INDOOR PROPAGATION MODELS AND RADIO PLANNING FOR WLANS

Rui Lopes, Paulo Freixo e António Serrador
ISEL – Instituto Superior de Engenharia de Lisboa, Rua Conselheiro Emídio Navarro No.1, 1950-062 Lisboa, Portugal.

Keywords: WLAN, Indoor Propagation Models, 2.4GHz Measurements, Planning

Abstract: WLANs are nowadays at the top of the mass market networks technologies. They are essentially implemented indoors, where the traditional planning tools are not yet focused. In spite of the concern to improve the radio planning quality, the existing propagation models can still be sharpened for better outcomes, mainly in large buildings. A new propagation model is proposed and evaluated with measurements at 2.4GHz and also a planning tool is presented, with the ability to execute coverage and capacity analysis on indoor multi-floors environments. This model adapts itself to multiple indoor scenarios following the performed measurements

1 INTRODUCTION

Wireless Local Area Networks (WLANs) systems are nowadays right in the center of the market burst of wireless communications. They are helping the information society to evolve in a new sense of wide band capabilities and network flexibility deployment. In spite of the important role that this technology already plays, the implementation process is still not being done by a careful planning method, like it is done for indoor Global System for Mobile Communications (GSM), for instance. Nowadays it is not unusual to see large networks with a substantial number of Access Points (APs), being based on empirical methods such as power measurements. This elementary approach carries with it some problems such as failure in deploying the full site capacity potential. Besides coverage, also traffic estimation is usually neglected during the network deployment process, leading to an unbalanced system. The demands for WLAN systems today are becoming higher as the numbers of users grow and as the applications and Hot Spots possibilities expand. With the quality issue on the front line, as well as the economic impositions, the network architecture must be considered as a critical point of business.

The essential purpose of this work is the study of the indoor propagation models within the WLANs operating frequencies. The theoretical study will lead to an improved model, based on existing ones, which will account for obstacles losses as well as associated environment power decay index. The presented propagation models will be evaluated by measurements at 2.4GHz. Based on these measurements an attenuation table for typical obstacles on the radio path such as walls, doors and so on, is presented. Apart from this, power decay index with distance (n) is determined on different scenarios like: alleyways, office rooms, classrooms and hardware and software laboratories.

The final stage of this work is to present a planning tool, developed for the IEEE 802.11b standard, which is called: *InPlanner*. The *InPlanner* tool is able to perform the radio planning, concerning coverage and capacity. The coverage is based on the studied and proposed propagation models and the Friis law (Foerster, 2002). The capacity analysis is based on simple traffic source models and on an inquiry to a population ranging from the students to professional/office communities. The considered services are a set of traditional network applications: World Wide Web (WWW), File Transfer Protocol (FTP), video streaming, chat and e-mail.

Having an empirical validation of the theoretical models and with the proposal of a planning tool, this study aims to give a valid contribution to the planning of indoor WLANs.

This paper is divided into seven Sections. This Section presents the paper's subject and introduces the main concepts used throughout the text. Section 2 describes a set of propagation models associated with indoor radio propagation. In Section 3 a new

Lopes R., Serrador A. and Freixo P. (2004).
INDOOR PROPAGATION MODELS AND RADIO PLANNING FOR WLANS.
In *Proceedings of the First International Conference on E-Business and Telecommunication Networks*, pages 87-92
DOI: 10.5220/0001390500870092

propagation model is proposed, containing the best features of two known models. Section 4 has the description of the work developed regarding radio measurements, including the obstacles attenuation table and the *n* determination process for different environments. The *InPlanner* tool is presented in Section 5. In Section 6 results are discussed, comparing the propagation models attenuation curves with measurements. The attenuation curves derived from the propagation models for some link examples are also compared with the measured results. Finally there are some conclusions in Section 7.

2 INDOOR PROPAGATION MODELS

There are several complex propagation mechanisms. All of them have a direct influence in the trajectory that a radio signal performs between transmitter and receiver, influencing its phase, amplitude and direction. The diffraction phenomenon occurs whenever a radio wave stands with a solid obstacle with dimensions considerably greater than the wavelength, because the radio wave tends to contour it. The scattered wave effect appears when the path has obstacles with sizes comparable or smaller than the wavelength. This causes a sub-division of the wave front in several others. Reflection occurs when the radio wave reaches an obstacle with dimensions considerably larger than the wavelength. The reflected wave may reinforce or degrade the signal level at the receiver. In indoor environments this effect has a substantial weight, being the main source to the multipath effect. The effect of radio wave penetration makes it possible for the radio waves to transpose obstacles found in their path. Other effects, like refraction, which causes a shift on the propagation direction and the wave guide effect causing the *n* value in some cases (mainly Alleyways) to be smaller than 2, have a substantial weight in the indoor scenario.

All the phenomena described above cause the appearance of multipaths between transmitter and receiver. The reflected rays will travel further distances to reach the receiver, causing more energy losses comparing with the direct ray. At the receiver all the original ray samples will combine producing the final signal. This could cause serious waveform distortions leading to bit errors or intersymbolic interference.

Propagation models allow an accurate path loss prediction, which is decisive to a correct AP position choice. Propagation models are divided into four different types (Neskovic, 2000):

- Empirical models with narrow band information – They are represented by simple math equations estimating the losses.
- Empirical models with wide band information – These models provide (usually in table format) values for average delay spread and typical power decay index.
- Theoretical models for time variations – These ones could be used for example, to estimate the received signal Doppler spectrum.
- Theoretical deterministic models – This type of models simulate the physical phenomena regarding radio waves propagation. They contain narrow and wide band channel information.

The models considered in this work are the empirical ones with narrow band information.

2.1 Free Space Attenuation

The free space attenuation model is the base for all empirical models with narrow band information. The free space condition is achieved when there is Line of Sight (LoS) between transmitter and receiver, with full clearance of first Fresnel ellipsoid. In this case, the only accounted attenuation that is accounted for results from wave energy dispersion through space (1).

$$L_{fs[\mathrm{dB}]} = 10 \times n \times \log\left(d_{[\mathrm{m}]}\right) + 20 \times \log\left(f_{[\mathrm{MHz}]}\right) - 28 \quad (1)$$

This is a very simple model, where n=2 and d represents the distance between transmitter and receiver and f represents the frequency.

2.2 Linear Attenuation Model

The linear attenuation model (Devasirvatham, 1990), considers a linear relation between distance and power decay as shown in (2), where α is the attenuation coefficient in dB/m.

$$L_{lam[\mathrm{dB}]} = L_{fs} + \alpha_{[\mathrm{dB/m}]} \times d_{[\mathrm{m}]} \quad (2)$$

2.3 Keenan's Model

Keenan's model (Keenan, 1990) considers n=2 for all situations, but takes into account the attenuation for walls and floors. Its expression can be viewed in (3).

$$L_{K[\mathrm{dB}]} = L_1 + 10 \times \log\left(d_{[\mathrm{m}]}\right) + n_f \times a_{f[\mathrm{dB}]} + n_w \times a_{w[\mathrm{dB}]} \quad (3)$$

Where:
L_1 – propagation losses at 1 meter with L_{fs}.
n_f – number of floors between transmitter and receiver.
a_f – floor attenuation.

n_w – number of walls between transmitter and receiver.
a_w – wall attenuation.

2.4 ITU-R P.1238-1 Model

The indoor model proposed by ITU (4) (ITU, 1999), doesn't consider a fixed n. It provides a table with several values for the N parameter, which depends of the indoor environment scenario. It also accounts for attenuation caused by floors but not by walls. The walls losses information is given by N.

$$L_{ITU\,[\mathrm{dB}]} = 20 \times \log(f) + N \times \log(d) + L_f(n_f) - 28 \quad (4)$$

Where: L_f stands for a floor penetration factor provided by (ITU, 1999) and it depends on n_f. N is the losses coefficient factor regarding distance. It also depends on the environment and is also defined in (ITU, 1999).

2.5 One Slope Model

The One Slope Model (OSM) adapts itself to the environment characteristics through its n parameter shown in (5). The philosophy is identical to ITU's approach with N. When n =2 or N=20 the free space condition is assumed. OSM does not account explicitly for the existence of either floors or walls. Both occurrences are expressed through n.

$$L_{OSM\,[\mathrm{dB}]} = 20 \times \log(f) + n \times 10 \times \log(d) - 28 \quad (5)$$

The n value is defined in (Tarokh, 2002) and it depends on the environment characteristics, walls and floors.

2.6 COST 231 Multi-Wall Model

The COST 231 Model (COST, 1999) for the indoor scenario assumes the existence of walls adding to the n condition of OSM. It can be view in (6) the influence of walls attenuation, which stands on the path between transmitter and receiver. M is the number of walls and L_i the attenuation of each one.

$$L_{MW\,[\mathrm{dB}]} = L_1 + 10 \times n \times \log(d) + \sum_{i=1}^{M} L_i \quad (6)$$

3 PROPOSED MODEL

In this Section a new model is proposed based on the peculiarities of each of the models presented in Section 2. All of them, except Keenan's model, introduce variable relations between distance and n, depending on the environment. However the n value presented by most of the models is general to a building, not accounting for possible different rooms crossed with different propagation conditions for each (Figure 1). Considering these characteristics and also the obstacles attenuation, it is possible to maximize the best features of all models in one single model. In (7) different rooms are taken into consideration (propagation conditions), identifying it with particular n for each and introducing the walls and floors attenuation.

$$L_{[\mathrm{dB}]} = 20 \times \log\left(f_{[\mathrm{MHz}]}\right) - 28 + 10 \times n_p \times \log\left(d_{[\mathrm{m}]}\right) + \\ + \sum_{i=1}^{N_W} \left((n_i - n_{i+1}) \times 10 \times \log\left(d_{i[\mathrm{m}]}\right) + a_i \right) \quad (7)$$

Where:
L – Proposed propagation model.
N_W – Number of crossed walls.
n_p – power decay index on point "p", where the attenuation is measured.
d_p – distance between the transmitter and point "p".
d_i – distance between the transmitter and obstacle i.
n_i – power decay index of room before obstacle i.
a_i – obstacle i attenuation.

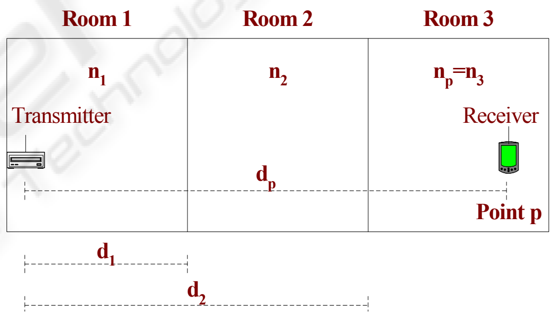

Figure 1: Example for 3 rooms with different n values, and 2 obstacles (walls).

Figure 1 specifies the parameters of (7) and Figure 2 compares all presented models for the scenario presented in Figure 1.

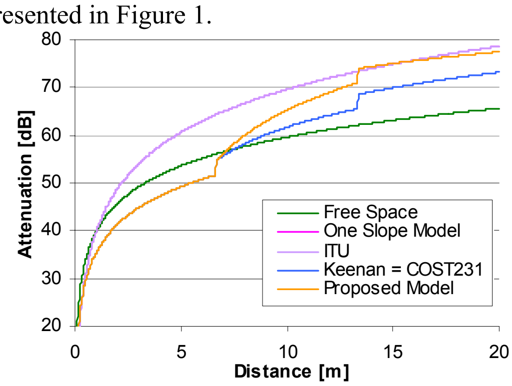

Figure 2: Propagation models comparison.

4 MEASUREMENTS

Radio measurements were performed to characterize *n* for different environments and also to obtain some obstacles attenuation at 2.4GHz. Besides, measurements are required to evaluate the models performance (Mikas, 2003). An AP was used as a transmitter and a laptop computer with WLAN PCI card antenna as a receiver, associated with *NetStumbler*® tool.

Table 1: Obstacles attenuation measurement

Obstacle	Atten. [dB]
Wood door on a brick frame	6.64
Double wood door on a brick frame	0.93
Fiber door	2.67
Simple glass window	4.48
Double glass window	6.40
Brick wall (14 cm)	11.80
Metal closet (1.5 m height)	14.43
Metal closet (2 m height)	23.64
Electromagnetic radiation "shielded" wall	20.47
Concrete floor with false metal ceiling	77.95

Phenomena listed in Section 2 cause fluctuations on the signal's power level, making it vary through time around an average value. Therefore, it is considered that each measure is concluded when the number of power level samples is enough to converge to its average as shown in Figure 3. This is the loss value calculated by the models of Sections 2 and 3.

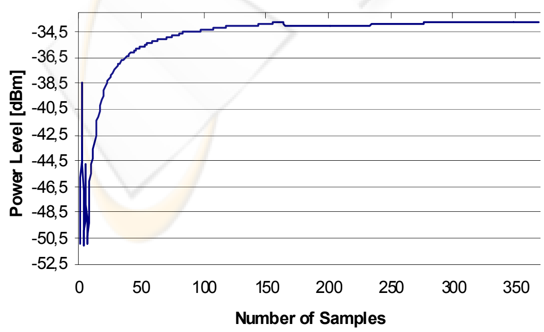

Figure 3: Retrieving power level technique.

A set of "obstacles" were defined, being measured their correspondent attenuation at 2.4GHz (Table 1).

Table 2: The *n* values for different scenarios

Alleyways	Class rooms	Office rooms	Labs
1.5 to 1.9	2.2 to 2.7	1.5 to 3.3	1.3 to 2.4

Table 2 presents *n* measurements, up to 4 different types of scenarios: alleyways, classrooms, office rooms and electronics/computers equipment laboratories (Labs).

5 PLANNING TOOL

The indoor planning tool, *InPlanner*, developed for this study allows the following features: 2D display of bit rate with different coverage areas (mapped by colors), informing the exact percentage of occupied area for each rate. Red for 11Mbit/s, orange for 5.5Mbit/s, yellow for 2Mbit/s and green for 1Mbit/s (Figure 4).

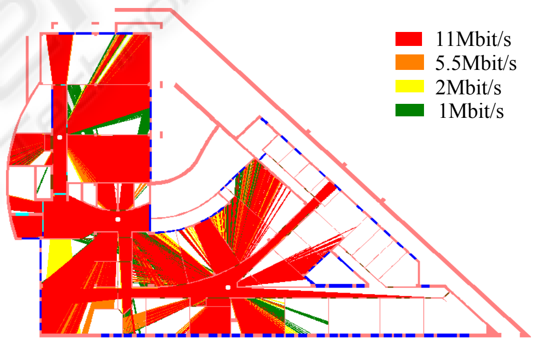

Figure 4: Bit rate mapping.

The bit rate areas depend on power level and Signal to Interference Ratio (SIR) on each point of the plant (Figure 3). It also allows the estimation of best server areas and C/I mapping. Besides coverage estimation, this tool also estimates traffic load. It's possible to introduce office and student users throughout the plant, distributed randomly or in selected positions. It simulates: WWW, FTP, E-Mail, Chat and video streaming, according to CSMA/CA protocol.

To simulate E-Mail, FTP and video streaming, an On/Off traffic source model is used. Each of these packet services are considered continuous in the same session. Once one of this services session's gets possession of the medium, it locks it until the session ends. WWW and Chat have a second level of simulation. Being each session divided into periods of data transfer and reading time (to visualize the WWW pages and Chat messages throughout the session). The service arrival process is exponential distributed. Each service duration was based on a campus local inquiry for students and various office companies for office users. The number of sub-sessions for WWW and Chat are given by geometrical distribution and data volumes by Pareto distribution (ETSI, 1998).

It outputs average delay for each AP on the different floors. It uses the obstacles attenuations (Table 2), the n values for different environments (Table 1) and it allows to a user to choose the propagation models, described in Section 2.

The propagation model can be chosen and all of the parameters changed. Link Budget parameters like the emitted power and antenna gains are programmable, just like the receiver's sensibility and C/I limits. Also, all the average values for traffic simulation are changeable. Figure 4 shows a view of bit rate mapping with three APs. Figure 5 exemplifies how best server mapping is shown on plant. Each color identifies the area covered by an AP.

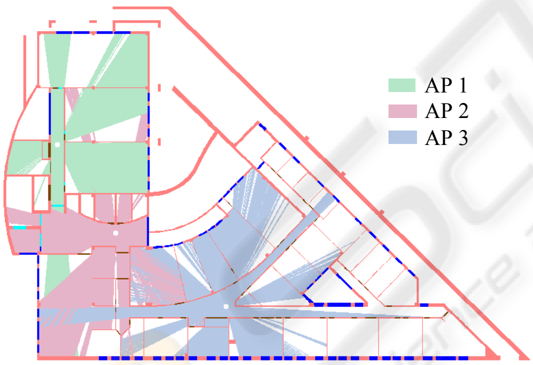

Figure 5: Best server example.

6 ANALYSIS OF RESULTS

Using the results from measurements described in Section 4, all the described models in Sections 2 and 3 are now put to test. Two typical examples are considered to illustrate two measured scenarios. The first one is an office area, with a link analysis throughout 6 office rooms. Power levels are measured in 8 points. The floor plant is shown in Figure 6, where the measured points are represented by blue dots.

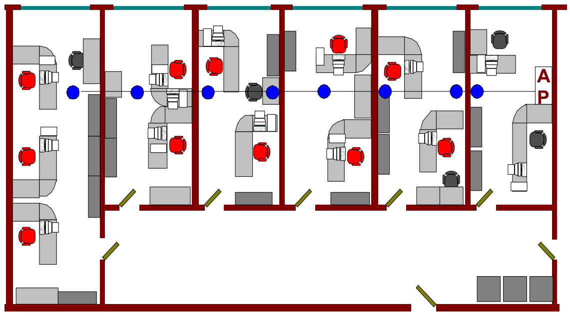

Figure 6: Office Area (example 1).

The attenuation for each point is surpassed using the Friis law. The proposed model considers different n for each room and the walls attenuation, which is shown in Table 1. Figure 7 contains the attenuation curve for all models and also the measured values for all points. The n value used in all rooms for the proposed model is 2.5. One Slope Model has n=3 and N for ITU is 30, being there the recommended values for office environment, just like α=0.57 for LAM model and n=2 (Mikas, 2003) for COST 231.

As shown in Figure 8, the proposed model has the better behavior on points 3, 4, 5, 6, 7 and 8. Point 1 is best modeled by Free Space, Keenan's Model and COST 231 model. Free Space Model has the best approximation also for Point 2.

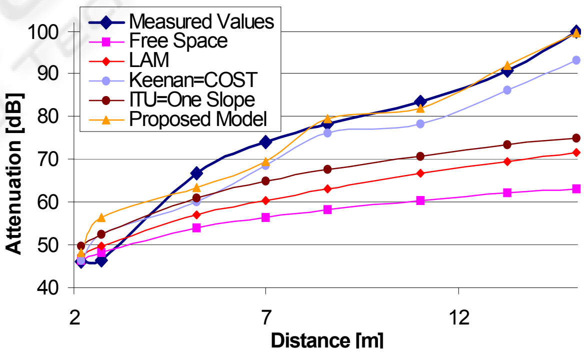

Figure 7: Comparision of all models (example 1).

Figure 8 represents the evolution of the Absolute Error with distance for example 1. It can be seen the significant improvement as the distance and the number of obstacles increases. There is some similarity with COST 231 and Keenan's model, but the differences are expected to be greater if the type of environment would be more than one, like in this example.

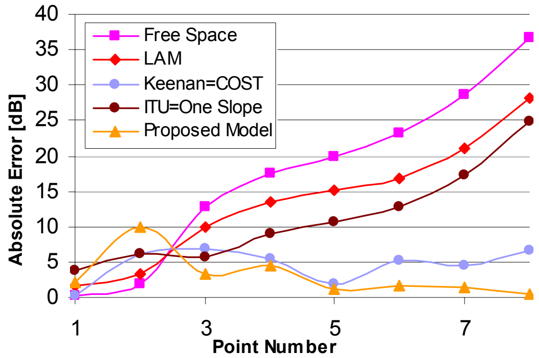

Figure 8: Absolute Error (example 1).

The second example represents a link with only one point measured. The transmitter and the receiver are separated by a fiber door (2.67dB attenuation) between them. The transmitter is placed on an electronics laboratory and the receiver on a class room. The distance between the transmitter and the door is 6.4m. The distance between the receiver and the door is 2.28m.

Table 3 has the Absolute Error for all models. The n value for One Slope and COST 231 and the N value for ITU, as well as the α for LAM are defined for office environment.

Table 3: Absolute Error for example 2

Propagation Model	**Absolute Error [dB]**
One Slope and ITU	1.4
Proposed Model	1.6
LAM	2.9
Keenan and COST 231	5.2
Free Space	7.9

7 CONCLUSIONS

Despite the better results on shorter distances (not relevant for coverage purposes), with one obstacle, for One Slope and ITU model, the proposed model has a good performance when compared with measurements. Even in the long distance cases with more than one obstacle between transmitter and receiver (when different environments are crossed). The developed planning tool *InPlanner* has the capacity to implement this model and also to perform traffic simulations, allowing coverage and capacity planning.

This work stands as a contribution to the planning methods required for the emerging technology of WLANs. More tests must be carried out to evaluate the proposed model with more different scenarios (shopping malls, train stations and so on), with the correspondent n index and other obstacles attenuation determination.

The growing number of different applications supported by WLANs, demands a continuous work to improve the quality of radio planning. The refining of the power decay index for the target environments, as well as the determination of a large number of obstacles attenuations should be considered.

REFERENCES

Neskovic, A., Neskovic., N, and Paunovic, G., 2000. Modern Approaches in Modeling of Mobile Radio Systems Propagation Environment. In *IEEE Communications Surveys*. The Electronic Magazine of Original Peer-Reviewed Survey Articles.

Foerster, J., 2002. In *IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)*, Channel Modeling Sub-committee Report DRAFT. Intel Research and Development.

Devasirvatham, D., Banerjee, C., Krain, M., and Rappaport, D., 1990. In *Multi-frequency radiowave propagation measurements in the portable radio environment*. IEEE International Conference on Communications.

Keenan, J., and Motley, A., 1990. In *Radio coverage in Buildings*. Br.Telecom Technol.J.vol.8,no.1.

ITU-R P.1238-1, 1999. In *Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 900 MHz to 100 GHz*. Question ITU-R 211/3.

Tarokh, V., Ghassemzadeh, 2002. In *S.S. The Ultra-wideband Indoor Path Loss Model*. IEEE P802.15-02/277-SG3a and IEEE P802.15-02/278-SG3a.

COST 231, 1999. In *Digital Mobile Radio towards Future Generation Systems*.

Mikas, F., Zvánovec, S. and Pechac, P., 2003. In *Measurement and prediction of signal propagation for WLAN systems*. Department of Electromagnetic Field, Czecalch Techni University.

ETSI, 1998. In *Universal Mobile Telecommunications System (UMTS); Selection procedures for the choice of radio transmission technologies of the UMTS*. UMTS 30.03 version 3.2.0, Sophia Antipolis, France.