Improved Path Loss Prediction Model for Short Range Indoor Positioning using Bluetooth Low Energy

Subha Viswanathan and Sreedevi Srinivasan
Connected Devices Business Unit
Cisco Systems Pvt Ltd
{subhvisw,sreedsri}@cisco.com;{subharaj26,sreedevigct}@gmail.com
Chennai, India

Abstract—**Achieving short range accuracy is an ongoing challenge in Indoor Positioning methods for providing location based services. Wireless positioning is a key enabler for location based services and many research papers have been published for indoor positioning using Bluetooth, Wi-Fi, ZIGBEE, IR etc. The published research suggests that position of wireless beacon can be determined based on the time of arrival and the measured signal strength. But, the margins of error in the calculated value using the published formulae, negatively impacts the efficacy of most indoor positioning applications. This paper recommends methods to improve the accuracy of the calculated value when using Bluetooth LE technology. Methods used for Indoor positioning as compared to Outdoor positioning need to handle attenuation factors such as Multipath fading, diffraction, reflection etc. These become especially critical for short ranges of ~3m which is the general range of influence for a display unit. Hence, modelling a very short range Path Loss Prediction becomes imperative. This paper proposes a new Path Loss model for very short range between 10-12 ft with better accuracy and miniscule error rate.**

Keywords—Bluetooth Positioning, Path Loss Prediction, FreeSpace Model, RSSI

I. INTRODUCTION

As we are moving towards the Internet of Things (IoT), the number of sensors deployed around the world is growing at a rapid pace. Market research has shown a significant growth of sensor deployments over the past decade and there will be more! These sensors continuously generate enormous amounts of data. However, in order to add value to the raw sensor data, we need to understand it. Collection, modelling, reasoning, and distribution of context in relation to sensor data become important. One such identification of services in relation to sensor data is the Indoor Location Tracking.

To model the Indoor location, we considered Received Signal Strength Indication (RSSI) instead of Time of Arrival. Received Signal Strength Indication (RSSI) utilizes the characteristic of radio propagation over space.

Generally, the positions here are determined by having at least 3 reference nodes. The position information is obtained using methods like triangulation; trilateration methods [1, 6], fingerprinting RSSI though Inquiry [17] etc. The published results pertains to the range of 5 to 50 meters .In this paper, a new Path Loss Model for RSSI in the range 0 to 3m (0 to 12 ft) is proposed using a single reference node. The new model shows better accuracy in the Path Loss Prediction model and has miniscule error rate compared to the traditional path loss model. This model can be augmented to achieve better distance estimates for a range of 3metres in combination with accelerometer/gyroscope measurements [2].This proposed Path Loss Model is derived based on the results obtained from extensive measurements and analysis conducted through series of experiments.

This paper is organized as follows. Section 2 deals with the analysis on selection of infrastructure for indoor localization. In section 3, the model for Indoor Localization below 10feet is proposed followed by the derivation of the Path Loss Model Equation. In the fag end of the section, the results of the experimental data with Conclusion and future work are detailed.

II. BACKGOUND AND RELATED WORK

RSS based localization is an attractive topic where many researchers have proposed techniques by using existing infrastructure to deploy positioning systems. When the number of nodes for localization increase it would lead to additional hardware and setup will be costly. Low Power, Low data rate, radio frequency (RF) nodes are ideal for RSS localization as it requires minimal data.

Bluetooth LE became the candidate for Path Loss Prediction algorithm improvisation. Bluetooth LE operates in the 2.4GHz ISM band with only 40 channels spaced 2MHz apart. Wireless LAN and other applications based on the IEEE 802.11 specification also operate in the same unlicensed 2.4 GHz ISM band. To diminish the impact of such interference a technique known as Adaptive Frequency Hopping is used in Bluetooth LE, which allows to adapt to the environment by identifying fixed sources of interference and excluding them from the list of available channels.

This paper has the primary focus on improving the Path Loss prediction model with more accuracy using

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Bluetooth LE for a short range ~3m which can be applied for display unit circle of influence. This indicates a need for identification of factors that characterize the environment to model the Path Loss Prediction.

All electromagnetic waves have inverse relationship with the distance and the received power. This fact clearly proves that by calculating the difference between transmission power and received power, the distance can be obtained. This component is called "Path Loss" and this Path Loss varies for different environment. This leads to the need for a Path Loss Prediction model and characterization of environment.

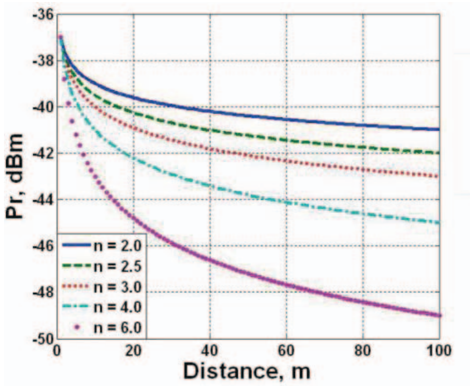

Fig 1: Effects of Path Loss Exponent [21]

For outdoor and indoor environments, the received signal strength varies due to different attenuation factors as shown in the fig [1]. In indoor environment, the signal strength is not linear as the distance linearly increased because of scattering, reflection and diffraction that gives raise to multi-path fading [18]) and indoor shadowing[19] effects. From experiments, it was observed that non-linear path loss becomes more serious as the size of indoor area (for example, a room) is small, leading to difficult accuracy achievement.

III. EXPERIMENTAL SETUP

In order to reduce interference effects, we chose Bluetooth Smart technology that is low cost, long battery life with a proximity profile supported. TI based Bluetooth Smart Dongle and Key fob reporter was considered for experiments as shown in the figure [2] below

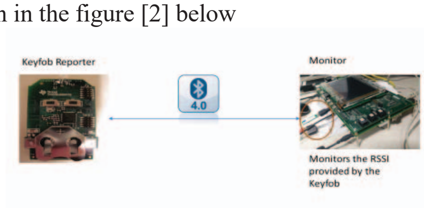

Figure 2: Experiment Setup using Bluetooth LE

Three environments were chosen for this purpose. The closed room 10ft and 20ft distance and office open space environment. Bluetooth LE is used to capture a series of RSSI values at every 2 ft distance as mentioned in figure [3] below

Distance	RSSI	Measured RSSI(Free Space Model)	Measured RSSI(ourModel)	Measured RSSI (Friis Equation)
1	207	207	207	200.5832322
2	205	200.9794001	202.181305	194.5626323
4	201	194.9588002	197.3758924	188.5420324
6	189	191.436975	185.2117966	185.0202072
8	189	188.9382003	192.5239546	182.5214325
9	195	187.9151498	195.5490027	181.498382
10	193	187	191.0367242	180.5832322
11	183	186.1721463	182.0487799	179.7553785
12	177	185.4163751	176.7831003	178.9996073
14	191	184.0774393	188.6028077	177.6606715

Fig 3: Comparison Table of Empirical values with Predicted RSSI

The Transmit Power is maintained constant at -23dBm. Various statistical methods were analyzed including variance, mean and median and finally Median was considered to remove the outliers. Based on the empirical Values and statistical analysis, a new model was proposed that characterizes the environment with minimal error compared to the existing Path Loss Model.

IV. EXISTNG PATH LOSS MODELS

A. Log Distance Path Loss Model

Using the standard free-space radio propagation formulation, it is possible to represent the measured received signal strength indicator (RSSI) as shown below .In equation 1, n = 2 for free-space and n > 2 (empirically adjusted) for RF challenged environment like office indoor.

$$RSSI = RSSI_0 - 10.n.log_{10}(d_E) \qquad (1)$$

B. Rappaports Path Loss Model

In typical path loss model [11], n takes multiple values, for office buildings, ranging from 2.76 to 4.33, based on location type. In addition, the term X_σ was introduced in this model to account for slow-fading phenomenon in RF challenged environment like office setup with cubicles.

$$RSSI = RSSI_0 - 10.n.log_{10}(d_E) + X_\sigma \qquad (2)$$

X_σ is a zero-mean lognormal distributed random variable with σ (dB) ranging from 4.3 to 12.8 for different location in office premises. This slow fading component is referred to as Rayleigh Fading effect in [16]

C. Friis Transmission Model

A simplified formula for Path Loss between two isotropic antennas also known as Friis Transmission Equation [20] is

$$Path\ Loss\ L = 20.log_{10}(4.\pi.d/\lambda) \qquad (3)$$

This means

$$RSSI = RSSI_0 - 20.log_{10}\ (4.\pi.d/\lambda) \qquad (4)$$

Typically, for flat-Earth or free space model the above equations holds good. But for indoor environments, within the range of < 3m, the attenuation factor takes a different form from the log-normal distribution. Hence a new wave propagation model is re-designed. The foundation of the proposed model is based on work by Liberti et al. [11], where the channel model is considered to be a power decay function and the multipath noise is modeled as lognormal distribution with standard deviation of σ (dB) as shown in equation (2) whereas the proposed model suggests the multipath noise to be modeled as Log Distance Path Loss and the channel modelling is a sinusoidal wave with a particular spatial frequency based on various environments. On extensive experiments, it is observed that the error rate of Prediction is almost zero in Office Premises as shown in fig 6.

V. PROPOSED MODEL

Combining the results of various Path Loss Models, and extensive experiments carried in office premises at different locations and choosing 10ft and 20 ft rooms, it is observed the empirical values of RSSI for a range ~3m, there is power decay, but the decay is not a log-normal distribution but it is damping sinusoidal in nature. The same behavior observed is also mentioned in this paper [4]. The model suggested in this paper [4] considers the sinusoidal behavior of the RSSI <3m and constants are calculated with other reference nodes as base. The damping nature of the RSSI signal is logarithmically distributed.

Space	Spatial Wavelength
10ft Room	2.2
20ft Room	5
Open Space	6

Fig 4: Effect of Spatial Wavelength

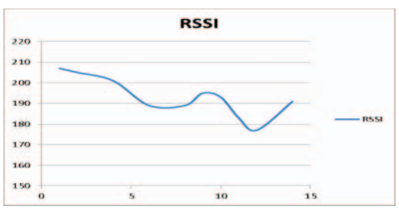

Fig 5: RSSI Behavior < 3m

With extensive experiments and observation, combining the results of the enlisted models, a new improved propagation model is suggested for <3m where the environment is charectized by the spatial wavelength of the measured value. The amplitude of the sinusoidal RSSI does not vary for different environments indoor and hence concludes that spatial wavelength of the RSSI is the factor that characterizes a particular environment as shown in figure [4]. The proposed model is applicable for LOS Measurements with same antenna height between reference node and blind node.

A. Derivation of Proposed Model

From Rappaports model

$$RSSI = RSSI_0 - 10.n.\log_{10}(d_E) + X_\sigma$$

For short range <3m the RSSI is sinusoidal in nature. Hence the attenuation factor cannot be constant but a sinusoidal equation. Based on empirical values, the proposed model suggests the attenuation factor

$$n = (A/20).\cos(2.\pi.d/\lambda) \qquad (5)$$

where A is the Amplitude of the RSSI which is approximately ~8 for almost all environments and λ is the wavelength which varies based on different environments and attenuation factors as shown in Table [4]. The X_σ mentioned in Rappoparts model as the standard deviation, the proposed model suggests considering Log Distance Model because the RSSI behavior is a damping sinusoidal wave where the damping factor is a logarithmically distributed based on Log-Distance Model for Freespace. Hence the improvised proposed Path Loss Model is

$$RSSI = RSSI_0 - [(A/20).\cos(2.\pi.d/\lambda).\ 10.n.\log_{10}(d_E)] - FSPL \qquad (6)$$

Where FSPL is the Free Space Path Loss Model

For orientation factor, repeated experiments were conducted by placing the Keyfob reporter at right angles to the reference node. This factor is added in the model as per the paper[4] θ in the proposed equation as follows

$$RSSI = RSSI_0 - [(A/20).\cos(2.\pi.d/(\lambda+\theta).\ 10.n.\log_{10}(d_E)] - FSPL \qquad (7)$$

Hence the proposed Path Loss Model

$$PL = [(A/20).\cos(2.\pi.d/(\lambda+\theta).\ 10.n.\log_{10}(d_E)]\text{-}FSPL \qquad (8)$$

VI. RESULTS

RSSI readings taken from the experiments often contain unwanted "spikes" and "troughs" owing to interference and channel hopping etc. The readings are taken in groups for each annotated distance and use only the median value of those observations for our calculation. Since multiple measurements are taken and in known orientations ($\theta = 0$) or ($\theta = 90^0$), the only unknown factor for characterizing the environment is the spatial wavelength

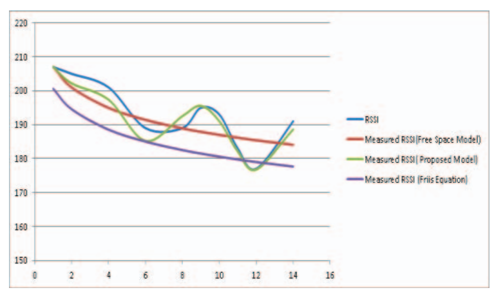

Fig 6: Proposed Model Vs Measured RSSI Comparison Graph

A comparison graph was plotted for every 2ft with RSSI measurements taken from the median to avoid the spikes with the calculated RSSI as shown in fig [6].From the plotted graph, the pattern of RSSI behavior predicted is in similar fashion with the measured values

From our experiments, it is observed that the path loss prediction error rate is almost miniscule and is 0 in most of the distance measurements. The maximum error rate experienced in the proposed model is 3dB which occurs in the range of 1m as shown in the table below [7] and the error rate is reduced to 0 > 1.5m in office environments

RSSI	Measured RSSI(Free Space Model)	Measured RSSI(ourModel)	Error Rate (Proposed Model)	Error Rate(Log Distance Model)
207	207	207	0	
205	200.9794001	202.181305	-2.818695031	-4.020
201	194.9588002	197.3758924	-3.624107608	-6.041
189	191.436975	185.2117966	-3.78820343	2.436
189	188.9382003	192.5239546	3.523954641	-0.06
195	187.9151498	195.5490027	0.54900275	-7.084
193	187	191.0367242	-1.963275781	
183	186.1721463	182.0487799	-0.951220121	3.172
177	185.4163751	176.7831003	-0.216899697	8.416
191	184.0774393	188.6028077	-2.397192295	-6.922

Fig: 7: Error Rate of Freespace and Proposed Model

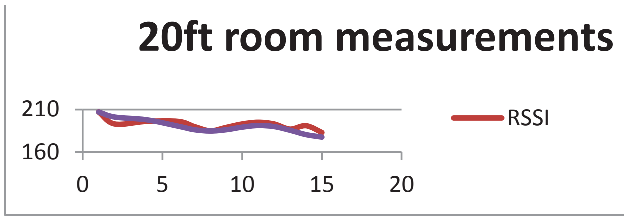

Fig 8:20ft Room Measurement

VII. CONCLUSION AND FUTURE WORK

From the results, it is concluded that the signal strength for Indoors have spatial periodicity superimposed with logarithmically decaying channel variations. The frequency is due to the multipath noise, the wavelength characterizes the environment by having polarization and angle of orientation as constant factors. It is observed that in-room environment has slightly higher error rate compared to the office premises as depicted in figure [8]. Further the error rate increases as the room size becomes smaller. Hence more study has to be conducted on the shadowing effects and noise factors that constitute the signal strength behavior in the room.

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