Methodology for Analysis of the Coverage Probability of WLAN Using the Padé Approximant

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***Abstract* — This paper proposes a methodology for analysis of the signal reception probability in a 2.4GHz Wireless Local Area Network (WLAN). For validating this methodology a measurement campaign was carried out in an indoor environment using an access point as signal transmitter, and a notebook computer, equipped with a wireless board, as receiver. Twenty five average power received values were collected in this environment. Considering that the number of samples was insufficient for statistically characterize the environment, the colleted data was expanded using an Artificial Neural Network (ANN). The propagation loss was calculated using the expanded data in an adapted Padé Approximant model. It was included also, in the model, the number of obstacles intersected by the signal, as well as the loss due to each kind of obstacles. The obtained results were compared to a classical literature model.**

***Index Terms* — WLAN, Empirical Propagation Model, Probability, ANN, Padé Approximant.**

I. INTRODUCTION

The increasing demand for indoor wireless applications, such as wireless LAN, “Smart house”, etc., creates a need to efficiency and performance. While designing indoor wireless systems one is required to place the access points (at ranges that do not exceed 100 m) in a way that will provide an optimal coverage of the building area. The indoor wireless propagation scenario studied in this work considers access points located inside the building. The motivation for this research is the establishment of specialized indoor communication systems. Investigators have tried to compute and to determine a radio coverage that will predict a suitable spanning antenna for each building characteristics and wireless system requirements. There are many models, developed in recent decades, which describe the propagation of signals in indoor environment [1]–[4]. Several papers [5]-[8] propose methodologies for determining the sufficient number of transmitters (access points) needed to cover an area with WLAN service. There are a few software [9]-[10] available in which the user can insert the blueprint of the building to be analyzed, report the existent walls, the penetration loss at that obstacles, and in a few cases, choose a propagation model for calculating the signal loss. These programs, besides the high cost, limit the loss type and values at each obstacle and do not allow the inclusion of new models in its analysis. The full understanding of these models and their unification to a more applicable one will allow a better behavioral prediction and better capabilities in the design of indoor communication networks. The indoor radio propagation environment is specified by many features and characteristics and is very complex [1]-[4]. Due to this fact, dealing with these characteristics and with different propagation models, used to calculate them, has to be done efficiently and accurately. Every indoor communication system has a different structure and requirements due to their various applications. Calculating path loss for an indoor environment is a difficult task. This is because of the variety of physical barriers and materials within the indoor structure, one cannot exactly predict the loss of signal energy. Obstacles such as walls, ceilings and furniture, usually block the path between receiver and transmitter. Depending on the building construction and layout, the signal usually propagates along corridors and into other open areas. In some cases, transmitted signals may have a Line-of-Sight (LOS) to the receiver. In most cases a Non-Line-of-Sight (NLOS) conditions i.e., the signal path is obstructed. Finally, those who are involved in the wireless discipline whether as a designer or a user must be aware of the interiors and exteriors construction materials, and of the obstructions locations of a building to best position wireless equipment.

In order to contribute in the prediction of the behavior of signals in indoor environments this paper presents a methodology for analysis of the signal reception probability in a 2.4GHz WL AN. In which it is possible to insert any existent model, including number, type and loss due to each kind of obstacle intersected by the signal in its path from transmitter to receiver. This methodology presents, as a final product, a graphical representation of the coverage probability in every point of the building. For this probability study, it is necessary to measure the received power in several points. This work can be difficult if, for instance, the building has restricted access areas which occur in most cases. To avoid that arduous job, it was taken only a few points of measurements. The expansion of the data was made by the use of an Artificial Neural Network (ANN). With the expanded data and considering the minimal reception power of – 76dBm (according to the IEEE standard for 802.11g [11]), a reception probability was calculated in each point of the building. In order to achieve more precise values, an adapted propagation model was used [12] that considers the presence and the loss of each obstacle intersected by the signal. It was used the attenuation factor model [4], [6] for comparison with the model presented.

This paper is organized in the following way: section II presents the environment and the methodology description used in the measurement campaign; section III shows the models used for the coverage assessment; section IV presents the results and finally the conclusion is present in section V.

II. MEASUREMENT CAMPAINGN

A measurement campaign was performed to obtain the reception power data in a number of points of the studied building.

A. Environment

Measurement was performed in a building of the Computer and Electrical Engineer Laboratory of the Federal University of Pará (UFPA). This two floors building is built out of brick with concrete slabs. The separation of a few rooms is made out of prefabricated walls. This building was recently concluded, therefore there is no furniture or people working in it. Fig. 1 shows the front of the building, corridors and walls that separate the several rooms.

Fig. 1. From up left clockwise: front of building, second floor corridor; room separated by wall, and room separated by brick wall.

B. Measurement Methodology

In this section it will be described the measurement methodology used for obtaining the received power from the access point. The steps performed are outlined below:

1) Determination of the measurement point – along the building, points were marked where the measurements will be performed. The number of points in each room varies according to the room size.
2) Measurement in each point – in each previously marked point, it was positioned a notebook running the NetStumbler software [13] receiving the signal for an average period of 3 minutes;
3) Data treatment – the average received power was calculated for each point;
4) Results – the coordinates of each point and its corresponding power value, as well as the coordinate of the access point and its transmitted power (18dBm), were laid out in a worksheet.

Fig. 2 shows a blueprint illustration of the ground floor of the building with the marked points where the measurements were taken. The circle on the left side (corridor), represents the location of the access point (AP). Although the measurements were taken on both floors of the building, in this paper, only the results for the ground floor will be considered.

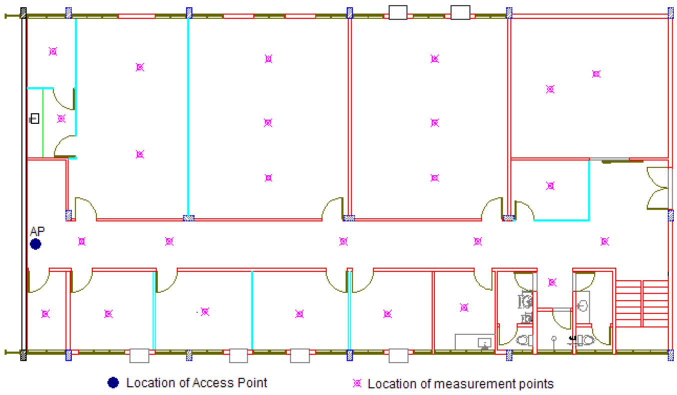

Fig. 2. Blueprint of the ground floor with the location of access point (AP) and the measurement points.

III. MODELS

Two models were used for calculating the propagation loss in each point. This section presents the characteristics of each model.

A. Padé Approximant Model

The model used in this paper was proposed by [12] and can be described in the following way:

$$L = L_0 + 10 n \log\left(\frac{d}{d_0}\right) + f(n_p; a, b) \qquad (1)$$

where:

L_0 = free space loss (dB);
n = path loss exponent;
d = transmitter-receiver distance (m);
d_0 = reference distance (m);
$f(n_p; a, b)$ = Padé approximant.

The Padé approximant formula uses second degree polynomials in the numerator and denominator, with adjustment parameters a and b; n_p representing the number of walls/floors intersected by signal path between the transmitter and receiver. The Padé approximant is given by:

$$f(n_p; a, b) = \frac{a + \frac{a b n_p}{2} + \frac{1}{12} a b^2 n_p^2}{1 - \frac{b n_p}{2} + \frac{b^2 n_p^2}{12}} \quad . \tag{2}$$

In the original model [12], n_p, as mentioned before, represents the number of walls and floors intersected. In this paper, however, this parameter is related not only to the number of floors and walls, but also to the loss in each one of the obstacles. So, n_p will be given by:

$$n_p = \sum_{i=0}^{N} L_{fi} n_{fi} + \sum_{j=0}^{M} L_{wj} n_{wj} \tag{3}$$

where:

L_{fi} = attenuation in floor type i;
n_{fi} = number of floors type i;
N = total number of types of floors;
L_{wj} = attenuation in walls type j;
n_{wj} = number of walls type j;
M = total number of types of walls.

B. Attenuation Factor Model

The model to path loss prediction for indoor wireless communications in multifloored buildings [4],[6] incorporates in its equation factors that consider the loss on walls and floors. Its equation is given by:

$$L = L_0 + 10 n_{SF} \log\left(\frac{d}{d_0}\right) + FAF\,[dB] + \sum PAF\,[dB] \tag{4}$$

where:

L_0 = free space loss (dB);
n_{SF} = attenuation coefficient in the same floor;
d = transmitter-receiver distance (m);
d_0 = reference distance (m);
FAF = floor attenuation factor (dB);
PAF = wall attenuation factor (dB).

The PAF is obtained by the attenuation on each wall multiplied by the existent number of walls of the same type.

IV. RESULTS

A. Data Expansion

As mentioned before, on the ground floor measurements were taken in 25 points. The number of samples is insufficient for any statistical analysis; therefore, in order to expand this data a two dimension interpolator was created. It was based on an Artificial Neural Network (ANN). This topology has been used together with the training algorithm "*Resilient Back-Propagation*" that uses the method of iterations and readjusts the synaptic weights after all sub-layers standards is presented to the network. Three layers were used: input layer, intermediate layer (hidden) and output layer, each one of them associated with an activation function. The input and intermediate layers are formed by 16 and 8 neurons respectively, using a *sigmoid* activation function, whereas the output layer is formed by 01 neuron working with a *linear* activation function [14].

B. Signal Reception Probability

The probability of the signal reception at each point of the building was obtained through the following classical power function relationship given by:

$$\text{Prob} = \begin{cases} \alpha \left(1 - \frac{P_r}{P_L}\right)^{\beta} & P_r > P_L \\ 0 & P_r \le P_L \end{cases} \tag{5}$$

where:

α = scale parameter (positive);
β = shape parameter (positive);
P_r = received power;
P_L = threshold power [9].

For β small, the probability drops slowly from 100% and more rapidly as it approaches 0%. This situation is reverted for large values of β. The parameters depend mostly on power transmitted, received and operation frequency, considering implicitly the distance between transmitter and receiver. These parameters can be experimentally determined, since in the proximity of the transmitter the signal reception probability is 100%. And at distance near the limiting distance (threshold received power) the probability can measured taken into account the specifications of the receiver. In this paper was used, for comparison purposes, the value β = 0.15; α is computed from β.

The highest value of P_r used was -30dBm, which corresponds to 100% probability of reception of the signal. The threshold power value (P_L) adopted was -76dBm, which corresponds to the minimum probability of reception of the signal. The value of P_L was established by IEEE standard [11]. Fig. 3 shows the signal reception probability (%) *versus* the received power (dBm) given by Eq. 5.

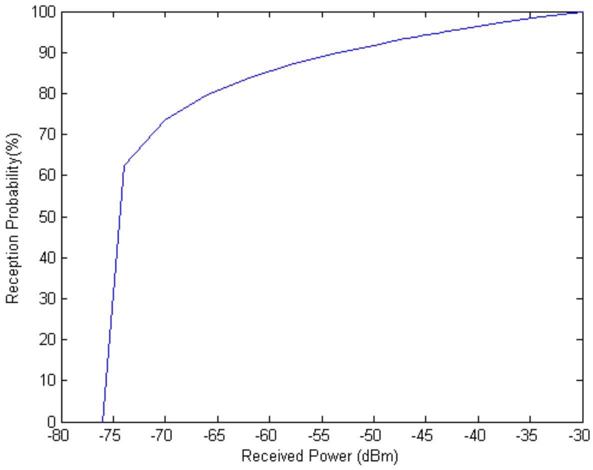

Fig. 3. Signal reception probability *versus* received power.

C. ANN Results

Fig. 4 shows the results of signal reception probability obtained through the ANN.

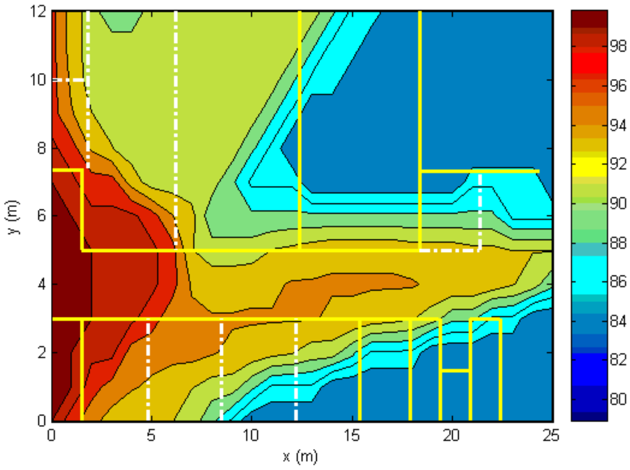

Fig. 4. Visualization of signal reception probability (%) through expanded data by ANN in all the area of the building [y(m).x(m)].

The data obtained by the neural network does not take into account the presence of obstacles, as observed on Fig. 4. In order to obtain the probability, empirical indoor propagation models were used taken into account the presence of obstacles, as well as, the loss of each one. In this case the ANN was used only to expand the data. The probability was calculated from the received power, obtained by the propagation loss models using the ANN data.

C. Padé Approximant Model Results

In order to use the Padé approximant model, it was necessary to create an algorithm capable of detecting the presence of obstacles and insert the loss of each one of them. Usually the blueprint of the building is made in Computer Aided Design (CAD) software. This software generates a pure text archive, with DXF extension, that contains among other things the dimensions and location of the walls. The type of wall is usually an available data. It is then possible to know how many, which and what kind of walls the signal intersects. In the studied building there are two kinds of walls, Fig. 4: brick (full line) and partitions wall (doted line). The loss of each kind of wall was obtained from [15], 3.66dB for the brick wall (2.51 GHz) and 0.43dB for the partitions wall (2.72GHz). The parameters *a* and *b* of Padé approximant are calculated adjusting the data from ANN to the model using a least square routine.

Fig. 5 shows the signal reception probability on the area of the floor when using the model with the Padé approximant. Observe that there is a better probability definition due the presence of walls.

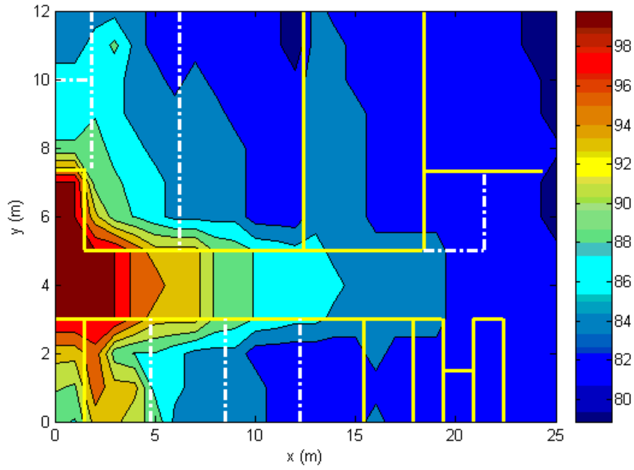

Fig. 5. Visualization of signal reception probability (%) through the expanded data by the ANN using Padé approximant model.

D. Attenuation Factor Model Results

Another model used for probability analysis was the model described by Seidel-Rappaport [4], [6]. In that model, the loss due the wall is simply the loss in each wall multiplied by the number of existent walls of the same type, as explained before. Fig. 6 presents the signal reception probability with the received power obtained by the propagation loss calculated by the Seidel-Rappaport model. It can be observed in this model, a weak relationship between the signal propagation and the walls of the building, and the minor prominence of the signal reception probability levels.

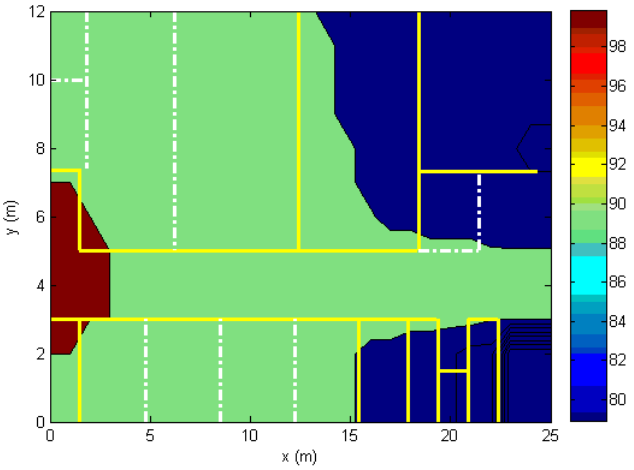

Fig. 6. Signal reception probability (%) through the expanded data by the ANN and received power obtained from Seidel-Rappaport model.

V. CONCLUSION

This paper presents a methodology to calculate and visualize the signal reception probability above the required threshold power to establish the service in a WLAN. In order to validate this methodology, a measurement campaign was carried out and an artificial neural network was used to expand the number of data obtained, in order to analyze the signal reception probability. Two models were used to improve the accuracy of the method: Padé approximant model and attenuation factor model. These models consider the presence of obstacles, in the case of this paper, the presence of walls and the loss at each one. A comparative analysis of the performance of the both models, it was observed that the Padé approximant model presents a RMS error of 4.2dB smaller that one presented by the attenuation factor model, whose RMS error is 5.4dB. This methodology allows the insertion of any propagation loss model and as an example, analyzes the coverage area of an access point. In conclusion, for future development, can be mentioned the creation of a computational environment with an easy user interaction for model insertion, providing also the types and loss for floors/walls.

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REFERENCES

[1] Bertoni, H. L., *Radio Propagation for Modern Wireless Systems,*Prentice Hall PTR, NewJersey , 2000.

[2] Blaunstein, N., *Wireless Communication Systems, Handbook ofEngineering Electromagnetics,* Ch. 12, 417–489, Marcel Dekker, NY, 2004

[3] J. D. Parsons, "Mobile Radio Propagation Channel", New York, Wiley, 2000.

[4] T. S. Rappaport, "Wireless Communications Principles and Practice", EUA, Prentice Hall, 2002.

[5] S. R. Saunders, "Antennas and Propagation for Wireless Communication Systems", New York, Wiley, 1999.

[6] S. Y. Seidel, T. S. Rappaport, "914MHz Path Loss Prediciton Models for Indoor Wireless Communications in Multifloored Buildings", *IEEE Transactions on Antennas and Propagation*, vol. 40, n° 2, February 1992.

[7] A. Eisenblätter, H-F Geerdes, "Wireless Network Design: Solution-Oriented Modeling and Mathematic Optimization", *IEEE Wireless Communications*, vol. 13, n° 6, p. 8-14, December, 2006.

[8] K. Jaffrès-Runser, J-M Gorce, S Ubéda, "QoS Constrained Wireless LAN Optimization within a Multiobjective Framework, *IEEE Wireless Communications*, vol. 13, n° 6, p. 26-33, December, 2006.

[9] http://www.ekahau.com, accessed 05/19/2007.

[10] "I-Prop Indoor Propagation Simulation Tool, Internet presentation, http://www.i-prop.cz, accessed 05/19/2007.

[11] IEEE Standards for 802.11g, p. 28, 2003, http://standards.ieee.org/getieee802.

[12] S. G. C. Fraiha, J. C. Rodrigues, R. N. S. Barbosa, H. S. Gomes, G. P. S. Cavalcante, "An Empirical Model for Propagation-Loss Prediction in Indoor Móbile Communications Using the Padé Approximant", *Microwave and Optical Technology Letters*, vol. 48, n° 2, p. 255-261, February 2006.

[13] www.netstumbler.com, accessed 05/19/2007.

[14] S. Haykin, "Neural Network: Principles and Practice", 2nd Edition, Artmed Ed, Porto Alegre-RS, 1999 (in Protuguese).

[15]R. M. Buehrer, A. Safaai-Jazi, W. Davis, D. Sweeney "Ultra-Wideband Propagation Measurements and Modeling: Final Report", DARPA NETEX Program Viginia Tech, January 2004.