UNIVERSITI PUTRA MALAYSIA

PROACTIVE TRAFFIC-ADAPTIVE TUNING OF CONTENTION WINDOW FOR WIRELESS SENSOR NETWORK MEDIUM-ACCESS CONTROL PROTOCOL

NESAE MOUZEHKESH PIRBORJ

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By

NESAE MOUZEHKESH PIRBORJ

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

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DEDICATION

This thesis is dedicated to my parents and all those whom I have ever loved and will love...

God bless you all...

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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Chairman: Nor K. Noordin, PhD

Faculty: Engineering

The ongoing advances in wireless networks have further expanded the boundaries to the new and challenging area of Wireless Sensor Networks (WSN). Unique properties of sensor nodes such as limited energy storage, constrained processing capabilities and the especially different environments they are usually deployed in have prompted the need of novel protocols in all the layers of the communication stack. A Medium Access Control (MAC) protocol is responsible to sufficiently provide access to a shared medium. Therefore effective techniques in order to reduce the probability of collisions while contending for the medium can be established in a MAC protocol for it organizes the specific time slot a node can have access to the channel. The need for further improving the current applied MAC protocols for WSN in order to reduce the probability of collisions while being energy aware has motivated this research. Sensor MAC as the very first MAC protocol for WSN has been designed on top of the IEEE 802.11 MAC protocol along with some added features to meet the special requirements of a WSN. However the Back-Off scheme of Sensor MAC (S-MAC) is based on a fixed Contention Window (CW) size. This is known as a significant trouble spot in S-MAC in the sense that the delay produced during collisions and idle listening can be so critical to the limited battery lifetime of a sensor node. IEEE 802.11 MAC protocol follows a static approach for obtaining the back-off time and resets the CW to its default minimum upon just one successful transmission and doubles it each time it faces a collision. While the back-off algorithm of IEEE 802.11 suffers from unfairness for its faulty behaviour in both high and low traffic loads the back-off mechanism in S-MAC suffers from a fixed CW size. Reducing the undesired idle listening time caused by unnecessary long back-off times when traffic is low and also decreasing the probability of collisions in situations with high traffic load due to the fixed CW size in S-MAC have motivated our research. We have tried to come up with a dynamic back-off algorithm for S-MAC that can extract the current traffic information of the network and engage them in estimating the contention window from which the back-off time is chosen. Our approach is a proactive algorithm to get the CW of the neighbouring nodes ready before contending for the medium. The performance of our algorithm has been measured in terms of average delay, average throughput, delivery ratio, and average energy efficiency. It is shown that our back-off scheme has reduced the delay by 47% and has decreased the energy consumption up to above 15% over the current S-MAC implementation. The delivery ratio and throughput have been improved up to 44% and 28% respectively.

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

PENUMPUAN PENALA TRAFIK-TETINGKAP PROAKTIF PENYATA UNTUK RANGKAIAN PENDERIAAN TANDA WAYAR PROTOKOL KAWALAN AKSES SEDERHANA

Oleh

NESAE MOUZEHKESH PIRBORJ

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Kemajuan yang berterusan di dalam bidang rangkaian tanpa wayar telah mengembangkan sempadannya menuju kepada sebuah bidang yang mencabar rangkaian Penderia Tanpa Wayar (WSN). Nod penderia yang unik seperti penyimpanan tenaga terhad, kekangan keupayaan pemprosesan terutamanya di pesekitaran yang berbeza dimana nod-nod ini kebiasaanya diletakkan telah mendorong keperluan protokol-protokol novel di dalam semua lapisan komunikasi. Medium Access Control (MAC) bertanggungjawab untuk menyediakan akses yang cukup kepada perkongsian medium. Ini bermakna, teknik yang berkesan untuk mengurangkan kebarangkalian perlanggaran semasa bertanding untuk pengantara boleh dibangunkan dalam sebuah protokol mac untuk ia mengatur slot masa tertentu sesebuah nod yang mempunyai akses kepada saluran. Keperluan untuk menambah baik penggunaan protocol MAC mengurangkan kebarangkalian pelanggaran dan pada waktu yang sama telah meransang kajian ini. Penderia MAC sebagai protocol MAC yang pertama untuk WSN telah di reka bentuk di atas protocol IEEE 802.11 bersama dengan penambahan ciri untuk memenuhi keperluan sesebuah WSN. Walaubagaimana pun, skim Back-OFF S-MAC adalah berdasarkan saiz Contention

Window yang tetap. Ini dikenali sebagai masalah dalam S-MAC yang paling ketara dalam konteks kelewatannya yang dihasilkan semasa pelanggaran dan pendengaran serta boleh menjadi sangat kritikal kepada jangka hayat bateri yang terhad dalam sesebuah nod penderia. Protokol MAC IEEE 802.11 mengikuti pendekatan statik untuk mendapatkan masa back-off dan menetap semula CW kepada nilai lalai minimum setelah satu penghantaran berjaya dan menggandakannya setiap kali berlakunya perlanggaran. Sementara algorithma back-off mengalami kegagalan di dalam kedua-dua trafik (trafik rendah dan tinggi), kekurangan mekanisma back-off dalam S-MAC adalah daripada saiz cw yang tetap. Pengurangan masa pendengaran disebabkan oleh masa Back-Off yang panjang dan tidak diperlukan semasa trafik rendah dan juga mengurangkan kebarangkalian perlanggaran dalam situasi-situasi trafik beban tinggi oleh sebab saiz cw yang tetap dalam s-mac telah merangsang kajian kami. Kami telah mencuba untuk menhasilkan algorithma back-off dinamik untuk s-mac yang boleh mengestrak maklumat trafik semasa jaringan dan menggabungkan mereka dalam menganggar pernyataan tetingkap dari mana masa back-off dipilih. Pendekatan kami adalah menghasilkan sebuah algoritma proaktif untuk mendapatkan cw nod-nod yang bersebelahan bersedia sebelum bertanding untuk pengantara. Prestasi algoritma ini telah di ukur dalam konteks kelewatan purata, throughput purata, nisbah penghantaran dan purata keberkesanan tenaga. Ini menunjukkan skim back-off ini telah mengurangkan kelewatan sehingga 47% dan telah mengurangkan penggunaan tenaga sehingga melepasi 15% daripada perlaksanaan S-MAC semasa. Nisbah penghantaran dan thruoghput telah ditingkatkan sehingga 44% dan 28% masing-masing.

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APPROVAL

I certify that an Examination Committee has met on …………….. to conduct the final examination of Nesae Mouzehkesh Pirborj on her Master of Science thesis "Proactive Traffic Adaptive Tuning of Contention Window in Medium Access Control Protocol with Energy Conservation for Wireless Sensor Network" in accordance with Universiti Putra Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree.

Members of the Examination Committee are as follows:

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

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Date: 11 February 2010

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.

NESAE MOUZEHKESH PIRBORJ

Date:

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LIST OF ABBREVIATIONS

ACK	Acknowledgment
ADC	Analog to Digital Convertor
AODV	Ad-hoc On-demand Distance Vector (routing protocol)
AWK	a perl or C++ script to interpret the results (**AWK** stands for **A**ho, **W**einberger & **K**ernighan, the authors of this language)
BEB	Binary Exponential Back-off
B-MAC	Berkeley Medium Access Control
BT	Back-off Time
CBR	Constant Bit Rate
CDMA	Code Division Multiple Access
CPU	Computer Processing Unit
CSB	Channel Status Bit
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 Coordination Function Inter Frame Space
D-MAC	Data gathering Medium Access Control Protocol
EIED	Exponential Increase Exponential Decrease
FDMA	Frequency Division Multiple Access
GHz	Giga Hertz
Kbps	Kilo byte per second
LAN	Local Area Network

LEACH	Low Energy Adaptive Clustering Hierarchy
MAC	Medium Access Control
MACA	Multiple Access Collision Avoidance
MACAW	Multiple Access Collision Avoidance for Wireless
Mbps	Mega byte per second
MANET	Mobile Ad hoc Network
NAV	Network Allocation Vector
NAVC	Network Allocation Vector Counter
NIC	Network Interface Card
Otcl	Object tool command language
PCF	Point Coordination Function
PHY	Physical
QoS	Quality of Service
RAM	Random Access Memory
RTS	Request To Send
SDMA	Space Division Multiple Access
SIFS	Short Inter Frame Space
S-MAC	Sensor Medium Access control
Std	Standard
SYNC	Synchronization
TCL	Tool Command Language
TDMA	Time Division Multiple Access
T-MAC	Time-out Medium Access Control
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network

Z-MAC	Zebra Medium Access Control

LIST OF SYMBOLS

d_{cs}	Carrier sense delay
$d_{end-to-end}$	End-to-end delay
d_{proc}	Processing delay
d_{prop}	Propagation delay
d_{trans}	Transmission delay
$Coll_i$	i^{th} collision in a virtual transmission time
dBm	Power ratio in decibels
E[B]	Average back-off time
$E[B_1]$	Average back-off time for only one active station
E[Coll]	Average length of a collision in a virtual transmission time
$E[N_c]$	Average number of collisions in a virtual transmission time
E[S]	Average length of a successful transmission time
$Idle\_p_i$	i^{th} idle period in a virtual transmission time
f	Traffic function
M	Number of immediate (1-hop away) neighbors of a node
BT_{thre}	Threshold for the back-off time
l	load
$\overline{m}$	Average message length
$n_{coll-avg}$	Average number of collisions
n_{coll}	Number of collisions
N_c	Average number of collisions in a virtual transmission time
p	Parameter to sample the back-off time from a geometric distribution
p_{min}	Minimum value for p

q	Packet length distribution
t_{slot}	Time slot
t_v	Virtual transmission time
α	Busy rate
α_2	Smoothing factor
τ	Propagation delay
τ_{opt}	Optimal channel access probability
ρ_{max}	Capacity (Maximum throughput)
T_{receive}	Time when a packet is successfully received
$T_{\mathrm{ready\text{-}to\text{-}send}}$	Time when a packet is ready to send
W_{init}	Initial value for contention window

CHAPTER 1

INTRODUCTION

1.1 Background

With the extensive growth of a wide range of monitoring applications and phenomena such as public health care, target detection and tracking, environmental e just to name a few, wireless sensor networks have proved to be the only right solution for all these event-driven applications.

They exhibit a network of low-cost, low power nodes composed of elementary communication tools such as memory, processor and a radio or transceiver. These sensor nodes are usually scattered randomly in an area of interest to collect information about the event that is about to happen. The self-organized sensor nodes are expected to be autonomously operating ever after being deployed, leaving them in a situation of no external control [2].

A Medium Access Control (MAC) protocol organizes access of all nodes to a shared medium by deploying some scheduling algorithms to specify who and when can occupy the channel for the current transmission. The MAC design space for a WSN is limited by always considering an energy aware behaviour when enhancing any other traditional performance parameters such as latency, throughput and fairness. WSN-specific MAC protocols follow the basic design principles of IEEE 802.11 Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol developed for wireless Local Area Networks (LANs). However due to the unique properties and limitations of sensor nodes, much energy will be wasted from these reported sources: Idle listening, overhearing, collisions, traffic fluctuations and protocol overhead [2] , which will be later discussed in Chapter 2.

In this thesis we focus on providing an energy aware operation of the MAC protocol by reducing the collisions in Sensor MAC or S-MAC [Ye, Heidemann & Estrin. 2002] as the first MAC protocol for WSN which is designed on top of the IEEE 802.11 MAC protocol. IEEE 802.11 MAC protocol employs a Binary Exponential Back-off (BEB) algorithm to alleviate the probability of collision and adjusts the Contention Window (CW) for the next transmission based on an exponential behaviour which is discussed in depth in the next section. While the BEB mechanism in IEEE 802.11 changes the size of the CW exponentially the size of the CW in S-MAC is fixed. Many alternatives of MAC protocols for both WLANs and WSNs (mostly for WLANs) have been proposed introducing some novel techniques that can lead to a more proper size of the CW. In summary, while manipulating the back-off behaviour of IEEE 802.11 standard to have a more effective control on the usage of medium has been an active research area for years, there have been also remarkable attempts recently to address the problem of fixed CW in S-MAC in similar ways.

1.2 Problem Statement and Motivation

Besides the primary task of creating the network infrastructure for establishing links between the randomly distributed nodes [3], MAC protocols also take control of the radio, the most power consuming component of a sensor node. In contrary to Bluetooth and mobile ad-hoc networks, as the closest peers to sensor networks, there are larger number of nodes, a lower transmission power (~ 0 dBm) and also less radio range than that of Bluetooth or MANET [3].

Extensive researches such as those discussed later in the related literature brought in Section 2.8 in Chapter 2, show that the probability of collisions can be reduced to a great extent by a wise scheduling of the sensor node's transceiver, telling it when to access the channel so that it faces less collisions and thus less amount of delay. Collisions are only one of the sources of more produced latency and consequently a waste of energy in a WSN. Other sources reported in the literature are idle listening (as the most power consuming one), overhearing and control packet overhead which will be detailed later in Chapter 2.

A collision happens when two or more sensor nodes try to contend for the medium at the same time as there is only one common channel. It is obvious that when a collision happens extra time should be taken due to the retransmission of corrupted packets which leads to a smaller delivery ratio and overall throughput of the network. The probability of a collision will be reduced if each node contends for the medium in a proper time slot. IEEE 802.11 defines two methods for accessing the channel in a time slot; 1) Distributed Coordination Function (DCF) which is a contention-based one and 2) Point Coordination Function (PCF) which is a contention-free method. IEEE 802.11 MAC protocol DCF adopts two different schemes for sending and receiving data packets which are: 1) Two way handshaking also known as the basic CSMA/CA scheme and 2) Four way handshaking scheme also known as CSMA/CA with RTS/CTS. Both these schemes are also discussed in Chapter 2.