Modelling of Losses Due to Different Types of Walls and Empirical Model for Indoor Wi-Fi System

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Abstract—**It is not possible to deploy Wi-Fi (Wireless Fidelity) system by just placing transmitter at different places and than checking which place is good for installation of transmitter. It is very difficult and time consuming. ITU (International Telecommunication Union) model is one method to model the loss, but it is not suitable for Wi-Fi system. In this paper efforts are made to model the losses due to walls of different types and attempt is made to design model for indoor Wi-Fi system. The designed model is compared with ITU model and from testing observed that by using designed model loss can easily be modelled for a Wi-Fi system operating on 2.4GHz frequency.**

Index Terms: **Wi-Fi, Indoor Propagation, Loss Coefficient.**

I. Introduction

The demand of RF (Radio Frequency) device is increasing day by day. Everyone wants to access internet at home, office or at public places without any wired connection. This demand force to analyze the signals not only outside but also inside the buildings [1]. Indoor propagation includes the losses due to roof, wood walls, glass wall, concrete walls, reflection, refraction, diffraction and scattering from objects inside the building [2]. The loss due to roof, walls and path loss can easily model, but the losses due to reflection, diffraction and absorption are not easy to model [3].

An empirical model is very useful to calculate the loss and by using one can determine the best location of transmitter [4]. In this paper in section II, by analyzing the loss due to different types of walls, a final model for indoor propagation has been produced.

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In Section III comparison of model done with ITU model [5], Section IV model testing and last section concludes the conclusion.

II. Model for Indoor Propagation

In indoor environment walls and shiny surface causes reflection losses, objects inside the room/ building cause's diffraction and absorption losses. It difficult to model these losses so it assumed that the loss due to reflection, absorption, scattering and diffraction was negligible.

A. *Path Loss Coefficient and Loss due to Roof:*

The path loss coefficient for indoor propagation is given by [3]

$$L_{Pth} = 37.6 + 34.1 \log (d) \qquad (1)$$

Also the general expression for loss due to roof is [3]

$$\text{Loss} = L_r = 4.34\omega\eta \qquad (2)$$

Where

ω = roof thickness

and η = roof loss coefficient and its value is 0.0307 [3].

But there is no general expression by using that one can calculate the loss due to different types and width of walls.

The above expression (2) can be used for calculation of loss due to different types of walls by finding the loss coefficient for different types of materials.

To find loss due to wall first make both reading infront and behind wall on same distance, which was

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done by calculating path loss from above path loss equation for both infront and behind. Subtracting the path loss of smaller distance from longer distance reading and adding the result to received signal strength of longer distance makes both readings on same distance. In case of glass wall width is very small 1cm or 2cm and it makes no difference as compare to brick and wood walls [3].

B. Losses due to Glass Wall:

Figure 1 shows the log (d) versus power received infront of glass wall (shown by ◊) and behind the glass wall inside the room (shown by *) of width 1cm.

Due to shiny surface of glass there are much variation in signal strength has been observed. When best line is fitted in both data using least square error estimation it observed that at log (d) 9.8 the loss is0.5 dB and its value is increased to 0.75 dB when log (d) is 11.2.

The other four observations are taken double glass wall of width 2cm. It was found that loss has value of 1.41, 1.25, 1.30 and 1.52dB.

From above observation the loss due to glass wall of width 1cm is 0.75dBm and loss due to glass of width 2cm is 1.52dB. On safe side the value of loss is 1dB for 1cm width and 2dB for 2cm width

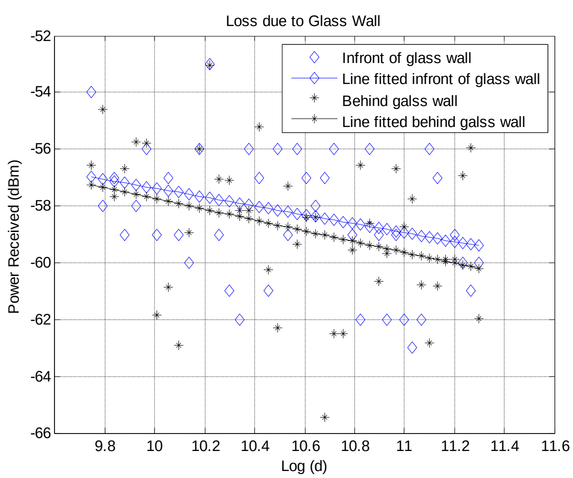

Fig.1. Log (d) versus Power Received in front and behind glass wall.

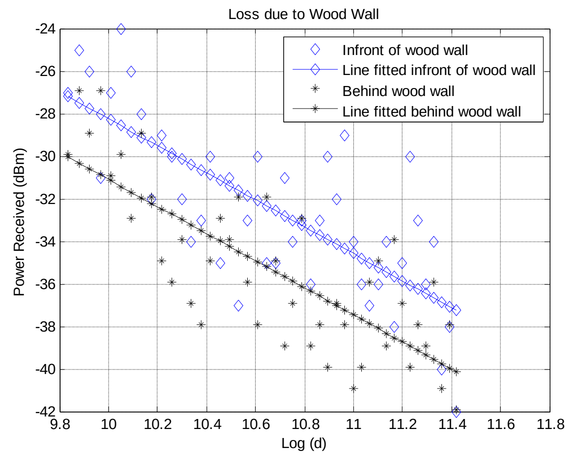

Fig.2. Log (d) versus power received in front of wood wall (blue line) and behind wood wall (red line).

has been taken.

From loss due to Roof [3]

$$\text{Loss} = 4.34\omega\eta$$

And the loss due to glass of width 1cm is 1dB

Therefore

$\eta = 0.23$

C. Losses due to Wood Wall:

From figure 2 it observed that both lines in front, behind are parallel and loss due to wood wall is 3dB. The other three observations were also taken on three different wood wall of width 10cm and it was founded that the loss has value of 3.12 dB, 3.39 dB and 2.87 dB. On safe side 3.5dB value of loss is acceptable for wood wall of width 10cm.

Since the loss due to roof [3]

$$\text{Loss} = 4.34\omega\eta$$

Since ω=10cm and loss is 3.5dB

Therefore $\eta = 0.0806$.

D. Losses due to Brick Wall:

In same way different observation has been taken on the brick wall of different width. It was founded that the two brick wall of thickness 12cm has loss of 3.85dB, 3.70 dB and brick wall of width 24cm has

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loss of 6.55 dB. On safe side the loss values 4dB for 12cm width and 7 dB for 24cm width has be taken.

From loss due to roof [1]

$$\text{Loss} = 4.34\omega\eta$$

As the loss has value of 7dB for 24cm brick wall

Therefore $\eta = 0.067$

By substituting η (width of wall) 12 cm, the loss found is 3.5dB, which is near to practical value.

E. Combining all the Losses:

By combing path loss coefficient, loss due to roof, loss due to brick, glass and wood the total loss becomes

$$L_{total} = 37.6 + 34.1 \log10 (d) + n\, L_r + n_1\, L_{g\omega +}\, n_2\, L_{w\omega +}\, n_3\, L_{b\omega}. \quad (3)$$

where d = distance in meters

L_r = loss due to roof

n = number of roofs between transmitter and receiver

$L_{g\omega =}$ loss due to glass walls

n_1 = number of glass walls between transmitter and receiver

$L_{w\omega\ =}$ loss due to wood walls

n_2 = number of wood walls between transmitter and receiver

$L_{b\omega =}$ loss due to brick walls

n_3 = number of roofs between transmitter and receiver

And the loss due to roof and walls can be found by

$$L_r = L_{gw} = L_{bw} = L_{\ ww} = \text{Loss} = 4.34\omega\eta$$

where

ω = width of the roof/wall in cm

η = loss coefficient, 0.0307 for roof, 0.2304 for glass wall, 0.0607 for brick wall, 0.0806 for wood wall.

Due to persons movement and how device is held on receiver side, a variations of 3-4dB in signal strength has been observed.

III. Comparison with ITU

According to ITU model the total loss is give by [5]

$$L_{total} = 20 \log_{10} f + N \log_{10} d + L_f(n) - 28 \quad (4)$$

ITU model for indoor propagation is only useful when transmitter is located on the roof of building [6]. It is more general model.

In figure 3 the straight line shows the loss modelled by ITU model and line with square shows the loss modelled by designed model. In this case only one roof was considered between transmitter and receiver. It was observed that at distance of 1m the loss modelled by ITU model is 54.6 dB and loss modelled by designed model is 41.7 dB. The loss using ITU model is high because it takes in account 15 dB of loss for single roof while loss by designed model is 4 dB.

The loss model by designed model depends upon the thickness of the roof. The difference of loss is 12 dB at 2m and 11dB between 2-3m and 10dB between 3-4m. In the case of transmitter and receiver on same floor then ITU model fails because this model does not include the loss due to walls, it only makes count the loss due to roof. This model is not well suited in case of Wi-Fi because of more than one transmitter on one floor and also it depends on the shape and size of building.

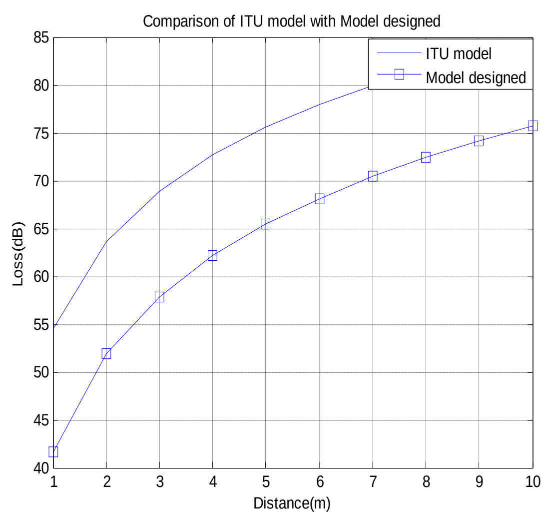

Fig.3. Comparison of ITU model with Model designed.

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IV. Model Testing

A. Model Testing at Location One:

The transmitter was located at stairs on 2nd floor having height of 8.73m from ground and the receiver was on 3rd floor at height of 9.9m. The difference in height of both was 1.17m. The obstacles between transmitter and receiver are one roof of 30cm, two concrete walls of 22cm and 30cm respectively and one wood wall of 10cm.

Figure 4 shows the coverage obtained on 3rd floor. Signal attenuates due to reflection and absorption causes by roof, brick and wood walls. Opposite to transmitter an elevator and some metal pipes were there, which also causes absorption and reflection losses. Furniture was also presence which causes absorption, diffraction and reflection losses.

In figure 4 the red colour shows the signal strength greater than -78dBm which was received beside the door. Signal strength between -78dBm to -81dBm showed by pink colour which received just beside the wood walls. Yellow colour represents the signal strength between -81dBm to -84dBm and in most of the area this strength was received. The signal strength received in the above below right corner was less than -84dBm which was near to threshold and some of the time connectivity has been lost due to very low signal strength. Coverage obtained using designed model was shown in the figure 5. In that figure the transmitter was located by "X" (red colour).

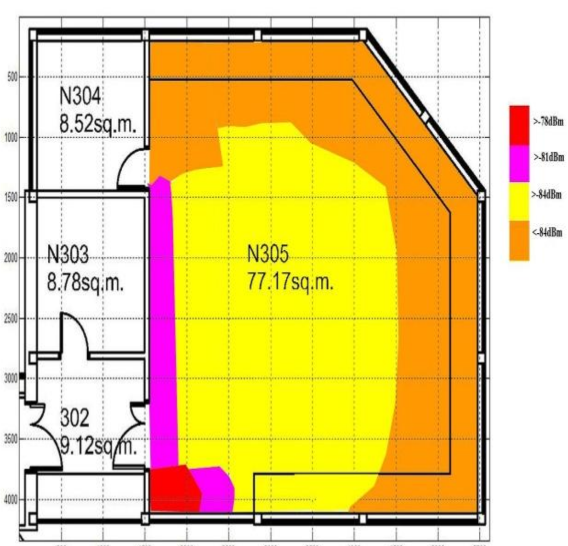

Fig.4. Signal strength received in 3rd Floor Lab.

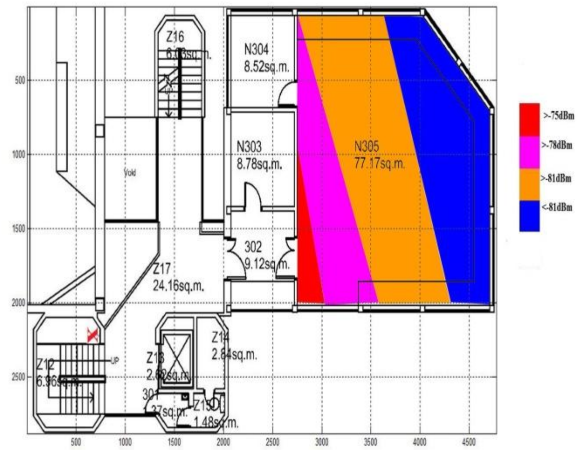

Fig.5. Coverage obtained using Designed Model.

Received signal strength was between -72dBm to -75dBm shown by red colour in bottom left corner, while in figure 4 it was -78dBm shown in red colour. The difference between theoretical and measured is of 5dB. As move away the signal strength between -75dB to -78dbm shown by pink colour, -78dBm to -81dBm shown by orange colour and in right corner was less than -81dBm. The difference between practical and measured in centre of lab was around 3dB.

B. Model Testing at Second Location:

In second case the transmitter was located on 4th floor and receiver on 5th floor. The height difference between transmitter and receiver was 3.85m. There was one roof of thickness 30cm, on concrete wall of 30cm and 4 glass walls each of width 2cm between transmitter and receiver. Glass walls causes' reflection, glass frame made of aluminium, concrete walls and roof causes diffraction, absorption losses.

Beside the gate shown in red colour figure 6 the signal strength received was greater than -79dBm. The most of the area was yellow colour and the received signal strength in that area was between -79dBm to -83dBm. The blue area represents the signal strength less -83dBm, at this signal strength some time connection is available some time no connection.

In Figure 7 "X" represents the transmitter on 5th floor while receiver on 4th floor. The signal strength in central area was between -75 to -81dBm and near to opposite wall shown by blue colour is less than -81dBm. The difference between measured and calculated using designed model is 4-5dB.

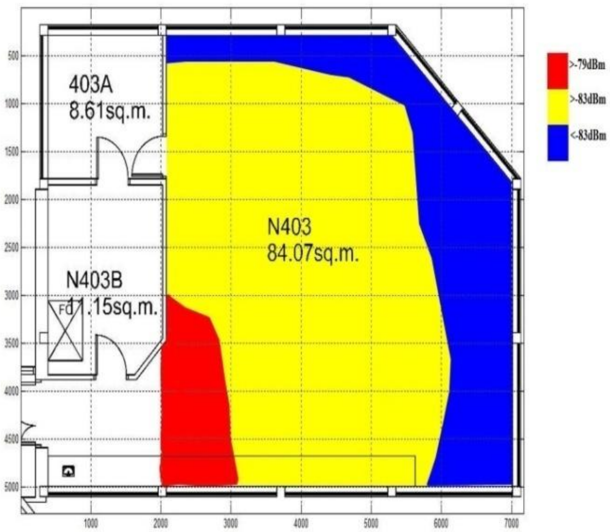

Fig.6. Signal Strength received on 4th floor.

V. Conclusion

From above observation it concluded that the loss due to walls depends on thickness and types of material from which they made. It also observed from final model that by modelling the losses due to path loss, losses due to roof and walls, system losses can easily be modelled. By testing model it observed that the difference between measured and calculated is of 4-5 dB which is considerable. This designed model is on 2.4 GHz frequency and can easily be used for mobile system operating at 1.8 GHz.

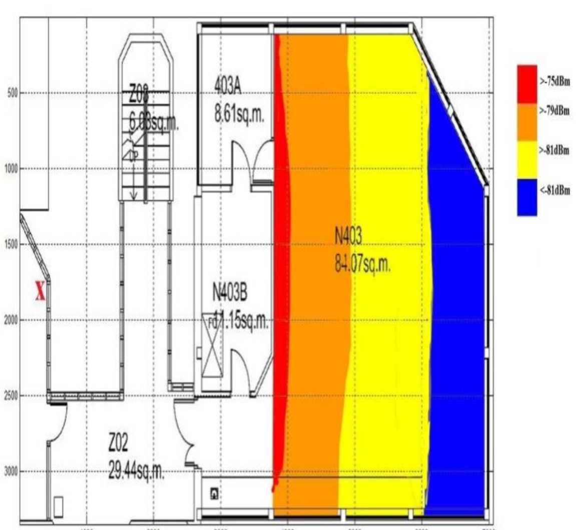

Fig.7. Coverage obtained on 4th floor using designed model.

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