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Performance Evaluation of Onboard Wi-Fi Module Antennas in Terms of Orientation and Position for IoT Applications

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ABSTRACT

With ever increasing demand of IoT based sensor systems, there is a need to assess the performance of wireless sensor networks especially in indoor environment. In these networks, antenna plays an important role. The performance of onboard antenna of the sensor module with respect to its height and orientation are examined in this paper. Several experiments were carried out mostly in indoor environment by changing orientation and height of the antennas. The performance is assessed on the basis of Received Signal Strength (RSS) and its modelling using linear, logarithmic and rational polynomial regression techniques which will characterize the channel in a particular environment. Out of all the combinations in terms of height of the antennas and their orientation, it is found for a given indoor environment, with transmitting antenna at a medium height facing upwards and receiving antenna with an inclination of 70^0 towards transmitter resulted in better performance with R^2_{poly} value of 86.81% and RMSE of 4dB. Therefore, this combination is suggested for wireless sensor networks in indoor environment for achieving the of cost-effective energy-efficient green IoT. The analysis would be useful for improving the efficiency and coverage of wireless sensor networks.

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1. INTRODUCTION

In the recent years it has been increasingly becoming common to have Internet-of-Things (IoT) enabled structures, environment and systems. IoT has become a key enabler for many applications like smart homes, cities, and smart farming. Many of these applications require good observability and controllability. The prominent problems faced by the IoT network are establishing an energy-efficient network and optimization in channel modelling for energy-efficient communication. Several researchers reported their work on techniques in IoT applications which saves power consumption of the modules [1, 2]. Easy implementation and commercial viability are the other primary important objectives of IoT manufacturers. Once the devices meet these objectives, they offer unparalleled flexibility for deployment within buildings without any hardwiring. Such devices minimizes the maintenance hassles and environmental impact [3].

As 5G communications have become order of the day, with the very large bandwidth at disposable, billions of IoT devices are coming up to make life convenient and comfortable. In wireless network, the communication channel performance is greatly affected by the surrounding environment. This is more true with indoor wireless networks. Even the small reflecting object can drastically affects the network's performance [4-7]. Among the various approaches to monitor and examine the surrounding environment, the most appropriate technique in recent years is wireless sensing [8]. There are wide coverage area networks and local area networks [9]. The former are expensive and do not offer easy deployment and movement [10]. The most popular short-range wireless networks are LoRa, ZigBee, Z-wave, Wi-Fi, and Bluetooth. Compared to other devices, Zig Bee,

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and Wi-Fi are being widely used in rapidly evolving IoT applications due to its low cost and easy deployment and use the same band of frequencies. Ibraheem and Hadi [11] investigated XBee devices data packets transmission paths and power consumption and proved that these modules offer high reliability having mesh topology and also multiple nodes can sleep whenever they are free.

Prediction of pathloss in a given environment using the IoT modules is more complex than with the conventional antennas operating with the same frequency band [12]. Therefore, more appropriate models are to be developed. The performance of line-of-sight and non-line of sight link are the functions of elevation angle between the transceiver module's antenna orientation and the communication environment's reflecting/ refracting/ diffracting / absorbing properties. The relative heights of the transmitting and receiving antennas plays a significant role in the modelling [13, 14]. This necessitates experimental data for various conditions for better channel modelling. Karimi Alavijeh et al. [15] proposed a statistical channel model based on the second moment of Received Signal Strength Indicator (RSSI) in a grass field outdoor scenario by placing a set of transciever antennas for different distances and orientations (0, 90, 180, 270 degrees). In their work, XBee-PRO 802.15.4 module at a 2.4 GHz omnidirectional antenna with 1.2dBi antenna is used. A statistical logarthemic regression channel model with RSSI variance and distance is developed and arrived an improvement of 22% localization accuracy when compared with constant covariance extended kalaman filter method with the same three nodes.

The development of the low-cost Wi-Fi missile telemetry system created remarkable financial savings during the training phase. Received Signal Strength, packet error rate, communication link quality were investigated in their work [16]. Indeed these low cost on board Wi-Fi module antennas are expected to be omnidirectional, but in practice they are not. We examined the effect of antenna orientation on RSS and found antenna offers the non-uniform radiation pattern. Brief details of the modules (Node MCU ESP8266 and Node MCU ESP8266 onboard WiFi Antenna) are given in Appendix A.

In the present work, we concentrated on the position and orientation of Wi-Fi antenna placed on the modules in the context of green energy-efficient IoT applications. As environment conditions such as building structures and wave propagation path cannot be changed, we considered only height, distance and oreintation of the antenna. To identify optimum position and orientation, we collected the Received Signal Strength (RSS) data from modules for nine different scenarios by changing the orientation and vertical position and modelled the indoor corridor propagation path. The corridor channel performance is evaluated using the linear regression, lognormal and polynomial regression models, and suggested the suitable one based on the received RSS values.

These results and analysis could be useful for optimum placement of sensors in indoor environment to avoid infrastructure issues, environmental and maintenance hassels. Further, the analysis is very much useful for localizing the source position even in the 11 to 22m region where severe multipath exists. In addition, the results can also be useful for assessing the performance of on board Wi-Fi anenna behaviour for Unmanned Aerial Vehicles (UAV).

2. IoT PROPAGATION PATHLOSS MODELS

There are several statistical pathloss models for predicting the behaviour of the wave propagation. Out of them three prominent models are considered in our work, namely linear, logarithmic regression and fourth order rational polynomial model. The most common statistical model is a linear regression model. It allows systematic interpretation on measured data to predict the wave propagation path in channel modelling. Still today many of the applications including predicting rice crop bio physical parameters in agriculture [17], research related to mammals [18] use this model. However, the model accurately predicts RSS values upto certain range in any of the polarization with respect to height after that the predicted values may not follow the real scenario measurements. Comparative analysis of Linear Regression, Lognormal along with ITUR and the Friis transmission model was made in our previous work [19]. The Present work is an extension of that work. In Friss equation, Pathloss exponent for free space assumes the value of '2'. However, in practical scenarios it can vary up to 5. The extension to this model where the plane of reflection with the environment is considered as the lognormal pathloss model [20]. The presented logarithmic regression model tends to follow the lognormal pathloss model and reasonably represents indoor experiments data.

As the Logarithmic Regression is parabolic shape, it emphasizes more closely on the RSS measurements for short distances. It is preferred because it fits well with measured data for a large variance [21]. The sensitivity of this model is examined by various authors with Root Mean Square Error (RMSE) and found that the results are stable [22, 23].

Whereas, rational polynomial coefficients are popular in photogrammetry and remote sensing applications. The rational polynomial model includes excess path loss due to diffractions from irregular heights between the transmitter and receiver [24].

These models are used to study the influence of change in the relative heights of modules and orientation of onboard antenna on RSS. These linear (y_{linear}) and logarithmic (y_{log}) and polynomial (y_{poly}) regression models have the following standard forms [25]:

$$y_{linear} = \beta_0 + \beta_1 x \quad x = 1,2,3 \ldots..21 \tag{1}$$

$$y_{log} = \beta_0 + \beta_1 * \log(x) \quad x = 1,2,..21 \tag{2}$$

$$y_{poly} = \frac{\beta_0+\beta_1 x+\beta_2 x^2+\beta_3 x^3+\beta_4 x^4}{x+\gamma} = \frac{\sum_i \beta_i x^i}{x+\gamma} \quad i = 0,1,2,3,4 \tag{3}$$

where 'β_0' is an intercept / constant term / a RSS at a reference distance 'x_0', 'β_1' is slope/ regression coefficient, 'β_i' , 'γ' are the coefficients of polynomial and 'y' represents the modelled received signal strength at a distance of 'x'. Initially, we examined the measured data using the linear and logarithmic regression models. Suggested better height and orientation of antenna from findings. Later, for better channel modelling, we proposed the fourth order polynomial model that modifies the linear and logarithmic regression models. We used classic regression models in our work, because these modles can be easily combined with the latest machine learning algorithms (Linear, quadratic Support Vector Machine Learning, Gaussian Process, and Neural Regression Models). Classic models perform the surpervised machine learning by supplying a known set of observations of input data 'x', and known responses 'y'. Classic models are utilized to expand the traning data set and extended to employ error componesation in machine learning algorithms [26]. Regression analysis is a quantitative method applied to establish the relation between the known variables (distance (x), height (h)) to unknown parameter (β). Table 1 lists the summary of reviewed works and distinctive characterstics along with the present work.

3. EXPERIMENTAL SETUP

Initially, an experiment is conducted in both outdoor and indoor for evaluating the radiation behaviour of Wi-Fi transceiver modules (ESP8266). One module is considered for transmitting and the other one for receiving purpose. Operating frequency range is 2412M -2484MHz and 2412MHz frequency is considered in this experiment. A separate setup is made with two stands with rotation facility to create the energy efficient communication link without the need of additional hardware (Figure 1).

The gain of antenna is very important factor in pathloss modelling. The antenna gain of these low cost sensors is not necessarily be the same in all directions. So, we examined the antenna performance by considering experimental measurements. In outdoor environment for fixed distances (Ex. 1m, 2m and 5m etc.,), the orientations of transmitting and receiving antennas are varied in different directions and observed the effect on RSS values. Similar behaviour is noticed in indoor environment also. These observations show that on board antenna on IOT modules are not isotropic in their performance. For evaluating the channel behaviour we focused on the Received Signal strength values. Antennas with identical performance are chosen for our experiments. So antenna gain will not have any significant effect on the modelling.

For outdoor measurements propagation path link is 1m and the modules are placed at a height of 0.76m from the ground. Each module is powered by two AA batteries (3.0V). A program is developed to scan the desired Wi-Fi networks available in the environment and to estimate the received signal strength of each module. Signal strength values are recorded with a sampling rate of 1 s. For indoor measurements, ground floor corridor (3.57x21m) of the Research and Entrepreneurship (R & E) Hub of CBIT is considered. For changing height of the receiver portable 2.7m long PVC pipe is used. The sketch of experimental setup is shown in Figure 2. The PVC stand is designed in such a way that that the module position can be adjustable at any point along the pipe, by sliding movement (Figure 3). This type of experimental setup is convenient for the investigation of the effect of height on RSS values.

In Figure 2, Rx1, 2, and 3 represent the receiver positions. 'Tx' is transmitter located at the end of the corridor (21 m). Care is taken while designing the receiver module setup so that reflection are minimum.

4. RESULTS AND DISCUSSION

In this section, initially the modules' RSS performance is analysed interms of relative orientation of antennas in

Figure 1. Outdoor experimental setup consisting of PVC stands, IoT modules and system

TABLE 1. Summary of Reviewed works and Distinctive Characteristics along with present work

	Ibraheem and Hadi [11]	Investigated on the usage of low-cost off-the-shelf hardware modules (XBee) in vehicle tracking systems	XBee devices data packet transmission paths and power consumption are investigated	Proved that these modules offer high reliability having mesh topology and also multiple nodes can sleep whenever they are free
1.	Manuel Eichelberger [14]	Proposed a indoor localization system with Aircraft signals	Presented the advantages and challenges faced by aircraft signals in using for localization. Detailed description given for ground station requirement, server requirement with hardware modules.	Prototype implementation achieved localization accuracy of 25 meters.
2.	Catherwood et al., [16]	Investigated on the potential use of off-the-shelf hardware modules (Arduino Due Wi-Fi transmitter) as a replacement to the expensive missile test telemetry flight guidance system	Presented the design, development, and testing details of Wi-Fi- missile telemetry system. Received signal strength and packet error rate, indicators of communication link quality are investigated.	The proposed design will significantly save the money and identified limitations with selected low-cost equipment, including firmware, UDP data throughput, optimal alignment and elevation of antennas.
3.	Sumi and Ranga [27]	Proposed a solution for giving priority to emergency vehicles in smarty with Internet of Things (IoT) and Vehicular Ad Hoc Network (VANET)	In the proposed solution, emergency vehicles are given priority for smooth passage through traffics. Algorithms are presented to overcome the traffic signals.	With the concept of IoT and VANET the proposed system improved the quality in congestion avoidance, transmission delay, travel time and response time for overcoming the traffic signals.
4.	Shaohua Yang et al., [28]	Developed a room occupancy detection system based on sensor array.	The sensor arry(ESP-12S Wi-Fi module, MH-Z14A CO_2 sensor module, DHT22 temperature and humidity sensor) information is evaluated using the subset regression models.	The proposed system achieved detection accuracy of 97.32% with running time less than 30 s.
5.	T Sridher et al., (proposed work)	Evaluated the performance of Wi-Fi on board antenna in terms of Orientation, Position and Height.	The performance of on board antenna of the Wi-Fi sensor module with respect to its height and orientation are examined in this paper. Comparative analysis of Polynomial regression, Logarithmic Regression and Linear Regression models are made.	From the experimental results the optimum orientation and height are identified. Fourth order rational polynomial expression satisfies well for the whole corridor.

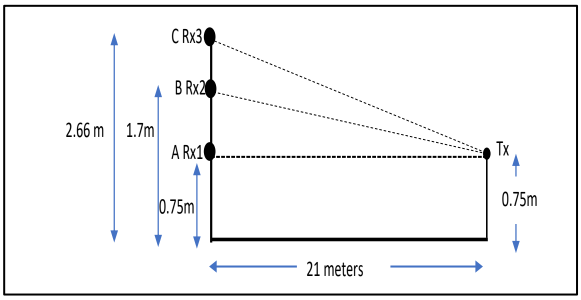

Figure 2. Sketch of experimental scenario at R&E Hub, CBIT, Hyderabad


Figure 3a. At 'A'


Figure 3b. At 'B'


Figure 3c. At 'C'

both outdoor and indoor environments. Later for a given indoor environment experiments are carried out with various antenna orientations and three receiver heights.

4. 1. Effects of Relative Orientation of Onboard Antennas As discussed in the previous section, for evaluating the performance of the module with respect to orientation of onboard 'F-Shaped' antenna the following procedure is implemented. Four scenarios arise with respect to the orientation of the transmitter (A) and receiver (B) antennas. In the first scenario both antennas face each other and is represented as (A+B+). In the second scenario Tx antenna faces the back side of Rx antenna(A+B-). In the third scenario, the Rx antenna sees the back side of the Tx antenna (A-B+). In the fourth and last scenario, the Rx antenna back side sees the back side of the Tx antenna (A-B-). '+' sign indicates the antenna is in the forward direction, and '-' indicates the reverse direction. The experimental sketch of transmitting and receiving antennas for a constant separation are shown in Figures 4 and 5. For a given transmitted power (-14dBm), the received power (RSS) at a distance of 1m is recorded and is shown in Figure 6 for outdoor environment. The sampling period is 1 sec. When the two antennas are facing each other (A+B+) maximum power is obtained (-29.5dBm). Least power is observed when the back of one antenna sees the back of the other antenna (A-B-) (-46.7dBm). When the antennas see the same direction (A+B- and A-B+) power levels are more or less very similar (-37.5 and -36dBm).

When antennas are facing in opposite direction, it is clear that there is a significant effect on the received signal strength (Figure 6). Changing of orientation of either of the antennas effects the RSS considerably. These observations show that all IoT modules are not isotropic in their performance. Similar behaviour is noticed for other distances (2m and 5m) and indoor environment also (Figures 7 and 8).

However, as the distance between transmitter and receiver increases, the effect of antenna orientations are

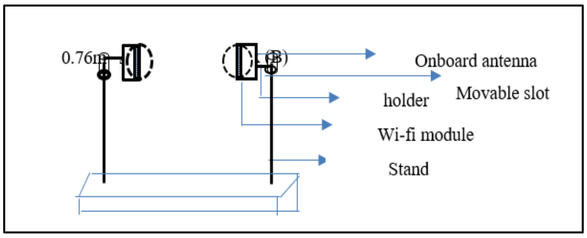

Figure 4. Sketch of transmitter and receiver antenna modules for experimentation

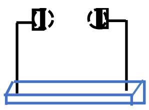

Figure 5a. (A+B+)

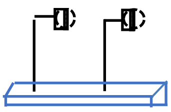

Figure 5b. (A+B-)

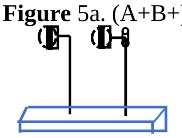

Figure 5c. (A-B+)

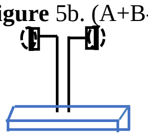

Figure 5d. (A-B-)

Figure 5. Different orientations of onboard transmitting and receiving

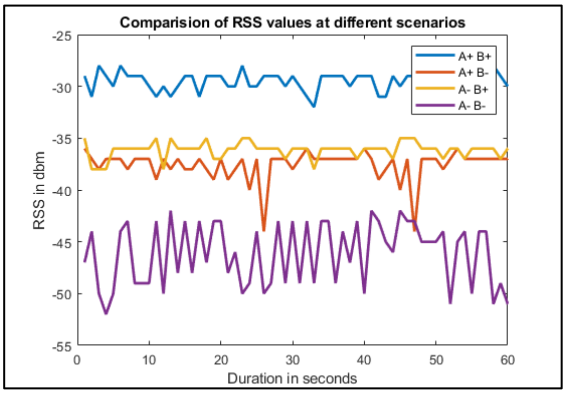

Figure 6. Comparison of RSS values with different orientations in outdoor environment

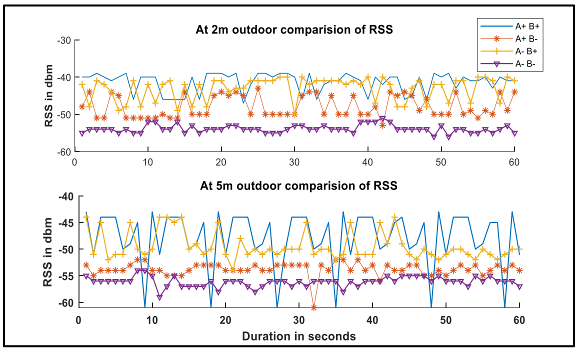

Figure 7. Outdoor RSS values for a path distance of a) 2m and b) 5m

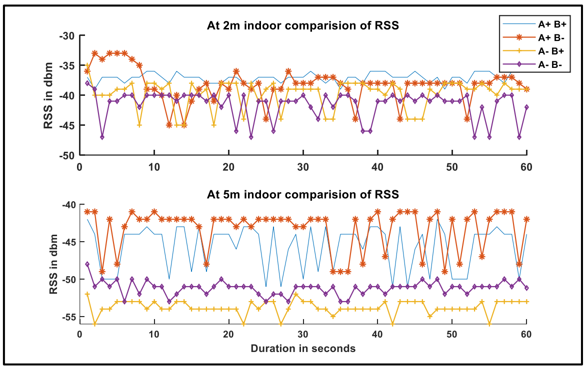

Figure 8. Indoor RSS values for a path distance of a) 2m and b) 5m

slightly less predominant in indoor environment. The measured average RSS values for all four scenarios in both indoor and outdoor are presented in Table 2.

At each location we have collected 60 samples, with sampling rate of 1 s. Increasing of sampling frequency will not have any significant effect on accuracy as the indoor environment is almost static. In dynamic conditions such as vehicle moving in ever changing environment, high sampling frequency may lead to improved accuracy. Table 2 presents the average of RSS samples (60) collected for each orientation for a given propagation path distance in indoor and outdoor environment. Increasing of sampling frequency will not

TABLE 2. Average RSS values of all scenarios in Indoor and Outdoor

Orientation of Modules	Indoor Received Power (dBm)			Outdoor Received Power (dBm)		
	1m	2m	5m	1m	2m	5m
A+ B+	-34.5	-37.1	-45.6	-29.5	-53.9	-47.7
A+ B-	-33.9	-38.3	-43.2	-37.5	-47.8	-53.4
A- B+	-32.8	-39.9	-53.7	-36.2	-43.1	-49.5
A- B-	-34.5	-41.5	-51.2	-46.7	-54.0	-56.1

have any significant effect on accuracy as the indoor environment is almost static. In dynamic conditions such as vehicle moving in ever changing environment, high samples may lead to improved accuracy.

Averaging the RSS values gives the smoothing the effect of the short term and long term fading. For any particular orientation of antenna, RSS is decreasing progressively with respect to distance in indoor and outdoor environment except for the scenario of (A+B+) in outdoor environment from 2m to 5m. For (A-B-) scenario the orientation effect is comparatively significant for the same distances. The effect of orientation on RSS values is less predominate in indoor, due to metallic structures of corridor such as doors, windows, wall obstructions and surface reflections [29].

4. 2. Effects of Height and Orientation of Receiving Antenna for a Given Height and Orientation of Transmitting Antenna in Indoor Environment

The modules' performance is evaluated using various heights and orientations of receiver inside a corridor (Figure 9). The sketch of position and orientation of Tx and Rx modules is shown in Figure 10. The transmitter module is facing upwards and is at a height of 0.76m and is moving in steps of 1m along centre line of the corridor. The receiver module along with the onboad antenna is placed at three different heights represented by A (0.75m), B (1.7m) and C(2.66m). For each height, measurements are taken for three receiver antenna orientations namely i) module facing towards source (Figures 10a, 10b and 10c) ii) module facing upwards (Figures 10d, 10e and 10f) and iii) module facing downwards (Figures 10g, 10h and 10i). This will result in 9 sets of recordings and details of each of these are as follows:

At each position (A, B or C), for each orientation of the receiving antenna, RSS values are measured for every 1m. Based on these values, linear and logarithmic regression models are developed and the same are shown in Figure 11(a-i) along with experimental data. The performance of regression models is evaluated in terms of statistical parameter 'coefficient of determination (R^2)'. The x-axis represents the source position in the corridor, and y-axis represents the RSS values. R^2 values are presented in each case.

It is clear from Figure 11, orientation and height of the module have significant effect on RSS for a given indoor environment. The data due to receiver positioned at location 'B' with the module facing down wards (Figure 10f) is well fitted to the logarithmic regression model better than any other described scenarios.

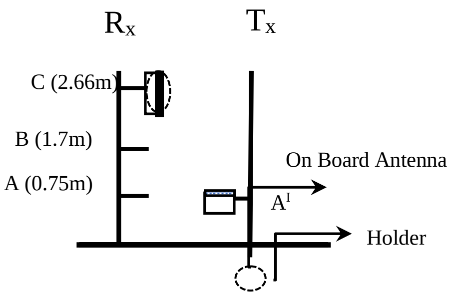

Figure 9. The Positions and Orientations of Tx and Rx modules

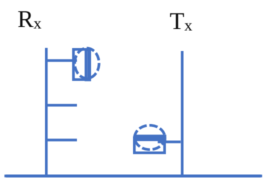

Figure 10a. Rx at 'C' facing towards source

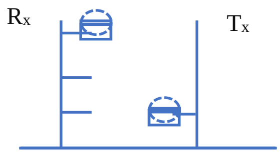

Figure 10b. Rx at 'C' facing upwards

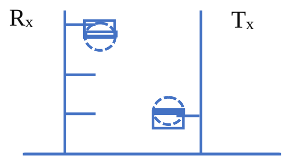

Figure 10c. Rx at 'C' facing downwards

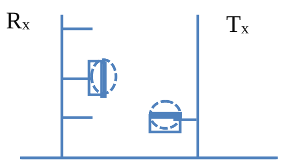

Figure 10d. Rx at 'B' facing towards source

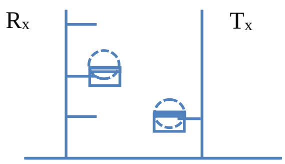

Figure 10e. Rx at 'B' facing upwards

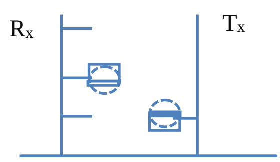

Figure 10f Rx at 'B' facing downwards

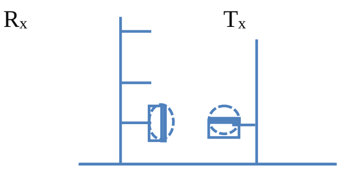

Figure 10g. Rx at 'C' faciing source

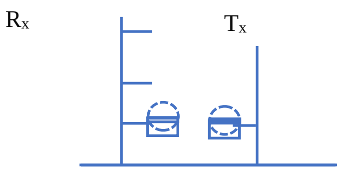

Figure 10h. Rx at 'C' facing upwards

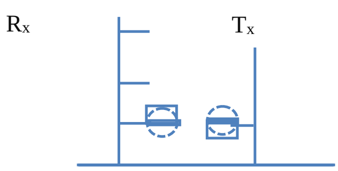

Figure 10i Rx at 'C' facing downwards

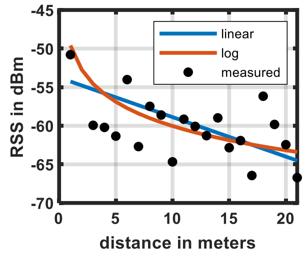

Figure 11a. Tx and Rx are as in Fig. 10a.
$model\ y_{linear} = -53.75 - 0.512x$
$model\ y_{log} = -49.598 - 4.53\ln(x)$
$R^2_{linear} = 32.8\%$
$R^2_{logarthemic} = 44.61\%$

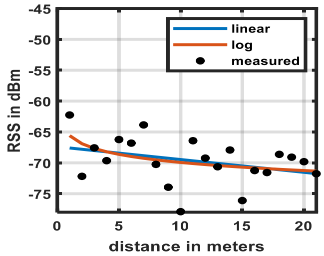

Figure 11b. Tx and Rx are as in Fig. 10b
$model\ y_{linear} = -67.38 - 0.207x$
$model\ y_{logarthemic} = -65.59 - 1.88\ln(x)$
$R^2_{linear} = 12.67\%$
$R^2_{logarthemic} = 17.35\%$

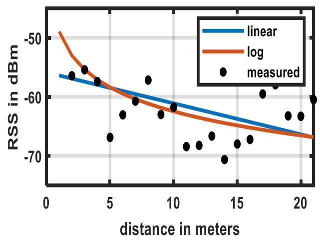

Figure 11c Tx and Rx are as in Fig.10c.
$model\ y_{linear} = -61.28 - 0.36x$
$model\ y_{logarthemic} = -56.02 - 4.3\ln(x)$
$R^2_{linear} = 17.62\%$
$R^2_{logarthemic} = 41.85\%$

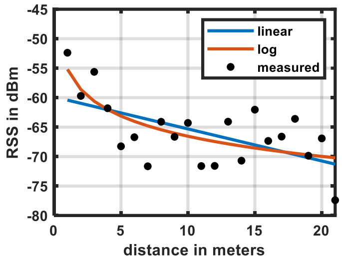

Figure 11d. Tx and Rx are as in Fig. 10d
$model\ y_{linear} = -55.864 + 2.815x$
$model\ y_{log} = -48.9548 - 5.8710\ln(x)$
$R^2_{linear} = 22.41\%$
$R^2_{logarthemic} = 48.61\%$

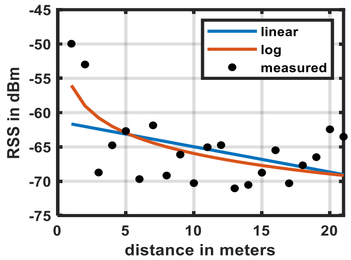

Figure 11e. Tx and Rx are as in Fig. 10e
$model: y_{linear} = -59.877 - 0.5432x$
$model\ y_{logerthemic} = -55.1963 - 4.9316\ln(x)$
$R^2_{linear} = 34.9\%$
$R^2_{logarthemic} = 49.87\%$

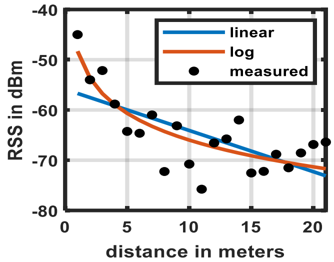

Figure 11f Tx and Rx are as in Fig. 10f
$model\ y_{linear} = -54.92 - 0.885x$
$model\ y_{logarthmic} = -46.31 - 8.49\ln(x)$
$R^2_{linear} = 44.18\%$
$R^2_{logarthemic} = 70.62\%$

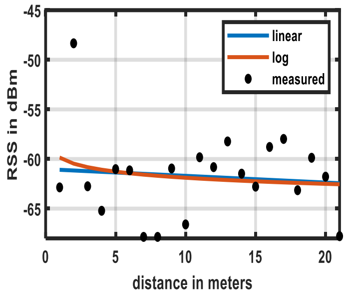

Figure 11g Tx and Rx are as in Fig.10g
$model\ y_{linear} = -61.023 - 0.0675x$
$model\ y_{log} = -59.85 - 0.8842\ln(x)$
$R^2_{linear} = 0.9\%$
$R^2_{logarthemic} = 2.78\%$

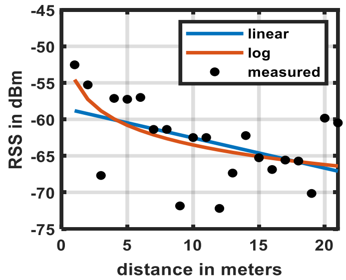

Figure 11h Tx and Rx are as in Fig.10h
$model\ y_{linear} = -58.4109 - 0.4134x$
$model\ y_{logarthemic} = -54.5641 - 3.8847\ln(x)$
$R^2_{linear} = 22.51\%$
$R^2_{logarthemic} = 34.51\%$

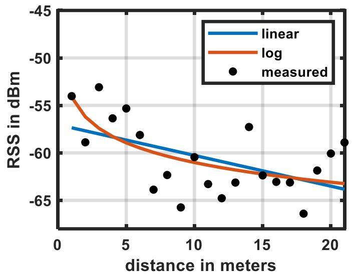

Figure 11i Tx and Rx are as in Figure 10i
$model\ y_{linear} = -61.28 - 0.36x$
$model\ y_{logarthemic} = -56.02 - 4.3\ln(x)$
$R^2_{linear} = 27.7\%$
$R^2_{logarthemic} = 41.14\%$

In the next set of experiments, we investigated the effect of inclination of the module and compared it with the other orientations. The position and orientation of the receiver antenna in 70^0 inclination at a height of 'B' is shown in Figure 12.

The measured RSS values along the corridor, for four receiver antenna orientations namely receiver antenna facing downwards, with the inclination of 70^0, facing towards the source, and facing upwards at a height of 'B' are presented in Figure 13.

The behaviour of RSS throughout the corridor is relatively better in antenna facing towards the source scenario (Figure 13). But, at the same time, the linear and logarithmic regression models are not satisfying the

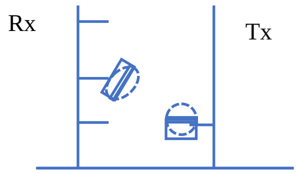

Figure 12. The Position of Receiver Antenna with 70^0 inclination

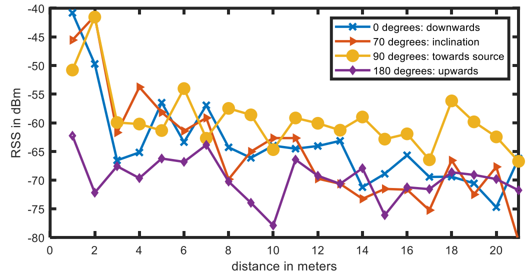

Figure 13. Comparison of RSS due to various orientations of Rx module

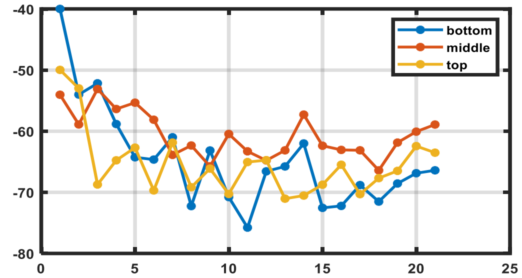

Figure 16. Comparison of RSS with respect to height

measured data (R^2: 22.41% and 48.61%). Whereas, with 70^0 orientation of receiver antenna satisfies logarithmic behaviour in an indoor environment with 79.56%.

It implies that the logarithmic model is well fitted with measured data at a height of 'B' with an inclination of 70^0 and provides the better indoor network coverage. The nonlinearities are well modelled at this height, with this inclination.

Similarly, we evaluated the performance of RSS with both transmitter and receiver module antennas facing each other as shown in Figure 14. It is noticed that, linear and logarithmic regression models are fitted only with 57% and 73.35% with the measured data (Figure 15).

There is no significant improvement in channel modelling as compared with the scenario of Figure 12.

Figure 16 is a comparison plot of measured RSS data with respect to the height for the scenarios of Figures 10a, 10d and 10g. 'x'-axis represents distance, and 'y'-axis represents RSS. It is obvious that at a height of 'B' measured RSS samples are stronger compared with the measured data due to other heights.

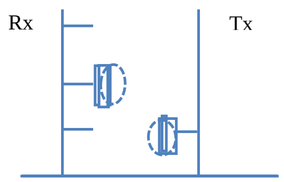

Figure 14. Both transmitting and receiving antennas are facing each other vertically

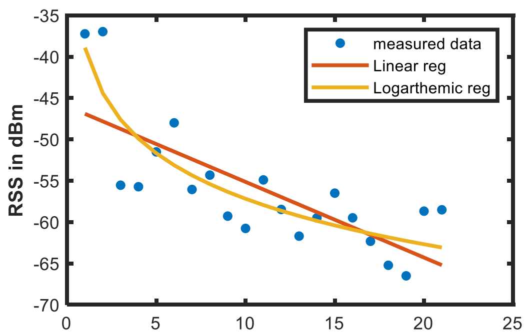

Figure 15. RSS measured data and Regression models when antennas facing each other

Table 3 compares linear and logarithmic regression models' R^2 for receiver at position 'B'. This helps in relating the performance of the models to the measured data due to different orientations of receiver antenna. Overall, when the transmitter and receiver are as in Figure 12, the estimated R^2 is better than other case. It indicates at the particular height of 'B' and when antennas inclined towards source provides good network coverage.

4. 3. Proposed Polynomial Pathloss Model

Keeping in view of the above mentioned results, especially with respect to height and orientation of the antenna, for a given set of conditions (receiver height of 1.7m, orientation of 70^0 and transmitter height of 0.75m) received signal strength of the radio signal at a frequency of 2.4 GHz , is modelled using the proposed fourth order polynomial model. The result of this model is presented in Figure 17. By increasing the order of the polynomial the skewness of the model will improve and it may follow the measured values. At the same time, the higher-order polynomial models increase the mathematical complexity in the selection of regression coefficients for prediction. In our case, it lead to the wrong position estimation in the 1-5 m region of the corridor. In the modelled data we have noticed spikes which are above the outliers for 1-5m region of the corridor and found its performance is degrading in terms of position accuracy. In our investigation we have tried even 5^{th} order polynomial which resulted in more spikes. So we

TABLE 3. Comparison of R^2 values for receiver antenna at height 'B' position with different orientations

Orientation of Modules	$R^2_{\_linear}$	$R^2_{\_logarthemic}$
0 degrees (Figure10f)	44.18%	70.62%
70 degrees (Figure12)	70.46%	79.56%
90 degrees (Figure10d)	22.41%	48.61%
180 degrees (Figure10e)	34.85%	49.87%

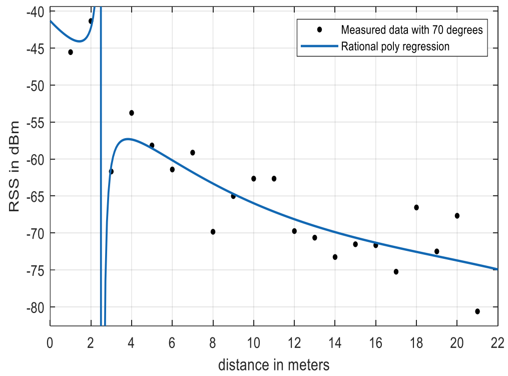

Figure 17. Measured and fourth order polynomial model

TABLE 4. Presents the values of coefficients of Linear, Logarithmic, and proposed fourth-order Rational Polynomial Regression model

Model	Expressions	Coefficients
Linear Regression (LR)	$RSS_{LR\ est} = \beta_0 + \beta_1(x)$ $where\ x = distance$	β_0 = -50.58 β_1 = -1.293
Logarithmic Regression (LN)	$RSS_{LN\ est} = \beta_0 + \beta_1(\log(x) + \log(\gamma))$ $where\ x = distance$ $\gamma = Rx.height$	β_0= -42.27 β_1 = -10.42 γ=1.7
Fourth Order Rational Polynomial Regression (Poly)	$RSS_{Poly\ est} = \left(\frac{\beta_0+\beta_1x+\beta_2x^2+\beta_3x^3+\beta_4x^4}{x+\gamma}\right)$ $where\ x = distance$ $\gamma = Rx.height$	β_0 = 105.7 β_1 = -33.87 β_2 = -3.897 β_3 = 0.1577 β_4 = -0.003 γ = 1.7

considered 4th order polynomial as a better option which is valid throughout the corridor. The list of model equations and values of polynomial coefficients are presented in Table 4.

It is observed that the results due to the polynomial model matches well with the measurement data with a R^2 86.81% and RMSE of 4dB over the 5.3dB of linear and 4.4dB of logarithmic regression (Table 5).

For the given conditions, our proposed fourth order polynomial model agree well with measured data by Figure 17, Table 5. All the experimental observations are function of the environment which invariably includes doors and walls. In depth analysis of main factors that affect the variability of the received signal power is likely to improve the model accuracy. In our proposed statistical model, accuracy in 1-5 meters region where spikes exists can be further improved by smoothing techniques [5, 30-32]. Further collecting the large amount of data and by adopting the latest technologies such as machine learning algorithms the model accuracy can be improved in the whole corridor region [33].

TABLE 5. Comparison of various performance parameters

Performance parameter	Linear Regression Model	Logarithmic Regression	4th order Polynomial Regression
R^2	70.46%	79.56%	86.81%
RMSE	5.3dB	4.4dB	4dB

5. CONCLUSIONS

The performance of antennas plays an important role in efficient operation of wireless sensor networks. Several experiments are conducted in this context using Wi-Fi modules with different orientations and heights mostly in indoor environment. These two aspects influence considerably the RSS values. It is found that when the antennas face each other better RSS performance can be achieved. This is especially true for outdoor conditions and also if the propagation distance is less than 5m. With increasing distance, the effect of orientation is becoming less predominant. For indoor measurements, three heights are chosen. Results indicated that when the receiver antenna is placed at 1.7m and with 70^0 inclination facing towards source performance is better. Once the optimum orientation and height are identified (Figure 12), RSS modelling is carried out. For the given set of conditions (receiver height of 1.7m, orientation of 70^0 and transmitter height of 0.75m), out of the three regression techniques, the performance of proposed rational fourth order polynomial regression is better. Over all experimental results proved that appropriate onboard antenna orientation and its height significantly improve channel behaviour in a given environment. It can be concluded that, rational polynomial regression is a better choice for predicting the indoor path loss.

6. ACKNOWLEDGMENT

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8. APPENDIX A

Brief details of node MCU Wi-fi Module and Wi-fi Antenna

A. NodeMCU ESP 8266

Node Micro Controller Unit (MCU) is an open-source software and works on 802.11b/g/n protocols. A product of Espressif in which analog wireless modulation technique is used to create a short-range line of sight device to device communication. It offers Pulse Width Modulation (PWM). RSS amplitude information is a function of the duty cycle, and phase information is a function of the pulse position [32]. Pulse width modulation maintains the uniform amplitude with a good Signal to Noise Ratio. The receiver sensitivity varies from -91dBm to -72dBm conforming the protocols of IEEE 802.11 b to 802.11 n, which is far better than the sensitivity of digital Long Range (LoRa) modules (-148dbm). The small compact size Printed Circuit Board (PCB) module integrates Wi-Fi antenna, RF balun, Power amplifier, Low noise receiver amplifier, filters, and power management modules. Configured NodeMCU modules maintains the channel space with at least 20 MHz between two modules to avoid the air interface.

B. NodeMCU ESP 8266 onboard WiFi Antenna

The inverted 'F' shape PCB trace onboard antenna plays an important role in channel characterization. These antennas are generally omnidirectional to offer wide coverage area advantage and tolerance to its rotation. Even though it is an omnidirectional antenna, in practice, it provides non-uniform radiation pattern. The radiated energy in the form of toroidal geometry is perpendicular to the antenna's longitudinal direction. The gain of the antenna is typically 2dBi.

Persian Abstract

چکیده

با افزایش تقاضا برای سیستم های حسگر مبتنی بر اینترنت اشیا، نیاز به ارزیابی عملکرد شبکه های حسگر بی سیم به ویژه در محیط داخلی وجود دارد. در این شبکه ها آنتن نقش مهمی دارد. عملکرد آنتن پردازنده ماژول حسگر با توجه به ارتفاع و جهت آن در این مقاله مورد بررسی قرار گرفته است. چندین آزمایش بیشتر در محیط داخلی با تغییر جهت و ارتفاع آنتن ها انجام شد. عملکرد بر اساس قدرت سیگنال دریافتی (RSS) و مدل‌سازی آن با استفاده از تکنیک‌های رگرسیون چند جمله‌ای خطی، لگاریتمی و منطقی ارزیابی می‌شود که کانال را در یک محیط خاص مشخص می‌کند. از بین تمام ترکیبات از نظر ارتفاع آنتن ها و جهت گیری آنها، برای یک محیط داخلی مشخص یافت می شود که آنتن فرستنده در ارتفاع متوسط رو به بالا و آنتن گیرنده با شیب 700 به سمت فرستنده عملکرد بهتری با R2poly دارد. مقدار ٪۸۶.۸۱ و RMSE 4dB بنابراین، این ترکیب برای شبکه‌های حسگر بی‌سیم در محیط داخلی برای دستیابی به اینترنت اشیا سبز مقرون‌به‌صرفه پیشنهاد می‌شود. تجزیه و تحلیل برای بهبود کارایی و پوشش شبکه های حسگر بی سیم مفید خواهد بود.