A new wireless sensor network wave propagation model based on zigbee protocol for protected mango greenhouse environment

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A thesis submittteed in fulfillment of the requirements for the degree of
Doctor of Philosophy in Computer Engineering

School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS

2017

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

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Date of birth : **1st July 1970**

Title : **A NEW WIRELESS SENSOR NETWORK WAVE PROPAGATION MODEL BASED ON ZIGBEE PROTOCOL FOR PROTECTED MANGO GREENHOUSE ENVIRONMENT**

Academic Session : 2014 / 2017

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ACKNOWLEDGEMENTS

Firstly and foremost, All thanks for **Allah**, Most gracious and Most Merciful for giving me the strength and guidance in finalizing this PhD. thesis.

I would like to use this opportunity to express my sincere gratitude to my supervisor, **Dr. Phak Len Eh Kan**, for his continuous encouragement, advice and motivation that enabled me to achieve all goals to complete this research.

Special thanks to my co-supervisor **Dr. Naseer Sabri Salim** for his kind support, invaluable suggestions and for his guidance throughout this project.

I would like to express my gratitude towards all those who gave me the possibility to complete this thesis.

Last but not least, sincere thanks and gratitude to **my family**, my wife Ebtissam and my children Ghaith, Ali, Mustaffa and Pan who inspired me by their, courage, support and patience throughout the period of my study.

Auda Raheemah Odhaib
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LIST OF ABBREVIATIONS

AC	Alternating Current
ADC	Analog to Digital Converter
APL	Application Layer
ARM	Advanced RISC Machines processor.
BS	Base Station
CC2420	Chipcon: single-chip 2.4 GHz IEEE 802.15.4 compliant RF transceiver designed for low power and low voltage wireless applications.
CCA	Clear Channel Assessment
COST	Cooperative Scientific research Technique
CSMA-CA	Carrier Sense Multiple Access with Collision Avoidance
DC	Direct Current
DSSS	Direct Sequence Spread Spectrum
ED	Energy Detection
EM	Electromagnetic wave
FHSS	Frequency Hopping Spread Spectrum
FITU-R model	Fitted The International Telecommunication Union-Recommendation Model
FOM	Free-space Outdoor Model
FPGA	Field Programmable Gate Array
FSPL	Free Space Path Loss Model
GFSK	Gaussian Filter Frequency Shift Keying
GHPLM	Greenhouse Path Loss Model
GIS	Geographic Information System

GPRS	General Packet Radio Service Modem Gateway
GPS	Geographical Positioning System
GSM	Global System communication for Mobile
GUI	Graphical User Interface
HTTP	Hyper Text Transfer Protocol
IEEE	The Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IP	Internet Protocol
IS	Irrigation Station
ISM	Industrial, Scientific and Medical band
ITU-R Model	The International Telecommunication Union-Recommendation Model
JN5148	NXP/JENNIC: ZigBee PRO Module with integrated antenna
LAN	Local Area Network
LOS	Line Of Sight
LQI	Link Quality Indicator
LR-WPAN	Low Rate - Wireless Personal Area Network
LSPM	Large Scale Propagation Path Loss Models
MAC	Media Access Control
MAPD	Mean Absolute Percentage Deviation
MAPE	Mean Absolute Percentage Error
MSP430	Mixed-Signal Microcontroller for low cost and low power consumption
NWK	Network Layer
O-QPSK	Offset- Quadrature Phase Shift Keying

OMNENT++	Objective Modular Network Testbed
OPNET	Optimum Network Performance Simulation Tool
OSI	Open System Interconnection Reference Model
PA	Precision Agriculture
PAMS	Monitoring System for Precision Agriculture
PASS	Precision Agriculture Sensing System
PC	Personal Computer
PE	Plane Earth Model
PER	Packet Error Rate
PHY	Physical Layer
$PL_{COST235}$	Path Loss by COST235 Model
PL_{FITU-R}	Path Loss by FITU-R model
PL_{FS}	Path Loss by by Free Space Model
PL_{ITU-R}	Path Loss by ITU-R Model
p_r	Received Power
P_t	Transmitted power
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RMS	Remote Monitoring System
RMSE	Root Mean square Error
R_{sens}	Receiver Sensitivity
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
R_x	Receiver

SMS	Short Message Service
SNR	Signal to noise ratio
SoC	System on Chip
SSE	Error Sum Square
T_x	Transmitter
UART	Universal Asynchronous Receiver-Transmitter
UBW	Ultra-wide band
UHF	Ultra High Frequency
USB	Universal Serial Bus
VHF	Very High Frequency
Wi-Fi	Wireless Fidelity-wireless internet
Wiss Model	Weissberger Model
WSN	Wireless Sensor Network
ZC	ZigBee Coordinator
ZED	ZigBee End Node
ZR	ZigBee Router

LIST OF SYMBOLS

P_t	Transmitted signal power (W)
P_r	Received signal power (W)
G_t	Transmitter antenna gain
G_r	Receiver antenna gain
?	The Wavelength (m)
d	The Separation Distance Between Transceivers Antenna (m)
f	Frequency (MHz, GHz)
$\mathrm{H_t}$	The Height of Transmitter Antenna (m)
$\mathrm{H_r}$	The Height of Receiver Antenna (m)
P	The midpoint between transceivers antenna (m)
r	First Fresnel Zone radius (m)
L	The total distance between transceivers antenna (m)
d1	The distance between the transmitter and point *p* (m)
d2	The distance between the receiver and point *p* (m)
$\mathrm{d_0}$	Reference distance (m, Km)
a	The path loss exponent
PL_{tot}	The total path loss (dB)
PL_{FS}	Free space path loss (dB)
PL_{PE}	Plane earth path loss (dB)
$PL(d_0)$	Path loss at the reference distance (dB)
X_s	The Gaussian distributed random variable (dB)
s	Standard deviation (dB)

PL_{veg}	Path loss due to vegetation existence (dB)
d_f	The vegetation depth (m)
A	Empirically calculated constant
B	Empirically calculated constant
C	Empirically calculated constant
PL_{Weiss}	Path loss by Weissberger Model (dB)
PL_{ITU-R}	Path loss by ITU-R Model (dB)
$PL_{COST235}$	Path loss by COST235 Model (dB)
PL_{FITU-R}	Path loss by FITU-R Model (dB)
R_{sens}	Receiver sensitivity (dBm)
PL_{thr}	Path Loss Threshold (dBm)
d_{max}	The maximum separation distance (m)
R^2	The goodness of fit
y_{actual}	The actual path loss measurements
$y_{average}$	The average of the actual measured data
$y_{fitting}$	The predicting data by linear curve fitting
$s^2_{y,x}$	The variation between the actual and predicting data
s^2_y	The variation between the actual and average of actual data
μ	The average of measured values
X_{model}	Prediction path loss by model
N	Samples number
PL_{PE}	Path Loss by Plane Earth Model
A	Radiation Angle (degree)

Model Baru Gelombang Perambatan Rangkaian Pengesan Tanpa Wayar Berdasarkan Protokol ZigBee untuk Perlindungan Persekitaran Rumah Hijau Mangga

ABSTRAK

Rangkaian pengesan tanpa wayar (WSN) adalah teknologi berpotensi dan ianya digunakan secara meluas untuk memantau dan mengawal keadaan alam sekitar bagi pertanian tepat. Penggunaan nod WSN dalam persekitaran sebenar berhadapan dengan kesesuaian pautan komunikasi dan liputan rangkaian khususnya dalam kes penggunaan nod tanpa wayar berhampiran dengan tanah dan juga kewujudan tumbuh-tumbuhan yang padat dimana ianya mungkin boleh menjejaskan isyarat perambatan. Pemodelan saluran komunikasi tanpa wayar amat penting untuk mencapai kejayaan dalam perlaksanaan sistem WSN persekitaran pertanian. Dalam WSN, ketepatan perambatan model 'path loss' membantu untuk kesesuaian penilaian prestasi realisasi, mencapai komunikasi yang boleh dipercayai, meningkatkan kecekapan kuasa nod rangkaian dan juga mengurangkan keseluruhan kos rangkaian tanpa wayar. Banyak model 'path loss' telah digunakan untuk pemodelan saluran komunikasi tanpa wayar tetapi kebanyakannya tidak sesuai untuk aplikasi WSN disebabkan oleh medium perambatan dan juga piawaian IEEE 802.15.4. Dalam penyelidikan ini, 'path losses' perambatan isyarat WSN dalam persekitaran rumah hijau mangga dikaji dengan menggunakan piawaian WSN berdasarkan ZigBee. Pelbagai pengukuran empirikal telah dijalankan untuk memeriksa kesan 'path loss' pada setiap bahagian pokok dengan ketinggian pemancar yang berbeza-beza untuk memilih ketinggian antena yang paling sesuai digunapakai dalam semua eksperimen bagi memperolehi model 'path loss' yang baru. Kepastian model perambatan 'path loss' yang baru untuk persekitaran rumah hijau (Greenhouse Propagation Path Loss Model - GHPLM) diperolehi berdasarkan teknik regresi. Model baru ini digunakan untuk mengira jumlah 'path losses' dan penggunaan nod rangkaian pengesan dalam bidang sebenar berdasarkan pengukuran jarak pemisahan maksimum. Hasilan daripada kerja ini telah membuktikan bahawa ketinggian antena dan kedalaman tumbuh-tumbuhan adalah dua faktor terpenting dalam pemodelan saluran. Model 'Plane Earth' (PE) juga tidak tepat untuk meramalkan 'path loss' dalam persekitaran sebenar disebabkan ianya berdasarkan pendekatan simplistik dan dianggap sangat optimis dalam senario perambatan sebenar seperti kes persekitaran rumah hijau ini. Dengan itu, gabungan model ini dengan model 'path loss' tumbuh-tumbuhan menghasilkan keputusan yang lebih menyakinkan dan ini boleh menggambarkan perlakuan sistem WSN yang betul apabila digunakan dalam persekitaran sebenar. Keputusan empirikal telah membuktikan bahawa model GHPLM adalah model terbaik jika dibandingkan dengan model-model empirikal perambatan 'path loss' sediaada. 'Mean Absolute Percentage Error (MAPE)' yang digunakan untuk mengukur perbezaan antara nilai sebenar dan nilai ramalan adalah 3.96% untuk model GHPLM berbanding dengan model 'path losess' tumbuh-tumbuhan yang lain dimana peratusannya adalah 44.55%, 41.07%, 31.82% dan 15.48% untuk model-model Weissberger, ITU-R, FITU-R and COST235 masing-masing.

A New Wireless Sensor Network Wave Propagation Model Based on ZigBee Protocol for Protected Mango Greenhouse Environment

ABSTRACT

The wireless sensor network (WSN) is the promising technology and it is widely used for monitoring and controlling the environmental conditions of precision agriculture. The deployment of the WSN nodes in real environments faces hard challenges of proper communication links and network coverage especially in the case of deployment of wireless nodes near the ground and the existence of dense vegetation which may impair the propagating signals. Modeling of wireless communication channel is important to achieve a successful implementation of WSN system in agricultural environment. In WSN, accurate propagation path loss models help for realization appropriate evaluation of the WSN performance, achieving more reliable communication, improving the power efficiency of the network nodes and decreasing the overall cost of the wireless network. There are many propagation path loss models used for modeling wireless communication channels, but most of them might not be suitable for the WSN applications due to propagation medium and the IEEE 802.15.4 standard. In this research, the WSN signal propagation path losses inside the mango greenhouse environment are investigated by using WSN based on the ZigBee standards. Various empirical measurements were conducted to examine the effect of each part of a tree on path loss with different transceivers' heights to select the best antenna heights that adopted in all experiments for deriving the new path loss model. Indeed, a new propagation path loss model for greenhouse environment (Greenhouse Propagation Path Loss Model - GHPLM) is derived based on a regression technique. This new model is used for computing the total propagation path losses and for deployment the wireless sensor nodes in the real field based on the maximum separation distance measurements. The outcomes from this work proved that the antenna heights and the vegetation depth are the two most important factors in channel modeling. The empirical results emphasize that the Plane Earth (PE) model is inaccurate for predicting path loss in real environments due to it is based on simplistic approaches and considered to be very optimistic in real propagation scenarios as the case in mango greenhouse environment. Thus, the combination of this model with the vegetation path loss model contribute more convincing results and can best describe the behavior of actual WSN systems when deployed in a real environment. The empirical results proved that the GHPLM model is the best candidate compared to other existing empirical propagation path loss models. The Mean Absolute Percentage Error (MAPE) that measured the difference between the actual and prediction path loss was 3.96% for the new GHPLM model compared to other vegetation path losses which were 44.55%, 41.07%, 31.82% and 15.48% for Weissberger, ITU-R, FITU-R and COST235 models respectively.

CHAPTER 1

INTRODUCTION

1.1 Background

Currently, agriculture requires advanced technology to improve the quality of yield, reducing environmental effects on crops, and protecting agricultural environments. Precision agriculture (PA) is beneficial towards these goals, and it is duly applied to observe environmental conditions, such as temperature, humidity, and light (Awasthi & Reddy, 2013). Furthermore, PA controls the amount of water, pesticides, and fertilizers in the agricultural field in order to enhance and improve the quality of the yields based on the required environmental conditions of the field (Awasthi & Reddy, 2013; Mestre et al., 2011). In agricultural environments, the PA relies on the use of modern technologies to promote variable management practices within a field (Mestre et al., 2011). The implementation of PA depends on the collection of huge amounts of information related to environmental conditions in the agricultural field and the status of the crops. Such information is usually gathered by the number of sensor nodes that are distributed in the field. The network sensor nodes cooperate to gather specified data, which is then conveyed to the main sink node via the internet, wireless network, or Local Area Network (LAN), where decision-making unit processes it and take action(s) based on system's setup (Keshtgary & Deljoo, 2012; Vougioukas et al., 2013).

The Wireless Sensor Network (WSN) is the promise technology for sensing the environmental conditions and the status of crops at suitable costs and accuracies

(Vougioukas et al., 2013). WSN includes a number of nodes, where each node consists of a number of units such as sensors, Radio Frequency (RF) communication unit (transceivers), processing unit (microcontroller), and power source unit (battery) (Vougioukas et al., 2013). The WSNs have been used in various agricultural applications for sensing and data acquisition, such as monitoring weather conditions of temperature, humidity, and soil moisture (Li et al., 2009; O'Shaughnessy & Evett, 2010), precision irrigation and valve control-based on weather and soil sensing (Evans et al, 2011), and precision livestock and the food industry (Ruiz-Garcia et al., 2009). The WSN's developers' adoption of the ZigBee protocol for the wireless sensors applications. The Zigbee is an open and global standard for WSN, aiming for low costs, low rates, and low power consumption. The ZigBee implements the upper layer (the network and application layers) of the Open System Interconnection Reference Model (OSI), and it relies on the IEEE802.15.4 protocol for the implementation of two lower layers (the Physical and Data Link Layers) (Feng et al., 2010).

The success of the WSN applications depends on the reliability of the communication between the wireless sensor nodes. Therefore, the well-known propagation mechanisms via the agricultural environment are critical for communication and sensing in such environments (Peng et al, 2012). The main issue for deploying WSN in real environments is determining the positions of the network nodes. It must be placed close enough to realize a reliable connection. The maximum separation distance between each two contiguous nodes depends on the output power of the transmitter, the gain of the antennas, and the attenuation that occurs due to free-space or obstacles (Vougioukas et al., 2013).

In wireless communication systems, the propagation path loss models are used to predict the path loss of the transmitted signals, calculating the average of power received, and determining the maximum allowable separation distance between two adjacent nodes (AlSayyari et al., 2014c). Such propagation path loss models are usually derived according to certain environmental properties where the transceivers are operating.

There are two main approaches for modeling wireless channels, namely the theoretical model (also called deterministic) and empirical model (also called a probabilistic model or statistical model) (Rappaport, 2002). Theoretical models report very accurate values for path losses, but these models are only occasionally available in practice because they are very complicated and can only be solved by numerical methods, which require exact environmental information related to the wireless channel, such as the geometry and the electrical properties of soil. This information is usually very difficult to obtain from real environments. The empirical models are derived based on actual measurements. The advantages of the empirical models over theoretical models include their ease of implementation and their ability to include all environment related parameters that affect the propagation of the radio (Meng et al., 2009b; Sharma & Singh, 2010).

1.2 Research Background

In WSN, the precise propagation path loss models can help to (Akyildiz & Vuran, 2010; Otero et al., 2010):

- Achieve proper evaluation and optimize the network's performance.
- Improving the power efficiency of wireless sensors.
- Achieving more reliable communication.
- Reducing the overall cost of the wireless network.

Many researchers have proposed and adopted different propagation path loss models for WSN nodes deployment planning in different environments. These researches can be classified into three groups. The first group of researchers adopted two of the most well-known model of large scale propagation path loss models i.e. Free Space Path Loss (FSPL) model and Plane Earth (PE) model for predicting path loss and determine the separation distance between the wireless nodes. Both models rely on simplistic approaches, and they are regarded as very optimistic for predicting path loss in real environment, such as the greenhouse environment, where there are obstacles between the wireless sensor nodes.

The evaluation of the WSN's performance was based on the available empirical propagation path loss models in simulation environments. This was the focal point of the second group of researchers. The simulation environments assumed that the signal propagation path between transceivers nodes is line of sight (LOS) situation (there are no obstacles between wireless nodes), therefore, the produced results will not reflect the actual scenario.

Contrarily, in the third group, the researchers proposed various propagation path loss models based on the actual measurements performed in different environments. The propagation path loss model for each environment depends on many factors, such as the type of the terrain, the objects that exist in this terrain, the hardware used in measurements, and the antenna heights of transceivers nodes.

Hence, existing wireless communication models are not optimal representation of WSN vegetation channel, and this work focuses on deriving an empirical path loss model, namely Greenhouse Path Loss Model (GHPLM) based on actual measurements conducted in a greenhouse environment for modeling this environment.