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D-Model: A New Perspective for Modeling Radio Signal Propagation in Indoor Environment

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Abstract: There are different approaches towards estimating the signal strength in indoor environment, which includes models such as empirical and deterministic models. Empirical Models are simple but less accurate whereas deterministic models have more accuracy but much more complex. In this paper we have identified some limitations of the most widely used empirical model i.e. 'Wall Attenuation Model' and presented a new empirical model called 'D-Model' to reduce the errors in earlier empirical models. D-model proposed that a single wall do not always attenuate the signal with constant dB loss but it varies with the distance of transmitter as well. D-model considers the wall not as a constant attenuation element but as an increase in the transmitter to receiver distance with a factor called 'D-factor'. We proved that D-model gives much more accurate signal strength estimations as compared to Wall Attenuation Model.

Key words: Indoor Propagation Model, wall attenuation Model, indoor radio signal modeling, Signal Strength Model, D-model.

INTRODUCTION

The rapid growth of Wireless networks in recent years lead to a demand of more precise radio signal propagation models for estimating the signal strengths at different location within the coverage area. Indoor Radio Signals are helpful in generation of signal maps inside a building that assists in different sorts of network management and location aware applications. An accurate signal propagation model will ease the process of building fingerprint database and can reduce the time taken for surveying the entire area for signal strength sample collections. Unfortunately despite of huge research, generation of Radio Signal Strength map is still not very much mature and there is always some accuracy problem in that, this is the reason why most of the Location Based applications in Indoor environment are based on fingerprinting, not on empirical Propagation models (Nilofer Tambuwala, 2007; B Li, 2006). Satellite Navigation and Positioning Lab is actively working on location determination through WiFi networks for indoor positioning (Kealy, 2009; Binghao, 2010; Li, B., 2005a; 2005c; 2006).

In this paper we suggested a more accurate and practical Signal Strength model for Indoor Environment using single wall attenuation with Distance factor (D-factor) so that it can further be enhanced to model the signal strength map in the whole building. We call this new model as 'D-model'. We carried out some experiments to point out the limitation of wall attenuation Model for varying transmitter distances, and then we presented the results of single wall experiments conducted in School of Surveying and Spatial Information Systems, University of New South Wales Sydney, with different wall types to validate the model and to prove the better accuracy of this model as compared to the traditional wall attenuation Model.

Related Research:

Modeling Radio Signal Propagation in indoor environment is an active research area since decades. Despite of some huge literature and experiments there is still some room for improvements in accuracy of Signal Strength estimation in indoor environment. None of the model is consider as that much accurate because of the reasons of multipath propagation, reflection, diffraction, and scattering. Different characteristics of multipath in an indoor environment are discussed in detail in (Remley, 2010). Indoor Radio Signal Strength is also affected by the changes in the building layout, environmental affects, human activity, type and quantity of indoor furniture and some other factors that are difficult to be addressed in a particular model (Yiming, 2006).

Mainly there are two classes of Radio propagation Models, Empirical Models and Deterministic Models. Empirical Models are easy to implement and are relatively simpler. These models are based on some path loss equation that represents the model. These models requires least site-specific parameters and able to compute signal strength with only a few parameters as inputs. Empirical models are less accurate but due to its simplicity these models are still the most widely used models in radio signal propagation estimations. On the other hand Deterministic Models are more complex and requires many site-specific parameters to be provided by the user.

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These models are computationally heavy and require more processing time. Deterministic models are based on physical principles of electromagnetic wave propagation and the building geometry. The accuracy of deterministic models is good but the requirement of exact site-specific parameters like electrical properties of obstacles are often unavailable or too expensive to include. Most widely used deterministic models are optical models like ray tracing. (Wölfle, 1999; Stäbler, 2008). Some of the researcher also proposed a combination of deterministic and empirical models to establish a semi-deterministic model. (Pechac, 2001; Holis, 2005; Pechac, 2000).

In this paper we tried to develop a more precise empirical model for Indoor Radio propagations that is simpler to implement as well as more accurate than other models. Most commonly used empirical models are (1) Log distance model, (2) wall attenuation model and (3) Site specific model (SaadBiaz, 2005).

1. Log-Distance Model: Log Distance Model or Single Slope Model (1SM) is the most fundamental and simplest model to estimate the signal strength at some particular position. As the name suggests, this model based mainly on the distance between the transmitter and receiver, in addition to that it also depends on the path Loss exponent value (n) and the dB power at some known distance.

$$P(d)_{dB} = P(do)_{dB} - 10\,.n.\log\left(\frac{d}{do}\right) \tag{1}$$

Where, P(d) is the Power in dB to estimate at some particular distance d, P(do) is the known power at distance do, n is the path loss exponent.

2. Wall Attenuation Model: Wall Attenuation model considers the number of walls of certain types in between the transmitter and receiver. This model suggests that a certain wall causes a particular and fixed dB loss in the signal strength irrespective of the distance of transmitter or receiver from the wall. (Keenan, 1990).

$$P(d)_{dB} = P(do)_{dB} - 10\,.n.\log\left(\frac{d}{do}\right) - \sum_{i=1}^{p} \alpha_i\,.N_i \tag{2}$$

For reference power at 1m, the equation becomes,

$$P(d)_{dB} = P(1m)_{dB} - 10\,.n.\log(d) - \sum_{i=1}^{p} \alpha_i\,.N_i \tag{3}$$

Where, α is the wall attenuation factor for wall of type i and N_i is the number of walls of type '*i*' between transmitter and receiver, and p is the number of different types of walls between transmitter and receiver.

This model added the term $\sum_{i=1}^{p} \alpha_i\,.N_i$ that represents the total loss due to the walls of different types.

Many researchers worked on different types of walls and their attenuation factors, (Alighanbari, 2006) presented the wall attenuation for different walls based on the material conductivity. Wall Attenuation Model is the most commonly used model nowadays for indoor signal strength estimations, and also used by RADAR (Bahl 2000).

3. Site-specific Models: Site-specific models tries to increase the accuracy of indoor radio propagation models by including each complex information of the indoor environment and site-specific parameters like building geometries, thickness of walls, material of walls and furniture (Hassan-Ali, 2010; Lott, 2001). A detailed study of building structure and signal mapping with different frequencies is investigated in (Young, 2010).

Proposed Model:

We propose a new Radio Signal Propagation Model called 'D-Model' that is based on the basic log distance model but incorporates a distance factor 'D-factor' for the walls between transmitter and receiver. The model is based on the following equation;

$$P(d)_{dB} = P(1m)_{dB} - 10\,.n.\log(d + D) \tag{4}$$

Where, the value of D-factor is dependent on the distance of transmitter from the wall, the angle with which the signal is incident at the wall, the type and material of the wall, and the thickness of the wall.

Our experiments showed that a certain wall does not always attenuate the signal with same dB loss but in addition to the type and thickness of wall, it also depends on the transmitter distance. So the constant wall attenuation factor used in wall attenuation model causes in-accurate model when the transmitter position changes. This variation of wall attenuation with the transmitter distance is also mentioned in (Hradecký, 2003)

Following experiment was conducted at the school of surveying and spatial information system, university of New South Wales at the 4th floor of EE building, fig-1.

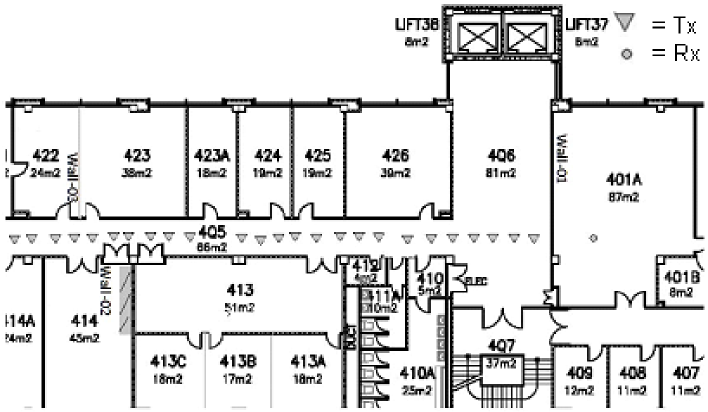

Fig. 1: Floor Plan of 4th Floor EE Building showing Transmitter Distance from Wall.

We used off the shelf IEEE 802.11 hardware for this study so that the produced results would be based on real environment and real setup.Netgear-wgr614l Access Point was used as the transmitter and Broadcom 802.11n Network Adaptor as the receiver for WiFi signals. The Receiver was placed stationary at 3m distance from a brick wall and the transmitter was moved along the axis as shown in fig-1. Signal strengths were measured for every location of transmitter by taking 30 samples of Received Signal Strength for each location and then averaging out the RSS of each sample at that particular transmitter position.

Fig-2 shows that the wall attenuation is not a constant value but it varies inversely as the transmitter is moved away from the wall, hence the commonly used model 'wall-attenuation model' do not give accurate readings when the Access Point is away from the wall and this variation is considerably increased at a distance of more than 6m.

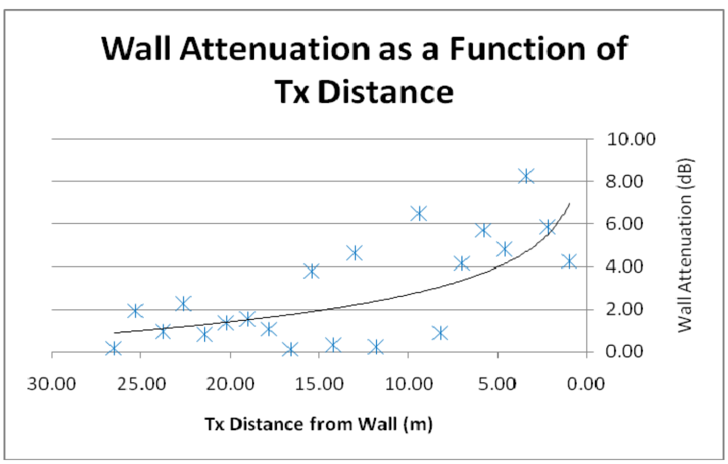

Fig. 2: Wall Attenuation as a Function of Transmitter Distance.

This behavior can be explained by considering the wall not as a constant attenuation element but as an element that causes an increase in the overall distance of the signal propagation hence a distance factor 'D' is added in the equation of 'D-model' to express this addition in the propagation distance. 'D' can be termed as equivalent propagation distance in the wall. In D-model, the distance between transmitter and receiver is not remains 'd', but 'd+D'.

Figure 3 is a comparison of both models, the Wall Attenuation Model and 'D-Model'. It is visible that when the Transmitter is placed within 6m of the wall, both the models are giving comparable results but when the transmitter is moved at a more distant location, wall attenuation model's accuracy is reduced considerably and in this situation our D-Model is still giving good results.

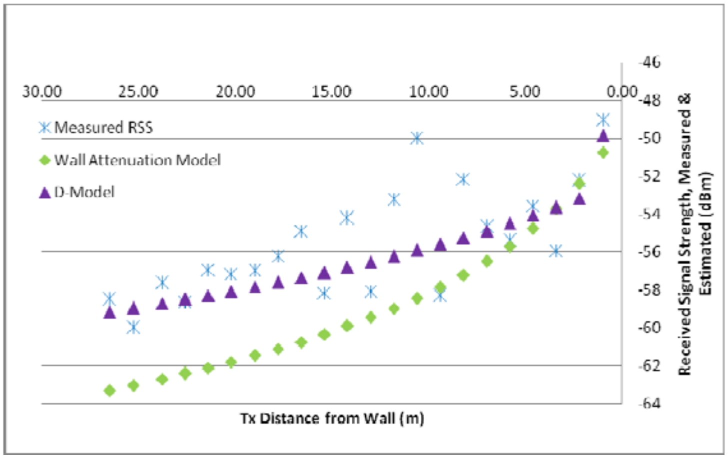

Fig. 3: Comparison of Wall Attenuation Model & D-Model, with varying TxD.

Table 1: RMS Error Comparison of Wall Attenuation Model and D-Model.

Transmitter Distance	Wall Attenuation Model	D-Model
If TxD< 6m	1.382	1.26359
If TxD> 6m	4.841	2.278321
Overall	4.331	2.099863

Table-1 Shows the comparison of Wall Attenuation Model and D-Model in terms of Root Mean Square Error, it is evident that at transmitter distance of less than 6m, both the models are giving comparable results but at more distant location of access point, the error of traditional wall attenuation model is very much high as compared to our D-model. The similar affect was expected on the observation of fig-2 which shows how rapidly wall attenuation factor changes after 6m. Overall D-Model shows smaller errors as compared to the Wall Attenuation Model.

In the above experiment, the values of P(1m) was -36dB, n = 1.45 (chosen for corridor with regression and curve fitting techniques), the wall attenuation as -6dB and D = 10m.

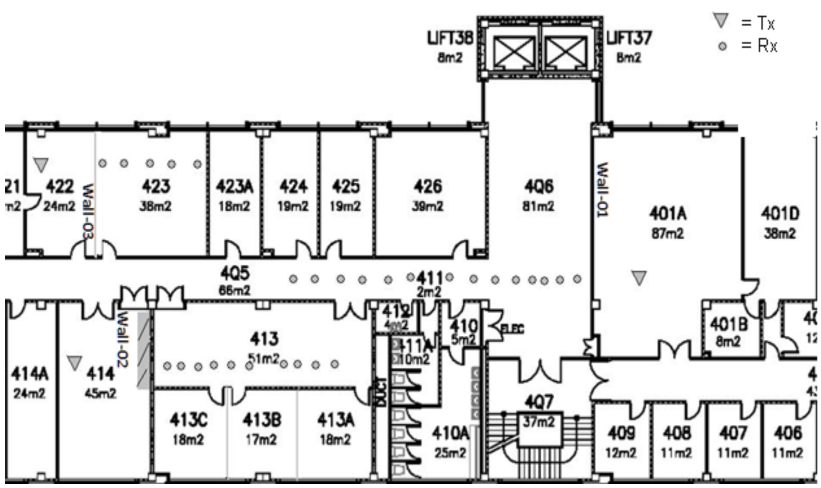

Fig. 4: Experimental Setup with Transmitter & Receiver positions with 03 different walls.

We then experimented with the same brick wall of type-01, but this time we used stationary transmitter and moving receiver, as shown in fig-04 with wall-01. The transmitter was placed in the room 401A at 3m distance from the wall and the receiver was moved along the axis in the hallway.

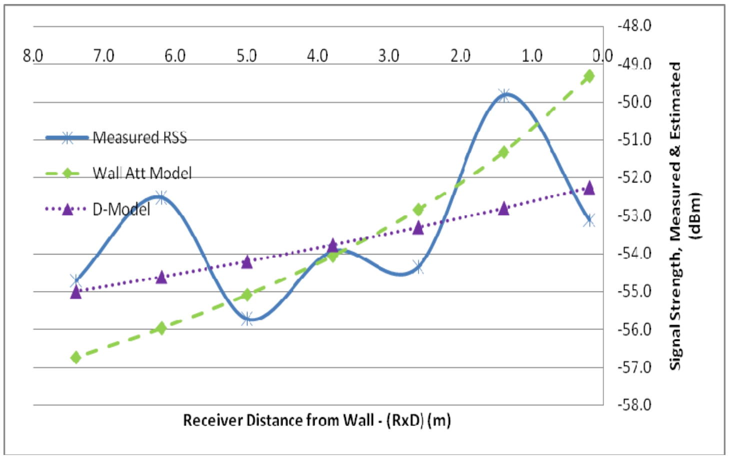

Fig. 5: Estimating Signal Strength with both Models, wall-01.

As the transmitter is placed at 3m, which is quite near to the wall so the traditional wall attenuation model gives comparable results with a wall attenuation loss of -6dB, but still our D-model gives better results, as shown in fig-5. This performance of D-Model is expected to be even better if the receiver is at a larger distance from the wall. also witnessed a similar accuracy reduction in signal strength estimation with increase in the receiver distance.

Table 2: RMSE Comparison of Wall Attenuation Model and D-Model for wall-01.

	Wall Attenuation Model	D-Model
RMSE	2.2461712	1.576025321

In order to compare different wall types, we repeated the experiment with two more walls, (1) brick wall with a book shelf full of books in front of that wall, between Room 414 and 413 and (2) a wooden office partitioning wall between Room 423 and 422.

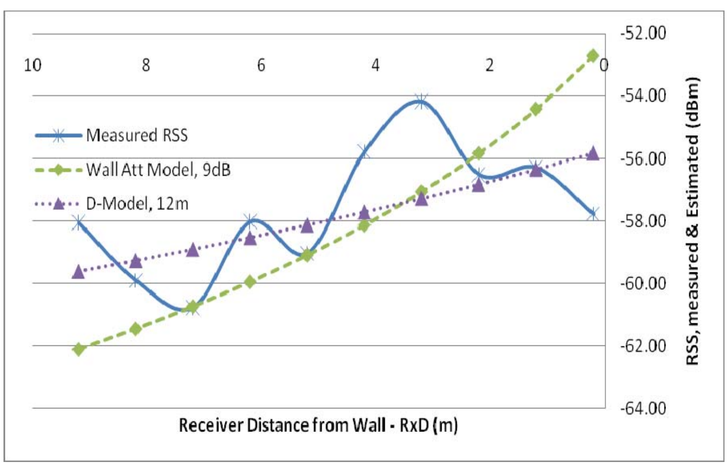

Fig. 6: Comparison of Wall Attenuation Model and D-Model for wall of Type-2.

When we experimented with a brick wall with a book shelf, the best value of D was found out to be 12m whereas the wall attenuation was found to be -8dBm. The transmitter was placed at a distance 4.6m from the wall and the receiver was moving away from the wall. The estimations of RSS obtained by both these models are plotted in figure-6.

Table 3: RMSE Comparison of Wall Attenuation Model and D-Model, Wall 02.

	Wall Attenuation Model	D-Model
RMSE	2.569545	1.56891

The 3rd wall chosen for the experiment was a wooden office partitioning wall between Room 422 and 423. The transmitter was place in 422 at a distance of 2.4m from the wall and the received signal strength was monitored at different receiver distance. The best value for D was found to be 2m whereas the wall attenuation was -4dB. This time again D-Model gives better results for the RSS estimation as compared to the wall attenuation model, as shown in fig-7 and table-4.

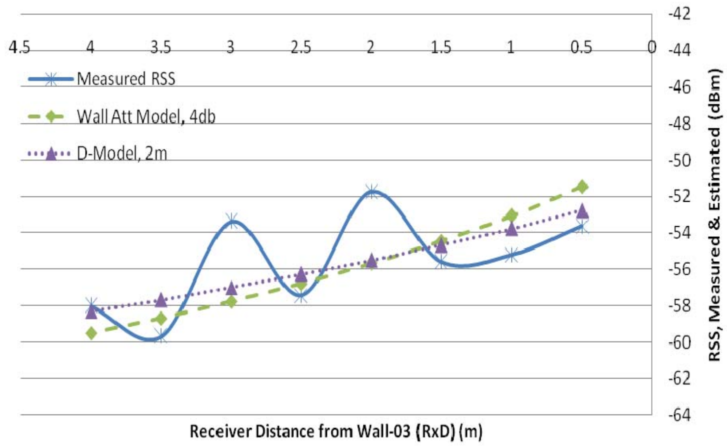

Fig. 7: RSS Estimation Comparison of Wall Attenuation Model & D-Model for Wall of Type-3.

From all the above experiments, It is evident that a particular wall do have attenuate the signal equally and hence the wall attenuation models do not give accurate estimates of the received signal strength. On the other hand D-model gives comparatively better estimates of received signal strengths in indoor environment but treating the walls as a distance ‘D’ which causes added attenuation in the free space path loss.

Table 4: RMSE Comparison of Wall Attenuation Model and D-Model, Wall 03.

	Wall Attenuation Model	D-Model
RMSE	2.48439	2.14047

Validity of The Model:

The D-Model is valid for any wall/portions in the indoor environment. The observations proved that it has given better results as compared to Wall Attenuation Model, especially at a larger transmitter distance from the wall. The accuracy of ‘D-Model’ is highly dependent on the selection of the value of ‘D-factor’ hence its value is to be chosen with care and experimental verification.

Conclusion:

In this paper, we introduced a new empirical model for WiFi signal propagation in indoor environment. Experimental results showed that D-Model gives more accurate results for signal strength estimation as compared to wall attenuation model. It has the answer for the variation of wall attenuation with changing transmitter distance. This model shows lower errors as compared to the traditional wall attenuation model that supposed constant wall attenuation for a particular wall. The experiments showed that different types of walls have different D-factor which causes increase in overall distance of transmitter to receiver, with no concept of constant wall attenuation i.e. dB loss.

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