Methodology for Fitting the Parameters of a Propagation Model for Private Mobile Radio Communication System

Paulo Roberto de Freitas and Horácio Tertuliano

Abstract— **The organizations providing public services, should not work without the use of proprietary communication technologies and critical mission infrastructure, which provide, to their actions and operations, the absolutely necessary conditions to carry out their purposes. These requirements such as availability, reliability and scalability are vital to the achievement of stringent performance targets set by government regulatory agencies. The present work proposes a methodology for the parameterization and adjustment of the Standard Propagation Model (SPM), a Radio Frequency (RF) propagation pattern, adequate and applicable to private critical mission communication and critical infrastructure networks, using the range of the pertinent spectrum destined to the authorized or dealers concerned, through a computational commercial tool of empirical RF prediction.**

Index Terms— **Critical Infrastructure, Propagation Model, Coverage Prediction.**

I. INTRODUCTION

INFORMATION and Communication Technologies (ICTs) have become an integral part of modern society, producing a profound behavioral impact that fills and influences human relations, in virtual social networks, in the entertainment (music and electronic video) or even in the critical applications of security and public services [1].

These public services as energy, transport, water and gas are provided, in general, by the utilities, which embrace the availability, high reliability, ease of using and scalability and are heavily regulated by governmental organizations [2].

It should be noted that although utilities use generic communications devices and, cumulatively, other commercial networks as a secondary communication option, these networks and devices does not have the required performance in event situations such as power outages, unfavorable weather, vandalism and other incidents. Commercial communication systems suffer, too, user overload and, in these situations, cause unavailability in services and systems

Thus the communication requirements demanded by utilities needs to be dedicated and must use preferential RF channels, with priority of access and available at any time to mobilize their field teams in contingencial situations, including the availability of the best area of coverage, within their respective regions of operation, with the minimum occurrence of shady areas.

This work intends to develop a methodology for the adjustment of the variables that define the SPM radio frequency propagation model, appropriate to the urban and suburban environments, applicable to the frequency bands commonly used by utilities, in their private mobile communication networks, using a commercial computational tool, which can treat and conform the model and compare predictions with field measurements, overcoming the lack of precision of the SPM model in the VHF range of the relevant spectrum.

II. OVERVIEW OF EMPIRICAL PROPAGATION MODELS

The empirical approaches are still widely used since they produce satisfactory results and require little computational processing. In this overview, the main empirical propagation models are in [3], [4], [5], [6], [7], [8], [9], [10], [11], [12] and [13], with some kind of statistical treatment, commonly adopted by commercial computational tools. Such empirical models use equations obtained from propagation measures in the field which result in predictions with adequate accuracy.

More recent works, using the methodology proposed in this article, can be found in [14], [15], [16], [17], [18] and [19], where it is possible to observe similar procedures.

Then, commonly, the propagation loss prediction strategy, that has been currently used, derives from empirical models and from a set of measures in the field. This methodology was used to this paper and, for this, field measurements were carried out using geo-processing systems and a data collection mechanism of received signal strength, after exporting to the computational prediction tool a set of information that includes: geographical coordinates, noise level, local morphology and other details of interest.

III. ATOLL® COMPUTATIONAL TOOL AND SPM MODEL

The Atoll® wireless network planning and prediction computing tool is a platform with a diversified technological capability that supports the deployments of simple Radio Access Network (RAN) and multiple Radio Access Technology (RAT) networks, involving the design steps of expansion and optimization. The tool incorporates the data manipulation and geographic maps, through geo-processing standard Geographic Information System (GIS), which allows

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employing the most common formats available. The simulations just as point-to-area coverage evaluation also includes the modeling of traffic and availability capacities and the feasibility of point-to-point links, including facilities for automatic frequency planning, site and cell allocation and calibration of propagation models [20].

The SPM propagation model is applicable to point-to-area technologies mobile or fixed as well as coverage predictions that can be evaluated by transmitter in the network, by signal level or interference in overlapping zones and in specific conditions, through closed polygonal that delimit areas by restricting calculations to a set of selected transmitters.

This model is based on the empirical formulas of Hata propagation and in (1) the general expression of the SPM model presents the terms and functions corresponding to the calculation of the expected power in the receiving devices [21]:

$$\begin{aligned} P_R = P_{Tx} - \big(K_1 + K_2 &* \log(d) \\ &+ K_3 * \log\left(H_{Txef}\right) + K_4 \\ &* Diff\ Loss + K_5 \\ &* \log(d) * \log\left(H_{Txef}\right) + K_6 \\ &* H_{Rxef} + K_7 * \log\left(H_{Rxef}\right) \\ &+ K_{clutter} * F(clutter) \\ &+ K_{hill,LOS}\big) \end{aligned} \tag{1}$$

where:

P_R	expected reception power (dBm)
P_{Tx}	transmission power (EIRP) (dBm)
K_1	offset constant (dB)
K_2	multiplication factor per $\log(d)$
d	distance between transmitter and receiver (m)
K_3	multiplication factor per $\log\left(H_{Txef}\right)$
H_{Txef}	effective transmitting antenna height (m)
K_4	positive multiplication factor by $Diff\ Loss$
$Diff\ Loss$	loss by diffraction in obstructions (dB)
K_5	multiplication factor per $\log(d) * \log\left(H_{Txef}\right)$
K_6	multiplication factor by H_{Rxef}
K_7	multiplication factor per $\log\left(H_{Rxef}\right)$
H_{Rxef}	effective receiving antenna height (m)
$K_{clutter}$	multiplication factor by $F(clutter)$

A. Assumptions and Constraints of the SPM Model

Despite the utilization of maps with reasonable resolutions with detailed data peculiarities of the ground occupation, there are considerable restrictions in the SPM model:

1) *The recommendations of the parameter set K_1, sampled only for GSM, UMTS, LTE and WiMax technologies, with operating frequencies varying from 800 to 3500 MHz;*
2) *The recommendations of the set of parameters K_n derived from empirical formulation applicable in areas that do not correspond to the relief, vegetation and regional constructive peculiarities;*
3) *The losses by morphology classes that are defined by the user of the tool and are dependent on subjective evaluation;*
4) *The use of the automatic calibration method, is strongly dependent on the quality and granularity of field measurements and the standard values of the K_n parameters.*

In this paper, based on the described fundamentals, the improvement of the accuracy and reliability of the SPM model will be sought, through data collection evaluation and by overcoming the mentioned restrictions, seeking to demonstrate the feasibility and applicability of the method used.

IV. METHODOLOGY

In this section, the field data collection environment is presented including the devices, applications, materials and equipment used in the generation and acquisition set of the measurement series, conduced to gather the collection of information necessary for the development of fitting process.

A. Transmitting Stations

The transmitting stations are located in two transmission and distribution substations of electric system, belonging to Paraná Electrical Energy Company (COPEL), in the municipality of Cascavel, in the southwest region of Paraná State, Brazil. The infrastructure available on the premises includes the self-supporting telecommunications towers and other subsystems. The details of the sites location are shown in TABLE I and the choice of locations sought to involve the environments representative of geographic areas of relief and occupation of ground, adequate to the modeling of the RF propagation researched.

TABLE I
FEATURES OF TRANSMITTING STATIONS

	Site Name	
	Pinheiros Substation	Cascavel Substation
Acronym	PHS	CEL
Location	24,93259719 S 53,445541643 W	24,995949987 S 53,455894453 W
Antenna Model	ARS COLV-100/4BX	ARS COLV-100/4BX
Antenna Gain	6 dBi	6 dBi
Antenna Azimuth	omni	omni
Antenna Height	70 m	55 m
Antenna Downtilt	0°	0°
Frequency Band	172,68125 MHz	172,68125 MHz
Tx Power	44 dBm	44 dBm

B. Receiving Station

The automotive data collect and reception station comprises the devices and equipment required to obtain the RF signal level measurements and geographic coordinates by storing the collection of information on the hard disk of the personal computer (Fig. 1).

C. A. Data Collecting

The process of automated measurement data collecting is implemented by a software application, which runs a program in script format that creates and writes a text file on the notebook hard disk, including the level signal read from the RF monitor and geographic coordinates read from the GPS device.

The measurement collection files and geographic coordinates are then concatenated, using the time as a synchronization reference, to be inserted or imported by the Atoll® program, in which the information bases, called continuous wave (CW) measurements, are created.

D. *Criteria for Sampling and Disposal in Data Collecting*

Numerous theoretical and experimental investigations of radio signals variations in irregular terrain or built-up areas have shown that the propagation of electromagnetic waves is approximately stationary in time under fixed conditions as opposed to spatial or mobile conditions variations of the level of RF signal [22].

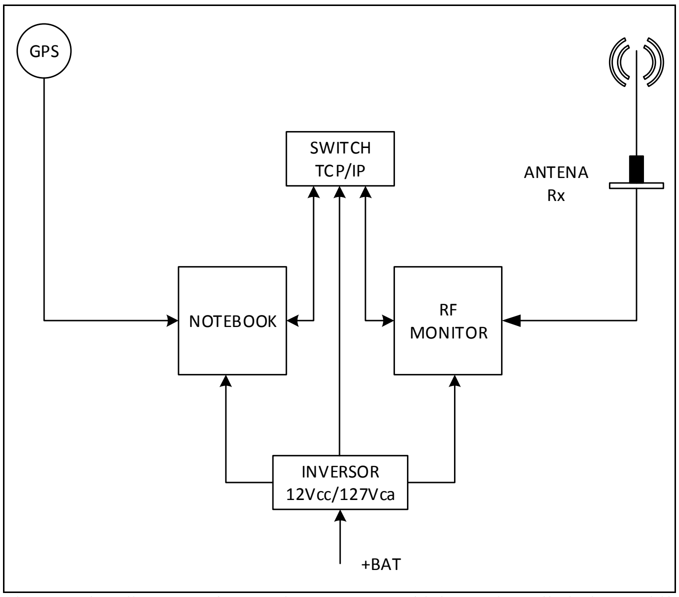

Fig. 1. The diagram of reception system, which set is called the mobile receiving station. The system is composed of the receiving antenna (0 dBi 1/4λ), the GPS receiver device, the RF Monitor instrument, the TCP/IP network router, the notebook that performs the relevant applications and other peripheral accessories.

In order to avoid these spatial or mobile variations of rapid and slow dispersions that may interfere in the collect of data and, consequently, in the appropriate sampling of the signal level measurements received in the mobile station, in [23] is proposed a criterion to obtain a local average, by approximation to a certain spatial length which represents the variations measured in a practically linear manner.

In addition, to eliminate or mitigate measurements with very large deviations (outliers), the data collection must be filtered to preserve the representativeness of the morphology and the terrain profile and also provides statistically valid results. In this way, the basic procedures to filter the measures considered improper to the adjustment and adequacy of the propagation model, can be divided into [24]:

1) *Filtering by morphology class;*
2) *Signal level and distance of the transmitter filtering;*
3) *Filtering by geographic conditions;*
4) *Homogeneity filtering.*

V. PARAMETERIZATION AND ADJUSTMENT OF SPM MODEL

The parameterization and adjustment of the SPM model after collecting and storage of the measurement information was carried out comparing the measured values with the results of the simulation in the Atoll® computational tool, including graphical plotting with level versus distance data.

Thus the non-linear regression model was used to investigate the relationship among variables, associate to the shape of the curve represented by the behavior of the RF signal and the attenuation suffered by the propagation of the electromagnetic wave.

According to this non-linear behavior of the RF signal, has chosen the mathematical model described in expressions (2), (3) and (4), whose parameters or coefficients adopt the format of an exponential function, where θ is the vector determined by the variables α and β that needs to be estimated [25].

$$y = f(x_1, x_2, \dots, x_n; \theta) \tag{2}$$

$$\theta = (\alpha, \beta) \tag{3}$$

$$y \approx \alpha x^{\beta} \tag{4}$$

A. *Adjustment of SPM Model*

The tuning process of the SPM propagation model was carried out with the help of the Atoll® computational tool version 2.8.3 which includes the possibility to modify the parameters associated to the referred model, based on a collection of field measurement data.

The procedure adopted for the adjustment and later development or adaptation of the SPM model, basically comprises the comparison of the regression curves of the measured signals, collected in the field with the regression curves of the calculated or simulated signals obtained by parameterization, with the purpose of minimizing the error between the values of the prediction of path loss and those found in the measurement.

The TABLE II presents the details of the adjusted coefficients and parameters for the SPM model, considering the original standard condition and the definitive modeling situation, whose values obtained in the final adjustment are highlighted. It is also possible to observe the detail of the automatic tuning of the SPM model, for the generic situation, in order to illustrate the variations of the coefficients.

TABLE II
DETAILING THE COEFFICIENTS AND ADJUSTMENT PARAMETERS

Parameters		Standard and Adjusted Coefficients Values		
		Default	Automatic Adjust	Final Adjust
Basic	K1 (*los*)	17,4	0	-18,5
	K2 (*los*)	44,9	56,31	44,9
	K1 (*nlos*)	17,4	4,37	-18,5
	K2 (*nlos*)	44,9	54,85	44,9
Effective Height	K3 (Tx)	5,83	-20	5,83
Diffraction	Method	*Deygout*	*Epstein*	*Deygout*
	K4	0	0,43	1
	K5	-6,55	-10	-6,55
Others	K6 (Rx)	0	0	0
	K7	0	0	0
	K (morpho)	0	1	0

VI. ANALYSIS OF RESULTS

This section explores the adjustment procedure of SPM propagation model and the concepts of the methodology used in this paper, describing the simulations performed with the proposed new configuration, illustrate for some route covered by the mobile station.

A. Route Traveled in Urban Area

The plotting of the measurement and simulation curves for the sampled urban route are shown in Fig. 2, which also show the non-regression measurement curves corresponding to the collected points signals in the field, in order to provide or establish a visual reference of regression curves.

The first observation, as a qualitative analysis, is illustrated by the apparent regularity of the concavity of the regression curves, which expresses the regular decay of the RF signal for the simulation, very close to the measured signal.

This behavior can be evaluated quantitatively through the statistical dispersion measure, given by the Pearson correlation coefficient, which evaluates the similarity in the curves or the linear association between the relevant variables [26].

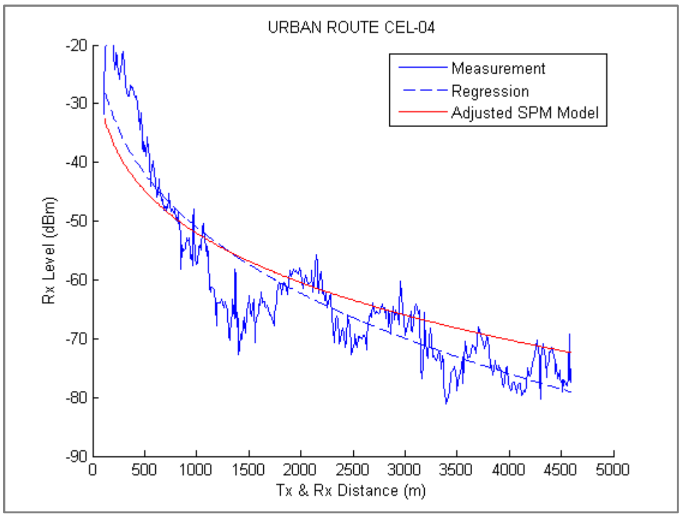

Fig. 2. The plotting curves for urban route named CEL-04, measured from Cascavel Substation. The inversion in the decay curves occurs due to the attenuation suffered by the RF signal that travels with influence of the diffraction losses present in the urban areas and that are not perfectly modeled in the simulation.

The correlation coefficients vary within the numerical range from -1.00 to +1.00, indicating a relation, for example, between measured and simulated continuous variables that, consequently, provide the establishment of two properties denominated strength and direction. As for strength, a correlation greater than or equal to 0.60 is considered strong and, as to the direction, if it is positive, determines the proportional relation tendency of these variables [27].

Mathematically, according to [28], the correlation coefficient of Pearson r can be expressed by equation (5):

$$r = \frac{\sum[(x_i - \bar{x})/s_x][(y_i - \bar{y})/s_y]}{(n-1)} \qquad (5)$$

Where x and y are all variables of the measurement and simulation sets, s is the standatd deviation of the respective sets and n is the number of variables of each set.

For the quantitative determination of the distance between the regression curves, which define an attenuation or gain along the route, the mean error, associated to the standard deviation and mean squared error measurements, are used to evaluate the difference of the signals [29].

B. Route Traveled in Suburban Area

The plot of the measurement and simulation curves for the sampled suburban route are shown in Fig. 3, which also present the respective regression curves that provide the subsidies for the qualitative previously applied analysis for the decay of the collected and simulated RF signal.

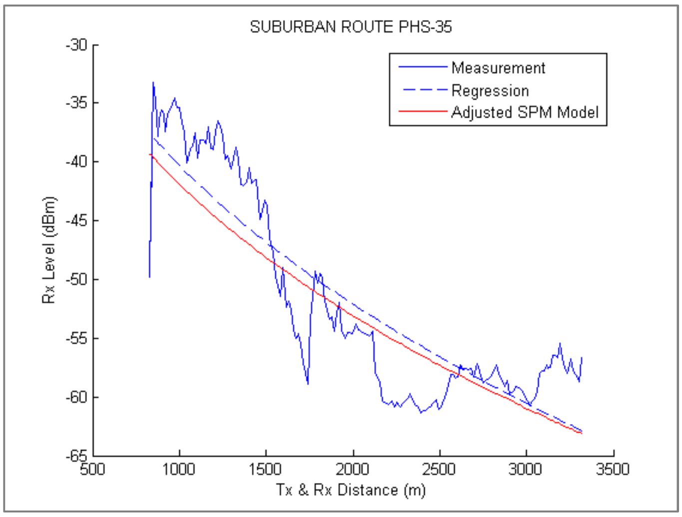

Fig. 3. The plotting curves for suburban route named PHS-35, measured from Pinheiros Substation. Two valleys can be observed in the RF signal measurement curve, possibly representing the contribution of losses caused by the abrupt changes of the relief along the route taken to collect the relevant metering set.

VII. VALIDATION AND GENERAL STATISTICS

The consolidation of the method of adjustment and validation of the SPM propagation model are presented in TABLE III, which, according to the global statistics, demonstrate the result achieved in the calibration of this model, corroborated by the calculation of the mean error value obtained in -0,25 dB, associated with a correlation coefficient of 0,87, confirming the approximation of the predicted or simulated values with the real values collected in the field. Noteworthy is also the calculated values found for the standard deviation and mean squared error, which determine the central tendency of the average data comparison and, consequently, point to a small dispersion.

TABLE III

GLOBAL STATISTICS

Statistics	Local	Mean Error (dB)	Standard Deviation (dB)	RMSE (dB)	Correlation
Global	—	-0,25	7,29	7,29	0,87
Per Transmitter	CEL	1,44	8,27	8,39	0,89
	PHS	-1,42	6,27	6,43	0,79

In order to demonstrate the functionality and operationally of the completed modeling, are presented in Fig. 4, the prediction diagrams or heat maps for the two transmission stations used in the development of this research, establishing the coverage areas and illustrating the propagation study using the new configuration SPM model.

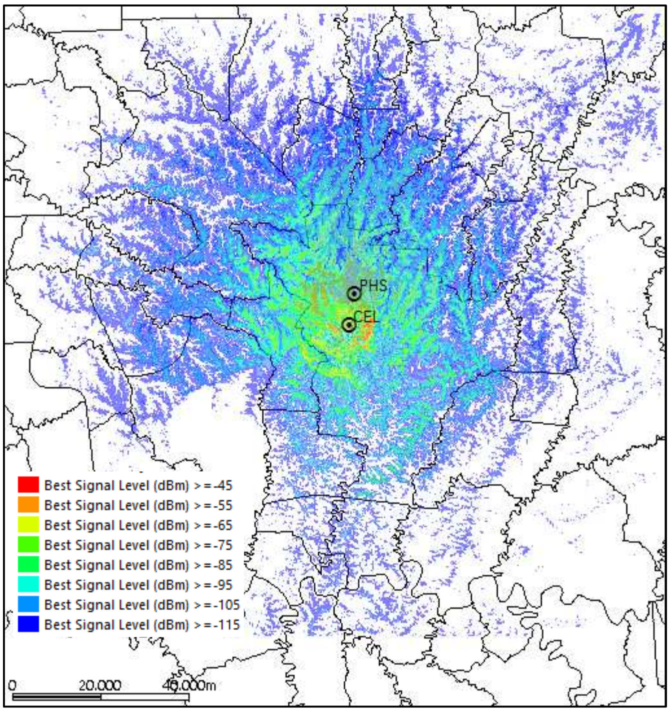

Fig. 4. The prediction coverage diagram with geographic scale bar and colored legend of received signal level on mobile station.

VIII. CONCLUSION

The requirements of information and communication technologies demanded by public services, especially for utilities, suppliers of energy, water, gas, among others, must have high availability and reliability, in order to provide fast responses of great performance, mainly in contingency and emergency situations.

Consequently, the use of mechanisms, processes and tools based on telecommunications technologies are fundamental in the mobilization of the fieldwork forces, especially in mobile communications, which employ point to area coverage infrastructure, supported by the use of voice and data transmissions in real time.

This paper presents an important contribution in the parameterization and adjustment of the SPM model, through a methodology capable of producing the prediction of RF coverage, applicable in critical mobile communication systems, elaborating an efficient method of preliminary diagnosis in planning and design of networks deployments with private limited services.

In this way the methodology used in this work was able to determine the effective calibration of the computational tool resulting in an average error around 1 dB, adapting the parameters of the SPM model and comparing fading curves and proving the effectiveness of the obtained results through statistical techniques of dispersion evaluation and data correlation.

In addition, the employability of the developed propagation model can be adopted by any computational tool, depending on the specific application for coverage studies in the VHF range of frequency spectrum, taking into account the urban and suburban similar areas.

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