ISM Band 2.45 GHz Propagation Studies in a Coastal Environment

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Abstract— Over the past decade there have been significant advances in Wireless Sensor Networks creating a shift in the paradigm of information acquisition. A single highly expensive dedicated sensor has no longer become viable within dynamic environments compared to larger cheaper networked micro-systems. While research has been conducted into the performances of implemented sea surface Wireless Sensor Networks, little is known on how seawater affects the 2.45 GHz ISM frequencies. This paper demonstrates that the propagation characteristics and subsequent signal path loss of low powered transceivers across a body of water, are sufficient for effective communication at reasonable distances for the deployment of a wireless sensor network.

Keywords—Propagation; IEEE 802.15.4; 2.45 GHz; Wireless Sensor Networks; WSN; Oceanography; Signal Path Loss;

I. INTRODUCTION

An increasing amount of research has been directed towards the construction and development of low powered inertial influenced wireless sensors for ocean monitoring. This ranges from below surface level to upper surface communication in many frequency ranges including but not limited to sub Mega-Hertz frequencies such as 433 MHz and 900 MHz to the higher ISM band 2.45 GHz implementations [1]. However most researchers choose to simulate theoretical distances while simulating harsh environments [2] or implement radiation networks with unknown effects on communication in higher ISM frequencies [3]. This paper reports observations on 2.45 GHz propagation signal loss in an open environment including Received Signal Sensitivity Indicator (RSSI), Link Quality Indicator (LQI) and subsequent packet loss information over five different tests. Section II contains background information into the current environment for propagation within the IEEE 802.15.4 2.45 GHz ISM band along with the background information for the intended purpose in relation to WSNs. Section III details the testing equipment, procedure and final chosen testing location. Section IV details the results captured with analysis against comparisons to higher elevation, open field, theoretical and lastly antenna placement. Section V presents current difficulties for the development of a low cost low power 2.45 GHz Wireless Sensor Network (WSN) in a dynamic ocean environment. Lastly section VI details all conclusions and the required future work in relation to the development of ocean deployed inertial based WSN.

II. BACKGROUND INFORMATION

The topic of sea surface wireless sensor networks has been a hot topic for research for the last decade. Improvements in hardware have lead to enhancements in power efficiency and propagation reliability. Standardization for the IEEE 802.15.4 MAC protocols has spawned the development of several wireless network protocols increasing the throughput for networked micro-systems. The effectiveness of large WSNs with inertial based nodes has proven to provide accurate wave height measurements rivaling single static sensors [3]. Although sea surface deployment of WSNs has been a success, little research has been conducted of the capabilities for the 2.45 GHz spectrum along the surface of the water and how the reflectivity of the water will affect the propagation characteristics.

III. TESTING EQUIPEMENT AND ENVIRONMENT

A. *Testing Hardware and Considerations*

The hardware chosen for testing was the Atmel SAM R21 Xplained Pro Evaluation Kit [4] for several key reasons relating to not only the required signal loss evaluation but also aspects pertaining to the goal of low cost, low power WSN. The ATSAMR21G18A microcontroller contains a built in AT86RF233 transceiver conforming to IEEE 802.14.5 ISM band 2.45 GHz specifications [5]. The R21 microcontroller has a maximum 4 dBm output with lower receiver sensitivity resolutions of 3 dB comparable to that of the majority of its counterparts of 4 dB. Both master and slave nodes use a vertically polarized monopole antenna. Figure 1 contains the high-level hardware architecture for the Master node testing device. It contains micro SD card for data storage, GPS module to aid in signal path loss testing and finally a six Degrees of Freedom (6DOF) Inertial Measurement Unit containing a tri-axial Accelerometer and a tri-axial Gyroscope. Both the master and slave device contain identical software with detection of the data storage module establishing which node of the pair is the master and the other the slave.

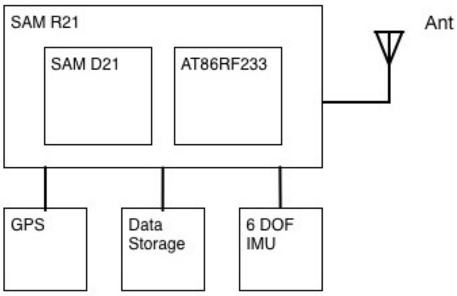

Fig. 1. Master Testing Device Hardware Architecture.

B. Software Packet Strucuture

The AT86RF233 transceiver is an IEEE 802.15.4 compliant transceiver with 64-bit IEEE formatted header addressing. For simplicity, this paper describes the application specific packet structure contained within the payload of the IEEE packet format.

The first byte for all packets sent between both the master and slave device is a command byte to describe the contents and subsequent processing the nodes must undertake. The two most important commands are the "Ping" followed by the "Ping Reply". Described by Table I, the master node sends a single byte packet containing the ping command to be received by the slave node. The slave node replies back to the master node with a 3-byte packet containing the ping reply command along with the RSSI and LQI for the slave device.

TABLE I. PACKET SOFTWARE STRUCTURE

Byte Order	**Packet Byte Information**	
	Byte Identifier	***Byte Description***
Byte 0	Command Byte	Determines how the node will process the packet.
Byte 1	Pair RSSI	Slave node Received Signal Sensitivity Indication data
Byte 2	Pair LQI	Slave node Link Quality

Afterwards the master node stores the RSSI and LQI for both nodes along with packet sequencing information. The AT86RFF233 transceiver has functionality that allows for the IEEE standard packet acknowledgment and packet auto-retransmit. To ensure that the results are not skewed, packet acknowledgment remains enabled however auto-retransmit on failure to receive an acknowledgement was disabled.

C. Testing Location and Procedure

Modelling the effects on higher angles of incidence, ensuring the test scenarios closely follow deployment conditions, testing was broken into two separate elevations. Figure 2 contains a photograph of the location to conduct both the 1.5 meter elevation, 0.3 meter elevation tests over water, located on the Gold Coast, Australia. The distance spanning from shore to shore was measured at 30 meters with a standard reel measuring tape and verified with a minimum 10 point satellite fix via GPS. A rubber inflatable boat was used to move the testing node from one side of the shore to the other. The location was deemed ideal for testing as the man made canal exit was similar to the majority of canal exists situated around the Gold Coast. The sloping banks also shielded the testing site from strong winds allowing consistent testing environments.

Fig. 2. Water Testing Location, Gold Coast, Australia. The water body is part of a set of artificial canals which open into the ocean.

Prior to the commencement of each test, the master node was set to conduct a full frequency scan of the IEEE 802.15.4 spectrum ensuring the testing can proceed without further outside influence. The testing procedure conducted for all tests were as follows; first both master and slave nodes were placed at identical locations, allowing the GPS unit to collect the starting position. The master node was slowly moved with as much consistency as possible over the full 30 meters over water. If the test conducted was at 1 Hz (refer to Table II), every 5 meters from the starting position the master node was paused to capture the possibility of any fluctuation in received signal.

IV. SIGNAL PATH LOSS

A. Comparison of Theoretical Calculations

For a baseline comparison of the data received, Figure 3 and 4 draws the received power as a function of distance for the transmitter and receiver at 1.5 meters and 0.3 meters respectively, using the standard 2-ray interference calculation method. Both open field results display data in accordance with the calculation, although exhibits less received power due to ground absorption. The field strength over the water path is generally lower than across a grassy field due to the potential scattering from surface ripples along the water. Meaning less multi-path interference is observed in the higher incident angles.

B. 1.5 Meter Elevation Performance Comparison

Figure 3 contains the compares the signal for a test conducted with both transmitter and receiver at an elevation of 1.5 meters. The darker red illustrates the test conducted over an open field line of sight. Notice the minimal amount of noise. The multi-path interference is clear. In stark contrast to the test that was conducted with the same parameters over water, the signal is a lot less stable, with highly fluctuating attenuation, an average of 15 dB. Compared to the open field test, the average reduction in signal strength over water was measured to be 10 dB less. It should be noted for all following figures a moving average was applied to get an approximation to the signal path loss.

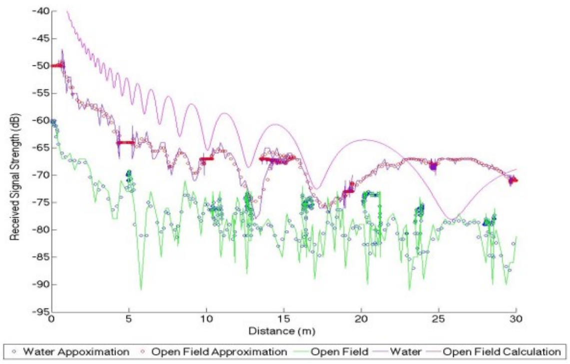

Fig. 3. Comparison of line of sight open field versus line of sight water at 1.5 meters elevation with theoretical calculation.

C. 0.3 Meter Elevation Performance Comparison

For a more realistic evaluation for the scenario and placement for a low cost WSN, a test was constructed to evaluate the performance of the 2.45 GHz signal path loss at an elevation of 0.3 meters. Figure 4, the open field measurement (shown in blue) contains the signal path loss for the master node in an open field. With a low reflectivity the signal degrades closely following its theoretical counterpart discussed previously, with little to no amounts of degradation until the lower limits of the signal sensitivity. The red data and approximated green illustrates the signal path loss over water with high amounts of signal reflectivity. At 5 meters the signal deviates +/- 5 dB of the mean. As the distance is increased the node is more susceptible to the reflections from the water creating the recoveries in received signal strength. At 30 meters both open air and low elevation data show identical signal strength with the exception of higher noise above water, however the noise is at a high enough mean that this has not affected packet transmission.

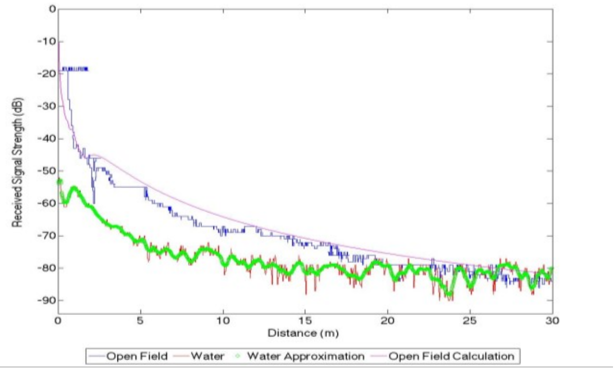

Fig. 4. Comparison of line of sight open field versus line of sight water at 0.3 meters elevation with theoretical calculation.

D. Signal Path Loss and Antenna Polarisation Direction

A short test was conducted to identify the cross-polarization performances, one antenna vertically placed, while the other antenna rotated 90 degrees in relation to the pair antenna with the top of the antenna facing towards the node. Figure 5 displays the comparison between the previous 0.3 meter elevation test with the red and aqua approximation the average received signal with the master node rotated 90 degrees. The results show the average signal is 10 dB less to its counterpart.

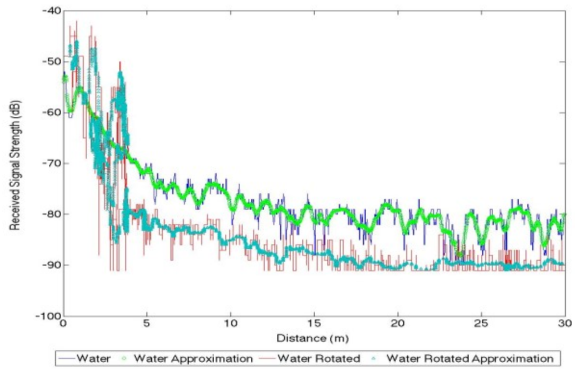

Fig. 5. Comparison of cross-polarisation above water at 0.3 meters elevation.

Between 0 to 3 meters a large spike in the signal is shown, previous research shows that the shallow angle of the transmitter creates high amounts of multipath interference [7][8] causing a higher than usual propagation of signal along the face of the water. The further the distance between the two nodes the higher the signal fading, with substantially less sensitivity to the direct line of sight propagation, based on the radiation pattern and rotation of the antenna, a contributing factor to the substantial degradation in signal. From the results, a maximum distance of 15 meters was obtained before the device reached the noise floor and subsequently high amounts of packets were lost.

E. Link Quality and Packet Loss

Table II contains the packet loss information for all tests conducted. The sample frequency was increased to 5 Hz for the 0.3 meter elevation tests in order to accurately capture the noise generated from the reflection along the surface of the water and so the number of packets sent was increased. For all omni-directional tests conducted, only a single packet was lost at 0.3 meters elevation over water.

TABLE II. PERCENTAGE PACKET LOSS

Test Type	Percentage Packet Loss	
	Packet Loss (%)	*Sample Frequency (Hz)*
1.5m Open Air	0% (845/845)	1
1.5m Water	0% (684/684)	1
0.3m Open Air	0% (2150/2150)	1
0.3m Water Horizontal	0.03% (2708/2709)	5
0.3m Water Vertical	5.22% (7030/7417)	5

V. SIMULATED VERSUS REAL WORLD OCEAN ENVIRONMENT

The primary objective for the project is to assist in transmission between tens to hundreds of nodes as part of mesh network in highly dynamic ocean environment, using primarily low cost low powered devices. It's been common practice in former research of inertial assisted sensors to mount the IMU device in a mechanical gimbal to reduce the amount of forces bleeding into accelerometer channels other than the global Z axis [3].

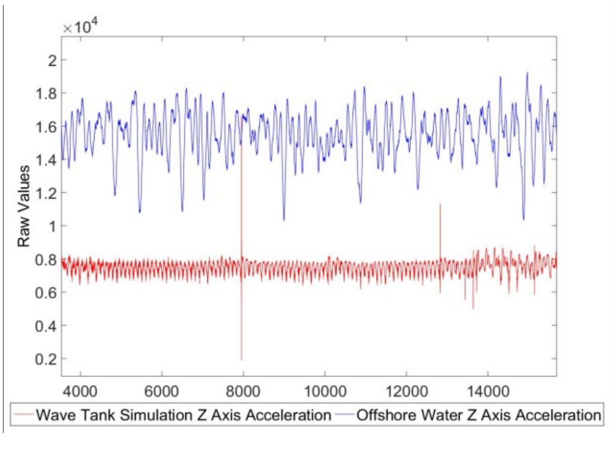

Fig. 6. Raw Z axis acceleration profile from 1 Hertz, 0.1 meter waves in a mechanical wave tank (red) verses Z axis acceleration in open water.

Figure 6 illustrates the comparison between the accelerometer profile captured in a wave tank (red) verses at open sea (blue). The 0.1 meter, 1 Hz wave tank simulation has clear defined peaks, each peak represents a single wave. In retrospect, unlike the wave tank simulation, the ocean has multiple surface waves generated from environmental factors such as the depth of the sea floor and rippling caused by wind. Factors that greatly affect the spatial detection of incoming waves.

VI. CONCLUSION AND FUTURE WORK

In conclusion, the results obtained from the conducted tests show that at relatively high elevation the above water, 2.45 GHz propagation is more susceptible to reflection from the surface of the water. With lower elevations reducing the amount of multipath interference and subsequently the amount of attenuation of the signal. From the tests conducted at 0.3 meters elevation, although the baseline test shows higher received signal strength initially, the signal propagated along water shows high amounts of recovery concluding with less than 0.1% packet error rate. Future work would require investigation into the effect of uneven reflectively of the water generated from surface rippling of the wind and how this effects propagation. This would also entail the investigation into how differing transmitter and receiver heights affect the performance of the network.

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