PERFORMANCE ANALYSIS OF IEEE802.15.4 WIRELESS SENSOR NETWORK TO MITIGATE IEEE802.11 WIRELESS LOCAL AREA NETWORK INTERFERENCE

NORAINI AZMI

UNIVERSITI MALAYSIA PERLIS

2016

Performance Analysis of IEEE802.15.4 Wireless Sensor Network to Mitigate IEEE802.11 Wireless Local Area Network Interference

by

Noraini Azmi
(1430211222)

A thesis submitted in fulfilment of the requirements for the degree of Master of Science in Computer Engineering

School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS

2016

DECLARATION OF THESIS

Author's full name	:	NORAINI BINTI AZMI
Date of birth	:	13 MARCH 1988
Title	:	PERFORMANCE ANALYSIS OF IEEE802.15.4 WIRELESS SENSOR NETWORK TO MITIGATE IEEE802.11 WIRELESS LOCAL AREA NETWORK INTERFERENCE
Academic Session	:	2014 - 2016

I hereby declare that this thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as:

☐	**CONFIDENTIAL**	(Contains confidential information under the Official Secret Act 1972)
☐	**RESTRICTED**	(Contains restricted information as specified by the organization where research was done)
☑	**OPEN ACCESS**	I agree that my thesis is to be made immediately available as hard copy or online open access (full text)

I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of _________ years, if so requested above).

Certified by:

....	....
SIGNATURE	**SIGNATURE OF SUPERVISOR**
880313-09-5150	DR. LATIFAH MUNIRAH KAMARUDIN
(NEW IC NO. /PASSPORT NO.)	**NAME OF SUPERVISOR**
Date: 27 JULY 2016	Date: 27 JULY 2016

ACKNOWLEDGEMENT

First and foremost, I am thankful to Allah for his blessing towards the completion of this thesis. I would like to offer my deepest gratitude to my supervisors, Dr. Latifah Munirah Kamarudin and Prof. Dr. Sabira Khatun for their continuous and relentless support and guidance throughout the duration of my study. I am also thankful to the reviewers who provided insightful comments that helps significantly improved this thesis. Apart from that, I am also grateful to my parent for their support and advices. Besides that, I also want to thank MyBrain15 for the financial support. Besides that, I also want to thank Centre of Excellence for Advanced Sensor Technology (CEASTech), Universiti Malaysia Perlis (UniMAP), Malaysia for providing support in terms of equipment and location for my experimental test. Finally yet importantly, I would like to thank those whom name not mentions that contribute either directly or indirectly towards the successful completion of this thesis.

Noraini Azmi

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3G	Third Generation
AP	Access Point
CCA	Clear Channel Assessment
CSMA	Carrier Sense Multiple Access
CST	Channel Selection Technique
ED	Energy Detection
IoT	Internet of Things
ISM	Industrial, Medical and Scientific
LOS	Line of Sight
LQI	Link Quality Indicator
MAC	Medium Access Control
OSI	Open System Interconnection
PHY	Physical Layer
QoS	Quality of Service
RF	Radio Frequency
RFID	Radio Frequency Identification
RSSI	Received Signal Strength Indicator
RX	Receiver
TDMA	Time Division Multiple Access
TX	Transmitter
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network

Kajian untuk Menganalisis Prestasi IEEE802.15.4 Rangkaian Sensor Tanpa Wayar bagi Mengatasi Masalah Interferens yang berpunca daripada IEEE802.11 Rangkaian Tempatan Tanpa Wayar

ABSTRAK

Rangkaian sensor tanpa wayar (WSN) digunakan untuk pelbagai aplikasi seperti robotik, penjagaan kesihatan, ketenteraan, dan lain-lain aplikasi yang memerlukan bekalan kuasa yang rendah, pemantauan dalam skala yang besar, ketepatan data yang tinggi, penghantaran data yang pantas dan juga kehilangan data yang minimum. Kualiti perkhidmatan (QoS) WSN sering terjejas oleh gangguan daripada teknologi tanpa wayar yang lain seperti rangkaian tempatan tanpa wayar (WLAN), Bluetooth, ketuhar gelombang mikro, telefon tanpa kord dan alatan USB tanpa wayar yang mempunyai kuasa penghantaran yang lebih tinggi dan jalur lebar yang lebih besar. Peningkatan peranti tanpa wayar menyebabkan pelbagai isu dan diantaranya adalah isu perkongsian frekuensi spektrum. Kebanyakan teknologi tanpa wayar terpaksa berkongsi jalur 2.4GHz kerana jalur frekuensi ini percuma dan tidak memerlukan lesen. Berbanding teknologi tanpa wayar yang lain, gangguan daripada peranti WLAN menyebabkan WSN mengalami kehilangan paket yang paling ketara. Oleh itu, kajian ini memberi tumpuan bagi menyiasat kesan gangguan WLAN ke atas prestasi WSN melalui perlaksanaan ujikaji. Kajian empirikal dilaksanakan bagi mengenalpasti kesan WLAN terhadap prestasi WSN dari segi pengesanan tenaga (ED) dan kehilangan paket. Satu titik akses (AP), komputer riba dan perisian IxChariot digunakan bagi menjana isyarat WLAN, manakala Waspmote digunakan sebagai nod WSN. Ujian dalam kajian ini dijalankan dalam dua persekitaran yang berbeza iaitu persekitaran terkawal dan tidak terkawal. Ujian awal mendapati bahawa tempoh imbasan perlu ditetapkan kepada 3 bagi mencapai nilai ED yang terbaik dengan mengambilkira ketepatan dan pengesanan yang salah. Keputusan bagi ujian yang dijalankan tanpa gangguan daripada WLAN menunjukkan bahawa nilai ED yang dikesan oleh WSN adalah dalam sekitar -84dBm dan tiada kehilangan paket. Manakala, ujian yang dijalankan dengan kehadiran satu AP (tanpa trafik) menunjukkan bahawa tiada kehilangan paket yang berlaku tetapi terdapat peningkatan dari segi bacaan ED daripada WSN iaitu -44dBm. Selain itu, kajian ini juga mendapati bahawa trafik dari rangkaian WLAN tidak memberi kesan yang ketara kepada ED yang dikesan oleh WSN (sekitar -41dBm) berbanding dengan apabila terdapat satu AP yang dihidupkan tanpa trafik (nilai ED adalah sekitar -44dBm). Walau bagaimanapun, trafik daripada WLAN didapati memberi kesan yang ketara kepada kehilangan paket WSN di mana kehilangan paket meningkat daripada 14% kepada 36% apabila trafik ditingkatkan daripada 10% kepada 30% dalam persekitaran terkawal. Ujian lanjut menunjukkan bahawa ofset antara frekuensi pembawa WLAN dan WSN mempengaruhi nilai ED yang dikesan oleh WSN. Nilai ED apabila frekuensi ofset antara WLAN dan WSN kurang daripada atau sama dengan 3MHz adalah -42dBm dan nilai ED bagi frekuensi ofset 8MHz dan 13MHz adalah -54dBm dan -68dBm. Di samping itu, kajian ini juga mengkaji prestasi WSN yang menggunakan satu saluran frekuensi yang sama sepanjang operasi. Kajian ini turut mencadangkan teknik untuk meningkatkan prestasi WSN dengan menggunakan pemilihan saluran yang dinamik. Teknik ini dapat mengurangkan kehilangan paket WSN daripada 7% kepada 0%.

Performance Analysis of IEEE802.15.4 Wireless Sensor Network to Mitigate IEEE802.11 Wireless Local Area Network Interference

ABSTRACT

Wireless Sensor Networks (WSN) technology is rapidly deployed in applications such as robotic, healthcare, military, environmental monitoring, and other low-power large scale monitoring that requires high data accuracy with possibly minimal latency and data losses. The Quality of Service (QoS) of WSN is often compromised by the interference from other wireless technologies that are high in transmission power and bandwidth such as Wireless Local Area Network (WLAN), Bluetooth, microwave oven, cordless phone and wirelessUSB. The ubiquitous increase in the number of wireless devices leads to the frequency spectrum occupancy issues as various wireless technologies are forced to share the free and unlicensed 2.4GHz frequency band. Compared to other wireless technologies, the interference from the WLAN devices caused a significant packet loss experienced by WSN. This study focuses on investigating the effect of WLAN interference on WSN performance through experimental study. This research provides an empirical study on the effect of WLAN on WSN performance in terms of Energy Detection (ED) and packet loss. A WLAN access point (AP) or router, laptops as end-client and IxChariot software are used to emulate WLAN traffic while Waspmote is used as WSN nodes. Tests had been conducted in two different environments, which is in controlled and uncontrolled environment. Preliminary test found that scan duration need to be set to 3 in order to achieve the best ED value after considering the tradeoff between accuracy and false detection. Result from this study demonstrates that ED is around -84dBm with no packet loss for test conducted without WLAN interferer. Similarly, test conducted with one WLAN interferer (without traffic) shows that there is no packet loss but there is high increase in ED reading that is approximately -44dBm. Besides that, this research found that the density of traffic yield from WLAN network does not significantly affect the ED (around -41dBm) by WSN in comparison to when the WLAN AP is simply turned on without traffic (ED value is around -44dBm). However, the WLAN traffic does affect the WSN packet loss where packet loss increases from 14% to 36% when traffic increased from 10% to 30% in controlled environment. Despite that, further tests revealed that the frequency offset between WLAN and WSN centre frequency did affect the ED by the WSN. The ED value when the frequency offset between WLAN and WSN is less than or equal to 3MHz is approximately -42dBm and the ED value for frequency offset is 8MHz and 13MHz is approximately -54dBm and -68dBm respectively. In addition, this research also studies the performance of WSN for fixed channel allocation. Besides that, this research also proposed a technique to improve WSN performance by performing dynamic channel selection. The technique reduces the WSN packet loss from 7% to approximately 0% packet loss.

CHAPTER 1

INTRODUCTION

1.1 Overview

Wireless technologies often opted as a means of communication as it reduces the dependency of the system towards the use of cable and physical structure installation, which in turn reduces the deployment cost. Wireless technologies available at this point in time include Bluetooth, cordless phone, GPRS, 3G, WiFi, WiMax, Zigbee, WirelessUSB, Radio Frequency Identification (RFID) and others. According to a survey conducted by ON World's, by the year of 2016, there will be approximately 24 million wireless enabled devices (Hatler, 2012). The ubiquitous increase of wireless technologies promotes the integration between the physical world with the external environment that encompasses many aspects of life, such as healthcare, agriculture, environmental, surveillance and others. This phenomenon is also known as Internet of Things (IoT).

Wireless Sensor Network or commonly known as WSN, is a short form of ‘‘wireless sensor and actuator networks’’ or ‘‘wireless sensor and control networks’’ that collect information from wireless sensor nodes and send control commands to actuators attached to the wireless sensor nodes (Yang, 2014). WSN is a subset of Wireless Personal Area Network (WPAN). Among the existing wireless technology, WSN is garnering attention as it provides an option for low data rate, low power transmission for short range wireless communication with longer lifetime. WSN also flexible in terms of routing and placement since it is self-organizing and has multi-hop capability which makes it suitable for unmanned, long term monitoring for deployment in dense and inaccessible areas such as in a forest, space-limited location or military area. The existing wireless standards available for WSN are IEEE802.15.4, Zigbee, WirelessHART, 6LowPan and ISA100. Besides that, there are a number of different WSN products developed by different companies as listed in Table 1.1. ONWorld predicted that in 2016, from the total of 24 million wireless enabled, approximately 39% will be new application that are uniquely enabled by WSN (Hatler, 2012).

Table 1.1: WSN from different developer

No.	WSN	Developer or Manufacturer
1	IRIS mote	Memsic Inc.
2	TMote Sky	Memsic Inc.
3	Eko Node	Memsic Inc.
4	Waspmote	Libelium Inc.
5	Arduino	Arduino
6	NI 3202	National Instrument

WSN consist of a large number of wireless sensor devices (also known as motes or nodes) that is small in size, battery powered and can be integrated with different sensors suitable with the applications. Among vast WSN applications, some key applications are smart house monitoring, agriculture (Mafuta et al., 2013), healthcare (Felisberto, Costa, Fdez-Riverola, & Pereira, 2012; Zhen, Li, & Kohno, 2007), environmental monitoring (Liu et al., 2011; Navarro, Davis, Liang, & Liang, 2013), military applications and other monitoring applications. Industries and developers from various monitoring background interested in WSN because it offers lower development cost, infrastructureless (does not require a transmission tower) and flexible compared to other wireless systems such as Wireless Local Area Network (WLAN) and Bluetooth. Despite that, there are many issues in WSN that need improvement and optimization such as interference and coexistence (Yang, Xu & Gidlund, 2010), quality of service (Nefzi & Song, 2010), routing (Usman et al., 2014), security (Christin, Mogre, & Hollick, 2010), processing capabilities, power supply, memory and storage. This study focuses in the coexistence and interference issues faced by WSN when operate in heterogeneous environments.

Instead of using wire or cable, wireless technologies use Radio Frequency (RF) as a communication medium. There are many frequency bands available in the RF spectrum however the popular ones is the 2.4GHz frequency band. Most wireless technologies operate in the 2.4GHz band since is it unlicensed, free, specifically allocated for Industrial, Scientific and Medical (ISM) applications and available worldwide which enabled the operation of the wireless technologies globally. Nonetheless, the 2.4GHz band is not only for WSN instead it is shared with other wireless technologies such as WLAN, Bluetooth, microwave oven, WirelessUSB and cordless phone. Hence, there is a tough competition among these wireless technologies in order to acquire the frequency spectrum resources and often WSN is at the loose end due to its low transmission power compared to other wireless technologies that use the same frequency space (Yuan, Wang, & Linnartz, 2007). As the number of wireless devices in the 2.4GHz frequency spectrum increased, the bandwidth of the electromagnetic wave available for data transmission becomes congested and soon will be limited (Sikora & Groza, 2005; Weber & Hildebrandt, 2012).

The interference introduces significant increase in the WSN packet loss, which in turn reduced the Quality of Service (QoS) of the network. This is the main concern for WSN since the competition with other technology for frequency spectrum does not favour WSN that is transmitting at low power and operates at much lower data rates and bandwidth. Despite the numerous research conducted to promote the coexistence and mitigate the interference issue in 2.4GHz band, the interference still remains as a significant issue and forecasted to be even serious in the future with the implementation of the fifth generation (5G) wireless technology in the year 2020.

Current IoT trends inspire the adoption of wireless technologies in healthcare and medical applications in order to improve the quality of life. Among application that utilise wireless technology for healthcare monitoring includes wearable healthcare devices monitoring vital signs (e.g. temperature, blood pressure, and heartbeat), monitoring athletes health status, assisted living and patient monitoring in hospital. In the near future, patient can be wirelessly monitored not only in hospital but also remotely from their home. At present, most healthcare devices utilises WLAN and Bluetooth technology (Saltzstein, 2012). However, WSN features comprise of low power consumption and longer deployment lifetime garners researcher attention to incorporate WSN in healthcare applications.

WSN deployed for mission critical application such as patient monitoring in hospital requires high data accuracy, reliability and low latency. For such mission critical application, packet drop is not permissible, as it might harm patient if the responsible person (e.g. Doctor, medical personnel) does not receive the critical data about the patient condition due to the dropped packet. Nevertheless, the interference from other wireless technologies and devices operating in the 2.4GHz increases the number of WSN packet loss, which leads to the reduction of the QoS of WSN. In order to have optimal quality of wireless sensor network for mission critical application, the coexistence and interference impact between WSN and other wireless technologies need to be investigated and mitigated. Figure 1.1 illustrates the interference in hospital environment scenario where multiple WLAN devices and WSN present.

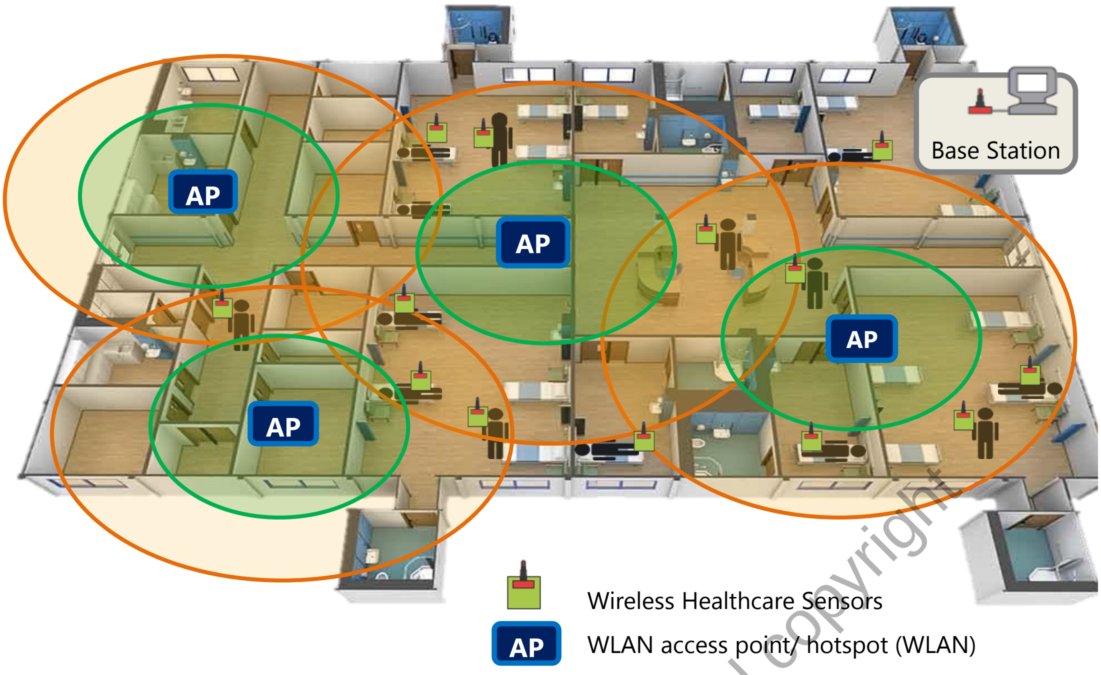

Figure 1.1: The IEEE802 wireless space

The subsequent section further elaborates on the problem that wants to be investigated and solved in this research. The objectives, research scope and brief methodology are also included. Finally, research contribution and the arrangement of this thesis are included at the end of this chapter.

1.2 Problem Statement

As the number of wireless technologies occupying the 2.4GHz frequency band increases, the spectrum band becomes congested and that leads to the degradation of QoS of WSN. Although existing solution such as retransmission mechanism (also known as packet retries) enable WSN to operate satisfactorily even in the most adverse interference conditions, retransmission is not affordable as it tends to waste time, consumes additional power, depletes the batteries and reduces the lifespan period of the sensor nodes. Furthermore, retransmission also increases the traffic hence further congests the frequency spectrum. Besides that, retransmission also increases the latency because the same packet is being retransmitted hence impractical especially for mission critical applications (Singh, Sharma, & Tomar, 2013).

Interference mitigation method such as keeping a suitable physical distance between wireless devices and ensuring sufficient frequency offset between the operating channel for different wireless technologies as suggested by Guo, Healy & Zhou (2010) and Hannan & Arshad (2013) is suitable for small number sensor nodes. Those methods is not applicable for randomly placed and freely moving subject such as patient that is attached with wireless sensors because patient can move around from various locations in the hospital such as ward, toilet, operating room and other location.

While the contributions of the previous works are significant, the existing solution such as retransmission, physical placement and channel separation is not adequate to overcome the interference issue experienced by WSN. Over the course of the last decade, the need to fully utilise the frequency spectrum resources raise the concept of Cognitive Radio (CR) where the transceiver can automatically detect when a frequency band is vacant and switch to that frequency band. CR enable secondary user to occupy the frequency band when the primary user is idle. Besides that, the increasing demands for higher data rates and recent proliferation of wireless technologies operating in unlicensed bands motivate the migration from the static channel allocation to dynamic channel allocation. Dynamic channel allocation has emerged as a new paradigm for more efficient resource allocations. This leads to the idea of utilising one of the popular spectrum sensing techniques that is known as Energy Detection (ED) (Abdulsattar & Hussein, 2012).

The coexistence among different wireless technologies using a different standard and operating in the 2.4GHz unlicensed frequency band has been studied extensively under different condition and applications. Numerous researches have been conducted to investigate the coexistence between different wireless technologies via experimental and simulation test such as in Garroppo, Gazzarrini, Giordano & Tavanti (2011), Guo et al. (2010) and Penna, Pastrone, Spirito & Garello (2009). Those studies focused on parameters such as Packet Loss Rate (PLR), Received Signal Strength Indicator (RSSI) and Link Quality Indicator (LQI). Compared to the extensive work on the performance of WSN in terms of packet loss rate under WLAN interference, less research has been done on ED measured by WSN under WLAN interference, which is one of the focused in this research. Apart from that, this research also experimentally investigates the coexistence of WLAN and WSN in a controlled and uncontrolled environment and proposed a technique to improve the QoS of WSN when interfered by WLAN devices.

1.3 Research Questions

This study investigates various approaches for coexistence and interference mitigation to improve the QoS of WSN. More specifically, the work presented herein was conducted to address the following research questions:

i. How does WLAN traffic affect the performance of wireless sensor network in terms of energy detection and packet loss?
ii. What is the performance of the existing WSN based-Zigbee under interference such as WLAN and does the existing technique able to effectively mitigate the interference?
iii. How effectively can the proposed technique be adopted to improve the QoS?

1.4 Research Aims and Objectives

The aims in this study are to analyse the WSN performance experimentally and to mitigate the IEEE802.11 interference experienced by WSN. In order to achieve the aims, the objectives of this research are:

i. To design a testbed using the testbed in Penna et al., (2009) as a reference and perform some modification and improvement to the testbed layout.

ii. To analyse the effect of WLAN traffic density on the Energy Detection (ED) value measured by WSN and the performance of WSN in term of packet loss.

iii. To develop an enhanced channel selection mitigation technique based on Zigbee to improve the performance of WSN.

iv. To test and compare the developed Channel Selection Technique (CST) with the existing Zigbee operation in terms of packet loss.

1.5 Scope of Research

Among the existing wireless technologies, this research interest is on WSN since it provides low data rate communication, low power consumption, longer lifetime and flexible in comparison to other wireless technologies. In focusing on WSN and WLAN, other technologies that also occupy the 2.4GHz frequency spectrum such as Bluetooth, cordless phone and microwave oven are not in the scope of this research as it was proven in the literature where WLAN contributes higher WSN packet loss compared to other wireless technologies (Sikora & Groza, 2005). Apart from that, this research only covers the 2.4GHz frequency spectrum. The 5GHz frequency spectrum is beyond the