Analysis of ISDB-Tb Signal Propagation in Indoor Environments

William Douglas Costa Fernandes and Alexandre de Almeida Prado Pohl

***Abstract*— This work presents an analysis of signal propagation in an indoor environment. Three empirical models were implemented: Modified Keenan-Motley, Log-Distance and Linear Attenuation. The simulation delivers a coverage map showing the reception power in the corresponding area, whose results are validated with experimental data acquired with a low cost test environment.**

***Keywords*— Indoor Propagation, Digital TV, ISDB-Tb.**

I. Introduction

The advent of digital TV in Brazil has allowed many improvements and innovations, both in the audiovisual quality transmission and reception of signals and in the provision of services, driven by the interactivity between the viewer and the broadcaster/internet service provider [1]. Furthermore, portability allows viewers to watch television programs on mobile devices like cell phones and portable TVs. The increasing necessity of receiving signals in indoor environments has pushed manufacturers into the development and implementation of robust modulation techniques and higher sensitive receiving schemes. At the same time, the problem has renewed the interest of researchers in the improvement and test of indoor propagation models.

Indoor coverage prediction models were not yet deeply discussed on literature for digital TV systems on the UHF range, although it was extensively covered for wireless data and cellular systems.

While models for propagation in the urban, suburban and rural areas are mainly determined by the path loss distance, models for the indoor signal prediction must include other variables like the reflection on internal walls and furniture. This paper reports on power measurements performed in the UHF (Ultra High Frequency) range in an indoor environment (lab room of the Federal University of Technology in Curitiba) and the use of available narrow band indoor propagation models to predict and compare calculated with measured data.

The transmission and reception of digital TV signals by utilities require use of sophisticated and high cost equipment. Often, in a research laboratory, such equipment is not available to perform all processing steps. In this work we use a low cost framework [1] for testing digital TV (DTV) with the use of a modulator installed on a PC (Personal Computer) and the use of a spectrum analyzer.

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This paper is organized as follows: Section II describes the propagation models and the test environment. Section III the simulation and experimental results followed by the conclusion in section IV.

II. CHARACTERIZATION OF INDOOR PROPAGATION

A. Empirical Indoor Propagation Models

Three different approaches for the prediction of indoor coverage have been investigated, but all of them are empirical narrow-band models. They are expressed in the form of simple equations, which give the path loss as the final result.

1) Modified Keenan-Motley Model: also named as multi-wall model, it was proposed in COST 231 [2] and gives the path loss as the free space loss added with losses introduced by the walls and floors penetrated by the direct path between the transmitter and the receiver. The modification inserted in the Keenan-Motley model [3] is a floor correction gain and the possibility of using different types of wall and floors. The path loss (L) equation used in our tests, with only walls on between the transmitter and the receiver is:

$$L = L_{FS} + L_C + \sum_{i=1}^{I} k_{wi}.L_{wi} \qquad (1)$$

where L_{FS} (dB) is the free space loss (FSL) between transmitter and receiver, L_C a constant loss (dB), k_{wi} the number of penetrated walls of type i, L_{wi} (dB) the loss of wall type i and I the number of wall types. L_C is a term which is added when wall losses are determined from measurement results by using the multiple linear regression. On this work, this term is zero. The sum term of the equation is added on Non-Line-of-Sight (NLOS) condition. When the condition between the transmitter and the calculated point is in Line-of-Sight (LOS), the final attenuation is derived only from the L_{FS} term. On this work, the situation of penetrated floors was not tested and for this reason was omitted on the equation above. The loss values of all wall types were empirically measured for each frequency used in the tests, as explained in section II.B.

2) Log-Distance Path Model: assumes a linear dependence between the path loss (dB) and the logarithmic distance [8]. It is also called as One Slope Model [2]. The path loss is given as:

$$L = Pl\left(d_0\right) + 10n \log\left(\frac{d}{d_0}\right) \qquad (2)$$

where L (dB) is the predicted attenuation at a d distance from the transmitter, Pl is the measured power at a d_0 reference distance, that is usually 1m, and n is the power decay index. It is noted that this model doesn't employ directly the frequency of the signal and that the knowledge of n is essential to a good accuracy of the propagation prediction. The power decay index can be obtained empirically by performing a series of measurements of power and distance in the environment, in which the prediction is made using a fitting approach for its estimation.

3) Linear Attenuation Model: in this model, the excess path loss (L) is linearly dependent on the distance added to the free space loss factor (L_{FS}) [2] [4] [5].

$$L = L_{FS} + \alpha . d \tag{3}$$

where α (dB/m) is the attenuation coefficient and d (m) the distance from the transmitter. The value of the attenuation coefficient can be determined, once more, using a fitting method, such as the Minimum Mean Square Error (MMSE), for instance.

B. Test Environment

The test scheme consisted on mapping the UHF power level inside a room characterizing its indoor coverage using the framework reported in [1]. The transmitter is based on a modulation board (DekTek DTA-115) with an RF output, driven by a PC (32 bits Core 2 Quad 2.4GHz Processor and 4GB RAM, OS Windows 7). The carrier frequency is adjusted in the UHF range. The transmission antenna was a monopole structure with unity gain that was used to distribute power equally on all directions. The modulation scheme was adopted in accordance to the International System for Digital Broadcast, Terrestrial, Brazilian version (ISDB-Tb), [9] with the configuration of 13 segments, 64QAM, I=2, Fec $\frac{3}{4}$, 3rd mode, and output power of -3dBm. The reception system consisted of a log-periodic antenna (11dBi of Gain), an Agilent spectrum analyzer and a commercial ISDB-Tb set-top box to decode and visualize the signal. During the alignment procedure, the reception antenna was always pointed to the transmitter. The height of both antennas (Tx and Rx) was set at 1m in relation to the floor.

The tests were accomplished inside the LCD (Laboratório de Comunicação de Dados) of UTFPR (Campus Curitiba), a $50m^2$ indoor environment. The lab is divided into three areas, as seen in Fig. 1 (the red thick lines in the figure point out to the walls that separate the areas. The other color objects in the figure represent obstacles in the signal path, such as tables, racks and closets). The environment was previously characterized according to the width and type of the walls, size and position of existing obstacles between the transmitter and the receiver antenna without people on the line-of-sight. During the tests the transmitter remained fixed and the reception antenna was moved around to cover the Lab area. 168 points were monitored using the spectrum analyzer, and 100 samples (one sample measured every 10 seconds) taken in each point, from which the mean value was calculated. Parameters such as the temperature and humidity in the lab were also monitored. These points were divided into two groups, according to the two different transmitter positions chosen for the measurements, in order to evaluate thoroughly the propagation models.

To evaluate the frequency dependency characteristic of the indoor propagation, three UHF carriers: #26 (635.143MHz), #45 (665.143MHz) and #60 (755.143MHz) were selected and measured in each antenna location. They were chosen because their spectrum was unoccupied and as separate as possible.

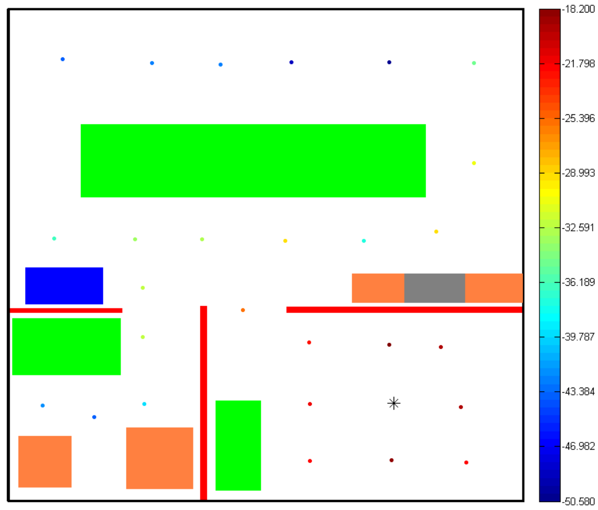

Fig. 1. Top view of the LCD area showing the walls that separate the environment. Green areas represent desks, orange represents racks and shelves and blue a closet. Color points represent the measured power (at 635.143MHz), where the axis on the right shows values in dBm. The transmitter is marked with a black asterisk on the right inferior corner.

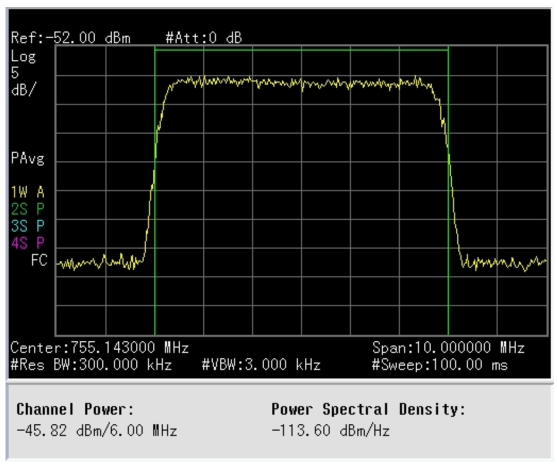

Fig. 2. Carrier #60 (755.143 MHz) measured at a reception point near to the transmitter.

Fig. 2 shows the 6MHz spectrum of carrier #60, as seen in the spectrum analyzer. Initially, the attenuation coefficients for each obstacle between the transmitter and the receiver were measured for each carrier. The measure consisted in obtaining the power without the obstacle and comparing it with the power with the obstruction. Once all the materials were characterized a map containing all these obstacles was drawn. The measured attenuation coefficients (L_{wi}) for each material and frequency were then inserted in the Modified Keenan-Motley prediction model to estimate more precisely the coverage inside the indoor environment. The power loss of the Tx and Rx cables were measured for the three employed carriers.

C. Indoor Coverage Prediction Software

An algorithm was written in MATLAB to implement the prediction models, which took into account the map of the indoor environment [6] [7]. This map is a three dimensional matrix, a bitmap image, where each pixel corresponds to one point with predicted power coverage. It contains the information of the position of each obstruction between the transmitter and the receiver antennas.

Before the simulation is accomplished, it is necessary to convert the map of the indoor environment onto the bitmap matrix. There is a scaling factor between each pixel and its real position that is used to perform the calculation of the received power. For the Modified Keenan-Motley model it is necessary to associate each different material (and its correspondent attenuation coefficient, L_{wi}) with a different matrix value, such as a color, to be interpreted by the software. The number of matrix indexes with the same colors between the transmitter and the receiver is the number of penetrated obstacles k_{wi}. Besides the bitmap matrix, the other inputs for the software are the EIRP (Equivalent Isotropically Radiated Power) calculation parameters, such as antenna gains, cable attenuations for each frequency, transmission power, channel frequency and the measured attenuation coefficients for each material. For each pixel of the input bitmap matrix the equation for the received power (P_r) is given on equation 4.

$$P_r = EIRP_{Tx} + EIRP_{Rx} - Att_{Channel} \quad (4)$$

The carrier attenuation ($Att_{Channel}$) depends on the adopted prediction model. The algorithm output is another matrix with each index containing the power level of its geographical position. For the test, the indoor map was converted into a 437x415 matrix with five different obstacles resulting in a distance of approximately 1.6cm between each pixel.

III. Measurement and Prediction Results

The values of the measured attenuation coefficients and the correspondent colors in the maps follow on table I.

TABLE I

MEASURED ATTENUATION COEFFICIENTS (dB) FOR EACH CHANNEL.

	Channel 26	Channel 45	Channel 60
Metal Locker: Orange	7.85	9.53	10.44
Wood Bookshelf: Gray	2.36	2.81	3.22
Closed Wood Locker: Blue	5.28	8.79	10.01
Plasterboard Wall: Red	3.10	3.71	3.90
Computer Table: Green	6.54	8.82	9.78

To obtain the power decay index, n, of the log-distance model and the attenuation coefficient, (α), of the linear model, a MMSE fitting method was adopted for each frequency and transmitter position. The values for n and (α) for all transmission scenarios (frequency and transmitter position) are shown in table II and an example for the fitting curves is demonstrated in figure 3.

TABLE II

ATTENUATION COEFFICIENT (α) AND POWER DECAY INDEX (n) FOR EACH SIMULATED SCENARIO

	Linear, α(dB/m)	Log-distance, n
TX1, Channel #26	-1.4014	2.8173
TX1, Channel #45	-2.0929	3.2411
TX1, Channel #60	-2.4486	3.4725
TX2, Channel #26	-0.8066	2.4818
TX2, Channel #45	-1.1858	2.7108
TX2, Channel #60	-1.5405	2.8421

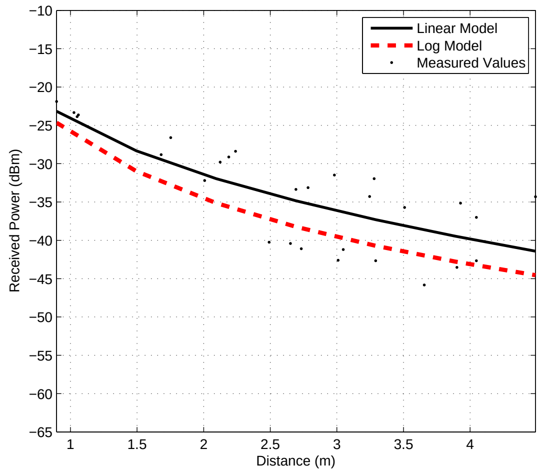

Fig. 3. MMSE fitting curves for the channel #45 with the transmitter in the center of the Lab (Tx2). The obtained parameters for the log-distance model were n = 2.71, d_0 = 2.71 and $Pl(d_0)$ = -34.08dBm and for the linear model α = 1.1858dB/m.

The prediction coverage maps generated by the software were in a total of eighteen: six for each propagation model, (measurement of three carriers for every one position of the transmitting antenna in the room). For labeling purposes, it was called as Tx1 the prediction maps with the transmitter (black asterisk) placed in the inferior right corner of the map and Tx2 the prediction maps with the transmitter placed in the center of the room.

Fig. 4 shows the prediction for the received power (dBm) using the Modified Keenan-Motley model on channel #26 and Tx2. Fig. 5 shows the prediction of the received power (dBm) of the Linear model on the channel #45 and Tx1. Fig. 6 shows the prediction of the received power (dBm) of the Log-distance model on the channel #60 and Tx2.

To compare the 2D power distribution given by the prediction models with experimental data, maps containing the errors between the models and the measured power were also generated. For instance, Fig. 7 and 8 shows the mean errors (dBm) calculated between the predicted received power (dBm)

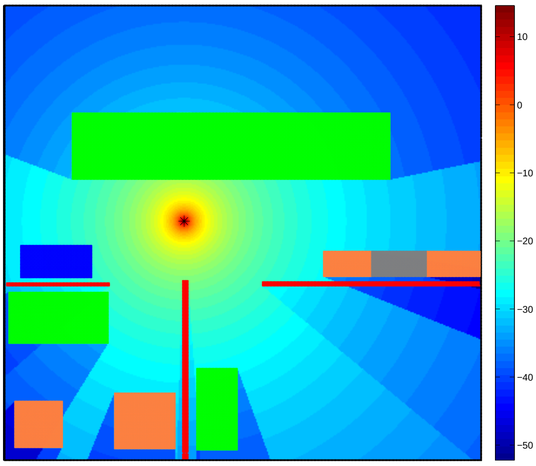

Fig. 4. Prediction of the received power (dBm) of the Modified Keenan-Motley model on channel #26 with the configuration Tx2.

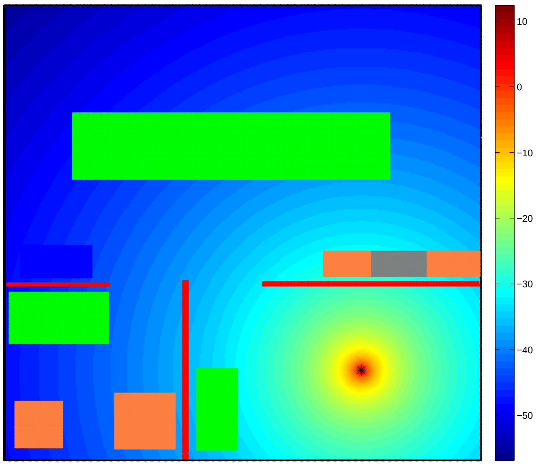

Fig. 5. Prediction of the received power (dBm) of the Linear Attenuation model on channel #45 with the configuration Tx1.

of the Modified Keenan-Motley model and the measured values on Tx1 on channel #26 and #60, respectively.

Table III also shows the mean error and corresponding standard deviation for each transmission case. Negative values indicate that the prediction delivers higher attenuation than the measured power values (the model is pessimist).

IV. Conclusion

As shown in Table I, the attenuation coefficient is very dependent on the characteristics of the material such as its thickness and type. Materials with more dense structure have a higher attenuation. The coefficient is also very affected by the employed carrier frequency. At higher frequencies, the wave beam is smaller becoming less subtle to diffractions on the obstacles. Under this regime, the wave is absorbed by the obstacle and the attenuation coefficient becomes higher.

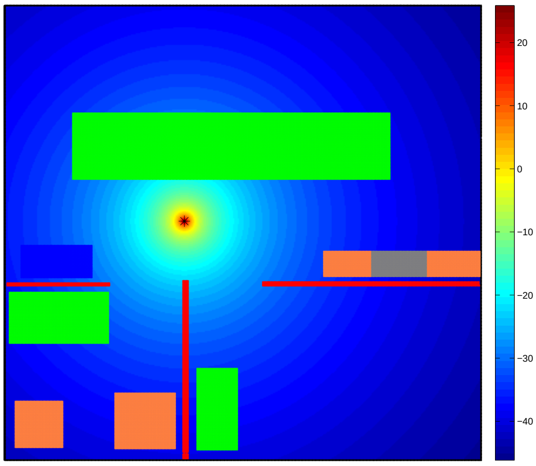

Fig. 6. Prediction of the received power (dBm) of the Log-distance model on channel #60 with the configuration Tx2.

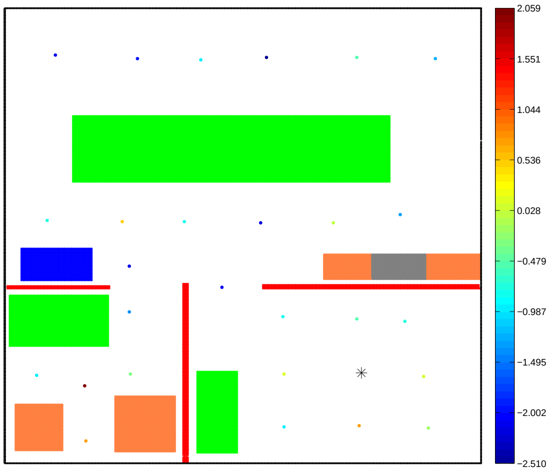

Fig. 7. Errors (dBm) of the prediction of the received power (dBm) of the Modified Keenan-Motley model on the channel #26 with the configuration Tx1.

Analyzing the dispersion of the measured points, the linear model is more accurate than the Log-distance model, once the mean error is much bigger in latter than in the former model.

Table III also shows that the Modified Keenan-Motley Model has achieved the best results. The averaged error between all the tested scenarios was 0.36dB and the averaged standard deviation (STD) was 0.90dB. Analyzing the position of the measured points with their correspondent error (Fig. 7 and Fig. 8), the points placed far from the transmitter have a bigger error than the closest points. Another characteristic is that at lower frequencies (Fig. 7) the diffraction acts more than in the higher channels (Fig. 8). This effect turns the model more pessimist for lower frequencies, or in other words, there is more power at the analyzed point than it is predicted by the model. The results of the Table III confirm this statement, once

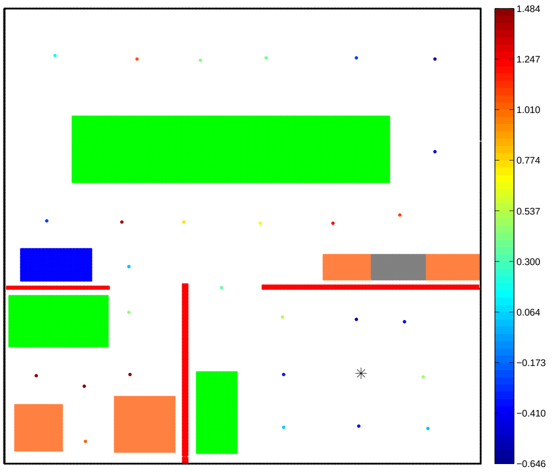

Fig. 8. Errors (dBm) of the prediction of the received power (dBm) of the Modified Keenan-Motley model on the channel #60 with the configuration Tx1.

TABLE III

ERRORS (dB) AND STANDARD DEVIATION FOR EACH SCENARIO.

Model, Configuration	**Error**	**STD**
Keenan-Motley, TX1#26	**-0.7658**	**1.0704**
Keenan-Motley, TX1#45	**0.0595**	**0.8163**
Keenan-Motley, TX1#60	**0.3517**	**0.6901**
Keenan-Motley, TX2#26	**-0.3977**	**0.9312**
Keenan-Motley, TX2#45	**-0.1392**	**1.0205**
Keenan-Motley, TX2#60	**0.4681**	**0.8861**
Linear, TX1#26	-0.4608	4.7190
Linear, TX1#45	-0.5251	5.7337
Linear, TX1#60	-0.6393	6.2851
Linear, TX2#26	-0.0953	2.7944
Linear, TX2#45	-0.0878	4.2161
Linear, TX2#60	-0.0754	3.7724
Log-Normal, TX1#26	2.3677	4.7422
Log-Normal, TX1#45	2.7239	5.6911
Log-Normal, TX1#60	2.9184	6.2665
Log-Normal, TX2#26	0.3851	2.7675
Log-Normal, TX2#45	2.4044	4.1569
Log-Normal, TX2#60	2.5208	3.7228

the mean error value is negative for channel #26 and positive for channel #60.

In most commercial models of set-top boxes, the sensitivity using 64 QAM is approximately -71dBm. Considering this reception characteristic, it is possible to affirm that the proposed empirical models modified to the UHF range (specially the Modified Keenan-Motley) can be employed with high accuracy to determine the reception of the digital TV signal. It is also relevant that with a low cost test environment the theoretical models can be validated successfully.

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