Chapter 241

Comparative evaluation of propagation prediction models for mobile communications applied to the city of Natal and Metropolitan Region

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ABSTRACT

The growth in demand for wireless communications has led researchers to devise new solutions and techniques aimed at increasing the capacity of networks and improving the quality of mobile communications services. The use of smaller and smaller cells, the use of progressively higher frequencies, and more complex propagation environments demand more accurate modeling and prediction techniques are part of this context. The prediction of coverage in a cellular system, especially in urban areas, is one of the most relevant aspects for mobile network operators. This work aims to present a comparative analysis of the application of several models in cross-section with the results of a campaign of propagation measurements in the city of Natal and the metropolitan region. Supported by the infrastructure of a mobile laboratory, the measurements were carried out in three areas with different characteristics of buildings, relief, afforestation, and heights of diversified towers, covering the central area of the city, a suburban area, and a coastal stretch bordered by dunes. The measurement campaign was made in the 800 MHz bands, using as a reference the control channel of the existing sites in the evaluated areas. The results obtained for attenuations were compared with the values calculated from the prediction models employed. The campaign of measurements proved the occurrence of a greater attenuation and more accentuated characteristics of oscillations of the power received in the central area of the city, evidencing the influence of the greater density of obstacles, variation of the condition of visibility point-to-point, greater traffic of vehicles and people and differences in the characteristics of afforestation and buildings in the streets of the region.

Keywords: Propagation Prediction Models, Wireless Communications, RF Attenuation, Cellular Systems, RF Measurements Indoors.

1 INTRODUCTION

In the terrestrial mobile radio environment, modeling the prediction of propagation losses is a complex task due to the different conditions observed in the existing architectural structures, in the afforestation, in the relief of the terrain, and in the flow of vehicles and people, among other aspects. Some of these factors, with the nature of random characteristics, cause changes in the power of R at medium Frequency (RF) captured at each point over time. The combination of Electromagnetic Theory, including the phenomena of reflection, diffraction, and diffusion, with Statistics has helped in obtaining better approximations for models of prediction. The so-called "large-scale models" seek to determine an estimate of the average value of RF power intensity for different distances between transmitter and receiver [1]. The coverage of a cell is also limited by the low transmission power of the cellular devices and varies with the frequency used, in addition to the gain of the antennas of the Base Radio Station. In the present study, the measurements were made with a reception power of up to (minimum) -115 dBm, a value already lower than the typical reception threshold in the SMP [2]. Diffraction occurs when rays bend around obstacles, reflection occurs when rays collide with hard, smooth surfaces, and scattering occurs when a ray splits into several, after an impact with a hard, rough surface [3].

Most cellular systems operate in urban areas where the situation of lack of line of sight between transmitter and receiver predominates. The effects observed in a mobile channel can be classified into three forms of fading [4]: spatial fading which is characterized by a variation in intensity as a function of distance and presenting two versions: slow (average of the set of signal fluctuations) and fast (variation around the mean value). The temporal fading, also called the narrow strip, corresponds to fluctuations resulting from various causes, especially the movements of the receiver and objects in the vicinity. Also influential in this case are changes in temperature, relative humidity, and opening and closing of doors. Selective fading is mainly caused by the occurrence of multipath propagation [5].

The measurements were carried out using the mobile laboratory infrastructure of the National Telecommunications Agency (ANATEL), covering three areas of Natal, with specific characteristics of buildings, relief, afforestation, and heights of diversified towers, covering the central area of the city, a suburban area and coastal stretch bordered by dunes. The work promoted a campaign of measurements in the 800 MHz bands, using as a reference the control channel of the existing sites in the areas under study. Based on the values of the measured RF powers, the characteristics of the transmitters of the Base Radio Stations (RBS), and the antennas, in addition to the coordinates of the points, the attenuations and distances involved were calculated in each measurement made.

The analyses were performed considering the reality of cellular systems with reduced cell coverage radio to provide greater frequency reuse and offer greater telephone traffic capacity. The predominance of telephone traffic per cell in the city of Natal was identified within a radius of less than 3 km to ERB. The frequency range used was 800 MHz, corresponding to the control channels of the respective sites, which adopt the FSK modulation technique [6].

The article is divided as follows. Section II presents an approach to the method used in the research, the theoretical framework, and the main models of mobile radio prediction. Section III describes the propagation environments evaluated in the work and presents the details of the Base Radio Stations of the area of the center of the city of Natal, the region located in the eastern region of the city, called Via Costeira, and the municipality of Extremoz. located in its metropolitan area. Section IV presents the results of the analyses of the distance attenuations of the ERBs and a comparison of the prediction models applied to the work. Finally, Section V brings the main conclusions of the work and the potential expectation of future work.

2 MIS A WHOLE AND THEORETICAL FRAMEWORK

The research method for this study was a case study, characterized by a campaign of propagation measures aimed at evaluating the coverage of mobile systems in Natal and its metropolitan region. The measurements were performed using an ANATEL vehicle properly equipped with an RF reception system, GPS, and a receiver antenna installed on top of the vehicle, adopting a spacing of around 80 meters between the measurement points. Special attention was given to the measurement campaign involving different streets of the city, including cross-positions, always to cover the variety of situations existing in the environment, involving some points in visibility, but most with varied obstacles, with different characteristics of relief and buildings. The measurement campaign was carried out in the hours between 14:30 and 17:30 hours, on weekdays without rain, corresponding to the average situation of vehicle traffic and pedestrian movement.

To carry out the measurement campaign, a Mobile Laboratory Station of ANATEL was used, whose characteristics of the embedded systems are detailed in [2]. The planning of a mobile network aims to ensure certain levels of performance and quality by establishing the network infrastructure for the necessary coverage, in contrast to the related costs. This process includes approximate models, estimates of signal power, and traffic demands, which should be improved by analyzing the operational conditions of the network in the field[1].

An important feature of the terrestrial mobile radio channel relates to the average attenuation of the RF signal as a function of the distance between the transmitter and receiver. The following equation simply describes slow fading as a function of distance in a situation without a line of sight [7]:

$$L(d)=L\ b-10n\log(d/d0) \quad (2.1)$$

In expression (2.3), L(d) is the attenuation in dB for the receiver at a distance d (meters) from the transmitter, n is the exponent of loss in the path, typically $2<n<5$ to be determined based on field checks, d 0 is the line-of-sight reference distance (meters) and the frequency f is given in MHz.

$$Lb=27.6\ dB-20\log(f)-20\log(d\ 0) \quad (\ 2.2)$$

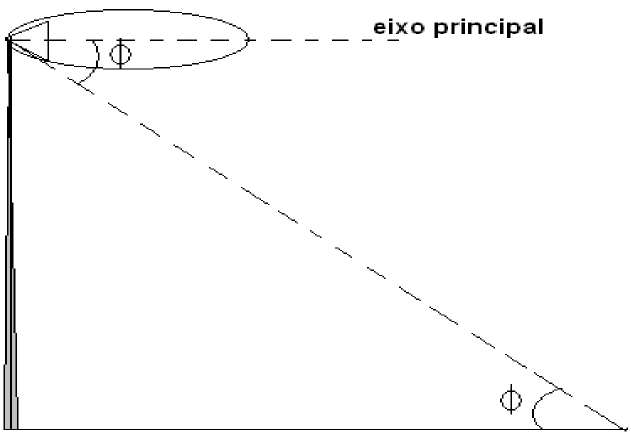
The propagation in free space (perfect outer channel) follows the quadratic law of power variation, with n=2. The classic model is used when there is a free line of sight between transmitter and receiver, applicable both in terrestrial microwave links and even in satellite communications. Although propagation in free space is a very simplified and particular situation, its understanding and calculation are useful for the development of more complex expressions that can better define propagation in different environments. The loss in propagation in free space is defined by the relation below indicated in equation (2.3). The expression of attenuation in the free space may or may not include the gains of the antennas [1].

P_L (dB)=10log P_1/P_R =-10log[(G_1 G_R λ^2)/(4Πd)^2]   (2.3)

In equation (2.3), PL is the effective loss of transmission in dB in the unobstructed path, not considering the effect of the antennas. This equation is valid only for values of d that correspond to points located in the area called the distant field of the transmitting antenna [4]. The distant field or Fraunhofer region of a transmitting antenna is defined as the region situated at a distance greater than the Fraunhofer distance, which provides the boundary between the near and far field, related to the antenna aperture and wavelength [8].

Due to the trend of reduction of cell radii, the study of propagation in areas close to the antennas of ERBs has become a relevant topic in propagation evaluations for mobile communications. In the case of an omnidirectional antenna with high gain, commonly used in regions with rural or suburban characteristics, in an area less than a radius of up to 1 km, there may be a reduction in the influence of the desired gain of the antenna, as a function of the angle of elevation of the antenna, as illustrated in the figure below [2].

Fig. 1- Propagation in areas near ERB



Fonte: Own authorship

The survey of statistical curves of measurements near an ERB may require adjustments that must be performed using correction factors depending on the variation of the effective gain of the antenna relative to the reception points and the influence of the orientation of the streets may also affect the results [2]. This real problem can be minimized a little, with the inclination of the ERB antenna, it can be done when the desired coverage area for the cell is small. The modeling of the field near the ERB requires a more complex equation, also considering the oscillatory nature of the electromagnetic field [9]. In the sizing of cellular systems such as LTE, input information related to the desired quality, coverage, and capacity should include variables such as the probability of blocking [10]. These parameters translate directly into Service Quality (QoS) for customers [11].

The influence of buildings and other obstacles present in the environment of propagation is a very complex topic, several researchers have presented the problem from the distinction between urban areas and suburban areas, seeking, in this way, to analyze separately the situations of higher and lower density of buildings [2]. The Random Walk Model of Wave Propagation was developed for application in microcells by Franceschetti et al. [12]. It is a stochastic model based on the theory of random paths that takes into account only two parameters: the number of obstacles and the absorption characteristic of these obstacles throughout the radio propagation environment.

Several experiments carried out in the 800 MHz bands, covering distances between 40 m and 4 km in tropical zones with thick vegetation and in large quantities, indicated a loss in the range of 40 dB per decade for this band. According to Alencar [3] the attenuation rate per foliage in the range of 50 to 800 MHz is 0.005 dB/m 0.3 dB/m (horizontal polarization) and 0.005 dB/m 0.51dB/m (vertical polarization).

The Okumura model contemplates a calculation procedure without an analytical basis and is fully based on measurements made in the Tokyo area and which led to the generation of attenuation curves as a function of distance and frequency [13]. An ERB antenna with a height of 200 meters and a height of the mobile station of 3 meters was used. In the prediction curves relative to the free space, the correction factor Garea (gain) for a given type of terrain is also given as a function of frequency. For the different heights of the antennas can be obtained the correction factors whose detailing can be found in [4]. The propagation loss equation proposed by Okumura is presented in equation (2.4), where L0 is the loss in free space, and A (f,d) is the additional gain (attenuation in reality) obtained from the experimental curves.

$$L=L0 +A(f,d)-G\ area-G(ht)-G(hr)\ (dB) \quad (2.4)$$

The Okumura model was not designed for computational use, as it involves several curves, yet it is still one of the most widely used prediction models in the world in urban areas, it applies in the band of 150 MHz to 3 GHz (the upper limit stems from extrapolation) at distances from 1 to 100 km, with antenna heights theoretically ranging in ERBs between 30 meters and 1,000 meters. The Hata model [14], explained in equation (2.5) elaborates an empirical mathematical formulation for the graphs of Okumura with the adaptive application for diverse situations in the band from 150 MHz to 1,500 MHz.

$$L_{50}(urbana)(dB) = 69{,}55 + 26{,}66\log(f_c) - 13{,}82\log(h_{te}) - a(h_{re}) + (44{,}9 - 6{,}55\log(h_{te}))\log(d) \quad (2.5)$$

Equation 2.5 is Hata's standard expression, from which it makes adaptations according to the type of propagation environment. L 50 (urban) corresponds to the average loss of RF power, FC is the frequency (MHz) of the carrier between 150 and 1,500 MHz, h te is the height of the antenna in the ERB and can vary from 30 to 200 meters, the is the height of the antenna in the mobile station, ranging from 1 to 10 meters and d is the distance of separation transmission or-receiver in km. The parameter a (h re) is the correction factor (dB) for the height of the antenna of the mobile station, which can be obtained from the alternatives considered: a large city, a small or medium city, a suburban area, and an open rural area. According to Rappaport [4], the results of Hata's model are very close to those of Okumura, for distances of 1 km.

Walfish and Bertoni's Model [15] takes into account the impact of the row of buildings to estimate the average signal power received from buildings using diffraction to estimate the average power of the signal received on the streets. In this model, it is considered that the buildings have constant spacing and heights. The expression applied to this model extracted from [14], is presented in equation (2.6), in which Lo is the attenuation in free space (dB), H is the average difference of height (m) between the E ERB and the height of the buildings, the constant A represents the intensity of the geometric influence of the buildings, f is the frequency in MHz, e d color the average distance between buildings:

$$L(dB)=L_0+57,1+A+\log(f)+18\log(d)-18\log(H)-18\log((17H+d^2)/17H) \quad (2.6)$$

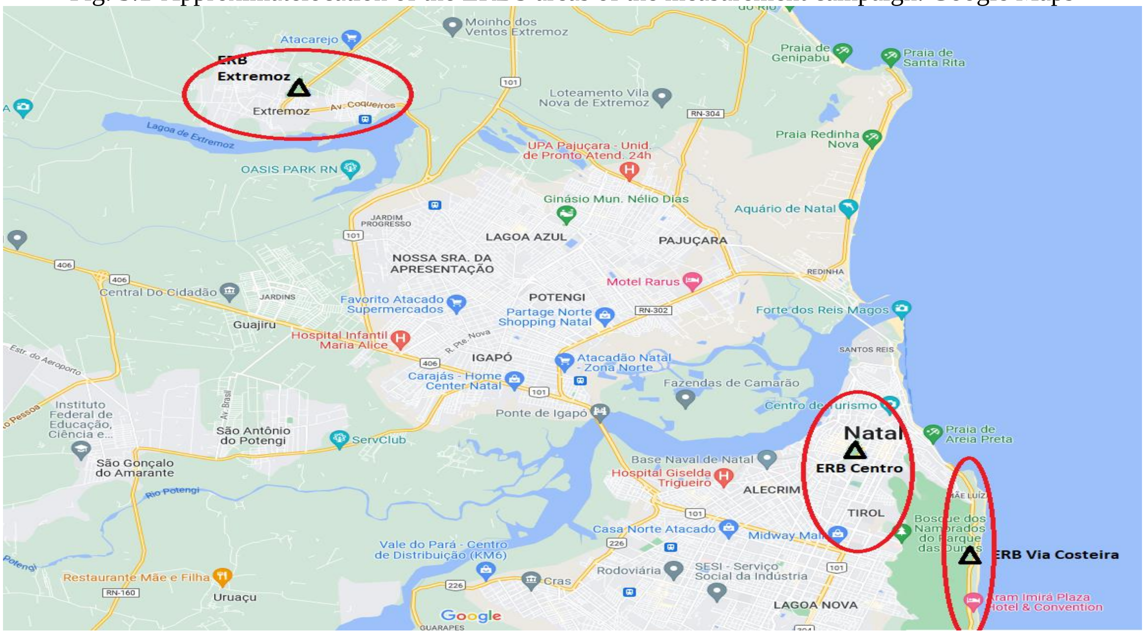
To consider the temporal variations of the intensity of the received field, at each point 100 (one hundred) measurements of the RF power of the received signal through the control channels were obtained and the average of the powers (medium level in dBm) measured was calculated. The total number of measurements made in Natal was 22,900 (twenty-two thousand and nine hundred), corresponding to the coverage of 99 (ninety-nine) points. The starting point of the measurements of each measured site was always chosen as the closest possible to the ERB.

Based on the values of the measured RF powers, the characteristics of the transmitters of the ERBs and the antennas, in addition to the coordinates of the points, the attenuations and distances involved in each measurement were calculated. Subsequently, these results were compared with the values calculated following the Models:1- Okumura-Hata (in the options: small urban area, large urban area, small city suburban area, large city suburban area), 2-Attenuation in Free Space, 3-Walfish-Bertoni [4].

3 DESCRIPTION OF PROPAGATION ENVIRONMENTS EVALUATED

The sites surveyed in the measurements, identified in Figure 3.1, have very diverse structural and environmental characteristics: the Centro Station has three sectorized cells, while the Via Costeira has two sectors and the Extremoz Station has only one cell, served by an omnidirectional antenna.

Fig. 3.1-Approximatelocation of the ERBS areas of the measurement campaign. Google Maps

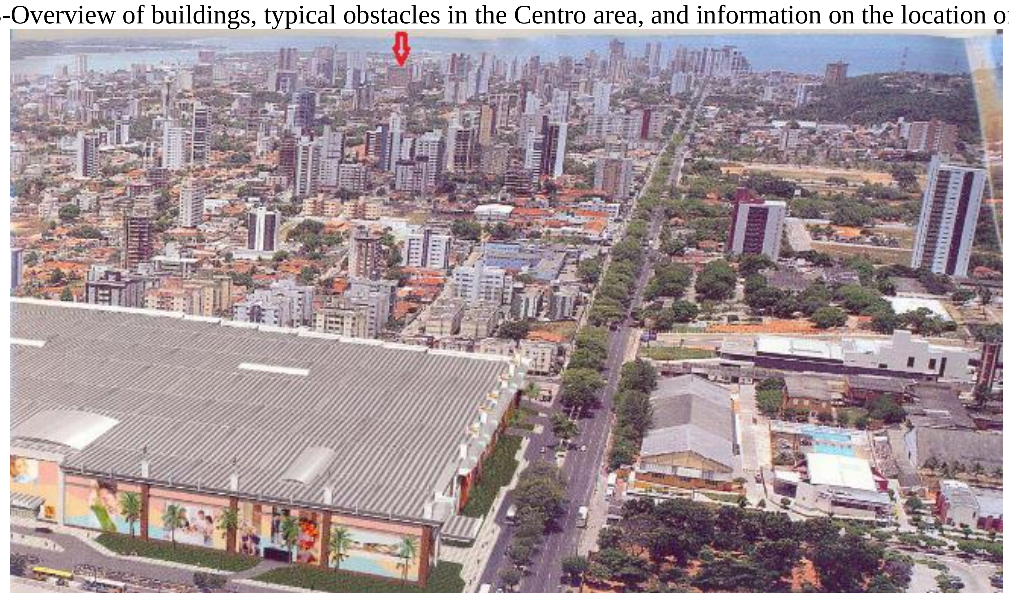


Fonte: Pinheiro (2006)

3.1 AREA COBERTA BY THE CENTRAL STATION

Theantenas d the Centro Station is installed at the top of the headquarters building of OI-RN, at a height of 64 meters, located in the corner of Avenida Prudente de Morais with Rua Jundiaí in Natal. The tested ERB consists of 3 120-degree sectorized cells, transmitters of 10 W of power, antennas DB-844H65VTX with a nominal gain of 14.6 dBi, frequencies of the 3 control channels: 879.81 MHZ, 879.69 MHZ, and 879.91 MHZ.

Figure 3.3-Overview of buildings, typical obstacles in the Centro area, and information on the location of the ERB.



Source: Pinheiro (2006)

3.2 AREA COVERED BY THE COASTAL STATION

The area located on the east coast of the city of Natal predominantly serves the Via Costeira, a highway that connects the beaches of Ponta Negra and Areia Preta, isolated buildings (hotels), and positions slightly above sea level with heights around 20 meters. The Via Costeira is between the Atlantic Ocean and a wall of dunes that make up an area of environmental preservation called Parque Lui

z Maria Alves. The Coastal Station also comprises the Mãe Luísa neighborhood located on dunes in a position perpendicular to the Via and with low buildings and part of the beaches of Miami and Areia Preta, along the final stretch of Avenida Café Filho. The transmitters used are 10 Watts, control channels in the frequencies of 79.54 and 879.99 MHz, the dipole antennas DB844H65E-XY with a gain of 13.1 dB are located in a tower at the height of 45 meters, corresponding to two cells sectorized in 120 degrees freeing the direction of the beach. The measurements made covered the Via Costeira, the neighborhoods of Mãe Luísa and Areia Preta.

Fig. 3.4 - Coastal Way and location of the Tower considered as a reference in the measurements.

Fonte Pinheiro (2006).

3.3 AREA COVERED BY EXTREMOZ STATION

The Area in the municipality of Extremoz located in the metropolitan region of Natal, with suburban characteristics with low buildings, but with irregular terrain and many trees of low height in the region near the lagoon of Extremoz. ERB transmitter with 10 Watts, control channel frequency in 880 MHz, omnidirectional antennas type ASP 977, Decibel manufacture, gain 8 of 1/2dB (+- 0.5dB), installed in a tower at the height of 45 meters from the ground.

4 RESULTS

The following are the results of the measurements obtained from the three areas evaluated and compared with the various prediction models employed inthis work. The Centro station, due to covering an area with greater complexity and variety of buildings, was evaluated with a greater number of measurement points. Due to the natural parking difficulties of the ANATEL vehicle seen in Figure 4.1, it was not possible to strictly follow Lee's method [16] which suggests the spacing of 40 λ.

Some of the measurements made very close to the ERB were those produced circumstantially by the various prediction models. This aspect was verified, for example, in the central station, the number of points near the ERB are bst by the structure of the station's building and by trees. The attenuation analysis in these cases, which involves the effects of the corners of the buildings, is the reason for special studies in the literature conducted in [17],[18],19], which will not be treated in the present study.

The analysis of the measurements made in the Center and in the Coastal Way, which use sectorized cells, was considered, at each point, the highest average value measured among the different control channels. The situation of the Extremoz ERB was the most simplified because it is an omnidirectional cell. The calculation of the measured attenuation was made considering, in addition to the measured power of reception, the information conferred on transmission power, and the gain of the transmitting antenna with the radial position of each point.

Thego of the receiving antenna is automatically removed from the measurement through the Thomson CSF manufacturing equipment, installed in the ANATEL vehicle, the gain of the transmitting antenna, especially in the cases of sectorized cells, takes into account the corresponding radiation diagram and the azimuths used [2].

The Hata Model was formally established for antenna heights s transmitters in the range of 30 meters to 1,000 meters [7]. The measurements made in Natal, at the sites: Centro (65 meters) Via Costeira (45 meters), and Extremoz (45 meters) meet this condition. Regarding distance, the model predicts applications between 1 km and 100 km. Considering the applications of the city of Natal and the characteristics of cells of reduced scope, distances between 0.05 km and 4.5 km per site were evaluated, which corresponds to measurements slightly exceeding the priority uptake limit in the direction of the ERB Mobile Station in each cell.

Based on the values of the measured RF powers, the characteristics of the transmitters of the ERBs, and the height of the antennas, in addition to the coordinates of the points, the attenuations and distances involved in each measurement were calculated. Subsequently, these results were compared with the values calculated following the Models:1- Okumura-Hata (in the options: small urban area, large urban area, small city suburban area, large suburban area city), 2-Attenuation in Free Space, 3- Walfish-Bertoni.

Figure 4.1- ANATEL equipped vehicle used in the field measurement campaign.

Fonte Pinheiro (2006).

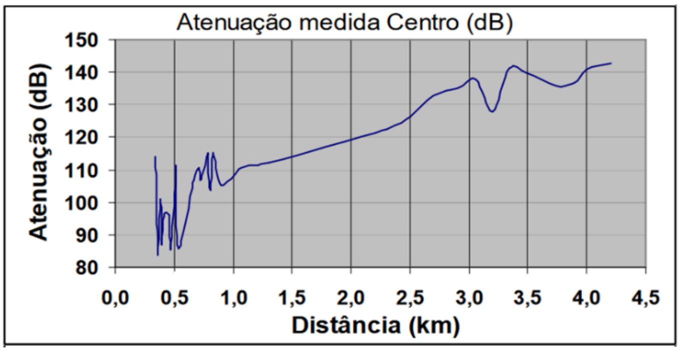
The graphs presented below illustrate the results of the attenuations that were calculated in dB, based on the field measurements of the RF powers, considering the frequency and gain of the antennas in each case. The results obtained are compared in the following sections with the predictions obtained with various models used in the research.

4.1 AREA COVERED BY CENTRO STATION

Figure 4.1 shows the measured averages of the attenuation values measured from the powers received in the range of 880 MH for the area of the Central Station. Figure 4.2 shows the attenuation plot (dB) measured in comparison with the values predicted in the Okumura-Hata models, for the same area of the Station.

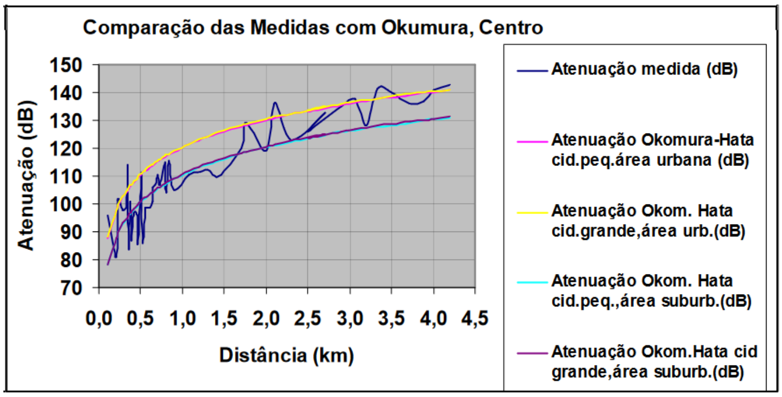
In the area of the ERB Center, the measured attenuation curve (dark blue color) reveals the predominance of increased attenuation following the increase in distance. On the other hand, the oscillations in the curve refer to aspects of non-uniformity of the propagation environment that is marked by variations in the relief, the characteristics of the buildings, the obstacles, and consequently, the restrictions of direct view. The two Okumura-Hata curves for urban areas practically overlap, as do those of suburban areas.

Figure 4.1- Graph of attenuation measured in the area of ERB Centro (48 points).



Fonte Pinheiro (2006).

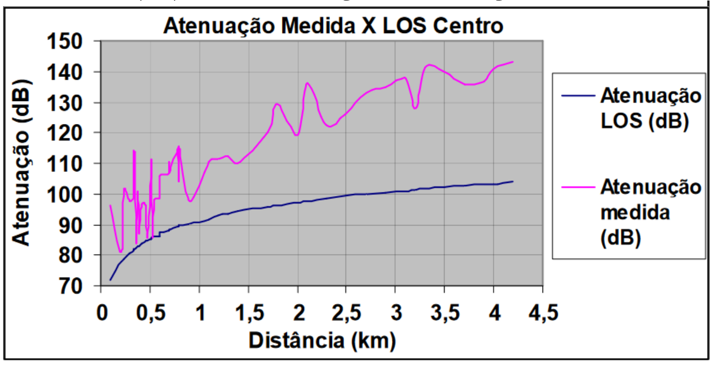
Figure 4.2-Attenuation (dB) measured compared to Okumura-Hata, area of the ERB Center



Source: Pinheiro (2006).

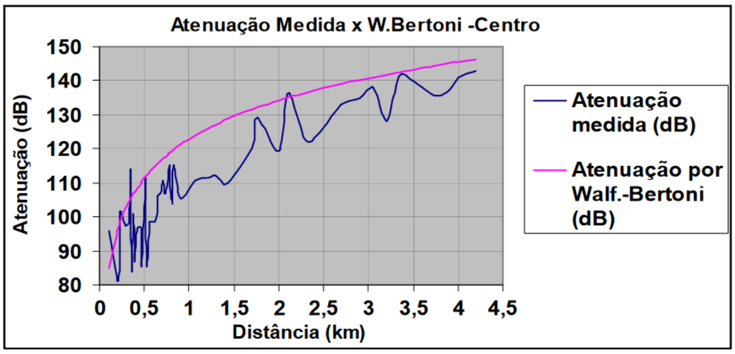
Figure 4.3 shows a comparison of the attenuation measured in the counterpoint field with the attenuation in the free space model (L.O.S.) and Figure 4.4 shows Attenuation (dB) measured compared to Walfish-Bertoni, for the area of the ERB Center.

Fig. 4.3- Attenuation (dB) measured compared to free space losses, ERB Center área



Source: Pinheiro (2006).

Fig. 4.4- Attenuation (dB) measured compared to Walfish-Bertoni, ERB Centro área

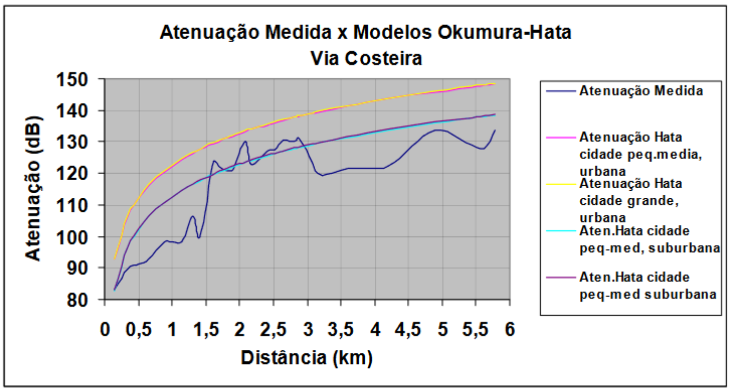


Fonte Pinheiro (2006).

4.2 AREA COVERED BY VIA COSTEIRA STATION

Figure 4.5 shows the attenuation graph (dB) measured and compared with Okumura-Hata prediction models in the area of the Coastal Way, where it can be observed that the oscillations are smaller than those verified in the measurement curve of the Centro area due to its characteristic of more homogeneous distribution of buildings in the region evaluated. The values of the s attenuations of the prediction predominate above the measurements, except for the interval between 1.5 and 3.0 km.

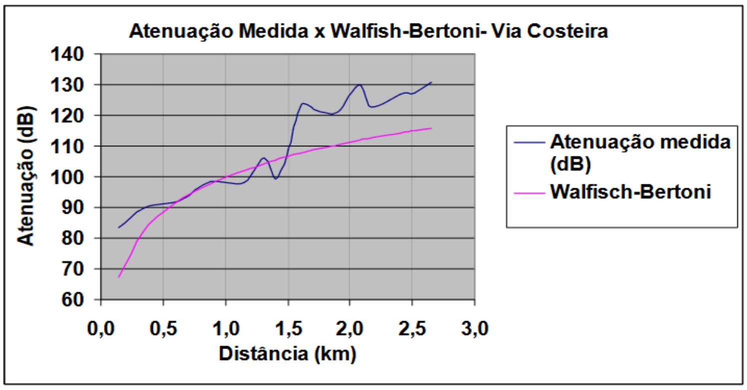
Figure 4.5- Attenuation (dB) measured, compared to Okumura-Hata in the Coastal ERB area, Natal.



Source: Pinheiro (2006).

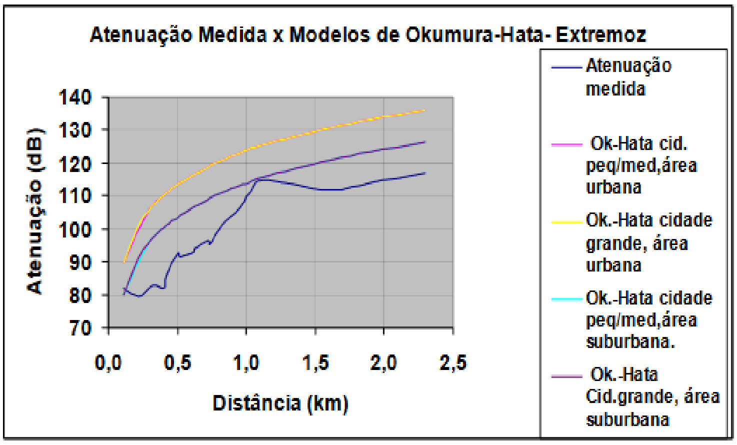
Figure 4.6 shows the comparison of attenuation measured in the area of the ERB of Via C in r and related to the Walfish-Bertoni method and Figure 4.7 shows the measured attenuation of Okumura-Hata in the ERB of the city of Extremoz.

Figure 4.6- Attenuation measured in the Coastal ERB area, compared to Walfish-Bertoni.



Source: Pinheiro (2006).

Figure 4.7- Attenuation measured in Extremoz with Hata models.



Source: Pinheiro (2006).

The measurements carried out in Natal demonstrated that the direct application of the traditional Okumura-Hata methods leads to results with a standard deviation between 8.2 and 20.5 about the real values. The errors are accentuated in the suburban areas (in the case s s evaluated with the regions of Extremoz and Via Costeira) and are minimized in the central areas (region of the Ccntro of Natal and the neighborhoods Petrópolis and Tirol) with a higher density of buildings, as illustrated in the s tables 4.1 and 4.2 a.r.

Table 4.2- Comparison of standard deviations to several methods and prediction for Extremo are

Prediction Method	Standard Deviation (dB) from the actual measurements. Area: Via Costeira
Free Space Mitigation (L.O.S.)	22,34
Okomura-Hata model for small town, urban area	15,91
Okomura-Hata model for big city, urban area	16,12
Okomura-Hata model for a small town, suburban area	8,24
Okomura-Hata model for big city, suburban area	8,37

Source: Pinheiro (2006).

Table 4.2- Comparison of standard deviations about several methods and prediction for Extremoz area.

Prediction Method	Standard Deviation (dB) from the actual measurements. Area: Extremoz
Free Space Mitigation (L.O.S.)	11,84
Okomura-Hata model for small town, urban area	20,47
Okomura-Hata model for big city, urban area	20,53
Okomura-Hata model for small town, suburban area	11,11
Okomura-Hata model for the big city, suburban area	11,16

Source: Pinheiro (2006).

5 CONCLUSIONS

This work carried out a comparative analysis of the application of several prediction models in cross-section with the results of a campaign of propagation measurements developed in the city of Natal and its Metropolitan region. Using the mobile laboratory infrastructure belonging to ANATEL, the measurements were made in three areas with characteristics of buildings, relief, afforestation, and heights of diversified towers, covering the central area of the city, a suburban area and a coastal stretch bordered by dunes.

The measurements made in the field proved the occurrence of a greater attenuation and more accentuated characteristics of oscillations of the power received in the area of the Centro station. This evidences the influence of the higher density of obstacles, variation of the condition of point-to-point visibility, and greater traffic of vehicles and people, in addition to differences in the characteristics of afforestation and buildings in the streets of this region

. The measurements in Natal demonstrated that the direct application of traditional Okumura-Hata methods leads to results with a standard deviation between 8.2 and 20.5 dB concerning the real values. The errors are accentuated in the suburban areas and near the coast (in the case tested the regions of the ERBs of Extremoz and Via Costeira) and minimized in the central areas (central region of Natal) with a higher density of buildings, as illustrated in the following table.

The Okumura-Hata Method applied to small cities and suburban areas proved to be the best result of approximation among the non-adapted alternatives, with the application of this method, although the option still evidenced relevant specific deviations. In the area of more accentuated rural/suburban characteristics (Extremoz) it was verified that the result of Okumura-Hata provides an error approximate to that obtained by the method of calculation by Attenuation in the Free Space. Them itigations measured in the three areas resulted in values generally below those predicted by the Okumura-Hata methods.

The Walfisch-Bertoni method provided results with deviations slightly above those obtained via Okumura-Hata for the Centro area but presented a better performance when comparing results obtained for the areas of Extremoz (mainly) and Via Costeira

The attenuation curve in the Centro area stood out as the most accentuated, while the correlated areas of Via Costeira and Extremoz have more tenuous and more similar characteristics, evidencing the influence of the greater concentration of buildings in the area of the Centro Station.

The campaign of field measurements and all the analyses carried out, gave rise to the possibility of carrying out future work resulting from aspects verified as the accentuated overlap of sectorized cells of the same ERB, where the power received from the three different transmitters was above the threshold of reception of the signal/noise ratio, thus justifying a more in-depth study considering. These implications for traffic planning are subject.

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