



**UNIVERSITI PUTRA MALAYSIA**

**SAN ENERGY EFFICIENT MAC LAYER DESIGN FOR WIRELESS  
SENSOR NETWORK**

**MOHAMMAD HOSSEIN FOTOUHI GHAZVINI**

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SENSOR NETWORK**

**By**

**MOHAMMAD HOSSEIN FOTOUHI GHAZVINI**

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

**October 2008**



## DEDICATION

*This thesis is dedicated to:*

*My parents who have supported me all the way since  
the beginning of my studies*

*AND*

*My wife who has been a great source of motivation and  
inspiration*

## **ABSTRACT**

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

### **AN ENERGY EFFICIENT MAC LAYER DESIGN FOR WIRELESS SENSOR NETWORK**

By

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**October 2008**

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Recent technological advances in sensors, low power integrated circuits, and wireless communications have enabled the design of low-cost, lightweight, and intelligent wireless sensor nodes. The IEEE 802.15.4 standard is a specific Wireless Personal Area Network (WPAN) standard designed for various wireless sensor applications.

Idle listening, packet collision, control packet overhead and overhearing are considered as energy consuming resources in WSNs. As the idle listening and packet collision are two major power consuming parts, we considered two solutions for reducing both of them to achieve an energy efficient protocol. We concentrate on the MAC layer design to overcome the energy consumption by radio management procedure and the backoff exponent mechanism. In the radio management, we analyze the contention part of the active duration of the MAC IEEE 802.15.4 standard superframe and allow nodes to enter the sleep state regarding to their available data for transmission instead of staying



awake for the entire active period. This method will be useful especially when sensors do not have any data to send. The proposed non-persistent Carrier Sense Multiple Access (np-CSMA) protocol employs backoff exponent management mechanism. This algorithm helps the network to be reliable under traffic changes and saves more energy by avoiding collision. It assigns different range of BE (backoff exponent) to each node with respect to node's contribution in network traffic. In our scheme a coordinator can observe the network traffic due to the data information associated with devices. It can manage the Personal Area Networks (PANs) devices by the beacon packet to go to sleep mode when they do not have any packet to send.

In this thesis, by using the sleep period together with backoff exponent management in our protocol design, the amount of energy consumption will be reduced. The proposed model has been compared to original 802.15.4 standard and the existing Adaptive Backoff Exponent (ABE) MAC protocol to illustrate the improvement. Moreover, the BE management algorithm derives better system performance such as end-to-end delay, throughput, packet delivery ratio and Link Quality Indicator (LQI). The proposed model has been designed in such a way that the introduction of extra sleep period inserted in superframe improves the energy efficiency while maintaining other system performance parameters. The proposed MAC protocol has improved the energy consumption around 60% as compared to ABE-MAC. The proposed MAC protocol with an extra radio management technique together with backoff management procedure can achieve 70% more energy saving than MAC IEEE 802.15.4 standard.

## **ABSTRAK**

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

### **SATU BENTUK REKA CEKAP TENAGA LAPISAN MAC UNTUK JARINGAN PENDERIA TANPA WAYAR**

Oleh

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Kemajuan terkini dalam teknologi penderia, litar bersepadu berkuasa rendah, dan komunikasi tanpa wayar telah membolehkan bentuk reka nod penderia berkos rendah, ringan, dan pintar dihasilkan. Piawaian IEEE 802.15.4 adalah satu piawaian khusus bagi Jaringan Kawasan Peribadi Tanpa Wayar (WPAN) yang bentuk reka untuk pelbagai aplikasi kawalan dan pengawasan tanpa wayar.

Terdapat empat sumber penggunaan tenaga dalam WSNs iaitu dengar melahu, perlanggaran paket, lebihan paket kawalan dan lebihan dengar. Oleh sebab dengar melahu dan perlanggaran paket adalah dua parameter yang utama dalam penggunaan tenaga WSNs, dua penyelesaian untuk mengurangkan parameter tersebut telah dipertimbangkan untuk mencapai penggunaan tenaga yang lebih efisien. Kami

menumpukan kepada bentuk reka lapisan MAC bagi mengatasi penggunaan tenaga melalui kaedah pengurusan radio dan mekanisma *backoff exponent* (BE). Bagi pengurusan radio, kami menganalisa tempoh aktif piawaian super kerangka MAC IEEE 802.15.4 dan nod dibenarkan memasuki keadaan tidur bergantung kepada kewujudan data untuk penghantaran berbanding berjaga sepanjang tempoh aktif. Kaedah ini berguna terutama apabila penerima tidak mempunyai sebarang data untuk dihantar. Protokol *Carrier Sense Multiple Access* (np-CSMA) tidak persis yang dicadangkan menggunakan mekanisme pengurusan *Backoff Exponent* (BE). Algoritma ini membantu rangkaian menyimpan tenaga yang lebih dengan menghindari pelanggaran dan menjadi lebih dipercayai perubahan trafik. Julat BE yang berbeza diberikan kepada setiap nod bergantung kepada sumbangan dalam rangkaian trafik. Dalam skim ini, satu koordinator boleh mencerap rangkaian trafik disebabkan oleh data maklumat yang disertakan bersama dengan peranti. Ia boleh mengurus peranti-peranti Jaringan Kawasan Peribadi (PANs) melalui paket penanda untuk bertukar ke mod tidur apabila tiada sebarang paket untuk dihantar.

Dalam tesis ini, bentuk reka protocol menggunakan tempoh tidur bersama-sama dengan pengurusan *backoff exponent* (BE) dapat mengurangkan jumlah penggunaan tenaga. Model yang dicadangkan telah dibandingkan dengan piawaian asal 802.15.4 dan protokol MAC *Adaptive Backoff Exponent* (ABE) bagi menunjukkan peningkatan. Tambahan pula, algoritma pengurusan BE menghasilkan prestasi sistem yang lebih baik seperti lengah hujung ke hujung, truput, nisbah penghantaran paket dan penunjuk kualiti pautan(LQI). Model cadangan telah bentuk reka agar pengenalan tambahan tempoh tidur dimasukkan dalam super kerangka manambah baik kecekapan tenaga memelihara prestasi parameter sistem yang lain. Protokol MAC yang dicadangkan

telah meningkat prestasi dengan menggunakan kurang 60% tenaga berbanding dengan ABE-MAC. Protokol MAC yang dicadangkan dengan teknik pengurusan radio bersama kaedah pengurusan backoff boleh mencapai sehingga 70% penjimatan tenaga berbanding piawaian MAC IEEE 802.15.4.



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I certify that an Examination Committee has met on 21<sup>st</sup> of October 2008 to conduct the final examination of Mohammad Hossein Fotouhi Ghazvini on his Master of Science thesis entitled “An Energy Efficient MAC Layer Design for Wireless Sensor Networks” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1980. The committee recommends that the candidate be awarded the relevant degree.

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## **DECLARATION**

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

---

**MOHAMMAD HOSSEIN FOTOUHI GHAZVINI**

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## LIST OF ABBREVIATIONS

ABE	Adaptive Backoff Exponent
ACK	Acknowledgment
AES	Advanced Encryption Standard
AODV	Ad hoc On-demand Distance Vector
BE	Backoff Exponent
BI	Beacon Interval
BMA-MAC	Bit-Map Assisted energy efficient MAC protocol
B-MAC	Berkley MAC
BO	Beacon Order
CAP	Contention Access Period
CBR	Constant Bit Rate
CCA	Clear Channel Assessment
CFP	Contention Free Period
CPU	Central Processing Unit
CSMA	Carrier Sense Multiple Access
CSMA-CA	Carrier Sense Multiple Access with Collision Avoidance
CTS	Clear To Send
CW	Contention Window
DCF	Distributed Coordination Function
DIFS	Distributed InterFrame Space
DS-MAC	Dynamic Sensor MAC
EMAC	Efficient MAC
FCS	Frame Check Sequence



FFD	Full Function Devices
GTS	Guaranteed Time Slot
LEACH	Low Energy Adaptive Clustering Hierarchy
LPL	Low Power Listening
LQI	Link Quality Indicator
LR-WPAN	Low Rate Wireless Personal Area Networks
MAC	Medium Access Control
MAN	Metropolitan Area Network
MFR	MAC Footer
MHR	MAC Header
MPDU	MAC Protocol Data Unit
MSDU	MAC Service Data Unit
NAV	Network Allocation Vector
PACT	Power Aware Cluster TDMA
PAN	Personal Area Network
PCF	Point Coordination Function
RSSI	Receive Signal Strength Indication
RTS	Request To Send
SD	Superframe Duration
SIFS	Short Interframe Space
S-MAC	Sensor MAC
TCP	Transport Control Protocol
TDMA	Time Division Multiple Access
T-MAC	Timeout MAC
TRAMA	Traffic Adaptive MAC Protocol



UDP	Universal Data Protocol
WBAN	Wireless Body Area Network
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network

## CHAPTER 1

### INTRODUCTION

Recent advances in micro-electromechanical systems, tiny micro processors and low power radio technologies have lead to the creation of low-cost, low-power, multi-functional, miniature sensor devices that can detect and react to changes to the physical phenomena of their surrounding environments. Wireless Sensor Networks (WSNs) typically consist of a base station or sink node and a number of wireless sensor nodes. Each sensor is a unit with wireless networking capability that can collect and process data independently. Figure 1.1 shows a sample sensor node. These small system platforms which integrate sensors, processors, and transceivers have been also referred to as motes.



**Figure 1.1: Small Sensor Device**

WSNs are envisioned for a wide range of applications, ranging from environmental surveillance, inventory tracking, health monitoring, and home automation to even networking in or around a human body. Sensor networks monitor phenomena as diverse as moisture, temperature, speed, and location by means of optical, motion,

thermistor and piezoelectric detectors. For many of these applications, the sensor networks will share some common features. Since nodes will be powered by small batteries, the radio, itself, together with the protocol stack design must be energy-efficient.

The term of “energy efficiency” is used in Wireless Sensor Networks as a major consideration and one of the most important requirements. Sensor nodes are expected to operate for long periods of time, running on batteries or ambient energy sources. Because the biggest consumer of energy is the radio, many researchers have focused on creating energy efficient or low energy consuming MAC protocols [1-5].

The most important challenge in relation to all WSNs is to minimize energy consumption. Increasing the energy efficiency of the network leads to prolong the battery and network lifetime. This may be achieved by considering energy awareness issues in all aspects of design and operation of each sensor node. Moreover, energy saving protocols and techniques need to be addressed for collective groups of communicating sensor nodes in order to have better overall performance and improved energy efficiency within the WSN.

Much of the development of WSNs, in recent years, has focused on new sensor node hardware, involving the integration of sensing and radio circuitry, as well as the design of suitable networking protocols to meet the requirements of low-cost and low-power operations. Despite all hardware progress, the lack of an energy-efficient protocol has delayed the maturation process of this technology [6].

Since wireless networks operate in a broadcast medium, these networks require a Medium Access Control (MAC) layer to resolve contention in a random multi-access environment. The MAC layer protocols must be sensitive to the specific needs of a wide variety of sensing applications. In an effort to make inexpensive sensors ubiquitous, these sensors tend to have limited processing capability, memory capacity, and battery life.

On many hardware platforms, the radio is a major energy consuming part. On the other hand, the MAC layer has a significant capability to control the radio activities. So, an optimal design of a MAC protocol may ameliorate energy saving operations. The lifetime of a sensor network can be increased significantly assuming all parts of protocol design be aware of energy dissipation. The major sources of energy wastage include: collision, idle listening, overhearing, and control packet overhead [2]. Energy management plays a very important role in MAC protocols for wireless sensor networks. Several studies [7-9] have concluded that the design of an energy-efficient MAC protocol should be based upon the collision avoidance and idle listening dimensions.

This research addresses specific route and method of producing energy-efficient network control mechanism, namely by means of maximizing sleep durations, minimizing idle listening, and limiting the amount of collision. Utilizing the backoff exponent management mechanism leads to a reduction in overhead and packet collision.

The succeeding subsections of this chapter are organized as follows: Section 1.1 describes the research question under investigation; in Section 1.2, the objectives of the research will be outlined. The thesis' scope is demonstrated in Section 1.3; Section 1.4 illustrates the study module in the form of a block diagram. The research's aimed contribution is delineated in Section 1.5. Finally, we shall provide the scheme for the remaining chapters of the thesis.

## **1.1 Problem Statement and Motivation**

Energy efficiency is considered as the main challenge for wireless sensor networks and it has a large impact on a given system's lifetime. Each sensor, within a WSN, consists of different energy consuming parts, namely the Central Processing Unit (CPU), the micro controller, the transmitter and the receiver. Several researches have intensively studied and proposed different methods to overcome the energy scarcity. These researches are divided into different categories: hardware circuits and communication protocol stack designs [10, 11].

In addition to hardware improvements, the lack of energy-efficient protocol motivated us to propose a new MAC protocol that can overcome the major resource of energy wastage. The existing standard of WPAN, introduces two distinct periods of active and inactive modes within the superframe. Obviously by considering the inactive mode and putting sensor nodes into sleep state this standard can achieve significant energy saving. However, there still remains a huge amount of energy consumption due to the idle listening within the active period of the superframe. In our design, the MAC protocol coordinates sensor node transmissions to extend sleep duration and avoid collision phenomena and thus conserve energy.



## 1.2 Aim and Objectives

The thesis is investigating an energy-efficient MAC protocol for wireless sensor networks. The purpose is to design a model to overcome the most energy consuming resources of energy in wireless sensor networks which are idle listening and packet collision. The sleep state has been defined inside the active mode of the 802.15.4 standard superframe to diminish the idle listening problem. Additionally, the backoff exponent management is considered in the protocol, in order to determine the appropriate backoff time due to the network traffic and avoid packet collision.

The primary goal of this research is to develop a MAC layer protocol that increases the network lifetime for wireless sensor networks. To achieve this aim, the following main objectives of the thesis ought to be accomplished:

- To reduce energy consumption in MAC 802.15.4 IEEE standard by developing the sleep state mechanism inside the active mode of the superframe.
- To implement the ABE-MAC - an enhanced MAC protocol on MAC IEEE 802.15.4 standard - as one of the benchmarks.
- To evaluate the performance of proposed MAC protocol in terms of energy consumption, system throughput, power efficiency, end-to-end delay, packet delivery ratio and Link Quality Indicator (LQI).
- To compare the performance of the proposed MAC protocol with 802.15.4 IEEE standard and ABE-MAC protocols.