Assessing the Performance of ZigBee RF Protocol using Path loss models for IoT Application

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Abstract. The picture of the IOT which forms interconnection between several gadgets through the internet. ZigBee is one of the emerging Internet of Things standards. Wireless communication occurs between XBee devices, which function as radio frequency (RF) devices. Both devices must be connected to the same network for data to be transmitted and received from one XBee module to another. In this paper, the performance of the XBee S2C module is evaluated in different environments and the ZigBee modules are evaluated in both indoor and outdoor environments with Line-of-sight (LOS) and Non-LOS criteria to know the signal intensity. The RSSI results for outdoor-to-outdoor and indoor-to-outdoor environments were obtained from the experiment conducted physically in a real environment. It is observed that the RSSI values decreased with an increase in the distance between the ZigBee coordinator the and ZigBee router.

Keywords: ZigBee Protocol, IoT, path-loss modelling.

1 Introduction

The rapid proliferation of the Internet of Things (IoT) has ushered in a new era of connected devices and applications, each demanding efficient and reliable wireless communication protocols The key features of modern IoT devices [3] consume less power and can be established free communication between them by using 2.4 GHz which is the ISB band that requires no permission from any authority. This is of four types: Bluetooth protocol, Zigbee protocol, and LoRa protocol.

Among these, ZigBee RF protocol has emerged as a prominent contender, owing to its low-power, cost-effective, and mesh networking capabilities. Zigbee is one of the emerging Internet of Things standards. ZigBee is based on the IEEE 802.15.4 standard. The Zigbee devices connect over the air wirelessly. Wireless communication occurs between Xbee devices, which function as radio frequency (RF) devices. Both devices must be connected to the same network for data to be transmitted and received from one Xbee module to another. Data is wirelessly exchanged between two devices. One of these devices in the Zigbee network will be a Coordinator device and the other will be a Router device.

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The ZigBee Coordinator (ZC) searches for an open channel on which to build a network. It is the network's initial device. The ZigBee Router (ZR) checks for active channels to join and then allows other devices to connect. In this article, we are going to conduct a performance evaluation field test for Zigbee protocol in environments such as indoor and outdoor localization and implement path loss models to analyze the range of Zigbee protocol.

2 Required components and configuration

The components required to perform this experiment are two Zigbee devices (as coordinator and router), and a power bank for the power supply. The specifications [5] of XBee S2C are Operating Frequency with 2.4 GHz (ISM band), Transmit Power up to 63mW (18 dBm), Receiver Sensitivity is 102 dBm, Range for indoor it supports up to 100 meters, for outdoor with line of sight is 1200 meters, Data Rate up to 250 kbps, Power Supply Voltage is 2.7v to 3.6.

2.1 X-CTU Software Description

XCTU is an open-source tool that supports the platform-independent to develop several applications with GUI interface to link Digi Rf components. It has made easier with GUI to get graphical view of network for estimating the signal strongness of each link and inspect API frames for XBees in API technique.

XBee Configuration

1. The XBee Shield is used to connect an XBee to a computer. We will be able to set up XBee and establish connections between RF modules with the aid of these tools [7]. Connect the XBee modules to the XBee shields and use the X-CTU software to connect to the computer.
2. Open X-CTU software. For the XBee module to get press the "ADD Device" key at the top-left-side of the window. Now, select the XBee device and click “Add Selected Devices”. Then, we can see XBee listed on the left. Click on the XBee module and the setting options will be displayed.
3. Settings to be updated to configure XBee as Router are-
   a. PAN ID: 2626
   b. JV Channel Verification: Enable
   c. NI Node Identifier: Router
   d. AP API Enable: API Enabled
4. Now, to add another XBee module, click the “Add Device” and select the module to be configured as Coordinator.
5. Settings to be updated to configure XBee as Coordinator are-
   a. PAN ID :2626
   b. CE Coordinator Enable: Enable
   c. NI Node Identifier: Coordinator
   d. AP API Enable: API Enabled

6. Once all the settings are loaded, we have to update the firmware by hitting the update button to make sure that the XBee is running on the latest firmware.
7. To perform the Range test [8], open the Tools menu and select the Range Test option. Start the discovery process with XBEE_COORDINATOR and add the selected device. Select the XBEE_ROUTER from the list on the right as shown in Fig 1.
8. Start the Range Test.

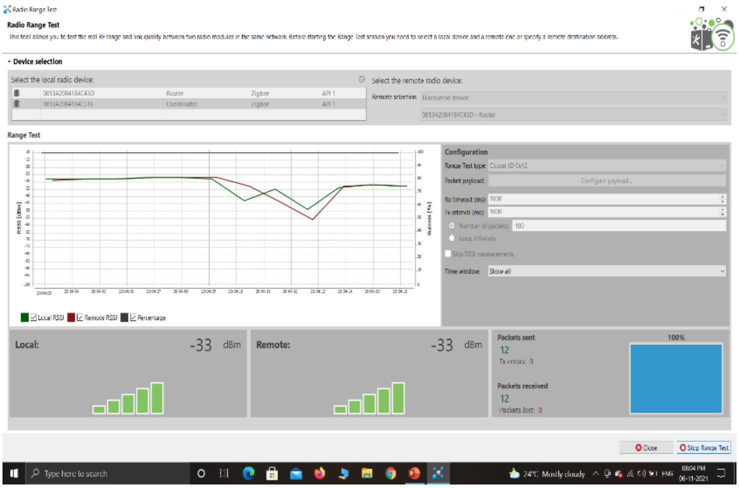

Fig. 1. X-CTU software displaying XBee range test

3 Related Work

In this research, S. Sadowski and P. Spachos analyzed Wi-Fi, Bluetooth low energy, and ZigBee wireless technologies for indoor localisation. When IoT devices are utilised, these technologies are compared in terms of localization accuracy and power consumption. For localization, the received signal strength indicator (RSSI) data from each modality were employed, and trilateration was applied. The findings of the experiments can be used as a guide for choosing a wireless technology for an indoor localization system based on the application requirements [1]. Shuaib and Khaled carried out indoor experiments to investigate the interference effects and throughput of Bluetooth and ZigBee while WLAN was present. The results reveal that when IEEE 802.11g and ZigBee coexist, throughput drops by 6%. In this research, they examined ZigBee performance and interference effects under a variety of settings, including indoor, outdoor, and coexistence with Bluetooth. The trials were carried out in real-world settings, demonstrating ZigBee signal deterioration across a variety of indoor and outdoor circumstances [2]. The experiment conducted by A. Patri and D. S. Nimaje in an underground coal mine in southern India are used to show a unique way for calculating the parameters of an appropriate radio propagation model. The path loss indices, as well as other critical characteristics for precise localization, were established using 2.4 GHz XBee modules and the ZigBee protocol [11]. Two common propagation circumstances, I2O and O2O, were investigated by Prashanth Ragam, D. S. Nimaje in this study with the aim of exploiting their transmission-reception difficulties and, as a result, their influence on the performance of the LoRa system. For both cases, the experimental and theoretical empirical assessment of LoRa data transmission and reception were measured and validated. The findings of an experimental test of both the LoRaWAN and ZigBee protocols show that the LoRa WAN paradigm has a huge amount of potential as a standard and as an enabling technology for open cast mines and remote areas that may benefit a lot from long-distance connectivity [3].

4 Field test

The field test for the performance evaluation of the Zigbee protocol is conducted at Kakatiya Institute of Technology and Science, Warangal under the following conditions with Latitude 18.052771 and Longitude 79.53848.

Fig. 2. Satellite map location of KITSW

The field test is performed with reference to satellite map taken by Google map as shown in above Fig 2 in both outdoor-to-outdoor and indoor-to-outdoor environment, and the packet loss is observed until the connection between the Xbee coordinator and the XBee router is lost.

4.1 Outdoor-to-Outdoor field test

XBee range field test is performed at KITSW by considering both XBee coordinator and router locations as the experiment is shown in the below Fig 3a and Fig 3b. The following are the details of the outdoor-to-outdoor XBee range field test its Location is College Playground, KITSW at Temperature 21 degrees (Celsius) and Humidity 66%.

As shown in Fig 3c it is observed that the RSSI values are dropped when Zigbee coordinator and Zigbee router are moved towards far way. In the outdoor-to-outdoor environment, the packets were received up to a range of 220 meters.

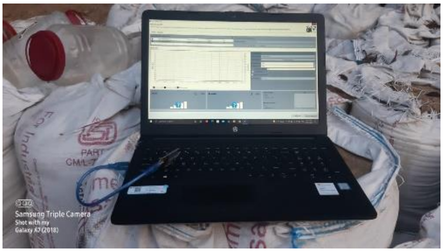

Fig. 3a. XBee coordinator location

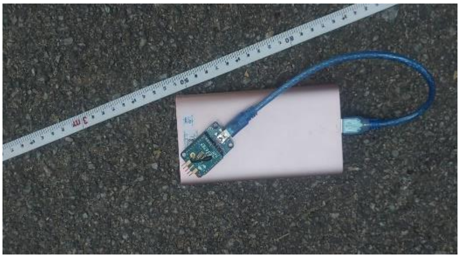

Fig. 3b. XBee router location

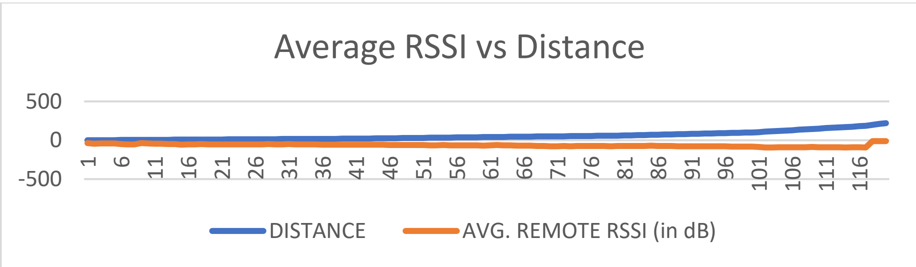

Fig. 3c. Average RSSI in outdoor-to-outdoor environment

Indoor-to-Outdoor field test

The following are the details of the indoor-to-outdoor XBee range field test between XBee coordinator and router locations as shown in Fig 4a and Fig 4b, at Temperature 27 degrees (Celsius) and Humidity is 49%.

Fig. 4a. XBee Coordinator location

Fig.4b. XBee Router location

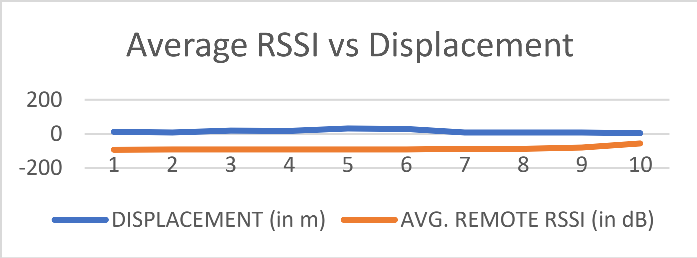

Fig. 4c. Average RSSI in indoor-to-outdoor environment

As shown in Fig 4c in the indoor-to-outdoor environment, the packets were received up to a range of 31.45 meters. The packet loss is observed after this range i.e., the connection between the Zigbee coordinator and Zigbee router is lost.

5 Path Loss Modelling

In this study, the path loss of the XBee S2C module has been determined experimentally at KITSW. Path loss refers to the loss in the signal path due to many effects [4] such as propagation medium, environment, the closeness between the sender and receiver nodes, and the altitude and longitude of the antenna. Path loss [6] is expressed mathematically as:

$$PL_{Measured} = P_t + P_r + G_t + G_r \tag{1}$$

Here $P_{t,}$ P_r denotes transmitter and receiver powers (dBm), Gt and G_r denotes transmitter and receiver gains (dB) with mentioned uniform values for each to 1.8 dB.

5.1 COST-231 Model

The COST-231 Model used for pathloss (PL) [6] prediction that is relevant to urban, suburban, and rural regions. The equation for the COST-231 model is given as:

$$PL = A + B \, log\,1\,0(d) + c \tag{2}$$
$$an = 46.3 + 33.9\, log(f_c) - 13.28\, log\,1\,0(h_b) - a(h_m) \tag{3}$$
$$B = 44.9 - 6.55\, log\,1\,0(h_b) \tag{4}$$
$$C = 0\text{For sub-urban areas} \tag{5}$$

Hata Model

The Hata Model is a radio propagation model [11] used for PL prediction in exterior environments that has microwave frequencies. The equation for the Hata model is given as

$$PL = A + B\,log\,10(d) - D \quad (6)$$
$$A = 69.55 + 26.16\,log\,10(f_c) - 13.82\,log\,10(h_b) - a(h_m) \quad (7)$$
$$B = 44.9 - 6.55\,log\,10(h_b) \quad (8)$$
$$D = 40.94 + 4.78[log\,10(f_c)]^2 - 18.33\,log\,10(f_c) \quad (9)$$
$$a(h_m) = (1.1\,log\,10(f_c) - 0.7)h_m - (1.56\,log\,10(f_c) - 0.8 \quad (10)$$

Log-distance model

The Log-distance PL model is a simple model used for PL prediction inside a building or heavily populated regions over time. The equation for the log-distance model is given as:

$$PL_{Predicted} = 20\,log\,10(f_{MHZ}) + 10n\,log\,10(d) - 28 + X_e \quad (11)$$

6 Results and outcomes

The performance evaluation [10] field test for Zigbee protocol is conducted in outdoor-to-outdoor and indoor-to-outdoor environments, and the range of Zigbee protocol is analyzed by implementing path loss models.

6.1 Outdoor-to-outdoor

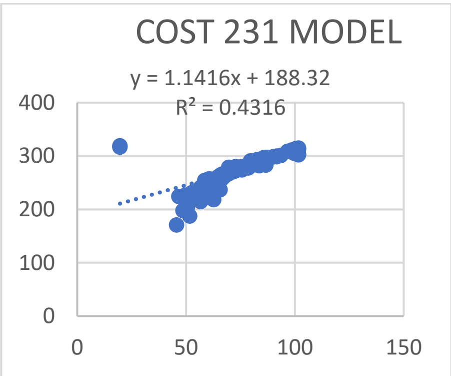

Fig. 5. PL vs COST-231

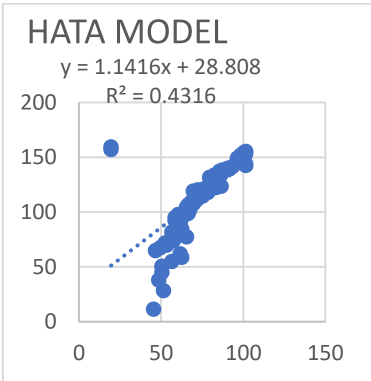

Fig. 6. PL vs Hata

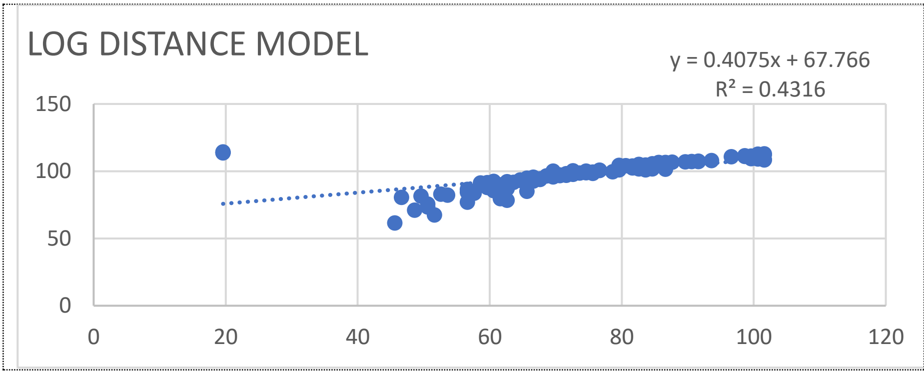

Fig. 7. Measured path loss vs Log-distance model

6.2 Indoor-to-outdoor

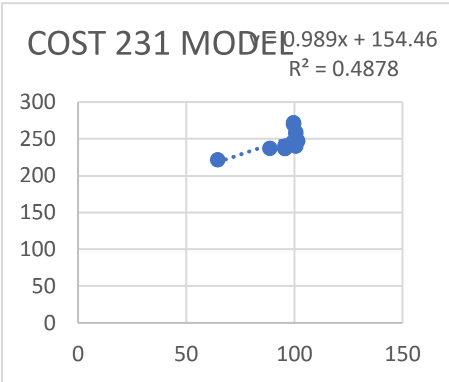

Fig. 8. PL vs COST-231

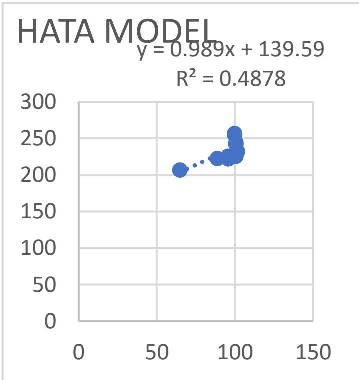

Fig. 9. PL vs Hata model

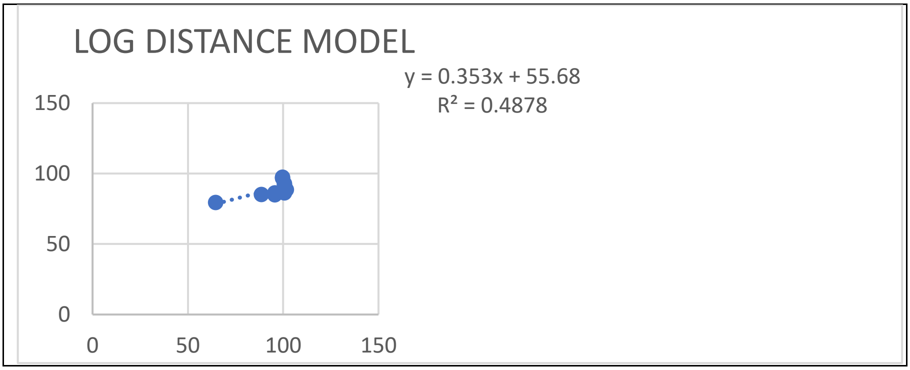

Fig. 10. Measured path loss vs Log-distance model

After implementing PL models for both Outdoor-to-Outdoor as shown in Figures 5,6,7 and Indoor-to-Outdoor environments [2] as shown in Figures 8,9,10 the conclusions got from above graphs from are given in table 1, table 2.

Table 1. Comparison of the developed predictor models (O2O environment)

Model	R^2	RMSE
COST-231	0.4316	199.1986
Hata	0.4316	45.08945
Log-distance	0.4316	27.25996

Table 2. Comparison of the developed predictor models (I2O environment)

Model	R^2	RMSE
COST-231	0.4878	44.2137
Hata	0.4878	39.95197
Log-distance	0.4878	2.789241

The predicted path loss models are compared in both Outdoor-to-Outdoor and Indoor-to-Outdoor environments.

6.3 Discussion on Results

In the presented Outdoor-to-outdoor results, three different radio propagation models have been evaluated based on their RMSE (Root Mean Square Error) values. These models include the COST-231 model, the Hata model, and the Log-distance model.

Interestingly, all three models yield identical RMSE values of 0.4316. However, their practical implications vary significantly. The COST-231 model, despite having the same RMSE as the other two models, produces a significantly higher value of 199.1986, suggesting potentially greater predictive errors or deviations from observed data. On the other hand, the Hata model and Log-distance model produce considerably lower values of 45.08945 and 27.25996, respectively, indicating a closer alignment with the actual observed data.

In the presented Indoor-to-outdoor three radio propagation models were assessed using their respective RMSE (Root Mean Square Error) values: the COST-231 model, the Hata model, and the Log-distance model. Surprisingly, all three models exhibited an identical RMSE value of 0.4878, indicating a consistent level of predictive error across the board. However, the practical implications of these results differed significantly. The COST-231 and Hata models displayed similar RMSE values, with COST-231 slightly higher at 44.2137, compared to 39.95197 for the Hata model. In stark contrast, the Log-distance model stood out with a considerably lower RMSE value of 2.789241, implying a much closer fit to the observed data.

The choice of which model to employ in a real-world scenario should consider the specific application, data characteristics, and the level of accuracy required. While RMSE provides a measure of predictive accuracy, the model's suitability for the task at hand remains a critical factor in making an informed decision.

7 Conclusion

Path loss models excel in comparative analysis due to their capacity to provide precise and environment-specific predictions of electromagnetic signal propagation, accounting for factors such as distance, frequency, interference, and obstructions. These models can be customized, validated, and calibrated to align closely with real-world conditions, accommodating a wide range of wireless technologies. Furthermore, their ability to offer quantitative metrics for signal strength evaluation facilitates informed decisions when selecting the most suitable communication protocol, making path loss models invaluable tools for optimizing IoT deployments and performance assessments

In conclusion, our assessment of the ZigBee RF protocol using path loss models for IoT applications underscores its robustness and suitability for diverse IoT scenarios, offering valuable insights into signal behavior in real-world environments. Path loss models are indispensable for optimizing ZigBee network design, but environmental factors significantly influence performance, necessitating distinct models for indoor and outdoor deployments. While ZigBee excels in small to medium-scale applications, scalability remains a challenge for larger deployments. Future research should focus on refining path loss models, exploring advanced modulation schemes, and addressing interference issues. Despite these challenges, ZigBee remains a compelling choice for IoT, with practical implications for network planners and policymakers aiming to deploy efficient and reliable IoT communication systems.

8 Future Scope

The future scope of research in assessing ZigBee RF protocol's performance using path loss models for IoT applications holds promise in refining path loss models for specific IoT use cases, tackling scalability issues through novel routing and mesh network strategies, exploring advanced modulation and interference mitigation techniques, improving energy efficiency and security measures, standardizing interoperability guidelines, conducting real-world deployment studies, integrating ZigBee with emerging cellular technologies, and promoting environmental sustainability. These avenues of research collectively aim to enhance the reliability, efficiency, and versatility of ZigBee in diverse IoT scenarios and contribute to the ongoing evolution of IoT communication systems.

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