ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 6, June 2013

Experimental Characterization of WSN propagation in Outdoor Environment (using TelosB Sensor Nodes)

NNEBE Scholastica Ukamaka[1], Onoh G. N.[2], Idigo V. E.[3], Azubogu A. O.[4]

Department of Electronic & Computer Engineering, Nnamdi Azikiwe University Awka, Nigeria[1, 3, 4],

Department of Electrical & Electronic Engineering Enugu State University of Science & Technology, Enugu, Nigeria[2]

Abstract*:* In this paper channel prediction model of an outdoor environment using TelosB sensor nodes is develop. A Wireless Sensor Network (WSN) testbed comprising of four sensor nodes was built at the library field of Nnamdi Azikiwe University Awka. One of the sensor nodes is attached to the laptop which becomes the sink while the other 3 were placed at 0^0, 90^0 and 180^0. RSSI measurement was taken at various distances up to 60m at the interval of 5m. The measured RSSI was used to develop the pathloss model of the environment using least mean square error method of linear regression analysis. The model developed was tested and the goodness of fit (R^2) of the model was found to be 0.83. This shows that the pathloss model developed could be applied to an environment with similar radio characteristics.

Key words: TelosB sensor nodes, WSNs, outdoor, Pathloss model

I INTRODUCTION

Radio links are known to be unreliable, as their behaviour unpredictably varies over time and space. The quality of the radio links greatly impacts network performance in many ways such as topology control, routing and mobility management. Three main causes of link unreliability includes; the environment, interference and hardware transceivers. In WSNs the radio transceivers transmit low power signals which make radiated signals more prone to noise, interference and multipath distortion. The low power transceivers rely on antennas with non ideal radiation patterns, which lead to anisotropic behaviour.

The performance of any transceiver, signal processing algorithm, channel coding e.t.c depends on its operation channel. For WSNs, this channel is the wireless propagation channel. Channels in sensor networks are distinct from channels in cellular/Wi-Fi systems, because of the location of transmitter and receiver. They are placed where the sensor need to be, not necessarily where they are best placed from communications point of view. For example, sensor nodes for pipeline monitoring are often placed underground very close to the pipes.

A WSN can be generally described as a network of nodes that cooperatively sense and may control the environment enabling interaction between persons or computers and the surrounding environment [1]. A large number of such sensors can be deployed in an area to achieve overall sensing objective. In addition to sensing and collecting data, these sensors are also equipped with processing capabilities to deduce how to route the data packets through the neighbours to an Internet-connected base station or sink.

Applications of WSN include tracking enemies in battle field, locating moving objects in building, tracking people inside building, gathering sensing information in hospitable locations, detecting terrorist in pipelines environment, leakage detection and environmental monitoring. A correct understanding and modeling of the propagation channel is thus, a vital prerequisite for understanding the performance of WSNs.

A propagation model is a set of mathematical expressions, diagrams, and algorithms used to represent the radio characteristics of a given environment [2]. The prediction models can be either empirical (also called statistical) or theoretical (also called deterministic), or a combination of these two (semi-empirical). The empirical models are based on measurements, while the theoretical models deal with the fundamental principles of radio wave propagation phenomena. On the basis of the radio environment, the prediction models can be classified into two main categories, outdoor and indoor propagation models.

In this research work, an experimental testbed of WSN of outdoor environment was developed. The wireless communication channel of the testbed was characterized and the pathloss model of the network developed. This paper is sectioned as follows; I Introduction, II Literature review, III Propagation models for WSN, IV Research methodology, V Result Discussion and VI Conclusion.

II LITERATURE REVIEW

In the wireless channel, the electromagnetic wave propagation can be modeled as a power law function of the distance between the transmitter and receiver. The free space propagation is used to predict received signal strength when the transmitter and receiver have a clear, unobstructed line-of-sight path between them. The free space power received by a receiver antenna which is separated from a radiating transmitter antenna by a distance *d* is given by [3]:

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

where P_t is the transmitted power, $P_r(d)$ is the received power which is a function of the transmitter-receiver (T-R) separation distance *d*, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, *L* is the system loss factor not related to propagation $(L \geq 1)$, and λ is the wavelength in meters.

The values of P_r and P_t must be expressed in the same units and G_t and G_r are dimensionless quantities. The miscellaneous losses L $(L \geq 1)$ are usually due to transmission line attenuation, filter losses, and antenna losses in the communication system. A value of $L = 1$ indicates no loss in the system hardware.

Many research works have been done on this area. The authors in [3] evaluated the Radio Frequency (RF) signal propagation inside a laboratory and outdoors using several experimental measurements. The measurements were realized with a portable spectrum analyzer with different antennas. T mote sky and micaz sensor motes were used.

In [4], the authors evaluated the Packet Error Rate (PER) and the RSSI both in indoor and outdoor environments through measurements by using off the shelf IEEE 802.15.4 radio.

The authors in [5] developed a model which is widely used for predicting the average path loss for mobile systems in urban areas. The model assumes that the street grid in a typical city organizes buildings into rows that are nearly parallel and that an idealized representation for the urban environment would be where the precise height and spacing of the buildings have been ignored.

In [6] Okumura carried out an experiment to measure the signal strengths in the vicinity of the city, Tokyo, over a wide range of frequencies, several fixed-site antenna heights, several mobile antenna heights, and over various irregular terrains and environmental clutter conditions. A set of curves relating field strength versus distance for a range of fixed-site heights at several frequencies was generated. Various behaviours in several environments, including the distance dependence of field strength in urban areas, and urban versus suburban differences were then extracted from these curves.

III PROPAGATION MODELS FOR WSN

Pathloss (P_L) represents signal attenuation as a positive quantity measured in dB and is defined as the difference (in dB) between the effective transmitted power and the received power. It may or may not include the effect of the antenna gains [7] as shown in the following equations.

$$P_r(dBm) = P_t(dBm) - P_L(dB) \qquad (2)$$

$$P_L(dB) = -10\log\left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right] \qquad (3)$$

$$P_L(dB) = -10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] \qquad (4)$$

Equation (3) was obtained by substituting equation (1) into equation (2). The free space model is only a valid predictor of P_r for values of d which are in the far field of the transmitting antenna. Equation (4) is obtained by assuming that $G_t = G_r = 1$. Equation (4) can be simplified to obtain equation 5.

$$P_L(dB) = 20\log_{10}(4\pi) + 20\log_{10}(d) - 20\log_{10}(\lambda) \qquad (5)$$

Substituting $\lambda(in\ km) = {}^{0.3}\!/_{f(MHz)}$ into equation (5) and simplifying produces a generic free space pathloss formula shown in equation (6) [8].

$$P_L(dB) = 32.5 + 20\log_{10}(d) + 20\log_{10}(f) \qquad (6)$$

In the experimental measurement carried out, a close-in distance, d_o of 1meter was used as a known received power reference point. The received power, $P_r(d)$ at any distance $d>d_o$, is related to P_r at d_o. The value $P_r(d_o)$ was measured in the radio environment by taking the average received power at many points located at a distance d_o from the transmitter. Equation 2 was used to determine the measured pathloss P_{Lm}, since the transmitted power P_t is known and received power Pr obtained in the experiment. In the experiment, P_t is set at $0dBm$. Both theoretical and measurement based propagation models indicate that average received signal power decreases logarithmically with distance, whether in outdoor or indoor radio channels. In the model, the average large scale pathloss for an arbitrary transmitter-receiver (T–R) separation is expressed as a function of distance by using a path loss exponent, n [9]

$$P_L(d) \propto \left(\frac{d}{d_o}\right)^n \qquad (7)$$

$$P_L(dB) = P_L(d_o) + 10n\log\left(\frac{d}{d_o}\right) \qquad (8)$$

In this model, P_L, represents the average path loss experienced between the receiver and sender in dB. $P_L(d_o)$ represents the reference pathloss in dB, when the transmitter-to-receiver (T-R) distance is at reference distance d_o, n is the pathloss exponent which indicates the rate at which the pathloss increases with distance, d_o is the close-in reference distance which is determined from measurements close to the transmitter, and d is the T – R separation distance. The value of n depends on the specific propagation environment. For example, in free space n is equal to 2, and when obstructions are present, n will have a larger value. The reference pathloss is calculated using the free space pathloss formula given by equation (6).

With linear regression, the pathloss exponent was determined from the measured pathloss and the predicted pathloss by minimizing in a mean square error sense, the difference between them. The sum of pathloss exponent [10] is given as;

$$E(n) = \sum_{i=1}^{k} \left\{P_{Lm} - P_{Lp}\right\}^2 \qquad (9)$$

where P_{Lm} is the measured pathloss in dBm at distance d, and P_{Lp} is the predicted pathloss in dBm obtained using equation 8. Substituting equation 8 into equation (9) for P_{Lp} yields equation (10a)

$$E(n) = \sum_{i=1}^{k} \left[P_{Lm} - P_L(d_o) - 10n\log_{10}\left(\frac{d}{d_o}\right)\right]^2 \qquad (10a)$$

Differentiating equation (10a) w.r.t n gives

$$\frac{\delta E(n)}{\delta n} = -20n\log_{10}\left(\frac{d}{d_o}\right)\sum_{i=1}^{k}\left[P_{Lm} - P_L(d_o) - 10n\log_{10}\left(\frac{d}{d_o}\right)\right] \qquad (10b)$$

Equating $\frac{\delta E(n)}{\delta n}$ to zero and dividing both sides by $-20n\log_{10}\left(\frac{d}{d_o}\right)$

yields,

$$\sum_{i=1}^{k}\left[P_{Lm} - P_L(d_o)\right] - \sum_{i=1}^{k} 10n\log_{10}\left(\frac{d}{d_o}\right) = 0 \qquad (10c)$$

The path loss exponent n is found by making n the subject of formula from equation (10c)

$$n = \frac{\sum_{i=1}^{k}\left[P_{Lm} - P_L(d_o)\right]}{\sum_{i=1}^{k} 10\log_{10}\left(\frac{d}{d_o}\right)} \qquad (11)$$

IV RESEARCH METHODOLGY

This research work presents the study of the outdoor experimental testbed for WSN. The testbed environment is the open field of the Library Complex of Nnamdi Azikiwe University, Awka. In the test environment, four TelosB sensors were used in the experiment. One of the sensor nodes was attached to the laptop and was used as the sink. The remaining three sensor nodes were placed at 0^0, 90^0 and 180^0 from the sink at the same distances while taking the measurements. The RSSI measurements were taken at several distances and the data obtained were recorded.

The sensor nodes used are the TelosB sensor nodes by crossbow which is an IEEE 802.15.4/ Zigbee compliant node. The nodes are composed of four main units namely; the Chipcon CC2420 transceiver, the MSP430 microcontroller, the power section which consist of two

AA (3V) batteries and the sensor section which consist of temperature (-40-123.8^{o}c), humidity (0-100%RH), visible light (320nm-730nm) sensor and slot for any two sensors of your choice. The pictorial representation of the experimental testbed during measurement is shown in figure 1.

Fig. 1 shows pictorial representation of the experimental testbed.

In the Test environment the Received Signal Strength Indicator (RSSI) in dBm, the temperature in ^{o}C, the humidity in RH, light intensity, Link Quality Indication (LQI) value and the frame size of the data were measured against the distance in meters. 5m up to 60m at the interval of 5m was used in the measurements. The data sent to the sink at different distances were recorded and saved. Data were sent every 5seconds and all the data history were kept unless cleared. The data are recorded in excel format. The data received were averaged and tabulated. The averaged data were used in data analysis. Since Signal Strength is affected by weather, different weather conditions were considered such as windy days, bright sunny days and rainy days.

A. Pathloss characterization of the environment: Library field of Nnamdi Azikiwe University.

The pathloss at a reference distance, $P_L(d_o)$, was determined empirically and Equation (2) was used to determine the measured pathloss, with the transmitted power set at *0dBm* and the received power measured at different distances. For example, at 1m which is the reference distance, d_o, the received power in dBm is -40.7, -46.0, -44.8, and -43.83 for nodes ID 301, 302, 303 and the average of the three nodes respectively. Applying Equation 2.6, for node ID 301

$$P_L(d_o) = \{0-(-40.7)\}dB \quad = 40.7dB$$

For node ID 302

$$P_L(d_o) = \{0-(-46.0)\}dB \quad = 46.0dB$$

For node ID 303

$$P_L(d_o) = \{0-(-44.8)\}dB \quad = 44.8dB$$

For the average of the three nodes

$$P_L(d_o) = \{0-(-43.83)\}dB \quad = 43.83dB$$

Also at 5m, the received power in dBm is -61.4, -64.1, -62.3, and -62.60 for node ID 301, 302, 303 and the average of the three nodes respectively.

For node ID 301

$$P_L(d) = \{0-(-61.4)\}dB \quad = 61.4dB$$

For node ID 302

$$P_L(d) = \{0-(-64.1)\}dB \quad = 64.1dB$$

For node ID 303

$$P_L(d) = \{0-(-62.3)\}dB \quad = 62.3dB$$

For the average of the three nodes

$$P_L(d) = \{0-(-62.60)\}dB \quad = 62.60dB$$

and so on. Table 1 shows the determined average pathloss of the environment.

Table.1: Average path loss of the testbed: Library field of Nnamdi Azikiwe University, Awka.

Distance (m)	Ave. Path loss P_L (dB) of node ID 301	Ave. Path loss P_L (dB) of node ID 302	Ave. Path loss P_L (dB) of node ID 303	Average Pathloss P_L (dB) of the 3 nodes
1	40.7	46.0	44.8	43.83
5	61.4	64.1	62.3	62.60
10	68.1	69.6	65.8	67.83
15	82.4	75.9	74.7	77.67
20	80.3	77.7	81.9	79.97
25	77.6	88.5	81.3	82.47
30	81.5	88.5	89.5	86.50
35	88.7	89.2	84.7	87.53
40	75.8	88.2	86.3	83.40
45	82.3	91.8	85.5	86.53
50	84.7	91.8	92.2	89.57
55	78.8	88.8	89.3	85.63
60	92.2	92.43	92.3	92.3

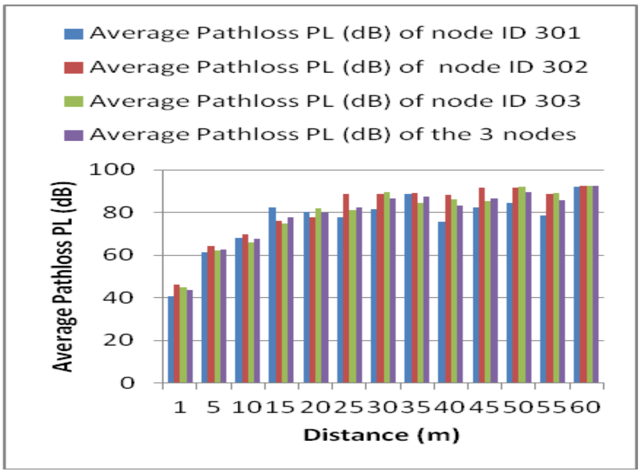

Fig 2: Bar chart showing the average pathlosses of the sensor nodes

Scatter plots showing the pathloss of the three sensor nodes and the average pathloss (dB) of the three sensor nodes against distance were implemented using Matlab as shown in Figures 3 and 4 respectively.

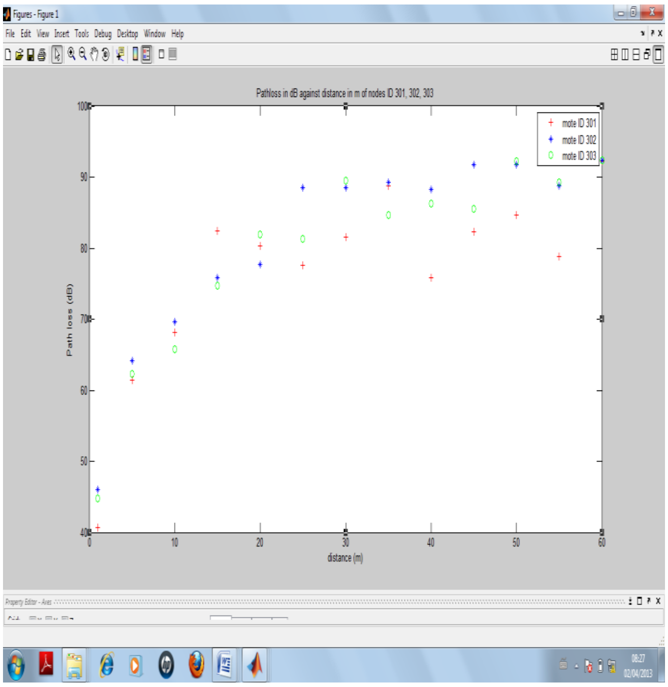

Figure 3: Plot of pathloss in dB against distance in m of the three sensor node.

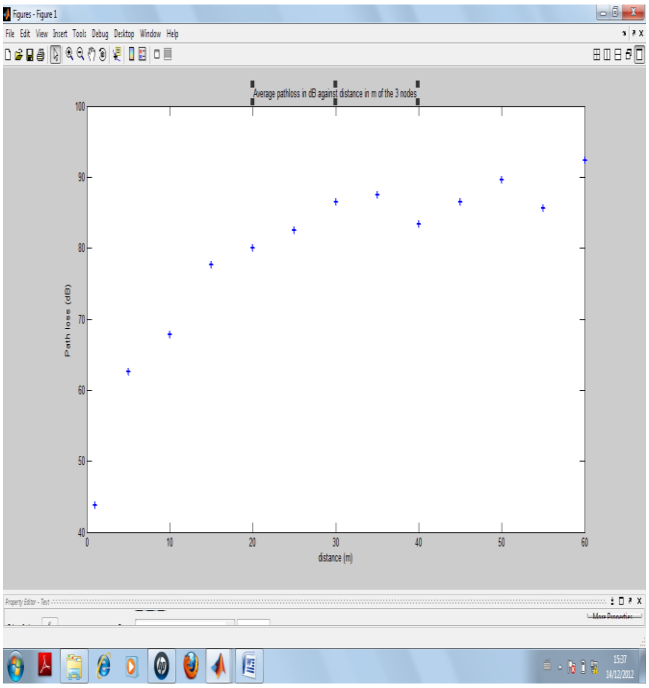

Figure 4: Plot of average pathloss (dB) of the three nodes against distance.

Equation 11 was implemented using Matlab to calculate the pathloss exponent as 2.67 for the testbed environment. The predicted pathloss was calculated by implementing Equation 8 in Matlab. The measured pathloss and the predicted pathloss were plotted on Matlab to show the correlation between the values. Table 2 shows the values of the measured and predicted pathlosses against distance.

Table 2: Average measured and predicted pathlosses of the testbed

Distance (m)	Average measured Pathloss P_{Lm} (dB)	Average predicted Pathloss P_{Lp} (dB)
1	43.83	43.83
5	62.60	61.96
10	67.83	70.52
15	77.67	75.32
20	79.97	78.66
25	82.47	81.34
30	86.50	83.36
35	87.53	85.15
40	83.40	86.70
45	86.53	88.06
50	89.57	89.28
55	85.63	90.39
60	92.30	91.39

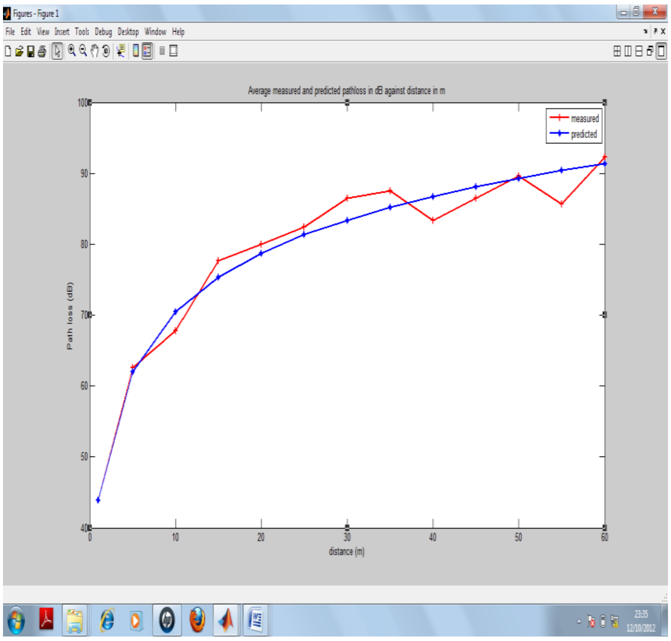

Figure 5: Plot of average measured and the predicted path loss against distance.

In order to characterize the environment, putting into consideration the fact that the surrounding environmental clutter may be vastly different at two different locations having the same transmitter-to-receiver (T – R) separation, Log-normal shadowing model was used. This leads to measured signals which are vastly different from the average value predicted by Equation 8. Measurements have shown that at any value of d, the pathloss $P_L(d)$ at a particular location is random and distributed log-normally about the mean distance as shown in Equation 12.

$$P_L(dB) = P_L(d_o) + 10n\log\left(\frac{d}{d_o}\right) + X_\sigma \qquad (12)$$

where X_σ is a zero-mean Gaussian distributed random variable with standard deviation σ , both in dB.

The value of σ is computed using Equation 13 [91].

$$\sigma(dB) = \sqrt{\sum_{i=1}^{k}\frac{(P_{Lm}-P_{Lp})^2}{N}} \qquad (13)$$

where P_{Lm} is the measured pathloss in dB, P_{Lp} is the predicted pathloss in dB and N the number of measured data points which is 13.

The value of σ was calculated to be 2.3 using Matlab. Putting the values of n, X_σ and $P_L(d_o)$ which are 2.67, 2.3 and 43.83 respectively into Equation 12 gives the model for the Outdoor WSN testbed using TelosB sensor nodes as shown in Equation 15.

$$P_L(d) = 43.83 + 10(2.67)\log(\frac{d}{d_o}) + 2.3 \quad (14)$$

$$\therefore P_L(d) = 46.13 + 26.7\log(\frac{d}{d_o}) \qquad (15)$$

The Equation, $P_L(d) = 46.13 + 26.7\log(\frac{d}{d_o})$, hence gives the path loss mathematical model for any random distance *d* from the transmitter, for the outdoor WSN testbed using TelosB sensor nodes. The model obtained is then simulated using Matlab as shown in Figure 6.

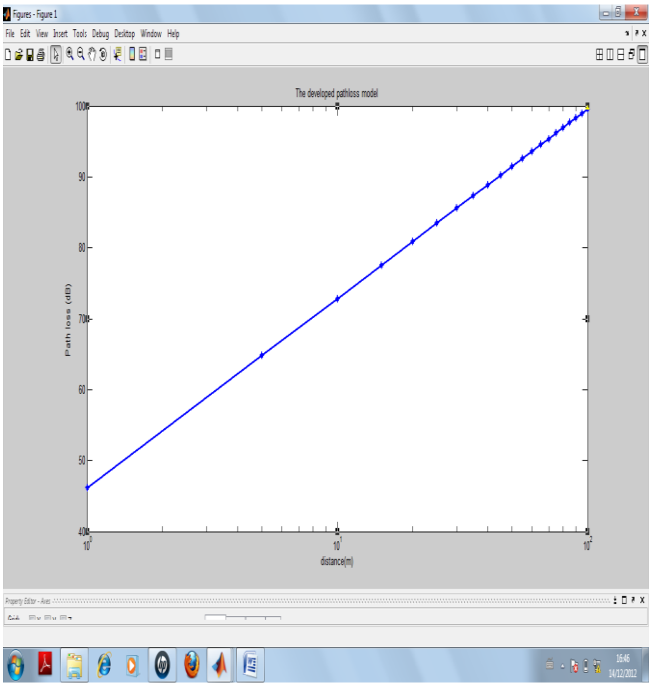

Figure 5: Plot of the developed path loss model in dB against distance of the outdoor testbed (library field of Nnamdi Azikiwe University)

The goodness of fit (R^2) of the pathloss model developed for the testbed was tested and found to be 0.83. This confirms that the model can generally be applied in pathloss determination of an area with similar radio characteristics. Therefore, this equation would be used to determine the pathloss values at known distances of the environment.

V RESULT DISCUSSION

The propagation of radio signals is affected by several factors that contribute to the degradation of its quality. The effects of these factors are even more significant on the propagation of wireless signals with low power radios, typically used in wireless sensor network. The quality of the link between two nodes is not static; it varies over time thus depends on channel fading. The channel fading is due to multipath transmission or shadowing and it is time dependent. Due to these facts, it is necessary to characterize the radio environment of the developed testbed. The path loss prediction parameters obtained using the log-normal shadowing model reveals that the path loss exponent value and the standard deviation caused by the shadowing effect are 2.67 and 2.3dB respectively. This path loss exponent is therefore considered to be accurate since it falls within the stated range of values of pathloss exponent. The measurements were performed in a field (outdoor environment) with grasses only.

VI CONCLUSION

In this work, WSN testbed using TelosB sensor nodes was built and the propagation channel of the testbed characterized. The path loss prediction parameters obtained using the log-normal shadowing model reveals that the path loss exponent value and the standard deviation caused by the shadowing effect are 2.67and 2.3dB respectively. This path loss exponent is therefore considered to be accurate since it falls within the stated range of values of pathloss exponent. The pathloss model of the testbed environment developed was tested and the goodness of fit (R^2) of the model showed that the model could be used to found the pathloss of an environment with similar radio characteristics at known distances. . Although the range of the TelosB node from their datasheet is 75-100m outdoor, at 70m the signal is no longer strong. This may be due to foliage in the field used, the undulating nature of the earth surface, and obstructions etc.

REFERENCES

[1] Verdone, R.; Dardari, D.; Mazzini, G.; Conti, A., (2008), "Wireless Sensor and Actuator Networks", Elsevier: London, UK.

[2] Stallings, W., (2005) "Wireless Communications and Networks", 2nd Edition, Prentice Hall.

[3] Joaquim A. R. Azevedo and Filipe Edgar Santos, (2007) "Signal Propagation Measurements with Wireless Sensor Nodes", University of Madeira, Portugal.

[4] Marina Patrova, Janne Riihijarvi, Petri Mahonen and Saverio Labella, (2007), "Performance Study of IEEE 802.15.4 using Measurements and Simulations" Department of Wireless Networks, RWTH Aachen University, Germany.

[5] Walfisch, J., and Bertoni, H., "A theoretical model of UHF propagation in urban environments," IEEE Trans. Antennas and Propagate, Vol. 36, pp. 1788– 1796, December 1988.

[6] Siwiak, K., Radiowave Propagation and Antennas for Personal Communications, 2nd Edition, Artech House, Inc., Norwood, Massachusetts, 1998.

[7] Rappaport, Theodore S., (2008), "Wireless Communications Principles and Practice",2nd edition, Prentice Hall, U.S.A.

[8] Siwiak, and Kazimierz, (1995), "Radiowave Propagation and Antennas for personnal communications"Artech House, Boston-London.

[9] Andrea Goldsmith, (2005), "Wireless Communications", Cambridge University Press, U.S.A.

[10] Gupta V., Sharma, S.C. and Bansal, M.C. (2009), "Fringe Area Pathloss Correction Factor for Wireless Communication", International Journal of Recent Trend in Engineering Vol. 1, No. 2.