UNIVERSITI PUTRA MALAYSIA

EFFICIENT BACK-OFF MECHANISM FOR MULTIMEDIA SUPPORT IN IEEE 802.11E

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EFFICIENT BACK-OFF MECHANISM FOR MULTIMEDIA SUPPORT IN IEEE 802.11E

By

AWS ALI SHAKIR AL-NUAIMI

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

February 2012

This thesis is especially dedicated to my family: first and foremost, to my dad, Dr. Ali Shakir, whose mentorship and financial support led me to apply for admission into the master degree programme.

Special thanks to my dear mum, brother and sister, without their continued moral and encouragement, this work will not have been possible. The psychological disturbance of having to part with a dear son and brother for solid years without seeing is in itself, in fact, a big sacrifice and hence deserves commendation.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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February 2012

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The IEEE 802.11e standard of Wireless Local Area Network (WLAN) has been designed for improving the Quality of Service (QoS) of real-time applications. The back-off mechanism used in MAC layer of this standard cannot be adjusted dynamically in the event of network situation change.

This research attempts to look into ways to produce an effective back-off mechanism that is adaptive dynamically to the network status and able to support QoS for real-time applications over wireless ad-hoc networks based on the IEEE 802.11e standard. The current research proposes a new algorithm so-called Dynamic Fast Adaptation of back-off algorithm for contention-based EDCA (DFA-EDCA) mechanism. The main concept of the DFA-EDCA algorithm is to use exponential functions to tune the back-off parameters adaptively according to changes in network

load and serve the time-bounded multimedia applications rapidly. In addition, the DFA-EDCA algorithm also provides an intra-AC differentiation mechanism to increase the back-off time randomness and achieve discrimination of the same traffic priority on different stations.

The proposed algorithm has significantly reduced both collision rate and packet delay simultaneously with an obvious increment in both system goodput and channel utilization ratio which leads to the quality improvement of multimedia applications. The performance evaluations are conducted by using NS-2 simulator. The simulation results demonstrate that the proposed algorithm has greatly outperformed the previous mechanisms such as the non-linear dynamic adaptation scheme of the minimum contention window (CW_{min} HA), dynamic adaptation algorithm of the maximum contention window (CW_{max} adaptation), Adaptive Enhanced Distributed Coordination Function (AEDCF), Random adaptive MAC parameters scheme RAMPS and the conventional EDCA mechanism.

The results show that proposed DFA-EDCA scheme has significantly decreased the collision rate in the whole network by 34.6 %, and reduced the mean audio and video delay by 18.5 % and 20.8 % respectively compared with CW_{min} HA scheme in the heavy load network. It also improves the goodput of the system by 19 % and the channel utilization ratio by 10.6 %. On the other hand, in the light load network, the DFA-EDCA improves the total throughput by 7.1 % and the total end-to-end delay by 8.3 % compared to RAMPS scheme.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

CEKAP BACK-OFF MEKANISME UNTUK SOKONGAN MULTIMEDIA DALAM IEEE 802.11E

Oleh

AWS ALI SHAKIR AL-NUAIMI

Februari 2012

Pengerusi: Alyani bt. Ismail, PhD

Faculti: Kejuruteraan

IEEE 802.11e standart Wireless Local Area Network (WLAN) dicipta khas untuk meningkatkan Quality of Service (QoS) bagi aplikasi real-time multimedia. Back-off mekanisme yang digunakan dalam MAC piawaian ini tidak boleh dilaras secara dinamik sekiranya berlaku perubahan keadaan rangkaian.

Penyelidikan semasa cuba untuk mengkaji cara-cara untuk menghasilkan yang berkesan back-off mekanisme di mana ia dapat menyesuaikan diri dengan beban saluran dan dapat menyokong QoS untuk aplikasi real-time yang lebih rangkaian wireless ad-hoc berdasarkan IEEE 802.11e standart. Kajian ini mencadangkan algoritma baru yang dipanggil Adaptasi Dinamik Fast algoritma back-off untuk perdebatan berasaskan mekanisme EDCA (DFA-EDCA). Konsep utama algoritma DFA-EDCA adalah dengan menggunakan fungsi eksponen untuk menala back-off

parameters adaptif mengikut perubahan dalam beban rangkaian dan berkhidmat aplikasi multimedia masa terbatas dengan masa yang lebih singkat. Di samping itu, algoritma DFA-EDCA juga menyediakan satu mekanisme intra-AC differentiation untuk meningkatkan kerawakan back-off time dan mencapai diskriminasi keutamaan trafik yang sama di stesen yang berbeza.

Algoritma yang dicadangkan itu telah dikurangkan dengan ketara kedua-dua kadar perlanggaran dan kelewatan paket serentak dengan kenaikan yang jelas di kedua-dua goodput nisbah penggunaan sistem dan saluran yang membawa kepada peningkatan kualiti aplikasi multimedia. Penilaian prestasi yang dijalankan dengan menggunakan simulator NS-2. Keputusan simulasi menunjukkan bahawa algoritma yang dicadangkan telah banyak mengatasi mekanisme sebelumnya seperti skim penyesuaian dinamik tak linear tetingkap perdebatan minimum (CWmin HA), algoritma penyesuaian dinamik tetingkap perdebatan maksimum (CWmax penyesuaian), Adaptive Enhanced Distributed Penyelarasan Fungsi (AEDCF), skim Random adaptive MAC tanjakan parameter dan mekanisme EDCA konvensional.

Keputusan menunjukkan bahawa dicadangkan DFA-EDCA skim telah dengan ketara mengurangkan kadar perlanggaran di seluruh rangkaian oleh 34.6%, dan mengurangkan min audio video dilewatkan sebanyak 18.5%, dan 20.8% masing-masing berbanding dengan skim CWmin-HA dalam rangkaian beban berat. Ia juga memperbaiki goodput sistem sebanyak 19% dan nisbah saluran penggunaan sebanyak 10.6%. Sebaliknya, dalam rangkaian beban ringan, DFA-EDCA memperbaiki jumlah throughput oleh 7.1% dan jumlah akhir-o-akhir dilewatkan dengan 8.3% berbanding dengan skim tanjakan.

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I certify that a Thesis Examination Committee has met on 8 February 2012 to conduct the final examination of Aws Ali Shakir Al-Nuaimi on his master of science thesis entitled "EFFICIENT BACK-OFF MECHANISM FOR MULTIMEDIA SUPPORT IN IEEE 802.11E" 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 Master of Science.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

AWS ALI SHAKIR AL-NUAIMI

Date: 8 February 2012

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LIST OF ABBREVIATIONS

ACK	Acknowledgment
AIFS	Arbitration Inter-Frame Space
AIFSN	Arbitration Inter Frame Spacing Number
AP	Access Point
AC	Access Category
AEDCF	Adaptive Enhanced Distributed Coordination Function
BSS	Basic Service Set
BE	Best Effort
BK	Background
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CTS	Clear To Send
CW	Contention Window
CW_{max}	Contention Window Maximum
CW_{min}	Contention Window Minimum
CBR	Constant Bit Rate
DCF	Distributed Coordination Function
DIFS	Distributed Inter-Frame Space
DE-AEDCA	Differentiation Enhanced Adaptive EDCA
DFA-EDCA	Dynamic Fast Adaptation of back-off algorithm for contention-based EDCA
ESS	Extended Service Set
EDCA	Enhanced Distribution Channel Access
EDCF	Enhanced Distributed Coordination Function

EDCA-LA	Enhanced Distributed Channel Access with Link Adaptation
EIFS	Extended Inter-Frame Space
EWMA	Exponentially Weighted Moving Average
FTP	File Transfer Protocol
FIFO	First In - First Out
FR	Frozen Rate
HC	Hybrid Coordinator
HCF	Hybrid Coordination Function
HCCA	Hybrid Coordination Function Controlled Channel Access
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IBSS	Independent Basic Service Set
ITU-T	International Telecommunication Union – Telecommunication
IFS	Inter-Frame Space
LAN	Local Area Network
L_{retry}	Retry Limit
MAC	Medium Access Control
MF	Multiplicative Factor
NAV	Network Allocation Vector
NS-2	Network Simulator 2
OSI	Open Systems Interconnect
OTcl	Object oriented extension of Tcl
PCF	Point Coordination Function
PHY	Physical Layer
PIFS	Priority Inter-Frame Space

PI	Proportional Integrator
PF	Persistence Factor
QoS	Quality of Service
QBSS	Quality of Service aware Basic Service Set
RTS/CTS	Request to Send/Clear to Send
RAMPS	Random Adaptive MAC Parameters Scheme
SIFS	Short Inter-Frame Space
SD-AEDCA	Load Adaptive EDCA with Enhanced Service Differentiation
TXOP	Transmit Opportunity
TC	Traffic Category
TCP	Transmission Control Protocol
Tcl	Tool Command Language
UDP	User Datagram Protocol
UP	User Priority
VoIP	Voice over IP
VCH	Virtual Collisions Handler
VBR	Variable Bitrate
WG	Working Group
WiFi	Wireless Fidelity
WLAN	Wireless Local Area Network
WMM	Wireless Multi Media

CHAPTER 1

INTRODUCTION

1.1 Overview

Wireless local area networks (WLANs) are widely used in many situations, as they provide an easy facility to collect and process information. The IEEE 802.11 is the most common wireless standard used in wireless local area networks (WLANs). The ad-hoc mode is one type of wireless networking mode that is used in a military environment [1] and it later came to the common life environment (for example, airports and hospitals). The main characteristics that attract attention in ad-hoc networks are the network topology and volume of traffic that can be handled over the network. This kind of networking has the ability to provide network support in areas that would be impossible for the wired counterpart. Figure 1.1 shows a sample of an ad-hoc network.

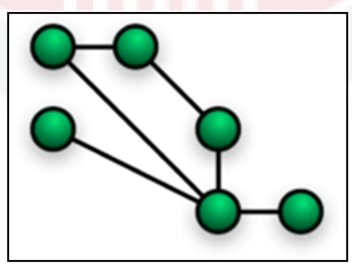

Figure 1.1. Small Ad-hoc Network

Referring to Figure 1.1, stations in ad-hoc networks are randomly distributed and have the ability to communicate with each other without the presence of a central controller such as an access point. Quality of Service (QoS) support is considered as one of the key challenges that must be overcome in order to realize the convenient benefits of ad-hoc networks. It is worth mentioning that the QoS is defined as the ability of a network to deliver consistent pre determined results or it is a set of service requirements to be met by the network while transporting a flow, as defined by the *Internet Engineering Task Force* (IETF) [2].

Concerning WLANs that are based on the IEEE 802.11 standard, all stations share the network capacity and no packet gets priority over any other. Despite its popularity, the standard lacks any built-in QoS support by virtue of supporting only the "best effort" services [3] [4]. Since the key concept of networking in wireless form without having to lay cables has become massively popular, an interest in sending data derived from multimedia services (e.g. video, audio, and data) has begun to grow rapidly in the WLAN arena. For various application levels, different requirements of QoS are needed. For instance, real-time applications such as audio and video conferences are delay-sensitive. Thus, packets have to be transported across the network within a proper time. On the other hand, the delay sensitivity in non real-time applications such as File Transfer Protocol (FTP) is not a critical issue whereby some delays can be tolerated.

Therefore, the IEEE 802.11 TGe (task group E) enhanced the original 802.11 Medium Access Control (MAC) protocol to meet QoS requirements for different applications in WLANs. They proposed a supplementary standard (i.e. 802.11e) which introduced a new coordination function for the support of applications with QoS requirements. The new coordination function combines two medium access mechanisms: the contention-based access mechanism known as *enhanced distributed* *channel access* (EDCA) and the contention-free access mechanism known as *hybrid coordination function* (HCF) *controlled channel access* (HCCA). The first mechanism delivers traffic based on differentiating user priorities (UPs). The second mechanism allows for the reservation of transmission opportunities (TXOPs) with the hybrid coordinator (HC). However, the IEEE 802.11e has been completed and published as part of the IEEE Std. 802.11-2007 [5] standard. As stated in [6], "the 802.11e will remain an important technology and therefore simple mechanisms for improving its performance will continue to be studied and eventually included in the evolving standard".

This thesis only considers the contention-based medium access mechanism (EDCA) and proposes some enhancements to it. EDCA provides classes of service mechanisms allowing packets to gain priority by defining four traffic classes, each with its own queue. By default, these queues would be reserved for audio, video, best-effort and background traffic. Differentiation among these classes is achieved by differentiating three key parameters as follows: TXOP duration during which a wireless station can send consecutive frames after it acquires the channel, the length of the contention window to be used for the back-off (CW) and the amount of time known as Arbitration Inter-Frame Space (AIFS) during which a wireless station senses the channel to be idle. These parameters can be used to provide differentiation over the channel access among flows with different priorities. The next chapter gives a more detailed description of EDCA Differentiation. Although the EDCA mechanism improves the QoS of real-time applications, the performance obtained is not optimal since the mechanisms used incur a high probability of collisions and high delays.

In the literature, several researchers have studied QoS in WLAN ad-hoc networks. It is observed that most of their researches are focused on solutions at the MAC sub-layer. As stated in [7], the QoS provisioning is not possible unless supported by the MAC protocol. To sum up, one aspect of the specification of IEEE 802.11e, the QoS support for delay-sensitive multimedia applications and the variety of techniques used to serve such sensitive applications, has opened an issue for the current research. This research focuses on the EDCA MAC sub-layer which deals with traffic priorities and the back-off procedure during each contention cycle at each wireless station.

1.2 Problem Statement

The enhancement of WLAN faces numerous obstacles and challenges that dramatically affect the general performance of these networks in terms of throughput, which includes a noticeable increase in time delays. Throughput and service delay are vital elements in Quality of Service (QoS) determination. With the ongoing improvements in wireless network standards by the Institute of Electrical and Electronics Engineers (IEEE) association to provide enhanced QoS for delay-sensitive applications, such as the IEEE 802.11e 2005, researchers are still attempting to provide solutions to solve wasted bandwidth and time delays that exist in the latest working standards.

One of the resulting problems that arise due to the working nature of some MAC techniques in a WLAN is the problem of increased collision rates for data packets sent on the shared wireless medium in parallel with an increase in the number of users. Current solutions for collision reduction suffer from large time delays on received data packets. Such problems face the WLAN infrastructure in general, and the Ad-hoc mode specifically, due to the absence of a central coordinating unit such as an access point (AP). In this matter, an insight into the exact issue and a performance analysis of the mechanisms used in data services is required to overcome such a limitation. The IEEE 802.11e standard was specifically proposed to support QoS for real-time applications as it has become an important factor in user networks today.

The aforementioned standard utilizes a differentiation protocol such the EDCA protocol which is based on access category priorities, as explained in the next chapter, to enhance and support such applications. Although the EDCA mechanism improves the QoS of real-time applications, the performance obtained is not optimal since the EDCA parameters still negatively affect the QoS of these applications. These parameters are not dynamically optimized for varying network conditions [8]. Such circumstances motivate the introduction of a dynamic and optimized solution to cope with such varying network conditions.

A binary exponential back-off algorithm is one of the mechanisms used in the EDCA protocol of the MAC sub-layer in IEEE 802.11. The discrete back-off timer measured in back-off slots is randomly selected from [0, $CW[i]$] in the contention procedure of every station [5]. Afterwards, the timer starts to decrease once every empty time slot for all access categories, while the channel is idle for the duration of the AIFS. Once a transmission is detected on the wireless channel, the back-off timer is frozen, and then resumes again after sensing an idle channel. When the back-off timer reaches zero, the station attempts transmit its data immediately. Upon each successful transmission, EDCA assigns a minimum value of $CW[i]$ for the next data frame with a specific priority in a consideration that the channel is not congested anymore.

Each time the transmission of a frame failed, the value of $CW[i]$ is doubled blindly and this continues until it reaches $CW_{max}[i]$ (i.e. the maximum limit of $CW[i]$). Under such circumstances, $CW[i]$ remains at $CW_{max}[i]$ until the frame can be successfully sent or the retry limit is reached then $CW[i]$ drops back to $CW_{min}[i]$. The frame is discarded if the number of retransmission attempts (i.e. the retry limit) has reached the maximum value allowed.

The first problem under this study is that the number of collisions for sent frames in a shared wireless medium increases due to the lack of a mechanism that could adapt the back-off window procedure for both successful and unsuccessful transmissions with regard to the channel status. As mentioned before, the standard routine immediately drops the $CW[i]$ parameter back to $CW_{min}[i]$ in case of a successful transmission regardless of the channel condition whether it is congested or not. Such a routine leads to a high collision rate in a highly loaded channel.

The assumption in the standard routine is that when several successful transmissions occur indicates that the wireless channel is not loaded which cannot be considered true. Thus, frequently setting $CW[i]$ down to the minimum size upon each successful transmission might lead to an encounter with a high loaded channel in some cases which would also further lead to repeated collisions and hence decrease the system performance rapidly.

Conversely, doubling the $CW[i]$ size blindly after each unsuccessful transmission is not favourable because it might lead to increased time delays in data frame arrival times. In fact, when the network is lowly loaded, frequent collisions in the medium might occur due to the choice of the same back-off time slot by another station at random. Therefore, doubling $CW[i]$ size blindly upon each collision might result in many time gaps during the back-off procedure.

The second problem is that the back-off countdown procedure is decremented periodically by one time slot for all access category (AC) priorities while the channel is idle given equal speeds of reduction for all access category priorities to access the wireless channel. In fact, such a back-off degradation procedure negatively affects the QoS of multimedia applications and results in even more degradation in the channel utilization and network performance, especially when there is contention among a few wireless stations. Furthermore, this procedure does not provide an intra-AC differentiation mechanism among the multiple access categories of the same priority level. When many stations attempt to transmit data of the same AC priority level on the same selected slot time after the back-off timer reaches zero, a collision will occur because all these stations will get the same probability of channel access. As the number of stations increases, the number of collisions increases too, leading to performance degradation of network throughput, channel usage and increased access delay.

Therefore, the possibility of collisions and time delays can be minimized to the lowest levels if each station contends for the wireless medium in a properly selected time slot. In other words, adopt a dynamic algorithm that adapts the contention window size and back-off countdown procedure according to the channel condition, i.e. in terms of recent channel activities. This is in addition to providing an intra-AC differentiation mechanism for the back-off counter to avoid wasting empty time slots and reduce packet collisions, which in turn leads to further improve the performance of whole wireless network and supports QoS for multimedia applications.

1.3 Motivation

One of the challenges in wireless networks of today is providing appropriate QoS support for the dramatically growing demand from the aspect of multimedia applications [9]. As recommended in [10] concerning QoS provisioning in IEEE 802.11 MAC, the time sensitive applications need to be adaptive to the channel condition in order to deal with the inherent fluctuation of wireless channels. In a shared wireless channel there are two major factors affecting the quality of real-time applications: collisions due to unsuccessful transmissions and delays due to wasted idle slots which result from back-off times at each contention period. These two problems are caused by ineffective algorithms used in the contention-based EDCA mechanism of the MAC sub-layer. The back-off algorithm is one of these algorithms that affect the performance profoundly. However, the above mentioned problems are inherently conflicting, which means reducing delays could increase the number of collisions and vice versa. As a result, a trade-off between wasting idle slots and the risk of frequent collisions and retransmissions should be considered. Therefore, it is desirable to carefully control the back-off procedure at each contention cycle to achieve better performance for multimedia applications. Since the back-off timer uses contention window size as part of the countdown procedure, the optimal setting of the contention window will affect the performance of the system. To this end, the research target is aimed at designing a good algorithm to manage the contention window size and enhance the degradation of the back-off timer under the EDCA protocol in order to provide appropriate QoS support for real time applications.

1.4 Aims of the Study

The aim of this research is to improve general network performance by designing and refining an algorithm that is able to reduce overall collision rates, reduce time delays and support time sensitive applications with a better QoS. As much as possible, the main target in this thesis is to design a dynamic back-off algorithm adaptive to the channel conditions and traffic priorities in the cases of both a successful and a failed transmission. This research should demonstrate that the algorithm presented has the ability to reduce collisions and delays on a shared wireless channel and give high performance at high and low network loads. The proposed algorithm will be mainly based on monitoring channel conditions in terms of average congestion rates of the channel during regular time periods. Then, exponential functions will be used to adjust the sizes of the contention window upon successful and failed transmission. Furthermore, the proposed algorithm will use a fast back-off reduction to serve the highest priority access category rapidly when the wireless channel is unloaded. In addition, the back-off timer in the proposed algorithm will provide an intra-AC differentiation mechanism among the multiple

ACs of the same priority level. Simulation results have shown that compared to the standard routine the proposed procedure achieves better performance in wireless LANs, and provides QoS support for real-time applications as well as reduces both the increased time delays and collisions of data sent to the medium.

1.5 Objective

This research aims to achieve these specific objectives as listed below to overcome some of network problems inherent in the EDCA of the MAC sub-layer.

1. To propose an efficient algorithm that is able to adapt the contention window size dynamically to the channel status in each contention cycle for improving the overall network performance.

2. To provide QoS support for multimedia applications by serving multimedia applications rapidly in each contention cycle in addition to reduce collision rates among ACs of the same priority level by solving the intra-AC differentiation problem.

1.6 Research Scope

In wireless local area networks, congestion may bring about degradation of overall channel utilization due to two important events; increased collision rates of data sent to the wireless channel and increased time delays. Both of these events affect the performance profoundly for stations whose data has to traverse a wireless channel quickly. Although EDCA allows setting different MAC static parameters for each access category to attempt to avoid occurrence of such problems and to provide QoS mechanisms for medium access, the performance obtained is still not efficient. This is due to the EDCA parameters not being adapted to the network loads or channel conditions [11]. Thus QoS support for IEEE 802.11e is still challenging and merits further study. Therefore, the main task of this thesis is to focus on QoS support in the IEEE 802.11e EDCA back-off mechanism in which time sensitive multimedia services should be improved. It is important to mention that the limitation of the proposed algorithm appears through using a small number of active station in which the proposed algorithm does not make a good impact in the system. Furthermore, one more limitation in this research is that the test-bed implementations in which there were no equipments to run the test-bed in real environment. Since the proposed algorithm is based on the channel measurement scheme, this modification is required into existing hardware.

1.7 Contribution

The main contribution of this study is developing an adaptive back-off algorithm that is able to adjust the contention window size dynamically upon successful and failed transmission based on up-to-date information obtained about channel activities. Moreover, the proposed algorithm adapts the back-off countdown procedure to the current channel condition and uses an exponential decreasing function, with different exponential decreasing rates for each access category in order to serve multimedia applications faster and maintain the QoS differentiation for these applications. Furthermore, to reduce the probability of choosing the same time slot for transmission by stations belonging to the same AC priority level, the randomness of the back-off timer has extended by using an offset function. The goals behind the proposed algorithm are to alleviate the overall collision rate, minimize packet delay and increase the performance of the network in terms of system goodput, network throughput and medium utilization in all network conditions. In addition, our algorithm improves the service of time-bounded applications.

1.8 Study Module

The direction of this research is illustrated in Figure 1.2. The bold lines represent the current research direction.

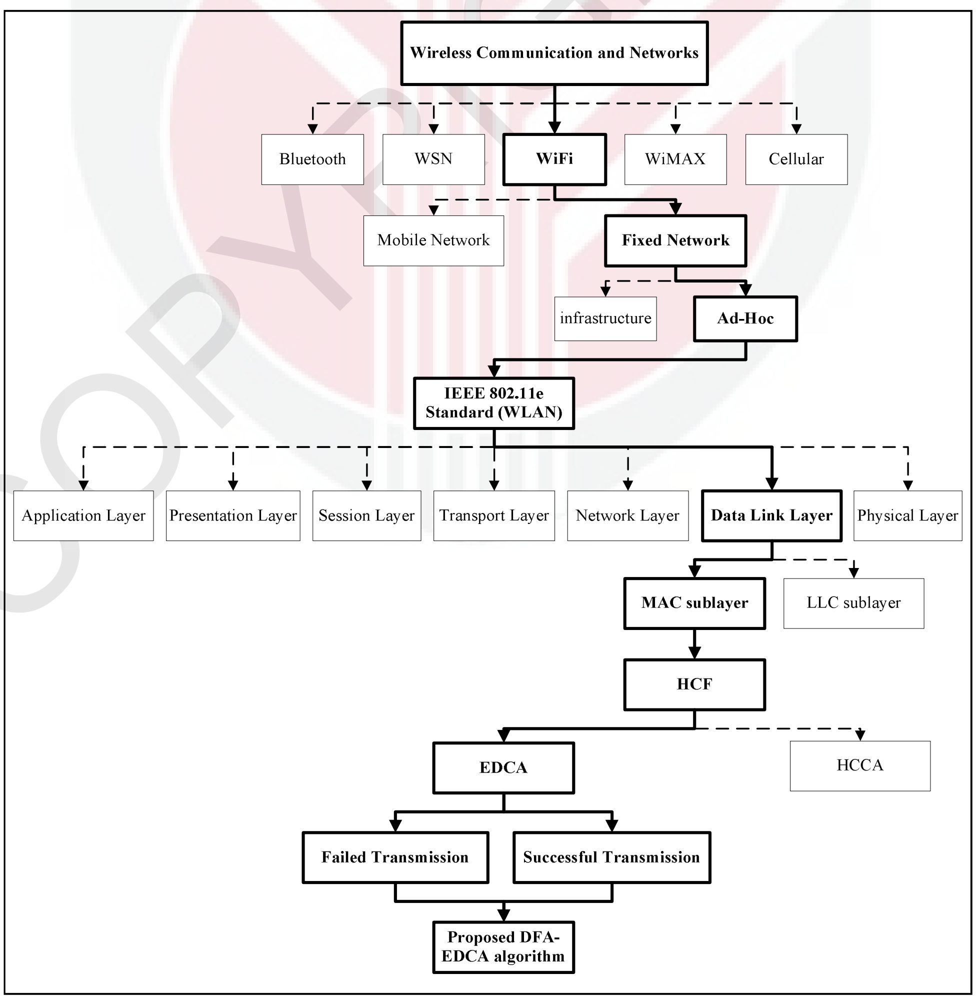

Figure 1.2. Study Module

1.9 Thesis Organization

This thesis is organized into five chapters including this introductory chapter. The rest of the chapters are arranged as follows:

Chapter 2 provides an overview of the subject related to the methodology of this research, and then summarizes several related back-off algorithms proposed by different researchers.

Chapter 3 is the main part of this thesis; it presents the problem analysis and describes the methodology used through this research which is mainly focused on the proposed solutions that are addressed in the objectives.

Chapter 4 presents the network simulation topology and scenarios used to simulate the new algorithm using an NS-2 simulator. Results of enhancement that have been obtained from the experiments conducted on different performance metrics are then presented and their implicit reasons are discussed in detail.

Chapter 5 concludes the overall study of this research and provides recommendations for future work.

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