Novel Energy Efficient Protocols with Realistic Radio Propagation Models for Wireless Sensor Networks in Agriculture

by

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A thesis submitted
In fulfillment of the requirements for the degree of
Doctor of Philosophy

School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS

2012

ACKNOWLEDGEMENT

All Praise and gratitude are due to Almighty ALLAH, Most Gracious and Most Merciful for giving me the strength and guidance in finalizing this PhD thesis.

I acknowledge, with sincere appreciation, the encouragement and guidance given to me by Prof. Dr. R. Badlishah Ahmad, who served as my advisor.

I am grateful to the Universiti Malaysia Perlis (UniMAP) and Ministry of Higher Education Malaysia (MOHE), for their financial support during the past years. Thanks to UniMAP, especially the Vice Chancellor, School of Computer and Communication Engineering, the dean and the administration staff in supporting my work.

Thereafter, I am deeply indebted and grateful to various individuals who have assisted me most generously in the completion of this research, namely: Prof. Dr. Ali Yeon Md Shakaff, Dr. David Ndzi, Dr. Massudi Mahmuddin, Dr. Ong Bi Lynn and Maz Jamilah Maznan.

My sincere thanks also goes to my fellow ECRC and CEASTech members, for the stimulating discussions. They have taught me much, and their feedback, and friendship have made my PhD. experience both more educational and more fun.

I would like to thank my family and my in-laws who have filled my life with happiness and have been my source of resilience in difficult times. Special thanks to my brother Kamarulzaman, who has been very helpful.

Dedicated to my mother Noridah Yangman and father Kamarudin Hussin for their innumerable prayers and encouragement. They have stood by me in everything I have done, providing constant support and love. To my daughter, Myiesha Nur Amira who has been a source of joy. She keeps my life filled with laughter and love.

Special thanks to my beloved husband, Ammar Zakaria who has been my best friend and my "true companion". I thank him for his unconditional love and never ending support.

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LIST OF ABBREVIATIONS

ADC	Analog-to-digital Converter
ANN	Artificial Neural Network
BPK-means	Balance Parallel K-means based Clustering protocol
CPU	Central Processing Unit
CSMA	Carrier Sense Multiple Access
DEE-MAC	Dynamic Energy Efficient TDMA-based MAC
EEG	Electroencephalography
FSL	Free Space Loss
GA	Genetic Algorithm
IEEE	Institute of Electrical and Electronics Engineers
ISM	Industrial Scientific and Medical
ITU	International Telecommunication Union
ITU-R	ITU-Recommendation
KMMDA	K-means Like Minimum Mean Distance Algorithm
LEACH	Low-Energy Adaptive Clustering Hierarchy

LNCA	Local Negotiated Clustering Algorithm
LOS	Line of Sight
MA	Maximum Attenuation
MED	Modified Exponential Decay
MF	Mobility Framework
MRR	Multiple Random Restart
NS-2	Network Simulator 2
NZG	Non Zero Gradient
PE	Plane Earth
PSO	Particle Swarm Optimization
RET	Radiative Energy Transfer
RF	Radio Frequency
RFID	Radio-frequency identification
RSSI	Received Signal Strength Indicators
SNIR	Signal to Interference and Noise Ratio
SNR	Signal to Noise Ratio
TDMA	Time Division Multiple Access

TEEN	Threshold Sensitive Energy Efficient Sensor Network
WirelessHART	Wireless Highway Addressable Remote Transducer Protocol
WLAN	Wireless Lan
WPAN	Wireless Personal Area Network
WSNs	Wireless Sensor Networks
6LowPan	IPv6 over Low power Wireless Personal Area Networks

Protokol Cekap Tenaga yang Novel dengan Model Perambatan Gelombang Radio yang Realistik untuk Rangkaian Penderia Wayarles dalam Pertanian

ABSTRAK

Rangkaian penderia wayarles (WSN) merupakan satu teknologi yang membawa harapan baru kepada pelbagai jenis aplikasi. Prestasi WSN bergantung kepada pelbagai faktor seperti parameter lapisan fizikal (iaitu tahap penghantaran kuasa dan pemilihan frekuensi) dan protokol komunikasi (MAC dan protokol laluan masa). Berdasarkan faktor-faktor ini, cabaran adalah dalam mereka bentuk dan menempatkan WSN dengan bekalan tenaga yang terhad dalam pelbagai jenis persekitaran di mana ketakandalan saluran pembiakan wayarles menyekat prestasi nod-nod penderia. Penyelidik telah melaburkan banyak masa dan usaha untuk membangunkan protokol komunikasi berprestasi tinggi. Walau bagaimanapun, masih tiada pendekatan yang mampu untuk memenuhi keperluan dan cabaran dalam aplikasi pertanian, terutamanya dalam reka bentuk simulasi protokol yang realistik. Tesis ini memberi tumpuan kepada simulasi realistik protokol baru yang cekap tenaga dan teguh kepada variasi dalam persekitaran perambatan gelombang radio. Protokol-protokol yang dicadangkan memastikan sambungan antara ahli-ahli kelompok dan ketua kelompok (CH), sesuai untuk rangkaian yang padat, beban rangkaian yang rendah dan yang paling penting ialah penggunaan kuasa secara efisen. Untuk mengatasi masalah ini, eksperimen dalam kawasan pertanian telah dijalankan untuk mengenalpasti model perambatan gelombang radio yang terbaik untuk reka bentuk dan penilaian protokol melalui simulasi. Berdasarkan model-model yang telah dikenalpasti, algoritma MAC yang direka untuk protokol berkluster seperti LEACH dalam bidang pertanian, AgriMAC telah dicadangkan bersama dengan algoritma kawalan penghataran yang dinamik kuasa, DytCon. Prestasi algoritma ini berbanding LEACH telah dibuat dari segi kecekapan tenaga dan jangka hayat rangkaian tersebut. Hasil kajian menunjukkan bahawa prestasi algoritma ini mencapai peningkatan yang besar dalam jangka hayat rangkaian berbanding LEACH. AgriMAC menghapuskan penalti kepada jangka hayat rangkaian apabila mempunyai bilangan kluster yang tinggi di antara 4 dan 10. Penambahbaikan sebanyak 4.8% berbanding nilai maksimum jangka hayat LEACH telah di capai. Dalam usaha untuk menyelesaikan pelbagai isu protokol berkluster seperti LEACH iaitu pembahagian rangkaian yang tidak seimbang dan jumlah bilangan ketua kelompok yang tidak optima pada setiap pusingan, satu protokol berkluster dan cekap tenaga bernama DynClust telah dicadangkan. Teknik klasifikasi k-means telah diadaptasi untuk membahagikan nod-nod penderia kepada kluster bersama dengan algoritma AgriMAC dan DytCon untuk mencapai jangka hayat rangkaian yang optima. Protokol ini mempamerkan sifat-sifat penting seperti kemantapan terhadap variasi dalam persekitaran perambatan radio, memerlukan penukaran paket kawalan yang rendah, mudah dan efisen. Protokol ini meningkatkan prestasi berbanding LEACH dari segi pengagihan kluster dan keahlian kluster. Dari keputusan simulasi, DynClust mencapai 318% penambahbaikan berbanding LEACH dalam jangka hayat rangkaian di persekitaran pembiakan radio yang berbeza. Ini meningkatkan kemungkinan untuk simulasi WSN yang lebih tepat dalam situasi yang dinamik dan persekitaran pertanian.

Novel Energy Efficient Protocols with Realistic Radio Propagation Models for Wireless Sensor Networks in Agriculture

ABSTRACT

A wireless sensor network (WSN) is an emerging technology that enables a variety of possible applications. The performance of a WSN depends on many factors such as the physical layer parameters (i.e. transmission power and frequency selection), and the communication protocols (MAC and routing protocols). Accounting for these factors, the technical challenges remain in designing and deploying a robust WSN with limited energy supplies in a harsh environmental condition, where the unreliability of wireless propagation channel restricts the performance of the sensor node. Researchers have invested a lot of time and effort into developing high performance communication protocols to meet the growing challenges of WSN. However, there is still no approach that is able to meet the requirements and challenges of agriculture application, especially in realistic simulation design of WSN protocols. This thesis focuses on the simulation of the proposed novel energy efficient protocols that are robust to variations in the radio propagation environment. The proposed protocols ensure the connectivity between the cluster members and cluster head (CH), applicable for dense networks, low network overhead and most importantly, energy efficient. To address this, an actual measurement on vegetation attenuation is carried out to ascertain the best propagation model for WSN protocol design and evaluation in a simulation platform. Based on these models, a MAC layer algorithm designed for clustering protocols such as LEACH, called AgriMAC is proposed, and it is combined with dynamic transmit power control algorithm, DytCon. The performances of these algorithms are compared with LEACH in term of energy efficiency and network lifetime. Results show that the performance of these algorithms achieves a substantial improvement in network lifetime compared to LEACH. AgriMAC eliminates the penalty of having more cluster heads to the network lifetime, where a steady performance is achieved when the number of cluster is between 4 and 10 with approximately 4.8% *improvements over the maximum network lifetime achieves by LEACH. In order to solve various issues of LEACH clustering protocol such as unbalanced network partitioning and variable number of cluster heads per round, a novel energy efficient clustering protocol, DynClust is proposed. The protocol combines a machine learning technique called k-means, where it groups the nodes into clusters with AgriMAC and DytCon to optimize the network lifetime. DynClust exhibits vital properties such as robustness against variations in the radio propagation environment, a very low control overhead, simple and yet efficient. The protocol improves LEACH in term of cluster distribution and cluster membership. From the simulation results, DynClust achieves approximately* 318% *improvements over LEACH in term of network lifetime in various propagation environments. These allow the possibility of WSN to be simulated accurately in dynamic and harsh agriculture applications.*

CHAPTER 1

INTRODUCTION

A Wireless sensor network (WSN) is a network of sensor that communicates wirelessly with each other. The network consists of distributed autonomous devices using sensors to monitor physical or environmental conditions such as temperature, light, vibration, air quality and motion. Each node in a WSN is equipped with a radio transceiver, microcontroller and energy source and its limitations on size and cost of node hardware results in corresponding constraints on resources such as energy, memory, computational speed and communication bandwidth.

WSNs applications deployment range from medical care (Patel et al., 2009), environmental monitoring applications such as early warning of disaster incident (Suzuki et al., 2007; Werner-Allen et al., 2006; Kumar and Ramesh, 2010), through to agriculture monitoring applications (Beckwith et al., 2004; Kim et al., 2010; Andonovic et al., 2010) as well as precision agriculture.

Since the applications, environments and their requirements for the network are diverse, WSNs implementations are usually application specified. The energy consumption, communication bandwidth and networking performances of nodes must be optimized based on application tasks. Some applications require the WSNs deployment to be widely spread, thus making its implementation more challenging.

In WSNs, the radio communication channel is susceptible to a variety of propagation impairments such as interference, reflections, scattering, and shadowing. These factors influence the network performance and system cost and need to be modeled accurately. Since the energy resource of the sensor nodes is a design constraint, therefore, the choice of the communication protocols is a key design parameter. For WSNs deployed according to site planning, classical propagation models for predicting the average path loss can be used. However, for some applications where the nodes might be buried in moist ground and covered by vegetation or other obstructing objects, these classical propagation models might not be valid for predicting the propagation path loss of a link. Therefore, characterization and modeling of the wireless propagation channel is necessary for the protocols design and deployment of a robust WSNs.

Furthermore, sensor nodes in WSNs system should operate with minimum possible energy to increase the sensor network lifetime. Thus, protocols and algorithm in WSNs must be optimally suited to the application requirements to achieve this target. The major challenges in the designing WSNs protocols are a combination of the constraint in deploying a large number of distributed nodes in a very harsh environment, limited energy supply and bandwidth. However, most of the published protocols in the literature are based on simple and unrealistic propagation models with too much assumptions. Therefore, the implementations of these protocols in real scenarios are questionable and far from reality. The focus of this research is to design energy efficient protocols for WSNs in agriculture considering a realistic wireless propagation channel and radio energy model, in order to improve the network lifetime.

1.1 Problem Statement

Recently, there has been a significant expansion of land use for plantations such as oil palm, rubber and other commercially cultivated crops, which requires WSNs as the enabling technology to improve quality assessment, control crop growing conditions and automate agricultural process. However, there are several challenges associated with designing and deploying WSN in agriculture environment. Agriculture applications usually involve wide area monitoring with hundreds to thousands of nodes that need to operate in harsh conditions where obstruction, interference and degradable radio signal are unavoidable. Deployed WSN systems are also expected to provide continuous monitoring for a long period, hence, adequate battery lifetime.

Many research studies in WSN have resulted in the proposal of many algorithms and protocols. However, most of the proposed protocols assume a highly idealized propagation model, unrealistic energy model with unlimited transmit power algorithm to assess and validate the protocol's performance, that are often too optimistic regarding the performance of WSNs. Thus, one of the objectives of this thesis is to provide a realistic simulation model using OMNeT++ by incorporating realistic parameters into the WSNs simulator using actual experimental results and real hardware specifications.

Most research work have been done either, on single hop, multi hop or cluster based routing protocols in WSNs. In order to have a better performance, multi-hop routing protocol is used since the method of directly sending data to the base station is inefficient (Akyildiz et al., 2002). However, the main limitation of multi hop routing is that the energy consumption of the sensor nodes close to the base station is higher since they need to send their own data as well as to relay data from other nodes. Clustering technique has been proven to optimize energy consumption and prolong network lifetime in many WSNs protocols. This method is also efficient and scalable, which is one of the important parameters in WSNs for application in agriculture, where the nodes are densely deployed.

Many cluster based routing protocols have been proposed for WSNs in the past few years. Although many of them produce good results based on some form of energy-efficient clusters, only few of them are application specific and extremely few of them carefully consider the effects of different physical propagation mechanisms in the environment when forming clusters. To the best of the author's knowledge, there is no communication protocol has been proposed in open literature that considers all three points together.

This thesis is directed towards designing energy efficient protocols for applications, which require continuous monitoring of agriculture environment with varying wireless channel conditions (i.e. the existence of foliage in propagation path). This work investigates various models based on actual experimental results to realistically model various aspects of propagation to enhance the quality of the simulations and radio energy model based on a hardware platform. A widely known clustering protocols called LEACH is modeled and evaluated to study the applicability of this protocol in agriculture. Enhancement of this protocol, in term of MAC layer protocols and transmit power control algorithm, is made to suit agriculture.

1.2 Research Objectives

This research proposes an energy efficient protocols for WSNs in agriculture. The highlight of this research is to bridge the gap between the simulation platform and real deployment setup. Thus, a holistic approach is conducted by taking realistic parameter into the WSNs simulator using an actual experimental value. In order to accurately design and evaluate the protocols, network simulator OMNeT++ is used and extended with vegetation propagation model based on experimental results and radio energy model based on real hardware platform. The specific objectives are as follows:

1. To model and evaluate communication protocols using OMNeT++ as a simulation platform. In order to achieve realistic design and evaluation, the following work are performed:-

   (a) To determine the propagation models that best describe the agriculture environment based on experimental results and to enhance OMNeT++ to support these models;

   (b) To implement a well-known cluster based routing protocol in OMNeT++ as a benchmark to evaluate the performance of the proposed protocols;

2. To improve energy efficiency and prolong network lifetime. In order to achieve this, the following work are performed:-

   (a) To propose MAC layer protocols for WSNs in agriculture;

   (b) To propose transmit power control algorithm for WSNs in agriculture;

(c) To propose a novel cluster based routing algorithm for WSNs in agriculture;

1.3 Thesis Organization

This thesis is organized as follows: Chapter 2 presents the background and literature review for this thesis. This chapter discusses the basic principles of WSNs and its applications. Target applications and design challenges associated with the applications are presented. This chapter also presents the scenarios to simulate and evaluate the network. In this chapter, current state-of-the-art energy efficient routing and MAC layer protocols for WSNs as well as the evaluation techniques that exist to design and evaluate WSNs protocols are discussed in detail. The simulator used to design and evaluate the algorithms and protocols is discussed in detail. An introduction to clustering algorithm and detailed descriptions of the k-means clustering algorithm, as the technique used in this thesis are presented. Then, the research methodologies used in this research are presented.

In Chapter 3, the measurements studies conducted to analyze the characteristics of wireless propagation channel in agriculture are presented. Based on the measurements studies, the propagation model that best describes the environment is determined. OMNeT++ is enhanced to model wireless propagation channel in vegetated environments.

Chapter 4 of this thesis describes the LEACH protocol modeling and evaluation that are developed in OMNeT++. Based on this study, several issues regarding LEACH evaluation technique and performance are discussed.

In Chapter 5, AgriMAC algorithms that improves LEACH MAC layer schemes is presented. This chapter also describes the radio energy model used in this thesis, as well as introduces a newly proposed dynamic transmit power algorithm, DytCon. Analysis and performance of both algorithms are discussed in details.

In Chapter 6, a novel cluster based protocols for WSNs in agriculture is proposed. The protocols called DynClust is based on modified k-means algorithm, a machine learning technique with AgriMAC and DytCon. The objective functions proposed is presented. A series of simulations are conducted using various network deployments to represent different types of agriculture scenarios to evaluate the performance of this algorithm. Moreover, a comparison is also made with benchmark algorithm designed for WSNs, LEACH and LEACH-AgriMAC.

Finally, in Chapter 7, a summary of the thesis is drawn and future work arising from this thesis is suggested.