UNIVERSITI PUTRA MALAYSIA

EFFECTIVE DOWNLINK RESOURCE MANAGEMENT FOR WIMAX NETWORKS

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EFFECTIVE DOWNLINK RESOURCE MANAGEMENT FOR WIMAX NETWORKS

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

Month and year of Viva Voce (*December 2018*)

DEDICATION

To my beloved family,

For their infinite and unfading love, care, support, patience and efforts.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

EFFECTIVE DOWNLINK RESOURCE MANAGEMENT FOR WIMAX NETWORKS

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December 2018

Chair : Masnida Hj Hussin, PhD
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The interest in Quality of Service (QoS) for broadband wireless access networks has been growing considerably because of the need for efficient data access, particularly in WiMAX networks. Unlike wireless LANs, WiMAX networks incorporate several QoS mechanisms to guarantee services for Internet applications, such as HTTP, FTP, VoD, and VoIP. These types of applications require additional performance criteria from the underlying network, such as reliability, timeliness, and guaranteed delivery, as well as different levels of service quality. However, in WiMAX downlink communication, such criteria are not sufficiently offered. This has led to QoS degradation, which burdens the ISPs. Furthermore, the existing resource management in WiMAX downlink communication lack the supporting effective scheduling, bandwidth allocation, and packet transmission as in one framework. Hence, a comprehensive framework that fulfils the QoS constraints in downlink communication has become more significant for all types of Internet applications. Herein, we propose a downlink communication framework called Effective Downlink Resource Management (EDRM) in WiMAX Internet infrastructure networks. It aims to achieve QoS assurances and high network performance for better user experiences. Our EDRM framework involves three functions: Class-Based Scheduling (CBS) algorithm, Dynamic Bandwidth Allocation (DBA) scheme and Link Session Management (LSM) policy. Each of these three functions contains various modules to deal with several services such as data traffic, bandwidth resources, and packet delivery, respectively. We implemented the EDRM framework in a simulated environment, using OPNET Modeler. In terms of jitter, we succeeded in recording 41% improvement in VoD, 45% enhancement of average delay for FTP, and 21% for HTTP in CBS among the other existing

algorithms. Meanwhile, in DBA, we recorded 15% of improvement in terms of network throughput and bandwidth utilisation, as compared to the other scheme. Finally, in LSM, we achieved 24% of improvement in packet delivery ratio and immense packet loss reduction as compared to the other competitive policy. Therefore, EDRM maximised the data transfer rate and reached effective transmission and utilisation in all the developed functions. Optimistically, the comprehensive resource management for downlink communication in WiMAX such as EDRM can have notable advantages and achieve substantial performance that lead to improved user satisfaction.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGURUSAN SUMBER MENURUN BERKESAN DALAM RANGKAIAN WIMAX

Oleh

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Pengerusi : **Masnida Hj Hussin, PhD**
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Kepentingan dalam Kualiti Perkhidmatan (QoS) untuk rangkaian akses wayarles jalur lebar telah berkembang dengan pesat berikutan keperluan akses data yang cekap, khusus dalam rangkaian WiMAX. Tidak seperti LAN wayarles, rangkaian WiMAX menggabungkan beberapa mekanisme QoS untuk menjamin perkhidmatan untuk aplikasi Internet iaitu HTTP, FTP, VoD, dan VoIP. Jenis aplikasi ini memerlukan kriteria prestasi tambahan daripada rangkaian asas seperti kebolehpercayaan, ketepatan masa dan penghantaran yang terjamin, serta tahap kualiti perkhidmatan yang berbeza. Walau bagaimanapun, dalam komunikasi WiMAX menurun, kriteria tersebut tidak sepenuhnya ditawarkan. Ini telah menyebabkan kemerosotan QoS yang membebankan ISP. Selain itu, pengurusan sumber sedia ada dalam komunikasi WiMAX menurun adalah kurang menyokong penjadualan yang berkesan, peruntukan jalurlebar, dan penghantaran paket yang disatukan di dalam satu rangka kerja. Oleh itu, rangka kerja komprehensif yang memenuhi kekangan QoS dalam komunikasi WiMAX menurun menjadi lebih penting untuk semua jenis aplikasi Internet. Kami memcadangkan rangka kerja komunikasi WiMAX menurun yang dipanggil Pengurusan Sumber Menurun Berkesan (EDRM) dalam rangkaian infrastruktur Internet WiMAX. Ia bertujuan untuk mencapai jaminan QoS dan peningkatan dalam prestasi rangkaian bagi memberi perkhidmatan yang lebih baik kepada pengguna. Pendekatan rangka kerja EDRM ini melibatkan tiga fungsi; algoritma Penjadualan Berasaskan Kelas (CBS), skima Peruntukan Jalur-lebar Dinamik (DBA) dan polisi Pengurusan Sesi Pautan (LSM). Setiap fungsi mengandungi pelbagai modul untuk menangani beberapa perkhidmatan seperti trafik data, sumber jalur lebar dan penghantaran paket. Kami telah melaksanakan rangka kerja EDRM dalam persekitaran simulasi, menggunakan Modeler OPNET. Daripada segi purata kelewatan,

kami berjaya merekodkan 41% peningkatan dalam VoD, 45% dalam FTP, dan 21% dalam HTTP di antara CBS dengan algoritma yang lain. Sementara itu, di dalam DBA kami berjaya mencatat peningkatan 15% dalam Penghantaran dan penggunaan. Akhirnya, bagi LSM, daripada segi nisbah penghantaran paket dan data kehilangan, kami peningkatan 24%. Daripada segi purata kelewatan, berbanding dengan dasar kompetitif yang lain. Tambahan pula daripada segi purata daya pemprosesan, EDRM memaksimumkan kadar pemindahan data serta mencapai penghantaran dan penggunaan yang berkesan dalam semua fungsi yang dibangunkan. Secara optimistik, pengurusan sumber komprehensif untuk komunikasi WiMAX menurun seperti EDRM memperolehi kelebihan yang ketara dan prestasi yang baik seterusnya dapat meningkatkan kepuasan pengguna.

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I certify that a Thesis Examination Committee has met on 21/12/2018 to conduct the final examination of (Zayd Ashraf Najeeb Shareef Beg) on his thesis entitled ("Effective Downlink Resource Management For WiMAX Network") in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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Signature: ______________________
Name of Member of Supervisory Committee: Dr. Abdullah Muhammed

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AAA	Authentication, Authorization, and Accounting
AB	Available Bandwidth
ABA	Adaptive Bandwidth Allocation
ABAS	Adaptive Bandwidth Allocation Scheme
AMC	Adaptive Modulation and Coding
AMLLQ	Adaptive Modified Low Latency Queuing
AMRE	Absolute Mean Relative Error
APDS	Adaptive Priority-Based Downlink Scheduling
APF	Adaptive Proportional Fairness
AR	Advanced Reservation
AQAPS	Adaptive Queue Aware Priority Scheduler
ASN	Access Service Network
ATM	Asynchronous Transfer Mode
BE	Best Effort
BPSK	Binary Phase Shift Keying
BS	Base Station
BS	Base Station
BWA	Broadband Wireless Access
CAC	Connection Admission Control
CBR	Constant-Bit-Rate
CBS	Classification-Based QoS Scheduling
CBWFQ	Class-Based Weighted Fair Queuing
CF	Collaborative Filtering
CID	Connection Identifier
CIR	Committed Information Rate
CoS	Class of Service
CPS	Common Part Sub layer
CS	Convergence Sub layer
CSN	Connectivity Service Network
CSPF	Constrained Shortest Path First
DBA	Dynamic Bandwidth Allocation
DCS	Delay Constrained Services
DES	Discrete Event Simulation
DHCP	Dynamic Host Control Protocol server
DLMAP	Downlink MAP
DNS	Domain Name Server
DR	Departure Rate
DTMC	Discrete-Time Markov Chain
DSID	Downstream Service Identifier Index
E-APF	Extended Adaptive Proportional Fairness
ECMP	Equal Cost Multi-Path
EDD	Earliest Due Date
EDF	Earliest Deadline First
EDRM	Effective Downlink Resource Management for WiMAX Networks

ELSP	End-to-end Label Switching Protocol
Eq.	Equation
EROs	Explicit Route Objects
ertPS	Extended Real-Time Polling Service
ES	Extended Sub-header
EXP	Experimental bits
FBA	Fuzzy Bandwidth Allocation
FCH	Frame Control Header
FDD	Frequency Division Duplex
FIFO	First in First out
FIS	Fuzzy Interclass Scheduler
FTP	File Transfer Protocol
GMPLS	Generalized Multiple Path Label Switching
GPS	Generalized Processor Sharing
GPTS	Grant per Type-of- Service
HMC	Hidden Markov Chain
HOL	Head of Line
HQA-DBA	Hierarchical QoS-Aware Dynamic Bandwidth Allocation
HTTP	Hypertext Transfer Protocol
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IGP's	Interior Gateway Protocols
iLSR	Ingress Label Switched Router
ISPs	Internet Service Providers
Kbps	Kilobits per seconds
LAN	Local Area Networks
LDP	Label Distribution Protocol
LSM	Link Sessions Managements
LSP	Label Switched Path
LSPPHS	Label Switched Path-Payload Header Suppression
LSR	Label Switching Router
LTE	Long-Term Evolution
MAC	Media Access Control
MAPD	Mean Absolute Percentage Deviation
Mbps	Megabits per seconds
MDRR	Modified Deficit Round Robin
MLLQ	Modified Low Latency Queuing
MIMO	Multiple Input and Multiple Output
MIP	Mobile Internet Protocol
MLSM	Macro-cell Label Switching Mechanism
MRT	Minimum Reset Time
MPDU	MAC Protocol Data Unit
MPLS	Multiple-Path Label Switching
MSS	Maximum Segment Size
MTU	Maximum Transmission Unit
MQC	Modular Quality of Service Command Line Interface
NRTPS	Non-real-time Polling Service

ODBA	On Demand Bandwidth Allocation
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiplexing Access
ONU	Optical Network Unit
OSPF	Open Shortest Path First
PBU	Proxy Binding Updates
PDOR	The Packet Delay Outage Ratio
PDU	Protocol Data Unit
PEU	Priority Elevation Unit
PHP	Penultimate Hop Popping
PHS	Payload Header Suppression
PF	Proportional Fair
PFEBA	Prediction-based Fair Excessive Bandwidth Allocation
PMP	Point-to-Multipoint
PMPLS	Proxy MPLS
PQ	Priority Queuing
PS	Privacy Sub layer
QAM	Quadrature Amplitude Modulation
QDBA	QoS-based Dynamic Bandwidth Allocation
QOS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RR	Round Robin
RSVP	Reservation Protocol
RTPS	Real-Time Polling Service
SAP	Service Access Point
SDU	Service Data Units
SEC	Seconds
SLA	Service Level Agreement
SPQ	Strict Priority Queuing
SSs	Subscriber Stations
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TE	Traffic Engineering
TGS	Throughput Guaranteed Services
TLSA	Two Level Scheduling Algorithm
TTG	Transmit Transition Gap
DCD	Downlink Channel Descriptors
UGS	Unsolicited Grant Service
UL-MAP	Uplink MAP
VBR	Variable Bit-Rate
VOD	Video on Demand
VOIP	Voice over IP
VRQ	Virtual Ranking Queue
WFQ	Weighted Fair Queuing
WHP	Weighted High Priority
WLP	Weighted Low Priority
WFICC	WiMAX Fair Intelligent Congestion Control

WIMAX	Worldwide Interoperability for Microwave Access
WIMPLS	WIMAX and MPLS networks
WMAN	Wireless Metropolitan Area Network
WRR	Weighted Round Robin

CHAPTER 1

INTRODUCTION

1.1 WiMAX Overview

The recent demands for high-speed Internet access and multimedia services have increased significantly for residential and business users and in rural areas. Therefore, researchers have considered Wireless Metropolitan Area Networks (WMANs) as a potential resolution for mobile communication technology. In addition, enormous developments in wireless networks have been implemented, which has led to the emergence of the Worldwide Interoperability for Microwave Access System, also known as WiMAX IEEE 802.16, to suit the continuing increase in the data communication speed.

IEEE 802.16 is a standard protocol that is deployed on the basis of the Broadband Wireless Access (BWA). It delivers high-speed communication access through adequate radio and wireless means to consumer and business markets (IEEE, 2006). WiMAX is considered the Fourth Generation (4G) of wireless networks and is established as a set of telecommunication technology standards that aims to provide wireless signals over long distances in cellular-type access. WiMAX can deliver boundless coverage, highly stable wireless access, high transmission rates, and better Quality of Service (QoS) (Andrews *et al.*, 2007). It offers reliable Internet speed and covers a metropolitan area of several kilometres (Huang *et al.*, 2007). Theoretically, a WiMAX base station can provide broadband wireless access in ranges up to 50 km for mobile stations, with a maximum data rate of up to 70 Mbps (So-In *et al.*, 2009).

Currently, WiMAX is used widely and particularly in rural areas. Thus, it is an attractive option for service operators in such areas that do not have an available wired access network. This makes it one of the topmost Internet providers for expediting the deployment process and saves installation costs (Rukmani & Ganesan, 2017). In addition, the WiMAX technology is a competing system to Long-Term Evolution (LTE) that succeeds in achieving a similar speed (Neves *et al.*, 2010; LTE, 2011). Both WiMAX and LTE are built on IP-based technologies and use similar modulation techniques (i.e., Orthogonal Frequency Division Multiplexing (OFDM)). Moreover, they both support advanced Multiple Input and Multiple Output antenna technology (MIMO). A WiMAX network consists of a Base Station (BS) with a number of Subscriber Stations (SSs), where SSs are located at user premises and each BS serves as the gateway for multiple SSs to access the backhaul network or the Internet, as shown in Figure 1.1.

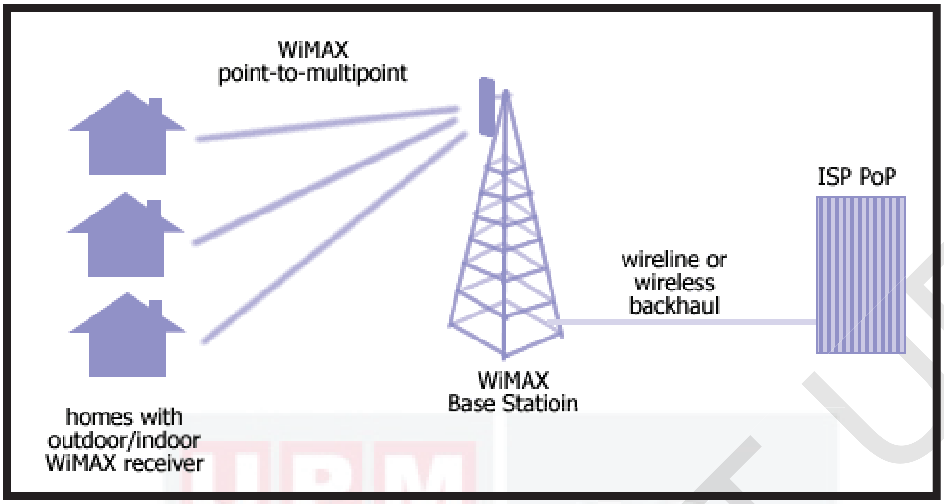

Figure 1.1: WiMAX PMP Mode (Conniq, 2012)

The downlink and uplink connections are controlled through the serving BS in the point-to-multi-point mode (PMP), this makes it capable of providing application and resource management techniques at the server side (Abichar *et al.*, 2006). In particular, the WiMAX protocol stack consists of a Physical (PHY) layer, a Security Sub-layer, a Media Access Control (MAC) layer, and a Convergence Sub-layer to provide different services and modules that we focused on in our study. These services include QoS scheduling, resource management, decision-making procedures, connection classification, and protocol data unit (PDU) operations, as shown in the IEEE 802.16 protocol stack (Figure 1.2).

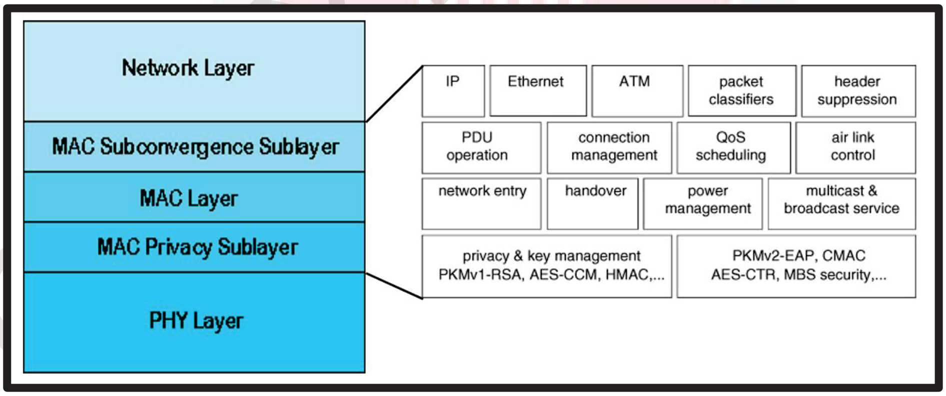

Figure 1.2: IEEE 802.16 WiMAX Protocol Stack (Seyedzadegan & Othman, 2013)

1.2 QoS in WiMAX Network

Over the past few years, communication services, such as streaming audio, video, and multimedia for residential and business users, have experienced rapid growth. This expansion of services has caused the communication traffic to suffer from congestion and become vulnerable. In fact, this has increased the strain to be sustained by the Internet Service Providers (ISPs), as multimedia services cause a sharp increase in the bandwidth demand and in the QoS needed to be delivered to the users (Cooklev, 2011).

In particular, multimedia services are required to provide QoS guarantees that are distinguished by performance metrics such as delay, jitter, throughput, and packet loss ratio. The QoS influences the service class algorithms, such as Best Effort (BE), Real-Time (RT), Non-Real-Time (NRT), and Unsolicited Grant Service (UGS), to achieve the assured level of performance to every data flow request. The QoS is degraded if its data flow packets experience scarce bandwidth, high packet loss rate, and large delay variation. An efficient utilisation of bandwidth could offer additional profits revenues for the ISPs by guaranteeing the QoS demands. Thus, supporting QoS guarantees for diverse multimedia services is the primary concern nowadays for most types of Internet providers such as WiMAX. Therefore, it becomes imperative for us as researchers to provide a comprehensive model that yields better QoS guarantees, improved resources utilisation, and enhanced delivery of service availability in all types of traffic communication classes for the betterment of the Internet service and to satisfy the users' needs.

As users pay for the consumed services, better service quality is demanded through the Service Level Agreement (SLA), which is considered an electronic contract (Lu *et al.*, 2011) that establishes all the relevant aspects of the service (i.e. functional and non-functional properties). For example, the providers advertise their services, each with varied QoS guarantees. Some of these QoS guarantees, however, may not be deliverable according to the initiated SLA during the actual service execution because of a heavy load. The providers need to determine the current deliverable QoS before the SLA is settled with the users and successfully configure and execute reactive dynamic actions for supporting dynamic infrastructure reconfiguration. As a result, the service providers must guarantee a high QoS for each application in the data centre and simultaneously achieve the optimal utilisation of their infrastructure. Hence, meeting the QoS requirements, such as response time, delays, packet drop, and throughput, in a dynamic environment with a dense load and varying capacity is still an open research problem.

1.3 Problem Statement

The high load of multimedia services has burdened the Internet providers to manage and allocate their network resources efficiently in order for them to deliver the respective satisfactory level of QoS. Recently, researchers (Rukmani & Ganesan, 2017; Sharma *et al.*, 2017; Chishti *et al.*, 2018) have attempted to improve the QoS. However, the complex management of the network scheduling and the distribution and estimation of bandwidth resources with efficient delivery in a fair manner remains one of the main challenges, particularly in the WiMAX network. Hence, the design of a flexible yet robust resource management approach with efficient packet delivery for such QoS provisioning is a crucial area of research.

We derived the first problem statement by investigating numerous previous works on improving QoS in WiMAX and particularly in the scheduling area to find the current research gap. In addition, during our investigation, we observed a gap in the bandwidth allocation and estimation techniques that also degrades the QoS in WiMAX network. This led to the formulation of the second problem statement. Meanwhile, by further investigating the QoS degradation in WiMAX networks, we found the gap that helped us to derive the third problem statement, which mainly focused on header incompatibility problems and inefficient packet delivery between WiMAX and MPLS (Wi-MPLS) networks. The following are the precise outlines of the current research problems:

- In response to the fairness principle that is introduced in WiMAX, the existing scheduling algorithms does not concern QoS in all traffic classes. Because the WiMAX workload is diverse and heavy, the consideration of only some traffic classes in the scheduling decisions leads to packet starvation and QoS degradation. Hence, it increases the communications delays and traffic jitters.
- In response to dynamic allocation of bandwidth, the WiMAX network desire on-the-fly information of the bandwidth capacity. However, the bandwidth quantification is a difficult procedure to perform accurately in the existing bandwidth-aware networks because bandwidth is a dynamic property. This has led misbehaviour of allocation algorithms which degrades overall QoS in terms of network throughput and utilisation.
- In response to traffic control by service providers, the existing issues of connection identification, signalling processes, and packet header incompatibility while integrating MPLS and WiMAX networks has led to inefficient packet delivery in the downlink tunnelling procedures that mainly impacted packet delivery ratio.

1.4 Objectives

The primary goal of this research was to model effective resource management for downlink traffic communication that delivers reliable multimedia services for wireless network users. This was accomplished by developing three different functions for our Effective Downlink Resource Management (EDRM) that aim to satisfy QoS guarantees in WiMAX network. The specific objectives are as follows:

- To develop a Classification-Based QoS Scheduling (CBS) algorithm to deal with the traffic diversity to ensure QoS guarantees in WiMAX networks where all traffic workload can be adaptively scheduled by a single scheduling module to reduce communication delays and traffic jitter by using priority elevation, virtual ranking queues, and packet provision modules.
- To propose a Dynamic Bandwidth Allocation (DBA) scheme that tackles the issue of quantifying the currently available bandwidth and provides a better analysis and decision-making process by using probe packet generation to increase throughput and provides better bandwidth utilisation using quantification and allocation modules.
- To propose a Link Session Management (LSM) policy for improving the QoS reliability in the tunnelling and reservation processes by upgrading the MAC header that solves header incompatibilities, connection identifications, and signalling procedures in Wi-MPLS networks to increase packet delivery ratio.

1.5 Scope of Study

WiMAX IEEE 802.16 was considered in this work to support QoS guarantees for diverse multimedia services in downlink transmission. Precisely, our work involved Layer 2 (MAC layer) where all the scheduling, allocations, and link management functions take place. We focused only on the Time Division Duplex (TDD) duplexing technology system with the Point-to-Multipoint (PMP) mode. Our scope was to design and propose a different algorithm, scheme, and policy to tackle various WiMAX network problems.

Furthermore, we defined our scope to remain only within a WiMAX network; hence, our modules might not be suitable for other types of platforms, as they were explicitly designed to fit only the WiMAX base stations and architecture. Moreover, the implemented model was explicitly designed on simulation software. Hence, real-world problems such as fade, attenuation, and other physical and environmental factors were neglected in our study.

1.6 Thesis Outline

Effective Downlink Resource Management for WiMAX Networks (EDRM) provides a variety of choices to the user with five types of traffic communication classes where each type provides the desired application. The service is prioritised according to the user preferences. Our EDRM framework classifies, schedules, allocates, and facilitates the users' packets with dynamic adjustments to ensure high speeds, ease of access, guaranteed QoS, and the preferred services priorities. The rest of this thesis is organised as follows. Chapter 1 focuses on the general introduction of the work. It presents the statement of the research problems, the objective of the study, and the scope of the work. Chapter 2 centres on the literature review which discusses the scheduling, allocation, and link management backgrounds and the related works. Chapter 3 discusses the research methodology, experimental/expected settings, performance metrics, development of the proposed functions, and the analysis and validation of the base works. Chapters 4, 5, and 6 present the findings analysis that is based on the performance metric measures and a comparison with previous works on CBS, DBA, and LSM, respectively. Chapter 7 presents a conclusion drawn from the entire work, the major research findings, and the recommendations for further studies. In the end, a short bio-data of the candidate and a list of publications based on the study are presented.

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LIST OF PUBLICATIONS

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