PERFORMANCE OF ELECTROMAGNETIC COMMUNICATION IN UNDERWATER WIRELESS SENSOR NETWORKS

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To my father, mother and brother,

You are the source of success in my life.

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ABSTRACT

Underwater wireless sensor networks (WSNs) composed of a number of sensor nodes that are deployed to conduct a collaborative monitoring task. Wireless signals are used for communication between the sensor nodes. Acoustic signals are the dominant signals used as a wireless communication medium in underwater WSNs due to the relatively low absorption in the underwater environments. Acoustic signals face a lot of challenges such as ambient noise, manmade noise, limited bandwidth, multipath and low propagation speed. Some of these challenges become more severe in shallow water environment where a high level of ambient and mankind noise, turbidity and multipath propagation are available. Therefore, electromagnetic signals can be applied as an alternative communication signal for underwater WSNs in the shallow water. In this project, the performance of EM communication in underwater WSNs is investigated for the shallow water environment. Theoretical calculations and practical experiments are conducted in fresh and seawater. It is shown that signals propagate for longer ranges in freshwater comparing to seawater. Theoretical results show that attenuation of electromagnetic communication in seawater is much higher than in fresh water. The attenuation is increasing with the increasing of frequency. In addition, velocity of the signal is increasing as the frequency is increasing while loss tangent is decreasing as the frequency increasing. Based on practical experiments, freshwater medium permits short ranges EM communication that does not exceed 25.1 cm for 2.4 GHz frequency. On the other hand, communication in seawater is very difficult to achieve for the same high frequency. Path loss exponent was estimated for freshwater environment based on log-distance path loss model. The estimation was achieved through a comparison between theoretical calculations and practical measurements. The path loss exponent for EM communication in fresh water was estimated to be in the range of 2.3 to 2.4.

ABSTRAK

Dangkaian sensor wayarles di dalam air (WSN) yang terdiri dari sejumlah nod sensor yang melakukan pengawasan gotong-royong. Isyarat Wireless yang digunakan untuk komunikasi antara node sensor. isyarat akustik adalah isyarat dominan digunakan sebagai media komunikasi wayarles di WSN bawah air kerana penyerapan yang relatif rendah di persekitaran bawah laut. Walaubagaimanapun, Isyarat akustik menghadapi banyak cabaran seperti kebisingan ambien, hingar buatan manusia, lebarjalur terbatas, gangguan isyarat dan kelajuan propagasi rendah. Beberapa cabaran ini menjadi lebih teruk pada persekitaran air cetek di mana kadar tinggi ambien dan hingar umat manusia, kekeruhan dan propagasi gangguan yang sedia. Oleh kerana itu, isyarat elektromagnetik dapat guna sebagai isyarat komunikasi alternatif untuk WSN di air cetek. Dalam projek ini, prestasi komunikasi EM WSN diselidiki untuk persekitaran perairan cetek. Kajian secara teori dan eksperimen praktikal dilakukan untuk air tewar dan air laut. Hal ini menunjukkan bahawa isyarat merambat lebih lama di air tawar berbanding dengan air laut. Keputusan Teori menunjukkan bahawa rosotan isyarat elektromagnet dalam air laut jauh lebih tinggi daripada di air tawar. Rosotan isyarat ini meningkat dengan meningkatnya frekuensi. Selain itu, kelajuan isyarat meningkat sebagai frekuensi yang semakin meningkat, sedangkan loss tangent yang menurun kerana frekuensi meningkat. Berdasarkan percubaan praktikal, air tawar membenarkan komunikasi EM untuk jarak dekat yang tidak melebihi 25.1 cm untuk frekuensi 2.4 GHz. Walaubagaimana pun, komunikasi di dalam air laut sangat sukar dicapai untuk frekuensi yang sama. Path eksponen loss dianggarkan untuk persekitaran air tawar berdasarkan model log-distance. Nilai anggaran dicapai melalui perbandingan antara teori dan pengukuran praktikal. Path loss eksponen untuk komunikasi EM dalam air tawar dapati berada dalam julat 2.3 sampai 2.4.

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$Pr(d)$ - Received power for distance (d) in (dBm)

$Pr(d_0)$ - Received power for reference distance (d_0) in (dBm)

$\tan\theta$ - Loss tangent

$PL(d)$ - Path loss for distance (d) in (dB)

$PL(d_0)$ - Path loss for reference distance (d_0) in (dB)

α - Attenuation in (nepers/m)

α_{dB} - Attenuation in (dB/m)

n - Path loss exponent

σ - Conductivity in (Siemens/m)

β - Wave number in (radians/m)

ω - Angular frequency in (radians/s)

u - Signal velocity in (m/s)

ε - Permittivity

μ - Permeability in (H/m)

λ - Signal wavelength in (m)

P_b - Probability of bit error

X_σ - Gaussian distributed random variable in (dB)

LIST OF ABBREVIATIONS

WSN - Wireless Sensor Network
IEEE - Institute of Electrical and Electronics Engineers
AUV - Autonomous Underwater Vehicle
EM - Electromagnetic
PRR - Packet Reception Rate
RSS - Received Signal Strength
DSSS - Direct Sequence Spread Spectrum
MAC - Media Access Control
SNR - Signal to Noise Ratio
O-QPSK - Offset- Quadrature Phase Shift Keying
BPSK - Binary Phase Shift Keying
LR-WPAN - Low Rate- Wireless Personal Area Network
CSMA/CA - Carrier Sense Multiple Access with Collision Avoidance
RSSI - Received Signal Strength Indicator
RF - Radio Frequency
ISM - Industrial, Scientific and Medical
AODV - Ad-hoc On-demand Distance Vector

CHAPTER 1

INTRODUCTION

1.1 Overview

Wireless sensor networks (WSNs) comprised of a number of sensor nodes (also named as motes) that are connected to each other to monitor and gather information from a specific environment. The environment can be the physical world, a biological system or Information Technology (IT) frame work [1]. Sensor nodes are interconnected through a multi-hop low power wireless links. They sense and gather data from the environment and send it to a base station. Internet or other networks can be used to deliver the gathered information to a control center where the data analysis and processing is done there. Sensors transfer the physical world captured phenomena into digital data, which can be stored and processed [2]. Sensors measures many things such as: distance, direction, speed, humidity, wind speed, soil makeup, temperature, chemicals, light, vibrations, motion, seismic data, acoustic data, strain, torque, load and pressure [3].

Sensor nodes can communicate between each other through wireless signals. Wireless signals used for communication in WSNs are electromagnetic, acoustic or optical signals. Electromagnetic radio signals are the dominant signals used in terrestrial WSNs. On the other hand, acoustic signals are preferred for underwater WSNs while Optical signals are not preferred for using in WSNs due to the need for line of sight between the communicating nodes.

Sensor nodes are connected to base stations (sinks) either via direct links or through multi-hop paths. In direct links, each node transmits the gathered data to the base station directly. In multi-hop paths, the gathered data by the sensor nodes is relayed by intermediate nodes until it reaches to the base station. Direct links are simpler than the multi-hope paths. However, sensor nodes connections through multi-hop paths results in more energy savings.

WSNs are divided into three main types. These types are: terrestrial WSNs, underwater WSNs and underground WSNs. Terrestrial WSNs are deployed terrestrially to monitor specified phenomena. Similarly, underwater and underground WSNs are deployed in the underwater and underground environment respectively.

Underwater WSNs are networks containing of a number of sensor nodes that are deployed in an underwater environment (oceans or rivers) to perform collaborative monitoring tasks. Underwater environment is divided into two types, depending on the depth of the water, which are deep and shallow water. In oceanic literature, shallow water refers to water depth lower than 100m, while deep water is used for deeper rivers and oceans[4]. In addition, water environment can be classified, depending on the value of conductivity, into seawater and freshwater. Seawater refers to the water environment with high conductivity that is typically substituted as 4 S/m while freshwater has a typical conductivity of 0.01 S/m.

Although acoustics are the dominant wireless signals used in underwater WSNs, many challenges arise from using these signals. Challenges become more significant if the acoustics are used in shallow water because turbidity, ambient noise and manmade noise in shallow water have bigger affection on the acoustic waves. In addition acoustic signals have limited bandwidth and low propagation velocity. Consequently, electromagnetic signals can be used for communication between sensor motes and especially in shallow water environment. In this project, the performance of using EM communication in underwater WSN deployed in the shallow water environment is studied. Theoretical and practical investigation will be conducted.

1.2 Problem Background

The dominant wireless signals used for communication between the sensor motes in underwater WSNs are acoustic signals. Acoustic signals experience a relatively low absorption in underwater environment. Therefore, acoustics are able to transport for long distances that can reach to several kilometers depending on the frequencies and the acoustic modems used. This makes acoustic waves the best signals that can be used for long range underwater communication.

Although acoustics can permit long range communication, many challenges rise from using this type of communication. The propagation speed of sound waves underwater is very slow comparing to electromagnetic signals. Typical speed of sound in water is 1500 m/s. The speed of sound in water increases with the increasing of temperature, salinity and the depth of water [5]. This slow speed requires more efficient communication protocol in the network to adapt with this limitation. In addition, acoustic signals have a limited bandwidth. Ambient noise, multipath, geometric spreading are additional disadvantages that can be added to acoustics.

The limitation factors of acoustic waves can have bigger impact in shallow water environment. In shallow water, signal Multipath problem can be more sever because the transmission distance of the signal is larger than the depth of water. Therefore, the signal will be reflected from the surface and the bottom of the sea or river. Moreover, shallow water contains more sink objects that increase reflections of the signal. Ambient noise and manmade noise are more severe in this type of environment. As a result, electromagnetic signals are more preferred to be used in the shallow water environment.

1.3 Problem Statement

Acoustic signal faces many challenges in shallow water. It yields poor performance where the acoustic transmission can be affected by turbidity, ambient noise and manmade noise. In addition, interference between acoustic signals generated by human with the one generated by marine animals can happen. Moreover, Multipath problem are more severe in this environment. An important limitation added to the acoustic signal is the low propagation speed (1500 m/s) which is about five orders of magnitude less than the propagation speed of electromagnetic signals. Moreover, Acoustics have a limited bandwidth (typically less than 15 KHz).

1.4 Project Aim

The aim of this study is to investigate and analyze the performance of electromagnetic signal in case of using it as the wireless communication signal in underwater wireless sensor networks and in the shallow water environment.

1.5 Objectives

The objectives of this project can be summarized in the following points:

1. To analyze the performance of EM signals in the underwater environment theoretically for sea and freshwater.
2. Developing a program in TinyOS operating system to embed in MICAz sensor mote.
3. Deploy the WSN test bed in underwater environment (sea and freshwater).
4. To observe the performance of the underwater WSN in terms of PRR (packet reception rate) and RSS (received signal strength).

1.6 Scope of the Project

The scopes of this project are defined as follows:

The project will investigate the characteristics of underwater EM communication such as loss tangent, attenuation and velocity for different frequencies. The calculations will be done for sea and fresh water environments. The experiment of the sensor motes will be conducted in fresh and sea water to obtain the received signal strength (RSS) and packet reception rate (PRR) with respect to distance. The frequency used in the test bed is 2.4 GHz radiated form CC2420 radio transceiver in MICAz mote. The project will also estimate the path loss exponent that can be used for fresh water environment based on log-distance path loss model developed for terrestrial communication.

1.7 Significance of the Project

This project studied the performance of EM signals in underwater WSN. The practical and theoretical outcomes of this study will contribute to verify the performance of EM signals in the shallow water environment of fresh and seawater. Depends on these outcomes, the feasibility of using these signals in underwater WSN can be determined.

1.8 Organization of the Report

This report consists of five chapters. Chapter 1 contains the introduction to the project, problem background, objectives, scope and significance of the study. Chapter 2 contains the literature review. It reviews the wireless sensor networks theory and the theory and importance of electromagnetic communication underwater. Chapter 3 illustrates the methodology of the project. It details the hardware and software tools used. In addition, it explains the methodology diagram of conducting the project. Chapter 4 explains theoretical and practical results obtained for fresh and seawater. The model used for estimating the path loss exponent and a proposed equation of log-distance path model for freshwater environment are also elaborated. Finally, chapter 5 concludes the report and suggests future works.

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