2.4 GHz Propagation Prediction Models for Indoor Wireless Communications Within Building

B. R. Jadhavar, T. R. Sontakke

Abstract*: Different propagation models are presented for multi-storied Quantitative models aural area, that predicts effect of wall partitions, number of floors and building layout at 2.4 GHz using IEEE802.11b wireless network. Propagation models have been developed for these two buildings based on number of floors between transmitter and receiver. These models are indoor location detection system designer which relate signal strength log of distance. The measurement shows that the standard deviation between measured and predicted path loss is 12.4124 dB for all locations in one building and as small as 8.0948 dB on same floor. And in other building it is 10.2854 dB and minimum 8.5454 dB for same floor measurements. Floor attenuation factor for two buildings are 18.0304 dB and 28.5687 dB when transmitter and receivers have one floor in-between. The concrete wall attenuation factor was found to be 4.86 dB and hard board partition attenuation factor was 2.45 dB. Also contour plots for equal signal strength for measured data are presented. The results are quite logical as per building structure/layout.

Index Terms*: WLAN, propagation model, free space, path loss model, floor attenuation factor, signal strength, contour plot.

I. INTRODUCTION

There is increase in demand of mobile communication which resulted in development of micro-cellular and pico-cellular mobile system operating outside and inside building. Radio propagation in 1.8GHz frequency band has been allocated for personal communication services. The deployment of pico cells is likely to be next step in the effort of mobile service providers to provide higher capacity networks. High data rate up to 11 Mbps is handled by WLAN operating 2.4 GHz. In the range of about 100 meters for outdoor and 30 meters for indoor. No wonder in future there will be increase in demand in speed and distance. These mobile systems operate in 2000 MHz band. For this systems, knowledge of mean signal strength is one of the essential factors for the design of mobile radio system.

To have satisfactory operation of mobile system in indoor environment there is desire to predict radio coverage within buildings so that optimum location of base stations can be chosen which maximizes capacity and minimizes co-channel interference. Such predictions are becoming very useful to mobile operators in cities like Pune where population is becoming dense and subscribers are demanding that coverage be provided within buildings.

In next generation system more stress is given on indoor environment because there is requirement of other services like position information of the mobile user inside large buildings, malls, hospitals, air ports, public places, factories and emergency services. GPS cannot work in indoor due to poor coverage of radio signal. Propagation prediction within buildings is difficult due to occurrence of various propagation phenomenon which depends on specific building structure.

Propagation in corridors and hallways has less losses than free space loss. Whilst signal propagating through walls and floors suffer significantly higher loss than free space. Also moving bodies inside building absorb the signal. In some situations windows can provide signal propagation from floor to floor by reflection and diffraction of signal from nearby building which complicates the situation further. From this it is clear that propagation prediction must make use of site specific information.

By making use of measurements in different buildings indoor propagation prediction has been previously investigated [1,12,14]. This is empirical type approach, uses free space model with attenuation factor to account for wall and floor losses, is best fitted to actual measurement data [2].

In order to characterize indoor radio propagation we have carried out measurement within two different buildings at 2.4 GHz. Mathematical and measured data approach is used. The Log Distance Path Loss Model is used as the mathematical approach while the measured data is also been used to observed the signal propagation. Both approaches are basically used for comparison and for obtaining the path loss coefficient, n which is applicable for frequency at 2.4GHz. The purpose of obtaining the n value is to represent the obstructions which exist in indoor propagation environment scenario. The value n is obtained from the measured data (path loss) and the path loss model itself (Log Distance Model) where the calculation is done by manipulating the path loss model equation and substituting the path loss into the mathematical model. The steps that used to obtain the n value shows how the approaches is being used while to come out with new path loss coefficient n value at 2.4GHz frequency. Although physical indoor propagation environments are complicated, a common and basic geometry structures that will give different effects on propagation can be classified as corridor, walls, floors and nearby buildings. In this research, measurements are taken in two different buildings at peak hour. We study path losses due to these structures are investigated and models for estimating propagation losses are developed. In section 2 various models

Manuscript received on July 2012.

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are summarized. In section 3 indoor test results for two buildings are given and suitable prediction model is found. While contour plots for equal signal strengths are plotted for buildings in section 4. And we conclude in section 5.

II. PROPAGATION MODELS (BACKGROUND)

This section briefly describes the experimental set up used for our propagation measurement. For this Microsoft windows based LAPTOP with WINDOWS 7 operating system was used. The experiment was carried out in two dissimilar college buildings. Both buildings are multistoried and equipped with furniture like benches, wooden and steel cupboards with other laboratory instruments. Measurement test bed was selected on second floor and first floor of two dissimilar buildings. Measurements taken at peak hour hence shadowing effect was there.

D-Link Wireless Router (Access Point) in room at 1 meter height above ground.

Figure 1

Transmission frequency was 2.4 GHz with 100 mW transmit power .Narrow band CW signal was used for transmission. TOSHIBA make Laptop installed with Netstmbler, Wirelessmon, and inSSIDer software. Mobile host (Laptop) was moved to different locations on the floor as well as on ground , 3rd and 4th floor. Care has been taken that Laptop was all the time oriented towards Access Point(D-Link Wireless Router). Even though three software's were installed, only one was used because all three gives almost same results. For the purpose of this work, we limit ourselves in considerations of the radio signal strength, which will lead us to focus on path loss analysis and building penetration attenuation. Bit error rate analysis is an entirely different scope and shall be analyzed elsewhere since it beyond scope of this paper. Our experiment proposes to simply collect a number of data points and to compare them with existing models.

If P_t is power transmitted from the transmitter, then $P_t = P_A + P_{S/R} + P_{refra}$

Where P_A is absorbed power, $P_{S/R}$ is scattered and reflected power, P_{refra} is refracted power. It may be assumed that P_A and P_{refra} hardly reach receiver so contribution due to this is negligible. Therefore the power received at receiver under LOS situation is $P_t = P_{S/R}$. Here $P_{S/R}$ plays dominant role. In NLOS situation due to building obstruction is much different. The signal received at receiver is

$P_r = (P_t + G_t + G_r) - PL$, PL is path loss due to building.

This path loss includes attenuation loss at two interfaces i. e. free space and walls, and other obstructions inside building. We mainly focus on determination of coverage area for selection of optimum number of base stations for reliable communication. Path loss depends on building structure and other details inside building. Hence for prediction of propagation channel for indoor environment reliable path loss model is required. A simple log-distance model [4] is use to determine attenuation of transmitted signal at transmission frequency f_T, when transmitter and receiver are in LOS situation.

$$PL(d)[dB] = PL(d_0)[dB] + 10 \times n \times log_{10}(\frac{d}{d_0}) \qquad (1)$$

The reference distance d_o which is taken here 1 meter is utilized to normalize to that which occurs at a distance d_0 from the transmitter and only the propagation effects are included. n is path loss exponent and d is distance between transmitter and receiver in meters.

For NLOS situation path loss can formulated as [1]. The attenuation loss at the same floor through wall/ partition crossings is determined from the following formula [13].

$$PL(d)(dB) = 10\log\left(\frac{d}{d_0}\right)^n + \sum_{p=1}^{P} WAF(p) + \sum_{q=1}^{Q} FAF(q) \qquad (2)$$

Where P and Q number of wall and floors between transmitter and receiver respectively

And n is path loss exponent, $WAF(P)$ and $FAF(Q)$ are wall and floor attenuation factors. The values of these parameters are determined by best fitting model (2) to measurement data from two dissimilar multi-floor college buildings of interest. The model has disadvantage that it cannot include distance dependent path loss exponent. As a result prediction accuracy can be poor in certain part of the building, especially at larger distances from the transmitter. Also it won't take in to account reflection and diffraction from the objects.

Free space path loss is usual reference point for some of the path loss models examined here is derived from Friis power transmission equation. $P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2}$ and for unity gain

$$P_r = \frac{P_t \lambda^2}{(4\pi d)^2}\ ; \qquad PL(d) = \frac{P_r}{P_t} = \frac{\lambda}{(4\pi d)^2}$$

Using close-in reference distance (1 meter) at the transmit end path loss formulas are derived leading to path loss estimates (in dB)

$$PL(d)_{free\ space} = 32.44 + 20\ log_{10}(f_c) + 20log_{10}(d)$$

Where f_c in MHz d is in meters

For 2400 MHz

$$PL(d)_{free\ space} = 101.04 + 20log_{10}(d)$$

(n=2 for free space)

Path loss prediction model is basically an empirical mathematical formulation for the characterization of radio wave propagation. The models are usually developed to predict the behavior of how the signal is propagated in a several environments and places. The Log Distance Model is the path loss model that will be used in this research. This model is an indoor propagation model that predicts the signal loss inside the building.

A. Log- Distance Model

This is given as

$$\mathrm{PL(d)} = \mathrm{PL(d_0)} + 10\ \mathrm{n}\ \log_{10}(\mathrm{d})$$

Where $PL(d)$ is path loss $PL(d_0)$ = power loss (dB) at 1m distance (30 dB), n is path loss coefficient, d is distance meter between transmitter and receiver.

From the above equation, the value n is computed as follows:

$$n = \frac{PL(d)-30}{10log_{10}(d)} \qquad \text{(A)}$$

This is commonly used one slope log-distance model

The traditional attenuation factor is given by

$$PL_{AF} = PL_{free\ space}(d) + A_F$$

$$PL_{AF}(d) = PL_{free\ space}(d) + A_F = 20log_{10}\left(\frac{4\pi d}{\lambda}\right) + A_F$$

Where A_F is attenuation factor due to walls, partitions, glass doors etc.

B. ITU Path Loss Model

The One-Slope model is a modified power law model [5]

$$P_r(dB_m) = P_t(dB_m) + K(dB) - 10nlog_{10}(^{d}/_{d_0}) \quad (3)$$

As in the Free Space Model, K equals -39 dB (reference path loss for 1 m). The path loss exponent *n* is calculated via a minimum mean square error (MMSE) fit to empirical data.

Finally, the ITU indoor path loss model is described by the following formula [6]:

$$PL = 20log_{10}(f) + 10nlog_{10}(d) + Lf(n) - 28dB$$

For $f = 2400\ MHz$ and $Lf(n) = 0$ (same floor)

$$PL = 39.6 + 10\ nlog_{10}(d) \qquad \text{(B)}$$

C. AFC Model

A more complicated attenuation factor model is extension of AFC model [3] [4].

$$PL(d) = 47.8 + 10 \times n\ log_{10}(d) \qquad \text{(C)}$$

And two slope model for corridor is

$$PL(d) = \begin{cases} 53.2 + 25.8log_{10}(d) & < 9\ meter \\ 56.4 + 29.1log_{10}(d) & > 9\ meter \end{cases}$$

D. The Movement of People

The movements of people greatly vary amplitudes of the transmitted signal and make the indoor channel non stationary even when either both the transmitter and receiver are stationed at a particular position or transmitter is fixed and receiver moves. The disturbances even for 20-30 seconds may result in deep fades. This is more noticeable at higher frequency and millimeter wave bands [14]. This affect the functioning of mobile communication systems operating in microwave and mm-wave bands. We tried to remove this dynamic effect due to movement of people by averaging around 50 readings in approximately in five minutes. We observed that the measurements are found different when large number of students were present in the department. We limit our study to first order propagation model, hence it is beyond scope of this paper.

III. INDOOR TEST RESULTS

The site selected for experiment is Engineering college building. The left wing of the building is for Electronics and Telecommunication Engineering and is on second floor where the transmitter is placed. The transmitter is D- Link Wireless Router. The site contains laboratories, staff rooms , HOD room and class rooms. The site is such that small scale phesnomenon is due to multipaths and reflection mechanism, not due to shadowing and obstructions. The measurement set up as shown in table 1. We look at in-building penetration and conducted number of measurements in indoor environment. The data points are collected from two different buildings with different floor plans.

The measurements are carried out on same floor, one floor below, one floor above, two floor above and three floor above. For two separate building data is averaged which gives some indication of what path loss may be expected for generic commercial building, which is the estimate we are looking for in order to estimate proper coverage in that area.

In polytechnic Institute building transmitter is located at north end of the building which is having triangular shape. The building is newly constructed and is having minor furniture.

Table : 1

Measurement set up	
Carrier frequency (GHz)	2.4
Band width (MHz)	100
Transmit power (dBm)	20
TX antenna height (m)	1.5
RX antenna height (m)	1.5

As shown in fig. 1 transmitter is placed 1.5 meter above ground level in the corridor of Electronics and Telecommunication Engineering Department and in polytechnic building transmitter placed in proposed drawing hall and receiver in our case Laptop was moved at different places in both the buildings. Polytechnic building is closed from all sides hence reception may be via LOS(in some places), through walls and multiple reflections. The signal get reflected from one side of the building to other side. The central area of the building is open to sky. The measurement were taken at peak hour when around 400 students were in the building. Then position of the base station was changed to another location and measurements were repeated.

With same transmitter position receiver was moved to one floor below, one floor above, two floor above and three floor above. In this building measurements are encouraging due to middle area open to sky. The measurements throughout the building are difficult to analyze accurately due to strong multipath creates rapid variations [8] [9] and also materials of the walls. The directivity pattern of the antenna also should be taken in to account and its polarization [10]. We have given general results that may predict the additional margin required for proper in-building coverage.

We observe that signal strength is significantly improved when LOS exist through windows and corridors to the transmitter. The signal strength received on third floor, fourth floor and fifth floor of Polytechnic building is significantly better than E &T/C building because of unique shape.

In Polytechnic building number of floors between transmitter and receiver can be seen to be severely influenced the path loss for a T-R separation. Thus the number of floors has an impact on n in the path loss model and should be considered for accurate path loss prediction. E & T/C department on second floor is showing different results than Polytechnic building due to having three meter wide passage. Here path

Table: 2 Parameters for Polytechnic Institute Building

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Description	Model A		Model B		Model C		Number of locations
	n	X_σ	n	X_σ	n	X_σ	
All Locations	4.9711	14.6238	4.2537	13.3488	3.6408	12.4124	480
Same floor (I)	4.1402	11.5931	3.4750	11.3904	2.9069	11.3591	73
One floor below	5.1917	16.1941	4.4971	14.5917	3.9038	13.2973	71
One floor above	5.0954	15.3905	4.4037	13.9776	3.8128	12.8396	69
Two floor above	4.9140	10.8938	4.2434	9.4804	3.6707	8.3884	66
Same floor (Ground)	5.3138	10.5795	4.5030	9.0443	3.8105	8.0948	93

loss is severe because of NLOS between floors. This building was constructed in 2006. Floor attenuation is highest for this building.

From the table 2 parameters for the path loss prediction for entire data set are n = 3.6408 and large standard deviation $X_\sigma = 12.4124$ dB We have selected model 3 because it is best fit for entire building. So it is not necessary to comment on other two models because n and X_σ are having large values as compared to free space path loss model. This large value of X_σ is typical for data collected from entire building and indicates actual measurements will be within $\pm 12.4124\, dB$ of actual predicted mean path loss. These parameters may be used in the model for a first order prediction of mean signal strength in polytechnic building. When transmitter and receiver are on same floor, the path loss is less severe and standard deviation is reduced slightly. For same floor we found $n = 2.9069$ and $\sigma = 11.3591$ dB using data from measurements. Since we are using here simple d^n path loss model, it does not take in to account the knowledge of concrete walls, hardboard partitions, furniture, moving bodies and number of floors between transmitter and receiver. In Electronics and Telecommunication Engineering building path loss increases with distance to the 3.7657 power as shown in table 3. Number of floors between transmitter and receiver severely influence the path loss for given T-R separation. Thus number of floors has impact on parameter n in the path loss model and for accurate path loss prediction large data is required.

In multi-floored environment the path loss is predicted from mean path loss exponent that is function of number of floors between transmitter and receiver.

$$\overline{PL}(d)[dB] = PL(d_0)[dB] + 10\, n_{multifloor} log_{10} \frac{d}{d_0} \quad (4)$$

For floor attenuation factor (FAF) which is a function of the number of floors and building type, may be added to the mean path loss predicted by a path loss model which uses the same floor path loss exponent for the particular building type. Hence mean path loss is

$$\overline{PL}(d)[dB] = PL(d_0)[dB] + 10\, n_{same\ floor} log_{10} \frac{d}{d_0} + FAF[dB] \quad (5)$$

In this case $PL(d_0)[dB]$ is 47.87 dB at 2.4GHz.

$$FAF = PL_{same\ floor} - PL_{through\ floor}$$

attenuation factor for this building is given in table 4.

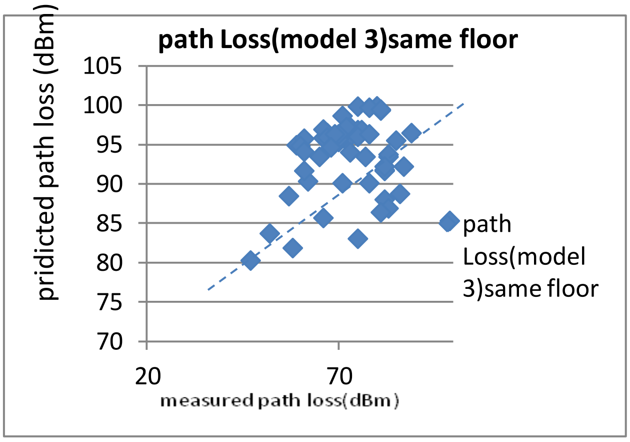
Electronics & Telecommunication Department

Description	n	$X_{\sigma dB}$	Locations
All locations	3.7657	10.2854	255
Same floor	3.1024	8.5454	88
One floor above	3.5769	9.3342	71
One floor below	3.7921	9.4471	46

Table : 3 Parameters for E&T/C building

In E and T/C building the signal received on different floor is weak and we observed weak signal at few places only. This may be because of building plan. In Polytechnic Building there_is possibility of multipath because central portion of the building is open to sky. We get heavy attenuation in E and T/C building while less attenuation in Polytechnic building. Hence we notice that in Polytechnic building there is definitely other factors that shows less FAF.

This may be due to multipath reflections(as shown in fig. 3) from opposite wing of the building. In E & T/C building there is no possibility of multi-paths and all measurements are underway in entire four floor building



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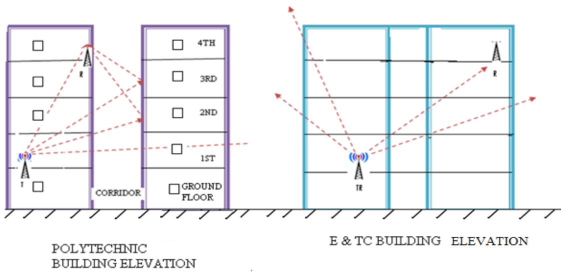

Figure 2

Description	FAF in dB	$X_\sigma dB$	Locations
Polytechnic Building			
Through one floor below	18.03043	13.29718	71
Through one floor above	18.22698	12.83962	69
Through two floor above	16.99385	8.388399	67
E & T/C Building			
Through one floor below	28.56878	9.855354	5
Through one floor above	34.0306	12.969	10
Through two floor above	24.63407	9.713442	4

Table : 4 floor attenuation factor model for two buildings.

IV. PATH LOSS CONTOUR PLOTS

Measurements were taken at different location in the building by keeping transmitter at fixed location on the ground floor and first floor. This data have been used to form contour of locations of equal signal strength for given transmitter location. In each figure transmitter location is indicated by 'T'. Curved solid lines indicates locations of equal signal strength from the transmitter in different steps. The amount of signal strength is indicated at the end of each curve. The contour plot of locations with equal received signal strength for Polytechnic building is given in fig. 3. The transmitter was located at North end of the building in proposed drawing hall.

The curved solid lines indicates contours of -35 dBm , -40dBm, -50 dBm, -55 dBm, - 60dBm, -70 dBm, -80 dBm, -85 dBm signal strength available from transmitter.

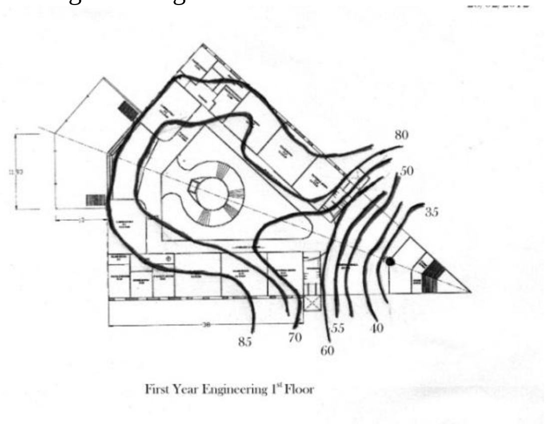

Figure 3

Notice that in fig. 5, there are toilets for ladies and gents to the right and left side of the building immediately after drawing hall. These toilets have dense construction and more number of partitions and signal gets attenuated heavily. Because of there is poor radio coverage to two wings of the building. While LOS exists to central portion and passages of two sides of the building. Hence good coverage to central region. Also this area open to sky, hence propagation is better than free space. This has waveguide effect hence energy get guided in that direction.

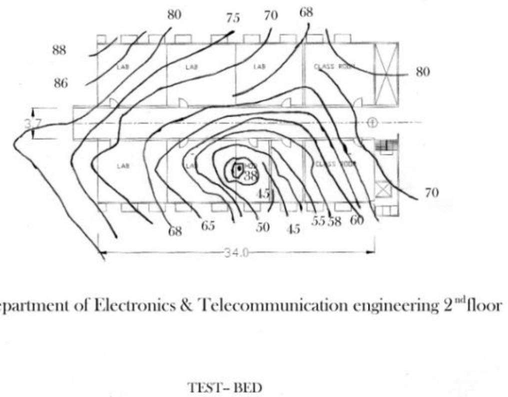

Figure 4

Moreover this building has thicker wall with hollow in between to avoid rain through windows. Hence least energy is escaped through walls. Hence better radio coverage to front portion of the building. Fig. 6 shows contour plot for the second floor of Electronics and Telecommunication building having five laboratories and class rooms to west side. East side of building is having six rooms including HOD and staff room. This side lot of furniture like steel cupboard and office tables are there. In this building transmitter is placed HOD room marked as 'dot'. Test bed size is 34 X 19 meters. Contours of location of signal strength -45 dBm, -50 dBm, -55 dBm, -65 dBm, -70 dBm, and -80dBm are plotted on test bed. In this building radio coverage is poor than free space due to more number of walls and less multipaths.

V. RESULTS AND DISCUSSION

This paper presents an extensive set of measurements acquired at Siddhant College of Engineering (Polytechnic Institute building and E &T/C floor) as a definitive example of commercial propagation topology for indoor. Path loss propagation models based on measured data at 2.4 GHz using D-Link wireless access point have been presented for two different buildings. The models are based on d^n exponential path loss vs. distance relationship. In free space path loss exponent is close to 2. For environment with many more obstructions between transmitter and receiver the path loss exponent can be much higher. Different models are proposed in the literature. These models are suitable for particular type of building. Particular model may not be suitable for building under consideration. Three models are compared for its performance for these two buildings.

We found model C to be more accurate. For Polytechnic building, considering model C the mean path loss exponent for same floor is 2.9069 by measurement at 73 locations. For the same building mean path loss exponent for three floor measurement is 3.6707 and average floor attenuation factor FAF is 16.99385 dB.

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Then for this model predicted mean path loss 10 meter of T-R separation using (4) is

$$\overline{PL}(10\,m)[dB] = PL(1\,m)[dB] + 10 \times 3.6707 log_{10}10$$
$$= 47.8 + 36.707 \;= 84.507\,dB$$

By another method we can find out using FAF and same floor measurement using (5).

$$\overline{PL}(10\,m)[dB] = PL(1\,m)[dB] + 10 \times 2.906\, log_{10}(10\,) + FAF$$
$$= 47.8 + 29.06 + 16.99 = 93.85\,dB$$

This is how without measurement path loss can be predicted for specific site.

The floor dependent path loss exponent may be used to model the effect of number of floors between transmitter and receiver. Attenuation factor for concrete wall, hardboard partition are found. These factors useful since they allow us find path loss in terms of free space path loss. It is also possible to predict received signal strength from contours for transmitter receiver located on same floor. For all our measured data, AF (hardboard) = 2.45 dB, AF (concrete wall) = 4.86 dB.

Received signal strength contours plot shows the difference between measured and predicted signal strength for building given here shows simple path loss model that use site specific information. Experiment is carried out using Laptop as a receiver and D- Link wireless router as a transmitter. The inSSIDer software is used which gives signal strength at particular location. Our results are quite satisfactory and encouraging. There are location where path loss is greater than 16 dB. The majority of locations are predicted to within $\pm\, 6\, dB$. The high error may be due to access point and wireless device used in the Laptop. The model 3 seems to be accurate and useful to communication system designer. The studies reported here is useful in modeling a first-order prediction of distance dependent mean signal strength level, and also in understanding the spectral power requirements inside a building.

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