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Analysis of Signal Propagation in an Experiment Room with Epoxy Covered Floor for Wireless Sensor Network Applications

A. Harun[1,4,*], *S.A.Z. Murad*[1], *M.F.* Ramli[2,4], *L.M.* Kamarudin[2,4], *D.L.* Ndzi[3], *N.A.M.A* Hambali[1], *S.N.* Mohyar[1], and *M.N.* Isa[1]

[1]School of Microelectronic Engineering, Universiti Malaysia Perlis (UNIMAP), Perlis, Malaysia
[2]School of Computer and Communication Engineering, Universiti Malaysia Perlis (UNIMAP), Perlis, Malaysia
[3]School of Engineering, University of Portsmouth, Portsmouth, UK
[4]Center of Excellence for Advanced Sensor Technology (CEASTech), Universiti Malaysia Perlis, Malaysia

Abstract. As sensor applications combined with wireless network becoming more of an everyday applications, the optimal deployment becomes ever increasing important as that would be a key important factor in the trade-off between cost and link quality. This paper reports on the effect of epoxy covered floor on signal propagation characteristics in an experiment room. Microchip developed motes were used to measure signal propagation in an experiment room where sensors would be deployed extensively. The results show that the signal strength for 30 cm antenna height provides a significant margin with respect to signal noise floor. As for the 5 cm antenna height, there is still around 25 dB margin in average before the signal reaches noise floor. Analysis shows that the log-distance model is the best fit to the measured data. Free Space Loss model seemed to under estimate the overall performance of the signals. An important conclusion from this study is that wireless mote deployment must consider the margin between the two signals of antenna heights and the margin to noise floor to avoid link quality deterioration especially for sensitive data acquisition applications.

1 Introduction

It is unquestionable that sensor application coupled with wireless sensor network (WSN) has introduced tremendous amount of applications that are important and applicable in many everyday tasks and activities. As their use becomes more widespread, especially in time critical applications, so too is the need to ensure that they are reliable and can meet quality of service requirements. Detailed knowledge of wireless signal propagation within the specific environment is essential to ensure reliability in network performance [1].

* Corresponding author: aziziharun@unimap.edu.my

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For specific wireless sensor deployment, such as in an experiment room, the link quality between the nodes is very important. Data are coming from various sensors located at multiple heights from the ground. Some sensors could be connected via long wires to wireless motes; however, some requires direct connection to wireless motes. To achieve the optimal deployment strategy for customized experiment room, it is necessary to exploit the entire spatial-temporal characteristics of propagation channel. In an effort to ensure the accuracy of indoor environment signal characterization, a comprehensive measurement activity has to be performed. All electromagnetic aspect of the channel has to be taken into consideration [2]. This paper reports on the effect of epoxy covered floor on signal propagation characteristic in an experiment room.

2 Literature Review

Application of WSN in data collection in customized application is one of the major uses that will have a profound impact on research communities. Until recently most studies in WSN have focused on the devices [3], protocols [4]-[6] and the network architecture [7]. Although there have been some studies focusing on signal propagation, such as in [8]-[11], specific signal propagation study for WSN network deployment in experimental room with epoxy covered floor has not been widely done. In an indoor propagation study, simple channel models such as the free space loss (FSL) given by Eq. (1) is often used.

$$\mathrm{L_{FSL}} = -27.56 + 20\log_{10}(\mathrm{d}) + 20\log_{10}(\mathrm{f}) \tag{1}$$

The parameter f is the frequency in MHz; d is the distance between the isotropic transmitting and receiving antennas in meters.

Indoor propagation is very much associated with Log-distance model. Gay-Fernandez et al. [12] have shown that WSN channel can be modeled using such model. The log-distance model is described by Eq. (2) [13].

$$\mathrm{P_r(d)} = \mathrm{P_{r_0}} - 10\alpha\log_{10}(\mathrm{d}) + \mathrm{X_\sigma} \tag{2}$$

where $P_r(d)$ is the received power (in dBm) at a distance d (in meters) from the transmitter, P_{r_0} is the signal strength at 1 m antenna separation, α is the path loss exponent and Xσ represents a Gaussian random variable with zero mean and standard deviation of σ dB. Due to the short-range nature of wireless sensor nodes, proper study need to be performed to ensure careful network consideration to avoid high costing in network implementation [14][15].

The study reported in this paper uses RSSI for estimating the signal strength received at the receiver given a certain value of transmitted signal. It has been reported in [11] that the RSSI can be predicted and modeled based on average signal strength over the distance of radius centered at the receiver. The model is given by Eq. (3).

$$\mathrm{RSSI} = -10\mathrm{n}\log_{10}(\mathrm{d}) + \mathrm{A} \tag{3}$$

where n is the signal propagation constant, d is the distance between transmitting and receiving antennas and A is the average of received signal strength at 1.5 m radius. The maximum range of the mote, in this study, is defined as the length of the room to be measured which is at 13 m.

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3 Equipments and measurements

This study has been performed using MICROCHIP mode utilizing Microchip manufactured RF chip which is ZIGBEE/IEEE802.15.4 compliant. The mote transmit in the 2.4 GHz – 2.5 GHz ISM band, however for this specific experiment the mote was programmed to transmit at 2.423 GHz. The mote uses supply voltage of 9.0 V and utilizes Omni-directional 8 dBi antenna. The noise floor for this mote is at -92 dBm.

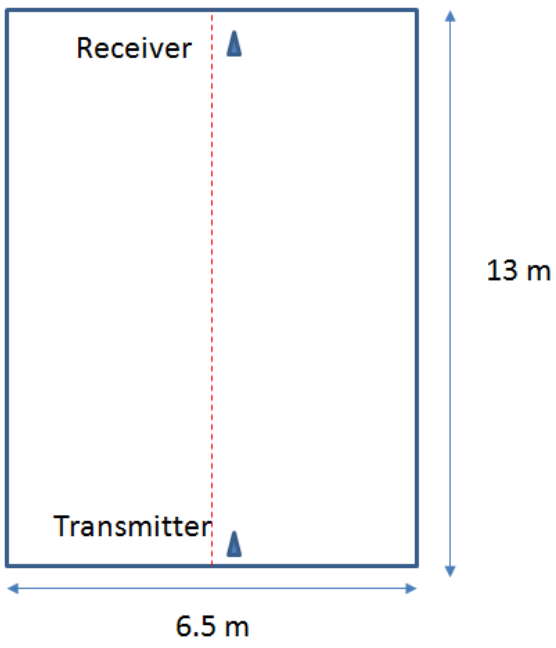

Fig. 1. Room dimension and setup of transmitter and receiver during measurement

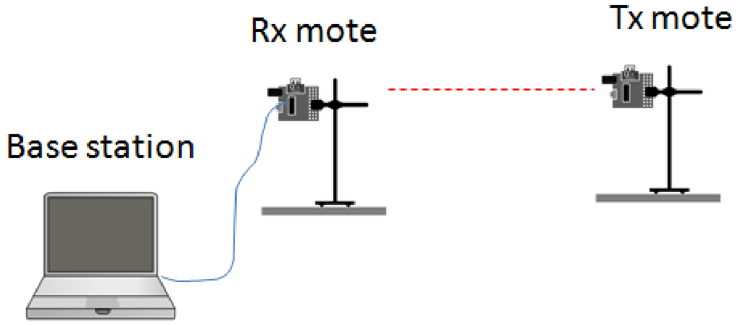

Fig. 2. Equipment setup for 30 cm antenna height

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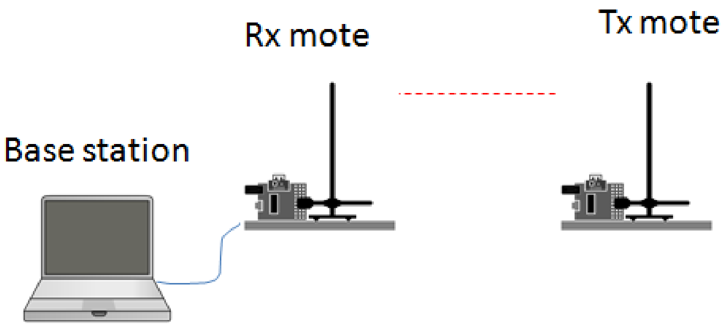

Fig. 3. Equipment setup for 5 cm antenna height

The measurements were performed in a room measuring 6.5 m by 13 m. The room is designed to be used for multiple types of sensor placements equipped with WSN motes to create network of WSN for real time data collection. The sensors are to be placed closed to the floor and around 25 cm to 30 cm all over the room for a customized application data collection. The room dimension is depicted as in Fig. 1. The maximum antenna separation was determined by the range available in the room which is limited by the room's width and length. During the study, the receiving nodes remained at a fixed position whilst the transmitting nodes were placed at specific distances from the receiver in a straight line. The experiments were carried out with antenna heights of 5 cm and 30 cm. The setting at 5 cm is to replicate placing motes on the floor for sensitive sensors requiring close proximity connection to mote while 30 cm setting is optimal mote placement for majority of the sensors. The setups are illustrated in Fig. 2 for 30 am antenna height and Fig. 3 for 5 cm antenna height.

4 Results and discussions

This section discusses the results obtained in indoor signal propagation measurement under the effect of epoxy coated floor. The results are presented based on the average RSSI values at various transmitting to receiving mote distances.

Fig. 4 compares the characteristic of signal propagation at 5 cm and 30 cm antenna heights. Signal profile with distance for both 5 cm and 30 cm antenna heights behaves almost similar for distance less than 2 m. However, after 2 m, signal profile for 5 cm antenna height shows greater power reduction that that for 30 cm antenna height. The difference in power level between the two antenna heights at 2 m until 4 m is almost 3 dB at the highest point. Signal strength for 30 cm antenna height shows an increasing trend between 5 m to 8 m distance while signal strength for 5 cm antenna height continues the reduction trend at this segment of the distance. Signal strength difference between the two antenna heights measures around 12 dB at the highest point. Nevertheless, as signal strength for 30 am antenna height shows decreasing trend after 8 m distance onward, signal strength for 5 cm antenna height starts the rebound and trending upward. At around 10 m distance signals at both antenna heights climb up for about 8 dB to 10 dB before starts showing downward trend again after around 11 m distance until signal strength for 30 cm antenna height reaches 56 dBm levels and signal strength for 5 cm antenna height reaches 64 dBm levels. Since the length of the room was limited, there are still about 28 dB margin before the signal strength hits the noise floor.

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Even though the signal variation between the two antenna heights are not very distinct, there is still about 8 dB to 12 dB margin between them which implied having motes on the ground or very close to ground would reduce the signal strength significantly compared to having the motes at 30 am antenna height. As such, any signal strength reduction at transmitter should take this into consideration to avoid hitting noise floor and deteriorated signal quality.

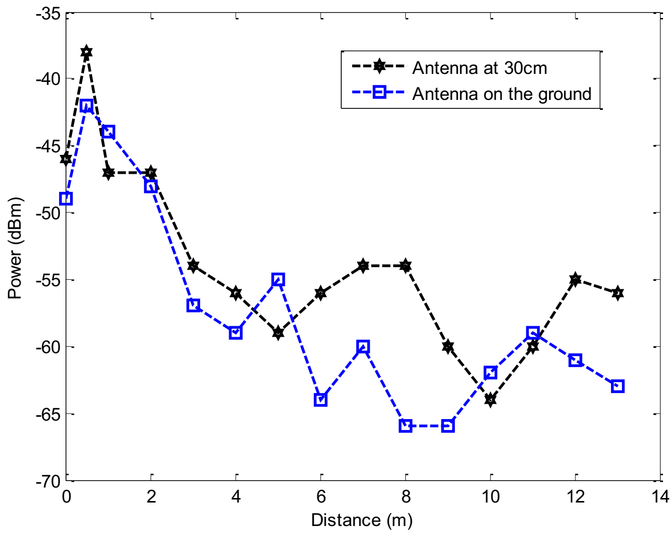

Fig. 4. RSSI variation over distance for both 30 cm antenna height and antenna on the ground (5 cm)

To model signal power variation with distance, the log-distance and FSL models were fitted to the data. Fig. 5 shows signal variation over distance for 5 cm antenna height fitted with log-distance and FSL models. The equation for log-distance model that describes the fitted model is given in the figure with root mean square error of 3.11. Based on the figure, FSL seems to have underestimated the signal strength for 5 cm antenna height on epoxy covered floor which resulted in bigger root mean square error of 11.99. Smaller variation in the signal power with distance contributed to low root mean square error for log-distance model.

Compared to results from 5 cm antenna height measurement, the signal decay with distance for 30 cm antenna height exhibited slightly larger variation in average thus contributed to higher root mean square error of 3.18 as depicted in Fig. 6.

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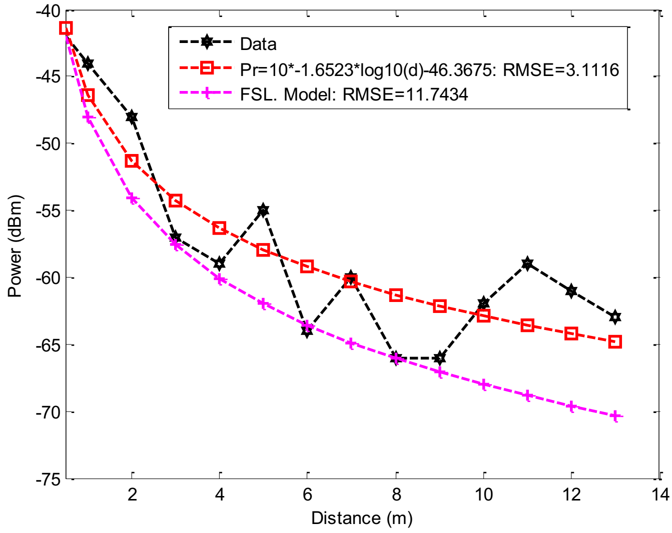

Fig. 5. 5 cm antenna height data with log-distance and FSL model fitting

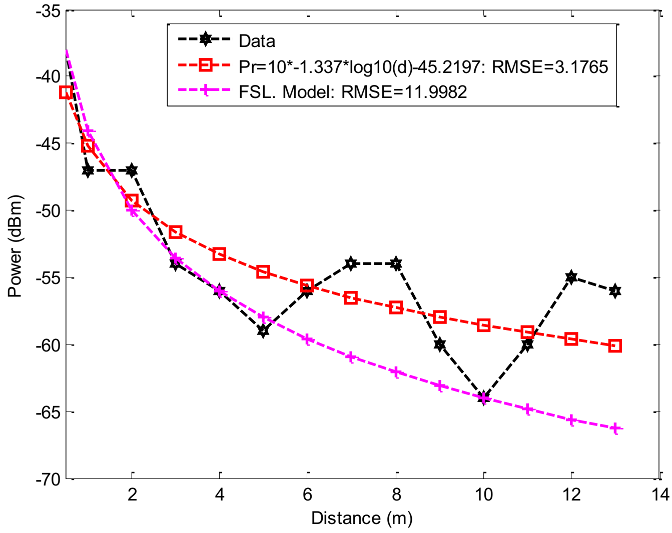

Fig. 6. 30 cm antenna height data with log-distance and FSL model fitting

It is apparent from the signal variations that both signals are undergoing severe attenuation throughout the distance in the room. Observable increase in signal strength for 30 cm antenna height at around 7.5 m to 8 m range was mainly contributed by first ground reflection occurred at 7.4 m range. Although the same reflection occurred in the signal propagation for 5 cm antenna height which occurred at 2 m range, the effect is insignificant due to the height of the antenna from ground. A summary of the log-distance model parameter values from fittings to the measured data is given in TABLE 1.

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Table 1. Summary Of Fitted Log-Distance Model Parameter Values

Mote Type	Antenna height	α	P_{r_0}	RMSE (dB)	Site
Microchip	30 cm	1.33	-45.2	3.18	Epoxy floor
Microchip	5 cm	1.65	-46.3	3.11	Epoxy floor

Conclusion

This paper has presented a wireless propagation study performed in an epoxy covered room customized for wireless sensor motes deployment. The results show that the signal strength for 30 cm antenna height provides a significant margin with respect to signal noise floor. As for the 5 cm antenna height, there is still around 25 dB margin in average before the signal reaches noise floor. It is also observed that the 25 cm difference in antenna height contributed almost 12 dB margin between the two antenna heights. Although ground reflection contributed fairly to 30 am antenna height signals, the effect is not obvious for 5 cm antenna height signals.

Analysis shows that the log-distance model is the best fit to the measured data. FSL model seemed to under estimate the overall performance. An important conclusion from this study is that wireless mote deployment must consider the margin between the two signals of antenna heights and the margin to noise floor to avoid link quality deterioration especially for sensitive data acquisition project. Any power optimization attempt would also require close attention to the margins.

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