ANALYSIS AND MEASUREMENT OF WI-FI SIGNALS IN INDOOR ENVIRONMENT

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ABSTRACT

The measurement and analysis of radio waves propagation play significant part in the plan and function of WLAN applications. This paper provides an overall coverage of the Wi-Fi in the indoor environment. In this paper radio waves propagation for indoor environments will be considered using the Wireless LAN 802.11b/g at the frequency of 2.4 GHz. This paper involves the study of the effect on building's structure and materials used within the access points set up at different locations and obtaining Wi-Fi measurements and comparing them with values predicted by classical model such as ITU Indoor Propagation Model. Measurements of signal strength using the Wi-Fi card utility will be carried out in the research. The aim of this paper is to study the conduct of signal strength when it travels through line of sight (LoS) and non-line of sight (NLoS) and results will be compared with an Indoor site general model of ITU.

KEYWORDS: *Measurement of Signals, Antennas & Propagation, WLAN, Radio Wave Propagation, Wi-Fi.*

I. INTRODUCTION

The fundamental components on which WLAN is composed of, are access points (AP) and the mobile clients (MC), typically a laptop or a PDA with a WLAN card. While for wired network communications, Ethernet cables are laid down all over the building and subsequently different buildings are linked to each other by using fibre optics. In Wireless LAN, in order to make a network infrastructure APs are positioned at different place all over a building and also if needed in outdoors as well. Then mobile clients communicate with each other by first communicating to the access points and then to the outer world.

A major principle of WLAN communication is that, network data is transmitted as modulated electromagnetic waves using antenna.

When radio waves transmit or travel from one device to another there are several issues one has to highlight. The radio energy attenuates as it propagates and when it passes through obstacles like glass, wood, concrete and metal surfaces. The mechanisms that occur when radio waves propagate: NLOS, reflection, diffraction and scattering. Scattering occurs when RF can reflect over obstacles which has rough surfaces and after reflecting the signal is dispersed which results in fading of signal.

In this paper the radio waves propagation will be investigated using the Wireless LAN 802.11b/g operating at frequency of 2.4 GHz. The paper involves the study of signal strength according environment of access points of Wi-Fi deployed in selected building for experiments. And also the effect of materials (glass, wood, and brick) on Wi-Fi signals in these buildings will be studied and reported. [1] – [4]

The goal of this research are to examine the propagation for WLAN 802.11b/g and involves the measurement and analysis of signal strength in various buildings selected for experiment by taking account the effect of surrounding environment on Wi-Fi at that particular location. In other words this research intends for a site general signal strength study and then the observation of the effect of obstacles (wood, glass and brick etc.) and other factors such as the presence of people.

II. WIRELESS LOCAL AREA NETWORK (WLAN) STANDARDS

Mostly wireless network equipment is subject to IEEE standardization. The IEEE standards for wireless LAN s describe the specifications for the physical layer and the Wireless LAN Medium Access Control (MAC) Layer. The standards describe these layers in detail in order to allow maker to use it as a directive for manufacturing wireless LAN card. There are different standards that are described as following: [4]

802.11 Standard

This is the initial standard which is not applicable to new products but it is found in several existing systems. Its main features include:

Direct Sequence (DS) and Frequency Hopping (FH)

Data rate of 2 Mbps using the 2.4 GHz frequency.

802.11b Standard

This is the current standard used, mostly in Europe It is backward compatible to 802.11 (DS)

Its main features include:

Direct Sequence (DS)

Data rate of 11 Mbps using 2.4 GHz.

802.11a Standard

This is the new standard, already available in the United States, but mostly not in Europe. The (American) 802.11.a Standard includes the following main features:

Orthogonal Frequency-Division Multiplexing

Data rate of 54 Mbps, using 5 GHz.

802.11g Standard

It is a standard that supports a higher data rate for 2.4 GHz spectrum by doubling the data rate. Offering compatibility with existing 802.11b systems. It has the following features:

Data rate of 22 Mbps with 2.4 GHz.

IEEE 802.11b/g

The 802.11g which has more data rate 53 Mb/s as compare to 802.11b with similar 2.4 GHz band the 802.11b/g become a power full Wireless LAN.

It has following main features:

ODDM – DSSS

Data Rate of 54 Mbps

Backward compatible to 802.11a

ETSI encourage deploying this standard in Europe as newer devices are coming in market with this standard. [4]

IEEE 802.11.n

The 802.11.n uses MIMO technology. It is a new technology with enhanced features like it can choose two frequency bands of 2.4 GHz as well as 5 GHz and with improved data rate. It has a data rate of 300 Mbps with a throughput of 144 Mbps. Also the range is also increased to more than 300 m in outdoors. The Standards describe these layers in detail in order to allow chip manufacturers to use it as a guideline for producing wireless LAN chips and cards. From the various types of WLAN standards, the 802.11b/g was chosen for the propagation prediction and measurements because primary it is been implemented wholly in the selected buildings and secondly due to less operating frequency the losses are less as compare to other frequencies and it provides mental satisfaction to the end user due to its cheap price and productivity of deployment. [4]

III. RADIO WAVE PROPAGATION

"Understanding of propagation radio signals is necessary for coming up with appropriate design, deployment, and management strategies for any wireless network. Radio propagation is to a great extent site-specific and varies considerably depending on the nature of area, frequency of operation, velocity of the mobile terminal, interface sources, and other dynamic factors. Precise classification of the radio channel through main parameters and a mathematical model is important for predicting signal coverage, data rate, effect of obstacles and determining the best position for installing base station".[4]

Propagation measurement means to calculate the field strength value from a transmitter at a given distance with a particular receiver, as every mobile client does not have a wireless utility. Propagation Path Loss is the loss rate when electromagnetic wave propagates from a transmitter to a receiver as transmitter propagates radio signals to all direction and receiver is located somewhere in the surrounding environment, and the ratio of received power to the transmitted power could be 1/100 meaning that the power of the signal is decreased to one hundredth of its original value at the transmitter. Field strength and received power values can easily be calculated from path loss by using the antenna parameters. Usually path loss is expressed in dB. The dB value of any variable X is given by: [5] - [6]

$$\mathrm{X(dB)} = 10\log(\mathrm{X})$$

3.1 Free Space Path Loss

Free space path loss is given as:

$$\mathrm{Loss} = \frac{\mathrm{P_{transmitted}}}{\mathrm{P_{received}}} = \frac{(4\pi)^2 \mathrm{d}^2}{\mathrm{GtGr}\lambda^2}$$

Where
Gt = Gain of the transmitter antenna
Gr : Gain of the receiver antenna
λ : Wavelength of the transmission (m)
d : Distance between the transmitter and the receiver (m)
In dB scale it is equal to

$$Loss = 20\log 4\pi + 20\log d - 10\log Gt - 10\log Gr - 20\log\lambda \qquad [6]$$

Table I: Typical parameters, based on various measurement results [7]

Frequency	Residential	Office	Commercial
900 MHz	-----	33	20
1.2-1.3 GHZ	----	32	22
1.8 – 2 GHz	28	30	22
4 GHz	-----	28	22
5.2 GHz	-----	31	-----
60 GHz	-----	22	17
70GHz	-----	22	-----

Table II: Floor penetration loss factors [7]

Frequency	Residential	Office	Commercial
900 MHz	———	9(1 floor) 19(2 Floors) 24(3 Floors)	———
2.8 – 2 GHz	4n	15 + 4(n-1)	6+3 (n-1)
5.2 GHz	_____	16 (1 Floor)	_____

Concluding from the above tables it is noted that the distance power coefficient N is more for offices as compared to home and commercial area environments. It is due the fact that the environment of office is very loud due to presence of people and also the office has a certain interior decor which also absorbs some Wi-Fi signals. The office equipment's which are being used e.g. Printer, fax machine, personal computers, telephones and photocopy machines etc. also contribute in effecting the Wi-Fi signals.

In this study only Site- general model has been used to study the behavior of signal strength due to its simplicity. [8]

IV. TOOLS USED

While conducting the experiment, following equipment was used to measure the coverage of Wi-Fi Signals in selected buildings.

- Acer Aspire 5920 Laptop,
- Peak USB wireless adaptor.
- Cisco-Aironet 1130 Access Point

V. METHODOLOGY

I placed the measuring tape on the floor and moved the laptop inch by inch away from the access point in all directions first with a LOS and the for NLOS areas of same access point. Initially I took readings for every 3 cm which is approximately a quarter wavelength of the Wi-Fi signal but it was too time taking and I used to finish a single room in whole day. It was also seen that the signals do not change much for a quarter wavelength, so I increased the step size to half a wavelength (6 cm) but still the reading was too similar to each other then I tried for a single wavelength and took readings for almost all the location with a step size of 12.5 cm because it is good to take readings of one wavelength and if I get large variations or see an abrupt change in the readings in a particular area then I broke my step size to smaller step size as there can be difference of +/- 6 dBm in readings for a single wavelength step size.

As all the access points are installed at some height the Pythagoras theorem was used to obtain the exact distance to the router.

As the reading was obtained on a MS Excel sheet then scatter plot was obtained using a Matlab program and then was compared with ITU as well as Small Zone Indoor Propagation empirical model.

For comparing loss against obstacles, following table will used as a reference to see the difference between practical losses and theoretical value. [9]

Table III: Common objects and corresponding attenuation in dB [7]

	2.4 GHz	5 GHz
Interior drywall	3-4	3-5
Cubicle wall	2-5	4-9
Wood door (Hollow- Solid)	3-4	6-7
Brick/Concrete wall	6-18	10-30
Glass/Window (not tinted)	2-3	6-8
Double-pane coated glass	13	20
Bullet-proof glass	10	20
Steel/Fire exit door	13-19	25-32

5.1 Discussion

The coverage map was drawn at those places where users/students use Laptops/ PDA more frequently. At some point the system receives fair signals; it is due to the fact that different machines produce noise which affects the Wi-Fi signal.

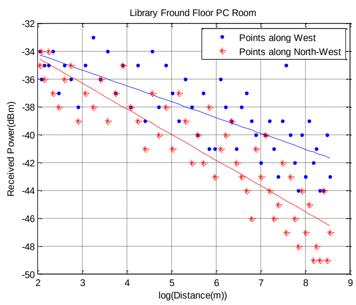

Fig. 1: Scatter Plot of received Power in PC Room at ground floor

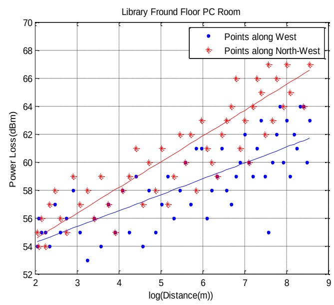

Fig. 2: Scatter plot of Power Loss Vslog(d) in PC Room ground floor

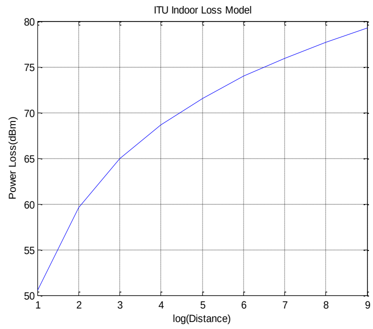

Fig. 3: ITU Loss Model for Indoor environment

While taking the scatter plot of the signals as shown in fig. 1 and fig. 2, for this room the readings were taken first along the West direction (in front of Access Point) and then along the North-West direction. These both reading are in LOS. Now comparing the results with the ITU Indoor propagation model as shown in fig. 3, it has been seen that the ITU loss is more than the measured readings at corresponding distance. As we live in a real world so there should be more losses as expected by ITU model, at 6 along x-axis practical measurement of Power loss is 62 dB while ITU model gives 74 dB. It is due the fact that ITU includes 15 dB as a floor penetration factor but in this case, floor loss was not considered because each of Library floor has got its own access points so that is why the loss seems to be more then what was supposed to be. While seeing the scatter plot in fig. 1 & fig. 2 along x-axis at 2-3, it has been noted that the signal varies more in the near field because this room has PC tables, the signal diffracts by the edges of the tables and there the reflection in signal is produced by the PC screen and also by the nearby painted walls. In the far field along x-axis after 5, the signal varies a little due to the fact that signal has travelled some distance and become stable and direct and reflect rays has very small difference in time when signal reaches at the receiver.[9]

VI. Effect of Glass on Wi-Fi signals in a Group Study room

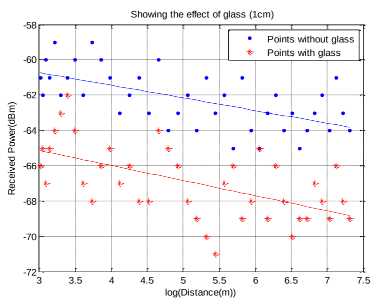

Fig. 4: Scatter plot of Received Power v/s log (distance) at Group Study Room

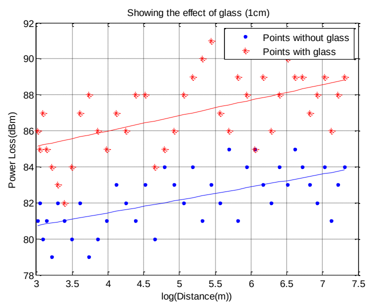

Fig. 5: Scatter plot of Power Loss v/s log (distance) at Group Study Room

6.1 Discussion

In whole building there are many group study rooms. All of these rooms have one wall of glass with aluminum frame. So it was decided to take readings in and out of this room along the glass wall to see the effect of glass on the Wi-Fi Signals. The signals were assumed to come from an AP which is installed behind the second floor lifts.

The glass that is used in this room was 1 cm thick. And it was found that there is a difference of nearly 4 dB in power loss while calculating the loss, with and without glass wall. If the thickness of the glass sheet is increased then the losses due to glass also increases and while at another location in library the thickness is 2 cm and the loss is found to be of 6 dB as concluded from figure 4 & fig. 5.

While comparing to the Table III: the loss due to glass is 2-3 dB. It's because in practical the signal faces other factors like reflection, diffraction & scattering do act their part in decaying of signal as the signal across the glass wall is NLOS. And also Table 3 does not show that what thickness of the glass that this table considers.

As the glass has a shiny surface so signal reflects when it strikes a glass while some signal does pass from the glass. [9]

The slope (m) of curve line for loss with glass wall was found to be 0.8546 with constant of 78.5729 and for without wall m reduces to 0.7174 and constant is 82.5744

So

$$\text{Power} \propto (\text{Distance})^{-\nu}$$

$$\text{Power} = \text{constt} * (\text{Distance})^{-\nu}$$

Applying log on both hand sides

$$\log(\text{Power}) = \text{constt} - \nu \log(\text{Distance})$$

$$\log(\text{Power}) = 82.5744 - 0.7174 \log(\text{Distance}) \text{ without wall}$$

$$\log(\text{Power}) = 78.5729 - 0.8546 \log(\text{Distance}) \text{ With wall}$$

By solving the above equations a model for glass loss can be formed.

VII. EFFECT OF BRICK WALL

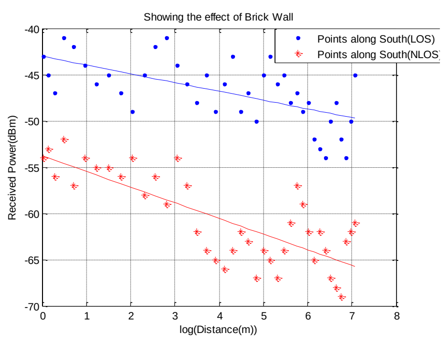

Fig. 6: Scatter plot of Received Power v/s log (Distance) for showing effect of brick wall

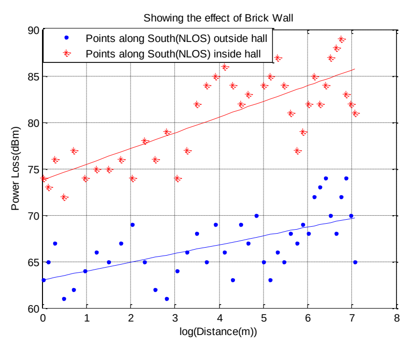

Fig. 7: Scatter plot of Power Loss v/s log (Distance) for showing effect of brick wall

The area of the sports hall is 550 m2. The composition of Sports hall is mainly of brick wall with a polished wooden floor, and the AP which is located near is 2 m high from the ground facing towards West. First readings were taken in passage way and then in the sports hall along south direction. Readings were taken for 8 meters with a step size of one wavelength (12.5 cm). The width of the width wall was measured to be 30 cm.

It has been observed that inside hall there is an increase of almost 10 dB initially while as the readings proceeded further away from the AP the loss tends to increase more as shown in fig. 6 and fig. 7. It is because readings were taken as the receiver was at the floor and the polished surface of wooden floor reflected the signals while the rough surface of the brick wall scatters the Wi-Fi signals. Also as readings were taken along the wall distance between receiver and AP tends be diagonal and thus increases the width of wall and thus the loss increases. While seeing the scatter plot for it has been observed that at 7 along x-axis the difference come out to be almost 16 dB. So it means that as the AP is idle at its position and the receiver is mobile if the ratio between the distance between these two remains constant then the loss also tend to be constant and if its varying like in practical, (the ratio of loss at the beginning and at the end) the loss increases. [9]

While comparing to the Table III: the loss due to brick is 6-18 dB. So here it comes in between the expected losses.

Now forming the power loss line equation.

For NLoS without wall m= 0.9504 & Constt = 63.0107

$$\log(\text{Power}) = 63.0107 - 0.9504 \log(\text{Distance})$$

For LoS with wall m= 1.6926 & constt = 73.7819

$$\log(\text{Power}) = 73.7819 - 1.6926 \log(\text{Distance})$$

VIII. EFFECT OF WOOD WALL

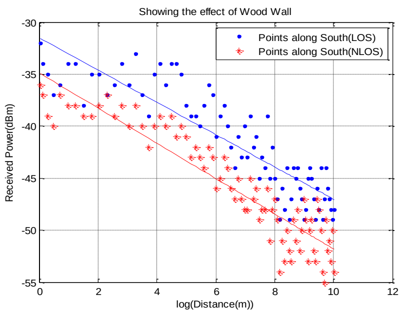

Fig. 8 : Scatter plot of Received Power v/s Distance for showing effect of wood wall

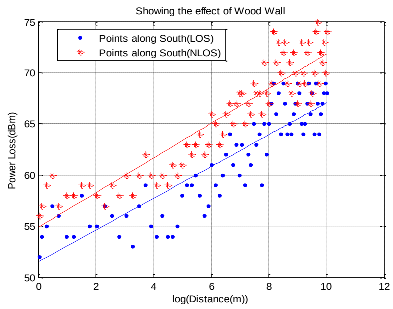

Fig. 9 : Scatter plot of Power loss v/s Distance for showing effect of wood wall

8.1 Discussion

There is a suite constituted of 3 rooms which are separated by a hollow wooden wall as shown in fig. 10. The thickness of this wall was measured to be 10 cm. out of these three rooms, central room has got the Wi-Fi access point.

The length of this room is 10 m while the width is almost 5 m each. Now for measuring the effect of the wooden wall readings had been taken along the whole central partition/wall of 10m and then readings were measured from the other side by the same way. A picture is shown below in fig. 10 to know the nature of this obstacle.[9]

Fig. 10: Pictorial view of the wooden wall along which loss was calculated.

After seeing the comparison between the readings of LOS and NLOS from fig. 8 and fig. 9 it has been observed that there is an increase of 5 dB in signal power loss after it travels through the hollow wooden wall. It is also been seen that practical losses come out.

So this means that signal refracts through the wooden wall and after it reflects and enters into the neighboring room it then reflects from the surface of the table, diffracts by the edges of the table and scatters by the rough surface of false ceiling. So if the depth of the wooden wall is increased then the power loss of the signal also increases. [9]

While comparing with Table III: the loss due to hollow wood is 3-4 dB. It's because in practical the signal faces other factors like reflection, diffraction & scattering do act their part in decaying of signal as the signal across the glass wall is NLOS. And also Table III does not show that what thickness of the wooden material that this table considers. This is explained and clear from the figure 8 and figure 9 which is the scatter plot for this specific scenario,

Now forming the power loss line equation. [5] [6]

For NLoS m= 1.5499 & Constt = 51.5115

$$\log(Power) = 51.5115 - 1.5499 \log(Distance)$$

For LoS m= -1.5499 & constt = 57.8741

$$\log(Power) = 57.874 - 1.5499 \log(Distance)$$

IX. RESULTS & DISCUSSIONS

Wide spread developments, implementations and explorations in the field of wireless communications has develop the interest of scientists and engineers in this field. Wireless LAN is basic entity of this wireless world. It is the most commonly used technology in our homes as well as offices now-a-days. Its importance increases with the increase in our dependency on communication with outer world via internet. As compare to Local Area Network, WLAN provide a hustle free environment and one can be mobile while connected to a network (internet). This technology is becoming very common among masses due to its simplicity. With the passage of time demand of WLAN is increasing and different shopping centers, hotels, airport and even some municipal communities in the world provides free Wi-Fi to attract customers and visitors.

In this paper Peak Wireless adapter is used to analyze the signal strength transmitted by Cisco-Aironet 1130 Access Point which is installed in the selected buildings. It has a power of 20 dBm that AP transmits with data rate of 54 Mbps and this data rate remain same till the power is decreased to -73 dBm and at -90 dBm the data rate decreases to 1Mbps.

Readings were taken in three buildings and were compared with ITU Indoor Communication Loss Model P-1238. It was found that practical readings that were taken differ at some places from the Theoretical model. It is because ITU Model is a general model and doesn't include any factor of obstacle's material that Wi-Fi signal face. It takes 15 dB loss for roof whether a roof is present or not which quiet high is. Also these models are empirical models while my work was practical. The path loss coefficient is 3 in ITU model which includes loss due to walls and also in practical the path loss co-efficient changes according to environment. This model doesn't contain any thing for reflection & diffraction, as due to reflection & diffraction our signal power can be increased (if signals or in phase) and can be decreased (if signals are out of phase). So that's why ITU model does not work fully for Indoor Communication and it shows more losses as compare to practical work.

After analyzing the Wi-Fi signal in different scenarios, following losses were observed:

Table IV: Obstacles and Corresponding Loss

Obstacle	Loss
Glass (1 cm Thick)	5 dB
Wood Wall (10 cm Thick)	6 dB
Pure Brick Wall (30 cm Thick)	17 dB
Roof (27 cm Thick)	15 dB

X. CONCLUSION

After analyzing the Wi-Fi signals in different buildings e.g. it is concluded that glass (1cm thick) produces loss of 5 dB, wood wall (10 cm thick)produces loss of 6 dB, pure brick wall (30 cm thick) produces loss of 17 dB while roof of 27 cm thickness produces loss of almost 15 dB. So ITU model & Small Micro zone Indoor Model doesn't have enough parameters for materials so that the results can be compared with it , that's why there is a need of new updated model indoor wireless communication to satisfy the behavior of the Wi-Fi signal when it faces obstacles in its way.

The losses that were calculated in Library were less as compared to other two buildings. It is due to the fact that other two buildings are mainly composed of Glass and wood, while library is made up of brick. So that's why there losses are more.

Apart from analyzing materials it is noted that the while reading signal strength in a room the losses tend to vary with the change in environment, i.e. losses tend to increase when calculated in rush hours because humans are made of some material and they can create a destructive interference and increases the loss.

XI. FUTURE CONSIDERATION

On the basis of this research work can be done to develop my own model which contains all the parameters that produce losses in Wi-Fi Signals. In this research the effect of outdoor environment (Trees, Weather, buildings) on Wi-Fi signal were not included. For the future work it is best if it can be realize and include for further works of this related research.

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Zeeshan Ahmad was born in Pakistan on Apr. 02, 1988. He received his bachelor degree in electrical engineering with specialization in communication engineering from Bahria University Islamabad, Pakistan in 2010. Later on, he came to Chongqing University China for master's degree in communication engineering in 2012. From 2010 to 2011 he worked in telecom sector on different Positions. He published his thesis in form of a book with Lambert Academic Publishing in Jun. 30, 2011, titled as Remote Monitoring System. He worked on

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