UNIVERSITI PUTRA MALAYSIA

EFFICIENT BACK-OFF MECHANISM FOR IEEE 802.15.4 WIRELESS SENSOR NETWORKS

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By

ZAHRAA D.A. QADAWI

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

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DEDICATION

قال تعالى

((وَعَلَّمَكَ مَا لَمْ تَكُنْ تَعْلَمُ ۚ وَكَانَ فَضْلُ اللَّهِ عَلَيْكَ عَظِيمًا))

النساء ﴿١١٣﴾

To the loving memory of my late father Dr. Dahham Abdulhadi, "May Allah bless him with his supreme benevolence" who is forever remembered.

To my caring, and lovely mother, who have supported me all the way since the beginning of my study

Special thanks to my dear brother Dr. AbdulRahman Dahham and his family for their moral support, inspiration and guiding hand on my life in Malaysia

To my brother and sisters: Dr. Harith, Radhwa, Zainab and Arwa for their love and motivation

To all those who have passed away in struggle for sovereignty of my fatherland

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

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By

ZAHRAA D.A. QADAWI

June 2013

Chair: Aduwati Binti Sali, PhD

Faculty: Engineering

In recent years, the demand for Wireless Sensor Networks (WSNs) has increased tremendously and gained world-wide interest. Their importance has been enforced by the fast delivery of several medium access control protocols. MAC protocols provide a great influence over the communication mechanisms and play a significant role in the performance of sensor networks. One of the major protocols of our interest is MAC protocol.

Different contention-based MAC Protocols for Wireless Sensor Networks (WSNs) have been proposed over the last few years. IEEE 802.15.4 is one of the most prominent MAC protocol standard designed for low-power, low-cost, and low-rate Wireless Personal Area Networks (LR-WPANs). The Contention Access Period (CAP) of IEEE 802.15.4 utilizes Carrier Sense Multiple Access with Collision

Avoidance (CSMA-CA) algorithm for its contention and channel access. In CSMA-CA, a long random backoff time causes longer average delay and lower channel utilization, while a small one gives high collision rate. Therefore, this thesis examines two main drawbacks of CSMA-CA algorithm; the first problem is that during CSMA-CA mechanism, a node tends to delay for a very limited number of *backoff exponent* (BE). The probability of collisions when two or more nodes choose the same number of backoff period is high. This insufficient backoff time affects system performance by causing more collisions among the contending nodes. The second problem is that CSMA-CA updates the contention window length without considering the number of contending nodes in the communication medium. Therefore, CSMA-CA is inefficient in terms of system throughput, reliability and energy efficiency. Thus, it is evident CSMA-CA degrades network performance as we will be demonstrated later and this motivates us to introduce a better backoff algorithm.

In this thesis, we propose EBA-15.4MAC that enhances the IEEE 802.15.4 MAC protocol. EBA-15.4MAC is based on two new important techniques; firstly, it updates the contention window size based on the probability of collision parameter. In other words, when the number of nodes increases in the network, the probability of collision will increase as well, so we include the probability of collision as a parameter to adapt the CW size. Hence, when the number of nodes increases in the network, a node delay for an extended period of time to give the nodes better opportunities to access the medium and therefore reduces contention among the nodes. On the other hand, when the level of collision decreases due to lesser number of nodes, nodes tend to delay for a shorter durations. Secondly, to increase the efficiency of EBA-15.4MAC algorithm, we propose a new scheme to resolve the problem of access collision arising from the small number of backoff exponent used by CSMA-CA. In this scheme, we allow the nodes to delay for a random backoff periods by employing a novel *Temporary Backoff* (TB) and *Next Temporary Backoff* (NTB). In this case, the nodes not only choose BE randomly as mentioned in the standard but they select TB and NTB between 10% to 50% of the actual backoff delay selected randomly by the node. By including a random selection of TB and NTB value within the whole existing backoff delay, EBA-15.4MAC minimizes the level of collision since the probability of two nodes selecting the same backoff period will be very low. By using these two new methods, the proposed algorithm significantly improves the overall system performance of IEEE 802.15.4.

To evaluate the performance of EBA-15.4MAC mechanism, the network simulator (NS-2) has been conducted. Simulation results indicate that EBA-15.4MAC outperforms significantly the IEEE 802.15.4 MAC protocol. Furthermore, it also significantly improve system throughput by up to 32% compared to the existing standard. It is also shown that, with a more appropriate MAC parameters setting, it is possible to reduce collision probability and achieve 99% delivery ratio. Furthermore, minimized energy consumption is achieved by approximately 15% especially for higher traffic load. In addition, it is shown that EBA-15.4MAC is able to maintain a very low average packet delay till 1.5packets/second traffic load compared to that of only 1.2packets/second for 802.15.4. Finally, it can be concluded that EBA-15.4MAC outperforms the original IEEE 802.15.4 MAC protocol.

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

MEKANISMA UNDUR BALIK CEKAP UNTUK RANGKAIAN PENDERIA WAYARLES IEEE 802.15.4

Oleh

ZAHRAA D.A. QADAWI

Jun 2013

Pengerusi: Aduwati Binti Sali, PhD

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Dalam tahun-tahun kebelakangan, permintaan terhadap Rangkaian Penderia Wayarles (WSNs) telah meningkat dengan ketara dan menarik minat seluruh dunia. Kepentingan rangkaian ini didorong oleh kepesatan pembangunan beberapa protokol kawalan capaian medium. Protokol-protokol MAC menyediakan pengaruh yang besar ke atas mekanisma perhubungan dan memainkan peranan yang jelas di dalam prestasi rangkaian penderia. Salah satu protokol yang menarik minat kami adalah protokol MAC.

Pelbagai protokol MAC berasaskan berasaskan pertandingan untuk WSN telah dicadangkan dalam tahun-tahun kebelakangan. IEEE 802.15.4 adalah suatu piawaian protokol MAC yang paling berpotensi yang direkabentuk untuk Rangkaian Kawasan Peribadi Wayarles kuasa rendah, kos rendah dan kadar rendah (LR-WPANS). Tempoh Capaian Pertandingan (CAP) IEEE 802.15.4 menggunakan algoritma

Capaian Pelbagai Deria Pembawa dengan Penghindaran Perlanggaran (CSMA-CA) untuk mekanisma pertandingan dan capaian saluran. Di dalam CSMA-CA, masa undur balik rawak yang panjang menyebabkan lengah purata yang lebih panjang dan penggunaan saluran yang lebih rendah, manakala yang lebih kecil memberi kadar perlanggaran yang tinggi. Oleh sebab itu, tesis ini mengkaji dua kelemahan utama algoritma CSMA-CA; masalah pertama ialah sewaktu mekanisma CSMA-CA, suatu nod cenderung untuk melengah selama bilangan eksponen undur balik (BE) yang sangat terhad. Kebarangkalian perlanggaran apabila dua atau lebih nod memilih tempoh undur balik yang sama adalah sangat tinggi. Ketidakcukupan masa undur balik ini memberi memberi kesan kepada prestasi sistem dengan menyebabkan lebih banyak perlanggaran di kalangan nod-nod yang bertanding. Masalah kedua ialah CSMA-CA mengemaskini panjang tingkap pertandingan tanpa mengambilkira bilangan nod yang bertanding di dalam medium komunikasi. Oleh itu, CSMA-CA adalah tidak efisien dari segi truput sistem, kebolehpercayaan dan kecekapan tenaga. Oleh itu, ia terbukti bahawa CSMA-CA menurunkan prestasi rangkaian seperti yang ditunjukkan kemudian dan ini memotivasikan kami untuk memperkenalkan algoritma masa undur balik yang lebih baik.

Di dalam tesis ini, kami mencadangkan EBA-15.4MAC yang meningkatkan protokol IEEE 802.15.4. EBA-15.4MAC adalah berasaskan kepada dua teknik penting; pertamanya, ia mengemaskini saiz tingkap pertandingan berasaskan parameter kebarangkalian perlanggaran. Dengan kata lain, apabila bilangan nod bertambah di dalam rangkaian, kebarangkalian perlanggaran juga akan meningkat, jadi kami memasukkan kebarangkalian perlanggaran sebagai parameter untuk mengadaptasi saiz CW. Dengan ini, apabila bilangan nod bertambah di dalam rangkaian, suatu nod melengah untuk suatu tempoh yang lebih panjang bagi memberi peluang kepada nod-nod lain untuk mencapai medium dan seterusnya mengurangkan pertandingan di kalangan nod-nod. Sebaliknya, apabila tahap perlanggaran berkurang disebabkan bilangan nod yang lebih rendah, nod-nod terdorong untuk melengah dalam tempoh yang lebih pendek. Keduanya, untuk meningkatkan kecekapan algoritma EBA-15.4MAC, kami mencadangkan suatu skim baru untuk menyelesaikan masalah perlanggaran capaian yang timbul akibat bilangan eksponen undur balik yang kecil yang digunakan oleh CSMA-CA. Di dalam skim ini, kami membenarkan nod-nod untuk melengah dalam tempoh-tempoh undur balik rawak dengan menggunakan suatu Undur balik Sementara (TB) baharu dan Undur balik Sementara Seterusnya (NTB). Dalam kes ini, nod-nod tidak sahaja memilih BE secara rawak seperti dinyatakan di dalam piawaian, tetapi mereka memilih nilai TB dan NTB di antara 10% dan 50% daripada lengah undur balik sebenar dipilih secara rawak oleh nod tersebut. Dengan memasukkan pilihan rawak nilai TB dan NTB dalam keseluruhan lengah undur balik sedia ada, EBA-15.4MAC mampu meminimumkan tahap perlanggaran kerana kebarangkalian dua nod memilih tempoh undur balik yang sama adalah sangat rendah. Dengan menggunakan dua kaedah baru ini, algoritma yang dicadangkan secara jelas dapat memperbaiki prestasi keseluruhan sistem IEEE 802.15.4.

Untuk menilai prestasi mekanisma EBA-15.4MAC, pensimulasi rangkaian (NS-2) telah digunakan. Hasil-hasil simulasi menunjukkan bahawa mekanisma EBA-15.4MAC mengatasi secara jelas protokol MAC IEEE 802.15.4. Selain daripada itu, algoritma EBA-15.4MAC secara jelas memperbaiki truput sistem sebanyak 32% berbanding piawaian sedia ada. Ia juga menunjukkan bahawa, dengan penetapan parameter-parameter MAC yang lebih sesuai, terdapat kemungkinan untuk mengurangkan masalah perlanggaran dan mencapai 99% nisbah penghantaran. Tambahan pula, penggunaan tenaga minimum sekitar 15% dicapai berbanding sistem yang tidak menggunakan EBA-15.4MAC terutamanya untuk beban trafik yang tinggi. Selain itu, didapati juga bahawa EBA-15.4MAC mampu mengekalkan lengah paket purata yang sangat rendah sehingga 1.5paket/saat beban trafik berbanding dengan hanya 1.2paket/saat untuk sistem yang menggunakan piawaian 802.15.4. Akhirnya, boleh disimpulkan bahawa EBA-15.4MAC mengatasi protokol MAC IEEE 802.15.4 yang asal.

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I certify that a Thesis Examination Committee has met on 7 June 2013 to conduct the final examination of Zahraa D.A. Qadawi on her thesis entitled "Efficient Back-off Mechanism for IEEE 802.15.4 Wireless Sensor 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 Master of Science.

Members of the Thesis Examination Committee were as follows:

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

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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.

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ZAHRAA D.A. QADAWI

Date: 7 June 2013

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LIST OF ABBREVIATIONS

ABE	Adaptive Backoff Exponent
ACK	Acknowledgment
ACS	Additional Carrier Sensing
AODV	Ad hoc On-demand Distance Vector
APL	Application Layer
BE	Backoff Exponent
BEB	Binary Exponential Backoff
BI	Beacon Interval
BLE	Battery Life Extension
BO	Beacon Order
BP	Backoff Period
BS	Base Station
CAP	Contention Access Period
CBR	Constant Bit Rate
CCA	Clear Channel Assessment
CFP	Contention Free Period
CRC	Cyclic Redundancy Check
CSMA-CA	Carrier Sense Multiple Access with Collision Avoidance
CW	Contention Window
DBA	Delayed Backoff Algorithm
DLC	Data Link Layer
EB	Enhanced Backoff
EBA-15.4MAC	Efficient Backoff Algorithm

EBE	Efficient Backoff Exponent
ECR	Enhanced Collision Resolution
EWMA	Exponential Weighted Moving Average
FFDs	Full Function Device
FIFO	First In First Out
GTS	Guaranteed Time Slot
IP	Internet Protocol
KEB	Knowledge-based Exponential Backoff
LLC	Logical Link Control
LQI	Link Quality Indicator
LR-WPANs	Low-Rate Wireless Personal Area Networks
MAC	Medium Access Control
MBS	Memorized Backoff Scheme
MEMS	Micro-Electro-Mechanical System
NO-BEB	Non-Overlapping Binary Exponential Backoff
NS-2	Network Simulator
NTB	Next Temporary Backoff
NWK	Network Layer
OSI	Open System Interconnection
PAN	Personal Area Network
PHY	Physical Layer
RFDs	Reduced Function Device
SB	StandBy
SD	Superframe Duration
SO	Superframe Order

STS	State Transition Scheme
TB	Temporary Backoff
TCL	Tool Command Language
TCP	Transport Control Protocol
TDMA	Time Division Multiple Access
TP	Temporary Period
UBP	Unit Backoff Period
UDP	Universal Data Protocol
WBANs	Wireless Body Area Networks
WSNs	Wireless Sensor Networks

CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, the demand for Wireless Sensor Networks (WSNs) has increased and gained world-wide attention. The advances of Micro-Electro-Mechanical System (MEMS) technology, has eased the development and deployment of smart sensors. Tiny sensors are small in size, low in cost, require low power, and with a limitation of process resources, they are cheaper to produce than traditional smart ones. Sensor nodes have the ability to sense and measure, and depending on several process characteristics, they are able to collect information from different environments and transmit processed data to the user field [1]. Many types of sensors, such as mechanical, thermal, biological, optical, and magnetic, can be connected to the default sensor node to measure the properties of real environments. Due to memory limitations and the difficulty of deploying these sensors, a radio transceiver was used to transfer data to a Base Station (BS); such as a laptop, personal device, or an access point [2]. Figure 1.1 shows a sample of a sensor node device.

Figure 1.1: Sensor Device [3]

Typically, WSNs consist of a few tens to thousands of sensor nodes that work together for certain regions to collect data about the environment. There are, generally, two types of WSNs: structured and unstructured [1]. In a structured WSN, it is important to pre-determine sensor nodes to enable them to be placed at fixed specific locations. The advantage of this type is that a smaller number of nodes can be implemented at lower cost and with simpler network maintenance. Owing to the placement of nodes at a specific location to provide area coverage, fewer nodes can be deployed. On the other hand, an unstructured WSN consists of a collection of sensor nodes that can be placed randomly in the field. In contrast, the network maintenance in an unstructured WSN proves extremely difficult due to the deploying of too many nodes in the field. Figure 1.2 shows the general architecture of sensor network which is consists of one sink node and a large number of sensor nodes placed in a large geographical area. A multi-hop communication techniques is used to transfer the data from sensor nodes to the sink [4].

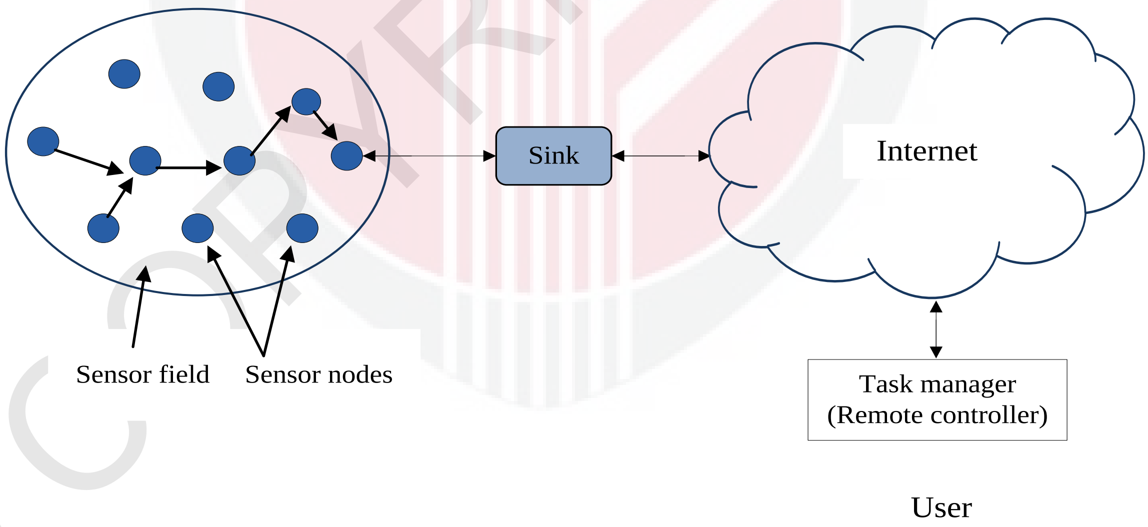

Figure 1.2: WSNs General Architecture[4]

Medium Access Control (MAC) protocol plays a vital role in the performance of WSNs. Sensor nodes are typically battery powered that makes change or replacement difficult due to the cost constraints. Therefore, energy-efficient MAC protocol is considered a primary goal of the wireless sensor network design [5]. There are some important key issues that need to be fulfilled in order to ensure a successful deployment of WSNs such as energy efficiency, reliability and scalability. To achieve energy-efficient requirements, collisions between the transmitting nodes should be minimised. This collision leads to packet drop thusly reducing throughput and causing energy wastage. In Section 2.4.2 and 2.4.3, we discussed in detail many factors that affect the behaviour of MAC protocol.

This chapter is organised as follows. Section 1.2 describes the research problems and questions under investigation. The research aims and objectives are discussed in Section 1.3. The thesis's scope is demonstrated in Section 1.4 while Section 1.5 introduces research contributions. The study module in terms of a block diagram is illustrated in Section 1.6. Finally, thesis organisation is responsible for providing the outlines for the remainder of the chapters within this thesis.

1.2 Problem Statement and Motivation

Medium Access Control (MAC) plays an important role in the performance of WSNs especially in the case of contention based protocols such as IEEE 802.15.4 standard [6]. It is a new wireless technology designed to achieve low complexity, low cost and low rate wireless networks such as Wireless Sensor Networks (WSNs). In addition, IEEE 802.15.4 standard defines the specifications of the PHY and MAC sub-layer for low-rate wireless personal area networks (LR-WPANs). It is able to operate via two different channel access methods: beacon-enabled mode and non-beacon enabled mode. The beacon is defined as a special synchronisation frame generated periodically by the coordinator node [7]. In this research, focus is on the beacon-enabled based IEEE 802.15.4 MAC due to its simplicity for WSNs application compared to the non-beacon enabled mode [8].

To address the requirements of the WSNs, IEEE 802.15.4 standard utilises the slotted carrier sense multiple access with collision avoidance (CSMA-CA) mechanism. During the implementation of CSMA-CA algorithm, the nodes used a blind backoff process [9].

In this research, we discussed and resolved two primary drawbacks of the CSMA-CA algorithm. The first problem occurs when a node that wants to transmit its data, delays for a random amount of time referred to as a backoff period (BP) that is set within a range [0, 2^{BE} -1], where BE is the *backoff exponent* that determines the number of backoff periods the device shall wait for before trying to access the wireless medium. The CSMA-CA is allowed to use a very limited range of BE determined by macMinBE and macMaxBE. The minimum BE is indicated by macMinBE=3 and the maximum BE by aMaxBE=5 according to the standard setting [6]. This limited number of BE increases the probability of two or more nodes choosing the same number of backoff periods that cause more collisions among contending nodes and effects network performance. The second most important problem is the *contention window* (CW) size. CSMA-CA algorithm updates the contention window length without considering the number of contending nodes in the communication medium. Therefore, CSMA-CA has been proven inefficient in terms of system throughput, reliability, and energy efficiency. From the problems mentioned above, it is quite evident that CSMA-CA behaviour degrades the network performance consequently, motivating us to introduce a better backoff algorithm. However, we have addressed in this research, the drawbacks of CSMA-CA algorithm as:

1. CSMA-CA updates the contention window size without considering the number of competing nodes in the communication medium. Therefore, CSMA-CA has proven insufficient in terms of system throughput and packet delivery ratio.
2. CSMA-CA uses very limited number of Backoff Exponent (BE) that increased the probability of two nodes selecting the same number of backoff periods. This will give rise to more collisions among the contending nodes and subsequently, affect the overall system's performance.
3. In CSMA-CA, the node performs carrier sensing only when the backoff process is completed. Hence, causing longer average delay.

In this study, a novel efficient backoff algorithm is presented that is, to the best of our knowledge, the first of its kind in terms of power efficiency, simplicity, and reliability. Specifically, we propose an efficient and adaptive backoff mechanism called EBA-15.4MAC as a feasible solution to the aforementioned CSMA/CA problems.

1.3 Aims and Objectives

The main aim of this research is to design an efficient and adaptive backoff mechanism that enhances the performance of IEEE 802.15.4 slotted CSMA-CA algorithm. To achieve these improvements, the following objectives are studied and accomplished:

1) To increase throughput and delivery ratio by proposing an efficient backoff algorithm that determines the appropriate size of CW based on the level of collisions detected by nodes.
2) To minimise the access collision, average delay and energy consumption of the proposed mechanism by employing a novel *Temporary Backoff* (TB) and *Next Temporary Backoff* (NTB).

1.4 Thesis Scope

The study area of this research focuses on WSNs. MAC protocols for WSNs can be classified into two main groups: scheduled-based MAC protocols and contention-based MAC protocols. Communication in scheduled-based protocols is based on reservation and scheduling technique [3, 10-12]. A scheduled-based MAC protocol is also referred to as a reservation-based MAC. For this type of protocol, each sensor node is able to send its data by reserving time slots for nodes that have transmittable data in order to conserve a significant amount of energy due to low radio duty cycle compared to contention-based protocols.

On the other hand, contention-based MAC protocols are widely used because of their simplicity and flexibility [10]. These protocols employ contention mechanism rather than clock synchronisation. For that matter, there is a need to distinguish between protocols that use a reservation of medium access and those that use a contention mechanism. IEEE 802.15.4 is a well-known contention-based MAC protocol that is used for study in this research. The standard uses random access method to control the access to the communication medium.

There are two different procedures for a channel access method that the standard can operate: beacon enabled mode and non-beacon enabled mode. In this work, the beacon-enabled mode is evaluated owing to its simplicity for WSNs applications compared to non-beacon enabled mode [8]. In addition, most of the unique features of IEEE 802.15.4 MAC like synchronisation, sleeping techniques and employing CSMA-CA mechanism, are found within this mode. The beacon-enabled mode utilises the slotted CSMA-CA mechanism for accessing wireless medium.

The slotted CSMA-CA algorithm uses insufficient random access method. In other words, when the nodes have data to transmit, they first wait for a random backoff period selected within the range [0, 2^{BE} -1], BE is the *backoff exponent* that determines the number of backoff periods the device will wait before trying to access the communication medium [6]. During channel access procedure, the CSMA-CA algorithm is allowed to use a very small range of BE (macMinBE – aMaxBE), where the minimum BE is indicated by macMinBE = 3 and the maximum by aMaxBE = 5. This limited number of BE allowed by the standard increases the probability of devices choosing the identical number of backoff periods and this causes more collisions among the contending nodes. The second problem that has been resolved in this research is the contention window length. IEEE 802.15.4 resets the window size to its minimum value after a successful packet transmission. The problem starts when the network load is heavy; more nodes attempt to access the channel to send their data. The serious contention cannot be resolved within a narrow backoff window, which results in the increase of the number of collisions. Hence, network throughput and delivery ratio reduces due to an increase in the probability of collision during data transmission. As such, the proposed enhancements in this thesis must serve to solve the aforementioned problems.

Therefore, to solve the low throughput and high collision rate of IEEE 802.15.4 standard, we studied the random backoff time and proposed an efficient and adaptive backoff mechanism (EBA-15.4MAC). It is designed based on two important principles: firstly, EBA-15.4MAC updates the *contention window* (CW) size based on the probability of the collision parameter. In other words, when the number of nodes increases in the network, the probability of collision will increase as well. In this case, we include the probability of collision as a parameter to adapt the CW size appropriately and accurately. Hence, when the number of nodes increases in the network, there will be a delay for an extended period of time to give the nodes better opportunities to access the medium and send their data successfully in order to reduce the contention among the nodes. On the other hand, when the level of collision decreases in the medium due to a lesser number of nodes, nodes tend to delay for shorter durations. Secondly, to increase the efficiency of EBA-15.4MAC, we proposed a newer more efficient scheme to resolve the problem of access collision due to a very small number of BE used by CSMA-CA. In this scheme, the node delay is caused by a random backoff period via the employment of a novel *Temporary Backoff* (TB) and *Next Temporary Backoff* (NTB). In this case, the nodes not choose the BE randomly as mentioned in the standard but they select TB and NTB between 10% to 50% of the actual backoff delay values that are randomly selected by the node. By including a random selection of TB and NTB within the whole existing backoff delay, EBA-15.4MAC minimises the level of collision since the probability of two nodes selecting the same backoff period is very low. By using these two new methods, the proposed algorithm significantly improves the overall system performance of IEEE 802.15.4.

To evaluate the performance of the proposed model, the network simulator (NS-2) was used. Two different scenarios are conducted in our simulation under various traffic generation loads and different numbers of active nodes. Simulation result of EBA-15.4MAC was compared with the original 802.15.4 standard and evaluated in terms of throughput, energy consumption, average delay, power efficiency as well as, delivery ratio. It can be concluded that EBA-15.4MAC significantly outperforms the IEEE 802.15.4 MAC protocol.

1.5 Research Contributions

The main contribution of this research is to improve the carrier sense multiple access with collision avoidance (CSMA-CA) mechanism for IEEE 802.15.4 MAC protocol by proposing an efficient and adaptive backoff algorithm. In this algorithm, two new techniques have been proposed. In the first scheme, we used the probability of collision as a parameter to choose the appropriate size of CW according to the level of access collision experienced by the nodes. Moreover, when the number of nodes increases in the network, the probability of collision will increase as well, so we included the probability of collision to adapt the CW size. In the second scheme, we allowed the nodes to delay for a random backoff period using a novel *Temporary Backoff* (TB) and *Next Temporary Backoff* (NTB). In this case, the nodes not choose BE randomly as mentioned in the standard rather, they select TB and NTB values that can be 10% to 50% of the actual backoff delay randomly selected by the nodes. By using these new techniques, the proposed algorithm minimises the level of collision since the probability of two nodes selecting the same backoff period will be low. Hence, the proposed algorithm significantly improves the overall system performance compared with the 802.15.4 standard.

1.6 Study Module

The summary of general steps studied in this research is illustrated in Figure 1.3.

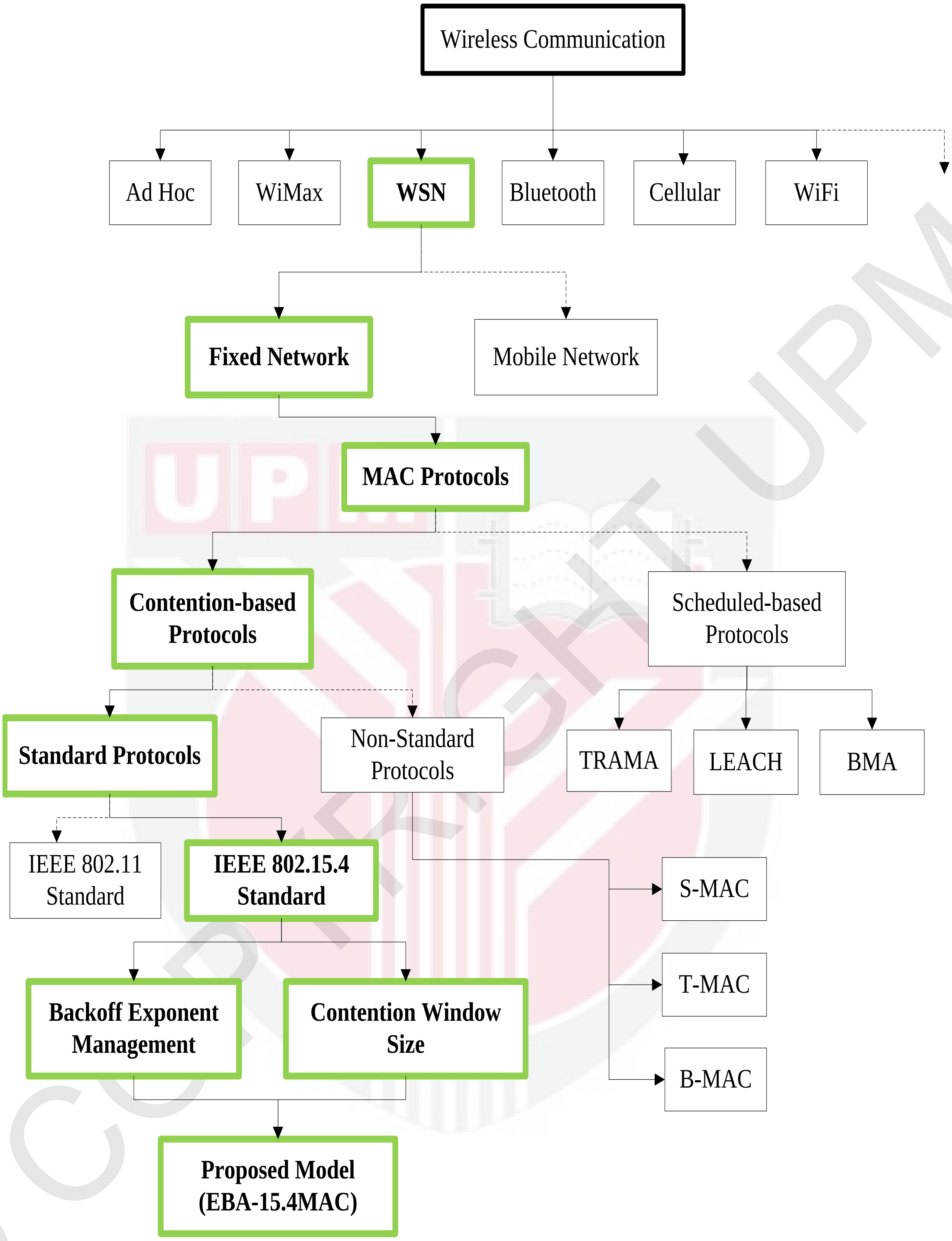

Figure 1.3: Study Module

1.7 Thesis Organisation

This thesis is structured as follows. Chapter 1 provides an overview of wireless sensor networks (WSNs), aims and objectives, the state of the problem and also highlights the main contributions of this research. Chapter 2 introduces a review of literature related to WSNs. This consists of different methods followed by other researches to solve the inefficient CSMA-CA algorithm in WSNs. In Chapter 3, we present the methodology of the proposed algorithm. Chapter 4 discusses the simulation results obtained from the proposed algorithm by using network simulator NS-2 with different scenarios and performance metrics as well as their comparisons. Finally, Chapter 5 concludes this research and furnishes recommendations for any future work.

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