allocation	36
2.3.2.2 An Adaptive QoS Architecture for IEEE 802.16.....	37
2.3.2.3 Queue Based Scheduling Approach for WMAN	38
2.3.2.4 Evaluation of QoS Schemes for IEEE 802.11	
Wireless LANs.....	39
2.3.2.5 Deployment Models and User Scenarios	40
2.4 Literature Review on group mobility	41
2.4.1 Performance Evaluation of 802.16e in Vehicle to Vehicle	
Channels	42
2.4.2 Group Mobility Model	43
2.4.3 Group Mobility in Ad Hoc Networks using Wi-Fi	46

2.4.4	Time Synchronization for 802.16e	47
2.4.5	Scheduling Algorithm.....	48
2.4.5.1	IEEE 802.16e for Last Mile Broadband Military Networks.....	49
2.4.5.2	Uplink Scheduling Algorithm for VoIP / Video Services in IEEE 802.16d/e System	51
 Chapter 3 Scheduling Algorithm for the Integration		
	WLAN and WiMAX with Base Station Assisted QoS	53
3.1	System Background	54
3.2	Proposed WLAN and WiMAX Integration Model.....	56
3.3	Proposed Mapping Scheme	58
3.4	Proposed Scheduling Algorithm	63
3.5	Simulation Results of Our Proposed Adaptive Scheduling Scheme.....	69
3.6	Improvised adaptive scheduling algorithm	78
 Chapter 4 QoS Scheduling in Group Mobility Scenario		
	with Centralized Control	85
4.1	System Background	88

4.2 Proposed Scheduling Algorithm	93
4.3 Simulation Results.....	97
 Chapter 5	 109
5.1 Conclusion.....	109
5.2 Future Recommendations	111
 Publications	 112
Bibliography.....	113

List of Figures

1.1	The User-Centric System	4
1.2	Heterogeneous Network.....	6
2.1	Basic Architecture of IEEE 802.11	16
2.2	Operations of MAC Super Frame.....	20
2.3	Basic Architecture of WiMAX Network	25
2.4	Integration Architecture	34
2.5	Proposed Interworking by Motorola	40
2.6	Virtual Track Based Group Mobility Model	45
2.7	Group Mobility in Ad Hoc using Wi-Fi (a)	46
2.7	Group Mobility in Ad Hoc using Wi-Fi (b).....	47
2.8	Proposed QoS Architecture for Last Mile Broadband Military Networks	50
3.1	Proposed Integration Model of WiMAX and WLAN at the Customer Premises Equipment.....	57
3.2	End to End Traffic Flow Establishment.....	62

3.3	Delay Comparison when rtPS Data rate twice that of nrtPS	71
3.4	Delay Comparison when nrtPS Data rate twice that of rtPS	72
3.5	Maximum Buffer Occupancy of nrtPS Queue when nrtPS Data Rate is twice that of rtPS	73
3.6	Maximum Buffer Occupancy of nrtPS Queue when rtPS Data Rate is twice that of nrtPS	74
3.7	Comparison of Adaptive Delay and Max_Latency	75
3.8	Buffer Remaining and the delay.....	79
3.9	Delay and the Alpha	80
4.1	Group Mobility with PMP Communication in Military Network.....	87
4.2	IEEE 802.16 Frame Structure.....	92
4.3	Group Mobility Simulation.....	97
4.4	Delay FeedBack in IEEE 802.16 PMP Systems	98
4.5	Comparison of Average End to End Delays when rtPS Data Rate twice that of nrtPS Data Rate.....	101
4.6	Comparison of Maximum Buffer Occupancy for Non-Real-Time Traffic when rtPS Data Rate Twice that of nrtPS Data Rate	102
4.7	Comparison of Average End to End Delays when nrtPS Data Rate twice that of rtPS Data Rate	104
4.8	Comparison of Maximum Buffer Occupancy for Non-Real-Time Traffic when nrtPS Data Rate Twice that of rtPS Data Rate	105

4.9 Comparison of Throughput for rtPS and nrtPS traffic when rtPS

Data Rate is twice that of nrtPS 106

4.10 Comparison of Delay Performance of One-way and Two-way Delay

Feedback Schemes 107

List of Tables

1.1 COMPARISON OF 3G NETWORK AND 4G NETWORK3

2.1 TRAFFIC CATEGORIES AND ACCESS CATEGORIES IN IEEE 802.11E22

3.1 TRAFFIC MAPPING FOR WLAN AND WiMAX.....60

3.2 DATA RATES FOR TRAFFIC SCENARIOS70

3.3 RESULTS FOR SCENARIO 2 COMPARING DIFFERENT TRAFFIC RATES,
MAX_rTPS_DELAY PARAMETER AND THE OBTAINED DELAY VALUES76

4.1 CINR FEEDBACK VS MCS98

4.2 MOBILITY PARAMETERS.....99

4.3 TRAFFIC PARAMETERS FOR SIMULATION.....99

4.4 TRAFFIC PARAMETERS FOR SIMULATION – NRTPS DATA RATE
TWICE THAT OF RTPS DATA RATE103

Abbreviations

AP	Access Point
BE	Best Effort Service
BS	Base Station
BSS	Basic Service Set
CCK	Complementary Code Keying
CFP	Contention Free Period
CID	Connection Identifier
CP	Contention Period
CS	Service specific convergence sub-layer
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CW	Contention Window
DCF	Distributed Coordination Function
DFS	Dynamic Frequency Selection
DIFS	DCF InterFrame Space
DL	Down Link
DL-MAP	Downlink Map

DS	Distribution System
DSA	Dynamic Service Addition
DSC	Dynamic Service Change
DSD	Dynamic Service Deletion
DSL	Digital Subscriber Line
DSS	Distribution System Service
DTIM	Delivery Traffic Indication Message
EDCA	Enhanced Distributed Channel Access
ertPS	Extended Real-Time Polling Service
FBWA	Fixed Broadband Wireless Access
FDD	Frequency Division Duplexing
FTP	File Transfer Protocol
HTTP	Hypertext Transfer Protocol
HCCA	Hybrid Coordinator Function Controlled Channel Access
HSDPA	High Speed Downlink Packet Access
IBSS	Independent BSS
IFS	InterFrame Space
LOS	Line Of Sight
MAC	Medium Access Control Layer
MPDU	MAC Protocol Data Unit
MPEG	Motion Pictures Expert Group
MSDU	MAC service data units

NAV	Network Allocation Vector
NLOS	Non-Line of Sight
nrtPS	Non-Real Time Polling Service
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PC	Point Coordinator
PCF	Point Coordination Function
PDA	Personal Digital Assistant
PDU	Protocol Data Unit
PHY	Physical Layer
PIFS	PCF InterFrame Space
PMP	Point to Multi Point
PS	Polling Service
QoS	Quality of Service
QSTAs	Stations which required Quality of Service
RS	Relay Station
rtPS	Real-Time Polling Service
SFID	Service Flow Identifier
SNMP	Simple Network Management Protocol
SNR	Signal to Noise Ratio
SP	Strict Priority
SS	Station Service

TDD	Time Division Duplexing
TDMA	Time Division Multiplexing
TPC	Transmit Power Control
TSPEC	Traffic Specification
UGS	Unsolicited Grant Service
UL	Up Link
UL-MAP	Uplink Map
VoIP	Voice over Internet Protocol
WiMAX	World-wide Interoperability for Microwave Access
WM	Wireless Medium
WNIC	Wireless Network Interface Card

Chapter 1

Introduction

1.1 Introduction

Next Generation Networks are aimed at providing the end users with technologies that are simple yet of better quality. As such, the focal point of research is shifting towards service provisioning and convergence of different technologies. It is estimated that Information Technology, Consumer Electronics, and Entertainment Industries will be joined by the Telecommunications Industry in the near future, to form a Common Digital Industry.

The terms 1G, 2G, 2.5G, 3G and 4G are attached to describe the development or rollout of network systems. 1G is characterized by analog networks providing simple voice only services. It has a very low real speed/throughput. The 2G network, which used digital signaling technologies instead, could carry text messages along with voice. This gave rise to the Short Messaging Service (SMS). In addition, 2G mobile phones are often integrated with a data modem which connects to the internet via a built in WAP browser software. In the current market, 2.5G (WAP and i-mode) networks use a packet-switch infrastructure to provide always-on internet connections to mobile phones. In an effort to make the Internet more accessible to mobile users and provide multimedia services, the 3G has been defined and is currently deployed worldwide. To facilitate the specification

of 3G network as a global, multimedia-enabled network, the 3rd Generation Partnership Project (3GPP) was formed. The goal of 3GPP is to specify a set of standards that will provide multimedia services as well as enable an interoperable worldwide network in the future.

1.1.1 Drawbacks in 3G Networks: Motivation for 4G Research

- 3G is primarily based on a wide-area concept. We need hybrid networks with wider bandwidth that utilize both wireless LAN (hot spot) concept and, cell or base-station wide area network design (WiMAX).
- To ensure connection ubiquity in combination with high bandwidth and mobility, the network architecture must be heterogeneous i.e. integration of multiple networks.
- 3G is not a fully integrated system and this imposes constraints that limit the provision of a full range of multi rate services as these services present different Quality of Service (QoS) and performance requirement.
- 3G performance might be insufficient to meet the needs of high-performance applications of the future like multi-media, full-motion video and wireless teleconferencing. This initiates the need for a network technology that extends the 3G capacity by an order of magnitude.
- The existence of multiple 3G standards makes it difficult to roam and interoperate across distinct service environments, in different frequency bands. This reiterates the need for global mobility and service portability.

1.1.2 4G Networks

4G wireless networks can support global roaming across multiple wireless and mobile networks—for example, from a cellular network to a satellite-based network to a high bandwidth wireless LAN to a high data-rate WiMAX. This feature allows users to access different services, increased coverage at the convenience of a single device and billing. This reduces the total cost and ensures reliable wireless access even with the failure or loss of one or more networks. Table 1.1 specifies the advantages of 4G networks over 3G networks.

Table 1.1 Comparisons of 3G Network and 4G Network

Features	3G (including 2.5G, sub3G)	4G
Major Requirement Driving Architecture	Predominantly voice driven - data was always add on	Converged data and voice over IP
Network Architecture	Wide area cell-based	Hybrid - Integration of Wireless LAN (Wi-Fi) and WiMAX
Speeds	384 Kbps to 2 Mbps	20 to 100 Mbps in mobile mode
Frequency Band	Dependent on country or continent (1800-2400 MHz)	Higher frequency bands (2-8 GHz)
Bandwidth	5-20 MHz	100 MHz (or more)
Switching Design Basis	Circuit and Packet	All digital with packetized voice
Access Technologies	W-CDMA, 1xRTT, Edge	OFDM and MC-CDMA (Multi Carrier CDMA)
Forward Error Correction	Convolution rate 1/2, 1/3	Concatenated coding scheme
Component Design	Optimized antenna design, multi-band adapters	Smarter Antennas, software multiband and wideband radios
IP	A number of air link protocols, including IP 5.0	All IP (IP6.0)

A list of all the key features which describe a new framework of 4G is illustrated in Figure 1.1, referred to as the “user-centric” system. Inspired by the Heliocentric Copernican theory, the user is located in the center of the system. The different key features defining 4G rotate around the users on orbits with a distance dependent on a user-sensitivity scale [1].

Figure 1.1 The User-Centric System

The combination of user friendliness and user personalization appears to be the winning concept in encouraging people to embrace any new technology. This is a time consuming process, involving a great deal of effort from the operator’s side. User friendliness exemplifies and minimizes the interaction between applications and users. In user personalization enables the operational modes of devices to be configured according to their preference, allowing the pre-selection of content of the chosen services.

In comparison to 3G, 4G is trusted to provide clients higher data rates, which is a clear and valuable advantage, made possible by Terminal Heterogeneity and Network Heterogeneity. Terminal Heterogeneity refers to the different types of terminals in terms of display size, energy consumption, portability/weight, complexity, etc. Network Heterogeneity refers to the increasing heterogeneity of wireless networks owing to the large number of available access technologies (e.g. UMTS, WLAN, WiMAX, Wi-Fi, Bluetooth and Cellular Networks). Various access technologies have to be integrated to achieve end-to-end QoS.

1.1.3 Challenges in 4G Networks

1.1.3.1 4G Architecture

The most challenging part of 4G networks is to create an architecture that supports Network Heterogeneity. A major obstacle in this heterogeneous model is that the different access networks must converge. This requires standardization efforts and business commitment to support it. The figure 1.2 shows the Heterogeneous Networks used in 4G Networks differing in terms of coverage, data rate, and architecture [1].

Besides offering support to the next generation of network services, the 4G networks will integrate the current technologies. One of the major issues involved in the transformation of 3G to 4G technology is Vertical Handover [2]. Vertical Handover in a WiMAX/WLAN system involves heavy signaling and network overhead, and requires the subscriber stations to have the protocol stack of both WLAN and WiMAX. On top of being prohibitively expensive and complex, this also means that the existing WLAN devices will not be able to switch over to 4G without hardware upgrades. Hence

integrating these two technologies into Customer Premises Equipment (CPE) is a more feasible solution. The integration will be without any change to WLAN devices and cost effective.

Figure 1.2 Heterogeneous Networks

1.1.3.2 Quality of Service (QoS) in 4G Network

Another major challenge in 4G networks is to achieve adequate Quality of Support (QoS). QoS is especially important in 4G networks as 4G is all about the integration of multiple networks. For instance, in 4G, the end-to-end communication in a complete wireless solution will involve multiple wireless networks. QoS can be varied across multiple networks, depending on channel characteristics such as bandwidth allocation, bit rates, fault-tolerance levels and handoff support. It also varies at the different levels like packet, transaction, circuit, user, and network levels [3, 4]. Since, each network has different QoS, it is hard to provide the end-to-end QoS to the users

involved in the communication. Thus, a careful evaluation is required to provide end-to-end QoS.

In order to achieve end-to-end QoS a wireless network should make its current QoS information available to all other wireless networks either in a centralized or in a distributed model. At the same time the QoS behaviour should be dynamic, i.e., it should be possible to modify QoS parameters and allocate resources variably during an active session. Also, the pro-negotiation and re-negotiation of QoS have to be supported by the wireless access networks, and they should be considered in the interworking of such networks. Since the QoS attributes between the wireless domains vary, mapping of various traffic classes is required to guarantee end-to-end QoS.

Another major QoS related issue in 4G wireless network is handoff delay [5]. Due to the authentication procedure that requires multiple-database access, message exchange and negotiation-renegotiation, the handoff delay in the inter-network is comparably greater than the intra-network. Since there is a considerable dissimilarity between the source and destination QoS, the end user may experience a significant drop in QoS. The handoff delay can be reduced significantly by deploying the Integration Management Entity (IME) in the Customer Premises Equipment (CPE) and by using Priority-Based Scheduling Algorithms.

1.1.3.3 Mobility in 4G Networks

One of the terms used to describe 4G is MAGIC - Mobile multimedia, Anytime Anywhere, Global mobility support, Integrated wireless solution, and Customized personal service [6]. Mobility is also an important factor in 4G networks as providing

high bandwidth and supporting QoS while wireless devices/users/vehicles are moving at high speeds is a challenging issue. Moreover group mobility is also a potential area of research, especially in military, disaster management and search / rescue applications. The vehicles in a group mobility scenario usually move in a relative speed as well as in the same direction with the comparative distance between them. Due to the diverse multimedia traffic with different priorities and QoS requirements, it is imperative to provide QoS support in military networks. Moreover the traffic flows in the above mention situation may require different priorities among them.

1.2 Motivation

1.2.1 Integration of WLAN and WiMAX

IEEE 802.11 is the WLAN standard for providing moderate to high speed data communication in a short range generally within a building [7, 8]. IEEE 802.16 (WiMAX) is the standard for broadband WMANs that provide the Internet access over a long range in outdoor environments [9]. However, it is susceptible to fading inside buildings. By integrating WLAN and WiMAX, we would be able to acquire the best of both these technologies. The integration will provide the viability of accessing internet anywhere anytime for mobile users which is required in the 4G networks. Though many researchers have proposed various integration schemes these schemes can be implemented only by modifying the existing user devices such as laptop, mobile phone, and PDA. The integration should instead be feasible with low cost and without or with fewer changes to existing user devices. This motivates us to propose an integration model to integrate WLAN and WiMAX at the customer premises equipment.

Providing end-to-end QoS for the real-time traffic and non-real-time traffic in such an integrated environment will be a challenging issue. In order to support QoS optimally, it needs several functions such as QoS negotiation and re-negotiation, QoS monitoring, QoS maintenance, but these functions are not supported by most of current communication protocols. The proposed scheduling algorithms in literature review to provide QoS for WLAN and WiMAX might not be suitable for an integrated WLAN-WiMAX system. These motivate us to develop a BS assisted adaptive scheduling algorithm to be implemented at the CPE which can provide QoS guarantee in terms of delay bound for real-time traffic and buffer bound for non-real-time traffic over the WiMAX access channel.

1.2.2 Group Mobility

Group mobility with centralized control is extensive in military networks and vehicular networks where hosts move in groups, generally in the same direction and separated only by a short distance. In the battle field, to leverage on information superiority such as just-in-time logistics, applications (teleconferencing, telemedicine and multimedia) require enormous improvements in terms of higher bandwidth, connection to a high speed backbone and QoS support. Providing QoS in terms of delay and delay variation in such scenarios is often complex since the wireless channel is subject to fading and erasures. Furthermore, the network needs to be able to provide priority services to messages based on their criticality. Some research work has been done in Adhoc networks using Wi-Fi [10]. Nonetheless such networks have some limitations due to its limited range and low power operation of Wi-Fi. The IEEE 802.16e broadband wireless access system is a feasible alternative that can meet such requirements [11].

The deployment of IEEE 802.16e will be faster and it can provide high speed wireless connectivity with low cost. Moreover The WiMAX PHY and MAC specifications can be utilized to establish a Point to Multi Point (PMP) mobile network topology with QoS provisioning. However, as the mobile nodes move away from the BS, their channel condition degrades and they are provided with lesser bandwidth due to the inherent modulation and coding schemes provided by the IEEE 802.16e MAC layer [11]. This bandwidth throttling might starve the bandwidth of real-time traffic and cause packet dropping. The IEEE 802.16e standard defines the signaling mechanism for information exchange between base station and mobile stations such as the connection setup, BW-Request. But it doesn't define any scheduling scheme for different flows. Further scheduling schemes need to be varied based on the network topology and deployment. This motivates us to develop an adaptive QoS scheduling algorithm that will be implemented at the mobile station to provide better QoS to real-time traffic flows i.e. to minimize end-to-end delay in the mobile WiMAX networks.

1.3 Objective

The above discussion led us to examine the existing WLAN and WiMAX technologies, the differences in their traffic flows and QoS requirements. In order to get the end-to-end QoS for various traffic flows in the WLAN and WiMAX integrated systems, a scheduling algorithm has to be proposed. The group mobility in military and emergency search / rescue operations also require an effective adaptive algorithm to provide priorities among various traffic classes and QoS for real-time traffic in terms of delay. Owing to its ease of deployment and low cost, IEEE 802.16e is the ideal technology for the above mentioned operations, and the Point to Multipoint protocol of IEEE 802.16e standard has to be examined to provide the scheduling algorithm.

The objective of our project is divided into two sections: Integration of WLAN and WiMAX, Group mobility. They are as follows:

1.3.1 Integration of WLAN and WiMAX

This section elaborates the objective to propose an integrated model of WLAN and WiMAX and the development of a scheduling algorithm to achieve end-to-end QoS.

1. To analyze the existing WLAN and WiMAX technologies, their various traffic flows priorities and QoS requirements
2. To propose a WLAN and WiMAX integration model by introducing an Integration Management Entity (IME) that maps the different traffic categories at the customer premises equipments (CPEs).
3. To advocate a base station assisted scheduling mechanism that will be implemented at the CPE to make sure that an application receives the QoS it requested.
4. To evaluate the effectiveness and efficiency of the algorithm through simulations QualNet simulator

1.3.2 Group Mobility

This section further expands on the objective of proposing an adaptive scheduling algorithm to provide priorities among various traffic classes and QoS for real-time traffic in terms of delay in the military and emergency search / rescue missions.

- 12 -

1. Analyze group mobility scenarios of IEEE 802.16e and provide a QoS scheduling scheme to minimize the end-to-end delay for real-time traffic when multiple traffic flows originate from mobile stations.
2. Devise an adaptive strategy to provide better QoS to real-time traffic flows in the mobile WiMAX networks. The adaptive algorithm should provide additional bandwidth to the real-time traffic flows by borrowing the bandwidth from the non-real-time flows when the former experiences increasing delay. The buffers of non-real-time traffic flows has to be controlled at the same time, keeping the non-real-time traffic within the maximum buffer limit even at substantially heavy traffic intensities, by limiting the provision of excessive bandwidth to the real-time traffic flows.
3. To test the efficiency of the proposed algorithm through extensive simulations using QualNet simulator.

1.4 Report Structure

In this Thesis, a brief review of WLAN, WiMAX technologies have been given. It also gives details of our proposed schemes; Integration of WLAN-WiMAX with base station assisted QoS and the Group Mobility with QoS in WiMAX.

Chapter 2 of the Thesis briefly reviews the system backgrounds of WLAN and WiMAX. It also examines the literature concerning the various integration models for the Integration of WLAN and WiMAX, and the diverse scheduling algorithms proposed to provide end-to-end QoS for real-time and non-real-time traffic. Subsequently this chapter

scrutinizes the various research works associated with the group mobility scenarios in mobile WiMAX.

Chapter 3 first provides the proposed integration model and the mapping, signaling mechanism used for the integration of WLAN-WiMAX. After that it explicitly presents the details of proposed the adaptive scheduling algorithm that achieves the end-to-end QoS for UGS, rtPS, and nrtPS traffic by mapping these flows with the WLAN traffic specifications. This chapter concludes with the simulation results carried out in QualNet Simulator.

Chapter 4 presents the details of the proposed scheduling algorithm that provide QoS for real-time traffic in the group mobility scenarios of the IEEE 802.16e standard when multiple traffic flows originates from mobile stations. It also describes the related simulation results.

Chapter 5 presents the conclusion and recommended future work.

Chapter 2

Literature Review

In this chapter, brief descriptions of the WLAN and WiMAX networks have been presented together with a detailed literature review on the integration of heterogeneous networks. The Chapter further describes integration model and scheduling algorithms to provide QoS in terms of delay for real-time and packet loss for non-real-time traffic flows. Group mobility issues in WiMAX such as mobility model, performance evaluation in Ad Hoc Networks have been analyzed. Various scheduling algorithms providing end-to-end QoS to the user applications in WiMAX networks have also been extensively discussed.

2.1 IEEE 802.11 WLAN

Section 2.1 reveals the basic description of WLAN such as architecture, different Institute of Electrical and Electronics Engineers, Inc (IEEE) standards for physical and medium access layer, frame formats, and QoS requirements of these networks.

IEEE 802.11 Wireless Local Area Network (WLAN) is a technology used to connect two or more devices without using wires [7]. WLAN offers high data rates of 54

Mbps within a 100m range mostly used within buildings. WLAN uses OFDM modulation or spread-spectrum to enable communication between the WLAN enabled devices. In WLAN senders and receivers share one frequency of the radio and the Uplink, Downlink. The devices in WLAN can be mobile or stationary. Generally WLAN is connected with wired LAN which acts as a backbone. Because of its easy installation and maintenance process WLAN has become a popular technology among private and public sectors. The popularity of WLAN technology and its widespread usage motivated us to take up its integration with WiMAX.

2.1.1 Basic Architecture of IEEE 802.11

The IEEE 802.11 is based on a cellular architecture which consists of several components that interact with each other to provide a WLAN [7, 8]. The system is subdivided into cells called as Basic Service Set (BSS) that supports station mobility transparently to upper layers. Each cell is controlled by a Base Station (BS) called Access Point (AP). Although WLAN can be formed by single cell with single AP, most of the WLAN is formed by several cells where the APs are connected with each other by Distribution System (DS). Figure 2.1 shows the basic architecture of IEEE 802.11.

The components of the WLAN are as follows:

Stations are the nodes capable of connecting to a Wireless Medium (WM) using Wireless Network Interface Card (WNIC) in a network. The stations are categorized into APs that are stationary nodes providing the access to the distribution services (DS) and Clients which are the user devices (mobile or stationary) such as laptops, desktop or PDA. AP transmits and receives the radio frequencies from the clients that are enabled with WNIC. The clients can communicate with each other through the APs.

Figure 2.1 Basic Architecture of IEEE 802.11

Basic Service Set (BSS) is the basic building block of IEEE 802.11 LAN. It consists of stations that can communicate with each other controlled by an AP. The BSS is a member of DS. There are two types of BSS. The Independent BSS (IBSS) also called as Ad-hoc network, has no APs and the stations within the IBSS can communicate with each other through other stations in the network and cannot communicate with another IBSS's stations. Infrastructure BSS has an AP, so the stations in one Infrastructure BSS can communicate with others through AP.

Distribution System (DS) is an architecture used to increase the network coverage area through interconnecting the BSSs via APs. It is a switch which can be connected via wired or wireless. DS enables the mobile device support by providing logical services necessary to handle destination mapping and seamless integration of multiple BSSs.

Extended Service Set (ESS) is a large coverage network area formed by a set of connected BSSs through DSs. The DS connects the APs in the ESS. Stations within the ESS can communicate with each other and mobile stations can roam from one BSS to other BSS within the same ESS.

IEEE 802.11 is the WLAN standard set by IEEE for providing moderate to high speed data communication in a short range generally within a building [7]. The IEEE 802.11 specifies the standard for “over-the-air interface” between the BS or AP and the WLAN enabled devices i.e. wireless clients. It resolves the compatibility issues among wireless LAN equipment by addressing the Medium Access Control (MAC) sub-layer and three Physical (PHY) sub-layers namely infrared (IR), Direct Sequence Spread Spectrum (DSSS) in 2.4 GHz and Frequency Hopping Spread Spectrum (FHSS) in 2.4 GHz band. IEEE 802.11d is an amendment over the IEEE 802.11 that provides support for global roaming [12]. IEEE 802.11e is an extension of the draft standard IEEE 802.11 [13]. It offers the standard for Quality of Service (QoS) for WLAN applications by modifying the Medium Access Control (MAC) layer. This is a critical enhancement that provides QoS to the delay-sensitive applications such as Voice over Internet Protocol (VoIP) and streaming multimedia. The 802.11e enhancements are designed to work with all possible 802.11 physical layers including 802.11, 802.11a, 802.11b and 802.11g.

2.1.2 IEEE 802.11 MAC Frame

The IEEE 802.11 MAC scheme is referred as Distributed Foundation Wireless MAC (DFWMAC) [14, 15]. The IEEE 802.11 MAC scheme defines two distinctive access methods to access the shared medium between several stations for the data communication; Distributed Coordination Function (DCF), Point Coordination Function (PCF).

Distributed Coordination Function (DCF) is the basic access mechanism which relies on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) algorithm and optional 802.11 RTS/CTS to share the medium between multiple stations. It is more suitable for asynchronous or burst traffic. The station senses the medium before a data frame is sent. If the medium is idle for at least a Distributed coordination function InterFrame Space (DIFS) period of time then the station will transmit the frame. If not, a backoff timer B that is measured in time slots is uniformly selected between 0 to CW-1 by the particular station where CW is Contention Window. The backoff timer is decremented by one for each time slot the medium remains idle. The frame is transmitted only when the backoff timer reaches zero. DFS does not have QoS guarantees. Hence there is no priority in frame transmission; a station which succeeds in accessing the medium may keep the medium till it finishes its transmission. Station that has a low bit rate will take long time to send its packet results in all other stations may suffer.

Collision avoidance is carried out by the virtual carrier sense mechanism using the transmission time field in the IEEE 802.11 frame. Each station in the network has an internal timer called Network Allocation Vector (NAV). When a frame is transmitted the sending station indicates the length of the frame transmission time including any

- 19 -

subsequent fragments and acknowledgement in the duration field of the frame. This frame is received by all other stations in the vicinity and it let the stations know how long the medium will be busy. The stations will update its NAV using the duration value in the time field of the frame. The station must wait till the NAV counts zero before it starts transmission.

Point Coordination Function (PCF) is an optional function in the 802.11 MAC which supports real-time traffic and provides contention-free transmission. PCF, a centralized polling-based access mechanism is available only in “infrastructure” mode that requires the presence of a BS or AP which acts as Point Coordinator (PC).

The AP starts PCF operation by polling each station with the PIFS delay. PIFS is the fundamental delay InterFrame Space (IFS) for the PCF. Throughout polling the AP seizes the medium and locks out all the asynchronous traffic making DCF out of working. During polling AP sends a CF-Poll frame with a piggybacked pending transmission if any to one of the mobile stations. If the polled station has data to send it will respond with the Data + CF-ACK frame or with a *CF-ACK* frame. Upon exchanging the frame sequence with one station the AP then poll the other stations in its mobile list by sending CF-Poll. The AP announces the end of the CFP by broadcasting a CF-End frame after it has finished polling all the stations or when the Contention Free Period (CFP) has expired.

2.1.3 MAC Super Frame of 802.11

AP sends “Beacon” frames at regular intervals usually every 0.1 seconds. The time between two consecutive Delivery Traffic Indication Message (DTIM) beacon frames is called as superframe. Each super frame consists of a Contention Period (CP) and a Contention Free Period (CFP) [14, 15].

In Contention Period DCF is used whereas in Contention Free Period PCF is used. AP contends for the medium at the end of CP using the PIFS. PIFS is shorter than the usual DIFS. This is to avoid the interruption of the DCF stations in the PCF mode. If the medium is idle, then the AP gets the medium. During the CFP, the AP sends Contention Free-Poll (CF-Poll) frames to each station, one at a time, to give them the right to send a packet. The polling is done by sending the CF-Poll frames to the high priority stations when they are clear to access the medium to send the data. Since the size of the frames transmitted by each station i.e. traffic intensity varies, the length of the CFP also varies. The AP broadcasts the actual CFP duration in the beacon, and the NAVs are updated accordingly. At the end of the CFP, all the stations reset their NAVs to zero and contend for the wireless medium using DCF until the next DTIM beacon arrives. Even though AP provides better management over the QoS the PCF has limited support and it does not define traffic flows into various classes to provide end-to-end QoS. In order to prevent starvation of low priority flows, the contention period must always be long enough for one maximum length frame. The operation of MAC super frame is given in Figure 2.2.

Figure 2.2 Operations of MAC Super Frame

2.1.4 QoS in IEEE 802.11

IEEE 802.11e is an extension of the draft standard 802.11 [13]. It describes Enhanced Distributed Channel Access (EDCA) and Hybrid Coordinator Function Controlled Channel Access (HCCA) schemes that provide QoS over existing Distributed Co-ordination function (DCF) and Point Co-ordination Function (PCF) schemes respectively.

The EDCA scheme classifies the traffic flows into one of four Access Categories (ACs): background traffic as AC_BK, best effort traffic as AC_BE, video traffic as AC_VI and voice traffic as AC_VO. Each AC has different values of (a) minimum contention window size (CW) (b) maximum contention window (CW) size and (c) Arbitration Inter-Frame Space (AIFS). The channel access priority is varied based on these values. For example, a higher priority traffic flow will have lesser value of CW and smaller AIFS. EDCA is contention based protocol making each flow within a wireless node to compete for a virtual channel. An AC with a smaller CW selects its random back-off period from a set of smaller numbers. The AIFS determines the time period an AC has to be delayed before its transmission occurs. Once the back-off timer of a particular AC expires, it would transmit a frame. EDCA mechanism can only provide a relative differentiation among service classes and does not guarantee throughput/delay performance [16]. It has also been shown that EDCA can starve lower priority flows [17].

HCCA is a contention-free media access mechanism which provides QoS service by using signaling, scheduling and admission control. The HCCA method combines some characteristics of the EDCA with the basic features of the PCF. It defines a super-frame containing a contention-free period followed by a contention period. During the

contention-free period, only the nodes which are polled by the AP are eligible to transmit for a burst period assigned by the AP. The 802.11e standard [13] defines eight Traffic Categories (TCs). TCs are characterized by traffic specifications (TSPECs). The TCs are grouped into the four ACs described in Table 2.1. In order to support QoS in 802.11e networks, service request and service level negotiation functionalities are introduced by the 802.11e. When a new traffic flow starts, the node needs to send a service request to the AP providing its TSPECs and the AP will perform admission control to decide whether or not to allow the new flow for service [18].

Table 2.1 Traffic Categories and Access Categories in IEEE 802.11e

Access Category For WLAN	Traffic Category For WLAN	Designation	Example
AC_BK	TC1, TC2	Background	Background internet Traffic, HTTP
AC_BE	TC0, TC3	Best Effort	FTP
AC_VI	TC4, TC5	Video, VoIP	MPEG, VoIP with silent suppression (VBR traffic)
AC_VO	TC6, TC7	Voice, T1	VoIP without silence suppression (CBR Traffic)

2.2 IEEE 802.16 (WiMAX)

Worldwide Interoperability for Microwave Access (WiMAX) is a broadband wireless technology aimed at providing Wide Area Network (WAN) access to stationary and mobile users [19]. WAN offers an alternative to cabled access networks such as fiber optic links, coaxial systems and Digital Subscriber Line (DSL) links. Section 2.2 provides a basic description about the WiMAX standard. Basic architecture, physical and medium access, frame structures and diverse QoS services are discussed here.

The WiMAX forum was formed in April 2001. IEEE 802.16 is the standard set by the IEEE community to support the development and deployment of WiMAX [9]. IEEE 802.16 describes WiMAX as "a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL". WiMAX provides higher data rates, telecommunication services, more scalability, and broader coverage than Wi-Fi [19].

Due to its' high bandwidth and wide coverage it may be suitable for interconnecting WLAN hotspots. The fundamental design of the WiMAX may allow the extension of the WAN protocols directly to provide back-bone support to WLAN hotspots. This is the primary motivation for us to consider integrating WiMAX and WLAN.

2.2.1 Basic Architecture of WiMAX

The basic IEEE 802.16 (WiMAX system) consists of one Base Station (BS) and one or more Subscriber Stations (SS) in a cell as shown in Figure 2.3. A WiMAX cell can cover an area with the radius of 2-10km and provide data rate more than 70 Mbps. The

802.16 standard enumerates two modes for sharing wireless medium; Point-to-Multi Point (PMP) and mesh network. Since we use PMP scenarios in our thesis we focus on PMP. The PMP operational mode can be compared with a typical fixed BWA scenario in which one centralized service provider serve multiple subscribers. In the PMP structure the BS acts as a central entity and control the activities such as admission, access to the medium, and data transfer with the QoS to and from SSs within the cell. It also acts as a coordinator and broadcast the same transmission to all the SSs within the same antenna sector. At the same time the transmissions from the SSs are directed to the BS which relays it to the destination.

Data transmission takes place through the mediums' two independent channels; Downlink channel (from BS to SS) is used only by BS and Uplink channel (from SS to BS) is shared between all SSs. In PMP network the data transmissions in uplink and downlink take place in separate time frames (TDD). Whereas in mesh network there is no central coordinator several BSs/mesh routers communicate with each other, and SS connects to a BS/mesh router. In the mesh network the Data traffic from a SS can be routed through the other BSs along a multi hop route to the destination BS or an Internet gateway. The access coordination is distributed among the SSs within the same antenna sector.

Figure 2.3 Basic Architecture of WiMAX Network

The IEEE 802.16 specifies the standard for the air interface between the BS and SS. In June 2004 the IEEE made an amendment on the existing IEEE 802.16 standard to support the fixed, PMP broadband wireless access service [9]. The IEEE 802.16d Wireless Metropolitan Area Network (WMAN) air interface standard [9] specifies:

- (a) Convergence sub-layer that classifies external network Service Data Units (SDU) and associates them with the proper service flow identified by the connection identifier (CID).
- (b) MAC Common Part Sub-layer (CPS) that provides system access, bandwidth allocation, connection establishment, and connection maintenance.

- 26 -

(c) Security sub-layer that provides subscribers with privacy across the network by encrypting connections between SS and BS.

(d) PHY layer that uses Orthogonal Frequency Division Multiplex (OFDM) with a 256 point transform designed for both Line of Sight (LOS) and Non-Line-of-Sight (NLOS) operations.

The mobile WiMAX standard (IEEE 802.16e), approved by the IEEE in December 2005, adds mobility features to the WiMAX in the 2 to 11 GHz licensed bands [11]. By enhancing the Orthogonal Frequency Division Multiple Access (OFDMA) the 802.16e supports both fixed and mobile wireless Non Line of Sights (NLOS) applications. 802.16e supports very high bit rates in both uploading to and downloading from a BS up to a distance of 30 miles. To enhance data transmission rate, an Adaptive Modulation and Coding (AMC) technique is supported in the IEEE 802.16e standard [11]. Since the quality of the wireless link between a BS and a SS depends on the channel fading and interference conditions, through AMC the radio transceiver is able to adjust the transmission rate according to the channel quality.

Adaptive modulation scheme allows the system to adjust the system modulation scheme according to the Signal-to-Noise Ratio (SNR) condition of the radio link [14, 15]. When the radio link is high in quality, the highest modulation scheme which gives the system more capacity is used, while radio link is low in quality i.e. during signal fade a lower modulation scheme is used to maintain the connection quality and link stability. This Adaptive Modulation scheme allows the system to overcome time-selective fading.

2.2.2 WiMAX MAC Protocol

IEEE 802.16/WiMAX uses a connection-oriented MAC protocol that provides a mechanism for the SSs to request bandwidth from the BS [11]. A 16-bit Connection Identifier (CID) is used primarily to identify each connection to the BS. During the transmission, on the downlink (DL) subframe the BS broadcast a burst of Medium access control Protocol Data Units (MPDUs) to all SSs in its coverage area. MPDUs are the packets that are transmitted in time slots, transferred between the bottom of the MAC and the PHY layer. MAC service data units (MSDUs) are transmitted within the MPDUs. MSDUs are the packets transferred between the top of the MAC and the layer above. MSDUs can be fragmented across MPDUs. Fragments of MSDUs can be packed within a single packed MPDU. Automatic Retransmission Request (ARQ) is used to request the retransmission of un-fragmented MSDUs and fragments of MSDUs.

Since the transmission is broadcast all the SSs listen to the data transmitted (MPDUs) by the BS. The SS process the MPDUs only if the MPDUs containing its own CID or explicitly intended for all the SSs i.e. it can be a control message. However, in the uplink (UL) subframe the SS transmits a burst of MPDUs to the BS in the Time Division Multiple Access (TDMA) manner.

The fixed WiMAX IEEE 802.16d standard utilize the OFDM 256-Fast Fourier Transform (FFT) and supports both Time Division Duplex (TDD) and Frequency Division Duplex (FDD) [9]. In Time Division Duplex (TDD) DL and UL subframes occur in different times but with the shared (same) frequency where as in Frequency Division Duplex (FDD) DL and UL subframes occur simultaneously on separate frequencies. In both modes, the length of the UL and DL subframe can be varied by the

BS Scheduler. For example in TDD mode, the length of the subframes is varied by allowing asymmetric allocation between UL and DL. The SSs can transmit and receive at the same time i.e. full duplex or at non-overlapping time intervals i.e. half-duplex [14, 15].

The on-air timing is based on consecutive frames that are divided into slots. The size of frames and the size of individual slots within the frames can be varied on a frame-by-frame basis under the control of a scheduler in the BS. While a connection is maintained between BS and SSs, the SSs may request the BS to change the QoS parameters for that connection. Even though the MAC layer specifies the extensive bandwidth allocation and QoS mechanisms, it does not specify the details of scheduling and reservation management.

Data transmission in the MAC layer takes place through the DL frame (from BS to SS) and UL frame (from SS to BS). The DL frame has a preamble, a DL_MAP, a UL_MAP, and TDM portion. The DL_MAP is used to define the slot locations of bursts of user data within the DL subframe and the profile of each burst. The UL_MAP is used to define the slot locations of bursts of user data in the subsequent UL subframe and profile of each burst. The SS uses the connection ID to identify the location of its data within the DL frame. The initial maintenance opportunity portions of a DL frame are the time slots used for bursts that are transmitted in contention to establish initial network entry. The contention opportunity portion of the frame allows SSs to send bandwidth requests through contention. The scheduled data portions are the time slots used for the bursts of data from SSs, and only those SSs that are given permission, are able to transmit the data via UL.

2.2.3 WiMAX MAC Layer Services

Since the characteristics of a wireless link are highly unpredictable and variable, it is much more difficult to provide QoS support to the wireless network than wired. The characteristic of wireless network may vary on a time-dependent basis or on a location-dependent basis. Wireless medium has excessive amount of interference and higher error rates. In order to handle such issues, QoS in wireless networks is managed at the MAC layer. The 802.16 MAC layer is designed to provide differentiated services to different traffic categories with different QoS requirements i.e. multimedia requirements such as Voice over Internet Protocol (VoIP) and Hypertext Transfer Protocol (HTTP) traffic.

The 802.16 MAC layer specifies four different scheduling services that are characterized by a mandatory set of QoS parameters, to provide QoS for multimedia applications. The standard also specifies mechanisms to be used in the UL in order to request bandwidth from BS. The scheduling services are as follows;

Unsolicited Grant Service (UGS)

It is designed to support real-time applications such as T1/E1 and VoIP without silence suppression with strict delay requirements. These applications generate data packets at periodic intervals. Since real-time applications are considered as constant bit rate traffic generally, a fixed amount of bandwidth is allotted for this service so as to minimize delay. UGS services use the unsolicited granting bandwidth-request mechanism in which a fixed amount of bandwidth on a periodic basis is requested during the setup phase of an UL connection and after that phase, bandwidth is never explicitly requested.

Real-time Polling Service (rtPS)

Real-time Polling Service (rtPS) supports variable bit rate real-time traffic such as Motion Pictures Expert Group (MPEG) video and VoIP with silence suppression. These applications generate variable-size data packets at periodic intervals with less stringent delay requirements. Since the size of arriving packets with rtPS is not fixed the SSs in the rtPS connections are required to notify the BS of their current bandwidth requirements. UL bandwidth allocation is based on a polling scheme. The BS implicitly polls each SS and the SS replies with a bandwidth request to obtain a grant for the messages that it can transmit. This scheme can guarantee QoS service to meet delay requirements.

Non-real-time Polling Service (nrtPS)

Non Real-time Polling Service (nrtPS) supports variable bit rate traffic such as File Transfer Protocol (FTP) which is delay tolerant. The nrtPS connections reserve some amount of the bandwidth to boost performance of bandwidth-intensive applications. The SSs in the nrtPS connections request bandwidth in the uplink subframe either by responding to broadcast polls from the BS or piggybacking a bandwidth request on outgoing MPDUs. Additionally, the BS grants uni-cast polls to nrtPS connections at a time-scale of one second or less. It also uses a polled approach like rtPS but does this to ensure there is no packet loss.

Best Effort (BE)

Best Effort (BE) supports data traffic such as media streaming and network gaming which do not have any specific delay requirement. Since the BS controls the access to the medium in the uplink direction, bandwidth is granted to SSs on demand.

The SSs in the BS connections request bandwidth in the uplink subframe either by responding to broadcast polls from the BS or piggybacking a bandwidth request on outgoing MPDUs.

Thus Section 2.2 has provided the basic architecture of WiMAX, physical and medium access layer, frame format, QoS of WiMAX and the diverse MAC services to provide QoS for all type of traffic flows.

2.3 Literature Review on Integration of WLAN-WiMAX

Researchers have paid much attention to the architectures of the integration of heterogeneous wireless networks. Some literature discusses about providing always best connected network among WLAN-WMAN. Providing QoS guarantee for real-time traffic in terms of delay and non-real-time traffic in terms of packet loss is a challenging issue. The issue of providing up-link delay bound between the wireless nodes and the AP has been extensively discussed in WLAN research. Section 2.3 unveils the literature review about the integration of WLAN-WiMAX with various QoS scheduling algorithms.

2.3.1 Literature Review on Integration

This section briefly describes the literature review on the integration of WLAN-WiMAX.

2.3.1.1 Integration Model for WLAN-WiMAX

The 4G will be a fully IP-based integrated network of networks achieved after the convergence of wired and wireless networks. The 4G network will offer any kind of service anytime, anywhere, at affordable cost and one billing. The 4G drafts [20] recommend the integration of wireless technologies like WLAN, WiMAX and 3G cellular.

Jackson et al [21] proposed an Always Best Connected Integration model that supports Always Best-Connected (ABC) Quality of service (QoS) to the applications in a WLAN, WiMAX heterogeneous network. Here the User Equipment (UE) in the network was enabled with both WLAN and WiMAX access capabilities. The paper mainly focused on QoS support to trigger the media Independent handover (MIH) that occurs between multiple access networks. The paper proposed a Generic Virtual Link Layer (GVLL) that was placed above the WLAN and WMAN MAC layer in the UE. This GVLL operates as a virtual MAC interface and makes the interoperability possible. The triggering was done by the GVLL and the best access network in terms of QoS support was chosen dynamically based on the parameters such as throughput, packet loss, and delay.

In order to choose the best possible access networks the checking of the best available network was carried out by the user during the admission of a call and whenever the QoS guarantee falls beyond the threshold. During the admission of a call, the admission request was sent to their respective access networks by the GVLL via both the interfaces. If one of the interfaces replied then the decision to activate the call was made by the user according to the QoS support. If both the interfaces replied, then the best QoS

support network was chosen by the GVLL. Since the authors had not considered the SNR parameter, if both access networks support the requested QoS then the call would be admitted in WLAN network. The authors assumed that the support for end-to-end QoS beyond the radio access was available. They target on QoS achievement for the calls at the MAC level, while integrating these two different MAC access technologies. They have modeled and simulated both the WLAN and WiMAX MAC layers.

Akkari et al [22] proposed an architecture that offers mobile users, roaming in next generation networks and service continuity without compromise the QoS. The architecture is shown in Figure 2.4. This was done by introducing an Inter-Domain Management module (IDM) responsible of guiding the vertical handover to WiMAX network capable of offering the user the same QoS and context parameters. The IDM was divided in to three entities. The vertical IDM (VIDM) responsible to perform the handover vertically, the horizontal IDM (HIDM) responsible to perform the handover horizontally, and the stand-by IDM (SIDM) responsible to perform the handover to WiMAX. The authors extend the Mobility and QoS Management Architecture (MQMA) to solve the vertical handover problem between the WLAN and UMTS. Here WiMAX mobility was considered as a stand-by destination and the users would be guided to the WiMAX networks if no recourses were available in UMTS or WLAN to perform the requested handover.

Figure 2.4 Integration Architecture

2.3.1.2 Mobility Management in Next Generation Networks

Haffajee et al [23] analyzes interactions between different layers and network entities which are necessary to provide QoS when interworking WLAN-WiMAX. An integration framework was proposed by mapping the DiffServ Code Point (DSCP) to the link-layer scheduling services in WiMAX and in WLAN according to their priorities. The authors treated two DiffServ Best Effort classes differently by setting the DSCP drop-precedence bits differently. The class with priority 0 had high drop precedence and the class with priority 1 had low drop precedence. Followed by a detailed call-flow to set up a QoS-enabled calls were described using message sequence diagrams. However, [23] does not provide any implementation details or performance analysis.

2.3.1.3 Ethernet-Based Integration

Hoymann et al [24] described two types of integration methods between the High Performance Metropolitan Area Network (HiperMAN) and High Performance Local Area Network (HiperLAN). HiperMAN and HiperLAN/2 have an IP Convergence

Layer (CL); therefore one of the methods was to connect them at the IP layer that might not be appropriate to guarantee an acceptable QoS for services like video-on-demand or teleconferencing. A better interworking solution should enable the exchange of QoS parameters between the two networks. So the appropriate method was connecting them at the Ethernet. The authors considered two different aspects for the interworking mechanism between HiperLAN/2 and WMAN. In the static mapping the Ethernet approach with priority tags has been used. In the dynamic mapping a MAC message has been added to the HiperMAN standard in order to obtain a temporary change of the QoS parameters. The simulation has been done in the wireless access radio protocol 2 (WARP2) simulation environments by implementing the HiperMAN (HM) as well as HiperLAN/2 (H/2) protocol stacks and the performance has been evaluated.

An Ethernet bridging mechanism was proposed in [25] for the efficient interworking between HiperLAN and HiperMAN standards. This paper gives a detailed description of the User Plane and Control Plane of an integrated device that implements an Ethernet-based interworking. The projected scheme did not classify the QoS for different traffic types and the mapping was not clearly done.

2.3.1.4 Integration at Access Point

Frattasi et al [26] introduced an AP, called WMAN/WLAN AP (WWAP) which uses the Ethernet-bridging interworking mechanism that essentially integrates a WMAN SS and a WLAN AP in order to provide the full interoperability between WMAN and WLAN standards. This mechanism mainly relies on the use of the Convergence Layers (CLs) of both standards because the CLs usually convert higher-layer packets of fixed or variable length into fixed-length Service Data Units (SDUs) that are handled by the Data

Link Control (DLC) layers. The WWAP combines a WiMAX SS and a WLAN AP in order to extend the WiMAX coverage. The simulations were done using the Wireless IP Simulator (WIPSim). In the simulation the authors only considered the Constant Bit Rate (CBR) video source i.e. UGS and a low priority data flow i.e. Best Effort (BE) and this paper does not provide any specific scheduling strategy that should be used to provide QoS guarantee.

2.3.2 Literature Review on Providing QoS in WLAN-WiMAX Integrated Network

2.3.2.1 Feedback Based Bandwidth Allocation

Even though IEEE 802.11e draft suggests a simple scheduler for the Constant Bit Rate (CBR), it did not provide any scheduler algorithm to provide QoS for real-time flows. During the data transmission, the suggested scheduler did not make use of the feedback information from the SSs to allocate the bandwidth dynamically. So it might not be suitable for burst traffic. In order to solve the above mentioned problem, Boggia et al [16][27] proposed a HCF Controlled Channel Access (HCCA) based dynamic bandwidth allocation algorithm, and a measurement based Call Admission Control (CAC) algorithm, that together provide delay guarantees to the real-time media flows in IEEE 802.11e networks. In this paper the proposed dynamic bandwidth allocation algorithm was designed using classic feedback control mechanism, which allows the HC to assign Transmission Opportunities (TXOPs) to the APs by taking into account the specific time constraints of each AP. It allocates the WLAN bandwidth by calculating the actual used resources rather than the average rates declared by data sources. The suggested CAC was an extension of the admission control algorithm proposed by the 802.11e working group.

When a new traffic flow starts, the node needs to send a service request to the AP providing its TSPECs and the AP will perform admission control to decide whether or not to allow the new flow for service. The algorithms have been implemented in the ns2 simulator and it has been shown that the proposed algorithm protect the WLAN from over-load and provides the bounded delay to multimedia flows.

Gakhar et al [27] insinuated an architecture to achieve the end-to-end QoS of an application that is being operated in an interworking system comprised of WiMAX and IEEE 802.11e networks. This was achieved by mapping the application's QoS requirements, originating in WLAN network, to a serving WiMAX network. First, the authors discussed the flow specification of an application and the mechanisms that ensure that the application's QoS requirements were known to the serving network.

2.3.2.2 An Adaptive QoS Architecture for IEEE 802.16

An adaptive QoS architecture for PMP 802.16 systems operating in TDD mode over wirelessMAN – OFDM physical layer was proposed by Msadaa et al [28]. The proposed architecture includes a Call Admission Control (CAC) module and a hierarchical scheduling algorithm. The CAC was performed when an SS or a BS attempts to establish a new active connection and also when a SS uses more or less robust DL or UL burst profile. It adopts a Min-Max fairness approach making efficient and fair use of available resources. The hierarchical scheduling algorithm flexibly adjusts UL and DL bandwidth. The issues such as resource management and scheduling are not handled by this scheme. Since the priority was given in the following order DLUGS> ULUGS> DLrtps> ULrtps> DLnrtPS> ULnrtPS> DLBE>ULBE, the QoS for the real-time and non-real-time traffic has not been achieved through this scheme.

2.3.2.3 Queue Based Scheduling Approach for Wireless Broadband

Niyato et al. [29] devised an adaptive queue-aware uplink bandwidth allocation that adaptively allocates bandwidth for polling services in the presence of UGS. Under the proposed bandwidth allocation scheme, the amount of bandwidth allocated for polling service can be adjusted dynamically depending on the traffic load variations and/or channel quality so that the desired level of packet-level QoS performances, such as protocol data unit (PDU) delay and PDU dropping probability, can be maintained. The authors considered an uplink transmission scenario from an SS to a BS through the TDMA / TDD access mode and single carrier modulation for UGS, PS, and BE traffic. An analytical frame work has been presented based on a discrete time Markov chain (DTMC) for the above bandwidth allocation and rate control schemes to analyze the QoS performance. Nevertheless, the proposed scheme treats real-time and non real-time services identically, and also does not adequately exploit QoS factors (e.g. maximum latency) in its scheduling. And also the real-time and non real-time traffic use the same queue and therefore the system cannot distinguish between the different QoS requirements of different traffic flows. Since the major difference between the two types of traffic is their tolerance to delay, it is important to separate them in different queues and explicitly incorporate the maximum latency specification of the real time traffic in the scheduling process itself.

Based on [29], Raghu et al [30] proposed a queue based packet scheduling algorithm to provide QoS for real time and non real time traffic, depending on their queue size and latency requirements. Here the author considered the real time and non real time traffic as two different queues. QualNet has been used to study the performance of the proposed algorithm. However, as the bandwidth requirement of each traffic classes varies time to time, this algorithm could not utilize the bandwidth wisely, resulting in wastage of

bandwidth. This has been a motivation for us to propose a dynamic scheduling algorithm that allocates the bandwidth to the various traffic classes, dynamically of course.

2.3.2.4 Evaluation of QoS Schemes for IEEE 802.11 Wireless LANs

Lindgren et al. [31] evaluates the different service mechanisms available in IEEE 802.11 wireless LANs using the ns-2 simulator. In the simulator all wireless stations were located within the transmission range of each other and there was no mobility in the system. The metrics used in the evaluation were throughput, medium utilization, collision rate, average access delay, and delay distribution for a variable load of real time and background traffic. The results were shown that the PCF performance was comparably low, while EDCF performs much better and the best performance was achieved by Blackburst.

Prioritized channel access, based on different Inter Frame Spaces (IFS), is a key component of the EDCF. The IFS-based priority schemes differentiate the priority classes according to their channel monitoring parameters. Bianchi et al. [32] introduced a novel mathematical model to evaluate the throughput/delay performance of IFS-based priority mechanisms applied to CSMA-CA with exponential backoff. To calculate the exponential backoff the authors only considered two different service classes, identified as class 1 and class 2 and use different discrete time scales, not only for each different priority class, but also for each different memory process (backoff counter, backoff stage) involved in the model. A station of class q has a backoff counter equal to b at the beginning of a slot-time. If the current slot-time was idle at the end of the slot-time, the backoff counter was decremented, and the station did start the next slot-time with backoff value $b - 1$. If the current slot-time was busy i.e. another station was transmitting, then the station froze the

backoff counter to the value b . As soon as the channel transmission ends, the considered station waits for an AIFS $_q$ time, after which de-froze the backoff counter. The station will thus start the slot-time immediately following the AIFS $_q$ with the same value b for the backoff counter, and this value will be decremented only at the end of the slot-time, if idle. Unlike all the previous works, the new mathematical model did not rely on multi-dimensional Markov chains. According to the authors the model was extremely accurate, regardless of the system parameters. Through studies of the model, we understand that the EDCA mechanism can provide only a relative differentiation among service classes, and does not guarantee throughput/delay performances.

2.3.2.5 Deployment Models and User Scenarios

The white paper [33] introduced a controlling Access Service Network Gateway (ASN GW) and common Authentication, Authorization, and Accounting (AAA) service functionality to provide service across WiMAX and WLAN networks when users move between them. The following Figure 2.5 shows how the Interworking has been done.

Figure 2.5 Proposed Interworking by Motorola

NextPoint™, a leader in fixed-mobile connectivity (FMC) solutions has introduced new mobility-enabling features to its Integrated Border Gateway (IBG) product suite [34]. Packet Data Interworking Function (PDIF) has applied to CDMA mobile networks, WLAN deployments, including Wi-Fi to integrate these to WiMAX deployments. TTG, a subset of the Packet Data Gateway (PDG) specification is applied to UMTS networks for inter-worked WLAN or WiMAX deployments. PDIF and TTG rely upon and enhance the security gateway to protect resources and packet data services from unauthorized access. With this functionality, NextPoint enables true mobility for users roaming between multiple IP networks.

Thus section 2.3 gives an overview of the preceding research works associated to the integration of WLAN-WiMAX such as integration model based on mobility, Ethernet, access point and multihop, evaluation of QoS schemes and deployment models. It also describes the scheduling schemes based on feedback mechanism, queue based mechanism to provide end-to-end QoS for the various traffic flows.

2.4 Literature Review on Group Mobility

Group mobility with centralized control is widely dominant in military networks and vehicular networks. In the defense war fighting leverage information superiority will require vast improvements in information transfer in terms of higher bandwidth, QoS support and connection to a high speed backbone. An array of military applications such as just-in-time logistics, teleconferencing, telemedicine and multimedia applications, require QoS support in terms of delay and delay variation. Providing QoS in such scenarios is often complex since the wireless channel is subject to fading and erasures. Moreover, the network needs to be able to provide priority services to messages based on

their criticality. The IEEE 802.16e broadband wireless access system is a viable alternative that can meet such requirements. Section 2.4 comprehensively describes the various works such as group mobility model and scheduling algorithms to provide end-to-end QoS interrelated to the group mobility.

2.4.1 Performance Evaluation of 802.16e in Vehicle to Vehicle

Channels

Beibei et al. [35] has evaluated the performance of an 802.16e system with different channel estimation methods of OFDMA air interface in two non-stationary vehicle to vehicle (V2V) channels; open area high traffic density (OHT) channel and urban (UOC) channel. The authors have classified the V2V propagation channel into 5 regions: UOC, urban-antenna inside car (UIC), small city (S), open area-low traffic density (OLT), and OHT. The “open” areas were highways. First the authors developed a non-stationary V2V channel models from empirical data then a three channel estimation schemes that apply to different scenarios were introduced. After that the performance of the 802.16e system over the proposed non-stationary V2V channel models was simulated using the uplink PUSC permutation in the frequency domain and random sub-channel scheduling in the time domain. The proposed channel estimation methods provide a good trade-off between channel estimation accuracy and computational complexity. The authors also illustrated that system performance in non-stationary channels was more volatile than in stationary channels. Though they did not take the frame structure or QoS specifications of 802.16e standard into account, they analyzed channel allocation and BER vs. E_b/N_0 for different propagation models.

2.4.2 Group Mobility Model

The mobility model is one of the most important factors in the performance evaluation of a mobile WiMAX. Usually, the random waypoint mobility model has been used to model the node mobility, where the movement of one node is modeled as independent from all others. However, in reality, especially in large scale military scenarios, mobility coherence among nodes is quite common. Group mobility is one of the typical mobility behaviors. Thus, to investigate such as military WiMAX scenarios, an underlying realistic mobility model is highly desired. Mobility models indeed have significant impact on the performance evaluation of network protocols such as routing protocols. Thus, it is essential to use the proper motion model while simulating and testing various network protocols.

Group mobility suggests the existence of task orientation and that this orientation will be known to the individual creating the simulation beforehand. Nodes that move in groups very often indicate the existence of a common goal, geographic or otherwise. The accurate representation of group structure has a significant effect on the overall simulation, particularly in the area of link stability. Blakely et al. [36] presented a Structured Group Mobility Model (SGMM) that parameterizes group structure and generates movement sequences for simulations in MANET.

The goal of the SGMM was to provide more realistic network behavior than more stochastic models such as the Reference Point Group Mobility Model (RPGMM) and Reference Velocity Group Mobility Model (RVGMM), especially in an environment where obstructions induce link breakages between nodes. The model was defined and the use of a node mobility model in creating simulations of several MANET scenarios was

demonstrated using the NS2 discrete-event network simulator. Even though the proposed model has some advantages it also has some drawbacks. The SGMM is more complex to use due to the need to develop parameters describing the formation of the group.

A Virtual Track based group mobility model (VT model) that closely approximates the mobility patterns in military WiMAX scenarios was devised in [37]. The developed scheme is capable of modeling various types of node mobility such as group moving nodes, individually moving nodes as well as static nodes such as sensors to describe heterogeneous mobility behaviors. The individually moving nodes and static nodes are not constrained by the same routes as group nodes. This diversity makes the VT model a good candidate for modeling realistic military scenarios. Switch Stations and Virtual Tracks have been introduced in the scheme in order to model group dynamics such as group merge and split. Figure 2.6 elucidates the virtual track based group mobility model.

Figure 2.6 Virtual Track Based Group Mobility Model

The VT mobility model is suitable for both military and urban environment. In the war field, the switch stations can be viewed as the gathering points or hot spots of military forces. The virtual tracks are roads or trails or valleys connecting those hot spots. The troops usually move following the predefined track. Virtual tracks restrain the movement of grouped nodes along tracks where group mobility is feasible (e.g., highways, valleys, etc). Mobile groups then can split or merge at switch stations. However in the urban environment, the virtual tracks can be viewed as the streets. The switch stations are then the intersections of the streets. In a suburban scenario, the virtual tracks can represent the highways and the switch stations are then viewed as the intersections of the highway where as the mobile nodes represent the cars running on the highway and the convoys of cars on the highway can only split at the intersections. The simulation has been done by implementing the VT mobility model in the QualNet network simulator and the results

shows that VT mobility model will play an important role in simulating emergency recovery and battlefield scenarios where various mobility behaviors typically coexist.

2.4.3 Group Mobility in Ad Hoc Networks Using Wi-Fi

Brown et al. [10] has described the implementation of a wireless mobile ad hoc network with radio nodes mounted at fixed sites, on ground vehicles, and in small (10kg) UAVs. The authors called this as Ad Hoc UAV-Ground Networks (AUGNets). Two scenarios had been considered for this type of network. In the first scenario the UAV with a better view of the nodes acts as a prominent radio node that connects the disconnected ground radios that may be caused by distance and/or terrain. Here the UAV maintains connectivity as an Ad Hoc relay. In the second scenario the networking enables groups of UAVs to communicate with each other to extend small UAVs' operational scope and range by Ad Hoc relaying between multiple UAVs. The network consists of mesh network radios assembled from low-cost commercial off the shelf components. The radio was an IEEE 802.11b (Wi-Fi) wireless interface and was controlled by an embedded computer. However, such networks have limited range due to low power operation of Wi-Fi unlike WiMAX. The two scenarios are illustrated in Figure 2.7 (a) and Figure 2.7 (b).

Figure 2.7 (a) Group Mobility in Ad Hoc using Wi-Fi

Figure 2.7 (b) Group Mobility in Ad Hoc using Wi-Fi

2.4.4 Time Synchronization for 802.16e

The first symbol in DL is a preamble that uniquely identifies the serving BS. It allows the MS to obtain initial synchronization including time acquisition, carrier frequency synchronization and cell identification. By exploiting the properties of the DL preamble, Tejas Bhatt et al devised an initial synchronization algorithm for time and carrier frequency synchronization and cell identification for downlink of OFDMA based mobile WiMAX [38]. The proposed method does not require prior knowledge of transmitted preamble for coarse or fine time synchronization however it only utilizes the preamble structure and inverse Fourier transform properties to obtain time/frequency synchronization. First in the Coarse Frame-Boundary Detection, since preamble is the first symbol in TDD frame, the authors exploited the time domain repetitive property to acquire coarse frame timing using efficient delay-correlation mechanism. In order to improve the accuracy of the timing estimation, the authors has proposed to utilize the conjugate-symmetry which returns fine time synchronization and enables frequency domain search of preamble and integer frequency offset. We will in the later chapter use this time synchronization to send feed-back message from the destination SS to the source SS.

2.4.5 Scheduling Algorithm

There have been extensive researches going on in the field of scheduling algorithm in IEEE 802.16e. The algorithms which might be useful to our research work have been explained in the following section.

An overview of scheduling algorithms in IEEE 802.16 networks is given in [39]. The authors have given an overview about OFDMA frame structure, the complexity of OFDM schedulers and current WiMAX Schedulers. They also explained about the services of WiMAX, the things to be considered before create a scheduler such as total available bandwidth, service flow specific scheduling policy, service flow QoS parameters, data queue backlog, and the request/grant mechanisms such as Contention, Polling, Piggyback, Connection air link quality. Finally the paper concluded with the reviews of some paper.

Gowda et al. [40] introduced a scheduling rule using flow metric for a mixture of real-time, non-real-time and best effort traffic through investigating the slot allocation for diverse QoS types in OFDMA based IEEE 802.16e WirelessMAN systems. For a downlink scenario, the authors proposed a flow metrics in which once the bandwidth needs of real-time and non-real-time were met the remaining bandwidth was allocated to BE to make use of the remaining bandwidth. The system model uses traffic flow queues as finite length buffers for each of the downlink flows. Simulation results were presented to compare the performance of the proposed rule with that of existing rules.

Singh et al. [41] developed a heuristic algorithm which is a radio resource sharing algorithm for QoS provisioning where both time and frequency slots were shared by users

on the UL and DL. In this algorithm in a slot, a particular sub-channel was assigned to the SS that can transmit maximum amount of data over it and the algorithm run for every class of traffic in the following order: UGS, rtPS, nrtPS, BE. In the devised algorithm the Slot definition is not very clear and there is no rectangular slot allocation. Another drawback of this, the best sub-channels get allocated to UGS connections, and there is no CAC and the QoS parameters were incomplete.

2.4.5.1 IEEE 802.16e for Last Mile Broadband Military Networks

Wongthavarawat et al. [42] established an Uplink Packet Scheduling (UPS) algorithm that provides QoS support of military applications using IEEE 802.16 fixed broadband wireless access standard. The proposed Uplink Packet Scheduling uses a combination of Strict Priority service discipline in the order of UGS, rtPS, nrtPS and BE. Different schedulers were proposed for individual traffic classes; Earliest Deadline First (EDR) for rtPS traffic flow, Weight Fair Queue (WFQ) for nrtPS, there was no scheduler for UGS. The remaining bandwidth was allocated to the BE. One of the disadvantages of the strict priority service discipline is that higher priority connections can starve the bandwidth of lower priority connections. Thus the system might be able to provide end-to-end QoS. There is no CAC and 2-D Mapping.

Figure 2.8 Proposed QoS architecture for Last Mile Broadband Military Networks

Figure 2.8 shows the proposed QoS architecture in which a detailed description of the UPS module, and Admission Control module were added at the BS and the Traffic Policing module was added at the BU. Once the connection was established the traffic policing enforces traffic based on the connection's traffic contract. At the beginning of each time frame, the UPS's Information Module collects the queue size information from the BW-Requests received during the previous time frame. Then it will process the queue size information and update the Scheduling Database Module. The Service Assignment Module retrieves the information from the Scheduling Database Module and generates the UL-MAP. BS broadcasts the UL-MAP to all BUS in the downlink subframe. BU's scheduler transmits packets according to the ULMAP received from the BS. A simulation

model was developed using C++ and showed that the above mentioned scheme provides QoS support to real time applications.

2.4.5.2 Uplink Scheduling Algorithm for VoIP / Video Services in IEEE 802.16d/e System

Lee et al. [43] have exploited an uplink scheduling algorithm for VoIP services in IEEE 802.16d/e system. The algorithm was developed to solve the problems like waste of UL resources, MAC overhead and access delay that were caused by the UGS algorithm, and the rtPS algorithm respectively through letting the BS to know the voice state transitions of the SSs. When using a voice codec with a Voice Activity Detector (VAD) or Silence Detector (SD), the SS can know whether its state is on or off by using a VAD or SD in the higher layer. This higher layer information can be known in the MAC layer by using primitives of Convergence Sublayer in IEEE 802.16d/e system. The authors made use of a reserved bit in the MAC header to signal the BS of transitions from the silent to non-silent periods and vice-versa and the bandwidth allocated during non-silent periods by the BS. The authors have considered only an independent VoIP flow and it might not be practical as uses reserved bit. A cross layer communication would be needed to tell the MAC layer of the transitions and analysis were not based on real frame values. The authors only considered UL scheduling.

Yang et al. [44] proposed a scheduling algorithm for real-time video applications. Here the video contains I, P, and B frames, where I-frames were very bulky and periodic in nature. The algorithm avoids over-lapping of I-frames during connection setup via CAC. It delays the connection start time such that a single frame does not get overloaded by I-frames. If the connection can not be established within a certain delay, it is rejected.

- 52 -

The scheme only considered the video traffic. It did not have any OFDMA scheduler and considered only UL traffic.

Thus section 2.4 has explicated the diverse works correlated to group mobility in WiMAX such as performance evaluation of V2V, group mobility models like Structured Group Mobility Model (SGMM), Virtual Track based group mobility model uplink (VT model). It also presents the various scheduling algorithms based on flow metric, radio resources sharing, VoIP, video, admission control and traffic queues to provide end-to-end QoS for the real-time in terms of delay bound and non-real-time in terms of buffer bound.

Chapter 2 concludes with the literature associated to the WLAN-WiMAX integration and the group mobility in WiMAX.

Chapter 3

Scheduling Algorithm for the Integration WLAN and WiMAX with Base Station Assisted QoS

From Chapter 2 we found that WLAN is a popularly used LAN standard which is capable of providing broadband internet access to end users with QoS. However, WLAN range is limited and generally used in-doors. On the other hand WiMAX is a new WMAN standard capable of providing broadband coverage over a large area covered by a base station. However path-loss and fading makes WiMAX reception poor within home and office buildings. Also most existing user equipments like PDAs and laptops do not have WiMAX stack to roam seamlessly between WLAN and WiMAX networks. Thus WLAN can be relied upon to provide last hop internet coverage while WiMAX can provide backhaul connectivity to the internet gateway. Such an integrated approach will attract more customers to sign up for WLAN as well as WiMAX services unlike most concepts in literature which require both WLAN and WiMAX stacks and radio at the user equipment increasing the cost.

From the literature review on WLAN in Chapter 2 we also found that, there have been numerous schemes proposed aimed to provide QoS. The IEEE 802.11e standard provides special mechanisms such as HCCA and EDCA to provide QoS for different traffic classes. Some researchers have also provided direct scheme through which delay-bound can be achieved for real-time traffic between user and AP. We can adopt such schemes directly in the integration model to achieve QoS between the end-user and AP. The mechanism of providing QoS on the WMAN link between the AP and the BS has not been specified so far. Different traffic classes at the AP need to be treated according to their QoS over the WMAN link. For example voice traffic such as VoIP without silent suppression would require end-to-end delay bound. This motivated us to provide an integration model and scheduling algorithm for the WMAN link to provide QoS.

Chapter 3 provides the detail depiction about the proposed scheme for the integration of WLAN- WiMAX. First it presents the precise details of MAC Layers of WLAN and WiMAX systems particularly in IEEE 802.11e and IEEE 802.16d that are needed for our scheme followed by the devised integration model. After that the scheduling algorithm that provides QoS guarantee over the WiMAX interface and the corresponding simulation results obtained from the simulator have been proposed.

3.1 System Background

Researchers have paid much attention to the architectures of the integration of heterogeneous wireless networks. Some literature discussed the issue of providing always best connected network among WLANs and WMANs, nonetheless, the architecture needs mobile nodes to be equipped with both MAC and PHY layers of WLAN and WiMAX systems and seamlessly handover scheme between the two. It will make end users'

equipments very complex and expensive. Nadine Akkari et al introduced an inter-Domain Management Module (IDM) responsible of guiding the vertical handovers to the WiMAX network capable of offering the user with the same QoS and context parameters.

The proposed adaptive QoS architecture for PMP 802.16 systems in [28] has given the priorities in a fixed order. Thus the available bandwidth might not be utilized to its extend. The paper [23] analyzed interactions between different protocol layers and among different network entities which are necessary to provide QoS when interworking WLAN and WiMAX networks. The HIPERMAN HIPERLAN2 interworking methods [24] described the Ethernet type of integration between the wirelessMAN/LAN.

The proposed Ethernet bridging mechanism in [25] for the interworking between IEEE 802.16 and IEEE 802.11 fell short of purposing any final architecture which, in the end, could support end-to-end QoS for an application being served over an interworking system between them. The discussed integrated AP method in [26] which combines a WiMAX SS and a WLAN AP has not provided any specific scheduling strategy that should be used to provide QoS guarantee. Providing QoS guarantee for real-time traffic in terms of delay and non-real-time traffic in terms of packet loss is a challenging issue.

The white paper [33] introduced a controlling Access Service Network Gateway (ASN GW) and common authentication, authorization, and accounting (AAA) service functionality to provide service across the WiMAX and WLAN.

3.2 Proposed WLAN and WiMAX Integration Model

From the above discussions, we decided that WLAN and WMAN networks can be integrated by providing proper mapping of traffic classes and integrating connection management signaling. While both WLAN and WiMAX networks aim to providing ubiquitous low cost broadband wireless Internet access, an architecture integrating these two types of networks will be a strong contender for next generation wireless network technology. In this section 3.1, we proposed an integration model for WLAN and WiMAX at the Customer Premises Equipment (CPE). The CPE is the special type of subscriber station with the capabilities of both WLAN and WiMAX radios. In the WLAN environment it acts as an AP.

In WLANs uplink and downlink may share same radio frequency. OFDM modulation or spread-spectrum is used to enable communication among the WLAN enabled devices. The devices in WLANs can be mobile or stationary. WLANs offer high data rates of 54 Mbps within a 100m range mostly used within buildings whereas WiMAX offer high bandwidth up to 70Mbps wireless back haul in a 5 km range generally covering a large outdoor environment. The WiMAX systems can operate in both licensed 10 and 66 GHz and unlicensed 2 and 11 GHz frequency ranges. Integrating the two networks at a CPE will bridge the advantages of both the systems and QoS without additional hardware requirement at end user devices like laptops or WLAN enabled mobile phones. The topology of our proposed network is given in Figure 3.1.

Figure 3.1 Proposed Integration Model of WiMAX and WLAN at the Customer Premises Equipment

Nevertheless providing QoS at such integrated CPEs is a challenging research issue. WiMAX standard incorporates QoS features at the MAC layer while the classical WLAN standard does not have QoS specifications. The 802.11e standard introduces QoS in the WLAN at MAC layer. In order to internetwork WiMAX and WLAN to provide extended broadband coverage, we need to couple the MAC layers of the both protocol stacks such that the end-to-end QoS can be achieved. There is a need for a robust scheduler to handle the MAC Protocol Data Units (MPDUs) arriving at the interface at the CPEs. The issue of providing UL delay bound between the wireless nodes and the AP has been extensively discussed in WLAN research.

3.3 Proposed Mapping Scheme

In this section, we have briefly described the proposed mapping scheme which maps the traffic classes of WLAN with the service classes of WiMAX. Mapping is necessary to provide the end-to-end QoS between the interconnected WLAN and WiMAX networks. As the mapping is done at the MAC level, we need to understand the basic architecture and MAC protocols of WLAN and WiMAX networks.

WiMAX consists of one BS and one or more SS. A BS and one or more SS can form a cell and multiple BSs can form a cellular network with the radius of 2-10km with data rate as more than 70 Mbps. The 802.16d standard enumerates two modes for sharing wireless medium: Point-to-Multi Point (PMP) and mesh network. WiMAX uses a connection-oriented MAC protocol that provides a mechanism for the SSs to request bandwidth from the BS. The QoS for the WiMAX is specified at the MAC layer. In our proposed integration architecture we have used the PMP mode of communication.

The IEEE 802.16d air interface standard specifies (a) convergence sub-layer that classifies network service data units (SDU) and associates them with the proper service flows identified by the connection identifier (CID). (b) MAC Common Part Sub-layer (CPS) that provides system access, bandwidth allocation, connection establishment, and connection maintenance. (c) Security sub-layer that provides subscribers with privacy across the network by encrypting connections between SS and BS. (d) PHY layer that uses OFDM with a 256 point transform. It is designed for both LOS and NLOS operations. In LOS, WiMAX uses a lower level frequency (2 GHz to 11 GHz) which is not easily disrupted by physical obstructions. The LOS connection is stronger and able to send data to a longer range i.e. up to 30miles with fewer errors. In NLOS, a fixed dish

antenna points straight at the WiMAX tower is used. In our simulation we have considered the LOS operations.

The IEEE 802.16d standard lays strong emphasis on QoS and defines four different types of services for different types of traffic flows. Unsolicited Grant Service (UGS) supports constant bit rate traffic. Generally, a fixed amount of bandwidth is allotted for this service so as to minimize delay. Real-time Polling Service (rtPS) supports variable bit rate real-time traffic. Uplink bandwidth allocation is based on a polling scheme. The BS implicitly polls each SS and the SS replies with a bandwidth request to obtain a grant for the messages that it can transmit. This scheme can guarantee QoS service to meet delay requirements. Non Real-time Polling Service (nrtPS) supports variable bit rate traffic which is delay. It also uses a polled approach like rtPS but does this to ensure there is no packet loss. Best Effort (BE) supports data traffic which does not need any QoS provisioning.

IEEE 802.11e describes Enhanced Distributed Channel Access (EDCA) and Hybrid Coordinator Function Controlled Channel Access (HCCA) schemes that provide QoS over existing Distributed Co-ordination function (DCF) and Point Co-ordination Function (PCF) schemes, respectively. The traffic flows in the EDCA scheme are classified into background traffic (AC_BK), best effort traffic (AC_BE), video traffic (AC_VI) and voice traffic (AC_VO) with the different values of minimum contention window size (CW), maximum contention window (CW) size, and Arbitration Inter-Frame Space (AIFS). As, the HCCA is a contention-free media access mechanism it provides QoS service by using signaling, scheduling and admission control by defining a super-frame containing a contention-free period followed by a contention period. During the

contention-free period, only the nodes which are polled by the AP are eligible to transmit for a burst period assigned by the AP. Here the traffic flows are divided into eight different traffic categories (TCs). TCs are further characterized by traffic specifications (TSPECs).

In our proposed scheme, appropriate mapping of traffic classes and integrating connection management signaling are done by introducing an Integration Management Entity (IME) at the CPE. The IME provides MAC level integration of both networks by mapping traffic categories and performing transparent connection establishment. We map the traffic classes in the following way given in Table 3.1.

TABLE 3.1 Traffic Mapping for WLAN and WiMAX

Access Category For WLAN	Traffic Category For WLAN	Designation	Service Class of WiMAX	Example
AC_BK	TC1, TC2	Background	Best Effort (BE)	Background internet Traffic, HTTP
AC_BE	TC0, TC3	Best Effort	non-real time Polling Service (nrtPS)	FTP
AC_VI	TC4, TC5	Video, VoIP	real-time Polling Service (rtPS)	MPEG, VoIP with silent suppression (VBR traffic)
AC_VO	TC6, TC7	Voice, T1	Unsolicited Grant Service (UGS)	VoIP without silence suppression (CBR Traffic)

The WiMAX protocol demands that every flow is registered at the CPE and BS. The CPE has to send connection establishment request to the BS with traffic FlowSpecs and the BS will provide bandwidth accordingly. The 802.11e TSPECs information such as average MSDU size, average traffic rate, minimum service rate, and delay bound etc., can be mapped on directly to FlowSpecs given by 802.16d. The end-to-end flow establishment is illustrated in Figure 3.2.

- (I.) The node on receiving a new flow request from the upper layers will generate a MAC message (ADD_REQ) for flow establishment. The message will contain the TSPEC of the new flow. The node starts a request timer once the ADD_REQ message is sent over the air interface to the CPE. The duration of the timer should include the maximum time the CPE might take to get a response from the BS.
- (II.) After receiving the request at the MAC layer of the CPE, the IME translates the TSPEC provided by the ADD_REQ into FlowSpec and generates a Dynamic Service Addition Request (DSA-REQ). The CPE also starts a request timer for the response.
- (III.) The BS on receiving the DSA-REQ, based on admission control decisions, sends a DSA-RESP. If the connection is admitted, the BS also sends a Connection identifier (CID) for that flow.
- (IV.) The CPE receives the CID and then informs the WLAN MAC of the flow acceptance which sends an ADD_RESPONSE with traffic stream identifier (TSID) to the subscriber node. The CID and TSID are mapped by the IME.

Figure 3.2 End to End Traffic Flow Establishment

In the following section, we proposed a scheduling strategy to provide end-end delay bound guarantee between CPEs and BS. At the CPEs, the arriving MAC protocol data units (MPDU) from the WLAN nodes are mapped to the service types shown in Table 3.1 and queued up into UGS, rtPS, nrtPS and BE queues. Out of these service classes, voice, video and FTP traffic need different kinds of QoS requirements. While voice has a very constrained delay parameter, video has a slightly flexible delay parameter whereas data transfer like FTP needs assured data transfer without losing data. In the following section, we present the BS assisted scheduling algorithm that will consider UGS, rtPS and nrtPS traffic queues and provide delay bound for rtPS connections while guaranteeing no data loss for nrtPS traffic.

3.4 Proposed Scheduling Algorithm

Meeting QoS requirement in wireless networks is an end-to-end problem. However most of the researchers address QoS from the provider's point of view and analyze network performance, failing to comprehensively address the QoS needs of applications. In order to provide end-to-end QoS, we consider a PMP WiMAX network where users application traffic is kept within a sector i.e. data traffic from a CPE is routed to another CPE within the sector through a BS. Every CPE generates an aggregate bandwidth request equal to the sum of average data rates of each flow which is provided by the TSPEC given in Equation (3.1) and sends it to the BS when polled. This aggregation of bandwidth is done for each individual SS which is in the same network. Equation (3.1) provides the total requested bandwidth by a particular SS.

$$B_{req}^{tot} = \sum_{j=1}^k AR_j^{ugs} + \sum_{j=1}^l AR_j^{rt} + \sum_{j=1}^m AR_j^{nr} \quad (3.1)$$

where k , l , m are the number of UGS, rtPS, nrtPS flows and AR_j^{ugs} , AR_j^{rt} , AR_j^{nr} are the average rate of each flow respectively. If the BS provides bandwidth based on the aggregate bandwidth request of the CPE, some part of the bandwidth is instantly given to the UGS traffic class. Since UGS is CBR traffic, it is served at a fixed rate equal to its average arrival rate. Amount of resources in terms of bytes given to UGS traffic class in each frame is given by,

$$B_{ugs} = \sum_{j=1}^k AR_j^{ugs} * (C_j^t - C_j^{t-1}) \quad (3.2)$$

where C_j^t is the current time and C_j^{t-1} is the last bandwidth allocation time of flow j . The remaining bandwidth is provided to the polling service comprising of rtPS and nrtPS traffic.

$$B_{poll} = B_{grnt} - B_{ugs} \quad (3.3)$$

This bandwidth must be efficiently shared between the rtPS and nrtPS flows such that in the rtPS flow, MPDUs will not cross their delay bound while nrtPS packets will not cross their buffer bound. The bandwidth (in bytes) allotted to the rtPS flows are given in Equation (3.4), and that allotted to non-real-time flows is given in Equation (3.5).

$$B_{tot}^r = B_{poll} * \frac{N^r * \alpha_i}{(N^r * \alpha_i + N^{nr})} \quad (3.4)$$

$$B_{tot}^{nr} = B_{poll} * \frac{N^{nr}}{(N^r * \alpha_i + N^{nr})} = B_{poll} - B_{tot}^r \quad (3.5)$$

where N^r , N^{nr} are the total number of MPDUs in the real-time and non-real-time queues respectively. In [30] α is considered as a ration between the maximum waiting time and of the rtPS and the maximum latency. In our proposed algorithm, α_i is a tuning parameter which varies the bandwidth division among the real-time and non-real-time queues, based on the feedback delay information and the guidance values provided by the BS. If the value of α is high, then more bandwidth will be given to rtPS. This excess bandwidth to the rtPS is borrowed from the nrtPS traffic flows. Thus, the bandwidth to the nrtPS will be reduced. If the α for the current scheduling time is i is lower, then there won't be any changes in the bandwidth allocation. The changes in α occurs only when the real-time traffic starts to drop the packets due to the lower bandwidth. The value of α for the current scheduling time i is chosen adaptively from;

$$\alpha_i = \begin{cases} \alpha_g - 4\delta & D < 0.85D_g \\ \alpha_g - 3\delta & 0.85D_g < D < 0.9D_g \\ \alpha_g - 2\delta & 0.9D_g < D < 0.95D_g \\ \alpha_g - \delta & 0.95D_g < D < D_g \\ \alpha_g & D > D_g \end{cases} \quad (3.6)$$

Here α_g is the upper limit of α provided by the BS. δ is a small step value. D_g is the guidance delay provided by the BS. BS provides an acceptable delay for every traffic flows. D is the feedback delay from the destination station. If the feedback delay D is higher than the acceptable delay D_g , then the value of α_g which is the upper limit of α provided by the BS is used as α_i . If the feedback delay D is lower than the acceptable delay D_g but higher than the $0.95D_g$ then the α_i value is calculated from $\alpha_g - \delta$.

If the feedback delay D is lower than $0.95D_g$ but higher than the $0.9D_g$ then the α_i value is calculated from $\alpha_g - 2\delta$. If the feedback delay D is lower than the $0.9D_g$ but higher than the $0.85D_g$ then the α_i value is calculated from $\alpha_g - 3\delta$. If the feedback delay D is lower than the $0.85D_g$ then the α_i value is calculated from $\alpha_g - 4\delta$. The bandwidth allocation for the rtPS and nrtPS traffic flows is done by applying the calculated α_i value into Equation (3.4) and Equation (3.5).

The reason to use the adaptive algorithm Equation (3.6) is to provide more bandwidth to rtPS flows only when needed. Otherwise, the excess bandwidth can be given to nrtPS flows. Further, in order to prevent nrtPS buffer overflow, a decision to increase α_i in Equation (3.6) has made, only if there is enough space in the nrtPS buffer after uplink scheduling to accommodate the arriving MPDUs in the next frame.

If α needs to be increased, the Equation (3.4) and Equation (3.5) are used to calculate the number of bytes that are going to be transmitted in the nrtPS flows for the

increased value of α . The remaining buffer is calculated in terms of number of MPDUs it can accommodate on an average. If K is the buffer size in bytes that is going to remain unoccupied after scheduling, $m=K/avg_MPDU_size$ will be the number of MPDUs that can be accommodated until the next uplink frame. Then, the probability of m or more arrivals before the next uplink frame is calculated using the Poisson arrival probability $\sum_{k=m}^{\infty} P(k)$. The threshold value P_{th} is the maximum number of MPDUs in the oncoming nrtPS traffic flow. If this probability is less than a threshold value P_{th} , then α is allowed to increase. If the probability is greater than P_{th} , then α used in the previous frame is made use of without any increment.

We have used a two dimensional Markov Chain based analytical model to compute the average delay that can be experienced by an MPDU starting from a source CPE and ending at a destination CPE through the BS. Let (n, m) define the state of the Markov chain just prior to the start of the uplink frame where n is the number of MPDUs in the nrtPS queue and m is the number of MPDUs in the rtPS queue at that instant. The state just prior to the beginning of the next uplink frame can then be found based on the number of rtPS and nrtPS MPDUs' arriving in the intervening frame and the number out of n and m that are transmitted from the respective queues during the uplink period. The respective transition probabilities $p_{ij,kl}$ from state (i, j) to (k, l) can then be calculated depending on the number of MPDUs transmitted in the rtPS and nrtPS queues and the arrival probabilities which can be derived from Poisson Equation (3.7) where $\lambda_{rtps}, \lambda_{nrtps}$ are average arrival rate of rtPS, nrtPS MPDUs and T_f is the frame time.

$$P_n(n) = (\lambda_{rtps} T_f)^n e^{-\lambda_{rtps} T_f} / n!, P_{nr}(m) = (\lambda_{nrtps} T_f)^m e^{-\lambda_{nrtps} T_f} / m! \quad (3.7)$$

These are used to compute the equilibrium state probabilities π_{ij} , $i \leq N$, $j \leq M$. The average queuing delays D_R and D_N in the rtPS and nrtPS queues are then respectively evaluated in Equation (3.9) where $\overline{N_{rtPS}}$, $\overline{N_{nrtPS}}$ are average queue size of real-time and non-real-time flows.

$$\overline{N_{rtPS}} = \sum_{i=0}^N \sum_{j=0}^M i \pi_{ij}, \overline{N_{nrtPS}} = \sum_{i=0}^N \sum_{j=0}^M j \pi_{ij} \quad (3.8)$$

$$D_R = \overline{N_{rtPS}} / \lambda_{rtps}, D_N = \overline{N_{nrtPS}} / \lambda_{nrtps} \quad (3.9)$$

The average access delay can be obtained by dividing it into two parts. The first part arises because a MPDU arriving randomly at a CPE queue will have to wait until the next uplink frame to transmit. This average delay τ_{SS} will be $\tau_{SS} = 0.5(T_U + T_D)$ where T_U and T_D are the respective durations of the uplink and downlink sub-frames. For the second part, the MPDU may be assumed to arrive at the BS at anytime during the uplink sub-frame and will have to wait until the next downlink frame. The corresponding average delay is $\tau_{BS} = 0.5T_U$. Assuming the average access delays to be the same for both real-time and non-real-time flows, the average end-to-end delay $\overline{D_{rt}^{MPDU}}$ ($\overline{D_{nr}^{MPDU}}$) for a rtPS (nrtPS) MPDU will be

$$\overline{D_{rt}^{MPDU}} = D_R + \tau_{SS} + \tau_{BS}, \overline{D_{nr}^{MPDU}} = D_N + \tau_{SS} + \tau_{BS} \quad (3.10)$$

There are two ways of providing assistance to the CPE.

Scenario 1: The BS calculates the average rtPS delay from Equation (3.10) for an initial value of α . Initially the value of α is fixed to 1. Subsequently, the BS calculates the average rtPS delay by increasing α in small step. The process of calculating the rtPS delay is to avoid the rtPS packet loss which occurs when the rtPS is given with lower bandwidth. As the rtPS traffic flows are delay bounded, it start to loose the packets while

delay occurs. This process is repeated until there is no significant decrease in rtPS delay. It has been shown that for a fixed scheduling, increasing α indefinitely will not provide significant decrease in delay. The BS then sends this value of α as α_g and the computed average delay as D_g to the CPE. The CPE uses the adaptive algorithm outlined earlier to allocate the bandwidth to the real-time and non-real-time traffic flows according to the computed α_g and D_g . When rtPS suffers delay, our adaptive algorithm allocates more bandwidth to the rtPS flow by borrowing the bandwidth from nrtPS flow. The value of α_g provides the maximum amount of bandwidth that can be borrowed from the nrtPS flow.

Scenario 2: The BS is provided with a *max_latency* parameter by the FlowSpec for the rtPS flows. The BS first computes the average rtPS MPDU delay by using the analytical model. This computation is done to find the maximum delay that an rtPS flow can take before start dropping the packets. If the computed delay is more than the *max_latency* parameter, the BS increases the value of α and again computes the average delay. At first the α is set to a predefined value. This process is repeated until the BS arrives at a value of α which can provide an average delay shorter than or equal to *max_latency*. If the BS cannot find a value of α that would provide the delay shorter than or equal to *max_latency* after I iterations, the BS stops the computation and sends the current value of α to the CPE for the use in the adaptive scheduling. In this case, the CPE uses *max_latency* as D_g for adaptive scheduling and the BS sends only α_g value.

3.5 Simulation Results of Our Proposed Adaptive Scheduling Scheme

We have simulated a WiMAX PMP scenario with six CPEs and one BS in QualNet simulator. Each CPE supports three incoming (UGS, rtPS, nrtPS) and three outgoing (UGS, rtPS, nrtPS) flows on the WiMAX interface. We used CBR traffic to emulate UGS flows and Poisson traffic to emulate rtPS and nrtPS flows arriving from the WLAN nodes. The total bandwidth on the WiMAX link was set as 30 Mbps. The TDMA frame size was set as 10ms and divided equally for uplink and downlink transmission. We studied the scenarios with different average Poisson traffic data rates for rtPS and nrtPS shown in Table 3.2. The simulations were run for 5, 10, 15 and 20 minutes and the results were averaged. The MPDU sizes were distributed exponentially with average size of 1000bytes. We used fixed data rate of 128Kbps with 300bytes MPDU size for UGS traffic. For the adaptive algorithm in the CPE, we used δ value of 0.25 in Equation (3.6). The maximum buffer limit was set as equal to the maximum queue occupancy for nrtPS data rate=1.3Mbps, rtPS data rate=650Kbps and $\alpha=4$ with fixed scheduling (which is later shown in Figure 3.5). This is reasonable because 1.3Mbps is assumed to be the maximum load on nrtPS queue in the system and the buffer occupancy is less compared to the value obtained for fixed scheduling with $\alpha=2$.

In order to decide whether α should be increased or not, we calculated the remaining queue size in terms of number of MPDUs (m) that can be accommodated as explained in Section 3.2. Then, we computed the probability that there would be greater than m arrivals before the next uplink frame in the nrtPS queue. We increased α if this probability is below 2.75%.

TABLE 3.2 DATA RATES FOR TRAFFIC SCENARIOS

Scenario	Traffic Rates	Scenario	Traffic Rates
A	rtPS-512Kbps nrtPS-256Kbps	G	rtPS-256Kbps nrtPS-512Kbps
B	rtPS-700Kbps nrtPS-350Kbps	H	rtPS-350Kbps nrtPS-700Kbps
C	rtPS-800Kbps nrtPS-400Kbps	I	rtPS-400Kbps nrtPS-800Kbps
D	rtPS-1Mbps nrtPS-500Kbps	J	rtPS-500Kbps nrtPS-1Mbps
E	rtPS- 1.2Mbps nrtPS-600Kbps	K	rtPS-600Kbps nrtPS-1.2Mbps
F	rtPS- 1.3Mbps nrtPS-650Kbps	L	rtPS-650Kbps nrtPS-1.3Mbps

Figure 3.3 Delay Comparison when rtPS Data rate twice that of nrtPS

The simulation results for Scenario 1 where the BS provides a delay guidance and respective α value are provided in figures 3.3, 3.4, 3.5 and 3.6. Figure 3.3 shows the simulation results in terms of average delay obtained for UGS, rtPS, nrtPS. The delay guidance D_g provided by the BS where rtPS data rate was made to be twice as that of nrtPS. It is clear from Figure 3.3 that the scheduler provides minimum delay to UGS since it's given the highest priority. It can be seen that the rtPS delay is close to the guidance delay obtained from the BS. The CPE effectively utilizes the α value obtained from the BS, which analytically computes the best α value to obtain minimum delay, and uses the adaptive scheduling to provide appropriate bandwidth to the rtPS and nrtPS flows so that the rtPS delay can be kept minimum while the nrtPS does not cross its buffer limit.

Figure 3.4 Delay Comparison when nrtPS Data rate twice that of rtPS

Figure 3.4 validates the results when nrtPS data rate is twice as that of rtPS. The inflow into the nrtPS queue is generally more than that of rtPS. Hence, according to the principle of the scheduling algorithm, the CPE tries to prevent the nrtPS queue from overflowing. Hence, it allocates more bandwidth to nrtPS queues resulting in less bandwidth allocation to rtPS. This results in a slight increase in actual rtPS delay and a slight decrease in the actual nrtPS delay shown in Figure 3.4 compared to the previous scenario shown in Figure 3.3. In Figure 3.5 we compared the adaptive scheduling nrtPS buffer occupancy with fixed scheduling nrtPS buffer occupancy given in [30].

Figure 3.5 Maximum Buffer Occupancy of nrtPS Queue when nrtPS Data Rate is Twice that of rtPS

Figure 3.5 shows that at lower data rates, the nrtPS buffer occupancy by our adaptive scheduling algorithm is higher compared to the fixed scheduling proposed in [30]. When the traffic rate increases, the adaptive scheduler reacts to approaching buffer limit and keeps the buffer occupancy below the maximum limit.

Figure 3.6 compares the maximum nrtPS buffer occupancy for both the adaptive and the fixed scheduling schemes when rtPS data rate is twice as that of nrtPS. It is generally not a problem for the scheduler to keep the buffer occupancy below the maximum limit since the inflow of nrtPS MPDUs generally is lower owing to lower data rate as compared with scenario illustrated in Figure 3.5.

Figure 3.6 Maximum Buffer Occupancy of nrtPS Queue when rtPS Data Rate is Twice that of nrtPS

Figure 3.7 shows the adaptive delay, guidance delay and max_latency for rtPS flow in scenario 2, where the BS iteratively calculates value of α that will keep the rtPS delay lower than the specified max_latency parameter. Here the max_latency is provided to the BS by FlowSpec. We set the iteration limit $I=4$. It can be seen from Figure 3.7 that the delay bound can be provided by the adaptive scheduler as rtPS delay is less than the guidance and max_latency values. More simulation results for this scenario is shown in Table 3.3

Figure 3.7 Comparison of Adaptive Delay and Max_Latency

TABLE 3.3 RESULTS FOR SCENARIO 2 COMPARING DIFFERENT TRAFFIC RATES,
MAX_rtPS_DELAY PARAMETER AND THE OBTAINED DELAY VALUES

Traffic	QoS Parameter max_rtPS delay	Guidance Delay provided by BS	Alpha value provided by BS	End-to-End Actual Delay for rtPS flow	max nrtPS buffer occupancy
rtPS 400Kbps nrtPS 800Kbps	11.00	10.83	2	10.10	3301
rtPS 400Kbps nrtPS 800Kbps	10.50	10.32	3	9.90	4205
rtPS 400Kbps nrtPS 800Kbps	10.00	9.99	4	9.82	4914
rtPS 800Kbps nrtPS 400Kbps	11.00	10.93	2	10.00	3565
rtPS 800Kbps nrtPS 400Kbps	10.50	10.32	3	9.90	4076
rtPS 800Kbps nrtPS 400Kbps	10.00	9.58	4	9.80	3197
rtPS 500Kbps nrtPS 1Mbps	12.00	12.01	2	10.40	4371
rtPS 500Kbps nrtPS 1Mbps	11.50	11.02	3	10.25	5682

- 77 -

rtPS 500Kbps nrtPS 1Mbps	11.00	10.70	4	10.10	5165
rtPS 1Mbps nrtPS 500Kbps	12.00	11.85	2	10.2	6526
rtPS 1Mbps nrtPS 500Kbps	11.50	11.17	3	10.11	6526
rtPS 1Mbps nrtPS 500Kbps	11.00	10.17	4	10.04	5717
rtPS 600Kbps nrtPS 1.2Mbps	13.00	12.52	2	11.25	6919
rtPS 600Kbps nrtPS 1.2Mbps	12.00	11.66	3	10.49	9337
rtPS 600Kbps nrtPS 1.2Mbps	11.00	10.83	4	10.20	6985
rtPS 1.2Mbps nrtPS 600Kbps	13.00	12.31	2	10.70	5797
rtPS 1.2Mbps nrtPS 600Kbps	12.00	11.61	3	10.34	5176
rtPS 1.2Mbps nrtPS 600Kbps	11.00	10.71	4	10.32	5176

3.6 Improvised adaptive scheduling algorithm

Our proposed adaptive scheduling algorithm allocates the excess bandwidth when packet loss occurs in the rtPS flow. This excess bandwidth is borrowed from the nrtPS flow. When allocating the excess bandwidth to the rtPS flow, the adaptive algorithm only considers the buffer remaining of the nrtPS flow. The excess bandwidth calculation is explained earlier. When the α value is increased more bandwidth is given to rtPS flow. When the α value is reduced, more bandwidth will be allocated to the nrtPS flow. In our earlier adaptive algorithm, increasing the value of α is done only by considering the buffer remaining in terms of MPDUs. This method of allocating bandwidth may not be sufficient enough to utilize the available bandwidth wisely. So, to solve the above mentioned issue we have considered both the buffer remaining and the actual bandwidth needed to reduce the rtPS delay. Here the actual bandwidth needed is the minimum bandwidth required to reduce the rtPS delay. By calculating this minimum required bandwidth, we can still provide more bandwidth to the nrtPS flow. To calculate the minimum required bandwidth we need to derive the relation between the delay and the bandwidth and relation between α and the bandwidth. then we need to find the relation between α and delay.

The minimum required bandwidth is calculated using the Table 3.3. Our simulation has been done with the buffer size of 10000. Using Table 3.3 we can calculate the remaining buffer which is available for the nrtPS traffic flow.

Relationship between Delay and Bandwidth (Buffer Remaining)

In order to find out the relation between delay and the bandwidth we have used the buffer remaining from Table 3.3. The straight line method has been used to draw the graph between the buffer remaining and the delay as such buffer in the y axis and the delay in the X Axis.

Figure 3.8 Buffer remaining and the Delay

From Figure 3.8, we have derived the relationship between buffer remaining and delay. The relation is as follows;

$$\text{Buffer remaining} = -2366.7 \text{ Delay} + 28811 \quad (3.11)$$

Relationship between Alpha and Delay

Using the straight line method, keep Alpha value at the X axis and Delay in the Y axis I derive the relationship between Delay and Alpha. Figure 3 shows the straight line between Delay and Alpha.

Figure 3.9 Delay and the Alpha value

$$\text{Delay} = -0.14\text{Alpha} + 10.36 \tag{3.12}$$

Relationship between Buffer Remaining and Alpha

Substitute Equation (3.12) in Equation (3.11) we will get the following equation.

- 81 -

$$\text{Buffer remaining} = 327.138\text{Alpha} + 4602 \quad (3.13)$$

$$\text{Alpha} = (\text{Buffer remaining} - 4602) / 327 \quad (3.14)$$

By the simulation we can find out the used buffer value. Total buffer is set to 10000 in the simulation. So, the remaining buffer value is equal to the maximum number of transmittable bits.

Buffer remaining = Total buffer – Used buffer = Maximum number transmittable bits

$$\text{Maximum number of bits transmittable} = \text{actual number of bits transmitted} + \text{buffer remaining} \quad (3.15)$$

Substitute Equation (3.11) in Equation (3.15)

$$\text{Maximum number of bits transmittable} = \text{actual number of bits transmitted} + (-2366.7 \text{ Delay} + 28811) \quad (3.16)$$

Actual number of bits transmitted can be calculated using Poisson arrival.

$$\text{Actual number of bits Transmitted} = \sum_{i=1}^N Xi \approx \text{Pois} \left(\sum_{i=1}^N \lambda_i = \left(\frac{\lambda^K \exp(-\lambda)}{K!} \right) \right) \quad (3.17)$$

- 82 -

Where $K = 0, 1, 2, \dots$

Substitute Equation (3.17) in Equation (3.16)

$$\begin{aligned} \text{Maximum number of bits transmittable} &= \\ \text{Actual number of bits Transmitted} &= \sum_{i=1}^N X_i \approx \text{Pois} \left(\sum_{i=1}^N \lambda_i = \left(\frac{\lambda^K \exp(-\lambda)}{K!} \right) \right) + \\ \text{Bandwidth remaining} & \quad (3.18) \end{aligned}$$

Substitute Equation (3.11) in Equation (3.18)

$$\begin{aligned} \text{Maximum number of bits transmittable} &= \\ \text{Actual number of bits Transmitted} &= \sum_{i=1}^N X_i \approx \text{Pois} \left(\sum_{i=1}^N \lambda_i = \left(\frac{\lambda^K \exp(-\lambda)}{K!} \right) \right) + (- \\ 2366.7 \text{ Delay} + 28811) & \quad (3.19) \end{aligned}$$

Relationship between Delay and Alpha

Substitute Equation (3.11) in Equation (3.14)

$$\text{Alpha} = ((-2366.7 \text{ Delay} + 28811) - 4602) / 327 \quad (3.20)$$

$$\text{Delay} = (327 \text{ Alpha} - 24209) / -2336.7 \quad (3.21)$$

Substitute Equation (3.21) in Equation (3.20)

Maximum number of bits transmittable

$$\begin{aligned} \text{Maximum number of bits transmittable} &= \\ \text{Actual number of bits Transmitted} &= \sum_{i=1}^N X_i \approx \text{Pois}\left(\sum_{i=1}^N \lambda_i = \left(\frac{\lambda^K \exp(-\lambda)}{K!}\right)\right) + (- \\ 2366.7((327 \text{ Alpha} - 24209) / -2336.7) + 28811) & \quad (11) \end{aligned}$$

By using the above equations we would be able to find the actual amount of bandwidth needed to satisfy the rtPS delay. Thus we can borrow only the actual amount of bandwidth needed from the nrtPS bandwidth. Thus nrtPS may get the excess bandwidth.

α_i value is calculated using the following equation:

$$\alpha_i = \begin{cases} \alpha_g - 4\delta & D < 0.85D_g \\ \alpha_g - 3\delta & 0.85D_g < D < 0.9D_g \\ \alpha_g - 2\delta & 0.9D_g < D < 0.95D_g \\ \alpha_g - \delta & 0.95D_g < D < D_g \\ \alpha_g & D > D_g \end{cases} \quad (3.6)$$

If α_i value is same as the Alpha Actual then the base station will use the Alpha Actual value as the new Alpha value.

If α_i value is greater than the Alpha Actual then the value of Alpha Actual is used as the new Alpha Value.

If α_i is less than the Alpha Actual then value of α_i is used as the new Alpha Value.

By applying these equations we maximize the bandwidth utilization.

In this chapter, we have provided traffic mapping and signaling details of connection establishment to integrate WLAN-WiMAX. The introduced IME will be implemented in the CPE to map the diverse traffic categories at the CPE. Furthermore to provide QoS guarantee in terms of delay bound for real-time traffic and buffer bound for non-real-time traffic over the WiMAX access channel, a BS assisted adaptive scheduling algorithm has been established. Chapter 3 concludes with the extensive simulations that shows QoS can be provided for real-time and non-real-time traffic over the integrated network through our proposed algorithm.

Chapter 4

QoS Scheduling in Group Mobility Scenario with Centralized Control

Group mobility with centralized control is widely prevalent in military networks and vehicular networks. In the battle field the information such as just-in-time logistics, teleconferencing, telemedicine and multimedia applications requires different priorities and QoS. Providing QoS for such application is often complex since the wireless channel is subject to fading and erasures. Furthermore, the network needs to be able to provide priority services to messages based on their criticality. There have been various researches done to address these problems. Some work proposed group mobility scenarios in Adhoc networks using Wi-Fi. Nevertheless these networks would not be appropriate to the military operations due to limited range, complex architecture and low power. The IEEE 802.16e broadband wireless access system is a viable alternative that can meet such requirements. The deployment of IEEE 802.16 wireless broadband network standard provides the following benefits; fast deployment, high speed wireless connectivity, and low cost. Moreover the IEEE 802.16e provides a robust PHY and MAC specifications for high data rate mobile communication. However, the issue of group mobility in mobile WiMAX networks has not been explored so far. Even though IEEE 802.16e provides

signaling mechanism it does not specify any scheduling or admission control algorithms that ultimately provide QoS support.

In this chapter, we have proposed a scheduling algorithm that offers robust communication and QoS for real-time traffic among a group of mobile nodes centrally controlled by a mobile BS is provided. The basic descriptions of 802.16e MAC Layer are also given. Then the chapter concludes with the corresponding simulation results.

Group mobility is a widespread scenario in military and emergency search / rescue operations, where hosts move in groups, generally in a same direction and separated only by a short distance. A reliable centralized communication control is preferred over distributed ad hoc communication topology which is subjected to frequent disconnections. For example, the communication between a battalion of tanks can be aerially controlled by an Unmanned Aerial Vehicle (UAV). The robust PHY and MAC layers of WiMAX networks will be ideal for such a scenario, which is also backed up by the long communication range offered. The topology of such a network is shown in Figure 4.1. Here the individual vehicles carry Mobile Station (MS) equipment onboard while the central controller in UAV carries an IEEE 802.16e BS.

Figure 4.1 Group Mobility with PMP Communication in military network

Considering the military operations, in the battle field leverage information superiority such as just-in-time logistics, teleconferencing, telemedicine and multimedia applications require enormous improvements in terms of higher bandwidth, connection to a high speed backbone and QoS support. There can be multiple traffic flows among MSs. The priority of the traffic flows may vary depend on the user requirements. There can be high priority delay intolerant voice traffic and low priority background data traffic, for example to exchange sensor information like temperature, pressure etc. These multiple traffic streams with different priorities between the MSs require different QoS provisioning. While real-time traffic needs hard dead-line on end-to-end delay, data traffic is more delay tolerant, however preferring loss less data transfer.

There are many broadband wireless technology standards with QoS support available, including IEEE 802.11e and IEEE 802.16. Though 802.11e WLAN standard supports QoS with 54Mbps data rate, it is often confined to limited range. Broadband wireless standard IEEE 802.16 [9] technology is specified to provide a robust last mile fixed broadband access. It provides extensive details for the PHY and MAC layers. The updated standard IEEE 802.16e standard supports mobile broad band with a central BS.

IEEE 802.16e is aimed at providing ubiquitous wireless broadband connectivity to both stationary and mobile devices, supporting data rates of up to 15 Mbps with the base station coverage of 2-7Km. It also provides mesh networking by interconnecting various MSs and BSs. Both standards [9] and [11] lay strong emphasis on QoS and define different traffic classes with separate QoS specifications for various types of multimedia traffic. Though the mobility of the BS is not mentioned in the latest standard [11], the BS can be considered as a mobile node with no functional change in its operation. In a group mobility scenario, the BS and the MSs continue behaving the same way specified by the IEEE 802.16e [11] standard as long as they are within the communication range of each other.

4.1 System Background

Researchers in [42] also support the use of IEEE 802.16 series of standards for military purposes due to its inherent robust PHY and MAC layers and QoS support. The MSs communicate with each other through the central BS, which tries to align itself such that it is within the communication range of all the MSs on the ground. It should be noted that the MSs can move at random and still be communicating with other MSs through the BS until as long as they remain within the communication range of the BS. The MS and the BS are time synchronized using various methods such as provided by [38]. The authors in [38] provided a synchronization scheme for time and carrier frequency in 802.16e network. They have shown that their synchronization scheme is suitable in multi-path as well as multi-cell environments.

Previously, many researchers have studied the mobility in ad-hoc networks, primarily based on IEEE 802.11 WLAN standard. The work [10] described the

implementation of wireless mobile ad-hoc network with Wi-Fi radio nodes mounted at fixed sites, on ground vehicles, and in small UAVs. The UAV acts as a mobile node that enables communication among ground radios. However, such networks have limited range due to low power operation of Wi-Fi unlike WiMAX. Some researchers have also studied vehicle to vehicle communication using 802.16e based OFDMA Scheme. The authors in [35] have done a performance evaluation over non-stationary vehicle to vehicle models. Even though vehicle to vehicle communication has many applications, the 802.16e is more suited in PMP mode and group mobility with centralized control can derive advantages from the mobility scheme proposed by IEEE 802.16e standard.

Group mobility models have been proposed and analyzed in general by many researchers [36, 37]. In the real world, group mobility refers to the group movement behaviors, for instance, the movement of a group of vehicles. Even though the vehicles in a group are likely to have similar movement tracks, the individual vehicles in a group tend to have relative mobility. The mobility vector of a mobile node can be considered as the sum of the group mobility vector shared by the members of a group, and the internal mobility vector which is the relative mobility of an individual node in the group. The mobility of a node is decided by the vector sum of the two mobility vectors and the group boundary. We have used a group mobility model available in QualNet in which the two mobility vectors are independently simulated by a random way point model.

The authors in [40] analyzed the MAC performance in a traditional cellular environment. Many researchers have developed scheduling algorithms on bandwidth allocation to improve IEEE 802.16 standard. An overview of scheduling algorithms in IEEE 802.16 networks is given in [39]. The authors in [41] developed a radio resource

sharing algorithm for QoS provisioning where both time and frequency slots are shared by users on the up-link and down-link.

A voice-activity based scheduling algorithm for VoIP flows in a WiMAX network is presented in [43]. The authors have considered only an independent VoIP flow. A scheduling algorithm for real-time video applications is proposed in [44]. The scheme only considered the video traffic. It didn't have an OFDMA scheduler and considered only uplink traffic. The authors in [29, 30] proposed queue based scheduling schemes to be implemented at the MAC layer to provide resource allocation for different multimedia traffic. However, in a group mobility scenario, when a vehicle, a MS, moves away from the BS, the signal to noise ratio between the MS and the BS will decrease as the channel quality degrades. This causes the WiMAX MAC layer to change the Modulation Coding Scheme (MCS) adaptively [40] to keep the same Bit Error Rate (BER) as before, thus reducing the bandwidth available to the MS which is moving away. The reduction in the available bandwidth will affect the real-time traffic and as a result, the MS might start dropping the MAC Protocol Data Units (MPDUs). The non-real-time traffic is more tolerant to delay and the mobile node will start dropping MPDUs only if its buffer is exceeded. In this chapter, we provide a MAC scheduling scheme that will adaptively allocate the available bandwidth between real-time and non-real-time flows such that even when the MCS is changed to have a lower throughput for a MS on the uplink, the real-time traffic is given enough bandwidth to meet its delay requirements till the non-real-time traffic starts to incur data-loss. To the best of our knowledge, this is the first time the issue of group mobility in WiMAX networks has been investigated and the corresponding solution for QoS provisioning has been proposed.

We consider a PMP group mobility scenario consisting of many MSs which communicate among each other under the control of a central BS using the IEEE 802.16e PHY and MAC specifications. Each MS has its own internal mobility vector while the entire group shares a group mobility vector as specified earlier. The data traffic from a MS will be routed to another MS within the same group through the BS. The IEEE 802.16e has emphasized on QoS framework though it does not specify any QoS scheduling scheme for real-time and non-real-time traffic. The IEEE 802.16e MAC layer protocol classifies external network Service Data Units (SDU) and associates them with the proper service flow identified by the Connection Identifier (CID). The MAC protocol provides system access, bandwidth allocation, connection establishment, and connection maintenance. The system also uses an adaptive modulation and coding scheme which can be changed based on the feedback Carrier to Interference plus Noise Ratio (CINR).

The IEEE 802.16e standard lays strong emphasis on the QoS framework and defines five different types of services for different types of traffic flows as listed below. Unsolicited Grant Service (UGS) supports constant bit rate traffic. Generally, a fixed amount of bandwidth is allotted for this type of traffic so as to minimize delay. Real-time Polling Service (rtPS) supports variable bit rate real-time traffic. Uplink bandwidth allocation is based on a polling scheme. The BS implicitly polls each MS and the MS replies with a bandwidth request to obtain a grant for the messages that it can transmit. This scheme can guarantee QoS service to meet delay requirements. Extended Real-time Polling Service (ertPS) is specially created to support VoIP traffic. The BS will be informed about the voice activity periods, during which it will allocate bandwidth to enable the traffic flow. Non Real-time Polling Service (nrtPS) supports variable bit rate traffic that is delay tolerant. It uses a polled approach like rtPS but this is done to ensure that there is no packet loss. Best Effort (BE) supports data traffic that does not need any QoS provisioning.

The 802.16e standard specifies a TDMA based frame format for communication. The frame is divided into UL subframe and DL subframe, which contains a frame control section having DL-MAP and UL-MAP as shown in Figure 4.2. The frame control section of the DL subframe will be received by all the MSs. The DL_MAP field in the frame control section specifies the location and duration of DL data burst in the frame for a particular MS. Similarly, a UL_MAP field specifies the location and number of time slots allotted for a particular MS to transmit its data on the UL in the next frame. Hence, all MSs listen to the frame control section in the DL frame, and receive / transmit data during the time slots designated to them by the BS. The frame control section is followed by the actual DL transmission bursts to different mobile stations. The transceiver at the BS switches to the receiver mode during the small Transmit Receive Gap (TRG) time. Then the BS receives data bursts from the mobile stations during the UL frame.

Figure 4.2 IEEE 802.16 Frame Structure

At any MS, when a new MPDU arrives from the upper layer that does not belong to the currently existing flows, it will be classified into one of the scheduling services and a new connection is created. In a polling scheme, the BS periodically polls every MS

which will send its bandwidth request for real-time traffic during the time slot allotted to it. The BS schedules each MS based on the aggregate bandwidth required by all the connections within the MS. The BS also provides all MSs with basic, primary and secondary management connections to send and receive MAC control messages and QoS information.

4.2 Proposed Scheduling Algorithm

In this section, we propose a scheduling algorithm that will be implemented at the MS. The algorithm considers the queue sizes of the real-time and non-real-time queues as well as the delay requirements of the real-time connections to allocate the UL bandwidth. We consider only real-time and non-real-time polling services for the scheduling. When polled by the BS, every MS generates an aggregate bandwidth request equivalent to the sum of average data rates of each connection within the MS.

$$B_{req}^{tot} = \sum_{j=1}^l AR_j^{rt} + \sum_{j=1}^m AR_j^{nr} \quad (4.1)$$

where l , m are the number of rtPS, nrtPS flows and AR_j^{rt} , AR_j^{nr} are the average rates of each flow respectively. The BS provides bandwidth to each MS based on the aggregate bandwidth request of the MS.

As each MS can randomly move within the group boundary and MSs on a whole are able to move farther away from the BS, their signal to noise ratios could decrease, as a result, the MCS has to be changed to maintain a constant bit error rate. The change in MCS leads to lower bandwidth availability to each MS on the UL and hence, directly affects the performance of the network. The increase on the delay may not be tolerable by the real-time traffic. Therefore, the available bandwidth must be efficiently shared

between the rtPS and nrtPS flows such that in the rtPS flow, MPDUs will not be transmitted beyond their delay bound. However, it also should not starve the transmission of the non-real-time traffic leading to buffer overflow. To achieve this, we enhance the adaptive queue aware scheduling algorithm outlined in [40] with consideration of the changes that the MCS undergo. Let N^r be the real-time queue size within a MS and N^{nr} the queue size of the non-real-time queue at the beginning of a UL frame. The bandwidth allotted to the rtPS flow in bytes can be given by Equation (4.2), and that allotted to non-real-time flows can be given by Equation (4.3).

$$B_{tot}^r = B_{poll} * \frac{N^r * \alpha_i}{(N^r * \alpha_i + N^{nr})} \quad (4.2)$$

$$B_{tot}^{nr} = B_{poll} * \frac{N^{nr}}{(N^r * \alpha_i + N^{nr})} = B_{poll} - B_{tot}^r \quad (4.3)$$

where B_{poll} (in bytes) is the bandwidth allotted by the BS to the polling service including real-time and non-real-time polling services at the beginning of frame i . α_i is a tuning parameter which varies the bandwidth division among the real-time and non-real-time queues based on the feedback delay information and the guidance values provided by the BS. By increasing α_i , more bandwidth can be allotted to the real-time flows that are borrowed from the non-real-time flows, thus reducing the delay of real-time traffic. We assume that the increase in real-time traffic delay is caused by the changes in MCS. If the MCS is changed back to provide higher data transmission rate to the polling services, the delay decreases, and we adaptively decrease α_i based on the delay thresholds given in Equation (4.4).

$$\alpha_i = \begin{cases} \alpha_0 - 4\delta & D_f < 0.85D_{\max_rt} \\ \alpha_0 - 3\delta & 0.85D_{\max_rt} < D_f < 0.9D_{\max_rt} \\ \alpha_0 - 2\delta & 0.9D_{\max_rt} < D_f < 0.95D_{\max_rt} \\ \alpha_0 - \delta & 0.95D_{\max_rt} < D_f < D_{\max_rt} \\ \alpha_0 & D_f > D_{\max_rt} \end{cases} \quad (4.4)$$

where $D_{\max_rt}$ is the delay specification of the real-time flow, D_f is the feedback delay from the destination and α_0 is the upper limit of α . We noticed in [30] that in such an algorithm, increasing α beyond a certain value will not have any significant improvement over the delay performance of the real-time traffic. δ is a small step value. The reason to use the Equation (2, 3) is to provide more bandwidth to rtPS flows only when needed. Otherwise, the bandwidth can be shared between the real-time and non-real-time flows based on their queue sizes. In addition, to prevent nrtPS buffer overflow, a decision to increase α in Equation (4.4) has been made. It is only if there is enough space in the nrtPS buffer after UL scheduling to accommodate the arriving MPDUs in the next frame. If α needs to be increased, the Equation (4.2) and Equation (4.3) are used to calculate the number of bytes that are going to be transmitted in the nrtPS flows for the increased value of α . The remaining buffer is calculated in terms of number of MPDUs it can accommodate on average. If K is the buffer size in bytes that is going to remain unoccupied after scheduling, $m=K/avg_MPDU_size$ will be the number of MPDUs that can be accommodated till the next UL sub-frame.

Then, the probability of m or more arrivals before the next UL sub-frame is calculated using the Poisson arrival probability $\sum_{k=m}^{\infty} P(k)$. If the probability is less than a threshold value P_{th} , then α is allowed to increase. If this probability is greater than P_{th} , then the value of α used in the previous up-link frame is retained without any change.

This scheduling process is repeated for every uplink frame by the scheduler, at each of the MSs.

The delay feedback needed for the proposed adaptive approach should come from the application layer of the destination MS. The destination MS's application layer must be able to give a feedback of delay incurred by the data packets to its MAC layer. The MAC layer should report the end-to-end delay encountered by the real-time traffic to the BS. One way of sending delay feedback is through the primary management connection provided to each MS. The packets sent from the source MS will carry a time stamp. The receiver at the other end will calculate the time delay using the time stamp information and current network time and report the delay to the MAC layer. This is possible since the MSs and BS can be time synchronized using schemes such as [38]. At the MAC layer, the delay information is mapped to the received CID and will be attached to a Dynamic Service Change (DSC) message as shown in the Figure 4.4.

This DSC message will then be sent to the BS over the primary management connection as described in [13]. At the BS, the CID is mapped to the source CID and the DSC message is forwarded to the source through the primary management connection of the source. We can utilize this delay feedback mechanism to modify the value of α in the current frame. The value of α for the current UL subframe time i is chosen adaptively from Equation (4.4).

4.3 Simulation Results

We have simulated a WiMAX PMP group mobility scenario with six MSs and one BS in a group using QualNet simulator. The group mobility scenario property assigned a common group mobility vector and internal mobility vector to each of the MS in the group. The MS was then bounded to the group boundary where it was still able to communicate with the BS. At the boundary, the CINR was equal to the lowest threshold.

Figure 4.3 Group Mobility Simulation

The MCS schemes used are given in Table 4.1. Each MS supported incoming real-time and non-real-time traffic and outgoing real-time and non-real-time traffic flows on the IEEE 802.16e interface. We used Poisson traffic to emulate rtPS and nrtPS flows to and from the MSs. The highest data rate on the WiMAX link was set as 30 Mbps where 2 Mbps was allocated for MAC management connections. The mobility parameters for the

nodes are given in Table 4.2. The TDMA frame size was set as 20ms and divided equally for UL and DL transmissions. We studied the scenarios with different average Poisson traffic data rates for rtPS and nrtPS traffic flows as shown in Table 4.3. For our simulation we have considered only one group with 6 MSs and BS

Figure 4.4 Delay FeedBack in IEEE 802.16 PMP Systems

TABLE 4.1 CINR FEEDBACK Vs MCS

CINR THRESHOLD (dB)	MCS
30	5/6 64-QAM
25	4/5 64-QAM
20	3/4 64-QAM
15	2/3 64-QAM
10	1/2 64-QAM

TABLE 4.2 MOBILITY PARAMETERS

Mobility Parameters	Values
Group pause	10s
Group maximum speed (mps)	10mps
Group minimum speed (mps)	2mps
Group internal pause	1s
Group internal minimum speed (mps)	5mps
Group internal maximum speed (mps)	5mps

TABLE 4.3 TRAFFIC PARAMETERS FOR SIMULATION

System Traffic Intensity	Average Data Rate of rtPS (Poisson arrival)	Average Data Rate of nrtPS (Poisson arrival)
0.33	512Kbps	256Kbps
0.45	700Kbps	350Kbps
0.51	800Kbps	400Kbps
0.64	1.0Mbps	500Kbps
0.77	1.2Mbps	600Kbps
0.83	1.3Mbps	650Kbps
0.89	1.4Mbps	700Kbps

The MPDU sizes were distributed exponentially with an average size of 1000 bytes. We obtained the end-to-end delay incurred. The simulation was run for 5mins, 10mins and 15mins and averaged over these readings.

We have compared the delays incurred by real-time and non-real-time traffic flows for three different scenarios (a) when nodes were stationary without scheduling scheme is employed (b) when nodes were mobile without adaptive scheme applied, i.e. the real-time flow uses its allotted bandwidth while the non-real-time flow uses its bandwidth allotted by the BS without any scheduling at the MS (c) when nodes were mobile with the adaptive scheme described above is being employed. For our adaptive algorithm in the MS, we used δ value of 0.25 in Equation (4.4). The maximum buffer limit was set as equal to the maximum queue occupancy for nrtPS in scenario (a).

Figure 4.5 shows the average delay for real-time and non-real-time flows obtained in the different scenarios. These delays were computed by averaging the delays of each real-time and non-real-time flow in the network. It can be seen that the scenario (a) with stationary nodes has the lowest real-time and non-real-time delay. When the nodes are mobile in the group mobility scenario (b), the delays of real-time and non-real-time traffic increase due to the adaptive changes in the MCS. By using the proposed adaptive strategy, it is shown that the real-time delay can be reduced at the expense of non-real-time delay, which has increased marginally. However, the non-real-time buffer occupancy would be controlled by the adaptive scheme outlined in section 4.2.

Figure 4.5 Comparison of Average End to End Delays when rtPS Data Rate Twice that of nrtPS Data Rate

The maximum buffer occupancy of the non-real-time traffic is compared for the three scenarios in Figure 4.6. From scenario (a), it can be seen that even for higher traffic intensities, the non-real-time buffer is under the control and does not increase beyond the buffer limit that is set to the maximum buffer size.

Figure 4.6 Comparison of maximum buffer occupancy for non-real-time traffic when
rtPS Data Rate Twice that of nrtPS Data Rate

TABLE 4.4 TRAFFIC PARAMETERS FOR SIMULATION – nrtPS DATA RATE TWICE THAT OF rtPS DATA RATE

System Traffic Intensity	Average Data Rate of rtPS (Poisson arrival)	Average Data Rate of nrtPS (Poisson arrival)
0.33	256Kbps	512Kbps
0.45	350Kbps	700Kbps
0.51	400Kbps	800Kbps
0.64	500Kbps	1.0Mbps
0.77	600Kbps	1.2Mbps
0.83	650Kbps	1.3Mbps
0.89	700Kbps	1.4Mbps

We have also analyzed the three scenarios using the rtPS and nrtPS data rates in Table 4.4. Now the nrtPS data rate is twice that of the rtPS data rate.

The comparison of the average end-to-end delays, when the non-real-time traffic rate is twice the real-time data rate as shown in Figure 4.7, can be seen that the higher data rate of nrtPS pushes up the rtPS delay slightly at higher traffic intensities compared to Figure 4.4, when nrtPS data rate is less than rtPS data rate.

Figure 4.7 Comparison of Average End to End Delays when nrtPS Data Rate Twice that of rtPS Data Rate

The maximum buffer occupancies of the three scenarios are compared in Figure 4.8. Since the data rate of non-real-time traffic is higher, the buffer occupancy in Figure 4.8 is higher than that in Figure 4.5 as expected. It can be seen that the non-real-time buffer occupancy is kept within the buffer limit in Figure 4.8 and the real-time delay is reduced considerably, in comparison to the non adaptive scheme as shown in Figure 4.7. This proves the effectiveness of the algorithm for different relative traffic rates of real-time and non-real time traffic.

Figure 4.8 Comparison of maximum buffer occupancy for non-real-time traffic when nrtPS Data Rate Twice that of rtPS Data Rate

We have also studied the throughput of the real-time and non-real time flows with the traffic parameters in Table 4.3. Generally, the rtPS flow is found to have a better throughput than the nrtPS flow as shown in Figure 4.9.

Figure 4.9 Comparison of Throughput for rtPS and nrtPS traffic when rtPS Data Rate is Twice that of nrtPS

We have also analyzed another scenario where the feedback delay provided by the destination to the source node carries a time-stamp. The MAC layer of the destination node puts time-stamp in the feedback MPDU which carries the delay information of the received packet. The source node reads the feedback information and also calculates the delay incurred by the feedback MPDU which provides it a round-trip delay. The source node can then use the average delay of these two delays to change the value of α in Equation (4.4).

This two way feedback scheme would enable the source to judge the channel conditions better and choose an appropriate value of α based on the delay information to and from the destination. However, it will increase the overhead in the network and

increase computation time at the MS. Hence, in order to mitigate the effect of overheads, we made the feedback information to be returned every 10th MPDU received by the destination from the same source.

Figure 4.10 Comparison of Delay Performance of One-way and Two-way Delay Feedback Schemes

The average delays of real-time and non-real-time traffic flows obtained from the simulations are shown and compared with that of the original feed-back scheme in Figure 4.10. This scheme is found to perform moderately poorer than the single delay feedback scheme whose result is shown in Figure 4.5 since the two-way feedback scheme increases the rtPS delay slightly.

In this chapter 4 we have analyzed the group mobility scenarios in military and search / rescue operation. We also discussed about the importance of various traffic flows

- 108 -

and their priorities and QoS requirements, followed by the diverse approach to address these problems. Further more a brief over view on the wireless metropolitan area network (WiMAX) IEEE 802.16e standard has given. We have provided the proposed adaptive scheduling algorithm that provides QoS for real-time traffic flow in terms of delay bound in the group mobility scenarios. The chapter comes to the end with the simulation results done in QualNet.

Chapter 5

5.1 Conclusion

In this thesis, we propose an integration model for the integration of WLAN-WiMAX technologies and an adaptive scheduling algorithm for group mobility scenario using WiMAX. The Thesis starts with introducing the objectives of our research work and motivation behind it. Chapter 2 gives a brief description about the WLAN and WiMAX standards. It also explains the various research works done by researchers to address the heterogeneous issues and the diverse algorithm to provide end-to-end QoS for the user applications.

In chapter 3 we have proposed a WLAN-WiMAX integration model by introducing an IME, which maps the different traffic categories at the CPE. We have provided the traffic mapping and the signaling details of connection establishment to integrate the two technologies. As our proposed integration model is using the traffic mapping to integrate WLAN and WiMAX, the existing user devices such as PDA, mobile phone and laptop do not require any hardware changes. Thus, the key advantage of our proposal is that the integration of the two networks does not require any modification to the existing user devices. Previously proposed algorithms by various researchers could only provide QoS guarantee for either the real-time or the non-real-time traffic flows. Nevertheless these algorithms have fixed schemes to allocate bandwidth between real-time and non-real-time, whereas in wireless networks the wireless medium tends to get

affected by the fading and packet erasures. So these algorithms might not be appropriate to wireless networks. In our Thesis we have proposed a BS assisted adaptive scheduling algorithm to be implemented at the CPE, which can provide QoS guarantee in terms of delay bound for real-time traffic and buffer bound for non-real-time traffic over the WiMAX access channel. The BS employs an analytical model to provide a delay guideline for real-time traffic used by the CPE to perform adaptive scheduling. By the proposed adaptive scheduling algorithm, the bandwidth allocation between real-time and non-real-time can be allocated dynamically. This will improve the performance of wireless network by utilizing the entire available wireless network resources. We have applied the algorithm into a scenario, where the traffic specifies a maximum delay parameter, as well as a scenario, where there is no such specification provided but the real-time delay is required to be least possible. The performance of the scheduler is studied through extensive simulations for both scenarios. It is shown that QoS can be provided for real-time and non-real-time traffic over the integrated network.

In chapter 4 we have explored the issue of group mobility with QoS support under the mobility framework specified by the IEEE 802.16e. Group mobility is an important scenario in military and emergency search / rescue missions. The traffic flows between base station and the mobile station in such scenarios have different priorities with diverse QoS requirements. Providing QoS guarantee in such scenarios is a very difficult issue. In this Thesis we have devised an adaptive strategy to provide better QoS to real-time traffic flows in the mobile WiMAX networks. The available bandwidth to an MS will be reduced when it moves away from the BS due to the changes in adaptive MCS. The proposed adaptive scheduling scheme, however, provides additional bandwidth to the real-time traffic flows by borrowing the bandwidth from the non-real-time flows when the former experiences increasing delay. The buffers of non-real-time traffic flows can also

be controlled at the same time, keeping the non-real-time queue size within the maximum buffer limit even at substantially heavy traffic intensities, by limiting the provision of excessive bandwidth to the real-time traffic flows. Also, the performance of the scheduler has been thoroughly studied via extensive simulations using QualNet simulator to prove the effectiveness of our proposed scheme.

5.2 Future recommendations

The 4G drafts recommend the integration of wireless technologies like WLAN, WiMAX and 3G cellular. In our Thesis we have proposed an integration model to integrate WLAN-WiMAX technologies. We also proposed an adaptive scheduling algorithm to provide end-to-end QoS for the real-time and non-real-time traffic flows. In the future, the WLAN-3G cellular networks or the WiMAX-3G cellular networks can be integrated using a proper integration model without compromising the end-to-end QoS.

In the proposed integration model for WLAN-WiMAX technologies we have only considered the UGS, rtPS, nrtPS traffic flows. We did not consider the Best Effort service defined by WiMAX MAC layer. However, the proposed algorithm could be extended to provide QoS guarantee for the Best Effort service.

We have also proposed an adaptive scheduling algorithm to provide QoS guarantee for the traffic flows in the mobile WiMAX. We only considered the rtPS and nrtPS traffic flows for the QoS guarantee. In the near future, the algorithm could be extended to provide QoS for the UGS and the Best Effort traffic flows.

Publications

Published

G. A. Prasath, C. P. Fu, and M. Ma, "QoS scheduling for group mobility in WiMAX," in 11th IEEE Singapore International Conference on Communication Systems , ICCS 2008, Guangzhou, China, 2008, pp. 1663-1667

Submitted

G. Arul Prasath (corresponding author), Cheng Peng Fu, Maode Ma, K.R. Raghu, "Integration at the Customer Premises Equipment (CPE); WLAN and WiMAX" submitted to The Institution of Engineering and Technology Communications Journal.

G. Arul Prasath (corresponding author), Cheng Peng Fu, Maode Ma, K.R. Raghu, "QoS Scheduling in Group Mobility Scenario with Centralized Control" submitted to Computer Communication Journal.

Bibliography

- [1] S. Frattasi, H. Fathi, F. H. P. Fitzek, R. Prasad, and M. D. Katz, "Defining 4G technology from the user's perspective," *IEEE Network*, vol. 20, pp. 35-41, 2006.
- [2] K. M. Rubaiyat, [Online], Available:
<http://www.ee.usyd.edu.au/~rkibria/Research.htm>. The University of Sydney, Sydney, [Accessed: 10 July 2008], [Cited:10 July,2008]
- [3] T. Braun, C. Castelluccia, G. Stattenberger, and I. Aad, "An analysis of the DiffServ approach in mobile environments," in *IQWiM-Workshop*, Germany, 1999.
- [4] A. E. P. Goulart, "Achieving end-to-end QoS through the application of an Internet resource management model to 4G systems," in *The Path to 4G Mobile workshop*, Helsinki, Finland, Sep. 2001.
- [5] C. Ger, P. Perry, and L. Murphy, "Application Layer Delay-centric Handover of Streamed Video in a 4G network," in *Information Technology and Telecommunications Conference (IT&T)* Limerick, Ireland, Oct. 2004.
- [6] J. Ibrahim, Frederick, and Maryland, "4G Features," *Bechtel Telecommunications Technical Journal*, vol. 1, pp. 11-14, 2002.
- [7] "IEEE Std 802.11-1997 Information Technology- telecommunications And Information exchange Between Systems-Local And Metropolitan Area Networks-specific Requirements-part 11: Wireless Lan Medium Access Control (MAC) And Physical Layer (PHY) Specifications," *IEEE Std 802.11-1997*, pp. i-445, 1997.
- [8] P. Brenner, "A Technical Tutorial on the IEEE 802.11 Protocol," *BreezeCom Wireless Communications*, 1997.

- [9] "IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems," *IEEE Std 802.16-2004 (Revision of IEEE Std 802.16-2001)*, pp. 0_1-857, 2004.
- [10] T. X. Brown, B. Argrow, C. Dixon, S. Doshi, R. G. Thekkekkunnel, and D. Henkel, "Ad Hoc UAV Ground Network (AUGNet)," in *ALAA 3rd "Unmanned Unlimited" Technical Conference*, Chicago, Sept. 2004, p. 8.
- [11] "IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigendum 1," *IEEE Std 802.16e-2005 and IEEE Std 802.16-2004/Cor 1-2005 (Amendment and Corrigendum to IEEE Std 802.16-2004)*, pp. 0_1-822, 2006.
- [12] "IEEE standard for information technology - telecommunications and information exchange between systems - local and metropolitan area networks - specific requirement. Part 11: wireless LAN medium access control (MAC) and physical layer (PHY) specification. Amendment 3: specifications for operation in additional regulatory domains," *IEEE Std 802.11d-2001*, 2001.
- [13] "IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 8: Medium Access Control (MAC) Quality of Service Enhancements," *IEEE Std 802.11e-2005 (Amendment to IEEE Std 802.11, 1999 Edition (Reaff 2003))*, pp. 0_1-189, 2005.
- [14] J. H. Schiller, *Mobile Communications*, 2 ed.: Addison-Wesley Longman Publishing Co., Inc., 2003.

- [15] W. Stallings, *Wireless Communications & Networks*, 2 ed. NJ, USA: Prentice-Hall, Inc. Upper Saddle River, 2004.
- [16] G. Boggia, P. Camarda, L. A. Grieco, and S. Mascolo, "Feedback-based bandwidth allocation with call admission control for providing delay guarantees in IEEE 802.11 e networks," *Computer Communications*, vol. 28, pp. 325-337, 2005.
- [17] G. Bianchi and I. Tinnirello, "Analysis of priority mechanisms based on differentiated inter frame spacing in CSMA-CA," in *IEEE 58th Vehicular Technology Conference (VTC 2003-Fall)*, 2003, pp. 1401-1405.
- [18] A. Lindgren, A. Almquist, and O. Schelén, "Quality of Service Schemes for IEEE 802.11 Wireless LANs—An Evaluation," *Mobile Networks and Applications*, vol. 8, pp. 223-235, 2003.
- [19] "IEEE 802.16: Broadband Wireless MAN Standard (WiMAX)", [Webpage], Available: <http://www.javvin.com/protocolWiMAX.html>. Javvin Technologies, Inc., California, USA, [Accessed: 15 July 2008], [Cited:15 July,2008]
- [20] D. Rouffet, S. Kerboeuf, L. Cai, and V. Capdevielle, "4 G mobile," *Alcatel telecommunications review*, pp. 160-164, 2005.
- [21] J. J. J. Roy, V. Vaidehi, and S. Srikanth, "Always Best-Connected QoS integration model for the WLAN, WiMAX Heterogeneous Network," in *First International Conference on Industrial and Information Systems*, Aug. 2006, pp. 361-366.
- [22] N. Akkari, S. Tohmé, and M. Doughan, "Wimax-Based Vertical Handovers For Next Generation Networks," *New Technologies, Mobility and Security*, Springer, pp. 207-216, 2007.
- [23] H. Haffajee and H. A. Chan, "Low-cost QoS-enabled Wireless Network with Interworked WLAN and WiMAX," in *First IEEE International Conference on Wireless Broadband and Ultra Wideband Communications (AusWireless 2006)*, Sydney, 2007.

- [24] C. Hoymann, S. Frattasi, and P. Coenen, "HiperMAN/HiperLAN/2 Interworking Methods," *IST-STRIKE deliverable D*, vol. 3, June 2003.
- [25] S. Frattasi, D. Aalborg, E. Cianca, and R. Prasad, "Interworking between WLAN and WMAN: an ethernet-based integrated device," *IEEE 59th Vehicular Technology Conference (VTC)*, vol. 4, pp. 2243 – 2247, 2003.
- [26] S. Frattasi, E. Cianca, and R. Prasad, "An Integrated AP for Seamless Interworking of Existing WMAN and WLAN Standards," *Wireless Personal Communications: An International Journal*, vol. 36, pp. 445-459, 2006.
- [27] K. Gakhar, A. Gravey, and A. Leroy, "IROISE: a new QoS architecture for IEEE 802.16 and IEEE 802.11 e interworking," *2nd International Conference on Broadband Networks*, pp. 607-612, Oct. 2005.
- [28] I. C. Msadaa, F. Filali, and F. Kamoun, "An Adaptive QoS Architecture for IEEE 802.16 Broadband Wireless Networks," *IEEE International Conference on Mobile Adhoc and Sensor Systems (MASS)*, pp. 1-3, Oct. 2007.
- [29] D. Niyato and E. Hossain, "Queue-aware uplink bandwidth allocation and rate control for polling service in IEEE 802.16 broadband wireless networks," *IEEE Transactions on Mobile Computing*, vol. 5, pp. 668-679, June. 2006.
- [30] K. R. Raghu, S. K. Bose, and M. Maode, "Queue based scheduling for IEEE 802.16 wireless broadband," in *6th International Conference on Information, Communications & Signal Processing* Dec. 2007, pp. 1-5.
- [31] A. Lindgren, A. Almquist, and O. Schelen, "Evaluation of quality of service schemes for IEEE 802.11 wireless LANs," *26th Annual IEEE Conference on Local Computer Networks, (LCN)*, pp. 348-351, 2001.
- [32] G. Bianchi and I. Tinnirello, "Analysis of priority mechanisms based on differentiated inter frame spacing in CSMA-CA," *IEEE 58th Vehicular Technology Conference (VTC)*, vol. 3, pp. 1401-1405 2003.

- [33] "WiMAX and WiFi Together: Deployment Models and User Scenarios", White Paper, Motorola, Intel, Nov. 2007.
- [34] Available:
http://www.nextpointnetworks.com/go.php?page=news_item&pid=237.
Nextpointnetworks Inc, [Accessed: 10 July 2008], [Cited: 10 July, 2008]
- [35] W. Beibei, I. Sen, and D. W. Matolak, "Performance Evaluation of 802.16e in Vehicle to Vehicle Channels," in *IEEE 66th Vehicular Technology Conference (VTC)*, Fall. 2007, pp. 1406-1410.
- [36] K. Blakely and B. Lowekamp, "A structured group mobility model for the simulation of mobile ad hoc networks," in *International Conference on Mobile Computing and Networking*, 2004, pp. 111-118.
- [37] Z. Biao, X. Kaixin, and M. Gerla, "Group and swarm mobility models for ad hoc network scenarios using virtual tracks," in *IEEE Military Communications Conference (MILCOM)*, Nov. 2004, pp. 289-294 Vol. 1.
- [38] T. Bhatt, V. Sundaramurthy, Z. Jianzhong, and D. McCain, "Initial Synchronization for 802.16e Downlink," in *40th Asilomar Conference on Signals, Systems and Computers, (ACSSC)*, Nov. 2006, pp. 701-706.
- [39] P. Ritun and J. Raj, "Scheduling in WiMAX Networks," in *Presented at WiMAX Forum AATG F2F Meeting* Washington DC: Washington University, Saint Louis, April. 2007.
- [40] H. Gowda, R. Lakshmaiah, M. Kaur, C. Mohanram, M. Singh, and S. Dongre, "A slot allocation mechanism for diverse QoS types in OFDMA based IEEE 802.16e systems," in *The 9th International Conference on Advanced Communication Technology*, Feb. 2007, pp. 13-17.

- [41] V. Singh and V. Sharma, "Efficient and fair scheduling of uplink and downlink in IEEE 802.16 OFDMA networks," in *IEEE Wireless Communications and Networking Conference, (WCNC)*, April. 2006, pp. 984-990.
- [42] K. Wongthavarawat and A. Ganz, "IEEE 802.16 based last mile broadband wireless military networks with quality of service support," in *IEEE Military Communications Conference, (MILCOM)*, Oct. 2003, pp. 779-784.
- [43] L. Howon, K. Taesoo, and C. Dong-Ho, "An enhanced uplink scheduling algorithm based on voice activity for VoIP services in IEEE 802.16d/e system," *IEEE Communications Letters*, vol. 9, pp. 691-693, Aug. 2005.
- [44] Y. Ou and L. Jianhua, "New scheduling and CAC scheme for real-time video application in fixed wireless networks," in *3rd IEEE Consumer Communications and Networking Conference, (CCNC)*, Jan. 2006, pp. 303-307.