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Results of Indoor Localization using the Optimum Pathloss Model at 2.4 GHz

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Abstract

Accurate pathloss prediction is essential for Received Signal Strength (RSS) based indoor localization applications. In this paper, experiments are performed using commercially available off-the-shelf hardware modules in indoor environment to identify the suitable pathloss model. Three prominent models are applied to the experimental propagation data and the results are compared. It is observed from the coefficient of determination (R^2), linear regression followed by lognormal model are doing better compared to ITUR model. For the selected indoor environment, the performance of lognormal is better as compared to the other models.

1 Introduction

Locating user position has become one of the basic requirements in day to day life. Indoor localization is gaining relevance due to the widespread advances of devices and technologies [1]. A current trend in addressing indoor localization is to use standard low-cost and already deployed technologies. A large number of Off-the-shelf Wi-Fi or Bluetooth modules are well known for low-energy consumption, data integration and low cost. These modules permit the microcontroller to access the wi-fi network for communicating from one device to other devices (ESP 8266). Because of these potential capabilities in interfacing with other networks or modules these are attracting more attention of design engineers in various advanced technologies like Internet-of-Things (IoT) and Device-to-device communication. In distance-based localization algorithms, Received Signal Strength (RSS) is used to estimate the distance between the transmitter and receiver. The obtained distance can be used to estimate the transmitter location using techniques like Monte Carlo localization [2], maximum likelihood estimation [3], multi-lateration [4] etc., Most of these modules operate in license free bands. In addition to the design of wireless communication network, a system designer has to do thorough analysis on measurement data. This analysis is useful for modelling the channel parameters [5]. Other important aspect in observation data is the pathloss. The pathloss imposes a limit on acceptable coverage area. These pathloss measurements are extensively useful in interference studies. Various methods are already existing in literature for predicting the pathloss [6-8]. The errors in the pathloss modelling impact the localization accuracy. In this paper, we modelled the pathloss using three prominent models and estimated position of the source.

2 Theoretical Background

Three prominent propagation path loss models namely Linear Regression (LR), Lognormal (LN), International Telecommunication Union Recommendations (ITU-R) are considered in our analysis. The relevant expressions and their significance are presented in Table I.

Generally, localization algorithms are classified as deterministic and probabilistic. Deterministic algorithms use similarity index with already existed fingerprint data base. Source position are estimated by comparing with the nearest fingerprint location and can be easily implemented. Whereas Probabilistic algorithms use statistical analysis and computational complexity is involved. These two categories are well compared elsewhere [9]. Out of several localization algorithms, the most prominent algorithms is the RSS based trilateration technique. It is most attractive because of its eventual simplicity and the required RSS measurements are given by the most of wireless trans receivers. It uses measured distance between the source and known receiver positions. The RSS trilateration is expressed as [10]:

$$A = \begin{pmatrix} 2(x_N - x_1) & 2(y_N - y_1) \\ . & . \\ . & . \\ 2(x_N - x_n) & 2(y_N - y_n) \\ 2(x_N - x_{N-1} & 2(y_N - y_{N-1}) \end{pmatrix} \quad (1)$$

$$B = \begin{pmatrix} x_0 \\ y_0 \end{pmatrix} \quad (2)$$

$$C = \begin{pmatrix} d_1^2 - x_1^2 - y_1^2 - (d_N^2 - x_N^2 - y_N^2) \\ . \\ . \\ d_n^2 - x_n^2 - y_n^2 - (d_N^2 - x_N^2 - y_N^2) \\ . \\ d_{N-1}^2 - x_{N-1}^2 - y_{N-1}^2 - (d_N^2 - x_N^2 - y_N^2) \end{pmatrix} \quad (3)$$

Based on the least square system, estimated position is

$$B = (A^T.A)^{-1}.A^T.C \quad (4)$$

where (x_0 , y_0) are the estimated source positions and d is the distance between the source and receiver, x_1, x_2, x_3… xn are the receiver modules' positions in 'x' direction and y_1, y_2, y_3 …y_n are the receiver modules position in 'y' direction. In additions to the mentioned advantages, RSS trilateration is a low-cost technology and no special hardware is required as such.

Table I. Selected Prominent Pathloss Models

S No	Method	Expressions	Significance
1.	Linear Regression [11]	$y = \beta_0 + \beta_1 x + \epsilon$; $\beta_1 = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sum(x_i - \bar{x})^2}$; $\beta_o = y - \beta_1 \bar{x}$ y is fitted pathloss due to linear regression, x is distance, β1 is pathloss exponent, β_o is Reference pathloss at a distance d_o, ε is error.	Fundamental statistical model. Suitable for best prediction of future data.
2.	Lognormal Pathloss [12]	$PL\_Lognormal = PL_0 + 10 n_{log} log_{10}\left(\frac{d}{d_0}\right) + \chi_g$ Where PL_0 is reference pathloss, 'n_{log}' is a lognormal pathloss exponent, χ_g is a shadowing parameter, d_o is reference distance in meters.	Basic model. Suitable to wave propagation, localisation concepts.
3.	ITU-R Pathloss Model [13]	$PL\_ITUR = PL_0 + n_{itu} log_{10}(d) + Lf(n)$ 'n_{itu}' is a distance power loss coefficient. It is 17 for 2.1GHz, LF(n) is a loss factor.	The distance power loss coefficient is included in the model.

3 Experimental Setup

For source localization, experiments are carried out in the ground floor corridor (5.37x21m) of Research and Entrepreneurship (R & E) hub of CBIT. Corridor is made of polished stone and concrete ceiling. Five Wi-Fi transceiver modules (ESP 8266), micro USB cables and laptop (4 GB RAM) for data logs are used in the experiment. The supply voltages are 2.5 to 3.6V. The modules operate in the frequency range of 2412-2484MHz. Typical operating frequency is 2400MHz. Other technical details of the modules are given in Table II.

Table II. Technical Specifications of Transreceiver (ESP8266 module)

S No	Parameter	Value
1.	Input Frequency	2412 – 2484MHz
2.	Sensitivity (DSSS , 1Mbps)	-98dBm
3.	Adjacent Channel Reduction (OFDM)	31dB

These Modules are powered by external supply and are programmed to operate as a transmitter and receiver. During the operation their userid (SSID) are visible in Wi-Fi configured devices (laptops or mobiles). Initially only three modules are used in the experiment. These receiver modules are placed at the vertices of an isosceles triangle (A, B and C as shown in Fig.1) with an adjacent side length of 10.6m to offer wide coverage. Whereas Transmitter module is moved along the center line of the corridor (dashed line in Fig.1) for doing experiments. By placing the receiver at the vertices of isosceles triangle, it expected to get best Dilution of Precision (DOP). From Table II it is clear that, channels are widely separated (31dB). Therefore, when all the modules are operating in the same environment at the same time the possibility of interference does not exist.

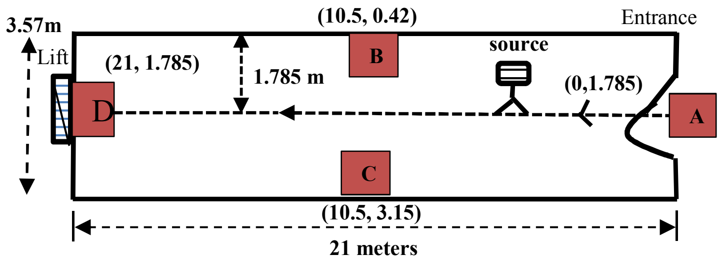

Fig.1 Experiment Scenario at R& E Hub, CBIT, Hyderabad

The transmitter and receiver modules are placed at a height of 75cm from ground level to avoid the ground reflections. A program is developed to estimate the received signal strength and is installed in the receiving modules.

4 Results and Discussion

In this section, the performance of three pathloss models are analyzed and subsequently used these models for source localization. For developing the pathloss models for the three receivers (A, B and C) RSS measurements are made by moving the source along the center line (dashed line) of the corridor. The measurements are taken for every 0.25m. The sampling period is 1sec. For each receiver, pathloss models (LR, LN and ITUR) are obtained based on the measurements.

A. Propagation Path Loss

Based on the measurements pathloss due to LR, LN are calculated. The corresponding plots along with ITUR model, Friis free space model and the experimental results are plotted in Fig.2

It is clear from Fig.2 that single order regression model provides a good fit to the experimental data. The slope (β1) and intercept (β0) of the regression model are the model coefficients for the LR and LN models. It is also evident from the Fig.2 that experiment data is significantly deviating from the free space pathloss model due to the environmental effects such as multipath. The performance of pathloss model with measured data is examined by using the R^2 value. In statistics the 'R^2' shows how bests the data fit to the straight line. From Table III it can be inferred linear regression model is better.

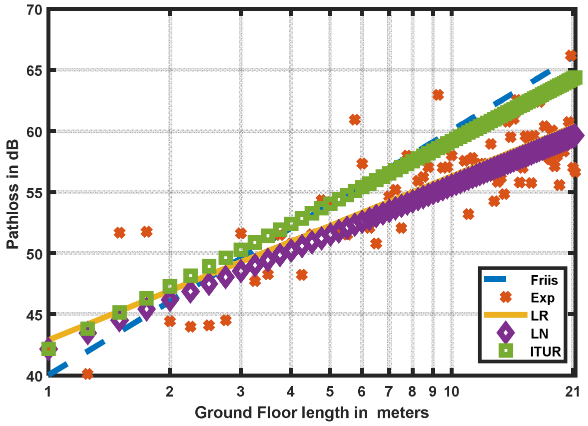

Fig.2 Propagation pathloss due to various models versus distance

TABLE III. Performance of Different Models in terms of R^2

S No	Model Name	R^2 (%)
1	LR	70.85
2	LN	68.66
3	IUT-R	37.84

B. Source Localization

A program is developed for localizing the source using trilateration principle. The inputs for the program are transmitter power, RSS, and operating frequency. Using these inputs, distances are calculated based on the propagation pathloss models (Table I). With the estimated distances and known receiver positions source is localized. Salient features of this process are given in Table IV.

Table IV. Salient Features in the source localization

Step 1	Place the receiver modules at presurveyed locations
Step 2	Collect the Received Signal Strength information for various source positions along the corridor
Step 3	Transform the signal strength information into pathloss
Step 4	Validate the pathloss data
Step 5	Model the pathloss values
Step 6	Find the distance from the transmitter to receivers using the pathloss models
Step 7	Apply localization technique (Trilateration)
Step 8	Estimate the distances between transmitter and receiver and formulate eqs. 1 and 3.
Step 9	Find the source position from eq.4
Step 10	Evaluate the position accuracy in terms of Distance Root Mean Square (DRMS) error

The best pathloss model in the given environment is expected to give better localization results. But without validating the measured data in indoor environment the measured localization accuracy is very poor due to randomness of received signal power. The RSS measurements are refined as a part of channel calibration and are reported elsewhere [14]. We noticed in our investigation that, the pathloss measurements on either side of B and C modules (towards A and D) will be different, even though the distances are same. Therefore, separate path loss models are developed. The data validation is done for all the receivers' data.

Fig.3 shows the localization results in indoor ground floor corridor of R&E Hub, CBIT. It is evident that the localization based on LN and LR models is performing relatively well compared to ITUR model.

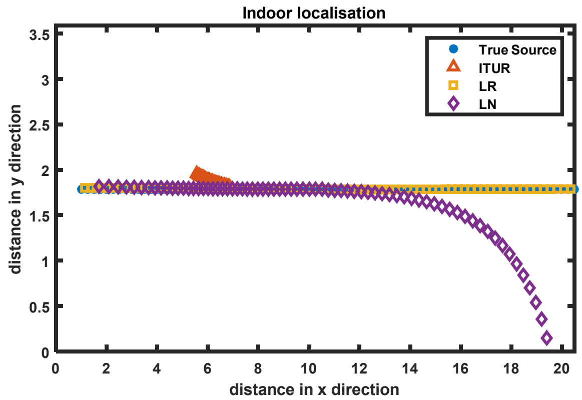

Fig.3. Localization of source in the Ground Floor

The performance of localization is evaluated using the DRMS value, it can be defined as

$$DRMS = \sqrt{\sigma_X^2 + \sigma_Y^2} \quad (5)$$

Where σ_x and σ_y are standard deviation errors of measured x and y directions. Table V shows the results due DRMS calculated in the corridor due to LR, LN and ITUR models.

Table V. Performance of different models in terms of DRMS

S No	Pathloss model	DRMS (meters)
1.	Linear Regression Model	0.065
2.	Lognormal Model	0.973
3.	ITUR Model	1.439

From Table V it is evident that horizontal accuracy is better for LN model. To investigate whether a 4th receiver will improve the localization accuracy or not, additional receiver is kept on the opposite side of corridor 'D' of (21, 1.785). Similar procedure is followed as before and the results are presented in Fig.4.

From Table V and VI it is evident that the improvement in positional accuracy is not significant by placing the receiver module at D.

Table VI. Performance of different models due to four modules

S No	Localization	DRMS (meters)
1.	Linear Regression Model	0.065
2.	Lognormal Model	1.460
3.	ITUR Model	1.495

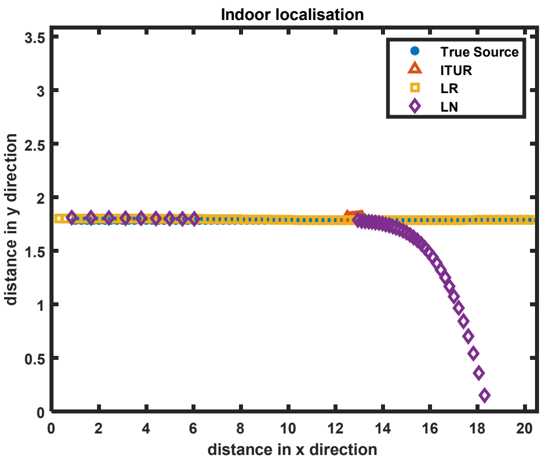

Fig.4 Localization of source in the ground floor corridor, R&E Hub, CBIT due to four modules

These results also indicate that to achieve good positional accuracy, it is necessary to place the modules in optimum positions (vertices of an isosceles triangle).

5 Conclusions

Experiments are performed with off-the-shelf hardware modules in R& E Hub of CBIT, Hyderabad. Three prominent propagation pathloss models are evaluated by comparing their performance inside a corridor. These selected pathloss models are used for range estimation in the context of localization. Using these models source localization in a given environment is done. It is found the performance of 'LN' is superior compared to other models. It is also found that optimum placement of modules is necessary to achieve the good positional accuracy. This kind of experiments can be extended to 5G frequencies for identifying the best indoor propagation path loss model.

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