Adjustments of Log-Distance Path Loss Model for Digital Television in Lima

J. R. Fernández, M. Quispe, G. Kemper, J. Samaniego and D. Díaz

***Abstract*—it is necessary to perform a proper planning for an efficient deployment of new infrastructure for transmission of digital television in countries that have adopted such technology. In that sense, the coverage prediction process, which makes use of path loss propagation models, plays an important role. The log-distance path loss model determines that the average power loss depends logarithmically on the distance and it has a parameter called propagation exponent which is required to be calculated for each studied environment. This paper describes the adjustments made to the log-distance path loss model using data from three sets of signal strength measurements in Lima, Peru. Through a series of iterations, two computationally simple models for estimating the average path loss were obtained. The performance of the models were evaluated comparing their results with those calculated using Okumura-Hata and the Rec. ITU-R P.1546 model, showing good results. The proposed strategy used here can be applied to any other environment of propagation to estimate the path loss.**

Keywords — Log-distance path loss model, field measurements, digital television, coverage estimation, propagation exponent.

I. INTRODUCTION

Digital terrestrial television (DTT) is a technology that allows multi-stream transmission of audio, video and data with a quality never before seen in terrestrial analog television systems. It also makes the reception of television signals for fixed, mobile, portable, and pedestrian receivers possible, besides the possibility of transmission and execution of interactive applications. To provide a good service, DTT requires having an adequate planning for its deployment using for that propagation models adjusted to the environment where it will be applied

A propagation path loss model predicts the difference between the transmitted power and the receiver power using empirical and deterministic methods or a combination of both. Empirical models, in general, require adjusting some parameter according to field strength measurements made in a particular environment.

This paper proposes two path loss models for outdoor locations in Lima. They were developed by adapting the general log-distance model to the particular conditions of propagation there. For this, it has been worked with several samples of power levels obtained from three measurement campaigns carried out at different times, by different working groups and using different instruments in many locations in Lima, according to recommendations of international organizations [1, 2]. Similar studies have been conducted in other cities for coverage evaluation purposes and propagation characterization of digital terrestrial television standards and cellular systems.

In [3] a path loss propagation model for digital television was obtained adapting the log-distance model based on field measurements in Curitiba (Brazil); the proposed model there predicts values of losses closer to the measurements than the ones obtained by other models like ITU-R P.1546 and Hata, for that city. Two sets of data were used: one for adjusting the log-distance model and the other to verify the accuracy of the model. In [4], the authors applied logarithmic regression to adjust data from field measurements in order to obtain a propagation model with two segments for a cellular base station. In this case, the performance was evaluated comparing the results given by the model with the used set of measurements and the values calculated using the COST 231 model. In this last paper, the authors did not compare the results from their model with a set of experimental data different from the ones used for adjusting such a model; moreover, the parameter used for estimating the error was not the standard deviation or the like.

The accuracy of the models proposed in this paper and the others, used for comparison with them, were evaluated comparing their predicted values with the data from two sets of measurements. The mean error and the standard deviation were calculated for each case.

The paper is organized as follows: Section II describes the methodology used for adjusting the log-distance propagation model and the resulting models; section III presents the results of the comparison between the Okumura-Hata, ITU-R P.1546 and the two models proposed in this paper with experimental data; finally, in section IV, the most important conclusions are presented.

II. LOG-DISTANCE PATH LOSS MODEL AND THE PROPOSED MODELS

A. Log-distance path loss model

The main criterion of this model is to consider the path loss as logarithmically dependent on the distance [5]. Thus, the path loss at a distance *d* (given in Km for all cases) of the transmitter is expressed as follows:

$$PL(d) = PL(d_0) + 10n\log\left(\frac{d}{d_0}\right) \qquad (1)$$

Where $PL(d_0)$ is a reference path loss value based on measurements obtained at a distance d_0. The parameter n represents the propagation exponent and it indicates the rate at which the path loss increases with distance.

The models proposed here were obtained using field strength measurements at 485 MHz band (Channel 16 UHF).

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Strictly speaking, to use this model for other frequency bands is necessary to verify the behavior of its parameters with new set of measurements, for each band.

The expression (1) is regarded as the log-distance model for an area with similar characteristics of propagation because it considers that the entire area of service can be described by a single value of the parameter n. However, in many cases it is necessary to divide the area into two parts, each of which has their own propagation exponent, denoted as n_1 and n_2:

$$PL(d)=\begin{cases} 10n_1 \log(\frac{d}{d_0}) + p_1, d_0 \le d \le d_f \\ 10n_2 \log(\frac{d}{d_f}) + 10n_1 \log(\frac{d_f}{d_0}) + p_1, d \ge d_f \end{cases} \quad (2)$$

Where p_1 is $PL\ (d_0)$. In [6], it is presented this model, which is named two-segments log-distance path loss, and it is evaluated some criteria for determining the values of n_1, n_2 and the distance, d_f, which is called breaking point and indicates the distance at which the propagation exponent is changed.

B. Model fit to the data obtained from measurements made in Lima

The data used in this study were collected in a measurement campaign conducted by the National Institute of Radio and Television of Peru, IRTP, in 2010, whose results were released by the Ministry of Transport and Communications, MTC. [7].

A total of 120 points were evaluated in that study and the field strength and MER (Modulation Error Ratio) values were measured and georeferenced. The transmitter system was located on the Marcavilca hill ("Morro Solar", 244 meters above sea level) in Chorrillos, Lima, and it consisted of a tower of 25 meter height.

The expression (1) requires getting a propagation exponent value that allows the best fit of the collected data; for this, in this paper is performed a iterative process trying to get the minimum value of mean square error between measured and estimated values from the model. The average error µ (dB) and the standard deviation σ (dB) were used to assess the accuracy of the model. The Pearson's correlation coefficient r was a parameter used to indicate the degree of linear relationship between variables.

The results of this approach are presented in Table I.

TABLE I. RESULTS FOR LOG-DISTANCE PATH LOSS MODEL OF ONE SEGMENT

Model	n	µ (dB)	σ (dB)	r
Log-distance	4.5	0.03	12.89	0.62

With these results, the path loss is expressed as follows:

$$PL(d)=79.84+45\log(\frac{d}{1.48}) \quad (3)$$

In (3) can be identified that the closest distance to the transmitter was 1.48 Km. To this distance a path loss value of about 80 dB was recorded. These values represent d_0 and $PL\ (d_0)$ respectively. The d_0 value was established considering the far-field zone of the transmitting antenna and geographical considerations that conditioned measurements in the vicinity.

A graph of estimated values, calculated with (3), and data from measurements is presented in Figure 1.

For the second case (the log-distance model of two segments), in addition to calculating the propagation exponents n_1 and n_2, it is necessary to determine the value of the distance that defines the breakpoint, d_f. In [6] are listed two ways to obtain this value. The first one is a formula resulting from the theory that the breakpoint is the distance at which the first Fresnel zone is obstructed by the ground. The consequence of that is expressed as a change in the propagation exponent value. This formula assumes the existence of line of sight between the transmitter and receiver.

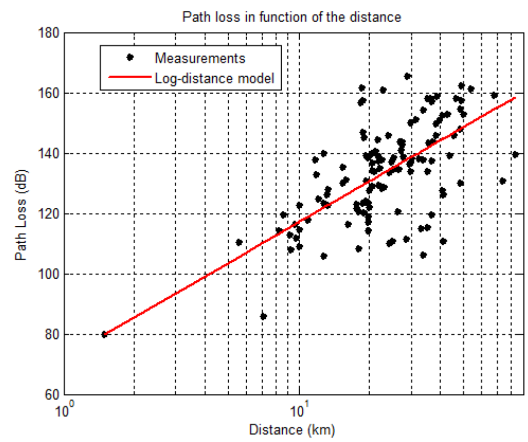

Fig. 1. Field measurements and estimates using the model of a one segment of "log-distance" model.

In the second way, the location of the breakpoint is an unknown variable before starting the iteration process. The iteration level where the estimated value provides the lowest average error allows identifying the breaking point. In [6], it is noted that when there is line of sight, the quality of the estimate provided by the model, whose breakpoint was obtained using the Fresnel criterion, presents a performance quite similar to that achieved using the minimum mean square error criterion. However, other research work considered the iterative process of testing as the main criterion. For example, in [8] it is recommended to use a correction factor for calculating the breakpoint from the first Fresnel zone, interpreting this factor as the effect of the environment on the propagation conditions. In [3], the breakpoint is determined, using iterative tests over distances located between two selected values depending on the environment. The distance at which the smallest mean square error is presented is taken as the breakpoint. This last criterion was adopted in this paper.

The Table II presents the propagation exponents obtained for the calculated breakpoint distance and the statistical accuracy of the approximations.

TABLE II. RESULTS FOR LOG-DISTANCE PATH LOSS MODEL OF TWO SEGMENTS

Model	n_1	d_f	n_2	µ (dB)	σ (dB)	r
Two segment Log-distance	4.7	15.31	3.6	0.002	12.77	0.62

The results shown in Table II define the log-distance model of two segments, which is expressed as follows:

$$PL(d)=\begin{cases} 47\log(\frac{d}{1.48})+79.84, & 1.4875<d<15.31 \\ 36\log(\frac{d}{15.31})+127.44, & d>15.31 \end{cases} \quad (4)$$

Figure 2 shows the path loss measurements and the estimated values obtained using (4).

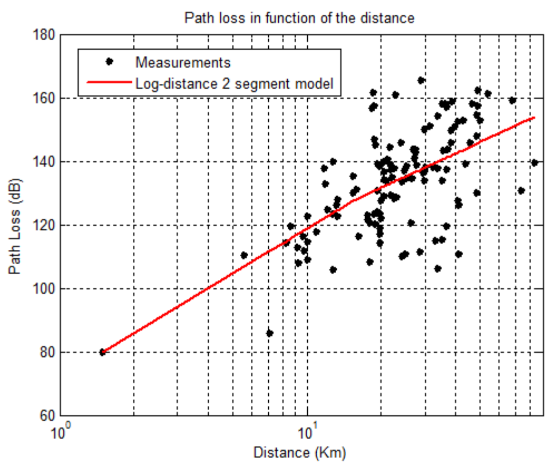

Fig.2. Field measurements and estimated values obtained using the log-distance model of two segments.

III. Results

A. *Performance comparison between the obtained models and other known models*

The Okumura Hata and ITU-R P.1546 are two of the most used and disseminated path loss models for digital television coverage calculation. For that reason, they have been utilized to compare their quality of prediction versus the results given by log-distance models developed here. Table III shows the mean error and the standard deviation values for these models.

TABLE III. DEVELOPED MODELS VS OKUMURA HATA AND ITU MODEL

Model	μ (dB)	σ (dB)
Okumura Hata	5.05	15.07
ITU-R P.1546	-2.75	13.53
Log-distance 1 segment	0.03	12.89
Log-distance 2 segment	0.002	12.77

Correction factor for a suburban area and small city was used in the Okumura Hata model. This correction gave more precision to the model when it is compared with measurements. The developed models, based on the log-distance model, have a higher accuracy compared to other models. While the Okumura Hata model has a mean error of approximately 5 dB and a standard deviation greater than 15dB, the average error is less than 0.5 dB and the standard deviation is less than 13dB for the models developed here. For the ITU model the average error is about 3 dB with a standard deviation of more than 13 dB. Thus, the developed models are the most suitable to use in Lima. In this case, the set of measurements used for comparison is the same used for the adjusting of the models. The following sub-sections present the results obtained from the comparison using two cases for different sets of measurements in Lima.

B. *Results for case 1*

To evaluate the accuracy of the developed models, two different sets of signal strength measurements were used. The first, collected by INICTEL-UNI in October 2010, consisted of 58 samples of signal strength obtained in different locations of the city. The Table IV presents the levels of the average error and the standard deviation for the developed models, the Okumura Hata and the ITU-R P.1546 model.

TABLE IV. COMPARISON OF RESULTS OBTAINED FROM THE STUDIED PROPAGATION MODELS: CASE 1.

Model	μ (dB)	σ (dB)
Okumura Hata	-2.96	11.34
ITU-R P.1546	6.7	10.42
Log-distance	8.76	11.61
Log-distance 2 segment	7.51	10.75

The Figure 3 shows the behavior of the estimation for this case. The absolute error does not exhibit a decreasing continuous trend, but it shows a decrease with fluctuations of between 1 to 4 dB and 6 to 12 dB. The good performance of Okumura Hata for the average error in this case show that almost the 90% of the samples has an error less than 14dB, while the ITU-R P.1546 model achieves 79%. For one and two segments models, these values are of 74% and 75% respectively.

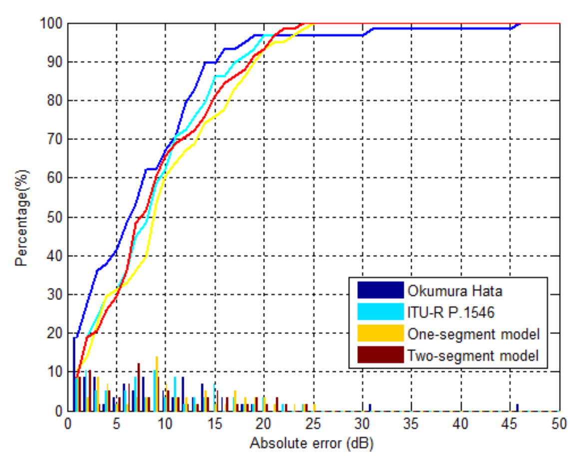

Fig. 3. Bars represent the PDF of absolute error in dB of each propagation model for the set of measurements of case 1. The solid lines indicate the respective CDF.

C. *Results for case 2*

For a second comparison, it was used a second set of measurements which was obtained from the Commission responsible for recommending the most suitable digital television system for Peru. The set consisted of 33 samples and the measurement campaign was carried out in April 2009. Table V shows the results obtained.

TABLE V. COMPARISON OF RESULTS OBTAINED FROM THE STUDIED PROPAGATION MODELS: CASE 2.

Model	μ (dB)	σ (dB)
Okumura Hata	17.71	20.19
ITU-R P.1546	9.18	12.44
Log-distance	9.19	12.53
Log-distance 2 segment	8.05	11.76

Figure 4 shows a comparison between the four considered models based on the absolute error in the estimated values. In this case, the Okumura Hata model present an almost uniform trend in the number of errors of up to more than 20dB, while the other three models have a more regular downward trend. For this second case, the estimation from Okumura Hata model gives an absolute error less than 14dB only in less than the 45% of the samples, while that, for the other models, this level is obtained for the 75% of the samples, indicating a better stability in the estimation.

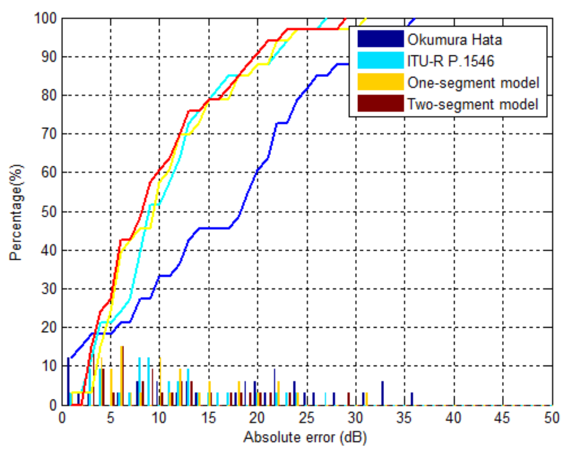

Fig. 4. Bars represent the PDF of absolute error in dB of each propagation model for the set of measurements of case 2. The solid lines indicate the respective CDF.

IV. CONCLUSIONS

This paper presented two adaptations to the log-distance path loss model which were developed based on a set of measurements obtained from a measurement campaign carried out in Lima. According to [5], acceptable levels of standard deviation in estimation of signal strength levels for large scale propagation models are usually between 10 to 14 dB, so that the estimates provided by the proposed models are acceptable. The propagation models expressed by (3) and (4) can obtain estimation with a mean error level between 7.5 and 9.2 dB and standard deviation between 10.7 and 12.6 dB. These values were obtained using two sets of independent measurements performed in many locations in the city.

In comparative terms, this paper shows that the models proposed here present a very competitive performance respect to the Okumura Hata and ITU-R P. 1546 models. In one of the tested cases, the two-segment model has accuracy better than 1 dB for the mean error and the standard deviation values compared to the other models.

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