STUDY OF VARIOUS INDOOR PROPAGATION MODELS

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ABSTRACT

Indoor Propagation modeling is demanded for the maintenance of indoors-wireless services. Propagation models provide estimates of signal strength and time dispersion in many indoor environments. These data are valuable in the design and installation of indoor radio systems. We propose improving existing channel models by building partitioning technique. Based on the measurement results the easy-to-use empirical propagation predication models were derived for both of the buildings with satisfactory accuracy. The result used to determine the path loss exponent and standard deviation. It similarly shows that the RSS values Vs distance help in determine the variation in multi-wall model and single wall.

Keywords: *Wireless LAN, Ekahau Heat mapper, Visi-site survey, propagation modeling, GPS.*

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*HCTM, Kaithal, Haryan

1. INTRODUCTION

Researchers have developed a variety of experimentally or theoretically based models to predict radio propagation in various frequency bands and for various types of environments. The past decades has witnessed a phenomenal growth in wireless communication. The need of wireless technology in offices, and all the working places gives revolution to the indoor propagation models. Indoor propagation is not influenced by weather conditions like rain, snow or clouds as outdoor propagation, but it can be affected by the layout in the building especially the use of different building material. Owing to reflection, refraction and diffraction of radio waves by objects such as walls, windows, doors and furniture inside the building, the transmitted signal often reaches the receiver through more than one path, resulting in a phenomenon known as multi-path fading [1][2].

The mechanism behind electromagnetic waves propagation are diverse, but can generally be attributed to reflection, scattering, refraction and diffraction. A signal radiated from an antenna travels along one of the three routes: ground wave, sky wave, or line of sight (LOS). Based on the operating frequency range, one of the three predominates. In [2], a review of popular propagation models for the wireless communication channel is undertaken. Macro cell (typically a large outdoor area), microcell (a small outdoor area), and indoor environments are considered.

For a small network in a limited area, only manufacturer’s information on the coverage range is sufficient to deploy the APs. The paper based on a site survey with a lot of measurements and experimental decisions. One common approach employs surveying of signal strength information in a particular area.

2. MODEL LOCATION

This research began by measuring signal strengths. The result obtained the average signal strength as well as the standard deviation at each location. Site survey using either a standard wireless device with a testing software tool or special sophisticated equipment is undoubtedly indispensable way to test existing WLAN networks - coverage, performance, etc.

Fig. 2.1 Coverage area.

The experimental area shown with the help of Google Earth in Fig. 2.1. So, the main goal of a site survey is to measure standard deviation

2.1 RECEIVED SIGNAL STRENGTH

Wi-Fi wireless networks are everywhere [3]. Visualize all Wi-Fi Networks: Ekahau HeatMapper will display the coverage area of all the access points in the area on a map. Fig.2.2 shows that the amplitude of signals varies for different AP's, which is located at the experimental area. This can help us to represent the strongest AP. VisiWave provides four effective methods for capturing data (one point at a time, continuous walks through the survey area, GPS positioning for outdoor surveys, and a custom dead-reckoning navigation device) making data collection quick and easy [3][4]. Find Security Problems and Open Networks:

HeatMapper displays if there are security issues in some networks, and shows the location of unsecured networks. GPS help to take the distance in feet's as well as in meters from the transmitter to receiver.

☑	SSID	RSSI	Channel	Vendor	Privacy	Max Rate	Latitude	Longitude	Network Type
☑	Homestar	-55	1	Netgear Inc.	RSNA-CCMP	54 (N)	43.608902	-116.308737	Infrastructure
☑	MetaGeek...	-55	1	Netgear Inc.	RSNA-CCMP	54 (N)	43.608902	-116.308737	Infrastructure
☑	Microwave...	-46	1	Ruckus Wire...	RSNA-CCMP	54 (N)	43.608902	-116.308737	Infrastructure
☑	MetaGeek...	-48	2	Netgear Inc.	WEP	54 (N)	43.608902	-116.308737	Infrastructure
☑	MetaGeek...	-55	5 + 1	D-Link Corpo...	RSNA-CCMP	300 (N)	43.608902	-116.308737	Infrastructure
☑	!@#$%^&*...	-55	6	Netgear Inc.	RSNA-CCMP	54 (N)	43.608902	-116.308737	Infrastructure
☑	MetaGeek...	-53	6	Netgear Inc.	RSNA-CCMP	54 (N)	43.608902	-116.308737	Infrastructure

13 / 13 AP(s) GPS: On Location: 43.608777, -116.308823 Speed(km/h): 0.24 Logging: Off

Fig.2.2 Map Survey for nearby located WiFi's.

There are lots of survey done with the help of GPS, which help in getting the exact distance between the transmitter and the receiver. Ekahau Heat Mapper shows that the signals are weak of AP1 as we gone far from the building. We can see that the RSS values from that AP are getting weaker as we move away from it.

2.2 LIMITATION OF INDOOR PROPAGATION MODELS:

Improved Propagation models are required to achieve reliable and accurate propagation and predictions. The various challenges facing the development of indoor propagation models are as follows:

1) Propagation measurements primarily dependent on unavailable building construction parameters such as wall thickness, materials, and indoor building structures.
2) A large number of prediction methods require computation of the effect of reflections and transmissions and hence become time consuming and computationally ineffective
3) Most of the techniques are applicable to high frequencies thus the dimension of some indoor structures may not necessarily satisfy the large dimensions compared to the wavelength criterion required by these methods.
4) Small-scale fading- it causes great variation within a half wavelength. Multipath and moving scatters cause it. Rayleigh, Ricean, usually approximates resulting fades or similar fading statistics measurements also show good fit to Nakagami-*m* and Weibull distributions [4].

3. PROPAGATION MODEL:

3.1 FREE SPACE PATH LOSS MODEL:

The spatial distribution of power at a distance d from a transmitter is, in general, a decreasing function of d. A distance power law of the form represents this function

$$P=l/d^{m} \qquad (3.1)$$

For free space, ***m*** is equal to 2 and it is said that the power gain follows an inverse square law. In an enclosed environment, however, this is not true anymore. I showed that when the transmitter and receiver were placed in the same living room, in sight of each other, the power decayed with a value of **m** ranging of 1.5 to 1.8. when the receiver was located within a room off the hallway, ***m*** ranged from **3** to **4.**

The path loss also varies with frequency. The measurement results indicate that loss through floors is greater at the higher frequency. It is found that at wavelengths in the millimeter range the radio wave cannot penetrate most common building materials such as brick and concrete block and that signal attenuation occurs more rapidly with distance [5]. Therefore the millimeter waveband seems to be a good choice for providing broadband services in a high-capacity frequency-reuse environment. The equation for FSPL is

$$\begin{aligned}\mathrm{FSPL} &= \left(\frac{4\pi d}{\lambda}\right)^2 \\ &= \left(\frac{4\pi d f}{c}\right)^2\end{aligned} \qquad (3.2)$$

Where:

- λ Is the signal wavelength (in meters),
- f Is the signal frequency (in hertz),
- d Is the distance from the transmitter (in meters),
- C is the speed of light in a vacuum, 2.99792458 × 10^8 meters per second.

Alexandra has given the values of ***m*** according to the building materials used in the environment. The degree 01 signal attenuation depends on the type of materials the signal encounters. Consequently, the construction materials can characterize the signal decay in an indoor environment.

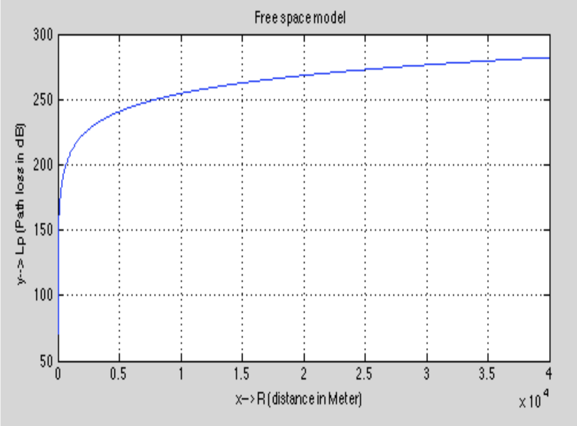


Fig. 3.1 Free Space Path Loss Model

We used visi-site survey software tool to verify the coverage of a specific AP and get a rough idea of the RSS values related to that AP. After covering the distance of 10 meter away from the source. It helps in creating the data for the survey which gives all the information related to wifi signals.

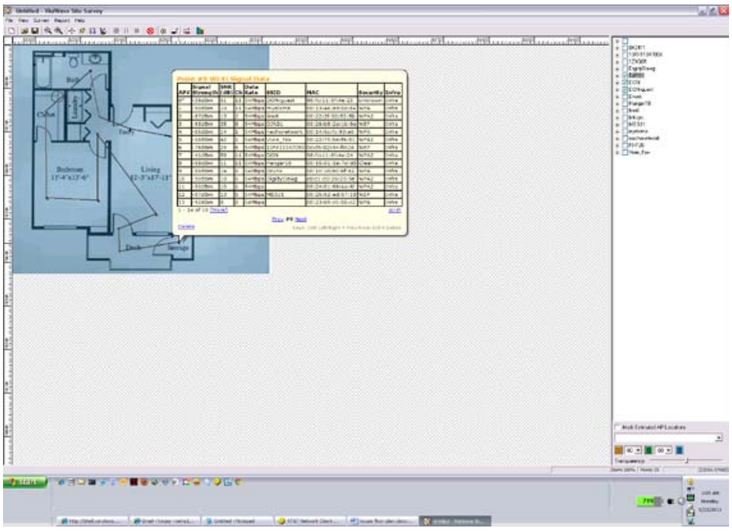


Fig. 3.2 List if AP, SNR, MAC, SSID etc.

The Fig. 3.1 shows that in free space there is no loss of data between the transmitted signal and receiver signal. The Fig. 3.2 shows AP list also contain MAC address, Max SNR, Min SNR, Avg. SNR.

3.2. EMPIRICAL MODELS

Both theoretical and measurement based propagation models indicate that average received signal power decreases logarithmically with distance. Empirical models help in reducing computational complexity as well as increasing the accuracy of the predictions [6]. The empirical model used in this study is Log-distance Path Loss Model.

3.2.1 Log-distance Path Loss Model

In both indoor and outdoor environments the average large-scale path loss for an arbitrary Transmitter-Receiver (T-R) separation is expressed as a function of distance by using a path loss exponent, n [10][9]. The average path loss PL(d) for a transmitter and receiver with separation d is:

$PL(dB) = PL(d0) + 10n\log(d), d0$ (3.2)

where n is the path loss exponent which indicates the rate at which path loss increases with distance d. Close in reference distance (d0) is determined from measurements close to the transmitter.

3.2.2 LOG-NORMAL SHADOWING

Random shadowing effects occurring over a large number of measurement locations, which have the same T-R separation, but different levels of clutter on the propagation path, is referred to as Log-Normal Distribution [7]. This phenomenon is referred to as lognormal shadowing. This leads to measured signals, which are vastly different than the average value predicted by (3.2). To account for the variations described above equation (3.2) is modified as:

$PL(dB) = PL(d0) + 10n\log(d) + X\sigma$ (3.3)

where Xσ is a zero-mean Gaussian distributed random variable with standard deviation σ. The close-in reference distance d0, the path loss exponent n, and the standard deviation σ, statistically describe the path loss model for an arbitrary location having a specific T-R separation.

Environment	Path Loss Exponent, n
Free Space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Table 3.1 Path loss exponents for different environments.

3.2.3 TWO-RAY MODEL

Unlike statistical models, site specific propagation models do not rely on extensive measurement, but a greater detail of the indoor environment is required to obtain an accurate prediction of signal propagation inside a building. The received signal Pr for isotropic antennas, obtained by summing the contribution from each ray, can be expressed as

$$P_r = P_t \left(\frac{\lambda}{4\pi}\right) \left[\frac{1}{r_1} e^{(-jkr_1)} + \Gamma(\alpha) \frac{1}{r_2} e^{(-jkr_2)}\right]^2 \qquad (3.4)$$

where Pt is the transmitted power, r1 is the direct distance from the transmitter to the receiver, r2 is the distance through reflection on the ground, and Γ(α) is the reflection coefficient depending on the angle of incidence α and the polarization [8].

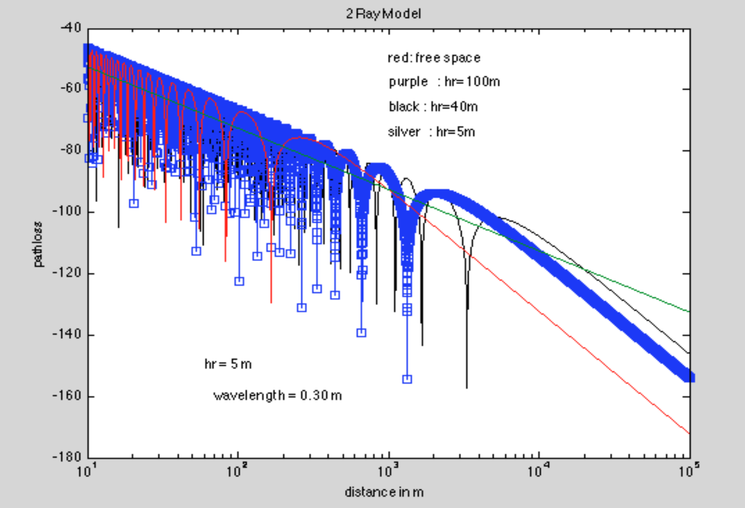


Fig.3.3 Two ray model.

The reflection coefficient is given by

$$\Gamma(\Theta) = \frac{\cos\Theta - a\sqrt{\epsilon_r - \sin^2\Theta}}{\cos\Theta + a\sqrt{\epsilon_r - \sin^2\Theta}}, \qquad (3.5)$$

where $\Theta = 90\text{-}\alpha$ and $a = 1/\varepsilon$ or 1 for vertical or horizontal polarization, respectively. εr is a relative dielectric constant of the reflected surface []. The signal strengths from theoretical and empirical models are compared in this study.

3.3 DETERMINISTIC MODELING APPROACH

Deterministic or semi-deterministic models are primarily based on electromagnetic wave propagation theory being as close to physical principles as possible. Most of the models known as ray tracing or ray launching are based on geometrical optics. Some simplifications lead to viewing the radio wave propagation as optical rays. It can be seen that diffraction and wave guiding effect of the corridor are considered. Since the multipath propagation can be fully de- scribed, other space-time properties like time delays; angles of arrival etc. can be determined. On the other hand, for a common planning only the propagation loss is sufficient and the cost for the accuracy is enormous [4][7].

3.4. PARTITIONED MODEL

These models are very easy and fast to apply because the prediction is usually obtained from simple closed ex- pressions. Also requirements on the input environment description are “reasonable”. But, at the same time, only the propagation loss without great site-specific accuracy can be predicted.

3.4.1 SINGLE-GRADIENT MULTI-FLOOR (SGMF) MODEL

The idea behind this model is that the distance dictates if the AP and receiver are located on the same floor the path-loss from the AP to the receiver using a distance power-gradient. The path-loss in the SGMF model is given by

$$Lp=L0+Lf(n)+10a *\log(d) \qquad (3.6)$$

Where L0 is the path-loss over the first meter, Lf (n) is the attenuation attributed to each floor, n is the number of floors between the transmitter and receiver, α is the distance- power gradient, and d is the distance between the transmitter and receiver [8]. The Table 3.2 gives the set of parameters suggested for three different environments.

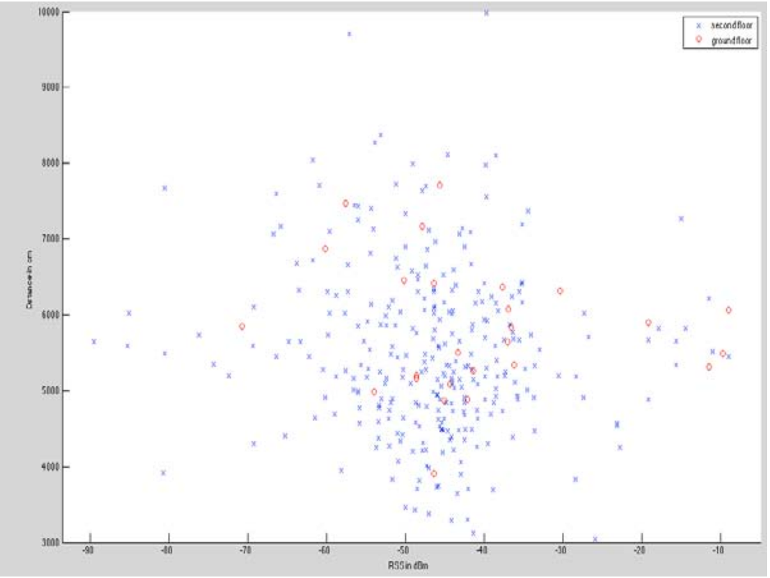


Fig.3.4 The performance of the second floor and ground floor

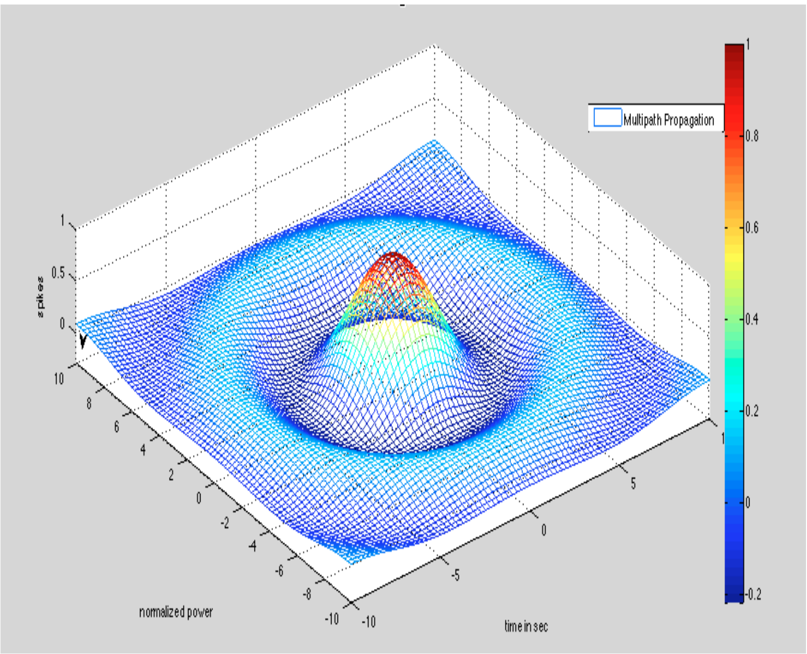
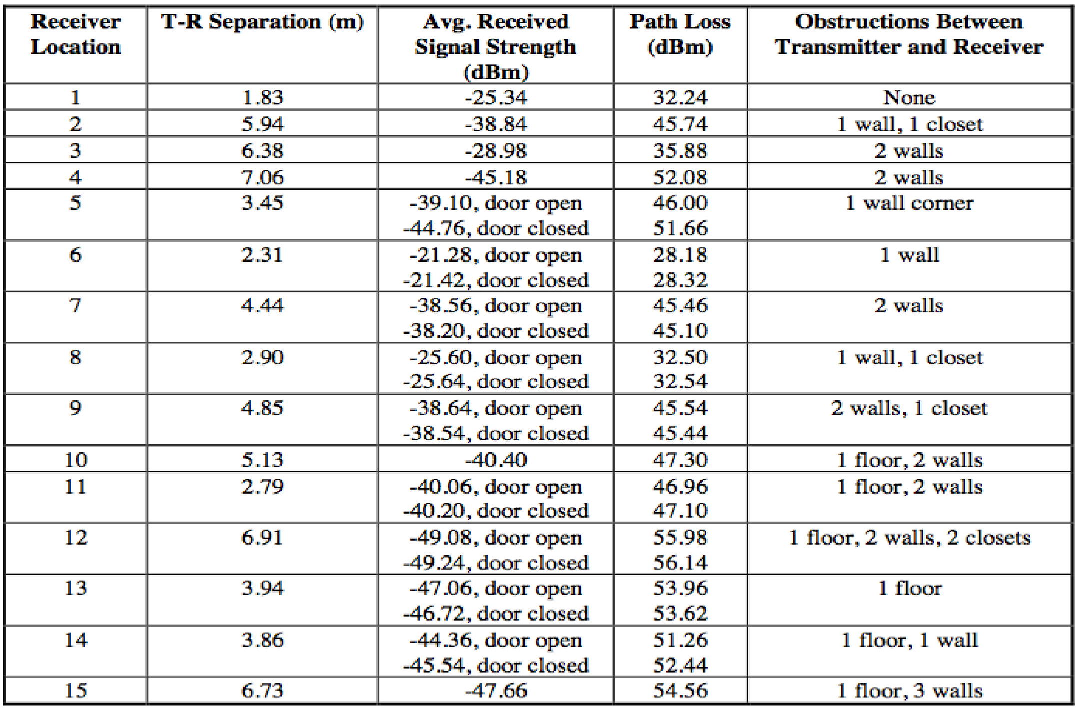


Fig.3.5 Signal Strength for SGMF



Receiver Location	T-R Separation (m)	Avg. Received Signal Strength (dBm)	Path Loss (dBm)	Obstructions Between Transmitter and Receiver
1	1.83	-25.34	32.24	None
2	5.94	-38.84	45.74	1 wall, 1 closet
3	6.38	-28.98	35.88	2 walls
4	7.06	-45.18	52.08	2 walls
5	3.45	-39.10, door open -44.76, door closed	46.00 51.66	1 wall corner
6	2.31	-21.28, door open -21.42, door closed	28.18 28.32	1 wall
7	4.44	-38.56, door open -38.20, door closed	45.46 45.10	2 walls
8	2.90	-25.60, door open -25.64, door closed	32.50 32.54	1 wall, 1 closet
9	4.85	-38.64, door open -38.54, door closed	45.54 45.44	2 walls, 1 closet
10	5.13	-40.40	47.30	1 floor, 2 walls
11	2.79	-40.06, door open -40.20, door closed	46.96 47.10	1 floor, 2 walls
12	6.91	-49.08, door open -49.24, door closed	55.98 56.14	1 floor, 2 walls, 2 closets
13	3.94	-47.06, door open -46.72, door closed	53.96 53.62	1 floor
14	3.86	-44.36, door open -45.54, door closed	51.26 52.44	1 floor, 1 wall
15	6.73	-47.66	54.56	1 floor, 3 walls

Table.3.2 Measurement for RSS values at first floor.

Fig. 3.4 displays that the performance of the signal strength with distance at second floor and ground floor. This graph shows that the performance of second floor is better than ground due to the presence of two AP’s at the same time. For showing the performance of first floor we used MATLAB in Fig. 3.5.

The formula for the SGMF+BP model is given by:

$$L_p = L_0 + L_f(n) + 10\alpha_1 \log(d_{wbp}) + 10\alpha_E \log\left(\frac{d}{d_{wbp}}\right) \qquad (3.7)$$

Where Lp is the path-loss over distance d in dB, L0 is the path-loss over the first meter in dB, Lf (n) is the attenuation attributed to each floor, n is the number of floors between the transmitter and receiver, α1, and αE are the distance-power gradients for the respective path sections, and dwbp is the dynamic AP specific wall breakpoint in meters [9].

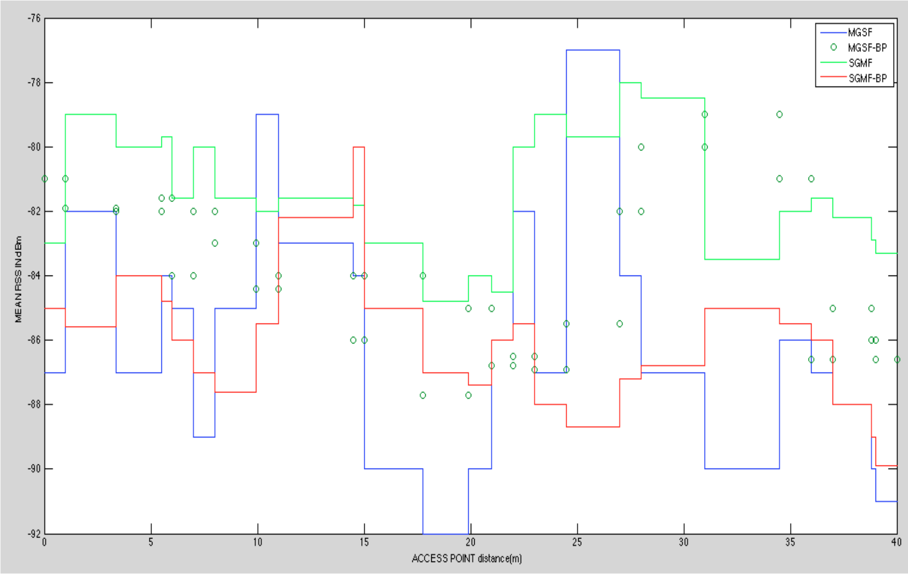


Fig.3.6 Performance of Partitioned Models at first floor

3.4.2 MULTI-GRADIENT SINGLE-FLOOR(MGSF) MODEL

The Multi-Gradient Single-Floor (MGSF) model most recently has been used to model the WiFi propagation path-loss in indoor environments.

The distance partitioned MGSF model,

$$L_p = L_0 + \begin{cases} 10\alpha_1 log\left(d_{wbp}\right) + 10\alpha_E log\left(d / d_{wbp}\right) \ ; d_{bp} > d_{wbp} \\ 10\alpha_1 log\left(d_{bp}\right) + 10\alpha_2 log\left(d_{wbp} / d_{bp}\right) \\ \qquad + 10\alpha_E log\left(d/d_{wbp}\right) \ ; d > d_{bp} \end{cases} \tag{3.9}$$

Where Lp is the path-loss over distance d in dB, L0 is the path-loss over the first meter in dB, α1 and α2 are the distance-power gradients for the path sections one and two respectively, and dbp is the breakpoint distance in meters. Table 4.1 gives suggested parameter sets for three environments defined for 802.11 standard in reference [9][10].

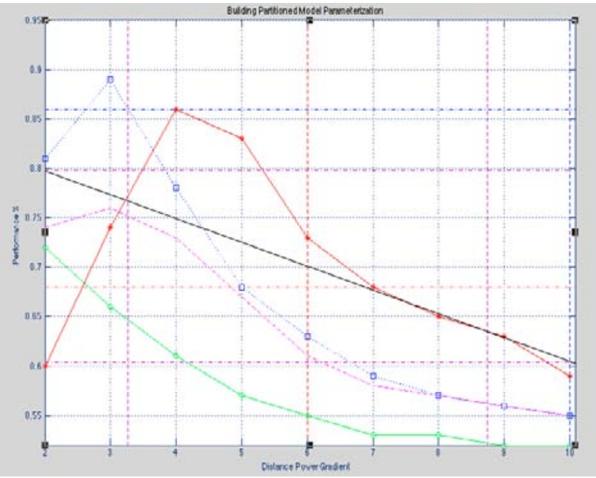
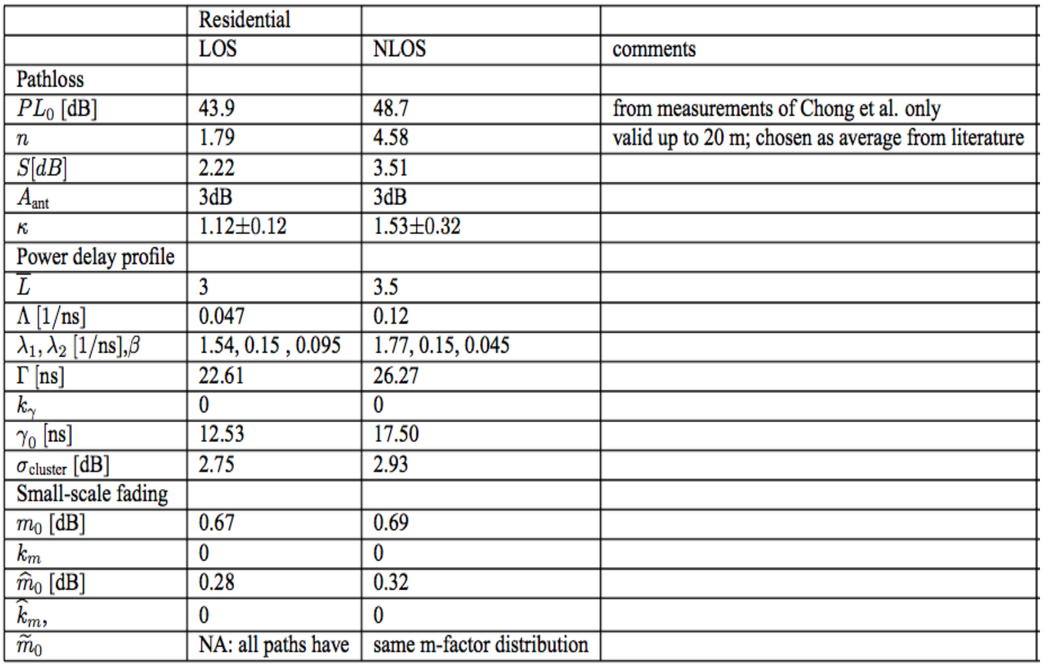


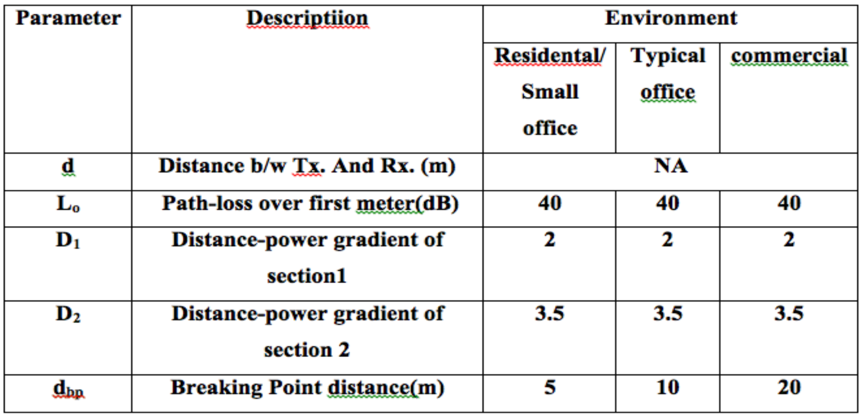
Fig.3.7 Building Partitioned model



	Residential		
	LOS	NLOS	comments
Pathloss			
PL_0 [dB]	43.9	48.7	from measurements of Chong et al. only
n	1.79	4.58	valid up to 20 m; chosen as average from literature
$S[dB]$	2.22	3.51	
A_{ant}	3dB	3dB	
κ	1.12±0.12	1.53±0.32	
Power delay profile			
$\overline{L}$	3	3.5	
Λ [1/ns]	0.047	0.12	
λ_1, λ_2 [1/ns], β	1.54, 0.15 , 0.095	1.77, 0.15, 0.045	
Γ [ns]	22.61	26.27	
k_γ	0	0	
γ_0 [ns]	12.53	17.50	
σ_{cluster} [dB]	2.75	2.93	
Small-scale fading			
m_0 [dB]	0.67	0.69	
k_m	0	0	
$\hat{m}_0$ [dB]	0.28	0.32	
$\hat{k}_m$,	0	0	
$\tilde{m}_0$	NA: all paths have	same m-factor distribution	

Table 3.3 Indoor Residential LOS and NLOS values

The MGSF+BP model's distance-power gradient was larger than the internal path distance-power gradient, which does not fit with the known path-loss environment. The interior paths should have higher path-loss due to interior wall and other physical obstructions. Fig.3.7 displays the building portioned model with the help of Table3.3 and Table 3.4.



Parameter	**Descriptiion**	**Environment**		
		Residental/ Small office	**Typical office**	**commercial**
d	**Distance b/w Tx. And Rx. (m)**	**NA**		
L_o	**Path-loss over first meter(dB)**	**40**	**40**	**40**
D_1	**Distance-power gradient of section1**	**2**	**2**	**2**
D_2	**Distance-power gradient of section 2**	**3.5**	**3.5**	**3.5**
d_{bp}	**Breaking Point distance(m)**	**5**	**10**	**20**

Table 3.4 MGSF standards for calculations

The First floor of the building taken into consideration for the MGSF model. In this we selected some distance from AP to calculate the path loss model in this area. Three AP's is assigned nearby so that the signal for each AP will be approximately same. In Fig.3.8 the performance of partitioned models will be differ in single floor with multiple floors. The distance-power gradient for this model is most likely artificially high due to the absence of the exterior wall path-loss and should result in lower performance than the other model with the exterior wall path-loss.

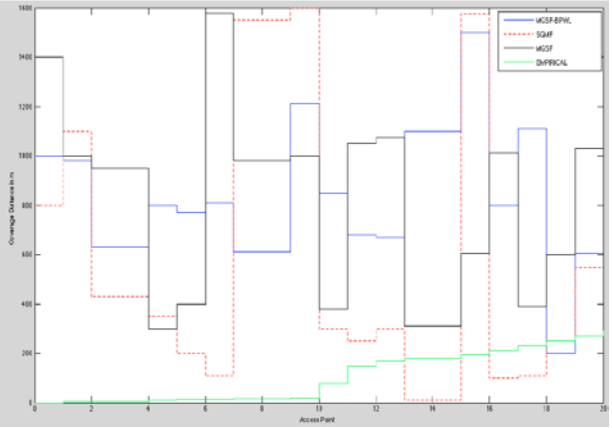


Fig.3.8 Coverage distance model prediction to empirical data comparison for each AP

The over predicted coverage could also be attributing to the higher mean RSS predicted by the models. Fig.3.9 and Fig.3.10 Signal Strength for MGSF and MGSF-BP. To overcome this short fall the footprints of the surrounding building could be added to future models.

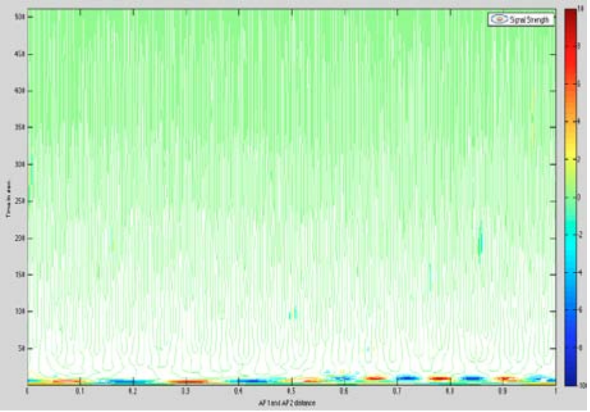


Fig.3.9 Signal Strength for MGSF

5. RESULT ANALYSIS

In this paper, we have pointed out the importance of propagation models in the development of indoor wireless communications. Propagation models provide estimates of signal strength and time dispersion in many indoor environments. These data are valuable in the design and installation of indoor radio systems. Site-specific propagation modeling by solving Maxwell’s equations is costly and impractical. The inclusion of diffraction theory can broaden its application to lower radio frequencies. The accuracy of ray-tracing techniques depends heavily on the accuracy and detail of the site-specific representation of the propagation medium. The SGMF model had a higher peak performance but the MGSF model had a slightly higher mean performance. The two methods for the design of large wireless local area networks site survey and software planning were compared. The drawbacks of site survey due to the time and space-varying environment were investigated using a simple experiment. The overview of available propagation models and its usage was given.

REFERENCES

1. SUZUKI, H.: ‘A statistical model for urban radio propagation’, *IEEE Trans. Communication* July 1977,COM-25, pp.673-680
2. HASHEMI, H.: ‘Simulation of the rural radio propagation channel’, *IEEE Trans. Veh. Technol.,* August 1979, VT-28, pp.213-224
3. BAJWA,AS.: ‘UHF wideband statistical model and simulation of mobile radio multipath propagation effects’, *IEE Proc. F.,* August 1985,132,(51,pp.327-333
4. RAPPAPORT, T.S., SEIDEL. S.Y., and SINGH, R : ‘900 MHz multipath propagation measurements for US digital cellular radio telephone’, *IEEE Trans. Veh. Technology* May 1990, VT-39, (2). pp.132-139
5. RAPPAPORT, T.S., SEIDEL, S.Y., and TAKAMIZAWA, IC: ‘Statistical channel impulse response models for factory and open plan building radio communication system design’, *IEEE Trans. Communication* May 1991.39, (5). pp.794-807
6. HASHEMI, H., THOLL. D., and MORRISON, G.: ‘Statistical modeling of the indoor radio propagation channel part I’. Proc. IEEE Vehicular Technology Conference, WC’92, Denver, CO, May 1992, pp.33&342
7. HASHEMI, H., LEE, D., and EHMAN. D.: ‘Statistical modeling of the indoor radio propagation channel: part 11’. Proc. IEEE Vehicular Technology Conference, WC’92, Denver, CO.,May 1992,pp.839843
8. HASHEMI, H.: ‘Impulse response modeling of indoor radio propagation channels’, *IEEE J. Sel. Areas Communication* September 1993,SAC-11,pp.1788-1796
9. Ben Slimane, S. & Gidlund, “Performance of wireless LANs in radio channels”, *IEEE Multi-access, Mobility and Telegraphic for Wireless Commun*ication December 2000, 5, 329-40.
10. MCKOWN, J.W., and HAMILTON, R.L.: ‘Ray tracing as a design tool for radio networks’. *IEEE Network,* November 1991,5, (6),pp.27-30
11. www.metageek.net/products/inssider
12. www.earth.google.com/
13. www.visiwave.com/