Longley-Rice model precision in case of multiple diffracting obstacles

Pavlos I. Lazaridis [(1)], Stylianos Kasampalis [(2)], Zaharias D. Zaharis [(3)], John P. Cosmas [(2)], Lidija Paunovska[(4)], and Ian A. Glover[(1)]
(1) University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK.
(2) Brunel University, London, UB8 3PH, UK.
(3) Aristotle University of Thessaloniki, GR-54124 Thessaloniki, Greece.
(4) Agency for Electronic Communications, Skopje 1000, FYR of Macedonia.

***Abstract*— Radio propagation models are very important in wireless communications. If obstacles exist within the Fresnel zones, knife-edge and round obstacle diffraction theory is used to predict path loss. A standard approach for predicting multiple knife-edge diffraction is to use simple geometrical constructions within the path geometry and thus to calculate an approximate total diffraction loss. In this paper, comparisons are presented between accurate field-strength measurements and simulation results derived from, the ITM (Irregular Terrain Model) coverage prediction, also known as NTIA-ITS Longley-Rice model, in conjunction with the 3-arc-second SRTM (Satellite Radar Topography Mission) terrain data. The Longley-Rice model is up this day the preferred model of the FCC (Federal Communications Commission) in the US for FM-TV coverage calculations. Comparisons are extended to the single knife-edge model and the multiple knife-edge approaches developed by Epstein-Peterson, Deygout, and Giovaneli. Inaccuracies and shortcomings of the Longley-Rice model in several multiple obstacle knife-edge type propagation profiles are indicated in the VHF-TV band frequencies.**

***Keywords*—Fresnel, ITM, Longley-Rice, NTIA-ITS, SRTM, Knife-Edge, Epstein-Peterson, Deygout, Giovaneli, VHF-TV.**

I. INTRODUCTION

Radiowave propagation is affected by a variety of factors that attenuate the received signal. Radio paths are frequently obstructed by mountains, buildings, trees, etc. Reflections, scattering and diffraction phenomena, can take place during electromagnetic wave propagation. Accurate prediction of the received signal is an important factor in designing broadcasting systems. In electromagnetic wave propagation theory, there are basically three types of path loss propagation models: Deterministic path loss models which use physical theories and require detailed environment information (terrain elevation maps) and produce the most accurate results. Empirical path loss models that are based on a great deal of measurement data are very simple but accurate enough in most cases. Semi-empirical or semi-deterministic models which combine the above two approaches.

This study compares coverage prediction results for VHF TV broadcasting in the region of Northern Greece and the neighboring FYR of Macedonia, with accurate field measurements taken by portable measurement equipment. A Rohde & Schwarz FSH-3 portable spectrum analyzer with tracking generator (100 kHz – 3 GHz), and a ± 0.7dB accuracy (factory calibrated), was used in our measurements. Also, two high-precision calibrated biconical antennas: Schwarzbeck SBA 9113 and BBVU 9135, with ± 1.0dB accuracy (factory calibrated), a precision log-periodic USLP9143 with approximately 6-7 dBi gain, a commercial Iskra P20 UHF-TV band log-periodic with a 6-7 dBi gain, and a low-loss, 1.8m long, cable Suhner GX-07272-D with N-type connectors were used.

Radio Mobile [1-2], which is based on the Longley-Rice model [3], is used for simulations in this paper. Radio Mobile uses the 3-arc-second Satellite Radar Terrain Mission SRTM maps [4], to create elevation profiles. In the Longley-Rice model double knife-edge and smooth Earth diffraction loss are calculated and combined with the use of an empirical weighting factor to produce the total attenuation for highly irregular terrain [5]. It is important to note that the original Longley-Rice model used in the Radio Mobile program has undergone some minor modifications in order to improve its accuracy and to avoid discontinuities of the predicted field-strength.

Single knife-edge diffraction and the calculation of path loss over a single sharp obstacle are based on the Fresnel-Kirchhoff's theory of optics. The dimensionless parameter υ is used to express the diffraction loss:

$$\upsilon = h\left[\frac{2}{\lambda}\left(\frac{1}{d_1}+\frac{1}{d_2}\right)\right]^{\frac{1}{2}} \quad (1)$$

or

$$\upsilon = \theta\left[\frac{2}{\lambda\left(\frac{1}{d_1}+\frac{1}{d_2}\right)}\right]^{\frac{1}{2}} \quad (2)$$

where :

d_1 (m): distance between transmitter and Knife-Edge
d_2 (m): distance between Knife-Edge and receiver.
λ (m): the wavelength of the electromagnetic wave.
h (m): effective height.
θ : angle (radians).
T : Transmitter.
R : Receiver.

The above parameters are shown in Fig. 1 and Fig. 2.

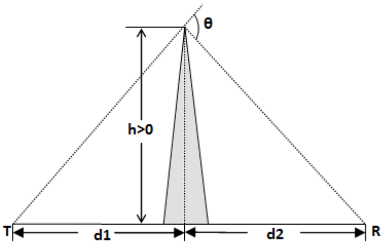

Fig. 1. Single Knife-Edge diffraction. Positive height h.

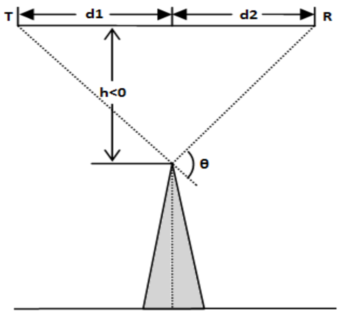

Fig. 2. Single Knife-Edge diffraction. Negative height h.

The following approximations must hold for this theory to be valid

$$d_1, d_2 \gg h \quad and \quad d_1 d_2 \gg \lambda$$

The received field strength of a knife-edge diffracted wave is given by the well known complex Fresnel integral.

$$\frac{E}{E_O} = \frac{(1+j)}{2} \int_{v_0}^{\infty} e^{-j\left(\frac{\pi}{2}\right)v^2} dv \qquad (3)$$

Where E_o is the free space field strength. Then the diffraction attenuation is calculated by the following equation.

$$G_d(dB) = 20log|F(v)|$$

An approximation for the above formula is, [6]:

$$G_d(dB) = 0 \qquad v \le -1$$
$$G_d(dB) = 20log(0.5 - 0.62v) \qquad -1 < v \le 0$$
$$G_d(dB) = 20log\left(0.5e^{(-0.95v)}\right) \qquad 0 < v \le 1$$
$$G_d(dB) = 20log\left(0.4 - \sqrt{0.1184 - (0.38 - 0.1v)^2}\right) \qquad 1 < v \le 2.4$$
$$G_d(dB) = 20log\left(\frac{0.225}{v}\right) \qquad v > 2.4$$

Double knife-edge, or in general, multiple knife-edge diffraction calculation methods are heuristic and approximate, and rely on simple geometrical constructions. Thus, Bullington's, [7], method replaces the whole profile by an equivalent single knife-edge and practically gives far too optimistic results. Deygout's, [8-9], model calculates the knife edge diffraction of the major or dominant obstacle as if the second obstacle did not exist and the diffraction of the secondary obstacle referenced to its horizons and adds the two knife edge losses to produce the total loss. It reduces to single-knife edge diffraction when there are no secondary obstacles. In the Epstein-Peterson, [10], model the link is divided into two 'hops', each involving just one diffracting edge. The total diffraction loss is calculated by adding the losses of each diffracting edge on its 'hop'. Giovaneli's, [11], method is a modification of Deygout's method and it can also easily be extended to multiple edges. The diffraction loss for more than two obstacles can be calculated using Vogler's, [12], method which is an exact mathematical but complicated and calculation intensive method.

Field strength is calculated from the formula below:

$E(dB\mu V/m) = P(dBm) - PL_{TOTAL}(dB) + 20log_{10}f_{MHz} - G(dBi) + 77.2$

And, Free Space Loss is calculated from the well known formula:

$PL_{FREE\ SPACE} = 32.44 + 20log_{10}\ f_{MHz} + 20log_{10}\ (d_{km})$.

II. Measurements and Comparisons

During the propagation of electromagnetic waves around the curved surface of the earth and over irregular terrain with obstacles, the phenomenon of diffraction takes place and the received signal can be severely attenuated. It is important to determine the attenuation of the received signal over such obstructions and calculate the field strength at the receiving point.

Therefore, in order to measure the signal strength of VHF TV transmissions, a measurement campaign was carried out in Northern Greece and the FYR of Macedonia, [13-18].

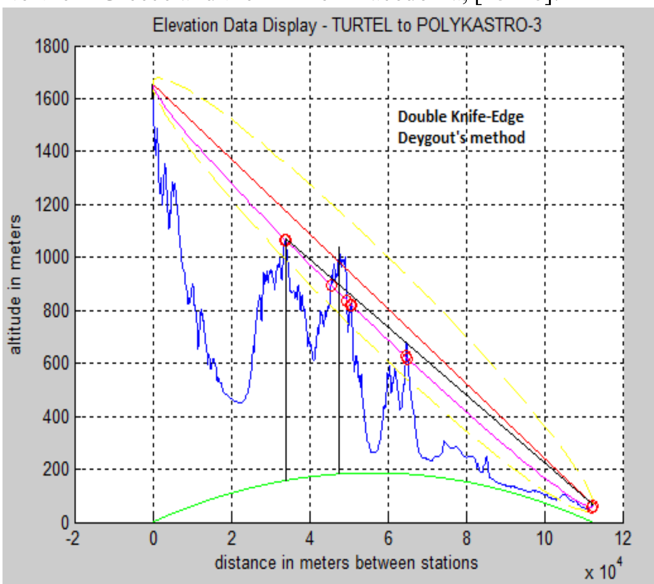

Fig. 3. Double knife-edge diffraction calculated by Deygout's method.

For simulations we used the Longley-Rice model (ITM) incorporated into the Radio Mobile program and SRTM terrain maps. We also used the Epstein-Peterson, Deygout, and Giovaneli methods. A program, which calculates diffraction losses from the above mentioned methods and uses the SRTM maps, was coded in Matlab. If there are no intersection points between the 0.6F zone and obstacles, it calculates Free Space

Loss, if there is one obstacle it calculates diffraction loss using single knife-edge theory and if there are two obstacles its computes diffraction losses using Epstein-Peterson, Deygout, and Giovaneli methods. Ground reflections were ignored in our knife-edge simulations.

Fig. 3 shows double knife-edge diffraction calculated by Deygout's method. A point-to-point analysis took place for analog TV Turtel, FYR of Macedonia, channel VHF 11, (f = 217.25 MHz & P = 8kW or 39dBW, net antenna gain = 8.0 dBd, ERP = 47 dBW or 50 kW, antenna height Ht = 45m, receiver antenna height Hr = 2.5m) and is shown in Table I.

TABLE I. Measurement Points and Results for VHF TV.

No.	Measurements Points Turtel ATV VHF Ch11- 217.25MHz LAT: 41.80293 LONG: 22.42255, Altitude 1590m	LAT LONG	E(dBμV/m)				
			FSH-3 Measurements	ITM – Radio Mobile 2-rays	Double Knife-Edge		
					Deygout	Epstein-Peterson	Giovaneli
1	EKO-POLYKASTRO (94,1Km/169.8degs)	40.969260 22.622050	59.8	63.9	55.5	55.7	62.5
2	POLYKASTRO-2 (101Km/169degs)	40.908330 22.651870	62.0	72.2	66.0	68.9	68.9
3	AG.ATHANASIOS-4 (109Km/169.1degs)	40.838070 22.668640	62.3	74.9	67.8	68.9	68.9
4	POLYKASTRO-3 (112Km/169.2degs)	40.809070 22.673190	73.3	77.2	66.6	69.7	66.8
5	POLYKASTRO (117Km/169degs)	40.795220 22.681800	76.0	79.9	77.0	75.8	76.6
6	THESSALONIKI (139Km/161.2degs)	40.615820 22.955730	54.5	43.1	54.5	56.5	56.5
7	AG.ATHANASIOS-6 (130Km/169degs)	40.652070 22.719100	57.4	64.2	68.4	68.9	60.3
8	NEGOTINO (44.6Km/215.6degs)	41.47592 22.10990	70.8	78.3	78.3	69.7	74.8
9	BOSKIJA (54.8Km/174.3degs)	41.31216 22.48819	65.4	57.8	59.4	67.3	58.7
10	VELES (51Km/258.3degs)	41.70822 21.82033	70.6	67.7	75.7	71.4	70.3
11	PETROVEC (70.6Km/283.9degs)	41.95314 21.59469	55.4	59.6	64.0	61.7	59.2
12	OKTA (64.6Km/280.3degs)	41.90413 21.65462	55.5	57.3	51.5	54.9	54.7
13	CRV VRV (58.4Km/275.4degs)	41.85039 21.72081	55.3	39.9	58.8	58.8	58.8

Differences between measurements (FSH-3) and simulations from various models with average error and standard deviation, are shown in Table II and Fig. 4. It is observed from Tables I and II and Fig. 4 that the Longley-Rice model can lead to large negative and positive differences from measured results (e.g. points 2, 3, 6, and 13 where the differences are larger than 10 dB). Generally speaking, diffraction attenuation is mostly overestimated by the Longley-Rice model and this can be easily seen at measurement points 6 and 13, where the three other models used in this study are very near to the measured result. Giovaneli's method has the best accuracy in the VHF TV case study with the lowest mean and standard deviations.

TABLE II. Differences, mean difference, and standard deviation between measurement and simulation results.

No.	Measurements Points Turtel ATV VHF Ch11- 217.25MHz LAT: 41.80293 LONG: 22.42255, Altitude 1590m	Differences (dB) between			
		FSH-3 & ITM	FSH-3 & Deygout	FSH-3 & Epstein – Peterson	FSH-3 & Giovaneli
1	EKO-POLYKASTRO (94,1Km/169.8degs)	-4.1	4.3	4.1	-2.7
2	POLYKASTRO-2 (101Km/169degs)	-10.2	-4.0	-6.9	-6.9
3	AG.ATHANASIOS-4 (109Km/169.1degs)	-12.6	-5.5	-6.6	-6.6
4	POLYKASTRO-3 (112Km/169.2degs)	-3.9	6.7	3.6	6.5
5	POLYKASTRO (117Km/169degs)	-3.9	-1.0	0.2	-0.6
6	THESSALONIKI (139Km/161.2degs)	11.4	0.0	-2.0	-2.0
7	AG.ATHANASIOS-6 (130Km/169degs)	-6.8	-11.0	-11.5	-2.9
8	NEGOTINO (44.6Km/215.6degs)	-7.5	-7.5	1.1	-4.0
9	BOSKIJA (54.8Km/174.3degs)	7.6	6.0	-1.9	6.7
10	VELES (51Km/258.3degs)	2.9	-4.8	-0.8	0.3
11	PETROVEC (70.6Km/283.9degs)	-4.2	-8.6	-6.3	-3.8
12	OKTA (64.6Km/280.3degs)	-1.9	3.9	0.5	0.7
13	CRV VRV (58.4Km/275.4degs)	15.4	-3.5	-3.5	-3.5
	Mean	-1.4	-1.9	-2.3	-1.4
	Standard Deviation	8.4	5.8	4.5	4.2

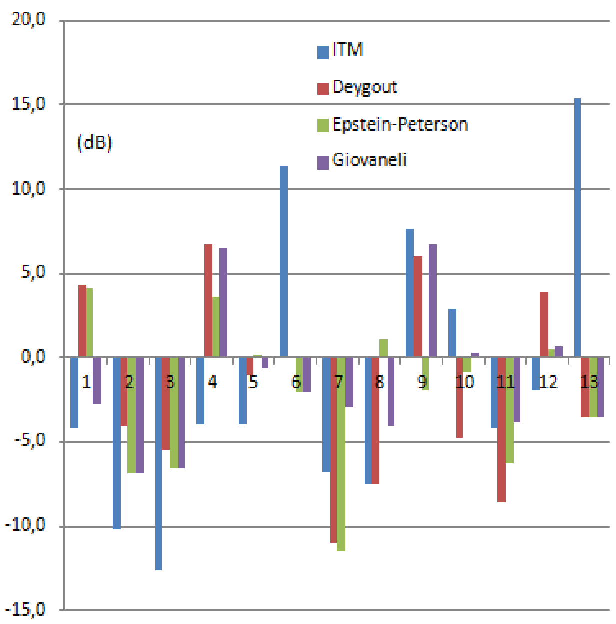

Fig. 4. Differences between measurements and simulations for VHF TV.

III. Conclusions

It is obvious that none of the above mentioned methods is accurate in all cases. The Longley-Rice model (ITM), that Radio Mobile used together with worldwide SRTM 3-arc-second data, incorporates single knife-edge and double knife-edge models, and produces satisfactory results in comparison to the measurement data, in most cases. However, the Longley-Rice model produces pessimistic results in regions with big obstacles and shadow areas, characteristic of mountainous terrain. Deygout, Epstein-Peterson and Giovaneli approaches are approximating multiple knife-edge diffraction using geometrical constructions. All these models produce satisfactory results, and they are classic, well established models, [19-20]. From our case study, it can be said that Deygout's method is as accurate as the Epstein-Peterson's method. Also, Giovaneli's method, which was presented as Deygout's improvement, actually gives somewhat improved results, at least in our VHF TV case study. A further improvement in diffracting loss calculation accuracy is expected from Vogler's rigorous method, [12].

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