Channel Propagation Model for Mobile Network Project in Densely Arboreous Environments

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***Abstract*— An electromagnetic wave propagation model in cellular frequency band for densely arboreous suburban environments is presented in this paper. In order to validate the proposed model, its results are compared with ones obtained from measurement campaigns carried out in a typical Amazonian city with suburban characteristics, i.e. low building surrounded by big trees, and some ones from literature. In addition, measurements with different transmitter heights were accomplished to study its influence in the signal propagation and the sensitivity response of the model. The model proposed agrees with some well-known models and measurements, including the critical case when the transmitter antenna height is close to the height of trees.**

***Index Terms*—** Empirical propagation models, mobile communication, probability density function, propagation in forests.

I. INTRODUCTION

Knowledge of the phenomena involved in the path loss propagation in forests is an important factor in the wireless telecommunications projects. However, the electromagnetic modeling of the radio wave in this type of environment has been a challenge due to the great complexity of the environment aspects. The physical and geometric parameters of the trees in the nature are randomized, so the areas with vegetation are difficult to find models to represent them, characterizing the environment and attending the system specificities like: frequency, transmitted power, antenna heights, etc. [1] - [3].

These factors have motivated UFPA researchers to develop path loss propagation models capable to include essential characteristics of suburban and densely arboreous environments, typically found in the Amazon region. [1], [4]-[6]

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The propagation channel is one of the most critical components of mobile communications systems, requiring an appropriate modeling of its elements in order to accomplish projects capable to attend the demands of different coverage areas.

The channel in this study consists of an aerial interface of a terrestrial mobile system in operation in Marituba and Abaetetuba cities, located in the State of Pará, both characterized by the occurrence of narrow streets with dense native forests [7].

The proposed model considers parameters that depend on the system and on the environment such as height and heterogeneities of the vegetation, transmitter antenna height and transmitter-receiver distance. In order to validate the proposed model, its results are compared with ones obtained from measurement campaigns carried out in the aforementioned cities. Furthermore, in order to explore all features of the proposed model, a sensitivity analysis is carried out in which the transmitter antenna height is set in 80, 70, 44, 14 m to study how this variation can influence the signal propagation. For all case studies, the model agrees with measurements, even in the critical case when the height of the transmitter antenna is close to the top of trees, exciting a lateral wave.

This paper is organized as follows: Section II presents the formulation problem as well as the modeling process. Section III describes the environment where the measurement campaigns were carried out and the methodology used during the campaigns. Section IV shows the validation and the sensitivity analysis of the model, comparing the results of measurement campaigns and the model for each transmitter antenna height. Finally, conclusions are presented in section V.

II. MODEL

This section presents a description of the terms included in the proposed model.

A. Specific Attenuation

The electromagnetic properties of the attenuation in the forest do not depend only on the density of trees but they also depend on other physical characteristics, for example, quantity of trees and its distribution in the forest. They also depend on the kind of existent trees in the forest.

The vegetation quantitative effect in the radio wave attenuation is considered along the wave path: the same path with vegetation has larger attenuation than an environment with absence of vegetation, for the same system setup and the same communication parameters used. The excess loss, in this case, is due to the foliage presence [5].

The specific attenuation is obtained by the ratio of the transmission loss and a limit distance and it is expressed in dB/m. The specific attenuation shows two different characteristics, one for the vegetation and other for the wave propagation mode. In the vegetation case, the specific attenuation measured is independent from the distance of the wave path and the mode propagation, if the environment considered is homogeneous. If the forest is not homogeneous, the specific attenuation varies point-to-point and, consequently, influences significantly the transmission loss and the

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respective mode propagation (direct, reflected or lateral wave). The specific attenuation is defined in the asymptotic limit as [9]:

$$\alpha = \lim_{d \to +\infty} \ln'[L(d)], \tag{1}$$

where: *L(d)* is the transmission loss in function of the distance *d*;

ln' is the derivative of the natural logarithm .

The specific attenuation can be expressed in terms of the received power (neper/m) in function of the distance:

$$\alpha[nep/m] = -0.5 \lim_{d \to +\infty} \ln'[P_r(d)], \tag{2}$$

that definition is in agreement with the theoretical studies [9] showing that, in homogeneous propagation environments, the variation of the received power with the distance assumes the following form:

$$P_r = Kd^{-\gamma} e^{-2\alpha d}, \tag{3}$$

where:

K and γ are parameters dependent on the environment;
α is the specific attenuation (1/m);
d is the transmitter-receiver radio distance (m).

The received power in (3), in decibels, is:

$$P_r = K_0 - 10\gamma \log(d) - 8.686\alpha d, \tag{4}$$

where $K_0 = 10log(K)$.

By definition, the transmission loss or propagation loss is given by:

$$L = 10\log\left(\frac{P_t}{P_r}\right), \tag{5}$$

where:

P_t is the transmitted power;
P_r is the received power.

As the transmitter can be located inside or outside the forest, the signal arrives at the receiver through a path direct and/or, reflected, diffracted or through lateral waves. In this paper, the transmitter antenna will be located in three situations: a lot above, a little above and on the top of the trees. The receiver antenna is fixed above a car. The equipment goes through the streets enclosed by trees and houses acquiring data. It is noticed then that the reflection and diffraction phenomena are, clearly, present in this scenery.

The Equation (4) describes the received power in homogeneous environments. For propagation in non homogeneous environments, this formulation can be still used with a few modifications, mainly in the specific attenuation (α), to compensate these effects. For example, S. S. Seker and A. Schneider

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[9] show that forests with predominance of trunks have their specific attenuation directly proportional to the density of number of tree trunks.

B. Environment Variability

The mobile cellular systems in operation in the Amazon region use, normally 800, 900 and 1800MHz frequency bands. The propagated signal presents a great absorption in the areas with high vegetation density, the problem becomes worse when the 1800MHz band is used. This fact has forced the mobile cellular companies to install the GSM900 system to increase the cell coverage. Besides the absorption problem, the environment causes a great variability in the received signal due to the environment randomness. Such fact should be compensated in the prediction loss propagation models including a randomized variable in their equations.

Considering the above mentioned, the proposed model was formulated using (4), where K_0 is a term that describes the relationship among the antenna heights, α is the specific attenuation for non homogeneous environments and χ is a random variable that characterizes the type of environment in study. Thus, the final formulation of the model is given by:

$$P_r = K_0 - 10\gamma \log(d) - 8.686\alpha d + \chi. \tag{6}$$

C. The K_0 Term

This term is related with antenna heights:

$$K_0 = a\left(\frac{h_t}{h_r}\right)^3 + b\left(\frac{h_t}{h_r}\right)^2 + c\left(\frac{h_t}{h_r}\right) + d, \tag{7}$$

where: h_t is the transmitter antenna height;

h_r is the receiver antenna height.

The coefficients a, b, c e d were obtained in two stages: initially curves of the received power versus distance were created for the experimental data and for (6), without K0 and random variable χ terms, with transmitter height at 14, 44, 70 and 80m. Starting from the difference between these curves, the errors between theoretical and experimental results for each height were calculated. After, considering the errors and the ration ht/hr, it was obtained a third degree polynomial fit (minimum square) which coefficients are a= -0.00169, b= 0.18269, c= - 6.2337 and d= 98.254.

D. Specific Attenuation of the Environment Studied (α)

The effects of non homogeneities environments can be compensated using an empiric specific attenuation. For different transmitter heights the specific attenuation has a cubic variation. Then, we can define the specific attenuation like an empiric equation given by:

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$$\alpha = \alpha_0 . \rho, \tag{8}$$

in (8), α_0 is an empirical constant that depends on environment characteristics and ρ is a factor that correlates the effects of the transmitter antenna height and the forest mean height.

$$\alpha_0 = \left(\frac{1}{1000} \right), \tag{9}$$

$$\rho = \frac{h_f}{h_t (h_t + h_f)}, \tag{10}$$

where: h_t is the transmitter antenna height;

h_f is the forest mean height.

E. Random Variable (χ)

The last term, of the general equation of the model (6), is the random variable χ that is obtained by computing the probability density function (PDF) of the experimental data, as well as its average and standard deviation. For the environment under analysis, this PDF follows a Rayleigh distribution [8].

III. Measurement environment

The measurement campaigns, accomplished to validate the proposed model, were carried out into two suburban and densely arboreous cities: Marituba and Abaetetuba. Both of them present houses, narrow streets and areas with typical vegetation of the Amazonian Forest. Their characteristics and the description of the methodology used in the measurement campaigns will be described in this section.

A. 900MHz - Marituba City

A measurement campaign was carried out at the suburban area of Marituba city, approximately 15km far from the state capital, Belém. This environment presents low buildings, narrow streets and densely arboreous areas; with typical vegetation of the Amazon Forest, see Fig. 1.

Fig. 1 – Marituba City.

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The transmitter antenna used in the measurement is omnidirectional with 2dBi gain that irradiates a CW wave at 890.43MHz. It was put in three different heights of a base station of a local cellular company, to study the effect of trees in the signal path loss.

The mobile receiver antenna, omnidirectional with 3dBi gain, was fastened on a car that traveled along three streets of the suburban area of Marituba city. These routes are shown in Fig. 2.

For each different transmitter antenna height (14 m, 44 m and 70 m), the receiver system (antenna and receiver equipment, GPS and a notebook with acquisition and storage data program) traveled the 3 routes of measurement. It was spent, in this campaign, an all day long; therefore, there are data acquired during the morning, the afternoon and night. The day was sunny, however, it rained in some moments of the measurement.

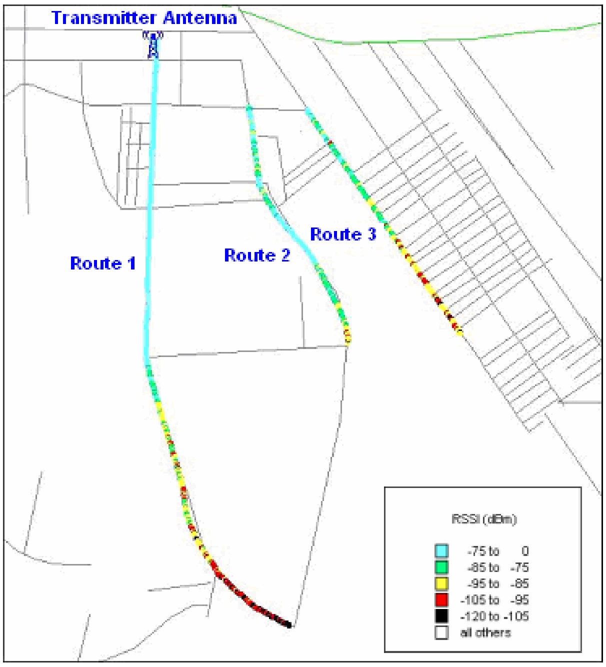

Fig. 2. Map with the measurement routes.

B. 1800MHz Band - Abaetetuba City

In this city, the transmitter antenna is a panel with 17.5dBi gain and the receiver antenna is omnidirectional with 0 dBd gain. The transmitted power was 44.5dBm at 1800MHz frequency band. The receiver system and the environment scenery were similar to Marituba city. The Fig. 3 shows a view of Abaetetuba.

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Fig. 3 – Abaetetuba City.

IV. RESULTS

A. 900MHz Band - Marituba City

Table I summarizes the path loss exponents for each transmitter antenna height used in the measurement campaign. These data were obtained experimentally. These data were used in all simulations.

TABLE I. ENVIRONMENT AND SYSTEM PARAMETERS.

Height, h_t (m)	**Path Loss Exponent, γ**
70	3.5
44	3.5
14	4.8

1) First Case: Transmitter Antenna at 70m

In Fig. 4, it can be observed that the proposed model fits the experimental data well. This result shows that the model represents the propagation channel very well when the difference between the transmitter antenna height and the top of trees is large. Table II summarizes the statistics for this case.

TABLE II. STATISTICS DATA FOR 70m.

Analyzed Data	**Distance(m)**	**Received Power Measured (dBm)**	**Received Power by Model (dBm)**
Minimum	207.4	-90.95	-83.55
Maximum	2095	-48.67	-49.97
Mean	1043	-71.20	-70.14
Standard Deviation	-	9.59	7.99

The mean error obtained among simulation and experimental data is 2.33dB.

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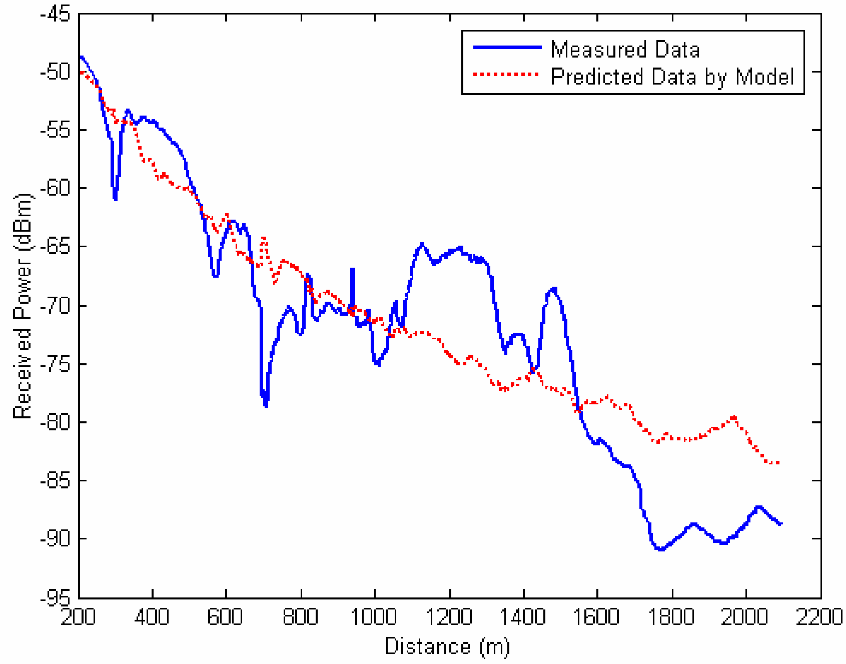

Fig. 4. Received power for the transmitter antenna at 70m.

2) Second Case: Transmitter Antenna at 44 meters

Fig. 5 shows that for a transmitter antenna at 44 m, the model again follows the experimental data. Statistics data for this case are shown in Table III:

TABLE III. STATISTICS DATA FOR 44m.

Analyzed Data	**Distance(m)**	**Received Power Measured (dBm)**	**Received Power by Model (dBm)**
Minimum	204.7	-89.51	-85.94
Maximum	1998	-35.98	-52.22
Mean	1010	-73.06	-73.48
Standard Deviation	-	9.56	7.65

The mean error between simulation and experimental data is 2.48dB.

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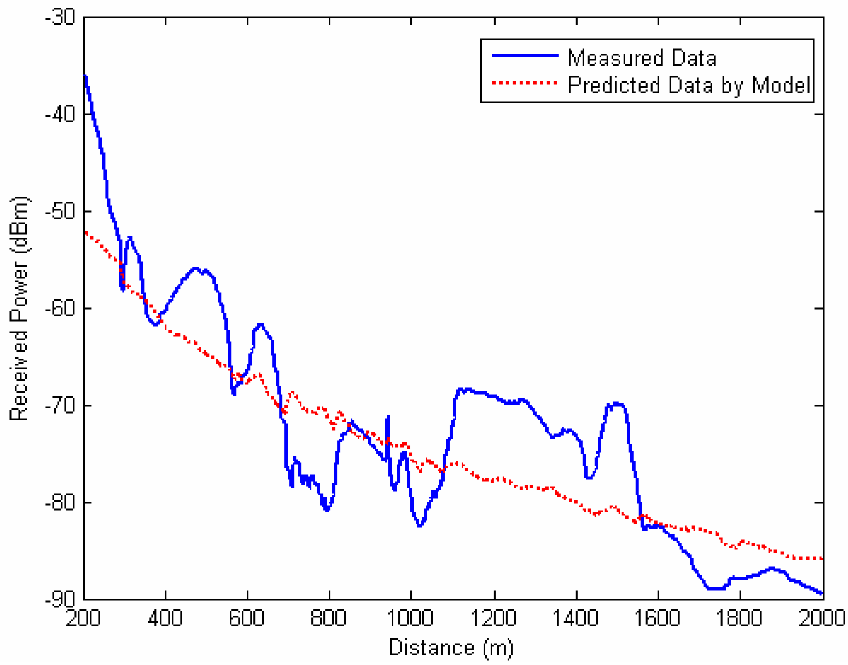

Fig. 5. Received power for the transmitter antenna at 44 m.

3) *Third Case: Transmitter Antenna at 14m*

Finally, the transmitter antenna was put at 14m. This height is considered critical, because the transmitter is in the same height of the forest, thus the propagated signal is totally submerged in the forest environment, therefore, a lateral wave is excited. It corresponds to a ray that is irradiated from the transmitter antenna in a critical angle and is propagated along the top of tree-air interface and arrives to the receiver antenna also through a critical angle. Depending on the distance between transmitter and receiver antennas, the direct and reflected waves or lateral wave can be dominant. The lateral wave is the main mechanism of transmission of the radio wave at long distances through the forest (considering transmitter and receiver located inside the forest). It is a component of a refracted field. The lateral wave provides a solid interpretation of many propagation aspects, among which can be highlighted the "gain-height" effect and the depolarization wave effects, that are strongly dependent on the parameters of the environment involved. This wave is resulted physically from a diffraction process [1]. It is worthwhile to mention that this critical situation is not predicted in the majority of the models of literature [5]-[6]. Even in this critical condition, it could be seen an outstanding agreement between results of theoretical model and the measurement campaign, Fig. 6.

The statistics data of this case are presented in Table IV. The mean error obtained between simulation and experimental data is 3.03 dB.

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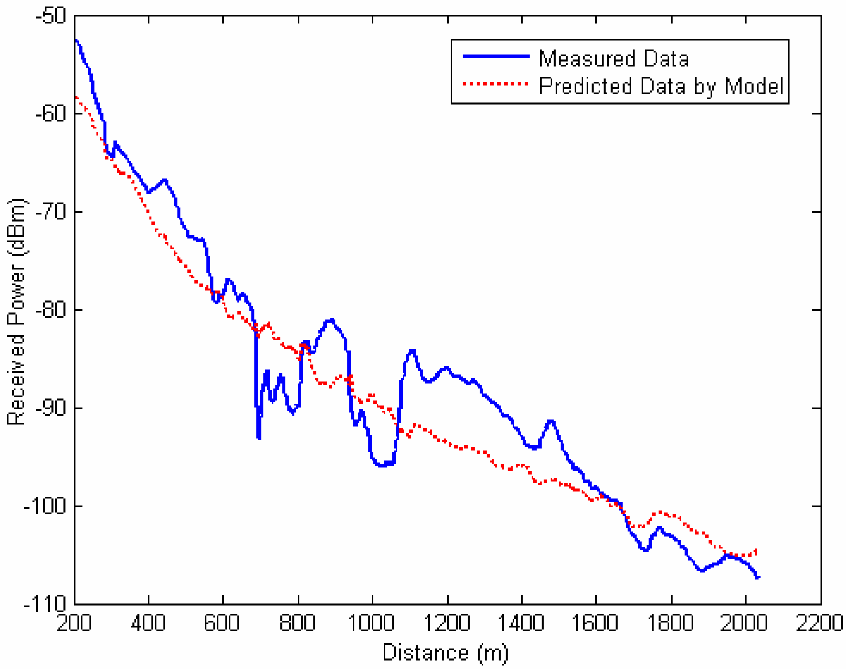

Fig 6. Received power for the transmitter antenna at 14 m.

TABLE IV. STATISTICS DATA FOR 14m.

Analyzed Data	Distance(m)	Received Power Measured (dBm)	Received Power by Model (dBm)
Minimum	206.1	- 107.5	- 105.2
Maximum	2035	- 52.48	-58.36
Mean	1010	- 87.00	-87.39
Standard Deviation	-	11.34	10.54

B. 1800MHz Band – Abaetetuba City

Fig. 7 shows that for Abaetetuba city where the transmitter antenna height is 80m and the path loss exponent is 3.2, the model follows again the experimental data.

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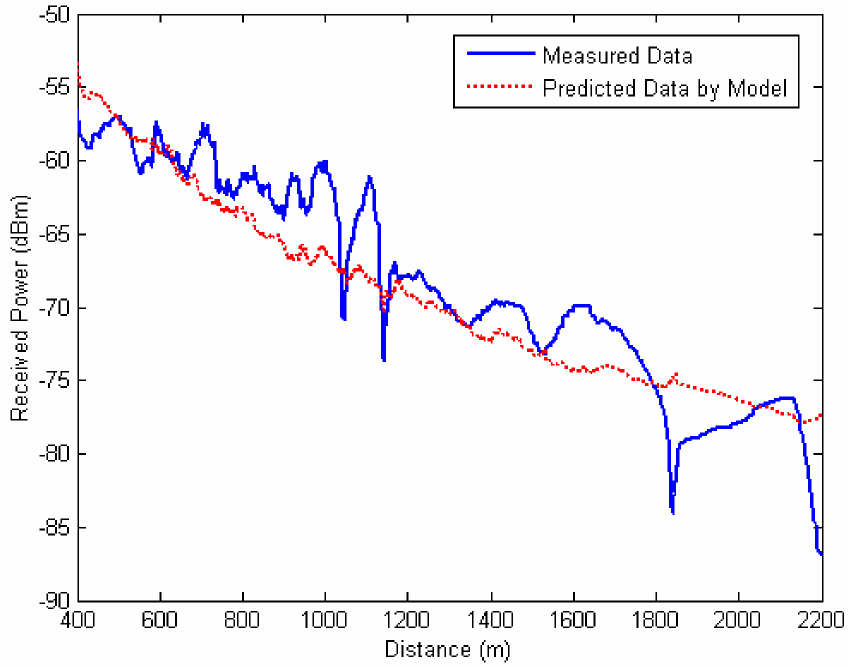

Fig 7. Received power for the transmitter antenna at 80 m.

Statistics data are presented in the Table V. The mean error obtained between simulation and experimental data is 1.23dB.

TABLE V. STATISTICS DATA TO 80m.

Analyzed Data	**Distance(m)**	**Received Power Measured (dBm)**	**Received Power by Model (dBm)**
Minimum	400	-87.04	-77.87
Maximum	2200	-56.53	-53.34
Mean	1034	-65.26	-66.4
Standard Deviation	-	6.23	5.46

C. Comparison with other Models

In order to test the accuracy of the model, the path loss, calculated from received power predicted by model, are compared with the prediction loss given by some well-known models. The models used are: Egli [8]; Lee [10]; Okumura-Hata[8]; Walfisch-Ikegami[8]; and Bertoni [11]. The statistics of errors are presented in Table VI and VII. Some results do not appear in tables due to model limitations in transmitter antenna height and/or frequency.

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TABLE VI. RESULTS OF THE COMPARISON WITH THE MODELS.

Model	14m Height (900MHz)			44m Height (900MHz)		
	Mean Error	Standard Deviation	RMS Error	Mean Error	Standard Deviation	RMS Error
Okumura -Hata	-	-	-	14.87	0.77	14.89
Walfisch-Ikegami	30.31	0.57	30.31	17.98	2.25	18.12
Egli	5.16	0.79	5.22	9.73	2.68	10.09
Lee	23.03	3.36	23.27	2.77	1.80	3.31
Bertoni	-	-	-	3.54	2.45	4.31
Proposed Model	3.43	2.68	4.35	1.63	1.07	1.94

TABLE VII. RESULTS OF THE COMPARISON WITH THE MODELS.

Model	70m Height (900MHz)			80m Height (1800MHz)		
	Mean Error	Standard Deviation	RMS Error	Mean Error	Standard Deviation	RMS Error
Okumura -Hata	13.27	0.79	13.29	8.54	1.93	8.76
Walfisch-Ikegami	14.48	2.57	14.70	7.24	4.25	8.40
Egli	6.97	3.02	7.60	-	-	-
Lee	7.32	2.94	7.89	11.74	4.82	12.69
Bertoni	7.52	3.02	8.11	5.23	3.78	6.46
Proposed Model	2.67	1.78	3.20	2.67	2.12	3.41

The results showed in Table VI and VII prove the accuracy of the proposed model in the arboreous environment.

V. CONCLUSIONS

This work presents a proposition for channel propagation modeling in suburban and densely arboreous environment, which are typical of Amazonian cities. This model considers the parameters that depend on the system and the environment such as vegetation height, heterogeneities of the environment, transmitter antenna height and transmitter-receiver distance.

To validate the proposed model, it was carried out a measurement campaign in two Amazonian cities. Results showed a good agreement in all the studied cases. Even when the transmitter antenna height is the same as the forest, one which is considered a critical case, the model still presented good results. Furthermore, the formulation of the model is simple, with low computational effort and the comparison with the other models demonstrate its good performance.

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