Modeling and simulation of the ITM model for point to point prediction on Digital Television Extensible to other technologies

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***Abstract*—This article addresses the main characteristics and structure of the most widely used propagation model to predict analogue and digital radio coverage in a point to point mode. The ITM model, ITS-67 (Institute of Telecommunications Sciences) V1.2.2. a.k.a ITM Longley Rice (Irregular Terrain Model), is deterministic and based on NBS (National Bureau of Standards) TN101 Vol.1&2. In this article, the ITM evolution in its different versions is analyzed, the four zones of the ITM are described as well as the signal attenuation level displayed in a continuous function between the Transmitter and the Receiver. The ITM V1.2.2 algorithms coefficients and profile are described and analyzed, including the calculation of the continuous function of reference attenuation, the terrain irregularity parameter Δh and variabilities. Then, three existing radio links part of a TVD radial previously measured, are simulated with the last version of Radio Mobile program and the results compared with the measurements.**

***Keywords*—Irregular Terrain Model (ITM), FSL, LOS, Diffraction, A_{ref}, ITM algorithms coefficients, Δh factor, Radio Mobile Simulation.**

I. INTRODUCTION

In the real world, the received levels of a radio signal are random, as they vary in time due to atmospheric influence in space, time and to terrain. The prediction models describe these variabilities by providing estimates of the general level of the received power and the expected deviations. The calculation of received signal levels of a radio link presents physical-mathematical-empirical challenges exponentially increasing in in broadcasting.

This paper addresses the complete structure of the ITM model *(Irregular Terrain Model),* considering its evolution, the description of each coefficient of its algorithms and the analysis of the 4 areas of ITM on DTV radio links; being a continuation of a former work of the authors [1].

Acknowledgments to Proyecto DICYT, Código 061813KC, Vicerrectoría de Investigación, Desarrollo e Innovación, Universidad de Santiago de Chile, Usach.

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A radio coverage involves detailed terrain information, land coverage *(clutter)*, environmental conditions as well as adequate processing and storage capacity of a computer. Therefore, methods are developed in which the field information is reduced to averages, naked eye inspections or resorting to parameters already extracted from other similar situations.

To avoid the noncompliance of those approaches with real coverage situations, ITS and ITU *(International Telecommunication Union)* recommendations resort to statistical variabilities to replace the uncertainty of approximations or averages.

Some of them are exclusively empirical models, some others are mix, empirical – deterministic based on field surveys and of course the electromagnetic theory. For that purpose, propagation models have been developed and implemented in a larger variety of computer programs, frequently used by telecom administrations as well as operators and consultants. Those programs are:

a) ITM, better known as Longley Rice, by the authors A.G. Longley, P. L. Rice ESSA TECHNICAL REPORT ERL 79-ITS 67 [2].
b) Recommendation UIT-R P.1546-4 developed by International Telecommunications Union. oct. 2009 [3].

ITM allows the prediction of broadcasting coverage under point-to-point and point to zone modes. However, due to present availability of processing and storage capacity of computers and precision Digital Terrain Elevation Data (DTED); the point to zone model has fallen out of use.

Besides introductory Section I, this document is organized as follows:

Section II presents the description of ITM, section III the structure of ITM and its algorithms, section IV simulation in Radio Mobile and section V, conclusions and future lines of investigation to develop.

II. ITM DESCRIPTION

A. ITM Model

The ITM is a deterministic model based on the electromagnetic theory but including empirical parameters where necessary associated with statistical analysis of terrain characteristics and field intensity measurements [2].

The ITM predicts the reference attenuation A_{ref}, which is added to free space attenuation (FSL) of a radio signal based on distance, environmental and geographical characteristics.

The ITM is basically a byproduct of Technical Note 101 Vol I y II NTIA *(National Telecommunications and Information Administration. USA)* [4], authors A.G. Longley y P.L. Rice, A.K Norton y A.P. Barsis (1966), later reviewed in 1967 [2]. TN101 is a huge compilation of the world's knowledge on radio propagation as of 1967. Its structure and algorithms are based over two hundred documents which established the foundations of radio link and coverture modeling, valid up to the present. Specifically, Vol. II of Technical Note 101 [5], is the cornerstone foundation of 1968 ITM Longley-Rice, still in plain validity and used by most of radio propagation software, commercial and freeware.

Figure 1 shows the sequence of ITM model evolution.

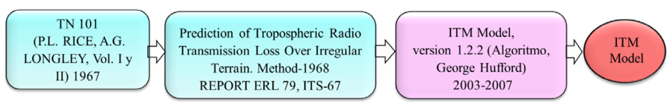

Fig. 1. Evolution of the ITM model. [2, 5, 6].

The ITM was designed as a simplification of the TN 101 [4] and specifically for a compiled program such as Fortran 66, meanwhile the TN 101 was basically a model for slide rule and paper maps. As of today, the ITM is practically included in all commercial propagation SW for links and coverages; and it's preferred by the various free of charge SW *(Freeware)*, mainly in Windows. The program is open and available from ITS in Fortran 77 and C++ [4]. Table I shows the main characteristics of the model.

TABLE I
ITM MODEL CHARACTERISTICS [6].

Characteristics	Description
Model	Deterministic
Based on	Electromagnetic theory
Modes	Point-to-point and point to zone (Area)
Zones	FSL, LOS, Diffraction and Scatter
Statistics	Variabilities: time, locations and situations

III. ITM STRUCTURE

The most important basic characteristics, subroutines and/or algorithms of the model structure are described heretofore.

A. ITM model structure

It starts assuming a hypothetical reference profile divided in four zones, as shown in Figure 2 with antenna heights, reference distances and elevations angles.

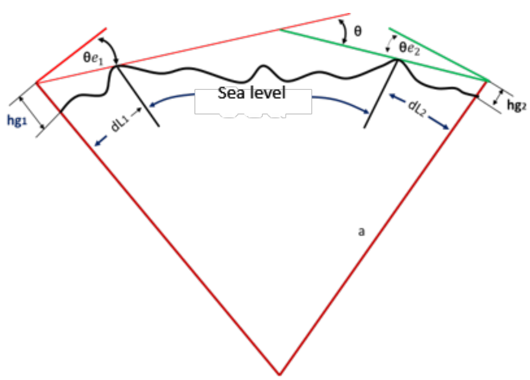

Fig. 2. Generic reference profile ITS-67-ITM [2].

The reference attenuation level between transmitter and receiver is deployed as a continuous function, which is added to Free Space Loss (FSL) in dB.

- ***FSL (A_{fs})*** *Friis equation*

$$A_{fs} = 32{,}44 + 20\log f\ (MHz) + 20\log d\ (km)\ \ [\text{dB}] \quad (1)$$

The four zones reference attenuation. Figure 3.

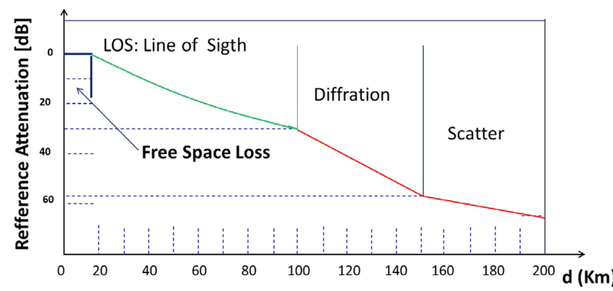

Fig. 3. ITM model Zones and additional attenuation to FSL [6].

Table II describes the 4 zones of ITM.

TABLE II
DESCRIPTION OF EACH AREA OF ITM [6].

Zone	Description
FS	Reference attenuation is zero, received level is equal to FSL
LOS	Reference attenuation includes the 2-Ray model, atmospheric absorption, clutter and diffraction extrapolation from the diffraction zone weighted by a factor function of Δh
Diffraction	The knife edge and smooth earth reference attenuation weighted by a factor function of Δh
Scatter	Troposcatter reference attenuation, starting from the interception of diffraction and scatter, linear reference attenuations. No weighted factor included

G. Hufford reference [7] describes the three A_{ref} main equations:

$$Aref \begin{cases} max(0,\ A_{el} + K_1 d + K_2\ ln\left(\dfrac{d}{d_{LS}}\right)),\quad d \le d_{LS} & (2) \\ A_{ed} + m_d d,\quad d_{LS} \le d \le d_x & (3) \\ A_{es} + m_s d,\quad d_x \le d & (4) \end{cases}$$

The 1st equation (2) defines the first two zones: FSL and LOS. In FSL zone, $A_{ref} = 0$, no additional attenuation to FSL.

In the LOS zone, A_{ref}, is composed of two overlapping attenuations.

a) 2-Ray attenuation model.
b) Extension of the linear diffraction A_{diff} to LOS zone.

The ***a)*** attenuation is calculated by a classical 2- Ray model but, to calculate extension ***b)***, ITM first calculates the diffraction zone to define a dB straight-line, which will be extended to the LOS zone. That straight-line defines the A_{diff} diffraction attenuation which is calculated by the second of the three equations (3).

The A_{diff}, diffraction attenuation is based on the combination of the knife edge model A_k *(Fresnel-Kirchoff)* and the smooth spherical earth model A_r *(Vogler)* [7]. The weighted contribution of both equations to A_{diff} is defined by another coefficient, function of Δh.

The third equation (4), defines another straight line based on the reference attenuation by *Scatter.* The scatter and diffraction lines intersection define the end of the diffraction zone and the beginning of scatter [7].

B. Coefficients of ITM algorithms [7]

The core of link calculations for broadcast coverage along a radial, resides on the coefficients calculation on the three equations already mentioned to define A_{ref} [7]. They are:

$$A_{el}, K_1, K_2, A_{ed}, m_d, A_{es}, m_s \; y \; d_x$$

The ITM program calculations in C++ (or Fortran) involve 107 algorithms in 1.263 code lines.

For 2-Ray model, ITM calculates the intercept of the of the reflected ray First Fresnel zone over a.s.l terrain elevations corrected by earth curvature - and then a regression line (least squares) of terrain variations referred to that line. Then with that input, the Δh irregularity parameter is calculated [7$_{3.10}$]. However, the regression (trend line) isn't calculated with the classical method but with a set of numerical shortcuts applicable to C++.

It consists in replacing the x-axis distances by intervals and its dimensions, and shifting the x – axis origin (x=0) to the median point of X values of elevation dispersion. As the intervals are symmetrical positives and negatives, its sum is zero.

The displacement of the X axis and its conversion to intervals it's also used for the calculation of effective antenna heights $h_{e1,2,}$ the 2-Ray model and the irregular terrain parameter Δh. [8$_{53}$].

Equations 5 y 6 calculate the effective heights of transmitter and receiver antenna as shown in Figure 4.

$$h_{e1} \; = \; h_{g1} + \; (Z_0 - \; Z_a) \qquad (5)$$

$$h_{e2} = \; \; h_{g1} + \; (Z_n - \; Z_b) \qquad (6)$$

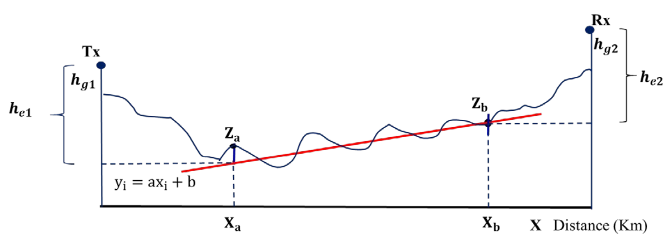

Fig. 4. Profile and effective antenna heights $h_{e1,2}$ [8$_{45\text{-}46}$]

The horizons to obstructions are calculated over effective curvature Earth γ_e by means of the subroutine, reference [8$_{47}$] which also calculates the angles over the horizontal to obstructions. Figure 2.

To define the span of each section: LOS, Diffraction y and Scatter; ITM uses a "virtual" concept of smooth round earth and the diffraction attenuation over this smooth earth (round earth attenuation). This attenuation is calculated determining the distance of each antenna to the smooth earth horizon with effective curvature γ_e grazing the zone established to calculate the effective height of each antenna over $Z_{a,b}$ [8$_6$].

C. A_{ref} Continuous function calculation

- *Diffraction zone*

Figure 3 shows the reference attenuation A_{ref} as a continuous function from Tx to Rx, divided in zones of different functions. In each zone there is at least two points to define an interpolation line.

As stated in reference [9], if a link includes the three main zones *(FSL is part of LOS),* a total of 7 points are required. Figure 5 shows those seven points for a link over a hypothetical reference profile.

- *Two points on LOS zone (d_0, d_1)*
- *Two points in diffraction zone (d_3, d_4)*
- *Two points on scatter zone (d_5, d_6)*
- *One transition point between LOS and diffraction (d_2)*
- *A transition point between diffraction and scatter (d_x)*

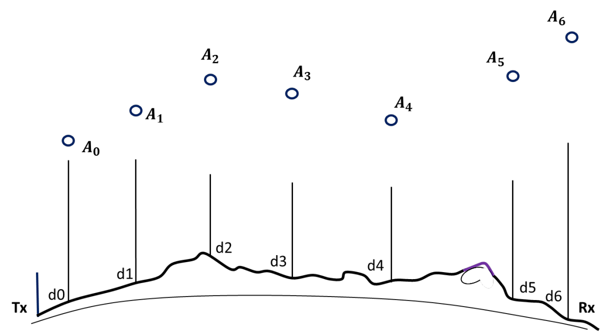

Fig. 5 The 7 points of a profile [9].

D. Diffraction range coefficients [7]

Points d_3 and d_4 are defined with the equations in [7$_{4.2}$] and [7$_{4.6}$] references. The attenuation coefficients A_3 and A_4 are calculated with Fresnel-Kirchoff algorithms for knife edge and Vogler's for smooth round earth A_r. [8$_9$] and [8$_{14}$]. The diffraction attenuation A_{diff} is the weighted sum of *both*, [8$_{4.11}$].

Those attenuations originate a straight-line with a slope m_d and A_{ed} intersection with the origin of the distances. [7$_{4.7,4.8}$], which is a diffraction value extrapolated to distance zero.

E. Coefficients for LOS range [7]

- *LOS zone*

The LOS range is defined by a combination of a 2-Ray model and an extended attenuation from the diffraction zone. The program starts by setting a tentative point d_2 [7$_{4.26,4.27}$] which will also be the interception of the A_{diff} line with A_{LOS} curve which shall also pass through d_0 and d_1 points.

K_1 and K_2 coefficients are calculated by [8$_{15 \text{ to } 19}$] sub routines and [8$_{15 \text{ t0 } 19}$] algorithms, by means of iterations.

Those subroutines also calculate the 2_Ray attenuation A_t completing both contributions: diffraction and 2-Ray reflection.

F. Scatter range Coefficients [7]

- *Scatter Zone*

The ITM defines points d_5 and d_6 to trace the scatter's attenuation straight-line and the corresponding attenuations A_5 and A_6 [7].

That originates a straight-line representing the reference attenuation and the intercept of A_{scat} with A_{diff} which defines point d_x where the reference attenuations are equal, as shown in Figure 6.

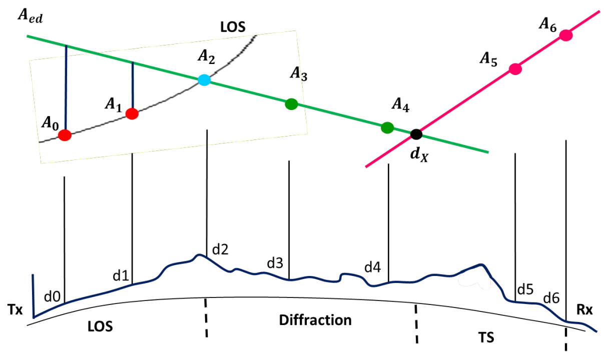

Fig. 6. The 4 zones of ITM [9].

G. Irregular terrain factor Δh in ITM

The *Δh* irregularity factor, as well the names Longley-Rice are practically the trademark names of ITM. The calculation of *Δh* parameter starts with the same algorithms used in the effective heights, Figure 4, calculating the regression line (tendency line-least squares) of terrain elevations, with the exception that for *Δh* the elevations are considered above sea level not corrected by effective earth curvature [10].

Then *Δh* is calculated by the positive and negative differences of the elevations referred to the tendency line, classified in deciles and then discarding the 1st and 10th, so *Δh* is the difference between 2nd and 9th deciles, as shown in Figure 7.

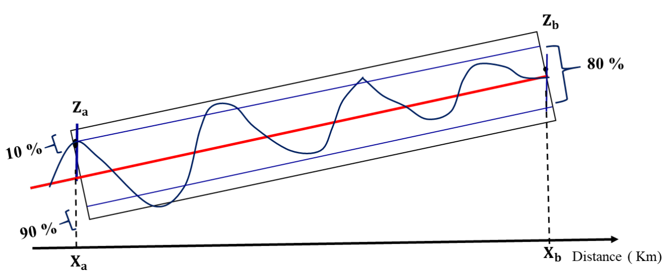

Fig. 7. *Δh* Structure [10].

The definition of *Δh* is different for the Point to Area (zone) mode than Point to Point. On Point to Point mode, *Δh* is calculated along the reflected ray F1 interception with the reflection plane, whereas in the Point to Area is calculated as global parameter of the zone, by resorting to iso *Δh* curves-if available-or even by the estimation of an experienced engineer.

H. Variabilities

Usually propagation prediction models consider the variability of the signal as a two-dimensional mode: Time and Locations defined as the probability of a signal, on a random location, to be over a specific level by a percentage of time. But ITM is also based on the statistic concept "measurement of the probability".

Those variabilities are not referred to fast changes of signal levels, usually produced by multipath propagation analyzed by channel models.

Reliability and confidence

Reliability and confidence are expressed in a three-dimensions model: Time, Location and Situation, in probability percentages.

Time and Locations are related to reliability. "Situations" is an overall confidence parameter reflecting the relationships between reliability parameters and different modes of operation: Spot, Accidental *(individual),* Mobile and Broadcasting. Besides that, it also relates to the confidence and experience of the design engineer in relation to the parameters involved in the link calculations as well as installation aspects. It is also the proper factor to "calibrate" the predictions in a specific area where statistics or field surveys, previously performed on similar projects.

The location variabilities are valid only in situations where there is not precise elevation and/or clutter data. ITM is very clear on the subject: if precise elevation data is available, location percentage is 50%. Same criterion is adopted by ITU Recommendations related to propagation variabilities [11].

IV. SIMULATION

The objective of this simulation stage consists on the analysis of each path profile and the associated radio propagation mode, specifically the E dBµV/m field strength calculated with Radio Mobile and its comparison with real field strength measurements of a survey performed following the protocols established by ITU in the Handbook-reference [11,12].

A. Simulation on Radio Mobile

To compare link measurements with ITM predictions, the V11.6.5 of Radio Mobile developed by Roger Coudé (Canadá) was implemented for the simulation, with SRTM1 *(Shuttle Radar Topography Mission)* as a source of Digital Terrain Elevation Data (DTED) [1,13]. To take advantage of the 1 arcsecond granularity of SRTM1, the required map was implemented with pixels matching DTED elevations density. Per default Radio Mobile calculates one record per pixel, therefore will be a complete set of data (Elevation, Fresnel clearance, Free Space, etc.) for each pixel along the path, which can be exported to an Excel for further data analysis.

The links have a common transmitter: TXCH24 (DTV) (Ch24) with the center frequency of 533 MHz, P_{tx} 14.850 KW, and a down tilted omni antenna, max. gain 13,21 dBd (15,36 dBi). Total Tx cable loss and filters are 1,5 dB. The receiver antenna used in the measurements survey is a wideband BicoLog dipole in the range 30 to 1.000 MHz, G_{ant} = 1dBi [14].

Figure 8 show the radiation patterns of the Tx antenna. In addition to the normal data required for the simulations of a regular link, TV broadcasting requires special omnidirectional antennas with a vertical down tilt all around the 360° of horizontal coverage. That data has been obtained from the antenna manufacturers and the proprietary antenna pattern files had to be converted to the *.ant format used by Radio Mobile [15].

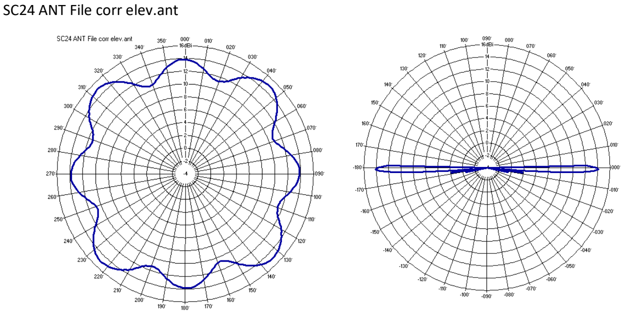

Fig. 8. Tx antenna horizontal /vertical radiation patterns.

Figure 9 map shows the locations of the Tx antenna and the test receiver, at nominal 5, 10 and 15 km where the measurements were performed with a 10 m antenna height, under ITU protocols, [11,12] and the average FS recorded.

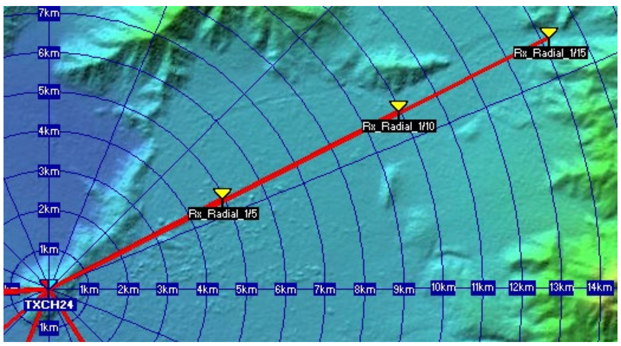

Fig. 9. Map showing transmitter /receivers locations.

Then, the calculated field strengths (E dBμV/m) will be compared with the measurements.

Because of the locations on the area, each link has a different azimuth and elevation for the beam from the Tx antenna.

Therefore, the effective antenna gain will be different for each link. RM program calculates the effective gain for each link as shown in Figure 10.

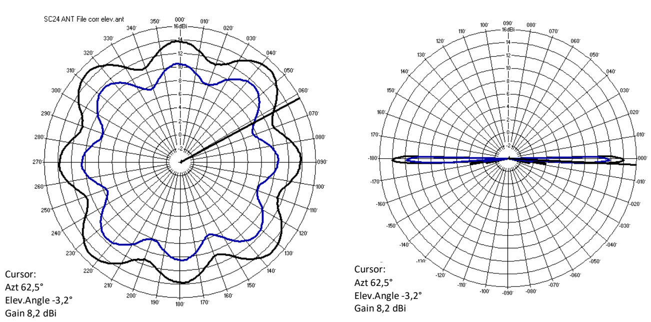

Fig. 10. Tx radiation patterns with azimuth/elevation corrections Radial 1/5.

Same process is performed for the other 2 radials as seen in Table III.

TABLE III
EFFECTIVE ANTENNA GAIN (Tx) FOR EACH LINK

Receiver	Antenna effective gain (dBi) Tx	Antenna effective gain (dBd) Tx
Rx_Radial_1/5	7.8	5.7
Rx_Radial_1/10	11.7	9.5
Rx_Radial_1/15	11.5	9.3

B. Profiles

Figure 11 shows the drawing of the path profile for 5 km link Exported from the RMpath feature of the Radio link panel. The 5 km link shows a minimum clearance of 2.1F1, a 2-Ray obstruction attenuation of -0.9 dB (gain) and a calculated field strength of 103.3 dBμV/m.

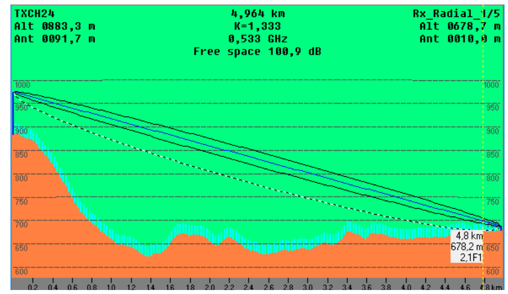

Fig. 11. First measurement point, Rx_Radial_1/5.

Same procedure for the next two links (nominal 10 and 15 km). The main parameters are shown in Tables V and VI.

The Radio link panel of Radio Mobile gives valuable information about the algorithms applied by the program to calculate $A_{ref.}$. On top of the link profile, there is a line of dB attenuations which form part of A_{ref}: Obstruction, Urban, Forest and Situations and is shown in Figure 12.

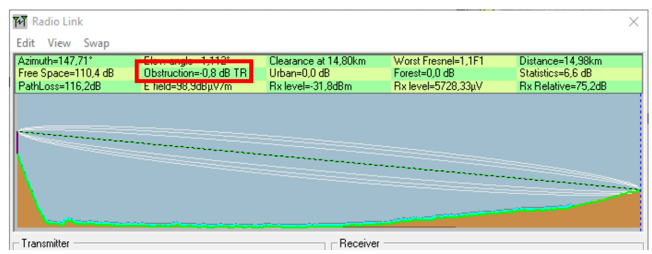

Fig. 12: Location of obstruction label.

- Urban: attenuation along the path when the beam is obstructed partially or totally by constructions.
- Forest: same but produced by Vegetation.
- Situations: contribution discussed in "Variabilities".
- Obstruction: Is the attenuation produced by LOS, Diffraction and Scatter models. By means of a "label" next to the obstruction parameter.

Radio Mobile informs the user on the model being used to calculate those attenuations. In case of RM 2-Ray model, the reflection coefficient of the reflected ray is calculated from terrain roughness not accounting for urban or forest attenuation of reflected ray. On Table IV, labels and descriptions are shown.

TABLE IV
LABELS ASSOCIATED TO OBSTRUCTIONS

Symbol	Description
Obstruction TR	Obstruction 2-Ray model
Obstruction TRI	Obstruction 2-Ray interference model
Obstruction ITM	Obstruction ITM model.
Obstruction Mix	Transition 2-Ray /ITM.

It should be said at this point, that RM since V 10.0.1[13], does not follow the LOS model of ITM defined by points d_0, d_1 *and* d_2. Instead it implements a classical 2-Ray model.

The label TR is very important for a link analysis evaluation of the contribution of the 2-Ray.

Table V shows a summary of the propagation calculations, as provided by Radio Mobile for each measurement point.

TABLE V
RADIO MOBILE PROPAGATION CALCULATIONS

Measure ment point	Prop. Mode.	Minimum clearance	Att Obstr. (dB)	Urban. Loss (dB)	Forest. Loss (dB)	Statistics . Loss (dB)
Rx_1/5	LOS	2.1F1	-1.9/TR	1	0	6.6
Rx_1/10	LOS	1.4F1	0.9/TR	0	0	6.6
Rx_1/15	LOS	0.2F1	4.2/ TR	0	1	6.5

Table VI shows predicted field strength values for each reception point.

TABLE VI
FIELD STRENGTH FOR EACH LOCATION

No.	Measurement point	Measured FS E(dBµV/m)	Simulation Radio Mobile E (dBµV/m)	ITU-R P.1546 E (dBµV/m)
1	Rx_1/5	88.60	103.20	103.43
2	Rx_1/10	73.08	99.30	97.01
3	Rx_1/15	59.05	91.70	77.76

Table VI evidences a substantial difference between predictions and measurements, which exceeds an expected 10 dB average standard deviation error for path loss models [15]. Links 1/14.4 dB; 2/29.2 dB; 3/32.7 dB. To check this on ITM/RM model, a prediction with ITU-R P.1546-4 was conducted. Per table VI, RM and P.1546 nearly match each other the received values. On link 3, RM is far out from the measurement and P.1546 is closer, but still out of the error's tolerance.

For links 1 and 2, part of RM differences can be explained by the fact that it does not consider clutter to calculate the 2-Ray loss (gain), but only terrain roughness from DTED. Also, RM's urban and vegetations losses are based on very imprecise land coverage data. Also, since 2009 RM abandoned the average LOS model replacing it by a classical 2-ray, which is more precise but, in absence of precise clutter data may produce received levels swing from -30 to +6dB with just 1λ variation on antenna height.

But those losses are not involved in P.1546 calculations. Being a model based on empirical curves, it´s more difficult to explain such a gap from measurements.

In case of Link 3 the situation is different. It´s a LOS with only 0,2F1 clearance, on the boundary between LOS and diffraction. An inspection with Google Earth 3D shows the presence of high buildings and vegetation close to the receiver which are not taken in account by the clutter map.

Presently, as described on Conclusions the authors are working on the subject with new tools intended to reduce the errors to an acceptable level.

V. CONCLUSION

The most used propagation model: ITM, was deeply analyzed and applied to the prediction by the Radio Mobile Freeware. The analysis included a description of the Reference Attenuation and the algorithms of the sub routines used by the SW for the four zones involved in the simulation of a link or a coverage radial: FSL, LOS, Diffraction and Scatter.

The required system parameters for the simulation of three measured links part of a DTV radial were loaded in the program, including: Network parameters, transmitter and receiver specs, antenna patterns, DTED for map generation and variabilities. The reception points were inspected with the resources of Google Earth Pro–3D and Street view, as well as the deployment of the beam over the Tx–Rx path. This to evaluate eventual terrain features not detected by DTED.

The comparison of measured and predicted Field Strengths showed unexpected differences that exceed what is usually accepted for the complex phenomena involved in these types of environments. The calculations were checked with the link data exported from RM to a *.txt file and then to Excel, not finding, with the present available tools the source of discrepancies.

A future work is under consideration to expand the analysis up to 24 locations in Santiago, on Ch 24 and Ch 33, and 22 in Valparaíso on Ch 33; with different antenna heights making a total of 140 links involving TR, MIX and ITM models, and distances up to 53 km. That network has already been surveyed with the same ITU protocols. Furthermore, the simulations are planned to be also performed with ITU P.1546-5 empirical model if available. Depending on the outcome of new simulations, a few representative measurements may be repeated with high directivity antennas to discard multipath.

REFERENCES

[1] H. Kaschel, S. Cordero, and E. Costoya, Member IEEE "Modeling and Simulation of point to area prediction on Digital TV, extensible to other technologies and its validation with actual field records". IEEE ICA/ACCA, Curicó, Chile, 2016.

[2] A.G. LONGLEY P. L. RICE ESSA TECHNICAL REPORT ERL 79-ITS 67, Prediction of Tropospheric Radio Transmission Loss Over Irregular Terrain, A Computer Method, 1968.

[3] I. Joo y Ch. Sin. "GNSS Jamming Propagation Prediction Simulator Based on ITU-R P.1546 Model "16th International Conference on Control, Automation and Systems (ICCAS), Korea, octubre, 2016.

[4] NTIA, National Telecommunications and Information Administration https://www.ntia.doc.gov/home

[5] P.L. Rice, A.G. Longley, K.A. Norton, and A. P. Barsis. "Transmission loss predictions for tropospheric communications circuits", Technical Note 101, U.S (NTIA-ITS), 1967.

[6] G. A. Hufford, A. G. Longley and W. A. Kissick, "A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode". US Department of Commerce, NTIA Report 82-100, pp. 6-18, April, 1982.

[7] G. Hufford, The its Irregular Terrain Model, version 1.2.2, itm.alg.pdf Agosto, 2002. https://www.its.bldrdoc.gov/resources/radio-propagation-software/itm/itm.aspx

[8] G. A. Hufford. The its Irregular Terrain Model, version 1.2.2, itm.pfd National Telecommunications and Information Administration Institute for Telecommunication Sciences 325 Broadway Boulder, 3328, U.S.A.

[9] Shumate, Givens & Bell. "The Irregular Terrain Model (ITM) Averaging System ". IEEE Broadcast Technology Society Newsletter. Volume 16, Number 2, pp. 19-21, Number 3, pp. 22-23, Number 3, pp. 22-23, Number 2, pp. 26-27, Number 1, pp. 23-25, 2008.

[10] S. Shumate, Givens & Bell. "Longley-Rice's Faulty Subroutines, Part Part 1: Z1SQ1, 2: dlthx". IEEE Broadcast Technology Society Newsletter. Volumen 16, Number 2, pp. 16-17, pp. 26-27, 2009.

[11] Comprobación Técnica del Espectro, Radio communication Bureau, Geneva 20, Switzerland, pp. 219-220, 2011.

[12] E. Costoya A. "Informe Demostración de mediciones de intensidad campo de televisión digital" Colegio de Ingenieros de Chile A.G., octubre, 2013.

[13] Radio Mobile, Freeware by VE2DBE, http://www.ve2dbe.com/english1.html, julio, 2018.

[14] I. Brown, Radio Mobile Hanbook y Radio Mobile Companion. Traducción al español: Ing. Eduardo Costoya, Colegio de Ingenieros de Chile. Santiago de Chile, 2015.

[15] C. Phillips, D. Sicker, D. Grunwald. Bounding the practical Error of Path Loss models. University of Colorado: Boulder. Co. March 2012.