Enhancement and Characterization of Indoor Propagation Models

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Abstract - Radio signal attenuation and path losses depend on the environment and have been recognized to be difficult to calculate and predict. Past studies of the signal propagation, in an indoor environment have used several models with varying degrees of success and complexity. The aim of this paper is, by a precise description of the analytic model for an indoor environment, and uses it for determining the signal strength in an indoor environment. From the characterization, we propose improving existing channel models by building partitioning technique. Experimental data in this paper were processed in MATLAB. The result shows that the RSS values Vs distance help in determine Path Loss, Free Space path Loss, The results explains the variation in multi-wall model and single wall model, comparison between the empirical model with building partitioned model.

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

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1. INTRODUCTION

Recently wireless local area networks (WLANs) have emerged as flexible communication systems, which have been implemented as an extension or alternation for a wired LAN within buildings. Using electromagnetic waves WLANs transmit and receive data over air interface, minimizing need for wired connection, thereby it enables user mobility in covered area without losing connectivity to the backbone net [1].

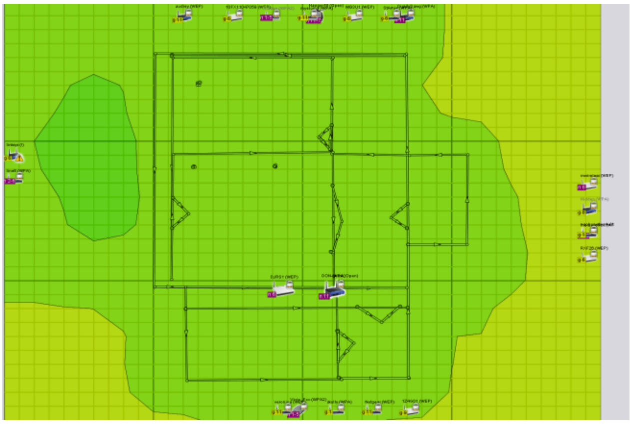


Fig. 1. Example of predicted coverage of WLAN APs

In such cases, a model of the environment is a useful design tool in constructing a layout that leads to efficient communication strategies [2]. For the indoor environment, there are two types of elements; namely static and dynamic elements. The static elements are such as natural and manmade materials. The dynamic element comprises of moving objects.

The IEEE 802.11 standard is divided into two main layers: the Medium Access Control layer (MAC) and the Physical Layer (PHY). These two layers allows a functional separation of the standard and, most importantly allow a single data protocol to be used with several different RF transmission techniques.

In this thesis basically there are two approaches. The first is 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. The database is later used to determine the location of a mobile device by a particular pattern-matching algorithm [4]. The second method comprises of software planning using propagation models. Angle of Arrival (AOA) refers to the method that the position of a mobile device is determined by the direction of the incoming signals from other transmitters whose locations are known. Once a propagation model has been verified, an environment can be quickly entered into such a model to provide propagation characteristics for initial evaluation.

2. Site Survey

I began research by measuring signal strengths in an open corridor in the Master's Loop Building. At different location, 200 readings of the signal strength were taken. From these readings, I obtained the average signal strength as well as the standard deviation at each location. The building partitioned method made use of site-specific information readily available from Google EarthTM to find the coordinates of the building footprint containing the AP with the help of GPS.

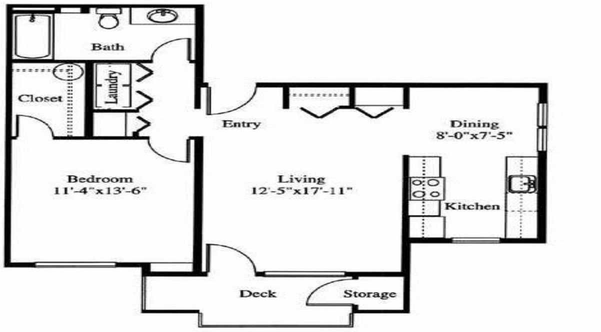


Fig.2.1 Floor Plan of experimental area

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. 2.2 Coverage area of Indoor dimensions.

The experimental area shown with the help of Google Earth in Fig. 2.2. So, the main goal of a site survey is to measure enough information to determine the number and placement of access points that provides adequate coverage.

2.1 Visualize wireless network and Signal Strength

Wi-Fi wireless networks are everywhere. VisiWave Site Survey provides advanced data collection and visualization capabilities that form a complete wireless [11]. Visualize all Wi-Fi Networks: Ekahau HeatMapper will display the coverage area of all the access points in the area on a map. Fig.2.1 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.

Fig.2.3 The amplitude of signals varies for different AP's.

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 [12]. Find Security Problems and Open Networks: HeatMapper displays if there are security issues in some networks, and shows the location of unsecured networks.

2.2 Propagation Characteristics:

Between transmitter and receiver, the wireless channel is modeled by several key parameters. Different kinds of fading occur; they are often separated in three types [10][7].

a. Distance Dependence

The path loss is approximated by

$$PL = PL0 + 10n \times log\ (d) \qquad (1)$$

where n is the path loss exponent, which varies with terrain and environment.

b. Large-scale Shadowing

It causes variations over larger areas, and is caused by terrain, building, and foliage obstructions. This means that its attenuation x measured in dB is normally distributed N (m, σ), with mean m and standard deviation σ. The probability density function of x is given by the usual Gaussian formula:

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} \times \exp \frac{-(x-m)^2}{2\sigma^2} \qquad (2)$$

c. 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 [3].

3. Related Work:

We began our analysis by looking for a relationship between the RSS and the distance between the AP and the measurement point. In simple channel models the RSS is calculated as a function of the distance between the AP and the receiver.

3.1 Estimation of Path Loss Exponent:

The mean path loss exponent 'n' is computed from the measured data using linear regression such the difference between measured and estimated received power is minimized in a mean square error sense over a wide range of measurement locations and T-R separations [5]. For these data, a 1m-reference distance was chosen and we assume PL□d0 □□is due to free space propagation from the transmitter to a 1m-reference distance. Taking into account antenna gains (6 dBi) and system cable losses (17 dB) for our system, this leads to 41.9 dB at 2.4GHz over a 1m free space loss. The measured value is found to be 46.0 dB, which has a difference of 2-5 decibels nominally. The results obtained from the measured data, n is estimated to be 3.25. The equation for FSPL is

$$\mathrm{FSPL} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi d f}{c}\right)^2 \qquad (3)$$

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.

For propagation distances *d* much larger than the square of the antenna size divided by the wavelength, the far field of the generated electromagnetic wave dominates all other components.

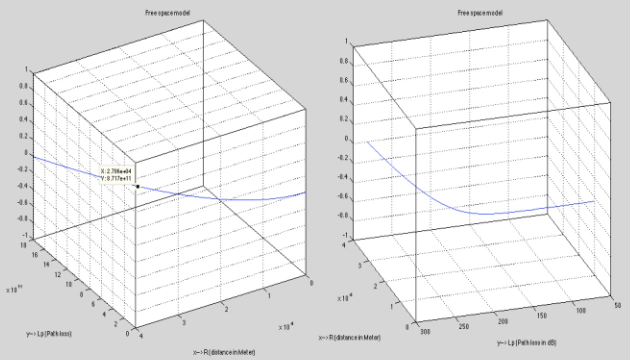


Fig. 3.1 Free Space Path Loss Model in 3D by changing X-y axis.

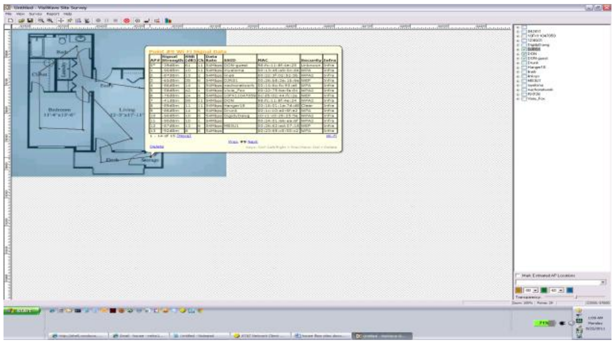


Fig. 3.2 List if AP, SNR, MAC, SSID etc.

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. We used this software 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. Similarly, we can check our signal strength of the particular AP with the help of VisiWave Survey to check the accuracy of the result. We can see that the RSS values from that AP are getting weaker as we move away from it, i.e. from the first floor to the ground floor of the building and from front to the back of the building.

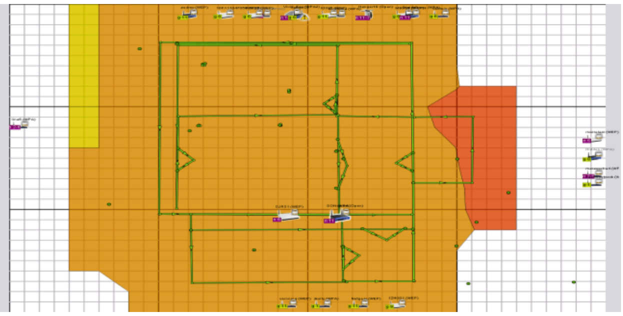


Fig. 3.3 Weak AP signal at the second floor

	AP1	AP2	AP3	
MAC	98:fc:11:8f:4e:24	98:fc:11:8f:4e:25	00:26:b8:2e:1b:6e	Distance In meters
SSID	DON	DON-GUEST	DJRS1	
Channel	11	11	6	
SIGNAL STRENGTH IN dBm	-38	-39	-66	1
	-38	-41	-66	2
	-39	-46	-60	3
	-37	-44	-59	4
	-36	-43	-61	5
	-35	-42	-61	6
	-42	-48	-54	7
	-38	--55	-60	8
	-40	-54	-60	9
	-37	-51	-60	10

Table 3.1 AP's signal strength with 1door and all windows closed.

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 as in Fig. 3.3, with the help of Table 3.1 and Table 3.2. It helps in creating the data for the survey which gives all the information related to wifi signals.

In free space, the power radiated by an isotropic antenna is spread uniformly and without loss over the surface of a sphere surrounding the antenna. An isotropic antenna is a hypothetical entity!! Even the simplest antenna has some directivity. For example, a linear dipole has uniform power flow in any plane perpendicular to the axis of the dipole (Omni directionality) and the maximum power flow is in the equatorial plane.

The received signal shows the variation with distance in cm. Second way to collect the data is the distance of the transmitted power from the AP and the receiving power of the signal with the help of Internet speed. The data collected at the ground floor of the building where AP2 placed. If they are both indoors the strongest signal path is most likely through the floors between the AP and receiver, but if the receiver is outdoors then the strongest signal path is more likely to be through the exterior wall for example through a window.

Survey Information	
Number of Wifi data points	39
Number of Data Points (Associated)	39
Number of Spectrum Data Points	0
Number of AP readings taken	1459
Ave. number of AP's seen at every Point	11.8
Channel seen (% of AP readings)	1(17%), 2(8.5%), 6(28.1%), 8(4.4%), 11(42.0%)
Data rate seen (% of AP readings)	54Mbps(100.0%)
Number of AP discovered	15
Total number of Points (Ignore AP filter)	39
Survey Trail Length	11659ft
Distance between all Data points	14549ft
Ave. distance between all data points	373.05ft

Table 3.2 Survey Information

3.2 Experimental Setup:

Four different scenarios are considered for measurements. The scenarios used will help in developing signal loss equations, by which a generalization for propagation in an indoor environment at 2.4 GHz can be obtained. The scenarios are described as follows:

- Closed Doors and Windows: The closed doors and windows are used for signal measurements. There are two main doors and 4 windows are closed.
- Open corridor: An open corridor is used for signal measurements. The corridor is open on one side and closed with a wall on the other side. This corridor is 13′7″ high and 15′7″ wide. Path loss exponent (n) is 1.688 for AP1 and 1.63 for AP2. Standard deviation (σ) is 3.5773 for AP1 and 3.2642 for AP3.
- Living room: A living room with furniture is considered for signal measurements. This room is 11′-2″X13′-8″. Path loss exponent (n) is 1.258 for AP1 and 1.263 for AP2. Standard deviation (σ) is 3.7607 for AP1 and 4.053 for AP2.

3.3 Computational Setup:

Initially set the number of APs to 1: N = 1; then the necessary number of APs is found through the following steps.

1) Solve the constraint condition of path loss for each receiver using equation (3);
2) Solve the power received by an antenna in free space using equation (4);
3) If the solution exists, then *N* is the desired number;
4) Otherwise, *N* is increased by 1: *N*= *N* +1; 5) Gotostep1.

4. Propagation Models

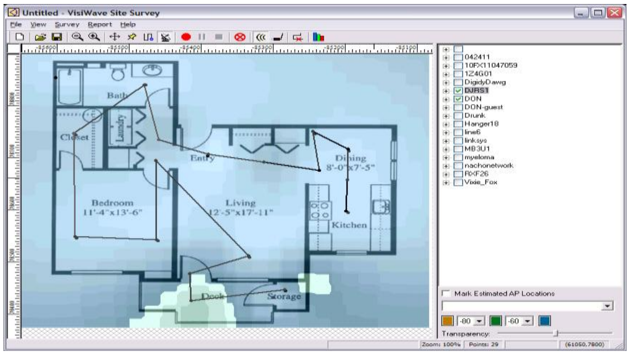
Propagation models provide estimates of signal strength and time dispersion in many indoor environments. These data are valuable in the design and installation of indoor radio systems. Just a few years ago, actual channel measurements were the principal source of information about the characterization of indoor radio propagation.

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

$$Lp=L0+Lf(n)+10a *\log(d) \qquad (4)$$

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.



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☐ DigidyDawg
☑ DJRS1
☑ DON
☐ DON-guest
☐ Drunk
☐ Hanger18
☐ line6
☐ linksys
☐ MB3U1
☐ myeloma
☐ nachonetwork
☐ RXF26
☐ Vixie_Fox

Fig.4.1 AP1 and AP2 Signal Strength

The Table 4.1 gives the set of parameters suggested for three different environments. Fig. 4.1 and 4.2 shows the area under the influence of 1 AP at the floor.

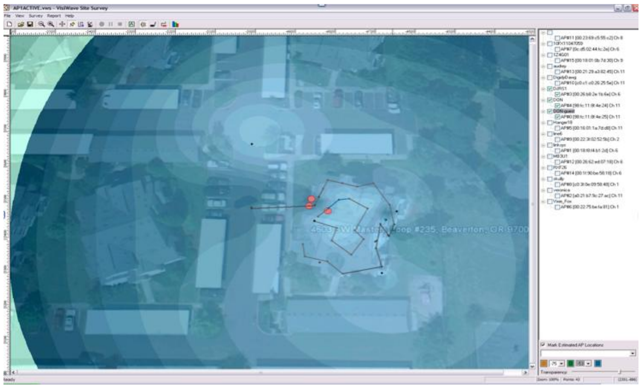


Fig.4.2 Single Gradient model with tracking points

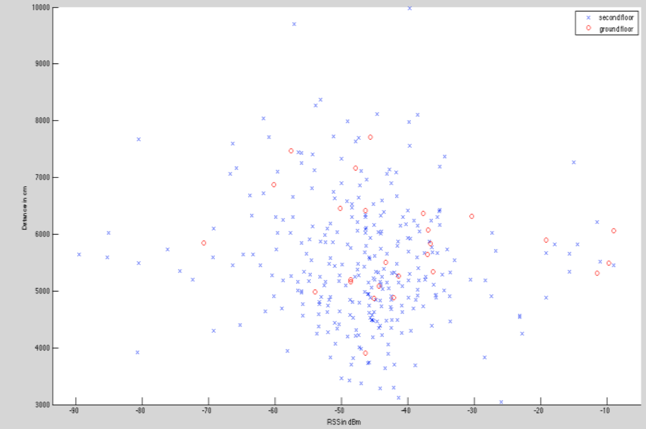
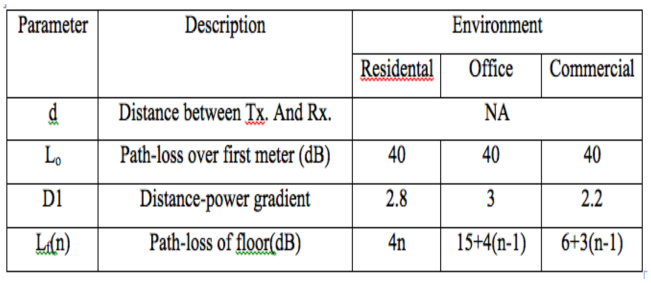


Fig.4.3 The performance of the second floor and ground floor



Parameter	Description	Environment		
		Residental	Office	Commercial
d	Distance between Tx. And Rx.	NA		
L_0	Path-loss over first meter (dB)	40	40	40
D1	Distance-power gradient	2.8	3	2.2
$L_f(n)$	Path-loss of floor(dB)	4n	15+4(n-1)	6+3(n-1)

Table 4.1 Single Gradient MultiFloor Models

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

$$L_p = L_0 + L_f(n) + 10\alpha_1 \log(d_{wbp}) + 10\alpha_E \log\left(\frac{d}{d_{wbp}}\right) \qquad (5)$$

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 [6].

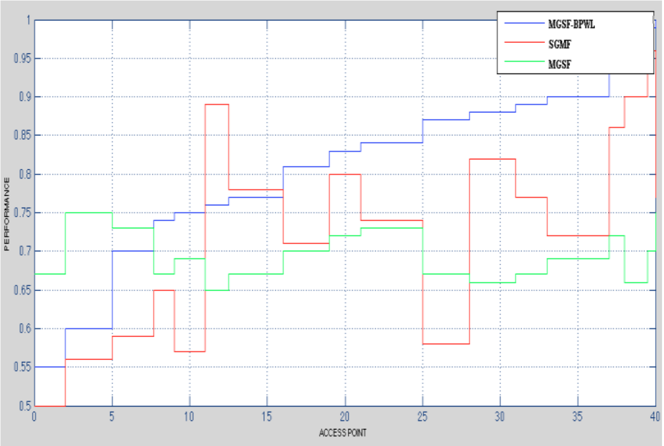


Fig.4.4 Performance of Models with AP

We then add the exterior wall penetration loss to the SGMF+BP to produce a model we denote as SGMF+BPWL. The SGMF+BPWL formula is given by

$$L_p = L_0 + L_f(n) + 10\alpha_1 \log(d_{wbp}) + 10\alpha_E \log\left(\frac{d}{d_{wbp}}\right) + L_W \qquad (6)$$

Where Lw is the path-loss for the exterior wall in dB. The values of the power decay factor *n* vary depending on the type of building and indoor environment. The value *n* = 2 correspond to the propagation in free space. Values smaller then 2 are utilized for prediction of the signal propagation in corridors, where the decrease of the power decay factor is caused by a wave-guiding effect [9].

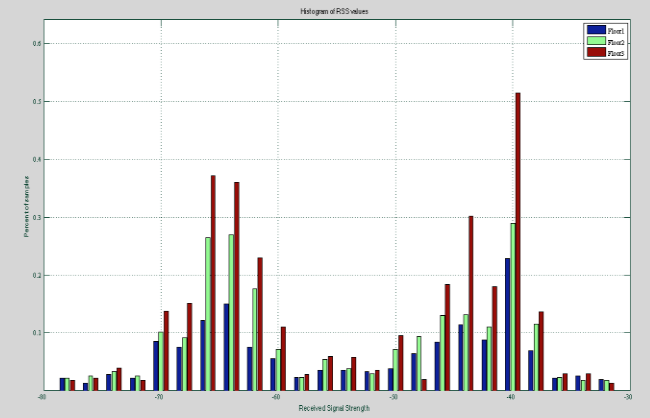


Fig.4.5 Performance of signal strength at each floor

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,

$$L_p = L_0 + \begin{cases} 10\alpha_1 \log(d) & ;d<d_{dp} \\ 10\alpha_1 \log(d_{bp}) + 10\alpha_2 \log(d/d_{dp}) & ;d>d_{dp} \end{cases} \qquad (7)$$

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 [8].

Wall Material	Thickness	K=1
Plywood	0.4 cm	L_{w11}=0.9dB
Rough Clipboard	1.5cm	L_{w21}=3.0dB
Glass Plate		L_{w31}=1.0 dB
Double-Glazed window with a 12mm air layer	2.0 cm	L_{w41}=2.5dB
Concrete block wall reinforced	30.2 cm	L_{w51}=12dB
Max. Thickness of Plaster	13.5cm	L_{w61}=10dB

Table 4.2 MGSF standards for calculations

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 4.3 multiple floor single gradient

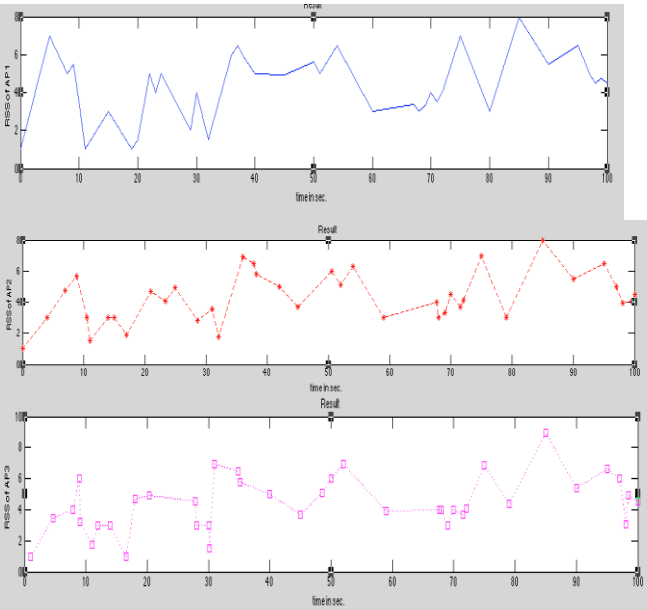


Fig. 4.6 Variation of AP's with time

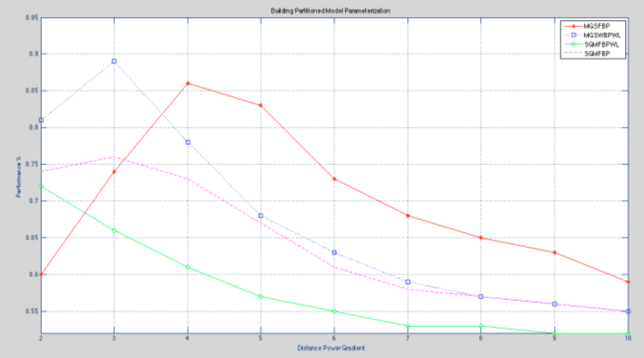


Fig. 4.7 Building Partitioned model performance

5. Result Analysis

Signal Strength measured at the first floor of the Master's Loop Building, which shows the tracking data as well. 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.

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