Journal of Theoretical and Applied Information Technology
31st August 2015. Vol.78. No.3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

NATURAL GRASS PATH LOSS MODELING BASED ON WIRELESS SENSOR NETWORK DEPLOYMENT

[1]AUDA RAHEEMAH , [2]NASEER SABRI, [3]PHAKLEN EHKAN, [4]M.S.SALIM, [5]OMAR KHALDOON A.
[1, 2,3] School of Computer and Communication Engineering
University Malaysia Perlis
[1,4,5] Ministry Of Higher Education & Scientific Research Of Iraq, [1]Al-Muthanna University, [4]Nahrain University
E-mail: [1]odaalzerkany@yahoo.com

ABSTRACT

Empirical propagation models (EPM) have got high interest in both research and various applications due to their speed of execution and their limited dependence on detailed knowledge of the terrain. This paper derives a model for predicting radio frequency propagation for Wireless Sensor Network (WSN) deployment in natural grass environment. Real time physical data of ZigBee WSN are collected and an empirical path loss prediction model is derived from the actual measurements. To validate the proposed model, two popular models, FSPL and PE models, are used and a comparison of results is conducted. The results show that the mentioned popular models with WSN wave propagation are inaccurate and cannot be used in predicting the path loss between wireless sensor nodes deployed in natural grass environments. Thus, a new propagation model is derived for natural grass Zigbee WSN and to be used adequately by researchers and developers.

Keywords: *Propagation model, Path losses, RF attenuation, RF propagation, WSN, ZigBee standard.*

1. INTRODUCTION

WSN wave propagation, nowadays, has got research with civilian, military and industrial societies of highly interest. Based on their affective execution limited reliance on detailed knowledge of the terrain. Although the study of empirical propagation models for mobile channels has been thorough, their applicability for WSN applications is yet to be properly validated.

Wireless Sensor networks (WSNs) which are composed of numerous of cost effective, low power wireless sensing nodes with limited communication and computing resources are abruptly participating in diverse applications. WSANs offer efficient, low cost solutions to a wide range of applications in both civilian and military fields, such as, environment monitoring, telemedicine, precision agriculture, fire detection, enemy and intruder detection and tracking, battlefield surveillance, building and home automation, seismic activities and traffic regulation [1]. Currently, the most promising of WSN technology in agriculture field is ZigBee [2,3,4]. This protocol has been widely adopted by WSN developer's community; it relies on the IEEE 802.15.4 standard [5]. ZigBee technology is a low rate, low cost, low power consumption wireless node protocol aiming to remote and automation application systems. ZigBee is expected to provide low power and cost connectivity for nodes that need a long operation of battery of several years with low data rate. The ZigBee standard is expected to transmit over 10-75 meters based on the RF power output consumption for specific application and the environment, and operates in the unlicensed RF worldwide 2.4 GHz with 250 Kbps data rate [1].

Since vegetation areas are covering a large portion of the Earth's surface, the propagation of radio waves in vegetation has long been of researcher's interest. Radio waves propagating in vegetation usually experience much higher path loss than in environments without vegetation. Therefore, well known of the propagation mechanisms through vegetation is critical for communication and sensing in such environments. However, WSN nodes are spatial distribution in the field and must consider all the parameters that may have affected the wireless channel communication [6].

To determine the behavior of electromagnetic waves, a precise model of propagation must be adopted, however models normally used in wireless communication might not be precise describe the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

wireless sensor network. WSN nodes are spatially located, usually near the earth's surface, thus may induce absence of main ray between sender-receiver nodes, which is known of no line of sight (NLOS) status occur, although WSN nodes have spatially short distance distribution. Therefore, WSN propagation waves may face obstacle like trees, fence, building and dense foliage [1].

During deployment of WSN, wireless sensor nodes can be placed in predefined locations [7], thrown randomly in the field or placed using a combination of both approaches [8]. The distance separating nodes is usually determined according to the sensing functionality and wireless transmission capability of sensor nodes. In wireless communications, radio frequency (RF) path loss models are often used to predict the average received power of the transmitted signal as its power density decays as a function of the distance. Such models are typically created according to environmental characteristics where the transmitter and receiver operate. In WSN, accurate RF models are expected to help in achieving proper evaluation and optimization of network performance during the deployment planning process [9], to improve power efficiency of sensor nodes [10], and to make the localization and target detection applications that depend on knowledge of the received signal level more reliable [11].

There are two dominant channel modeling approaches: theoretical (or deterministic) and empirical (or probabilistic) [12].

Most of the published work in WSN adopts one of two simplistic path loss models: Free Space Path Loss (FSPL) and Plane Earth (PE) path loss models [13, 14]. Both of these models are based on simplistic approaches and are considered to be very optimistic in near ground propagation scenarios as the case in various outdoor applications of WSN. In practical applications, prediction of the WSN deployment, performance critically depends on one's ability to model the propagation of the radio signal between the nodes, which depends fundamentally on the type of terrain and the type of objects and foliage on the terrain [15]. Differences in RSS readings of WSNs deployed in outdoor environments with different ground properties have been reported in [16, 17, 18, 19, 20]. This paper presents a model for the path loss prediction in WSN that are deployed on natural grass environments.

2. RELATED WORK

Manuscripts Propagation models are used extensively in network planning, particularly for conducting feasibility studies and during initial deployment. They are also very useful for performing interference studies as the deployment proceeds. These models can be generally classified into deterministic and probabilistic. The laws governing electromagnetic wave propagation to determine the received signal power at a particular location are defined by deterministic models. On the other hand, probabilistic models are those based on observations and measurements alone. These models are the least accurate, but require the least information about the environment and use much less processing power to generate predictions [21].

For open-space environments, most of the published work relies on FSPL and Plane Earth (2-Ray) model [22, 23, 24]. The fundamental assumption behind the FSPL model is that the transmitter and receiver have a line-of-sight (LOS) communication with no obstructions or reflections of any kind. In practical situations, “there are almost always obstructions in or near the propagation path or surface from which the radio waves can be reflected.” [25]. Therefore, the FSPL model is considered a very optimistic model to predict received signal strength (RSS) between two sensor nodes, as it does not take into account obstructions, reflections, or other effects between transmitter and receiver. Meanwhile, the Plane Earth model considers two waves from the transmitter to the receiver (i.e., A direct and ground reflected wave). The PE model assumes the separation between the transmitter and receiver is much larger than antenna heights [12]. In addition, it often represents the ground as a flat surface of perfectly conducting. Such simplistic approach leads to predictions that are not very accurate in almost all real-world scenarios. This is because different grounds have different properties, which govern the reflection of an incident wave [12].

Several empirical path loss models have been proposed for different outdoor deployment scenarios of WSN. In [20], for example, the authors present two empirical path loss models based on RF measurements of WSNs deployed in sparse tree and long grass environments. Meanwhile, [19] presents RF measurements and empirical path loss model for WSN deployment in artificial turf environments. In [17], the authors present an empirical path loss model for wireless sensor nodes deployed in dense tree environments. The authors continue their work in characterizing

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

signal propagation in different environments by providing RF measurements and an empirical path loss model for concrete surface environments [18]. Authors of [16] presents RF measurements and empirical path loss model for WSN deployment in agricultural fields and gardens. The parameters of the empirical path loss models in [16], [17], [18], [19] and [20] were found to be different from one environment to another due to the differences that exist in the wireless channels of such environments.

3. PATH LOSS MODELS

The signal path loss is essentially the reduction in power density of an electromagnetic wave or signal as it propagates through the environment in which it is travelling. The step of choosing a path loss model that fits the application is important in planning a communication system [26]. Basically, above mentioned propagation models, deterministic model or probabilistic model [27], path loss predictions are made using techniques outlined below:

3.1 Deterministic Models

Deterministic models (theoretical models) approach depends on the knowledge of the physical laws of the wireless channel such as electrical properties of the ground [12].

3.1.1 Free Space Path Loss (FSPL) Model

FSPL model is the loss in received signal strength when LOS status exists in free space [28, 29, 30]. This model shows a decreases form of received signal power which it is inversely proportional to the square of the distance separate transmitter and receiver units. Friis equation (1) for this model is [32]:

$$P_r = \frac{P_t \times G_t \times G_r \times \lambda^2}{(4\pi)^2 \times d^2} \qquad (1)$$

where P_r, P_t is the received, transmitted signal power respectively. G_t and G_r are the antenna gain of transmitter and receiver respectively, λ is the wavelength and d is the distance between transmitter and receiver. The FSPL model can be expressed in terms of decibels, equation 2, where d is the distance in meter, and f is the signal frequency in MHz;

$$PL_{FSPL} = -27.56 + 20\log_{10}(f) + 20\log_{10}(d) \qquad (2)$$

3.1.2 Plane Earth (PE) model

In this model, height of antenna will contribute in the received signal [32]; as in equation 3, the received signal power will be a function of antenna height and the separation distance

$$P_r = \frac{P_t \times G_t \times G_r \times h_t^2 \times h_r^2}{d^4} \qquad (3)$$

Where h_t and h_r are the transmitter and receiver antenna heights, respectively (in meter). Path loss can be calculated by equation 4.

$$PL_{PE}(dB) = 40\log_{10}(d) - 20\log_{10}(h_t) - 20\log_{10}(h_r) \qquad (4)$$

The free space path formula is not fully applicable where there are others interaction, such as reflection, detraction, scattering and etc. as in real environmental applications. Nevertheless, this formula can be used to give an indication of what to be expected [32].

3.1.3 Foliage Models

In real environments of a communication system, reflections, scattering and diffractions create more than a single path between transmitter and receiver. Multipath propagation is particularly likely when the antennas have low gain and are near ground or close to other large reflection of heavy foliage or building. The total signal voltage at the receiver will experience varying degrees of destructive or constructive interference due to variable phase delay that occur along different paths. Most terrestrial wireless communication systems may require signals to pass through/over foliage at some area along its propagation path. Thus, WSN applications, such as agricultural application, may face the challenge of impairing the signal due to the existences of vegetation and crops. Many studies have been carried out to characterize and model the effects of vegetation experimentally. They have been reviewed and summarized into several well-known through-vegetation loss models, such as Weissberger's modified exponential decay model [34], ITU Recommendation (ITU-R) [35], COST235 model [36] and FITU-R model [37].

3.2 Probabilistic Models

Probabilistic Models are based on actual RF measurements of wireless channels. Advantages of empirical path loss models over theoretical path loss models include their ease of implementation and their ability to include all environment-related

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

factors that affect the propagation of the radio wave throughout actual measurements [12].

3.2.1 Log-distance Model

The log-distance expression indicates that the average signal power decreases logarithmically with the distance [38]. Some radio channels, for indoor or outdoor signal propagation, follow the log-distance model, which is given by (5):

$$PL_{dB}(d) = PL(d_0) + 10\,\alpha \log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \qquad (5)$$

Where $PL\ (d_0)$ is the path loss at the reference (d_0), α is the path loss exponent that represents the rate of the path loss values increase as a function of log of distance and (X_σ) is the normally distributed random variable with zero mean and σ standard deviation.

3.2.2 Power Regression

In [26] it has proposed a model for the precision Agriculture environment using power regression. The mathematical expression used to be:

$$d = aS^b \qquad (6)$$

In which d is the distance (in meters) between the transmitter and the receiver and S is the received power (in dBm). The Least Squares Method is used to determine the coefficients (a and b) of the equation.

4. EXPERIMENTAL SETUP

RF propagation measurements were made in a football stadium in the Perlis northern state of Malaysia. The football stadium has natural grass. In all RSS values that were recorded, the transmitting and receiving antenna pair had a LOS communication. The experiment was carried out during the daytime in a scenario where there were no obstructions or nearby objects that could have altered the strength of received signals. Figure 1 shows the experimental setup.

Figure.1 Photography Of The Experimental Measurements

4.1 Wireless Nodes

The wireless nodes, used to acquire the path attenuation data, are based on the IEE802.15.4 transceivers from Jennic Technology and the low power 8-bit (0dBm), both the receiver and the transmitter are equipped with a omnidirectional antenna [39]. The nodes used in this work consist of two modules of Jennic wireless nodes, one acts as coordinates (Receiver node) and the other acts as an end device (transmitter node) as shown in Figure 1.

4.2 Methodology

Throughout the experiments, the intent was to place a transmitting node at the center of the designated deployment field and collect RSSI readings at eight different distances (i.e., 5, 10, 15, 20, 25, 30, 35, and 40 meters) and along sixteen different 22.5 degrees separated radials. Therefore, an area of 80m x 80m is ideally needed to carry out each outdoor deployment scenario experiment. Given the relatively narrow width of the football field (i.e., around 50m), the experiment was divided into two parts, with each part consisting of an area of 40m x 80m. For each part, the received signal strength (RSS) readings were collected at eight different distances and along eight different 22.5 degrees separated radials (i.e., 0,22.5, 45, 67.5, 90, 112.5, 135, and 157.5 degrees).

The IEEE 802.15.4 standard operates in the 2.4 GHz ISM along with other applications such IEEE 802.11 and Bluetooth [40], sharing the same frequency band. As a result, the 2.4 GHz ISM band is quite noisy. For this reason, the experiments described in this work used the channel 15 (2425 MHz frequency) which is found less noisy.

Journal of Theoretical and Applied Information Technology
31st August 2015. Vol.78. No.3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The antennas used in this experiment have omnidirectional radiation patterns with heights of 20 centimeters above the ground.

In each experiment, RSS readings are collected at 128 measurement points. 300 RSS samples are collected for each of the measurement points, providing sufficiently large datasets for approximating important statistical properties of the environment path loss, such as path loss exponent, path loss at reference distance, and shadowing effects. Therefore, the RSS value provided for each of the 128 measurement points is an average of 300 RSS samples. The receiving node was connected to a laptop, where all the RSS readings were recorded directly.

5. EXPERIMENTAL RESULTS

The RSS values collected in the football stadium were converted into path loss values. This is because the path loss is considered an independent quantitative that exists outside the transmitting and receiving system's parameters. The path loss is a positive quantity that represents signal attenuation, and it is used to measure the degradation in the strength of the signal as a function of distance. For the sake of simplicity, the focus of the discussion for the rest of this paper will be placed on path loss rather than RSS. Generally, the relationship between the path loss, transmitted power, and received power can be expressed by equation (7):

$$PL_{total} = P_t - P_r + G_t + G_r \qquad (7)$$

Where PL_{total} refers to the path loss, Pt refers to the transmitted power, Pr refers to the received power, and G_t and G_r refer to the transmit and receive antenna gain, respectively. Table 1 presents the path loss values of the 128 measurement points and Table 2 summarizes its statistical properties.

Table 1: Path Loss [dB]

Radial		Distance [meter]							
	Degree	5	10	15	20	25	30	35	40
Part 1									
1	0	69	78.2	89	92.2	97.8	105.4	103.8	110.2
2	22.5	69	79.8	88.6	94.6	97.8	98.6	107	107.4
3	45	68.6	79	89.8	95.8	98.6	103	100.5	106.2
4	67.5	69	78.2	88.6	92.2	99	101.4	104.5	105.8
5	90	69	75	90.2	93.8	99	100.6	105.4	107.4
6	112.5	68.6	81	88.6	94.6	98.2	100.6	104.5	106.6
7	135	69.8	81.8	88.2	92.6	97.4	97.4	105.4	105.4
8	157.5	69	82.6	90.6	91.8	98.2	99.4	105	105.8
Part-2									
1	0	69.4	79.8	90.2	98.6	102.2	103.4	104.5	107
2	22.5	70.2	81	91.4	92.2	10[illegible].8	101.8	105.3	105.8
3	45	69.8	81	90.2	97	99	105.8	105.3	107.4
4	67.5	72.2	81.8	91	94.6	100.2	105.8	105.3	107
5	90	72.2	80.2	90.2	97.8	101	105.8	105.3	106.6
6	112.5	69.8	81	87	94.6	97.4	99.4	105.4	107
7	135	70.2	77	87.8	92.2	99.8	102.6	107	107.4
8	157.5	69.8	79	88.2	94.6	100.6	105.8	104.2	105.4

Table 2:Avarege Path Loss [dB] And Standard Deviation

	Distance [meter]							
	5	10	15	20	25	30	35	40
Average Path Loss [dB]	69.72	79.77	89.35	94.32	99.25	102.30	105.05	106.77
Standard Deviation [dB]	1.06	1.92	1.223	2.05	1.48	2.75	1.43	1.13

Figure 3 illustrates the average path loss values presented in Table 2 versus the log of distance. Additionally, the linear regression line illustrated in the Figure 3 and its equation in (8).

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

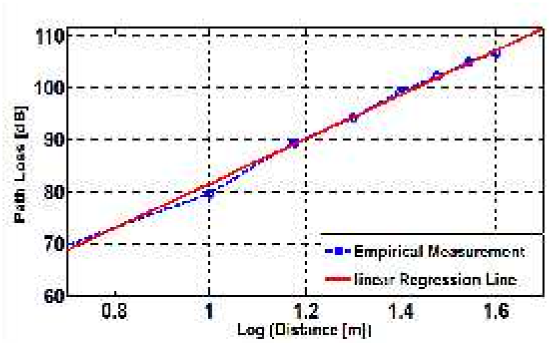

Figure 3: Average Path Loss And Linear Regression Line

From Figure 3, it is clear that the path loss increases as a function of distance. Nevertheless, the variations caused by multipath fading happen most likely as a result of the reception of two waves, which can either be constructive when the direct and ground reflected waves arrive in phase or destructive when they come out of phase [41]. However, such variation may be modeled using equation (5) (that's known as log-normal equation). The linear regression equation is:

$$y = 42.62x + 38.99 \tag{8}$$

To model the path loss for RF propagation in the natural grass environment, we correlate the above equation with the log normal equation in (5), which results in the proposed path loss equation and parameters presented in Table 3.

Table 3: Natural Grass Path Loss Model

Environment	Path Loss Model	n	$PL(d_o)$	X_σ
Natural Grass	42.99x+39.22	4.26	38.99	1.63

Where, $PL\ (d_o)$ is the path loss at the reference distance (d_o =1 m), X_σ is calculated as the average of the standard deviation values presented in Table 2.

Table 4 presents the path loss values obtained from Free Space Path Loss (FSPL), Plane Earth (PE) and the Natural grass path loss models. The parameters used to obtain the path loss values in the FSPL and PE models are the same as in the actual measurements.

Table. 4:. Path Loss Predicted By FSPL, PE and Natural Grass Models

Model	Distance [meter]							
	5	10	15	20	25	30	35	40
FSPL	54.1	60.1	63.6	66.1	68.1	69.6	71.0	72.1
PE	55.9	67.9	75.0	80.0	83.8	87.0	89.7	92.0
Natural Grass	69.7	79.8	91.7	96.3	99.3	102.3	105.1	108.0

Figure 4 illustrates the path loss values that are obtained from the three models presented in Table 4.

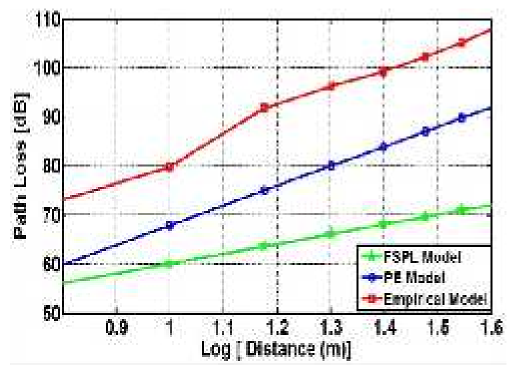

Figure 4: Empirical Measurements And Path Loss Predicted by FSPL and PE Models

From Figure 4, it is clearly seen that large differences exist between the path loss predicted by the empirical and theoretical models. The differences in path loss prediction can be evaluated statistically, using Absolute Percentage Error (APE) and Mean Absolute Percentage Error (MAPE), which is shown in table 5.

In Table 5, The comparison between largely used theoretical models (FSPL and PE) and the proposed model produces large MAPEs (29.77% and 16.24%). The large MAPE between FSPL model and the proposed model indicates its unsuitability of FSPL as a path loss prediction tool for sensor nodes deployed in natural Grass. Meanwhile, from Table 5, it is clear that APEs between PE model and the proposed model decrease as the distance increases. However, the MAPE indicates that PE model is still inaccurate in predicting the path loss in such environments.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 5: APE (%) AND MAPE(%)

Model	Distance							
	5m	10m	15m	20m	25m	30m	35m	40m
FSPL	22.38	24.69	30.64	31.36	31.42	31.96	32.45	33.24
2 Ray	19.80	14.91	18.21	16.93	15.61	14.96	14.65	14.81

6. CONCOLUSION

Accurate RF path loss models have various advantages in WSN, which include the facilitation of the planning process of WSN deployment, improvement in localization and target tracking applications that rely on the knowledge of RSS, and enhancement in battery efficiency of sensor nodes.

In this paper, A new natural grass path loss model is derived based on empirical measurements in the field. The experiment was carried out in a football stadium in the Perlis northern state of Malaysia. The collected path loss measurements of the new model were compared with well known theoretical path loss prediction models (FSPL model and PE model). The comparison demonstrated large differences between the new model measurement values and these obtained from the theatrical models, the predicted path loss values of FSPL were too optimistic, while the PE predictions was more realistic but are still inaccurate.

Thus, this research provides a new empirical path loss propagation model that to be adopted by researchers for natural grass WSN propagation aspects.

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