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Propagation Models Comparison by Propagation Features

Alberto Leonardo Penteado Botelho

Abstract — **The propagation model is a critical point for predicting the coverage area. The complexity of the coverage prediction is enhanced by the possibility of SFN (Single Frequency Network) operation, which allows the installation of auxiliary relays in shadow areas. By knowing the techniques used by each propagation model, it was possible to use the literature as a reference to categorize the types of paths by the propagation situation. This paper presents a comparison study of the simulated propagation models in the Progira software with field measurements in a massive SFN of RecordTV Rio, in the city of Rio de Janeiro. The comparison considered the error mean in all the paths and each of types of paths, so it was possible to obtain an overview of which propagation model is best suited for each propagation situation. It presents details of the techniques used in propagation models, a brief review of the main propagation models and the mean of errors for each type of paths. The results presented contribute to a better interpretation of which propagation model or the propagation model technique can be more efficient in a micro-region, which can optimize the planning of an auxiliary transmission.**

Index Terms — **Terrestrial Digital Television, Propagation Model, Single Frequency Network, Reflection, Refraction, Diffraction.**

I. Introduction

The SBTVD (Brazilian Digital Television System) is a digital terrestrial television standard adopted in Brazil, developed from the evolution of the Japanese standard ISDB-T (Integrated Services Digital Broadcasting Terrestrial) standard. The terrestrial television stations are composed of a network retransmitting stations that aim to expand the coverage area of the main generation station [1]. A trustworthy prediction coverage allows the planning of the transmission system so that the irradiations can maintain the desired levels.

SBTVD has an important frequency reuse feature, which is the operation in SFN (Single Frequency Network), as it allows a television generating station to operate with its transmitting stations on the same frequency [2].

SFN adds a greater complexity in the prediction of coverage, considering that the legislation allows the installation of auxiliary retransmitting stations in shadow areas without the need of acquisition of new conferment, as long as it does not increase the area of provision of the service, maximizing the necessity for a prediction of reliable coverage in micro-regions [3].

An important challenge of the coverage prediction is the choice of the best propagation model that best suits the conditions of propagation of the studied locality.

A comparison between models of propagation of a massive SFN in the locality of Rio de Janeiro, concluded that the propagation model ITUR P.1812-3 in the dense urban geographic region option, presented smaller average error when comparing with field measurements [4].

SBTVD allows the installation of auxiliary stations to cover small areas without coverage. These shadow areas may have a distinct propagation characteristic, where the lowest mean error propagation model may or may not predict the field strength with the highest fidelity. A propagation model with the smallest mean error in the specific micro region propagation characteristics can optimize signal intensity prediction with maximum fidelity.

This work intends to categorize the types of paths according to the propagation features. Each propagation model uses a distinct technique, but many techniques use the same concepts.

knowing the techniques used by propagation models, it is possible to categorize the paths, using the literature as a reference to distinguish propagation situations.

By categorizing the paths, it is possible to compile mean errors for each type of paths and provide the broadcaster with greater security by proposing a specific propagation model to study a micro-region.

The Progira coverage area prediction software was used and made available by LM Telecom [5] and the field measurement in the metropolitan area of Rio de Janeiro was made available by RecordTV Rio (Record Television of Rio de Janeiro Ltda).

This article is divided into seven sections, in addition to this introductory section. In Section II, a brief description of the effects of radio propagation on terrestrial television transmissions is presented. In Section III, the techniques used by the most important propagation models in the literature are presented. Section IV presents a brief summary of the propagation models presented in this study. In Section V, the best techniques of comparison of propagation models are demonstrated. In Section VI, the results of the average error for each type of path are presented. Finally, in Section VII, the main conclusions and final considerations of the work are presented.

II. Radiopropagation

The video, audio and data generated in the television studio are encoded, modulated and sent by RF to the transmission system which amplifies the power and radiates the signal through the transmission antenna. The antenna radiation patterns describes antenna gain in each horizontal and vertical azimuth direction [6].

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In transmission, the electromagnetic wave travels from the transmitting station to the receiver at the opposite end, where the path traveled by the Fresnel zone can vary from a line of sight to a line that is severely obstructed by buildings, mountains or vegetation [7].

In free space, the electromagnetic waves disperse in all the radial ones and their energy is dissipated by the environment [8].

When the electromagnetic wave focus on a surface interface separating two environments, one part of the wave is reflected to the first environment, a second part of the wave is refracted to the second environment and a third part bypasses the environment and diffracts. The resulting reflection, refraction and diffraction phenomena depend on the electromagnetic characteristics of the environment and angle of incidence [9].

The best method to maximize the coverage area is to adjust the installation of the equipment by field measurement, but the high costs and the time involved make it deterrent. With knowledge of the topographic and environmental characteristics, it is possible to use a mathematical tool to predict field strength throughout the service area [6]. When making trustworthy predictions of coverage, the necessity for field measurements to adjust the coverage area is reduced, optimizing time and cost [10].

The path is the representation of the topographic survey along the route between transmission and reception. Through the profile of the link, it is possible to get an overview of the obstacles, the points of reflection and the influence of the land [3].

The Propagation Model is the mathematical tool that describes how the signal is radiated during the path between the transmitter and the receiver, which is intended to predict signal power throughout the service area. Several propagation models are available in the literature, where each model presents specific algorithm [7].

III. Propagation Models techniques

The propagation models available in the literature use different techniques, however, many of the different techniques present the same concepts [11].

Scattering of electromagnetic energy in free space is characterized by the absence of a body capable of influencing the propagation between transmission and reception and should be considered the dispersion of energy in the atmosphere [12].

Troposphere Refraction occurs because the refractive index of the atmosphere changes with depth, which causes the slope of the wave path downwards and its index depends on pressure, temperature and humidity of the atmosphere [12].

Figure 1 shows the geometry of free space propagation and refraction propagation, where IR_{EL} represents the free space irradiation and IR_{RFR} represents the refractive irradiation in the troposphere.

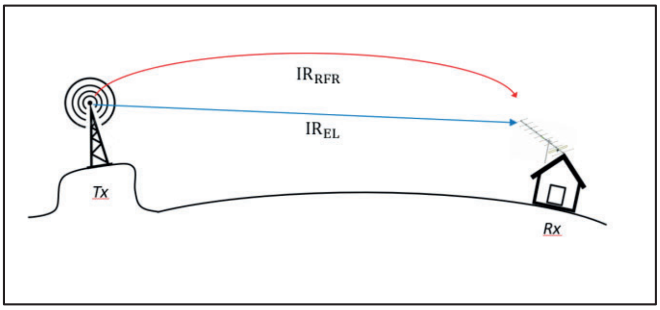

Figure 1: Geometry of propagation in free space and by refraction.

The refractive index in the atmosphere may vary in different climatic regions. Climatic correction curves can be applied [13].

Reflection occurs in line of sight, where the signal is transported by a direct line and by a line reflected in different phase. If the terrain is scratchy, there may be more than one reflection and its index depends on the electric characteristic of the terrain [13]. Figure 2 shows reflection propagation geometry, where IR_{EL} represents free space irradiation and IR_{RL1} and IR_{RL2} represent reflection irradiation.

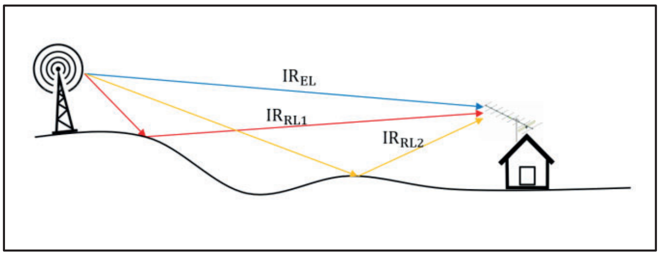

Figure 2: Geometry of propagation by reflection.

Diffraction in obstacle knife edge assumes that there is a knife-shaped obstacle. The diffraction index depends on the angle and the distances between the transmitter and the obstacle and between the obstacle and the receiver. In the existence of two or more obstacles, the equation must be systematically repeated [14]. Figure 3 shows the geometry of diffraction propagation in knife edge obstacle, where IR_{Dif1} represents the irradiance between the transmission and the Gf (ridge of the knife edge obstacle) and where IR_{Dif2} represents the irradiation between the Gf to the reception.

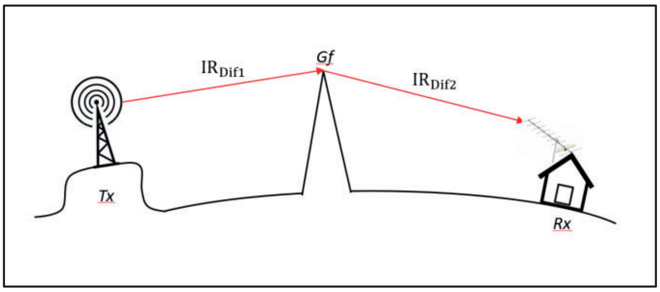

Figure 3: Geometry of propagation by diffraction in knife edge obstacle.

Diffraction in rounded obstacle assumes that the radius of curvature of the obstacle corresponds to the radius of curvature at the apex of a parabola adjusted to the profile of the obstacle in the vicinity of the top. The diffraction index depends on the angle and the distances between the transmitter and the tangent of the obstacle and between the tangent of the obstacle and the receiver [15]. Figure 4 shows the geometry of diffraction propagation in rounded obstacle, where IR_{Dif1} represents the irradiance between the transmission OAr (rounded obstacle tangency tip) and where IR_{Dif2} represents the irradiation between OAr and reception.

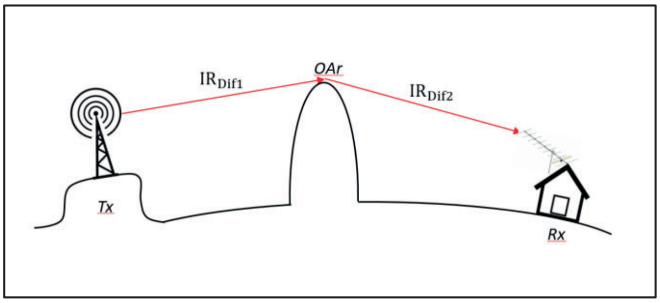

Figure 4: Geometry of propagation by diffraction in rounded obstacle.

Diffraction by the terrain assumes that the line of sight is obstructed by the terrain. The refractive index depends on the distance, the antenna height, the electromagnetic constant of the terrain, the frequency, the radius of the earth and the terrain characteristic that can be smooth, irregular rounded or knife-shaped [13]. Figure 5 shows the geometry of diffraction propagation by the ground, where IR_{DifT} represents the irradiance between the transmission to the reception by the terrain.

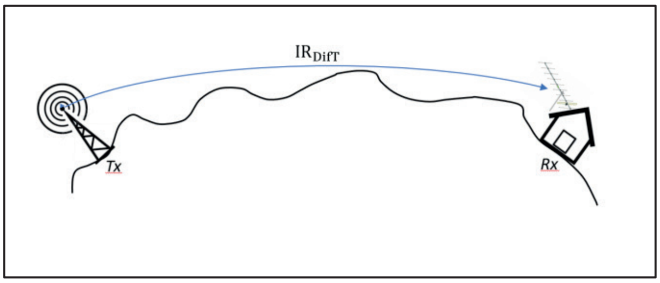

Figure 5: Geometry of propagation by diffraction of the terrain.

Delta Bullington Diffraction, considers a sequence of knife-edge obstacles and adds diffraction across the terrain with part of Bullington. The slopes are calculated in relation to the baseline uniting the height of the transmission to the reception and the line of sight. The diffraction index depends on the angle and the distances between the transmitter and the vertex and between the vertex and the receiver [16]. Figure 6 shows the geometry of the Delta Bullington propagation, where IR_{dB1} represents the irradiance between the transmission and v (vertex) and where IR_{dB2} represents the irradiance between v and receive.

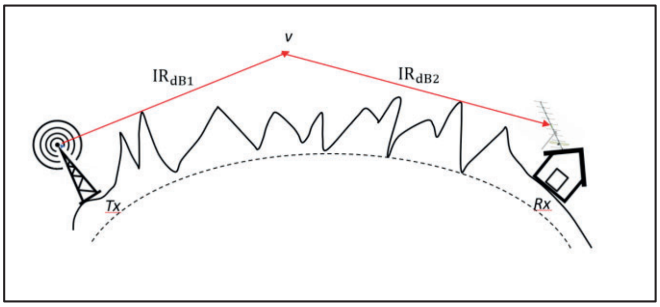

Figure 6: Geometry of propagation by Delta Bullington.

Propagation curves interpolate and extrapolate field strength curves derived empirically as a function of distance, antenna height, frequency, and percentage time. The height of the antenna relative to the ground simulates the effects of propagation [17]. Figure 7 shows propagation geometry by propagation curves, where IR_{El} represents the irradiance between transmission and reception, the NMT represents the average level of the terrain and the $HNMT$ represents the height of the antenna in relation to the average level of the terrain.

Models based on propagation curves can apply correction curve of variation of terrain heights between transmission and reception [18].

Loss in clutter uses map of buildings and vegetation. Each polygon of the clutter is characterized by parameters of height of buildings or trees, indication of their density, degree of absorption and clutter height that can be known or estimated. In the polygon, the effects of loss, reflection and diffraction are simulated [19]. Figure 8 shows the geometry of the propagation by losses in the clutter, where IR_{El} represents the irradiation between the transmission and reception, IR_{Clt} represents the irradiation in the clutter, IR_{Dif} represents the diffraction irradiation at the top of the clutter and IR_{Rl} represents reflection irradiation.

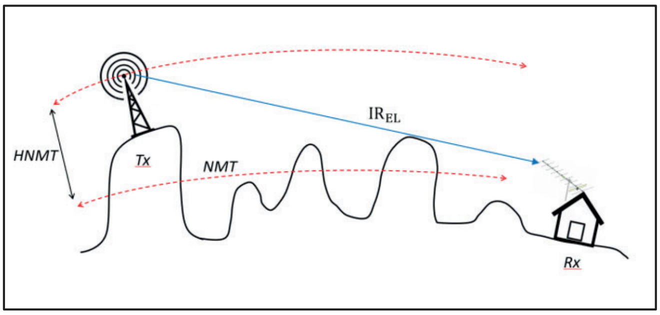

Figure 7: Geometry of propagation by propagation curves.

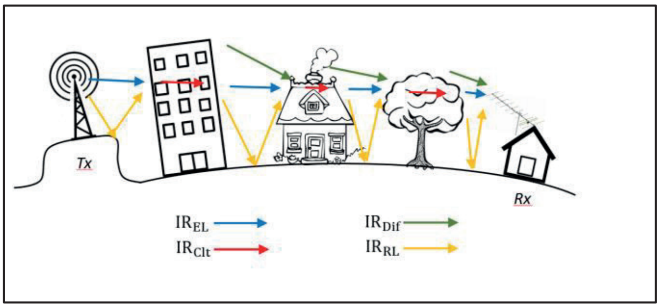

Figure 8: Geometry of propagation by clutter losses.

The clutter location variability refers to the height correction curve of the receiving antenna. The higher the receiving antenna is in relation to the clutter, the smaller the effects of the clutter [16].

IV. Propagation Models

Free space is a model that calculates the field strength, considers only the scattering of electromagnetic energy and neglects the effects of reflection, refraction and diffraction [9].

Longley-Rice is a propagation model based on calculations of losses in the path of the electromagnetic wave. In line of sight, the model considers refraction in the troposphere and reflection in smooth or irregular terrain. With obstructed line of sight by a peaked formation, it considers diffraction in obstacle knife edge with or without reflection. With obstructed line of sight by convex formation, it considers diffraction in rounded obstacle with or without reflection. With an obstructed line of sight by a sequence of obstacles, it considers diffraction by the terrain. Longley-Rice also considers climate correction curves [13].

Okumura-Hata is a model of propagation curves developed by Okumura and synthesized in equation by Hata. It has propagation curves for different levels of urbanization [20].

Deygout-Assis is a propagation model based on calculations of losses in the path of the electromagnetic wave developed by Deygout. With line of sight, it considers calculation of scattering of electromagnetic energy. With a view obstructed by one or more peaked formations, it considers diffraction in knife edge obstacles [14]. Assis extended the Deygout model to a line of sight obstructed by convex obstacles and considered diffraction in a rounded obstacle [21].

ITUR P.370-7 is a model of propagation curves drawn from data obtained in the Mediterranean and North Sea regions for field strengths exceeded by 50% of locations for different percentages of time. It has correction curves of variation of terrain heights [18].

ITUR GE06 is a model of propagation curves for field strengths exceeded by 50% of locations for different percentages of time. It has propagation curves for different climatic regions [22].

ITUR P.526-11 is a propagation model based on calculations of losses in the path of the electromagnetic wave. With line of sight, it considers calculation of scattering of electromagnetic energy. With a line of sight obstructed by one or more convex formations, it considers diffraction in a rounded obstacle. With obstructed line of sight by a peaked formation, it considers diffraction in obstacle knife edge. With obstructed line of site by two peaked formations or obstruction in smooth terrain, it considers diffraction by the terrain. With a line of sight obstructed by a sequence of obstacles, it considers Delta Bullington [15].

ITUR P.1546-5 is a model of propagation curves for field strengths exceeded by 50% of locations for different percentages of time. It has correction curves for obstruction and curves for correction of wide differences between the transmission and reception antenna heights [17].

CRC-Predict is a model that calculates losses in the clutter. Each polygon results in losses by refraction, reflection and diffraction. It has curves of location variability of the receiving antenna in relation to the height of the clutter. For regions with clutter data with very small obstacles, consider the dispersion, refraction and climatic correction curves of the Longley-Rice propagation model and the localization variability of the Okumura-Hata propagation model [19].

ITUR P.1812-3 is a propagation model based on calculations of losses in the path of the electromagnetic wave and losses in the clutter. With line of sight it considers refraction in the troposphere. With obstructed line of sight by smooth formation, it considers diffraction by the terrain. With obstructed line of sight by irregular formation, it considers Delta Bullington. The calculations consider losses in the clutter. Each polygon results in losses by refraction, reflection and diffraction. It has curves of location variability of the receiving antenna in relation to the height of the clutter [16].

V. Propagation Models Comparison

The best method for comparing propagation models is to analyze the mean field measurement error with each of the available propagation models.

For the field measurement, RecordTV Rio was chosen in the metropolitan region of Rio de Janeiro. The metropolitan area of Rio de Janeiro has a very varied predominant terrain, with high cliffs, seas of hills, hills and valleys, representing the most complex situation of propagation and of great challenge for propagation models. The complexity of the propagation is enhanced by RecordTV Rio operating in massive SFN, in the most varied transmission situations, with Special Class main station, 2 Class A retransmitters stations and 11 auxiliary stations.

RecordTV Rio provided 41 field measurements for this work. 19 measurements from the main station transmission, 14 measurements from the retransmitter stations and 8 measurements from the auxiliary stations. The field measurement sites were distributed in the metropolitan region of Rio de Janeiro to represent the maximum diversity of propagation characteristics.

The field measurement used a measurement instrument with a resolution of 10 kHz and a measurement range of 130 dBμV. The antenna used has a gain of 14 dBi at the center frequency of 623 MHz, corresponding to the television channel 39, realized at 10 meters of height in relation to the ground and attenuation of cable and connectors of 2 dB.

The software used to predict the coverage area was Progira, [23]. Progira offers 10 propagation models. The propagation models have selectable options of climate, population density or terrain type, thus all models with all selectable options were considered, totaling 37 variations of propagation models.

There is no single criterion for deciding the best method for comparing propagation models, but the mean error should be as small as possible [24].

DMA (Absolute Mean Deviation) calculates the arithmetic mean of the absolute deviations of each measure, does not take into account whether it was overestimated or underestimated, and it is important to analyze which model of propagation that approximates the field measurement by simple mean, according to Equation 1.

σ (Standard Deviation) computes the square root of the ratio of the sum of the squares of the deviations and is important to analyze if the results obtained by the propagation models are scattered over a wide range of values, according to Equation 2.

RMS (Root Mean Square) is a statistical measure of the magnitude of a variable quantity of discrete values, where the mean error is low by canceling positive and negative errors when added and it is important to designate if the errors are addictive and tend to more or less, according to Equation 3 [25].

$$DMA = \frac{1}{N} \sum_{i=1}^{na} |VM - VP| \qquad (1)$$

$$\sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^{na} (VM - VP)^2 - N \times \frac{1}{N} \sum_{i=1}^{na} (VM - VP)^2} \qquad (2)$$

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$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{na}(VM - VP)^2 + \sigma^2} \qquad (3)$$

Where:
DMA = Absolute Mean Deviation;
σ = Standard Deviation;
N = Number of samples;
na = sample;
RMS = Root Mean Square;
VM = Measured value in field;
VP = Measured value in software.

VI. Results

When comparing the values measured in the field with the simulated values in the software, it was possible to calculate DMA, σ and RMS of each propagation model, according to Table I.

When analyzing each model in isolation, Table I concludes that the ITUR 1812-3 propagation model, in the dense urban geographic region option, presents the smallest mean error and is the most reliable to be used in the Rio de Janeiro study. In analyzing the techniques of propagation models, Table I concludes that the models that employ losses in the clutter, present better efficiency.

Table I - Average error of all paths compared to field measurement.

Average (dB)				
Propagation Model	Selectable Option	DMA	σ	RMS
ITUR 1812 -3	Dense Urban	6,9	1,4	7,2
ITUR 526 -13	General Method	7,6	1,5	7,9
ITUR 1812 -3	Forest / Urban	8,1	1,6	8,5
CRC -Predict	Continntal / Great Lakes / Maritime Overland / Maritime Oversea	8,9	2,4	9,4
ITUR 1812 -3	Suburban	9,1	1,7	9,5
ITUR1 812 -3	Database	9,1	1,7	9,5
Deygout -Assis	Knife Edge	9,6	2,2	10,1
ITUR G06	Rural / Open / Suburban	9,6	2,2	10,1
Okumura - Hata	Quasi Open	10,3	2,1	10,8
ITUR 370 -7	Rural	10,5	1,9	10,9
ITUR 370 -7	Suburban / Urban	10,5	1,9	11,0
Deygout -Assis	Main Rounded	10,5	3,0	11,2
Okumura - Hata	Open	10,9	2,3	11,5
ITUR 1546 -5	Rural / Open	11,0	2,8	11,6
ITUR 1546 -5	Suburban	11,1	2,9	11,7
Longley -Rice	Equatorial	11,8	2,4	12,3
Longley -Rice	Maritime Temperate Oversea	11,8	2,4	12,3
Longley -Rice	Desert	11,8	2,4	12,3
Longley -Rice	Maritime Temperate Overland	11,8	2,4	12,3
Longley -Rice	Continental Subtropical	11,8	2,4	12,3
Longley -Rice	Maritime Tropical	11,9	2,4	12,4
Deygout -Assis	Rounded	12,3	4,0	13,3
Longley -Rice	Continental Temperate	12,6	2,7	13,1
ITUR 526 -13	Rounded	12,9	3,4	13,6
Free Space	---	15,9	3,2	16,6
Okumura - Hata	Suburban	15,9	2,8	16,6
ITUR G06	Urban	16,6	3,2	17,3
ITUR 1546-5	Urban	18,8	3,9	19,7
ITUR G06	Dense Urban	21,5	3,9	22,4
ITUR 1546 -5	Dense Urban	22,3	4,2	23,2
Okumura - Hata	Urban	22,7	3,9	23,6

When analyzing the terrain and environmental characteristics of each path, there is a heterogeneous distribution of propagation conditions. When comparing the terrain geometry of each path with the techniques described in Section III, it is possible to categorize the path by the propagation characteristic.

21 paths have a line of sight with very high transmission heights in relation to the terrain, in which the HNMT exceeds 400 meters. Under these conditions, the Fresnel zone travels a high distance from the ground and clutter, reducing the effects of propagation on the terrain. 6 paths have a line of sight with low transmission heights in relation to the terrain, in which the HNMT is lower than 150 meters. Under these conditions, the Fresnel zone travels very close to the ground and clutter, increasing the effects of propagation on the terrain.

9 paths are obstructed by a knife-shaped elevation. Under these conditions, propagation diffraction predominates in the knife edge obstacle.

3 paths are obstructed by two or more knife-edged elevations. Under these conditions, diffraction propagation predominates in knife edge obstacles, which can be calculated by systematically repeating a knife edge algorithm or Delta Bullington algorithm.

2 paths are totally obstructed in all their extension. Under these conditions, predominates propagation by diffraction of the terrain.

Table II compares the values measured in the field with the simulated values by software, only in the line of sight paths, with HNMT above 400 meters.

Table II - Medium error of line of sight and HNMT links above 400 meters compared to field measurement.

Average (dB)				
Propagation Model	Selectable Option	DMA	σ	RMS
ITUR 1546 -5	Rural / Open	3,6	0,8	3,8
ITUR 1546 -5	Suburban	3,6	0,8	3,8
ITUR G06	Rural / Open / Suburban	4,0	0,9	4,3
ITUR 1812 -3	Clutter Dense Urban	5,3	1,5	5,8
Okumura -Hata	Open	5,8	1,4	6,3
ITUR 1812 -3	Forest / Urban	6,2	1,8	6,8
Okumura - Hata	Quasi Open	6,8	1,9	7,4
CRC -Predict	Continntal / Great Lakes / Maritime Overland / Maritime Oversea	6,9	1,8	7,5
Deygout -Assis	Rounded	7,0	2,0	7,6
Deygout -Assis	Knife Edge	7,0	2,0	7,6
ITUR 526 -13	General Method	7,4	2,1	8,1
ITUR1 812 -3	Clutter Database	7,7	2,1	8,4
ITUR 1812 -3	Clutter Suburban	7,8	2,1	8,4

Longley-Rice	Equatorial	7,9	2,1	8,6
Longley-Rice	Maritime Temperate Oversea	8,0	2,1	8,6
Longley-Rice	Maritime Temperate Overland	8,0	2,1	8,6
Longley-Rice	Maritime Tropical	8,0	2,1	8,6
Longley-Rice	Continental Temperate	8,0	2,1	8,6
Longley-Rice	Continental Subtropical	8,0	2,1	8,6
Longley-Rice	Desert	8,0	2,1	8,6
ITUR 526-13	Rounded	8,1	2,2	8,8
ITUR 370-7	Rural	8,1	2,1	8,8
ITUR 370-7	Suburban / Urban	8,1	2,1	8,8
Free Space	---	8,2	2,2	8,8
ITUR G06	Urban	15,1	3,5	16,2
ITUR 1546-5	Urban	15,1	3,5	16,3
Okumura-Hata	Suburban	18,3	4,4	19,7
ITUR G06	Dense Urban	20,7	4,8	22,2
ITUR 1546-5	Dense Urban	21,0	4,8	22,6
Okumura-Hata	Urban	27,0	6,3	29,0

When analyzing each model separately, Table II concludes that the ITUR 1546-3 propagation model, in the rural, open or suburban geographic region option, presents the smallest mean error and is the most reliable to be used in the study of Rio de Janeiro in situations with line of sight in very high HNMT. When analyzing the techniques of propagation models, Table II concludes that the models that use propagation curves, present better efficiency.

Table III compares the values measured in the field with the simulated values by software, only in the line of sight paths, with HNMT below 150 meters.

Table III - Medium error of line of sight and HNMT links below 150 meters compared to field measurement.

Average (dB)				
Propagation Model	Selectable Option	DMA	σ	RMS
CRC-Predict	Continntal / Great Lakes / Maritime Overland / Maritime Oversea	3,9	2,0	5,1
ITUR G06	Rural / Open / Suburban	4,3	2,4	5,7
ITUR 1812-3	Dense Urban	6,4	3,7	8,5
Okumura-Hata	Quasi Open	7,5	4,2	10,0
Okumura-Hata	Open	7,7	4,7	10,4
ITUR 370-7	Rural	9,1	5,0	11,9
ITUR 370-7	Suburban / Urban	9,1	33,9	80,2
Deygout-Assis	Knife Edge	9,6	5,0	12,6
Deygout-Assis	Main Rounded	9,6	5,0	12,6
Deygout-Assis	Rounded	9,6	5,0	12,6
ITUR 526-13	General Method	9,7	5,1	12,7
ITUR 526-13	Rounded	10,4	5,3	13,6
Free Space	---	11,1	5,5	14,4
ITUR 1812-3	Clutter Forest / Urban	11,6	7,0	15,5
Longley-Rice	Continental Subtropical	11,6	5,8	15,1
Longley-Rice	Desert	11,6	5,8	15,1
Longley-Rice	Equatorial	11,6	5,8	15,1
Longley-Rice	Maritime Temperate Overland	11,6	5,8	15,1
Longley-Rice	Maritime Temperate Oversea	11,6	5,8	15,1
Longley-Rice	Maritime Tropical	11,6	5,8	15,1
ITUR 1546-5	Rural / Open	11,8	10,9	17,9
ITUR 1546-5	Suburban	11,9	11,0	18,0
ITUR1 812-3	Clutter Database	13,2	7,2	17,3
ITUR 1812-3	Clutter Suburban	13,2	7,2	17,3
Okumura-Hata	Suburban	13,9	7,9	18,5
Longley-Rice	Continental Temperate	16,7	10,7	22,7
ITUR G06	Urban	17,9	8,9	23,3
ITUR 1546-5	Dense Urban	23,7	11,6	30,7
ITUR G06	Dense Urban	23,7	11,6	30,7
Okumura-Hata	Urban	23,9	12,3	31,2
ITUR 1546-5	Urban	28,6	17,0	38,3

When analyzing each model in isolation, Table III concludes that the CRC-Predict propagation model has the lowest mean error and is the most reliable to be used in the study of Rio de Janeiro in situations with line of sight in lowers HNMT. In analyzing the techniques of propagation models, Table III concludes that the models that use propagation curves and losses in the clutter, present better efficiency.

Table IV compares the values measured in the field with the simulated values by software, only in the links obstructed by a single knife edge obstacle.

Table IV - Medium error of the obstructed paths by a single knife edge obstacle, compared to field measurement.

Average (dB)				
Propagation Model	Selectable Option	DMA	σ	RMS
CRC-Predict	Continntal / Great Lakes / Maritime Overland / Maritime Oversea	4,1	2,1	5,1
ITUR 526-13	General Method	5,4	2,0	6,4
Deygout-Assis	Rounded	5,7	2,1	6,8
Deygout-Assis	Main Rounded	5,7	2,1	6,8
ITUR 1812-3	Forest / Urban	7,2	2,9	8,6
ITUR 1812-3	Suburban	7,4	2,8	8,8
ITUR 1546-5	Urban	7,4	3,3	8,9
ITUR G06	Urban	7,4	3,3	9,0
ITUR1 812-3	Database	7,5	2,9	8,9
ITUR 1812-3	Dense Urban	7,5	3,2	9,0
ITUR 526-13	Rounded	8,2	3,9	10,0
Deygout-Assis	Knife Edge	9,2	3,8	11,0
Longley-Rice	Desert	10,8	4,2	12,8
Longley-Rice	Continental Temperate	10,9	4,2	13,0
Longley-Rice	Continental Subtropical	11,0	4,3	13,1
Longley-Rice	Maritime Temperate Overland	11,0	4,3	13,1
Longley-Rice	Maritime Temperate Oversea	11,0	4,2	13,1
Longley-Rice	Equatorial	11,0	4,3	13,1
Longley-Rice	Maritime Tropical	11,3	4,3	13,5
ITUR 1546-5	Dense Urban	11,7	4,7	14,0
ITUR G06	Dense Urban	11,7	4,7	14,0
ITUR 370-7	Rural	12,0	4,9	14,4

ITUR 370-7	Suburban / Urban	12,0	4,9	14,4
Okumura-Hata	Suburban	13,1	5,5	15,7
Okumura-Hata	Quasi Open	13,4	6,1	16,2
ITUR 1546-5	Rural / Open	13,4	5,6	16,1
ITUR 1546-5	Suburban	13,4	5,6	16,1
ITUR G06	Rural / Open / Suburban	13,8	5,8	16,6
Okumura-Hata	Open	16,4	7,3	19,8
Okumura-Hata	Urban	16,4	7,2	19,8
Free Space	---	24,0	9,4	28,6

In analyzing each model in isolation, Table IV concludes that the CRC-Predict propagation model presents the smallest mean error and is the most reliable to be used in the Rio de Janeiro study in situations obstructed by a single knife-edge obstacle. In analyzing the techniques of propagation models, Table IV concludes that the models that use calculations of losses in the path of the electromagnetic wave and losses in the clutter, present better efficiency.

Table V compares the values measured in the field with the simulated values by software, only on paths obstructed by a sequence of knife-edge obstacles.

Table V - Mean error of the paths obstructed by a sequence of knife-edge obstacles, compared to field measurement.

Average (dB)				
Propagation Model	**Selectable Option**	**DMA**	**σ**	**RMS**
Deygout-Assis	Knife Edge	3,3	2,5	5,5
ITUR 526-13	General Method	5,7	5,2	10,0
Deygout-Assis	Main Rounded	8,1	8,4	14,8
ITUR 1546-5	Dense Urban	10,9	10,9	19,6
ITUR G06	Dense Urban	10,9	11,0	19,7
ITUR 1812-3	Dense Urban	11,2	11,3	20,2
Okumura-Hata	Urban	11,5	11,5	20,8
ITUR 1812-3	Forest / Urban	12,4	11,9	22,0
ITUR 1812-3	Suburban	12,4	11,3	21,8
CRC-Predict	Continntal / Great Lakes / Maritime Overland / Maritime Oversea	12,5	13,3	23,0
ITUR1 812-3	Clutter Database	12,5	11,5	22,0
ITUR 1546-5	Urban	12,8	11,2	22,3
Deygout-Assis	Rounded	12,9	13,6	23,6
ITUR G06	Urban	12,9	11,2	22,3
Okumura-Hata	Suburban	14,6	15,4	26,8
Longley-Rice	Equatorial	18,1	16,1	31,6
Longley-Rice	Maritime Tropical	18,1	16,0	31,6
Longley-Rice	Maritime Temperate Oversea	18,2	16,1	31,7
Longley-Rice	Continental Subtropical	18,3	16,3	31,9
Longley-Rice	Desert	18,3	16,5	32,0
Longley-Rice	Maritime Temperate Overland	18,3	16,3	31,9
Longley-Rice	Continental Temperate	18,3	16,4	32,0
ITUR 526-13	Rounded	18,7	19,0	33,9
ITUR 370-7	Rural	18,9	17,1	33,0
ITUR 370-7	Suburban / Urban	18,9	17,1	33,0
ITUR 1546-5	Rural / Open	21,7	21,4	39,0
ITUR 1546-5	Suburban	21,7	21,4	39,0
ITUR G06	Rural / Open / Suburban	22,0	21,7	39,5
Okumura-Hata	Quasi Open	25,5	24,5	45,4
Okumura-Hata	Open	30,5	28,4	53,8
Free Space	---	39,9	35,9	69,8

When analyzing each model in isolation, Table V concludes that the Deygout-Assis propagation model, with obstacle type selected for knife edge, presents the smallest mean error and is the most reliable to be used in the Rio de Janeiro study in situations obstructed by a sequence of knife-edge obstacles. When analyzing the techniques of propagation models, Table IV concludes that the models that use calculations of losses in the path of the electromagnetic wave and Delta Bullington algorithms, present better efficiency, however, the Deygout-Assis propagation model obtained a great advantage.

Table VI compares the values measured in the field with the simulated values by software, only in the paths with total obstruction in the course of the electromagnetic wave.

Tabela VI - Average error of the paths with total obstruction in the course of the electromagnetic wave, compared to field measurement.

Average (dB)				
Propagation Model	**Selectable Option**	**DMA**	**σ**	**RMS**
Okumura-Hata	Suburban	2,8	3,3	6,5
Okumura-Hata	Urban	6,2	8,1	14,8
ITUR 1812-3	Suburban	14,0	19,1	33,9
ITUR 526-13	General Method	14,1	19,3	34,3
ITUR1 812-3	Database	14,4	19,7	34,9
ITUR 370-7	Rural	15,7	21,8	38,3
ITUR 370-7	Suburban / Urban	15,7	21,8	38,3
Okumura-Hata	Quasi Open	15,8	21,7	38,3
ITUR 1812-3	Forest / Urban	16,1	22,1	39,1
ITUR 1812-3	Dense Urban	18,1	25,0	44,0
Okumura-Hata	Open	20,8	28,7	50,6
ITUR G06	Rural / Open / Suburban	39,6	55,4	96,6
Free Space	---	41,4	57,9	101,0
Longley-Rice	Maritime Tropical	46,5	65,1	113,6
Longley-Rice	Equatorial	46,7	65,4	114,1
Longley-Rice	Maritime Temperate Oversea	46,8	65,5	114,3
Longley-Rice	Continental Subtropical	47,2	66,1	115,3
Longley-Rice	Maritime Temperate Overland	47,2	66,1	115,3
Longley-Rice	Continental Temperate	47,4	66,4	115,8
Longley-Rice	Desert	47,7	66,8	116,5
Deygout-Assis	Knife Edge	47,9	67,8	117,4
ITUR 1546-5	Rural / Open	52,1	73,0	127,2
ITUR 1546-5	Suburban	53,3	74,7	130,1
ITUR G06	Urban	57,2	80,2	139,7
CRC-Predict	Continntal / Great Lakes / Maritime Overland / Maritime Oversea	58,5	82,0	142,8
ITUR G06	Dense Urban	62,6	87,9	152,9

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ITUR 1546-5	**Urban**	**70,9**	**99,6**	**173,2**
Deygout-Assis	**Main Rounded**	**75,6**	**106,3**	**184,8**
ITUR 1546-5	**Dense Urban**	**76,3**	**107,2**	**186,5**
ITUR 526-13	**Rounded**	**82,8**	**116,4**	**202,4**
Deygout-Assis	**Rounded**	**105,0**	**149,2**	**257,7**

In analyzing each model in isolation, Table VI concludes that the Okumura-Hata propagation model, in the suburban geographic region option, presents the lowest average error and is the most reliable to be used in the Rio de Janeiro study in situations of total obstruction in the path of the electromagnetic wave. The high errors of the other models of propagation, make it difficult to interpret which model of propagation technique is most efficient in situation of total obstruction.

VII. Conclusion

When comparing field measurements with a prediction of coverage of a massive SFN in the city of Rio de Janeiro, it is concluded that the ITUR P.1812-3 propagation model in the dense urban geographic region option presents the smallest average error and is what more adequate to the characteristics of the Rio de Janeiro terrain. It is also concluded that the models that employ losses in the clutter, present better efficiency.

The SFN added a greater complexity in coverage prediction. The possibility of installing auxiliary retransmitter stations in shaded areas, maximizes the need for prediction of reliable coverage in micro-regions.

For line of sight paths with very high HNMT, the propagation model ITUR 1546-3, in the in the rural, open or suburban geographic region option, presents the smallest average error and the techniques that use propagation curves, present better efficiency in line of sight with very high HNMT.

For line of sight paths with low HNMT, the CRC-Predict propagation model has the smallest average error, and the techniques that employ propagation curves and losses in the clutter have the best efficiency in line of sight with low HNMT.

For links obstructed by a single knife-edge obstacle, the CRC-Predict propagation model presents the smallest average error and the techniques that employ calculations of losses in the path of the electromagnetic wave and losses in the clutter, present better efficiency in a single knife edge obstruction.

For links obstructed by a sequence of knife-edge obstacles, the Deygout-Assis propagation model, with obstacle type selected for knife-edge, presents the smallest mean error. Even though models that use calculations of losses in the path of the electromagnetic wave and Delta Bullington algorithms have presented better efficiency, Deygout-Assis, with type of obstacle selected for knife-edge presented wide advantage of other models in a sequence of knife edge obstructions.

For paths in situations of total obstruction in the course of the electromagnetic wave, the Okumura-Hata propagation model, with suburban geographic region option, presents the smallest average error. The high errors of the other models of propagation, make it difficult to interpret the efficiency of which model of propagation in situation of total obstruction.

The results presented contribute to a better interpretation of which propagation model or propagation model technique may be more efficient in a micro region. This contribution can optimize the planning of an auxiliary station.

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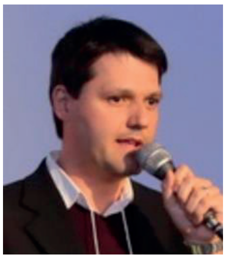

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