

# **UNIVERSITI PUTRA MALAYSIA**

QUALITY OF SERVICE MANAGEMENT ALGORITHMS IN WIMAX NETWORKS

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# QUALITY OF SERVICE MANAGEMENT ALGORITHMS IN WiMAX NETWORKS



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

September 2015

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

### Quality Of Service Management Algorithms In WiMAX Networks

By

#### **IBRAHIM SAIDU**

September 2015

### Chairman: Shamala Subramaniam, PhD Faculty: Computer Science and Information Technology

The IEEE 802.16 standard, popularly known as WiMAX, addresses broadband access technology for Wireless Metropolitan Area Networks (WMANs). It is anticipated to be a viable alternative to traditional wired broadband techniques due to its cost-competitiveness, ubiquitous access, and Quality of Service (QoS) capabilities. Because it is a wireless technology, in which resources are limited such as bandwidth and power; how to manage these resources while maintaining QoS to diverse applications become a critical issue. Therefore, efficient admission control, scheduling, and power saving schemes are essential in this network. Four algorithms have been proposed and developed in this research.

Firstly, a QoS-Aware CAC scheme for Mobile WiMAX networks is proposed to prevent the starvation problem of the highest and the lowest service classes due to the linear adaptation technique used to accommodate more users into the network as well as inefficient bandwidth utilization because of the way the adaptive reserved bandwidth threshold for handoff is adjusted. This scheme determines an admission criteria based on scheduling service classes. In the admission criteria, a bandwidth-degradation policy is used to admit more users in order to prevent starvation. An adaptive threshold has been introduced dynamically to adjust the reserved bandwidth threshold for handoff connections based on the traffic intensity of handoff requests to improve bandwidth utilization. In addition, an analytical model for the proposed scheme is developed.

Secondly, a Load-Aware Weighted Round Robin algorithm (LAWRR) packet scheduling discipline for downlink traffic in 802.16 networks is proposed to

improve the poor performance of scheduling algorithm that use static weights under bursty traffic. It dynamically determines the weight of each queue in the various classes based on current traffic characteristics and the static weight at the beginning of each base-station round.

Thirdly, an energy algorithm called the Efficient Battery Life-aware Power Saving (EBLAPS) algorithm is proposed to address the problems of minimizing energy at the expense of response due to how energy sleep parameters are adjusted based on the residual energy and the use of standard sleep mode algorithms consumes high energy because of frequent transition to listening mode in the case of light traffic. The energy sleep parameters: idle threshold, initial sleep parameters and final sleep parameters are adjusted according to the downlink stochastic traffic arrival pattern of a mobile station(MS) in order to reduce the high response delay as well as the high energy consumption. Moreover, an improved sleep mode control algorithm has been introduced to reduce the high energy consumption of the standard sleep mode algorithm. Simulation have been extensively used to evaluate the proposed algorithm.

Finally, Discrete Event Simulator (DES) is designed and developed in order to evaluate the performance of the proposed algorithms. The DES is validated by comparing its results with the results obtained from Qualnet, OPNET, and C simulators.

Substantial simulations have been extensively conducted to evaluate the performance of the proposed algorithms in comparison to the existing bandwidth and power management algorithms. Simulation results illustrate that the proposed QoS-Aware CAC scheme outperforms the compared schemes significantly in terms of reducing the New Connection Blocking Probability (NCBP), Handoff Connection Dropping Rate (HCDP), and also increase the throughput of the highest and the lowest service classes as well as the numerical results show similar performance with the simulation results. The results also show that the proposed LAWRR algorithm reduces average delay and packet loss. Furthermore, the results also show that the proposed EBLAPS algorithm outperforms the compared schemes significantly in terms of both the average response delay and the average energy consumption.

The results show that the proposed algorithms provide enhanced efficient bandwidth and power utilization, grant more connections, assure QoS guarantees to all service classes, and also extend the battery life. Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

# Kualiti Algoritma Pengurusan Perkhidmatan dalam Rangkaian WiMAX.

Oleh

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September 2015

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Piawaian IEEE 802,16, yang lebih dikenali sebagai WiMAX, memperkenalkan teknologi akses jalur lebar untuk Rangkaian Kawasan Metropolitan Tanpa Wayar (WMANs). Ia dijangka akan menjadi alternatif yang berdaya maju kepada teknik tradisional jalur lebar berwayar kerana kos daya saing, akses yang menyeluruh, dan keupayaan Kualiti Perkhidmatan (QoS). Oleh kerana ia adalah satu teknologi tanpa wayar, di mana sumber-sumber yang terhad seperti jalur lebar dan tenaga; persoalan untuk menguruskan sumber-sumber ini di samping mengekalkan QoS untuk aplikasi yang pelbagai menjadi isu kritikal. Oleh itu, skim kawalan kemasukan cekap, penjadualan, dan menjimatkan kuasa adalah penting di dalam rangkaian ini.

Pertama, skim CAC Kesedaran-QoS untuk rangkaian Mobile WiMAX dicadangkan untuk mengelakkan masalah ketandusan sumber yang paling tinggi dan kelas perkhidmatan yang paling rendah kerana teknik penyesuaian selari yang digunakan untuk menampung lebih ramai pengguna ke dalam rangkaian serta penggunaan jalur lebar yang tidak cekap disebabkan oleh cara penyesuaian simpanan pemulaan jalur lebar ketika pengambilalihan telah diselaraskan. Skim ini menentukan kriteria kemasukan berdasarkan kelas perkhidmatan penjadualan. Dalam kriteria kemasukan, dasar jalur lebar degradasi digunakan untuk menerima lebih ramai pengguna bagi mengelakkan ketandusan sumber. Penyesuaian permulaan telah diperkenalkan secara dinamik bagi menyesuaikan lebar jalur yang dikhaskan untuk pengambilalihan sambungan berdasarkan permintaan pengambilalihan penentuan trafik supaya dapat meningkatkan penggunaan jalur lebar. Di samping itu, model analisis untuk skim yang dicadangkan telah dibangunkan. Empat algoritma telah<br/>di cadangkan dan dibangunkan dalam penyelidikan ini.

Kedua, algoritma Wajaran Kesedaran-Memuatkan Round Robin (LAWRR) disiplin penjadualan paket untuk trafik pautan turun di dalam rangkaian 802,16 telah dicadangkan untuk meningkatkan prestasi algoritma penjadualan yang menggunakan berat statik ketika pecahan trafik. Ia secara dinamik menentukan berat setiap giliran di dalam pelbagai kelas berdasarkan ciriciri trafik semasa dan berat statik pada permulaan setiap pusingan stesen pangkalan.

Ketiga, algoritma tenaga yang dipanggil Kesedaran-Hayat Bateri Jimat Tenaga Cekap (EBLAPS) algoritma telah dicadangkan untuk mengatasi masalah meminimumkan tenaga yang digunakan disebakan oleh persoalan bagaimana parameter tidur tenaga diselaraskan berdasarkan baki tenaga dan penggunaan piawaian algoritma mod tidur yang memerlukan tenaga yang tinggi disebabkan oleh kekerapan peralihan ke mod pendengaran di dalam kes trafik rendah. Parameter tenaga tidur: pemulaan tidak aktif, parameter permulaan tidur dan parameter pengakhiran tidur diselaraskan mengikut reka bentuk ketibaan trafik pautan turun stokastik stesen mudah alih (MS) untuk mengurangkan kelewatan respon yang tinggi serta penggunaan tenaga yang tinggi. Selain itu, penambahbaikan algoritma kawalan mod tidur telah diperkenalkan bagi mengurangkan penggunaan tenaga yang tinggi oleh algoritma mod tidur yang sedia ada. Simulasi telah digunakan secara meluas untuk mengukur prestasi algoritma yang dicadangkan.

Keempat, Simulasi Berkeadaan Diskrit(DES) telah direka dan dibangunkan untuk menilai prestasi algoritma yang dicadangkan. DES disahkan dengan membandingkan keputusan dengan keputusan yang diperolehi daripada Qualnet, OPNET, dan C simulator.

Beberapa simulasi telah dijalankan secara meluas untuk menilai prestasi algoritma yang dicadangkan bagi membandingkan jalur lebar dan pengurusan kuasa algoritma yang telah sedia ada. Keputusan simulasi menggambarkan bahawa skim CAC Kesedaran-QoS yang dicadangkan mengatasi skim yang dibandingkan secara ketara dari segi mengurangkan Kebarangkalian Sekatan Sambungan Baru (NCBP), Kadar Kejatuhan Penyambungan Ambil Alih (HCDP), dan juga mening- katkan daya pemprosesan bagi kelas perkhidmatan yang tertinggi dan yang terendah termasuk keputusan berangka yang menunjukkan prestasi yang sama dengan keputusan simulasi. Keputusan yang diperolehi juga menunjukkan bahawa algoritma LAWRR yang dicadangkan mengurangkan purata kelewatan dan kehilangan paket. Selain daripada itu, keputusan yang di perolehi juga menunjukkan bahawa algoritma EBLAPS yang dicadangkan mengatasi skim yang dibandingkan dengan ketara dari kedua-dua segi purata kelewatan hasil dan juga purata penggunaan tenaga. Keputusan yang diperolehi menunjukkan bahawa algoritma yang dicadangkan memberi hasil jalur lebar dan penggunaan kuasa yang efisien, penyambungan yang lebih, member jaminan QoS untuk semua kelas perkhidmatan, dan juga memanjangkan hayat bateri.



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# APPROVAL

I certify that a Thesis Examination Committee has met on 10th September, 2015 to conduct the final examination of Ibrahim Saidu on his thesis entitled Bandwidth and Power Management Algorithms in WiMAX Networks 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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# LIST OF ABBREVIATIONS

AAS	Adaptive Antenna Systems
AMR	Adaptive Multi-Rate
ARQ	Automatic Repeat-request
ATM	Asynchronous Transmission Mode
APSM	Adaptive Power Saving Mechanism
AWRR	Adaptive Weighted Round Robin
BD	Bandwidth Degradation
BE	Best-Effort service
BLAPS	Battery Lifetime-Aware Power Saving
BPSK	Binary Phase-Shift Keying
BR	Bandwidth Reservation
BS	Base Station
BWA	Broadband Wireless Access
CAC	Connection Admission Control
CID	Connection Identifier
CNL	Computer Networks Laboratory
CPS	Common Part Sub-layer
CS	Convergence Sub-layer
CWS	Comprehensive WiMAX Simulator
DEE	Dipartimento di Elettrotecnica ed Elettronica
DES	Discrete Event Simulator
DL	Downlink

C

DSL	Digital Subscriber Line
EBLAPS	Efficient Battery Lifetime Aware Power Saving
EESM	Enhanced Energy Saving Mechanism
ertPS	extended real-time Polling Service
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
FIFO	First-In, first-Out
FTP	File Transfer Protocol
GPSS	Grant Per Subscriber Station
GSCAC	Greedy Shaper Call Admission Control
HCDP	Handoff Connection Dropping Probability
HP	High-Priority
IEEE	Institute of Electronics and Electrical Engineers
IMT-Advanced	International Mobile Telecommunications-Advanced
IPTV	Internet Protocol Television
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
ITU-R	International Telecommunication Union-Radio
LAWRR	Load-Aware Weighted Round-Robin
LB	Low-priority Buffer
LL-WRR	Low-Latency Weighted Round Robin
LOS	Line Of Sight
LSI	Last Sleep Interval

	LWX	Light WiMAX Simulator
	MAC	Media Access Control
	MCS	Modulation and Coding Scheme
	MIB	Management Information Base
	MIMO	Multiple Input Multiple Output
	MOB-SLP-REQ	Mobilization Sleep Request
	MOB-SLP-RES	Mobilization Sleep Request
	MOB-TRF-IND	Mobilization Traffic Indication
	MRTR	Minimum Reserved Traffic Rate
	mSIR	Maximum Signal to Interference Ratio
	MSTR	Maximum Sustained Traffic Rate
	MTU	Maximum Transfer Units
	MWRR	Modified Weighted Round Robin
	NCBP	New Connection Blocking Probability
	NDSL	Network and Distributed Systems Laboratory
	NIST	National Institute of Standards and Technology
	NLOS	Non-Line Of Sight
	nrtPS	non–real-time Polling Service
	ns-2	Network Simulator 2
	ns-3	Network Simulator 3
	Numbat	New ubiquitous mobility basic analysis tools
	OFDM	Orthogonal Frequency Division Multiplexing
	OFDMA	Orthogonal Frequency Division Multiple Access

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OPNET	Optimized Network Engineering Tools
PDUs	Protocol Data Units
PSCs	Power Saving Classes
РНҮ	Physical
PSC I	Power Saving Class type I
PSC II	Power Saving Class type I
PSC III	Power Saving Class type I
QoS	Quality of Service
QPSK	Quadra-Phase-Shift Keying
REAPM	Remaining Energy-Aware Power Management
RPI	Rensselaer Polytechnic Institute
RR	Round Robin
RRM	Radio Resource Management
rtPS	real-time Polling Service
SAPs	Service Access Points
SC	Single Carrier
SDUs	Service Data Units
SFID	Service Flow Identifier
TDD	Time Division Duplex
TRS	Temporary Removal Scheduler
UGS	Unsolicited Grant Service
UP	Uplink
VoIP	Voice over Internet Protocol

WiMAX	Worldwide Interoperability for Microwave Access
WINSE	WiMAX ns-2 Extension
WFIAC	Wireless Fair Intelligent Admission Control
WMAN	Wireless Metropolitan Area Network
WMAN	Wireless Metropolitan Area Network
WRR	Weighted Round Robin
WUSTL	Washington University in St. Louis

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### CHAPTER 1

#### INTRODUCTION

This chapter introduces the background for this research, identifies the research problems and motivations. It also presents the research objectives, the scope of the research and research significance. In addition, its research contributions, which justifies the benefits, and clarifies the implication of this research. Finally, this chapter summarizes the organization of this thesis.

#### 1.1 Background

Broadband Wireless Access (BWA) has gained growing acceptance worldwide recently. Due to the increasing demand for wireless multimedia applications such as Voice over Internet Protocol (VoIP), Internet Protocol Television (IPTV), interactive gaming and multimedia conferencing, to efficiently manage bandwidth becomes a challenge. In order to support these applications, mobile (MS) undergo frequent battery drain due to inappropriate power saving model. Hence, energy conservation is also a challenge. In this research, these two key issues will be studied in BWA networks. Several BWA technologies are used in wireless networks but this research work focuses on the technologies based on IEEE 802.16 standard. The IEEE 802.16 standard had its first completed version in 2004 [1], and is a fixed BWA also known as Worldwide Interoperability for Microwave Access (WiMAX).

The term 'WiMAX' was coined by the WiMAX Forum to support the WiMAX technology and promote its commercial use. The WiMAX Forum is an industry consortium with hundreds of members, including WiMAX operators, equipment vendors and component vendors, which was formed in June, 2001. The goal of the Forum is to prepare profiles for equipments that comply with the 802.16 standard and carry out interoperability tests to ensure that equipment of the various vendors can coexist. The second version of IEEE 802.16e was completed in 2005 [2] with the addition of mobility features. Since then, several versions have been evolving to address the constantly emerging problems, such as Management Information Base (MIB), management and procedures, support relay topology and centralized/distributed control, and Advanced Air Interface targeting data rates of 100 Mbit/s mobile and 1 Gbit/s fixed.

Therefore, WiMAX supports fixed, nomadic, portable, and mobile wireless broadband connectivity without the need for direct Line-Of-Sight (LOS) communication with a Base Station (BS). It also uses three licensed spectrum bands including 2.3 GHz, 2.5 GHz and 3.5 GHz with channel bandwidths of 5 MHz–20 MHz and a frame size of 5 ms. These spectrum bands and channel bandwidths as well as this frame size allows WiMAX to offer theoretical

rates of up to 75 Mbps with coverage of up to 50 km. However, demographic conditions, such as buildings, weather, and terrain, limit the range to about 10 km.

Furthermore, WiMAX provides a wider service coverage, a high speed data rate, and QoS guaranteed services. These features can be achieved by the use of radio resources such as bandwidth and transmission power. Radio resource is anything to allocate to each service class in order to provide its requested service. The use of these resources present several challenges which include wireless medium with limited bandwidth, QoS to service classes, handoff, and lifetime of battery-powered devices. Bandwidth and power management techniques are highly needed in order to efficiently managed these resources as well as guaranteed QoS requirements to service traffics.

### 1.2 Problem Statement

Numerous studies have been conducted on how bandwidth and power resources can be efficiently utilized while maintaining the QoS requirements to various application. Although some studies focus on Call Admission Control (CAC) schemes [3–7] and scheduling algorithms [8–11], others target power saving algorithms [12–15]. Despite these studies, several challenges are left unresolved in the main research resource management issue, which include:

Current CAC algorithms, involve the use of linear adaptation technique to create more opportunities to both the new and the handoff connections into the networks, which leads to starvation of the highest priority service class and the lowest priority service class. The schemes also use an adaptive threshold which dynamically changes, based on either the arrival of handoff or new connections by considering a fixed maximum reserved bandwidth threshold for handoff connections. This may lead to inefficient resource utilization when the new and the handoff connection arrival rate occur frequently.

The adoption of static weights in scheduling algorithms to differentiate QoS requirements for the various service classes lead to increasing queue sizes under bursts of input traffic because the algorithms send fixed numbers of packets. Moreover, packet loss may occur in the presence of heavy input bursts, hence reducing throughput. Therefore, the use of fixed weights is adequate for constant-rate classes because of its fixed weighting priority for each queue. However, it is not suitable for variable-rate classes, because of the need for variable weighting of priority levels. These algorithms distinguish classes according to their QoS requirements but performs poorly under bursty traffic.

The existing energy saving algorithms prolong the battery life of an MS by adaptively adjusting the three-sleep parameters: idle threshold, initial sleep window, and final sleep window according to the residual energy and the traffic load. However, the algorithms minimizes the energy consumption of the MS at the expense of the average response delay due to the effect of the remaining energy.

These schemes also use the standard sleep mode algorithm to adjust the sleep interval and the listening mode but frequently goes into listening mode when the traffic is low, which leads to high-energy consumption.

# 1.3 Motivation

WiMAX networks are one of the BWA technologies that support high data rates, large coverage, and QoS to various applications. Due to the scarce resources in WiMAX networks, such as bandwidth and transmission power, resource utilization becomes a critical challenge.

Three issue which have high impact on this are CAC, packet scheduling, and power saving.

### 1.4 Research Objectives

The main objective of this research is to propose resource management algorithms, which consists of CAC, packet scheduling, and power saving as well as the DES, for WiMAX networks. The detailed objectives are as follows:

1. To propose a QoS-Aware CAC With Bandwidth Reservation (BR) and Bandwidth Degradation (BD) algorithm in IEEE 802.16e Networks by introducing new admission criteria and an adaptive threshold in order to efficiently utilize the resources and assure QoS to various applications. In addition, to propose an analytical model for the proposed QoS-Aware CAC With BR and BD algorithm.

2. To propose a Load-Aware Weighted Round-Robin (LAWRR) algorithm for IEEE 802.16 networks that dynamically adjusts the weight based on the traffic load and the static weight in order to improve the QoS of different applications.

3. To propose an Efficient Battery Lifetime Aware Power Saving (EBLAPS) algorithm in IEEE 802.16e Networks that uses three energy saving parameters (idle threshold, initial sleep parameter and final sleep parameter) and an improved sleep mode control algorithm to extend the battery life of an MS and QoS guarantee to service classes.

4. To design and develop a DES for the resource management algorithms in WiMAX networks.

#### 1.5 Research Scope

This research focuses on QoS provisioning to various applications and the battery-life extension for MSs at the Media Access Control (MAC) layer in WiMAX networks. It first concentrates on how new and handoff connections are admitted into the 802.16e networks while ensuring the QoS of all the service classes as well as the best use of network resources. More focus is given to the admission criteria policy, an adaptive reserve threshold, for handoff connections. Then, on how to increase the service rate of the algorithms in 802.16 networks in order to increase the number of queued packets to be served under bursty traffic condition considering only four service classes in the Downlink (DL) direction. Finally, the adaptive adjustment of three energy saving parameters, idle threshold, the initial sleep window, and the optimized final sleep window, will be studied analytically to prolong the energy battery-life in IEEE 802.16e networks considering only the non-real time traffic in the DL direction.

### 1.6 Research Significance

Wireless communication is the leading communication technology with the highest number of subscribers worldwide because of its mobility feature. To satisfy the service requirements of these subscribers, there is need to have an effective and efficient way in assuring QoS and longer connectivity to the network by these subscribers as well as simultaneously optimize the available resources as the bandwidth and the transmission power are limited. The use of traditional approaches to achieve these requirements may lead to an inefficient resource utilization and failure to achieve subscriber's QoS requirements as well as quick depletion of the battery which leads loss of connectivity to the network.

WiMAX being one of the emerging broadband wireless technology is anticipated to efficiently managed the available resources and guaranteed QoS to each subscriber. With the efficient algorithms such as CAC, packet scheduling and energy saving, the QoS and longer connectivity to the work will be guaranteed for the subscribers; thereby attract more subscribers and hence the network capacity will be optimized. Thus, the overall revenue generated by the service providers will be increased.

### 1.7 Research Contributions

1. A QoS-Aware CAC With bandwidth reservation and degradation algorithm in IEEE 802.16e Networks has been proposed. The proposed algorithm determines bandwidth admission criteria based on a scheduling service class.

In these admission criteria, a bandwidth-degradation policy is used to admit more users in order to prevent starvation. An adaptive threshold has been introduced to dynamically adjust the quantity of reserved bandwidth for handoff-connections based on the traffic intensity of handoff requests to improve the efficient utilization of bandwidth. In addition, an analytical model for the proposed QoS-Aware CAC With BR and BD algorithm is also developed.

2. A LAWRR algorithm for downlink traffic in 802.16 networks has been proposed to improve the performance of WRR. It dynamically determines the weight of each queue in the various classes, based on current traffic characteristics, using the static WRR weight at the beginning of each base-station round.

3. An EBLAPS algorithm for the IEEE 802.16e networks has been proposed that extends the battery life of an MS. The three sleep parameters are analytically enhanced according to the downlink stochastic traffic arrival pattern of an MS in order to reduce the response delay as well as energy consumption. Moreover, an improved sleep mode control algorithm has been introduced to reduce the frequent transition to listening mode in case of low traffic.

4. DES has been designed and developed for the resource management algorithms such as CAC, packet scheduling, and power saving.

### 1.8 Thesis Organization

The rest of this thesis is organized as follows: Chapter two presents the evolution of the 802.16 standard and related research that address the CAC, packet scheduling and energy saving algorithms.

Chapter 3 presents the performance analysis strategies, research framework, and the proposed discrete event simulator used in this research and explores the stages in detail. The experimental setup and topologies as well as the performance metrics and validation of the model have been presented in this chapter.

Chapter 4 explores the design of the proposed QoS-Aware CAC With Bandwidth Degradation and Reservation Algorithm in IEEE 802.16e Networks. It presents the algorithm, and the analytical model of the algorithm. The chapter also presents the evaluation of the proposed scheme in terms of the throughput, new-connection blocking rate, and handoff-dropping rate. In addition, the numerical results and the simulation results have been compared.

Chapter 5 presents the proposed LAWRR algorithm for IEEE 802.16 networks. The chapter also presents the performance evaluation of the algorithm

and compares it with WRR algorithm.

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Chapter 6 presents the proposed EBLAPS algorithm in IEEE 802.16e Networks. The chapter also presents the performance evaluation of the algorithm and compares it with other algorithms.

Chapter 7 concludes the work and recommends some promising directions for further research.



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