UNIVERSITI PUTRA MALAYSIA

TIME DIVISION MULTIPLE ACCESS-BASED SCHEDULING ALGORITHM FOR QUALITY OF SERVICE ENHANCEMENT IN IEEE 802.11s WIRELESS MESH NETWORKS

ABDULNASSER AHMED MOHAMMED

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By

ABDULNASSER AHMED MOHAMMED

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

January 2021

DEDICATION

To my father,

To my mother, my brothers, my sisters, my lovely wife, and my Daughter Anwar.

Finally, To All whom I love.

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

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Chairman : Professor Borhanuddin bin Mohd Ali, PhD
Faculty : Engineering

Many challenges face the next generation of wireless communication systems that need to be bound to coexist with each other. The quality of service (QoS) and the performance restrictions are some of them which occur in TDMA in a multi-hop environment. There have been researches and standardization efforts to apply QoS at Media Access Control (MAC) layer. However, the significant performance parameters will directly impact the preparation of the information for the MAC layer before any schedule is run. The particular objective of this is the QoS and performance restrictions in wireless mesh networks based on IEEE 802.11s.

Consequently, the degradation of QoS in the network would occur in packet delay and packet loss. Packet delay occurs during the transmission process, where stations may release an Access Point (AP) through which they are connected and join another. Packet loss occurs when it has to wait for an excessive length of time and in the case of real-time streaming like video, where keeping them will not be useful and will only cause further delays to the subsequent packets, which adversely affects the QoS. Power consumption is another important metric that can be affected due to 'idle listening', which happens when a station is neither transmits nor receives ongoing communication through the shared medium. In particular, this thesis presents the scheduling of packets in multi-hop wireless mesh networks based on IEEE 802.11s. Two primary aspects are gathering the network information and how the information is used upon scheduling. This study introduces Enhanced Dynamic (ED-TDMA) to exchange the information between Stations (STAs) and Mesh Access Point (MAP), where the overlapping of the coverage area occurs. The utilization of this information follows this to support all the scheduling operations. During the first operation, information on the STAs in the neighboring network is provided from the MAPs. Next is, deciding the available STAs through the network side, followed by taking traffic

type into account. The first procedure is Optimum Dynamic Reservation (ODR-TDMA). It serves video users with packet delays higher than the threshold set in the network, thus maintaining its QoS. It reduces 15% of the packet loss and 17% of the average delay. It also increases throughput by 7%. The second procedure is High Priority Optimum Dynamic Reservation (HPODR-TDMA). It extends ODR-TDMA by giving STAs having higher delays than the higher delay threshold classified into three classes. Class I users experience a smaller packet loss and higher throughput compared to other classes. It succeeds in reducing the packet loss by 19% and increases throughput by 9%. The third Enhanced Peer Specific Power Saving Mode (E-PSPSM) focuses on power saving by switching between light sleep mode and deep sleep mode techniques. It decreases the power consumption in deep sleep mode by an average of 13%, the average delay by 16%, and increases throughput by 14 %. All these are achieved by way of the enhancement of the information exchange between STAs and MAPs. Subsequently, ODR-TDMA has the best performance in minimizing the packet delay while HPODR-TDMA gives the best performance in reducing packet loss and increasing throughput, and finally, E-PSPSM is the best in reducing power consumption.

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

ALGORITMA CAPAIAN BERBILANG PEMBAHAGI MASA BERASASKAN PENJADUALAN UNTUK PENINGKATAN KUALITI PERKHIDMATAN DALAM RANGKAIAN WAYARLES JEJARING IEEE802.11S

Oleh

ABDULNASSER AHMED MOHAMMED

Januari 2021

Pengerusi : Profesor Borhanuddin bin Mohd Ali, PhD
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Terdapat banyak cabaran yang dihadapi generasi komunikasi sistem tanpa wayar yang perlu disekat untuk mencapai kesatuan antara satu sama lain. Kualiti perkhidmatan (QoS) dan sekatan prestasi adalah beberapa di antaranya yang berlaku di TDMA dalam persekitaran multi harapan. Sejumlah individu dan organisasi sedang melakukan beberapa penyelidikan dan berusaha melakukan standardisasi untuk menerapkan dan membangunnya dalam lapisan MAC. Walau bagaimanapun, parameter prestasi yang ketara akan menerima kesan langsung dari penyediaan maklumat untuk lapisan MAC sebelum penjadualan dijalankan. Objektif khusus ini adalah QoS dan sekatan prestasi dalam rangkaian mesh tanpa wayar berdasarkan IEEE 802.11s. Akibatnya, penurunan QoS dalam rangkaian akan berlaku iaitu, penundaan paket dan kehilangan paket. Kelewatan paket berlaku semasa proses penghantaran di mana stesen boleh melepaskan titik akses di mana mereka disambungkan, dan bergabung dengan yang lain. Kehilangan paket boleh berlaku apabila perlu menunggu jangka masa yang berlebihan dan dalam hal penstriman masa nyata seperti video, di mana menyimpannya tidak akan berguna dan hanya akan menyebabkan kelewatan lebih lanjut pada paket berikutnya, dan ini memberi kesan buruk kepada QoS. Penggunaan tenaga juga merupakan matrik penting lain yang dapat dilaksanakan kerana 'pendengaran terbiar' yang berlaku ketika stesen tidak menghantar atau menerima komunikasi berterusan melalui media bersama. Khususnya, tesis ini ditulis dengan tujuan untuk menggambarkan penjadualan dalam rangkaian mesh tanpa wayar multi-hop berdasarkan IEEE 802.11s dengan lebih terperinci. Ada dua aspek utama untuk ini, yaitu pengumpulan informasi rangkaian, diikuti dengan bagaimana informasi tersebut digunakan semasa penjadualan. Kajian ini memperkenalkan Enhanced Dynamic (ED-TDMA) untuk menukar maklumat antara STA dan Mesh Access Point (MAP), di mana pertindihan berlaku di kawasan liputan. Ini diikuti dengan memanfaatkan informasi ini untuk mendukung semua operasi penjadualan. Semasa operasi pertama, maklumat mengenai STA di rangkaian tetangga diberikan dari titik akses mesh. Sebaliknya,

menentukan STA yang tersedia melalui sisi rangkaian, diikuti dengan mengambil kira jenis lalu lintas adalah operasi kedua. Tempahan Dinamik Optimum (ODR-TDMA) adalah prosedur pertama kajian ini. Ia melayani pengguna video dengan kelewatan paket yang lebih tinggi daripada ambang yang ditetapkan dalam rangkaian, sehingga mempertahankan QoSnya. Ini mencapai kejayaan dalam mengurangkan peratusan 15% kehilangan paket dan 17% dari kelewatan purata. Ia juga berjaya meningkatkan throughput dengan 7%. Prosedur kedua kajian ini adalah Tempahan Dinamik Optimum Prioriti Tinggi (HPODR-TDMA). Ini memperluas mekanisme ODR-TDMA dengan memberi lebih keutamaan untuk melayani STA yang mempunyai kelewatan lebih tinggi daripada ambang penundaan yang lebih tinggi di mana mereka diklasifikasikan menjadi tiga kelas. Pengguna Kelas I mengalami jumlah kehilangan paket yang lebih kecil dan throughput yang lebih tinggi berbanding kelas yang lain. Ia mencapai kejayaan dalam mengurangkan kehilangan paket untuk Kelas I dengan peratusan 19%. Sebaliknya ia meningkatkan throughput untuk Kelas I dengan peratusan 9%. Prosedur ketiga kajian ini yang dipusatkan adalah Enhanced Peer Specific Power Saving Mode (E-PSPSM) datang untuk menjimatkan penggunaan kuasa rangkaian dengan menggunakan mod tidur ringan dan teknik mod tidur nyenyak. Ini mengurangkan daya penggunaan dalam mod tidur ringan dengan rata-rata 13%. Dan 14% dalam mod tidur nyenyak. Ia berjaya mengurangkan kelewatan purata dalam mod tidur nyenyak 18%. Dan ini meningkatkan throughput dengan peratusan 19% dalam mod tidur ringan dan 14% dalam mod tidur nyenyak. Berdasarkan hasil kajian ini, kelebihan kaedah ODR-TDMA, HPODR-TDMA dan E-PSPSM yang dilaksanakan di sini telah dibuktikan melalui peningkatan jangka masa pertukaran maklumat antara STA dan titik akses jaringan. Selepas itu, ODR-TDMA mempunyai prestasi terbaik dalam aspek meminimumkan penundaan paket sementara HPODR-TDMA mempunyai prestasi terbaik dalam aspek meminimumkan kehilangan paket dan meningkatkan throughput dan E-PSPSM mempunyai prestasi terbaik dalam aspek meminimumkan penggunaan kuasa .

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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LIST OF ABBREVIATIONS

AP	Access Point
BS	Base Station
BSS	Basic Service Set
TDMA	Time-Division Multiple Access
FDMA	Frequency Division Multiple Access
CDMA	Code Division Multiple Access
CSMA/CA	Carrier Sense Multiple Access/ Collision avoidance
CRC	Cyclic Redundancy Check
DR-TDMA	Dynamic Reservation Time Division Multiple Access
ODR-TDMA	Optimum Dynamic Reservation Time Division Multiple Access
HPODR-TDMA	High Priority Optimum Dynamic Reservation – Time Division Multiple Access
E-PSPSM	Enhanced Peer Specific Power Saving Mode
ESS	Extended Service Set
FDMA	Frequency Division Multiple Access
FDR-TDMA	Fair Dynamic Reservation Time Division Multiple Access
GHZ	Giga Hertz
HWMP	Hybrid Wireless Mesh Protocol
IBSS	Independent Basic Service Set
IEEE	Institute of Electrical and Electronics Engineers
WLAN	Wireless local Area Network
LMDS	Local Multipoint Distribution Service
LTE	Long Term Evaluation

MAC	Media Access Control
MAP	Mesh Access Point
MBWA	Mobile Broadband Wireless Access
MCCA	Mandatory Controlled Channel Access
MP	Mesh Point
MPP	Mesh Point plus Portal
Nv	Number of Video Users
OFDM	Orthogonal Frequency Division Multiplexing
PSM	Power Save Mode
PSPSM	Peer Specific Power Saving Mode
PSPSM-SimQPN	Peer Specific Power Saving Mode with Simulation of Queuing Petri Nets
QPN	Queuing Petri Nets
QoS	Quality of Service
RF	Radio Frequency
RAM	Random Access Memory
Rslot	Bit Rate Per Slot
RV	Average Bit Rate Per Video User
STAs	Stations
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMN	Wireless Mesh Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Networks

CHAPTER 1

INTRODUCTION

1.1 Introduction

The integration between all communications networks is considered one of the main challenges in the communication world. Many protocols have been established for each kind of network to deal with different networks. Many issues have been considered: Quality of Service (QoS) and power-saving are just two of them. Enhancing the QoS to meet the communications requirements and meet user satisfactions with minor power consumption is one of the main challenges in wireless communications.

One of the exciting wireless communications technologies is Wireless Mesh Networks (WMNs) [1]. WMN can integrate many types of communications networks, one of which is WiFi, the commercial name for IEEE802.11 standards. WiFi enables wireless access for wireless devices to the internet within 100 m indoor and 300 m outdoor. Several standards and drafts function with WiFi are available; they are IEEE 802.11a, 802.11 b/g, 802.11n, 802.11e, and 802.11i. Each of them has its unique properties since they are constructed to support various criteria.

IEEE 802.11s encompasses all of the modifications made to the specification of earlier protocols. It was constructed based on the improvement of 802.11a/b/g/n for physical interface; 802.11e for access to the medium; and 802.11i for security [2]. IEEE 802.11s assimilates mesh networking services and protocols with 802.11 at the Media Access Control (MAC) Layer. Accordingly, it expected to broaden the utilization of mesh networks just as the 802.11a, b, and g standards enlarged wireless Local Area Networks (WLANs). The IEEE 802.11s-based WMN technology comprises (i) Mesh Point (MP), which serves as the fundamental entity in the network. It shares the same characteristics with the legacy 802.11 stations and is utilized to set up and support multi-hop paths to relay traffic. (ii) Mesh Access Point (MAP), which provides wireless access to wireless stations. (iii) Mesh Points Plus Portal (MPP) serves as a gateway to different networks such as the internet. (iv) User devices, or generically referred to as stations (STAs), can function with the legacy 802.11 interfaces. However, information regarding the mesh network might not be available to them [3].

IEEE 802.11s working group crafted standards that render the network more adaptable and tolerant to drawbacks vis-a-vis centralized infrastructure networks. The network should be able to sustain temporary congestions, single-node failures, and limited interference. It has an embedded capacity to detect adjacent nodes, establish connections, and locate optimal traffic paths [4]. The IEEE 802.11s deals with several addendums in its standard, i.e., topology learning, routing and forwarding, security, measurement, discovery and association, medium-access coordination, compatibility to 802.11 services, interworking, configuration and management. The standard is constructed to boost, consolidate and provide an efficient standard for WMNs, eliminate the constraints of preceding WLAN standards and integrate everything in one standard.

1.2 Background and Motivation

As has been alluded to above, a wireless mesh network integrates also integrates WLAN in the mesh network. WLAN mesh consists of WLAN devices with relay functions that communicate directly with each other instead of communicating via Base Stations (BSs) or Access Points (APs). The WLAN mesh network has many features, such as flexible broadband network configuration independent of the fixed network. WLAN has widespread use as a means of achieving broadband wireless communication. It is an area of ongoing technical innovation such as on the QoS and high-speed technology, where researchers have used many techniques to achieve these objectives. Maintaining them using the weighting factor is a commonly used approach where the weight given to data plays a significant enhancement in getting better QoS, less power consumption and fair scheduling [5-8]. Other features include higher data transmissions rate due to shortened communication distance, expanded network capacity through spatial frequency reuse, automatic network configuration, and improved robustness due to route recovery mechanism. The IEEE 802.11s standard envisions a small-to-medium scale WLAN mesh network configured with a maximum of 32 Mesh Points (MPs), including MAPs where each MAP can be connected to many STAs, enabling the entire network to accommodate several hundred terminals [9].

This chapter briefly introduces WMNs, problem statement, aim, objectives, research scope, thesis contributions, and thesis organization.

1.3 Problem Statement

A wireless mesh network (WMN) is a communication network that integrates different networks into one network. In WMN based on IEEE 802.11s, mobile mesh stations can establish a new mesh link and release others through mesh points. Each one of them runs its specific protocols to communicate with each other. However, there are some limitations when doing releasing and establishing new connections. These limitations can be addressed and summarized as follows:

- Packet delay can occur during the transmission process because of the dynamic environment in IEEE 802.11s, where stations may release an AP through which they are connected and join another.

- Packet drops can occur when it has to wait for an excessive length of time, and in the case of real-time streaming like videos, keeping them will not be useful and will only cause further delays to the subsequent packets, which adversely affects the QoS.

- A significant amount of power is wasted due to 'idle listening', which happens when a station neither transmits nor receives ongoing communications through the shared medium; it is just listening.

This thesis addresses these issues through adaptive scheduling algorithms, which will be shown to achieve the QoS requirements and keep power usage at acceptable levels. The algorithms depend on two main parameters; the number of video users and the decision weighting factor for choosing the number of users. This weighting factor lies be between 1 and 1.04, as will be explained in Chapter 3. The main algorithm works by finding the corresponding weighting factor for each video user, which guarantees that it achieves the QoS and reduces the power consumption of the network.

1.4 Aim and Objectives

The main objectives of this thesis are to propose an algorithm that aims to serve users who have higher delay than others to be done first. With a priority to those users, more emphasis is given to those who have higher delay than others, and classified into three classes is considered the second objective. On the other hand, saving power consumption is considered to be the third objective of this research.

The detailed objectives of this thesis are as follows:

1. To propose a method called Optimum Dynamic Reservation Time Division Multiple Access (ODR-TDMA) reduces packet delay occurring in multi-hop environments where stations may release an access point (AP) which they are connected to and join another.

2. To propose an algorithm that reduces packet loss and maintains high throughput when the number of stations is high by way of a dynamic scheduling method called High Priority Optimum Dynamic Reservation – Time Division Multiple Access (HPODR-TDMA). It classifies video streams having packet delays higher than a set threshold and then allocates extra slots according to their respective classifications.

3. To propose an algorithm called Enhance Peer Specific Power Saving Mode (E-PSPSM) that reduces the power consumption in WMN by putting the STAs into light or deep sleep mode, respectively, when not active.

1.5 Research Scope

This thesis focuses on the MAC Layer scheduling based on TDMA multi-hop as a critical enhancement in the 802.11s standard. It concentrates on packet delay when it propagates from the sender nodes to the MAP. Packet delay can occur during the transmission process because of the dynamic environment of IEEE 802.11s, where stations may release an AP and join another. As a result of that delay, packets may be dropped as late packets are no longer time in a real-time communication scenario. Additionally, power consumption for those delayed users increases while waiting to be served due to 'idle listening' where an STA is neither a transmitter nor a receiver on the shared medium.

1.6 Thesis Contribution

The main contributions of this thesis are as follows:

1. A method called Optimum Dynamic Reservation Time Division Multiple Access (ODR-TDMA) serves video users with packet delays that are higher than the threshold set in the network, thus maintaining its QoS,

2. An algorithm named High Priority Optimum Dynamic Reservation – Time Division Multiple Access (HPODR-TDMA) that classifies video streams having packet delays that are higher than a set threshold and then allocate extra slots according to their respective classifications,

3. An algorithm called Enhance Peer Specific Power Saving Mode (E-PSPSM) reduces power consumptions in the WMN by putting the STAs into light or deep sleep mode, respectively, when not active. It contributes to the improvement in packet delay, throughput and power consumption.

1.7 Thesis Organization

This thesis is organized as follows:

Chapter 1 presents the background, problem statement, objectives, research scope, thesis contribution, and thesis structure.

Chapter2 elucidates the background of the subjects related to the methodology employed in the thesis. It presents the literature review concerning several scheduling algorithms relevant to WMNs using the TDMA scheduling technique.

Chapter 3 presents the framework of the thesis and describes the stages in detail. Simulation experimental setup and topologies, and performance metrics and their evaluation methods are also presented. It describes the design and implementation of the QoS enhancement by using ODR-TDMA in wireless mesh networks based on IEEE 802.11s. It offers the new algorithm HPODR-TDMA for serving users with high priority. It shows a detailed description of dynamic scheduling for WMNs based on IEEE 802.11s. The procedure and implementation of the HPODR-TDMA algorithm are based on the ODR-TDMA method. The simulations are described in some detail. Finally, it presents E-PSPSM to reduce the power consumptions in WMNs based on IEEE 802.11s.

Chapter 4 presents and discusses the results for ODR-TDMA and HPODR-TDMA. It discusses the performance of ODR-TDMA, HPODR-TDMA and their impact on Dynamic Reservation TDMA and Fair Dynamic Reservation TDMA in terms of packet loss, packet delay and throughput. It also discusses the results for E-PSPSM and its impact on PSM and PSPSM-SimQPN in terms of power consumption, delay and throughput in light sleep mode and deep sleep mode, respectively.

Chapter 5 concludes the work and recommends directions for future research.

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