Performance Study of Wireless Sensor Networks in Aquaculture Environments

by

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

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UNIVERSITI MALAYSIA PERLIS

2014

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Acknowledgemet

First of all I would like express my gratitude to Allah with the words of Alhamdulillah for the enlighten and guidance that he provide to me until I was able to complete this Master Thesis as required. Thank you goes to my supervisors, Prof. Dr. Ali Yeon bin Md. Shakaff and Prof. Dr. Mohd Noor bin Ahmad for guiding and sharing their valuable knowledge, experiences and ideas with me. My heartfelt gratitude goes to my beloved parents, Allahyarham Tuan Haji Mohd Arif bin Abu Amin and Puan Hajjah Normah binti Osman for their sacrifices and cares. To my dear wife Asma bint Mat, thank you for your patience and sacrifice on everything that we share together. To my children, Muhammad Salahuddin and Siti Maryam, I love you both. Thank you to anyone who involved in this research especially from Sensor Technology and Applications Cluster Research, CEASTech, UniMAP, UUM and Fisheries Department for their morale support.

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LIST OF ABBREVIATIONS

6LowPAN	IPv6 over Low power Wireless Personal Area Networks
ACK	Acknowledge
BER	Bit Error Rate
CAP	Contention Free Period
CRC	Cyclic Redundancy Check
CSMA-CA	Carrier Sense Multiple Access Collision Avoidance
dBi	Decibels-isotropic
dBm	Millidecibel
DC	Direct Current
DO	Dissolved Oxygen
DSP	Digital Signal Processing
DSSS	Direct Sequence Spread Spectrum
EEPROM	Electrical Erasable Programmable Read Only Memory
FFD	Full Functional Device
GSM	Global System for Mobile Communication
GUI	Graphical User Interface
IEE	Institute of Electrical Engineers
IEEE	Institute of Electrical and Electronics Engineers
ISM	Industrial, Scientific and Medical
K	Rice Factor
LOS	Line of Sight
LR-WPAN	Low Rate Wireless Personal Area Network
MAC	Medium Access Control

MP	Monitoring Program
NiMH	Nickel Metal Hydride
NLOS	Non Line of Sight
NH_4^+	Ammonium
O-QPSK	Offset Quadrature Phase Shift Keying
P2P	Point to Point
PAN	Personal Area Network
PDF	Probability Density Function
PER	Packet Error Rate
RF	Radio Frequency
RFD	Reduced Function Device
RFID	Radio Frequency Identification
RSSI	Received Signal Strength Indicator
SMS	Short Messaging System
SPI	Serial Peripheral Interface
UHF	Ultra High Frequency
USART	Universal Synchronous / Asynchronous Receiver / Transmitter
V_{AC}	Alternating Current Voltage
V_{DC}	Direct Current Voltage
V_{RMS}	Root Mean Square Voltage
Wifi	Wireless Fidelity
WirelessHART	Wireless Highway Addressable Remote Transducer
WLAN	Wireless Local Area Network
WSN	Wireless Sensor Networks
χ^2	Chi square

Kajian Prestasi Rangkaian Sensor Tanpa Wayar di Dalam Persekitaran Perikanan

ABSTRAK

Kesan *multipath fading* adalah masalah biasa bagi perambatan isyarat atau gelombang elektromagnet. Bagi sistem Rangkaian Sensor Tanpa Wayar atau WSN (*Wireless Sensor Networks*), kesan ini mengurangkan prestasi sistem dengan mengakibatkan penolakan paket, kehilangan paket dan memendekkan hayat rangkaian. Kewujudan dan tahap kesan ini bergantung pada keadaan persekitaran sistem komunikasi. Untuk menyelesaikan masalah kesan *multipath fading* sistem *WSN*, kajian perambatan isyarat mesti dijalankan di persekitaran di mana sistem akan digunakan. Objektif kajian ini ialah untuk mengkaji perambatan isyarat peranti *WSN* dan kedudukan fizikal peranti tersebut yang mempengaruhi ciri-ciri perambatan isyarat, untuk mengesahkan peralatan analisis yang sesuai (Kadar Kehilangan Paket, purata kuasa yang diterima, sisihan piawai, ujian χ^2 kesesuain data dan Rice *K*) untuk kajian perambatan isyarat, untuk mengkaji perambatan isyarat bagi peranti *WSN* di tempat perikanan dengan tumpuan kepada isu kesan *multipath fading*, untuk mengurangkan kesan *multipath fading* dengan menggunakan kaedah pengawalan masa di antara penghantaran paket dan sebagai kajian kesesuaian sistem *WSN* di tempat perikanan. Eksperimen pertama telah dijalankan di kawasan luar terbuka (gelanggang sukan). Eksperimen ini dijalankan dengan meletakkan nod-nod pada kedudukan yang berbeza (menegak, mendatar dan rendah) dan pada jarak yang berbeza (10 - 40 m). Hasil kajian ini mendapati kedudukan menegak menunjukkan prestasi terbaik di dalam semua analisa. Lengkungan purata kuasa yang diterima adalah berturutan dan dapat diwakilkan dengan model persamaan polinomial kuasa dua. Daripada persamaan ini, jarak maksimum komunikasi dianggarkan sejauh 70 m sahaja. Eksperimen kedua dijalankan di tempat perikanan tertutup (tempat penetasan ikan). Di tempat ini, kesan *multipath fading* didapati adalah rendah di mana analisa sisihan piawai mendapati Tanki 3 mempunyai variasi data yang tinggi dan analisa Rice *K* menunjukkan komponen lurus bagi Tanki 9 adalah tidak berturutan. Setelah menghantar paket dengan 100 ms, kesan ini dapat diminimumkan dengan variasi data bagi Tanki 3 menjadi rendah dan komponen lurus bagi Tanki 12 menjadi berturutan. Eksperimen ketiga telah dijalankan di tempat perikanan terbuka (kolam ikan). Eksperimen ini mendapati kesan *multipath fading* di tempat ini adalah tinggi dimana terdapat nilai PER(Kadar Ralat Paket) bagi sisi D adalah melebihi 1%. Selepas menghantar paket pada 50 ms, kesan ini dapat dikurangkan di mana nilai PER berkurangan di bawah nilai 1%. Kajian ini menyimpulkan bahawa kesan *multipath fading* adalah wujud di tempat perikanan. Dengan menggunakan gabungan peralatan analisis PER, purata kuasa yang diterima, sisihan piawai, ujian χ^2 dan *Rice K* mampu menganalisis kesan *multipath fading*. Kesan ini boleh dikurangkan dengan mengawal selang masa di antara penghantaran data. Kajian ini mendapati sistem WSN boleh digunakan di tempat perikanan.

Performance Study of Wireless Sensor Networks in Aquaculture Environment

ABSTRACT

Multipath fading effect is a common problem of electromagnetic wave or signal propagation. For WSN (Wireless Sensor Networks) system, the effect is able to degrade the system by contributing to the problem of packet rejection, packet loss and shortening the network lifetime. The existence and level of the effect is totally depend on the conditions of the communication system environment. To solve the problem of the effect, a signal propagation study must be conducted in the environment where the system will be implemented. The objectives of this research is to study the signal propagation characteristics of WSN devices and the devices physical position that influence signal propagation characteristics, to verify suitable analysis tools (Packet Error Rate, average received power, standard deviation, goodness of fit χ^2 test and Rice K) for signal propagation study, to study the signal propagation of WSN devices in aquaculture environments with focusing on multipath fading effect issue, to minimise multipath fading effect by using the method of controlling time interval between packets transmission and to study the feasibility of WSN system to be implemented in aquaculture environments. The first experiment was conducted at an open outdoor area (sports arena). The experiment was conducted by placing the nodes in different positions (vertical, horizontal and low) at different distances (10 – 40 m) between nodes. The result shows the vertical position has the best performance in all analysis. The average received power curve is monotonic and it can be modeled by second order of polynomial equation. From this equation, the maximum range of communication is estimated at 70 m. The second experiment was conducted at an indoor aquaculture environment (fish hatchery). In this environment, the multipath fading effect is found at low level where the standard deviation analysis shows Tank 3 has high variation of data and the Rice K analysis shows the direct component of Tank 9 is not monotone. After sending packets at 100 ms, the effect has been minimised with the variation of data is become low for Tank 3 and the direct component of Tank 12 is become monotone. The third experiment was conducted at an outdoor aquaculture environment (fish pond). This experiment found that the effect at this environment is at high level, where the PER value for side D is more than 1%. After sending packets at 50 ms, the effect can be minimised with the PER value of Side D become less than 1%. This research concludes that the multipath fading effect is exist in aquaculture environment. By using combination of PER, average RSSI, standard deviation, χ^2 test and Rice K analysis tools is able to analyse the multipath fading effect. This effect can be minimised by controlling time interval between packets transmission. From this research is obtained that WSN is feasible to operate in aquaculture environment.

CHAPTER 1

INTRODUCTION

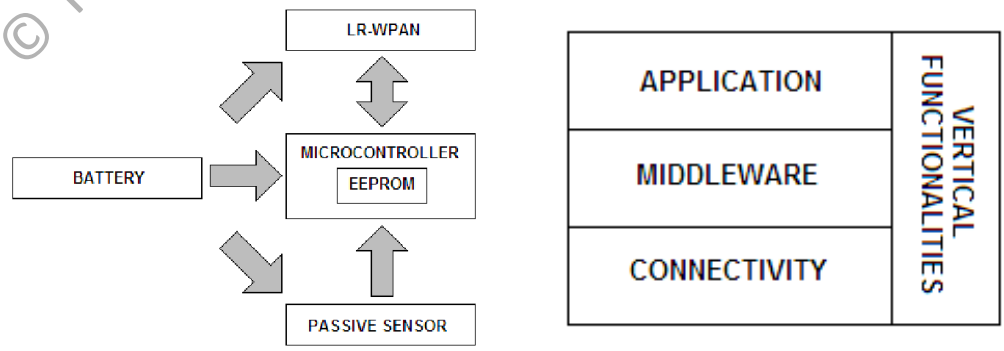
1.1. Background

A group of sensors that works together to sense environment parameters is very useful for monitoring system and scientific research. This system can help to improve certain techniques or mechanism of any fields. It can be an early warning system to avoid any system from crash. It can be an efficient intruder alarm of security system. It is useful for environmental protection and preservation.

Most conventional sensor systems use a lot of long cables and connectors. Cables and connectors are prone to failures resulting in the high cost of material, installation and maintenance. Because of these issues, a large number of sensors usage are not favourable. With the emergence of a new technology that is WSN (Wireless Sensor Networks), these costs and the related problems can be eliminated.

WSN can be defined from node and network perspectives. From the node perspective WSN is an embedded system that combines sensors, microcontroller and communication module that is powered by low voltage battery as shown by Figure 1.1(a). Sensors are the front end component that sense environment parameters such as temperature, humidity and pH. They can be a unit or multiple units and the same type or multiple types. Microcontroller coordinates node activities and process the sense data locally. By combining sensors and microcontrollers, sensors become smart and intelligent in terms of sensing capability and operations. Communication module

transmits the processed data to the next node as well as receives data from others. Usually the communication module use radio wave or microwave to communicate with each others. WSN protocol is less complex than the other wireless protocol such as WLAN/WiFi (IEEE 802.11 a/b/g) and Bluetooth (IEEE 802.15.3). Therefore, the protocol can be written and modified easily. Figure 1.1 (b) shows protocol architecture of WSN. Connectivity layer is applied in hardware and precisely manufactured, therefore developer can ignore the design of this layer. The lowest layer of WSN protocol that is implemented in hardware is called LR-WPAN (Low Rate Wireless Personal Area Network) with the standard of IEEE 802.15.4 (Chen, 2010). On top of LR-WPAN protocol, the commercial protocols like ZigBee, 6LowPAN, MiWi, WirelessHART etc were implemented that are available in market. This layer need to be configured only but not to be designed anymore. Developer has to develop program for application layer only. Sensor data can be displayed by alphanumeric characters that lead to low data rates communication design. This feature makes communication module consume less power for transmission and reception activities. The special thing about nodes is each unit is powered by a battery but can operate for a few months. This condition can be achieved by applying sleeping capability.



(a) Node functional block diagram (b) Node architecture

Figure 1.1 WSN node design

From network perspective, WSN consists of many nodes, a few routers and a base station that are connected wirelessly as shown in Figure 1.2. Nodes are distributed devices that sense the environment parameters. Routers are mediator that are for responsible to forwarding the nodes data. The base station collects all the data from nodes and routers, process them and relay them to other devices. The devices that can be connected to base station are telecommunication devices such as GSM (Global System for Mobile Communication) or internet, interface displays such as computer GUI (Graphical User Interface) or display panel or recording devices (database server or data logger). WSN can cover a large area and may consists of many nodes because it apply multihops communication. The network applies self-organise function that helps network topology to form automatically and change easily. The last reason to choose WSN is the use of free-licensed band to communicate with each other.

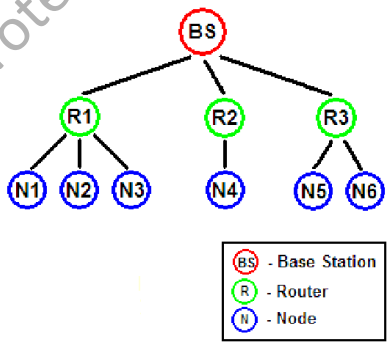


Figure 1.2 WSN topology

Aquaculture depends on water quality to produce fish. Good water quality helps to increase volume of fish production and return high revenue. While poor water quality affects fish mortality that decreases production and profitability. WSN can be used to monitor water quality. Fish farmer can gain benefit from this WSN application even though their challenges are to monitor large area, many ponds and variety of fish; they

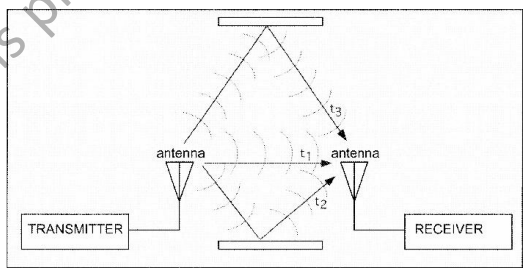
will still be able to manage water quality. Whereas, scientist can use WSN as a tool to improve water quality, to enhance production techniques and managements as well as developing new related applications.

Although to develop WSN application is not too difficult but to get WSN that operates in optimum conditions is challenging (Akyildiz, 2010). As mentioned before, WSN device is an embedded system. Any embedded system has performance constraints that are described by design metrics (Vahid et. al, 2002). An improvement made to certain metric will reduce the performance of others. There are several performance metrics for WSN system, such as energy consumption, data processing capacity, data processing and others of concern. One of the most important performance metric is the process of data transmission and reception.

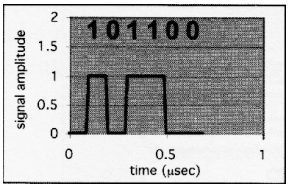
For data reception process of WSN system, the receiver will generate ACK (acknowledge) signal to the transmitter after a received signal has been accepted. After a period of time, if the transmitter is not receive any ACK signal, the transmitter will retransmit the signal. The retransmission process will be repeated in a few trials until the transmitter receive the ACK signal. However, the retransmission process consume more energy and will shorten the node lifetime for a node that is powered by battery. Retransmission process may also floods the network and it can degrade the efficiency of data delivery. The degraded of delivery process can lead to data loss problem. As a result, the system also may be degraded and cannot gather all information in the network. One of the contributors to the retransmission process is the faded signal propagation that is caused by the multipath fading effect.

1.2. Multipath Fading Effect

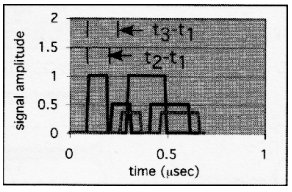
Multipath fading is one of the signal propagation problem that is influenced by the environment condition (Phaebua et. al, 2008). Dobkin provides example of how fading modifies the original signal. Figure 1.3(a) shows the transmitter sending a signal of a few bits. This signal creates 3 rays, t_1, t_2 and t_3. Ray t_1 is transmitted directly from the transmitter to the receiver. At the same time, rays t_2 and t_3 are propagated in different directions. Both rays are being reflected and also arrived at the receiver. Figure 1.3(b) shows the original transmitted signal and the receiver is expected to receive this signal. However, the receiver accepted 3 rays of the same signal at overlapping time as shown in Figure 1.3(c). As a result, the received signal of ray t_1 has been modified by rays t_2 and t_3. Figure 1.3(d) illustrates that this modified received signal cannot be interpreted by the receiver and then will be rejected.



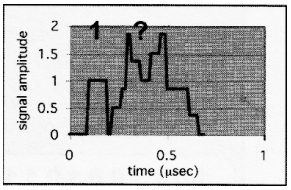
(a) Multipath scenario



(b) Transmitted signal.



(c) Multipath components.



(d) Received signal.

Figure 1.3: Multipath fading effect (Dobkin, 2005)

1.3. Problem Statement

There are several studies for WSN application system for aquaculture that has been done as described in Chapter 2. The studies that had been conducted are node development, system development and signal propagation. Among the research, the study on signal propagation is the least. It should be noted that a signal propagation study must be carried out before any other studies because a WSN system is not suitable for any application that its PER (Packet Error Rate) value is more than 1%. The signal propagation study for aquaculture applications is only carried out by (Harun, 2013). The problem with this study is that it does not specify the PER. Therefore, the feasibility for WSN systems to operate in aquaculture environments is still unknown.

One of the cause that increase the value of PER to more than 1% is the propagated signal has been faded due to the effect of multipath fading. Multipath fading effect degrades the WSN system. Preferably, this effect is completely removed but it is impossible. Therefore, the best way is to reduce this effect to a minimum level but for WSN system, the reduction method is still unknown.

Multipath fading effect is depends on environment condition and to solve the problem, a signal propagation study must be conducted in the environment where the system will be implemented. In this research, signal propagation studies were conducted in aquaculture environments to obtained the information of signal propagation characteristics in these environment and their multipath fading effect.

The study of signal propagation characteristics and multipath fading effect need certain method of analysing data. There a lot of methods to analyse signal propagation as described in chapter 2. The capabilities, performance and limits of these methods are for WSN system signal propagation studies are still unknown. The ignorance of this information leads to the problem of confused data interpretation and wrong conclusions.

If the problem of information ignorance of analytical methods can leads to the problem of confused data interpretation and wrong conclusions, the improper experimental setup can leads to the problem of distorted collected data. One of the improper experimental setup is the misplacement of WSN device position that does not follows their antenna radiation pattern and Fresnel zone rules. Therefore, the physical position of WSN devices must be studied too.

1.4. Objectives

The first objective of this research is to study the signal propagation characteristics of WSN devices and the devices physical position that influence signal propagation characteristics.

There are a number of WSN signal propagation studies using several analysis tools. These analysis tools have their own limitations and their effectiveness is still questionable. The second objective is to study the capability and performance of signal propagation analysis tools to analyse signal propagation data.

The third objective of this research is to study WSN signal propagation characteristics in aquaculture environment. The chosen environments are an indoor fish hatchery and an outdoor fish pond. This research concentrates on multipath fading effect in both environments.

A lot of research and texts discuss about multipath fading effect but very few provide solutions to this problem. The fourth objective is to test controlling time interval between packets transmission method to reduce the multipath fading effect.

The fifth objective is to study the feasibility of WSN to operate in aquaculture environment. WSN is feasible to operate when multipath fading can be minimised and PER value is less than 1%.

1.5. Scopes

This research is limited to one of the wireless protocols that is called LR-WPAN IEEE 802.15.4 2003. This protocol is chosen because the data rate is suitable for sensor data. That is why world wide trend is using LR-WPAN for WSN. Although there are research that used Wi-Fi and Bluetooth as WSN, these standard data rates are excessive for sensor operation.

This research has studied the signal propagation of point to point communication or between 2 nodes only. The failure of this communication can represent the entire network failure. Therefore, only this basic communication type was analysed.