

An Empirical Model for Propagation Loss Prediction in Indoor Mobile Communications Using Padé Approximant

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Abstract — This paper presents a model for path loss prediction in indoor mobile communications. It uses the free-space loss model added to an empiric function (based on Padé approximant), and a term that describes the sign randomness. In order to validate this model, a measurement campaign was accomplished at a typical 5 floors building of a university. The loss predicted by this model had a mean error of 4.78 dB and standard deviation of 6.05 dB in relation to the measured data. The proposed model doesn't need accuracy information of the environment in study, besides being adaptable to any indoor environment.

Index Terms — Distribution functions, indoor radio communication, loss measurement, mobile communication, Propagation loss models,

I. INTRODUCTION

The great growth on the number of users in the cellular communication system in the last years added to arise of WLAN's enhances the interest in the inherent phenomena to the indoor propagation environment. Objecting predict the losses in this type of environment, several models appear in the literature [1] - [6]. These models, in its majority, are based on the free-space model added to the floor and wall losses between the transmitter and receiver.

In this paper an indoor propagation loss model is proposed, it adds to the equation of the free-space loss model a term that describes the sign randomness and an additional empiric function of the number of floors among the transmitter and receiver antennas and the adjustment parameters (Padé approximant).

The main advantage of the model proposed in this paper is its interpolation and/or extrapolation capacity. For a study of propagation loss in a very high building, it is enough, with the proposed model, to make a measurement campaign in few floors. The loss in the others floors will be obtained by interpolation and/or extrapolation of the model.

To validate the proposed model a measurement campaign was accomplished in a 5 floors building of the

Institute of Superior Studies of the Amazon (IESAM-Belém-PA- Brazil).

Objecting to analyze the interpolation capacity of this model, only the data obtained in the ground, second and fourth floors will be used to find the parameters of the model. The data of the other floors, first and third, will be used to test the interpolation.

Section II presents a problem formulation in study, describing the proposed model. In the section III is made a description of the measurement environment. The section IV the procedures and equipments used in the measurement campaign are described. Finally, in the section V the path loss predicted by proposed model is compared with the results obtained during measurement campaign and with the predicted values by others well-known models in the literature.

II. PROBLEM FORMULATION

The free-space loss model considers the area between the transmitter and receiver as an area free of obstacles that can absorb or reflect the transmitted energy, besides to consider the atmosphere perfectly uniform and no absorbent. However, in practice, this model is not accurate to describe the real behavior of the radio mobile channel. Therefore, it's necessary to modify this model in order to consider the complexity of the environment analyzed in this paper.

The expression for the path loss model (PL), is function of the path loss exponent (γ), the loss in a reference distance (d_0) and the distance between transmitter and receiver (d), it is given by [6]:

$$PL(dB) = PL_0 + 10\gamma \log_{10} \left(\frac{d}{d_0} \right) \quad (1)$$

The component PL_0 is due to free space propagation from the transmitter to a 1 m reference distance (d_0).

The model proposed, considers the non-homogeneities of the environment adding to (1), a random variable (X) and an empiric term ($f(n_p, a, b)$) that is function of the number of floors (n_p) between the transmitter and the receiver and of the adjustment parameters a and b . The final expression is given by:

$$PL(dB) = PL_0 + 10\gamma \log_{10}(d/d_0) + X + f(n_p, a, b) \quad (2)$$

A. Path Loss Exponent (γ)

The path loss exponent (γ) indicates how fast path loss increases with distance. In the proposed model this exponent is described by a quadratic expression, given by:

$$\gamma(n_p) = -0.109n_p^2 + 0.853n_p + 1.51 \quad (3)$$

This γ expression was obtained from the loss exponents measured in the ground, second and fourth floors of the building in study. Considering those values, it was obtained a quadratic function that fitted those data and that could be used to obtain the exponents of the first and third floors. Therefore, to obtain the path loss exponents in the building in study, it isn't necessary to accomplish the measurement campaign in all floors of the building.

B. Random Variable (X)

The random component X , according to [5] can be expressed by:

$$X = x\sigma \quad (4)$$

Where x is a normalized random variable that characterizes the behavior of the distribution function found in the studied floors (ground, second and fourth), and σ is the standard deviation of the measured data.

The random variable x shows the local instantaneous variability in each point of the measured sign in the analyzed floors. In this way, the variability of the measured data tends to be the same because the measured environment presents similar layouts among the floors.

To characterize the random variable X were analyzed several distribution functions in the literature for the cellular mobile environments like Rayleigh, Log-normal, Rice, Nakagami-m, and Weibull [7] - [8].

C. The Floor Penetration Loss Factor

The term $f(n_p, a, b)$ in the equation (2) is a function of the number of floors (n_p) between the transmitter and receiver and the adjustment parameters (a, b) of Padé approximation [9] of degree two, numerator and denominator, of the exponential function. This term was proposed to describe the losses among floors, and is given by:

$$f(n_p, a, b) = \frac{a + \frac{abn_p}{2} + \frac{ab^2n_p^2}{12}}{1 - \frac{bn_p}{2} + \frac{b^2n_p^2}{12}} \quad (5)$$

The dependence of the path loss with the number of floors, in this paper, can be considered, in first instance, presenting exponential tendency. After obtaining the parameters (a, b) through the adjustment among the losses in the three floors and the equation (5), it was observed that the use of the rational function (Padé approximant) can describe the behavior of the measured data. The advantage of the use of the Padé approximant, in relation to the exponential, is better characterized for buildings with larger number of floors. This is due to the fact that of the exponential function possesses a unique tendency, while the rational function possesses variable tendency, in other words, its first and second derivatives can possess change of sign inside of the studied interval. The use of this approach, therefore, allows obtaining an interpolation and/or extrapolation more suitable.

D. The Proposed Model

Combining the equations (2), (3), (4) and (5) is obtained the general equation of the model.

$$PL(dB) = PL_0 + 10\gamma \log_{10}(d/d_0) + x\sigma + f(n_p, a, b) \quad (6)$$

In the following sections the environment and the measurement procedures will be presented with the subsequent validation of the proposed model.

III. THE MEASUREMENT ENVIRONMENT

In this section the measurement environment and the measurement procedures will be described.

The indoor measured environment is characterized as a typical 5 floors building of a university: with classrooms, laboratories, bathrooms, etc.

The walls are built of bricks, the slabs are made by concrete, the doors for the 1st to 4th floors are made by wood and the doors for the ground floor are made by aluminum. All the windows are made by aluminum and glass.

IV. MEASUREMENT SETUP

The measurement setup consists of a transmitter system, composed by a sweeping generator (model HP 83752A), an amplifier (ZHL - 42W) and an antenna (monopole, with gain of 3 dBi). During the measurement campaign, the transmitter set was located in the end of the corridor in the ground floor.

The receiver system is composed by a receiving antenna (monopole, with gain of 2.5 dBi), a spectrum analyzer (HP 8593E), a LNA amplifier, an acquisition board AD-DA (LAB JACK U12), a computer for storage data, and a prototype of a vehicle with a 5th wheel, that allows to measure the distance traveled by the receiver system [10].

The mobile receiver system traveled the corridors of all the 5 floors of the building (see Fig. 1), measuring and storing the sign received and the distance traveled by the system. The receiver antenna is connected to the spectrum analyzer, measuring the level of the sign received. The prototype of a vehicle with a 5th wheel measures the distance traveled by the system. The intensity of the sign measured for the spectrum analyzer and the sign measured for the prototype is sent to the computer through a converter board.

The data stored during the measurement campaign are treated and processed for subsequent use.

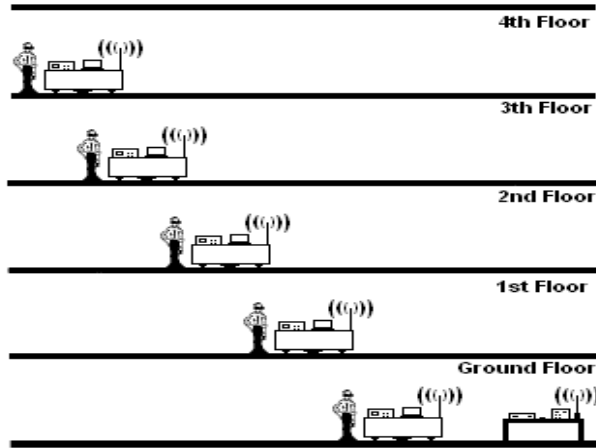


Fig. 1. Transmitter System located in the ground floor with the receiver system traveling by the others floors of the building.

V. RESULTS

After the collection and treatment data, is necessary to find the probability density function (*pdf*) that describes the random variable X shown in the equation (2).

The comparison among the distributions (Rice, Rayleigh, Weibull, etc) defines the best adjusted for the proposed model, it is accomplished through the chi-square test [1]. The distribution that has the smallest value of chi-square will be the chosen among the other tested distributions.

For all the measured floors the *pdf* that best described the behavior of the obtained data was Rayleigh. Therefore, x in the equation (6) is a random variable Rayleigh and σ its standard deviation. In the function $f(n_p, a, b)$, n_p assume the values 0, 2 and 4. The values of the parameters $a = -35.53$ and $b = -0.03$ were found using standard non-linear fitting procedures.

After the treatment of the measured data and the obtaining of the proposed model, the measured and

predicted propagation losses were compared in order to validate the model.

The Figs. 2-3 show the loss propagation with the radio distance for each measured floor. In all Figs, the solid line represents the measured loss and the dashed line represents the predicted loss of the model. The values predicted for the 1st and 3rd floor were obtained from the interpolation of the proposed model.

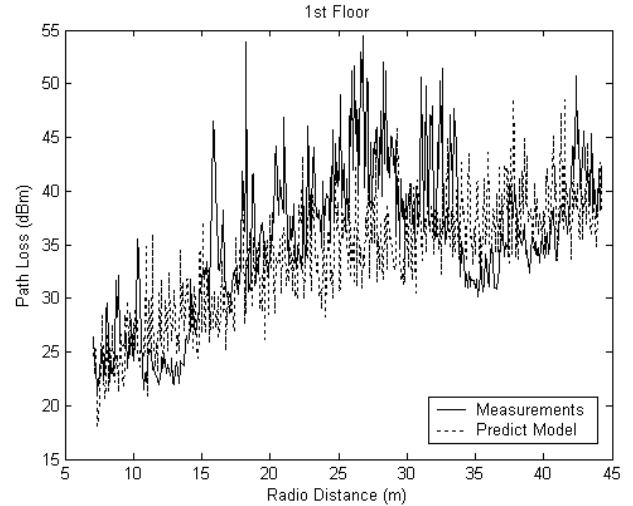


Fig. 2. Measured and Predicted Propagation loss for 1st floor.

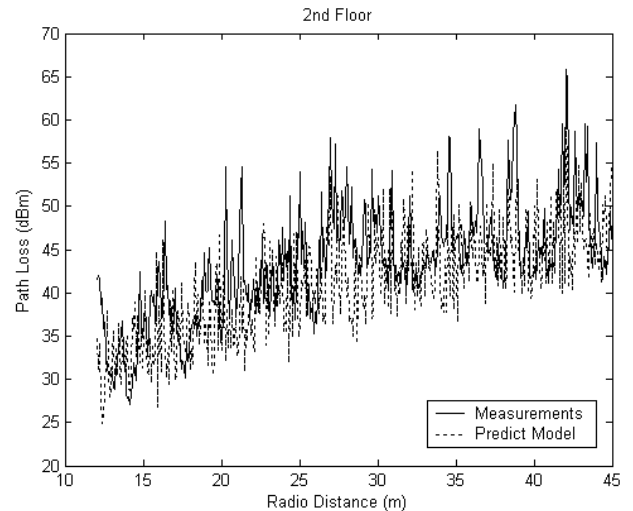


Fig. 3. Measured and Predicted Propagation loss for 2nd floor.

The measured data were also compared with values predicted by other models, such as: ITU-R [2], WLL - Wall and Floor Factor [2], COST231 [2], the models of Seidel-Rappaport, here designated as I (it doesn't consider loss in the floors) and II (it considers loss in the floors) [6]. The mean errors and standard deviation of the prediction obtained for all the floors are shown, as comparison, in Table I.

TABLE I
A STATISTICAL COMPARISON BETWEEN MODELS

Model	Mean Error (dB)	Standard Deviation (dB)
Proposed Model	4.78	6.05
COST231	4.80	6.08
Seidel-Rappaport II	4.82	6.12
WLL	9.48	10.53
ITU-R	10.10	11.17
Seidel-Rappaport I	33.08	34.25

In the Table I, it is observed that the proposed model, COST231 and Seidel-Rappaport II presented the best prediction results relative to mean errors and standard deviation. The COST231 model and the Seidel-Rappaport II model possess adjustment factors called L_c and FAF, respectively. However, in the references [2] and [6] there aren't mention how those adjustment factors were computed. For comparison effect with the proposed model, these factors were obtained, using the Nelder-Mead simplex method [11]. It is important to emphasize that the COST231, Seidel-Rappaport II, WLL, ITU-R and Seidel-Rappaport I models are not be able to interpolate or to extrapolate data, in other words, to optimize the model it is necessary to accomplish the measurement in all floors of the building in study. The advantage of the proposed model is the possibility to interpolate and/or to extrapolate the data, just because its adjustment factor (Padé approximant) is better defined than the parameters L_c and FAF. This advantage allows making a study in a building with many floors without, necessarily, acquire measures it in all floors. Therefore, it must to measure in some floors to find the *pdf* and the parameters of the Padé approximation. Obtained those data, the loss in the others floors can be obtained easily.

VI. CONCLUSIONS

This paper presents an empirical model for path loss prediction at indoor environment. It is based on the free-space model (that is a simple model; however, it has low accuracy). To consider the non-homogeneities of the environment are added to the free-space loss model, a random variable (X) and an empiric term ($f(n_p, a, b)$) that is function of the number of floors (n_p) between the transmitter and the receiver and of the adjustment parameters a and b , proceeding of the Padé approximant of the exponential function. In the studied building, the measured data were discriminated by a Rayleigh distribution. The presence of the random variable and of the empirical variables a and b turns the model easily adaptable to any indoor environment. The proposed model presents good results in the path loss prediction at indoor environment, quantified by the mean error and deviation

standard, as well as a good concordance between the measured and predicted propagation loss coefficients (γ). This model doesn't require a great computational effort and it isn't sensitive to the environment's geometry. Due to the path loss exponent and the adjustment factor (Padé approximant) being expressed by mathematical functions, this model, when compared with some models of the literature, has as advantage, the possibility of interpolation and/or extrapolation of the path loss, not needing measurements in all floors. This is easiness for the case of building with many floors.

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