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Analysis of digital TV signal reception: a case study for antennas transmitting in horizontal and elliptical polarization

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Abstract — This work presents results on the prediction and measurement of TV signal propagation in the Brazilian city of Maringá from antennas transmitting in the horizontal and elliptical polarization. Measurements were taken at forty -eight fixed locations and by the survey vehicle moving at constant speed along previously determined path ssumming approximately two thousand and seven hundred data points. A comparison of results obtained with chosen radiopropagation models and measured data is provided and discussed .

Key Words - Elliptical polarization a ntenna. Horizontal polarization antenna. Radiop ropagation models. UHF. Digital television.

I. Introduction

The Brazilian television broadcast system is an open, real time and free reception service present in 97.1% of the households [1]. In November 2003 the federal government signed the Decree 4.901 establishing the Brazilian Digital Television System – SBTVD [2], which was followed in 2006 by the Decree 5.820 that officialized its implementation [3]. The commercial broadcast of digital TV began in São Paulo on December 2, 2007. In 2016 the digital TV coverage reached more than 75% of the Brazilian population, about 152 million people. The analog TV broadcast switch off began in 2016 in Rio Verde, Goiás and by the end of 2018 1,378 Brazilian cities, corresponding to 128 million people, had their analog TV signals switched off [4].

The open TV market corresponds to around 60% of the entire national advertising market, with gross operating revenue of 29.55 billion reais in 2014 [5]. The open broadcast system in Brazilian households has been in existence for over sixty years and it sustains a successful and consolidated business model based on the transmission and reception of electromagnetic waves. Therefore, the study of the radiopropagation phenomena and the allocation of frequency bands used by television stations have always been a matter that needs to comply with current legislation and aims to maximize return of investment. At the same time, the demand of qualified engineers for developing digital television broadcasting projects has increased as they need to face different challenges, such as the requirements for establishing the reception threshold inside the intended coverage area.

A television broadcast project consists of the specification of the carrier frequency (channel), the transmission equipment, the transmission antenna, support structures (tower), cables, connectors, combiners and accessories.

The transmitting antenna is one of the main components of the television system. The role of the antenna is to transform the energy received from the transmitter into an electromagnetic field pattern that is sent out to the desired points of reception. Its main technical characteristics are the irradiation, gain and polarization diagram. The correct choice of the transmission antenna leads to the increase of signal penetration in the coverage area and contribute to the population adherence to the new technology. In addition to the conventional reception with an external antenna installed horizontally in the premises, the reception of digital TV signals can be also achieved using portable devices. This fact has motivated designers and antenna manufacturers to develop projects in which other types of polarization are employed in the transmission antenna.

In order to increase the TV signal penetration, the project designer needs to understand the impact of the transmission parameters (transmission power, radiant system, the type of antenna, its radiation diagram and polarization, among others) as well as of the environment issues on the signal propagation within the coverage area. In this way, studies are carried out based on radiopropagation models, either deterministic or empirical, that estimate the electromagnetic wave behavior over the propagation path. The comparison of results obtained by means of the propagation models with those obtained from field tests provides insights and technical references for the design improvement and/or refinement of the TV transmission system.

In this work we analyze the results of field tests carried out in the Brazilian city of Maringá, using two types of antennas, one transmitting in the horizontal and the other in the elliptical polarization mode. The results are compared with those predicted by radiopropagation models and discussed on the basis of their fitting into the models.

This paper is organized as follows: section II describes the radiopropagation models used to predict the signal strength within the coverage area; section III describes the characteristics of equipment and the field tests; section IV reports on the simulation and comparison with field results, followed by section V, which presents the conclusion and the final remarks about our contribution.

II. Propagation models

The prediction of the electric signal strength along a path is fundamental in order to understand the wave propagation and the limits of the coverage area. In this study we employed the propagation models known as Okumura (Hata), ITU-R 370-70, ITU-R 1546 and CRC-Predict to perform an estimation and comparison with data obtained from the field tests. Such models have long proved their consistency and were chosen because they are large-scale models, are able to predict the average field strength over large distances (hundreds of meters to kilometers) between the transmitter and the receiver and because of their applicability to the UHF band (in order to cope with the frequency range of the field measurements), not to mention that they are easily available through software tools. Other models have also been

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employed in this study; whose results can be found in [6]. The models were applied to the same field cenario and are summarized in the following section.

A. Okumura (Hata) - Open, Suburban e Urban

The Okumura model [7] was developed using data from measurements obtained in urban and suburban areas of Tokyo. The model considers a distance from transmitter to receiver up to 30 km, a transmitting antenna height of up to 200m and receiver antenna height of less than 10m. The model is applied to the open, suburban and urban scenarios with appropriate correction factors, depending on the region.

$$Lu = 69.55 + 26.16 \log f - 13.82 \log h_b - a_{hm} + (44.9 - 6.55 \log h_b) \log d \quad (dB) \tag{1}$$

In this equation f is the operation frequency in MHz, h_b is the height of the transmitting antenna in meters, a_{hm} is the height correction factor of the mobile antenna (see below) and d is the distance from the transmitter to receiver in kilometers. For a medium or small city, in which a suburban scenario applies, a_{hm} is given as:

$$a_{hm} = (1.1 \log f - 0.7) h_m - (1.56 \log f - 0.8) \tag{2}$$

For a big city (Urban):

$$a_{hm} = 8.29 (\log (1.54\, h_m))^2 - 1.1 \quad when\ f \leq 200\ MHz \tag{3}$$

$$a_{hm} = 3.20 (\log (11.75\, h_m))^2 - 4.97 \quad when\ f > 400\ MHz \tag{4}$$

in which h_m is the receiver antenna height (in meters). In suburban areas the equation is modified as:

$$Lsu = Lu - 2 \left(\log \left(\frac{f}{28} \right) \right)^2 - 5.4 \quad (dB) \tag{5}$$

And in rural, open areas, the equation is given as:

$$Lro = Lu - 4.48 (\log f)^2 + 18.33 \log f - 40.94 \quad (dB) \tag{6}$$

B. ITU-R 370

The ITU-R 370-7 describes the propagation model [8] for predicting the field strength of the broadcasting service in the frequency range of 30 to 1,000 MHz and for a distance of up to 1,000 km. The recommendation document presents attenuation curves for predicting the loss. The field strengths are adjusted to correspond to a power of 1 kW radiated from a half-wave dipole.

C. ITU-R 1546

The ITUR 1546 [9] describes the procedures to be followed for predicting the field strength of the broadcasting, land mobile, maritime mobile and certain fixed services, from 30 MHz to 3,000 MHz and for a distance from 1 km to 1.000 km. The Recommendation ITU-R P.1546, version 1, is used for the propagation estimation of broadcasting projects as defined in Attachment II of the Brazilian Telecom regulator (Anatel resolution 398, April 7, 2005) [10]. The model is an extension of the ITU-R.P370 model. Attenuation is derived from a family of curves, as in the ITU-R.P370, with a number of other correction factors added. The attenuation is obtained by the field strength interpolation as a function of distance, frequency, percentage time, and transmitting antenna.

D. CRC-Predict

CRC-PREDICT [11] is a propagation model developed by the Canadian government (Canadian Research Center, CRC) and it is based on physical optics and the Fresnel-Kirchhoff theory. The total loss is the sum of the diffraction losses on the ground and an estimation of the additional attenuation related to the clutter, which is defined as a set of polygons with the classification of the region according to the urbanization and vegetation. The intensity of urbanization and the type of vegetation are associated with an additional attenuation table due to the reflections originated in these scenarios. The norm also addresses reflections on the ground, tropospheric mirroring, variability of locations and temporal availability due to atmospheric effects.

III. FIELD TESTS

This section describes the field tests performed in the Brazilian city of Maringá. The digital transmitting station is located at Rua Santa Joaquina de Vedruna, 625, Zona 05, Maringá, State of Paraná, at the geographical coordinates of 23º 25' 29,3" S and 51º 57' 13,7" W. For the signal transmission, two slot type antennas were installed in the same tower at the height of approximately 54 meters, one transmitting in the horizontal polarization with a gain of 7.32 dBd (5.39 x) and the other transmitting in the elliptic polarization with a horizontal gain of 6.44 dBd (4.41 x) and vertical gain of 3.8 dBd. The antennas transmitted the signal with the same radiated power, but not simultaneously during the measurement campaign. As the employed antennas were from different manufacturers, some technical characteristics are different as, for instance, the gain. During the tests the transmitter power was set to ensure that the same radiated power was emitted by both antennas. This was accomplished by using the maximum effective radiated power, calculated according to:

$$ERPmax = Pt * GTmax * Ef \tag{7}$$

in which P_t is the transmitter output power in kW, GTmax is the maximum radiant system gain and Ef is the transmission line efficiency. The following data is used:

- Cable efficiency (the same for the two antennas): 0.93. It is calculated according to the recommendation given in [12];
- Horizontal polarization antenna: 7.32 dBd (5.39 x);
- Elliptical polarization antenna: 6.44 dBd (horizontal, 4.41 x).

First, given that 3.6 kW is set at the transmiter, the ERPmax for the elliptical polarization antenna is calculated as

$$ERPmax = 3.6 \text{ kW x } 4.41 \text{ times x } 0.93 = 14.76 \text{ kW}. \quad (8)$$

On the other hand, fixing the 14.76 KW as the ERPmax, the transmitter power for the horizontal polarization antenna is calculated as:

$$14.76 \text{ kW} = PT \text{ x } 5.39 \text{ times x } 0.93 \text{ or } \quad = 2.94 \text{ kW} \quad (9)$$

In summary, the transmitter power for the horizontal polarized antenna was adjusted to 2.94 kW and for the elliptical polarization antenna the transmitter power was set to 3.6 kW, both having an ERPmax of 14.76 kW.

Table 1 summarizes the technical characteristics of the transmitting station.

TABLE 1
TECHNICAL CHARACTERISTICS - TRANSMISSION STATION

Technical characteristics Transmitting station	Description
Canal	Channel 41, (632 to 638 MHz) with a 6 MHz band
Encoder	Manufacturer NEC, Model: VC 7301 (HD) and VC7010 (LD)
Multiplexador	Manufacturer NEC, Model: MX-1500
Modulator	Linear manufacturer, Model: IS8001
Transmitter	Power: 3.6 KW (*elliptical polarization antenna*) Power: 2.94 KW (*horizontal polarization antenna*)
Transmission line	Type: Coaxial-50 Ohms
	Diameter: 1 5/8 "
	Length: 64 meters
	Manufacturer: RFS-*Radio Frequency Systems*
	Model: HCA-158-50J
	Attenuation: 1.69 dB every 100 meters
Horizontal polarization antenna	Type: Slot
	Polarization: Horizontal
	Gain: 7.32 dBd or 5.39 times
	Installation: 54.05 meters
Elliptical polarization antenna	Type: Slot
	Polarization: elliptical-70 \% H and 30 \% V
	Gain Horizontal : 6.44 dBd or 4.41 times
	Gain Vertical : 3,8 dBd or 2.4 times
	Installation: 54.00 meters

For monitoring the reception signal at both, fixed and mobile location points (henceforth denoted only as points unless stated otherwise), a field survey vehicle was used. The vehicle is composed of home antennas, field strength meters, GPS (Global Postioning System) receivers for geolocation, TV monitors, a digital signal reception converter, coaxial cables, dividers, a camera and a retractable 8-meter mast to which the antennas were fixed. Two identical antennas were used for the fixed reception of the digital TV signals: one installed in the horizontal and the other installed in the vertical position, as shown in Figure 1. Both were fixed on the mast and elevated to a height a viewer would usually install them in his residence. The objective was to measure the signal composition on both linear polarizations at each reception point. The antennas with 8 elements each and a gain of 11 dBi were manufactured by Proeletronic [13] and specified for operation in the range from 470 to 890 MHz, corresponding to channels 14 to 83. For the mobile reception a monopole omnidirectional antenna, model DTV-150, manufactured by Aquarium [14] was used and installed on the top of the survey vehicle. Table 2 presents a summary of the technical specifications of both antennas.

Fig. 1. Receiver antenna installed vertically and horizontally

TABLE 2
TECHNICAL CHARACTERISTICS – RECEPTION STATION

Technical characteristics of reception		Description
GPS		Manufacturer: Garmin - model: 3Plus
Monitor		Manufacturer: Sansung 20" model: T20C310LB
Converter		Manufacturer: Aiko model: HD-1018
Spectrum analyzer		Manufacturer: Agilent
Splitter		Model: Greatek 1:2 5-2400 MHz
Antenna Fixed Reception	Type	Periodic Log
	Manufacturer	Proeletronic
	Model	Total Band
	Frequency range	470 to 890 MHz
	Quant. Elements	8 elements
	Gain	11 dBi
Antenna Mobile Reception	Type	Monopole
	Manufacturer	Aquário
	Model	DTV-150
	Frequency range	30 to 890 MHz
	Quant. Elements	Omnidirectional
	Gain	3 dBi
Cabo (tipo)		Coaxial/Ethernet and power supply
Cabo (comprimento)		10 m (fixed antenna) and 2 m (monopole)

For the measurement with the horizontal-based and elliptical-based polarization 48 points were selected at fixed locations: 30 points within Maringá and 18 points selected in 10 other nearby municipalities (Marialva, Angulo, Paiçandu, Sarandi, Astorga, Mandaguaçu, Floresta, Itambé, Bom Sucesso and Mandaguari), as shown in Figure 2. The mobile reception was performed along highways and streets totalizing 2700 points: a) approximately 1270 points measured in the streets of downtown Maringá, near buildings and subject to greater incidence of multipath; b) 850 points along the Colombo Avenue in Maringá, as shown in Figure 3; c) 225 points along the highway connecting Maringá to Marialva and d) 240 points along the highway connecting Maringá to Mandaguaçu.

Fig. 2. Google Earth image - fixed points in Maringá

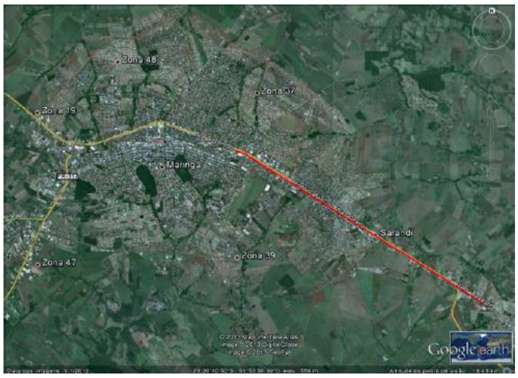

Fig. 3. Google Earth image: path taken (red) at Maringá - Marialva highway for the mobile reception measurements.

First the signal was transmitted using the horizontal polarization based antenna and measurements were taken at the fixed sites and along the mentioned path. The process was repeated along the same path using the elliptical polarization based antenna. The received power (dBm), the carrier-to-noise ratio (C/N, dB), the modulation error rate (MER) and the signal spectrum were measured and recorded. Measurement of the oneseg signal (low definition) was taken with the moving vehicle along the highways and streets using the monopole antenna, the GPS receiver, the spectrum analyzer and a notebook running a software developed by the Universidade Tecnológica Federal do Paraná. Measurements of the geographic coordinates, the received power and symbol error rate (MER) were taken every 6 seconds, corresponding to a separation of 10 to 15 meters within a region, depending on the speed of the vehicle, although attempst have been made to keep it as constant as possible.

IV. SIMULATION AND RESULTS

Two software tools, Signal EDX [15] and CRC-COVLAB [16] were employed. These packages contained the propagation models needed to predict the received power in the coverage area. The tools require may use digitized ground files and information on the type of obstacles at each point, known as clutters. The transmission and reception parameters are found in Table 1 and 2, respectively.

The antenna diagrams were also considered (input). By using the scale of the horizontal antenna diagram given by ratio E/Emax of antenna diagram in each of its plane and matching the various gains at the corresponding azimuths and elevations, it was possible to estimate the relative gain in each direction and angle. This information was used as input variables into the propagation models. Based on the measured and computed data a statistical analysis was perfomed and the mean error, the mean error in absolute values and the RMS error were obtained. A figure of merit, defined as the hit rate, was used to compare how close the measured results were from the data obtained using the propagation models. To facilitate the visualization and interpretation, the data was ranked according to a scale that varied from 0 to 5. For instance, when measured and calculated power levels presented a difference between 0 and 2 dB, such data was given a score 5. When the difference was between 2.01 and 4 dB, a score 4 was assigned, a difference between 4.01 to 6 dB was given a score 3, for differences between 6.01 to 8 a score 2 was used, differences between 8.01 dB to 10 dB were scored as 1 and when the difference was above 10 dB the score was 0. Thus, the higher the score, the more accurate is the used propagation model for that particular region.

A. Measuement at the fixed locations

In order to compare which models were most suited for characterizing the propagation loss, Figure 4 and Figure 5 show the RMS error (dB) and the hit rate, respectively, concerning calculation and measured data at the 48 fixed points, taking into account the type of antenna used in the transmission. The comparison shows that the minimum values of the RMS error were verified for the ITU-R370 model, which delivered an error of 8.5 dB for the elliptical, and 9.6 dB for the horizontal polarization antenna, respectively, as seen in Fig, 4. Considering the hit rate, the CRC-Predict model presented the highest score (1.9) among all models for both antenna types, as shown in Figure 5.

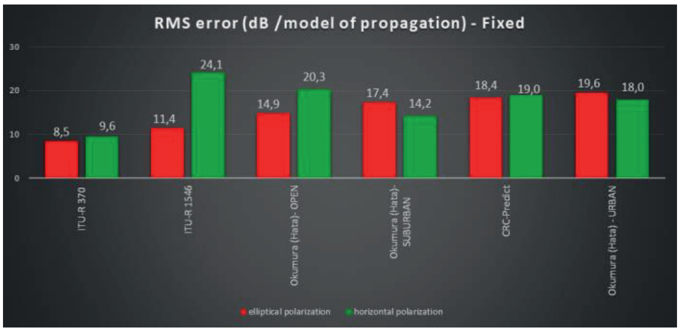

Fig. 4. RMS error in dB for each propagation model - fixed points

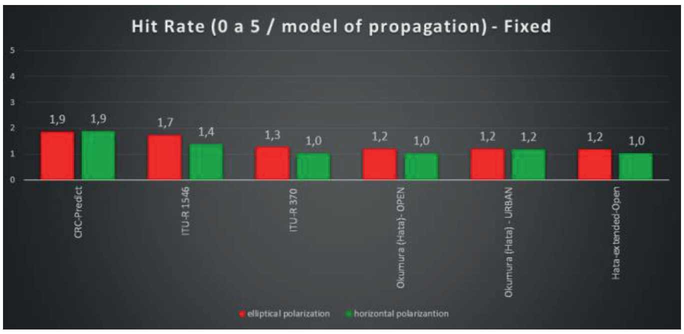

Fig. 5. Average hit rate (0 to 5) for each propagation model - fixed points

Figures 6 and 7 show the received power (dBm) versus distance (km) behavior for the transmission with the horizontal polarization, in which data points were plotted considering the increasing distance from the antenna. In Figura 6 the ITU-R REC. 370 model is used, while in Figure 7 the CRC – Predict model is employed for estimating the loss. Figures 8 and 9 show results of the received power versus distance behavior, but for the transmission with the elliptical polarization antenna. For all cases we observe that the measured data agrees well with estimated values delivered by the ITU-R Rec. 370 and CRC models, within the calculated error range.

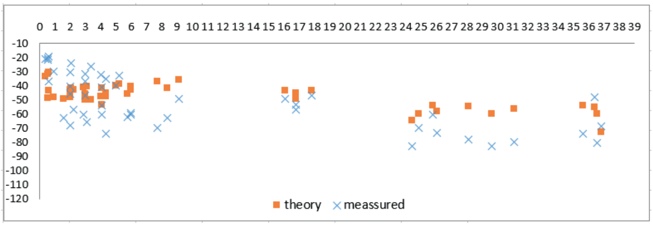

Fig. 6. Received power level (dBm) x distance from the point (km) - model: ITU-R REC. 370 - horizontal polarization – 48 fixed points

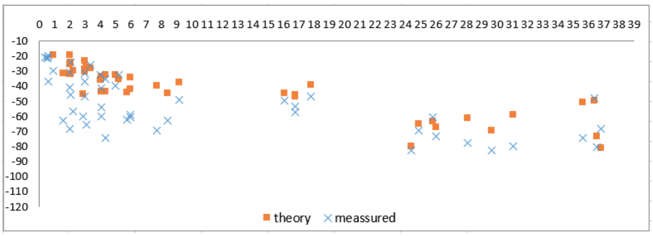

Fig. 7. Received power level (dBm) x point distance (km) - model: CRC Predict - horizontal polarization – 48 fixed points

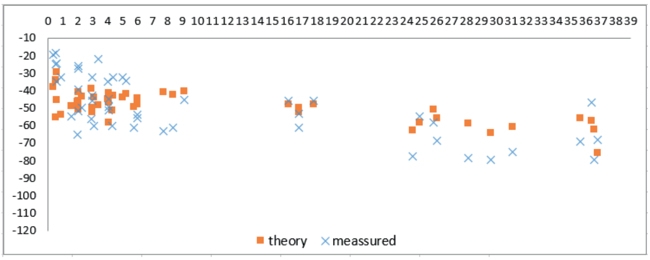

Fig. 8. Received power level (dBm) x point distance (km) - model: ITU-R REC. 370 - elliptical polarization – 48 fixed points

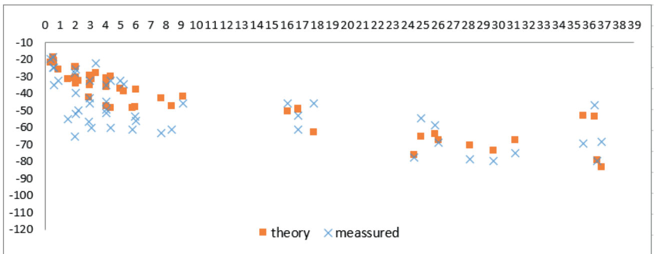

Fig. 9. Received power level (dBm) x point distance (km) - model: CRC Predict - elliptical polarization – 48 fixed points

B. Measurement with the moving vehicle

Figures 10 and 11 show results for the RMS error (dB) and the hit rate corresponding to 225 points of signal reception taken along the Maringá - Marialva highway. Figure 10 shows the RMS error for the transmission with the horizontal and eliptical polarization antennas. It is observed that the Okumura (Hata) Suburban presented the lowest RMS error for the transmission with the elliptical polarization antenna, followed by the ITU-R Rec. 370 and the Okumura (Hata) OPEN, with 5.8, 6.9 dB 7.7 dB, respectively. However, the calculated RMS error for the transmission with the horizontal polarization is higher (13.9 dB for the Okumura (Hata) Suburban and 10.8 dB for the ITUR-370, respectively).

Figure 11 shows the hit rate data. In this case, the ITU-R 1546, the ITU-R 370 and the Okumura model (Hata) Suburban with an average score of 2.8, 2.7 and 2.3, respectively, for the elliptical polarization antenna are considered the models that best describe the propagation along that path. The hit rate scores for the transmission with the horizontal antenna are, however, lower.

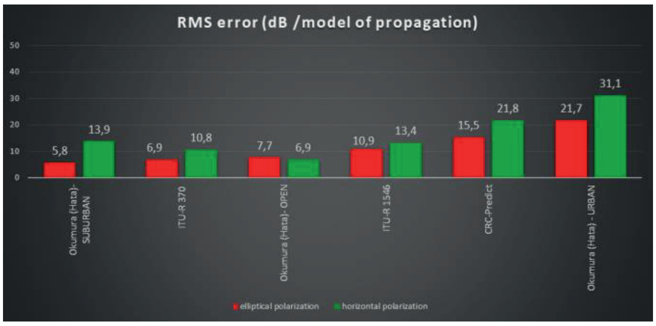

Fig. 10. RMS error in dB for each propagation model - moving points: Maringá to Marialva highway

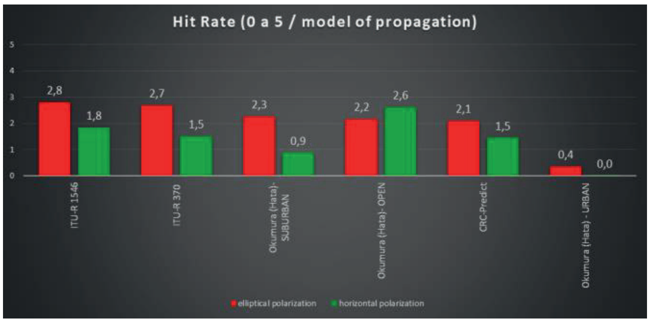

Fig. 11. Average hit rate (0 to 5) for each propagation model - moving points: Maringá to Marialva highway

Figure 12 and Figure 13 show the plot of the measured and calculated received power (dBm) versus distance (km) for signals transmitted with the horizontal and elliptical polarization antennas along the same highway. The Okumura (Hata) OPEN and the ITU-R 1546 propagation models were employed for the comparison based on the transmission with the horizontal and elliptical polarization antennas, respectively. The total distance covered along the path was 15,9 km. It is possible to observe that the compatibility with the calculated data is improved for distances longer than 6 km.

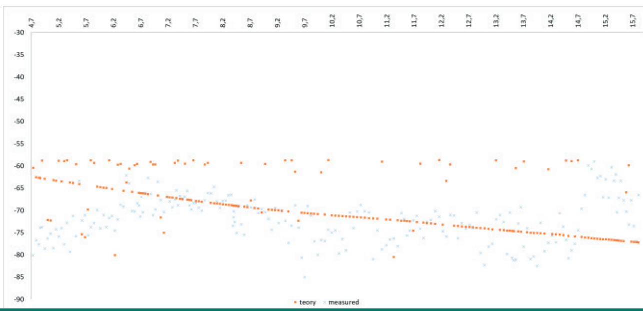

Fig.12 - Received power level (dBm) x distance from point (km) - model: Okumura (Hata) Open - Horizontal polarization - moving points: Maringá to Marialva highway

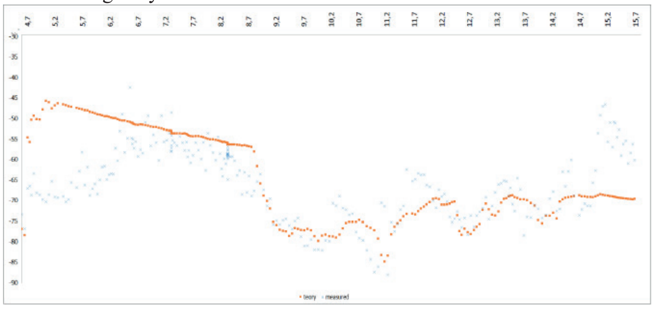

Fig.13- Received power level (dBm) x distance from point (km) - modelo: ITUR 1546 - elliptical polarization - moving points: Maringá to Marialva highway

Based on the results obtained through comparison from of figures of merit of RMS error and hit rate, Table 3 presents a summary listing the best models according to each measuring condition (fixed or moving) and region. The established criteria established for choosing the best results were the lowest values for the RMS error and the highest for the hit rate.

TABLE 3
BEST MODEL OF PROPAGATION BY REGION

Region	Number of points	Best model Horizontal polarization	Best model Elliptical polarization
Fixed	48	ITUR 370	ITUR 370
Fixed	48	CRC Predict	CRC Predict
Movement-Center	1270	Okumura (Hata) - Suburban	Okumura (Hata) - Suburban
Movement-Av. Colombo	850	Okumura (Hata) - Suburban	Okumura (Hata) - Suburban
Movement-Maringá Marialva Highway	225	Okumura (Hata) - Open	ITUR 1546
Movement-Maringá Mandaguaçu Highway	240	Okumura (Hata) - Open	Okumura (Hata) - Open

V. CONCLUSION

The estimation of propagation losses is a complex task due to the large number of variables involved, such as terrain conditions along the path of propagation, environmental conditions and man-made obstacles, such as houses and buildings. Even large concentrations of people close to the receiver may interfere with the propagation. Therefore, propagation models are important and relevant to the project designer, but their use requires a previous understanding of their application and limitations concerning a particular environment. In this way, the present work was first motivated by the proper application of the radiopropagation models and the analysis of their numerical results. The work was also motivated by the observation and understanding of the influence of the transmitting antenna, considering their polarization configuration and impact on the signal strength at the receiver site. The measurement campaign was perfomed in the city of Maringá, located in the State of Paraná, and surrounding region.

The results are compared with those predicted by radiopropagation models and discussed on the basis of their fitting into the models. The figures of merit of RMS error and hit rate were used to perform the comparison. For measurements taken at fixed points in the city of Maringá the analysis shows that the ITU-R 370 and CRC predictions are the propagation models that best fit the measured data. Figures 4 and 5 also show that results obtained for the transmission with the horizontal and elliptical polarization differ only slightly for such models and no evidence is shown that one polarization performs better than the other. For measurements taken with the moving vehicle, considering the data from Figures 10 and 11, the analysis shows that Okumura (Hata) Suburban and the ITU-R 1546 are the propagation models that delivered the best results. However, concerning the signal reception, results point out to a better better performance for the transmission with the elliptical polarization antenna along the Marialva to Maringa highway as compared to the results obtained with the horizontal polarization antenna. Other results concerning the measurement campaign in the region of Maringá and associated analysis can be seen in [6], which basically lead to the same conclusion for the cases presented in this work.

Future work could explore the application of propagation models taking into account a detailed environment database (such as, details of buildings and obstructions). Measurement campaigns performed in other regions and the application of the same analysis could provide system designers with more trustfull data for future projetcs. In this way, that the present work contributes to the establishment of good practices for the specification of broadcasting projects and helps broadcasting professionals to improve their understanding of the signal coverage in regions similar to the ones covered in this study.

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