

# Longley-Rice model prediction inaccuracies in the UHF and VHF TV bands in mountainous terrain

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**Abstract**— Coverage prediction is of prime importance for TV broadcasting. A classic model used for TV coverage prediction is the Longley-Rice ITM (Irregular Terrain Model). Other well-known multiple knife-edge diffraction models are the Epstein-Peterson, Deygout, and Giovaneli methods. In this paper, comparisons are presented between accurate field-strength measurements, taken by a Rohde & Schwarz FSH-3 portable spectrum analyzer using precision calibrated antennas and calculated results from the Longley-Rice model, and the multiple knife-edge models in conjunction with the 3-arc-second SRTM (Satellite Radar Topography Mission) terrain data. Calculations are limited to the main 2 knife-edges of the propagation path. The Longley-Rice model predicts received field strength accurately in most cases even in mountainous terrain with multiple diffracting obstacles in the VHF and UHF TV Bands. However, in some long distance fringe reception areas field-strength is underestimated by the Longley-Rice model, while it is accurately calculated by the multiple knife-edge diffraction models.

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

## I. INTRODUCTION

The necessity of accurate point-to-area prediction tools arises from the huge demand in designing broadcasting systems for digital TV and cellular communications. Up to now, a considerable number of coverage prediction models for radio coverage have been developed. In electromagnetic wave propagation theory three are the main types of propagation models: empirical models that are based on a big quantity of measurement data are very simple but not very accurate.

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Semi-deterministic models that are based on measurement data and electromagnetic theory of propagation, which are more accurate. And, deterministic models based on theoretical physics, like diffraction theory and Fresnel theory, require a large amount of geometrical data about the propagation terrain profile but are the most accurate, and generally preferred.

The purpose of this paper is to compare coverage prediction results for VHF and UHF TV broadcasting in the region of Thessaloniki – Greece, with accurate field measurements taken by our measurement equipment. Longley-Rice simulations in this paper are using Radio Mobile (it is presented as a Radio Propagation and Virtual Mapping Freeware), [1-2], that is a program based on the Irregular Terrain Model (known as the Longley-Rice Model), [3], and uses the 3-arc-second SRTM maps, [4]. The classical approach for single knife-edge diffraction and the calculation of path loss over a single sharp obstacle is based on the Fresnel-Kirchhoff's theory of optics. The dimensionless parameter  $v$  is used to express the diffraction loss:

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

where:  $h$  is the height of the obstacle,  $d_1$ ,  $d_2$ , are expressed in meters (m) and  $\lambda$  is the wavelength of the electromagnetic wave, in meters. The received field strength of a knife-edge diffracted wave is given by the well known complex Fresnel integral:

$$E = \frac{E_0}{2} (1 + j) \int_{v_0}^{\infty} e^{-j(\frac{\pi}{2})v^2} dv \quad (2)$$

The diffraction attenuation is given by the following equation:

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

An approximate solution for the above equation provided by Lee is:

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

Bullington, [5], proposed a simplified method that replaces the whole profile by a single knife-edge. In practice, this method gives far too optimistic results. Epstein and Peterson [6] proposed a method that estimates the diffraction loss appropriately at each obstacle or knife-edge and then adds the losses. Also, Deygout, [7-8], proposed another more accurate geometrical construction in order to take into account multiple diffracting knife-edges. Giovanelli [9] method is a modification of Deygout method that could result in a better accuracy in some cases. This method can be easily extended to multiple knife-edges. A rigorously exact diffraction loss for more than two knife-edges can be calculated using Vogler's method, [10]. In general, as a function of Path Loss (PL), field strength is calculated from the formula below:

$$E(\text{dB}\mu\text{V/m}) = \text{ERP}(\text{dBW}) - \text{PL}(\text{dB}) + 20\log_{10}f_{\text{MHz}} + 109.35,$$

Free Space Loss is calculated from the well known formula:

$$\text{PL}_{\text{FREE SPACE}} = 32.44 + 20\log_{10}f_{\text{MHz}} + 20\log_{10}(d_{\text{km}}), \text{ and total Path Loss, } \text{PL}(\text{dB}) = \text{PL}_{\text{FREE SPACE}} + \text{PL}_{\text{DIFFRACTION}}.$$

## II. MEASUREMENTS AND COMPARISONS

The propagation of electromagnetic waves over irregular terrain with obstacles includes diffraction attenuation of the received signal. It is important to determine the diffraction losses over such obstructions. Therefore, in order to measure the signal strength of UHF DVB-T and VHF ATV transmissions, a measurement campaign was carried out around the city of Thessaloniki [11-17], located in the north of Greece and the neighboring FYR of Macedonia. A Rohde & Schwarz FSH-3 portable spectrum analyzer with tracking generator (100 kHz – 3 GHz), and a  $\pm 0.7\text{dB}$  accuracy (factory calibrated), was used in our measurements. Also two high-precision biconical antennas: Schwarzbeck SBA 9113 and Schwarzbeck BBVU 9135, with  $\pm 1.0\text{dB}$  accuracy (factory calibrated), a precision log-periodic Schwarzbeck 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, 1.8meters long, cable Suhner GX-07272-D 50 Ohm, with N-type connectors were used.

For simulations the Longley-Rice model (ITM) incorporated into the Radio Mobile program was used. The Epstein-Peterson, Deygout, and Giovanelli methods coded in Matlab were also used for comparison purposes. Parameters  $h$ ,  $h_1$ ,  $h_2$  in some cases were negative because the Line of Sight (LOS) line did not intersect with the obstacles, which means that the line of sight was clear, but the 0.6 of Fresnel zones (0.6F) intersected with the obstacles. Ground reflections were ignored in our knife-edge calculations. Separation distances between obstacles were much larger compared to wavelength. A program, which calculates diffraction losses from the above mentioned multiple diffraction methods and uses the SRTM terrain 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 it computes diffraction losses using Epstein-Peterson, Deygout, and Giovanelli approach. Fig. 1 shows double knife-edge

diffraction calculated by Deygout method. Details that show the knife-edges and the intersection points between the 0.6F Fresnel zone and obstacles are shown in Fig. 2.

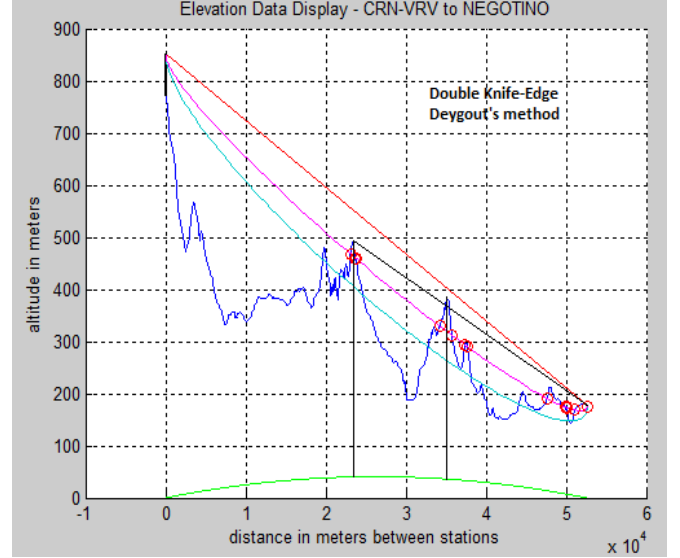


Fig.1. Double knife-edge diffraction calculated by Deygout method.

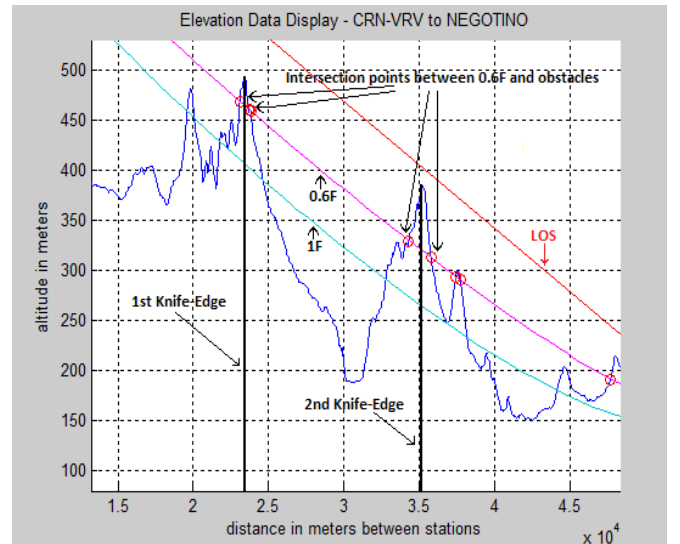


Fig. 2. Details of diffracting obstacles. Double knife-edges and the 0.6F Fresnel zone line are shown.

A point-to-point analysis for Greek Public DVB-T, channel UHF 23 ( $f = 490\text{MHz}$ ,  $P = 1.6\text{ kW} = 32\text{dBW}$  and net antenna gain = 10 dBd, i.e. ERP = 42 dBW or 16 kW, transmitter antenna height  $H_t = 70\text{m}$ ) and for DVB-T for Boom TV Boskija, FYR of Macedonia, channel UHF 21 (474 MHz) & UHF 40 (626 MHz) ( $P = 800\text{W} = 29\text{ dBW}$  and net antenna gain = 10 dBd, i.e. ERP = 39 dBW or 8 kW, transmitter antenna height  $H_t = 40\text{m}$ ) is shown in Table I. The presented measurement points are selected to contain diffracting obstacles in the propagation path profile. Differences between measurements (FSH-3) and simulations from Irregular Terrain Model (Longley-Rice model), and simulations from the Deygout, Epstein-Peterson, and Giovanelli models limited to 2 knife-edges, are shown in Table I.

TABLE I. Measurement Points and Measurements for UHF DVB-T.

| TRANSMITTER : Hortiatia Greek Public Ch23 (490 MHz).<br>LAT: 40.597648, LONG: 23.099793, altitude 870m, Ht = 70m.<br>P = 1.6 kW, Antenna Gain = 10 dBd, ERP = 16 kW (42 dBW). |                                       |                        |                            |                                     |                   |                      |           |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|------------------------|----------------------------|-------------------------------------|-------------------|----------------------|-----------|
| No.                                                                                                                                                                           | DVB-T<br>Measurements<br>Points       | LAT<br>LONG            | E(dBμV/m)                  |                                     |                   |                      |           |
|                                                                                                                                                                               |                                       |                        | FSH-3<br>Measure-<br>ments | Radio<br>Mobile<br>Longley-<br>Rice | Double Knife-Edge |                      |           |
|                                                                                                                                                                               |                                       |                        |                            |                                     | Deygout           | Epstein-<br>Peterson | Giovaneli |
| 1                                                                                                                                                                             | KILKIS*<br>(53.8km/333deg)            | 41.026849<br>22.805656 | 53.4                       | 50.6                                | 60.6              | 60.6                 | 60.6      |
| 2                                                                                                                                                                             | EVZONI<br>(68.8km/321deg)             | 41.081410<br>22.588160 | 71.9                       | 72.4                                | 73.8              | 71.9                 | 71.6      |
| 3                                                                                                                                                                             | DOIRANI<br>(70.7Km/293deg)            | 41.180127<br>22.764170 | 60.6                       | 59.7                                | 64.5              | 65.7                 | 61.5      |
| *Single knife-edge<br>Boom DVB-T Boskija Ch21(474 MHz) , LAT: 41.27108, LONG: 22.67142.<br>Altitude 710m, Ht = 40m, P = 800W, Antenna Gain = 10 dBd, ERP = 8 kW.              |                                       |                        |                            |                                     |                   |                      |           |
| 4                                                                                                                                                                             | POLYKASTRO3<br>(63Km/180deg)          | 40.809070<br>22.673190 | 67.5                       | 63.7                                | 67.7              | 67.8                 | 67.8      |
| Boom DVB-T Boskija Ch40 (626 MHz).                                                                                                                                            |                                       |                        |                            |                                     |                   |                      |           |
| 5                                                                                                                                                                             | POLYKASTRO3<br>(63Km/180deg)          | 40.809070<br>22.673190 | 65.1                       | 61.3                                | 67.5              | 67.4                 | 67.4      |
| 6                                                                                                                                                                             | EKO-<br>POLYKASTRO<br>(33.8Km/187deg) | 40.96926<br>22.62205   | 82.3                       | 84.5                                | 82.9              | 70.3                 | 79.8      |

TABLE II. Differences between measurements and simulations: UHF DVB-T.

| TRANSMITTER : Hortiatia Greek Public Ch23 (490 MHz).<br>LAT: 40.597648, LONG: 23.099793, altitude 870m, Ht = 70m.<br>P = 1.6 kW, Antenna Gain = 10 dBd, ERP = 16 kW (42 dBW). |                                                                                         |                          |                       |                                    |                         |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|--------------------------|-----------------------|------------------------------------|-------------------------|
| No.                                                                                                                                                                           | DVB-T<br>Measurements<br>Points<br>CH23 - 490MHz<br>LAT : 40.597648<br>LONG : 23.099793 | Differences (dB) between |                       |                                    |                         |
|                                                                                                                                                                               |                                                                                         | FSH-3<br>&<br>L-R        | FSH-3<br>&<br>Deygout | FSH-3<br>&<br>Epstein-<br>Peterson | FSH-3<br>&<br>Giovaneli |
| 1                                                                                                                                                                             | KILKIS*<br>(53.8km/333deg)                                                              | 2.8                      | -7.2                  | -7.2                               | -7.2                    |
| 2                                                                                                                                                                             | EVZONI<br>(68.8Km/321deg)                                                               | -0.5                     | -1.9                  | 0.0                                | 0.3                     |
| 3                                                                                                                                                                             | DOIRANI<br>(70.7Km/293deg)                                                              | 0.9                      | -3.9                  | -5.1                               | -0.9                    |
| Boom DVB-T Boskija Ch21 (474 MHz) , LAT: 41.27108, LONG: 22.67142.<br>Altitude 710m, Ht = 40m, P = 800W, Antenna Gain = 10dBd, ERP = 8 kW<br>(39 dBW)                         |                                                                                         |                          |                       |                                    |                         |
| 4                                                                                                                                                                             | POLYKASTRO-3<br>(63Km/180deg)                                                           | 3.8                      | -0.2                  | -0.3                               | -0.3                    |
| Boom DVB-T Boskija Ch40 (626 MHz).                                                                                                                                            |                                                                                         |                          |                       |                                    |                         |
| 5                                                                                                                                                                             | POLYKASTRO-3<br>(63Km/180deg)                                                           | 3.8                      | -2.4                  | -2.3                               | -2.3                    |
| 6                                                                                                                                                                             | EKO-POLYKASTRO<br>(33.8Km/187deg)                                                       | -2.2                     | -0.6                  | 12.0                               | 2.5                     |
| Average                                                                                                                                                                       |                                                                                         | 1.4                      | -2.7                  | -0.5                               | -1.3                    |
| Standard Deviation                                                                                                                                                            |                                                                                         | 2.5                      | 2.6                   | 6.7                                | 3.3                     |

From Tables I and II it is observed that both the Longley-Rice model and the classical multiple diffraction calculation models of Deygout, Epstein-Peterson, and Giovaneli are very accurate in predicting received field-strength in this case study in the UHF-TV Band, errors and standard deviations being small.

Another point-to-point analysis took place for analog TV Turtel, FYR of Macedonia, channel VHF 11, ( $f = 217.25$  MHz &  $P = 8$  kW or 39dBW, net antenna gain = 8.0 dBd, ERP = 47 dBW or 50 kW, antenna height  $H_t = 45$  m, receiver antenna height  $H_r = 2.5$  m) and is shown in Table III.

TABLE III. Measurement Points and Results for VHF TV Turtel.

| No. | Measurements Points<br>Turtel ATV<br>VHF Ch11- 217.25MHz<br>P = 8 kW (39 dBW)<br>Antenna Gain = 8 dBd<br>Ht = 45m<br>ERP = 50 kW (47 dBW)<br><br>LAT: 41.80293<br>LONG: 22.42255,<br>Altitude 1590m | LAT<br>LONG          | E(dBμV/m)                                             |                   |                  |      |           |
|-----|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|-------------------------------------------------------|-------------------|------------------|------|-----------|
|     |                                                                                                                                                                                                     |                      | FSH-3<br>Measurements<br>Longley-Rice<br>Radio-Mobile | Double Knife-Edge |                  |      | Giovaneli |
|     |                                                                                                                                                                                                     |                      |                                                       | Deygout           | Epstein-Peterson |      |           |
| 1   | VODNO 1051m<br>(87 Km, 282 degs)                                                                                                                                                                    | 40.83807<br>22.66864 | 86.9                                                  | 84.8              | 85.2             | 85.2 | 85.2      |
| 2   | EKO-POLYKASTRO<br>(94.1Km/170 degs)                                                                                                                                                                 | 40.96926<br>22.62205 | 59.8                                                  | 62.0              | 53.5             | 53.7 | 60.5      |
| 3   | POLYKASTRO-2<br>(101Km/169 degs)                                                                                                                                                                    | 40.90833<br>22.65187 | 62.0                                                  | 70.0              | 64.0             | 66.9 | 66.9      |
| 4   | AG.ATHANASIOS-4<br>(109Km/169.1deg)                                                                                                                                                                 | 40.83807<br>22.66864 | 62.3                                                  | 72.5              | 65.8             | 66.9 | 66.9      |
| 5   | POLYKASTRO-3<br>(112Km/169.2deg)                                                                                                                                                                    | 40.80907<br>22.67319 | 73.3                                                  | 74.4              | 64.6             | 67.7 | 64.8      |
| 6   | POLYKASTRO<br>(117Km/169deg)                                                                                                                                                                        | 40.79522<br>22.68180 | 76.0                                                  | 78.0              | 75.0             | 73.8 | 74.6      |
| 7   | THESSALONIKI<br>(139Km/161.2deg)                                                                                                                                                                    | 40.61582<br>22.95573 | 54.5                                                  | 41.1              | 52.5             | 54.5 | 54.5      |
| 8   | AG.ATHANASIOS-6<br>(130Km/169deg)                                                                                                                                                                   | 40.65207<br>22.71910 | 57.4                                                  | 62.7              | 66.4             | 66.9 | 58.3      |
| 9   | NEGOTINO<br>(44.6Km/215.6deg)                                                                                                                                                                       | 41.47592<br>22.10990 | 70.8                                                  | 76.5              | 76.3             | 67.7 | 72.8      |
| 10  | BOSKIA<br>(54.8Km/174.3deg)                                                                                                                                                                         | 41.31216<br>22.48819 | 65.4                                                  | 56.1              | 57.4             | 65.3 | 56.7      |
| 11  | VELES<br>(51Km/258.3deg)                                                                                                                                                                            | 41.70822<br>21.82033 | 70.6                                                  | 66.0              | 73.7             | 69.4 | 68.3      |
| 12  | PETROVEC<br>(70.6Km/283.9deg)                                                                                                                                                                       | 41.95314<br>21.59469 | 55.4                                                  | 58.0              | 62.0             | 59.7 | 57.2      |
| 13  | OKTA<br>(64.6Km/280.3deg)                                                                                                                                                                           | 41.90413<br>21.65462 | 55.5                                                  | 55.6              | 49.5             | 52.9 | 52.7      |
| 14  | CRV VRV<br>(58.4Km/275.4deg)                                                                                                                                                                        | 41.85039<br>21.72081 | 55.3                                                  | 38.2              | 56.8             | 56.8 | 56.8      |
| 15  | PROFITIS ELIAS<br>(140 Km, 158 degs)                                                                                                                                                                | 40.64032<br>23.04020 | 79.8                                                  | 75.3              | 75.1             | 75.1 | 75.1      |

Differences between measurements (FSH-3) and simulations from various models, with average error and standard deviation, are shown in Table IV. It is observed from Tables III and IV that the Longley-Rice model can lead to large negative and positive differences from measured results (e.g. points 4, 7, 10, and 14 where the differences are around 10 dB or larger). Generally speaking, diffraction attenuation is mostly overestimated by the Longley-Rice model and this can be easily seen at measurement points 7 and 14, where the three other models used in this study are very near to the measured result. Giovaneli method has the best accuracy in this VHF TV case study with the lowest standard deviation, followed closely by Epstein-Peterson. Longley-Rice in this case study has an almost double standard deviation than other methods.

TABLE IV. Differences, mean difference, and standard deviation between measurement and simulation results, Turtel VHF-ATV.

| No. | Measurements Points<br>Turtel ATV<br>VHF Ch11-<br>217.25MHz<br>LAT: 41.80293<br>LONG: 22.42255,<br>Altitude 1590m | Differences (dB) between |                       |                                     |                         |
|-----|-------------------------------------------------------------------------------------------------------------------|--------------------------|-----------------------|-------------------------------------|-------------------------|
|     |                                                                                                                   | FSH-3<br>&<br>ITM        | FSH-3<br>&<br>Deygout | FSH-3<br>&<br>Epstein –<br>Peterson | FSH-3<br>&<br>Giovaneli |
| 1.  | VODNO 1051m<br>(87 Km, 282 degs)                                                                                  | 2.1                      | 1.7                   | 1.7                                 | 1.7                     |
| 2   | EKO-POLYKASTRO<br>(94.1Km/169.8degs)                                                                              | -2.2                     | 6.3                   | 6.1                                 | -0.7                    |
| 3   | POLYKASTRO-2<br>(101Km/169degs)                                                                                   | -8.0                     | -2.0                  | -4.9                                | -4.9                    |
| 4   | AG.ATHANASIOS-4<br>(109Km/169.1degs)                                                                              | -10.2                    | -3.5                  | -4.6                                | -4.6                    |
| 5   | POLYKASTRO-3<br>(112Km/169.2degs)                                                                                 | -1.1                     | 8.7                   | 5.6                                 | 8.5                     |
| 6   | POLYKASTRO<br>(117Km/169degs)                                                                                     | -2.0                     | 1.0                   | 2.2                                 | 1.4                     |
| 7   | THESSALONIKI<br>(139Km/161.2degs)                                                                                 | 13.4                     | 2.0                   | 0.0                                 | 0.0                     |
| 8   | AG.ATHANASIOS-6<br>(130Km/169degs)                                                                                | -5.3                     | -9.0                  | -9.5                                | -0.9                    |
| 9   | NEGOTINO<br>(44.6Km/215.6degs)                                                                                    | -5.7                     | -5.5                  | 3.1                                 | -2.0                    |
| 10  | BOSKILJA<br>(54.8Km/174.3degs)                                                                                    | 9.3                      | 8.0                   | 0.1                                 | 8.7                     |
| 11  | VELES<br>(51Km/258.3degs)                                                                                         | 4.6                      | -3.1                  | 1.2                                 | 2.3                     |
| 12  | PETROVEC<br>(70.6Km/283.9degs)                                                                                    | -2.6                     | -6.6                  | -4.3                                | -1.8                    |
| 13  | OKTA<br>(64.6Km/280.3degs)                                                                                        | -0.1                     | 6.0                   | 2.6                                 | 2.8                     |
| 14  | CRV VRV<br>(58.4Km/275.4degs)                                                                                     | 17.1                     | -1.5                  | -1.5                                | -1.5                    |
| 15  | PROFITIS ELIAS<br>(140 Km, 158 degs)                                                                              | 4.5                      | 4.7                   | 4.7                                 | 4.7                     |
|     | Average                                                                                                           | 0.9                      | 0.5                   | 0.2                                 | 0.9                     |
|     | Standard Deviation                                                                                                | 7.7                      | 5.5                   | 4.4                                 | 4.1                     |

One more point-to-point analysis for analog TV Crn-Vrv, VHF Ch 6 ( $f = 182.25\text{MHz}$ ,  $P = 10\text{kW} = 40\text{ dBW}$ , Antenna Gain =  $8.5\text{dBd}$ ) is shown in Table V. Some of the presented measurement paths are selected to contain diffracting obstacles. So in Table V and in column 'Number of Obstacles' 0 means Free Space propagation, 1 means one obstacle and Single Knife-Edge propagation, and 2+ means two or more obstacles and Double Knife-Edge diffraction calculations.

In our calculations only the double Knife-Edge models were used, although in some cases there were more than two obstacles. This was done in order to get equivalent comparisons between our code and the Longley-Rice model, because the latter uses only the double and single Knife-Edge models. Refraction was taken into account by using the effective earth radius coefficient  $k = 1.33$ .

Average errors and standard deviations between measurements (FSH-3) and simulations from Longley-Rice, Deygout, Epstein-Peterson and Giovaneli models are shown in Table VI. It is observed from Tables V and VI that the Longley-Rice model can lead to large negative and positive differences from measured results (e.g. points 4, 6, and 7

TABLE V. Measurement Points and Results for VHF TV Crn-Vrv.

| No. | Measurements Points<br>CRN VRV ATV VHF<br>CH 6 (182.25MHz) ,<br>P = 10 kW (40 dBW)<br>Antenna Gain = 8.5dBd<br>Altitude 772m, Ht = 80m<br>ERP = 70 kW<br>(48.5 dBW)<br><br>LAT: 41.85931 LONG:<br>21.73846 | LAT<br>LONG            | Number of Obstacles | E(dBμV/m)             |                              |                                          |
|-----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|---------------------|-----------------------|------------------------------|------------------------------------------|
|     |                                                                                                                                                                                                            |                        |                     | FSH-3<br>Measurements | Longley-Rice<br>Radio-Mobile | Double Knife-Edge                        |
|     |                                                                                                                                                                                                            |                        |                     |                       |                              | Deygout<br>Epstein-Peterson<br>Giovaneli |
| 1   | VODNO 1051m<br>(30.8Km/292.5degs)                                                                                                                                                                          | 40.838070<br>22.668640 | 0                   | 95.7                  | 95.8                         | 95.6<br>95.6<br>95.6                     |
| 2   | PETROVEC 1<br>(15.8Km/311.3degs)                                                                                                                                                                           | 41.953140<br>21.594690 | 1                   | 94.3                  | 103.6                        | 98.8<br>98.8<br>98.8                     |
| 3   | VELES<br>(18.1Km/158.0degs)                                                                                                                                                                                | 41.708220<br>21.820330 | 1                   | 95.0                  | 96.8                         | 99.8<br>99.8<br>99.8                     |
| 4   | NEGOTINO<br>(52.5Km/144.0degs)                                                                                                                                                                             | 41.475920<br>22.109900 | 2+                  | 67.4                  | 81.4                         | 81.7<br>81.7<br>82.7                     |
| 5   | BOSKILJA<br>(86.9Km/134.0degs)                                                                                                                                                                             | 41.312160<br>22.488190 | 2+                  | 51.9                  | 44.4                         | 53.8<br>58.7<br>58.7                     |
| 6   | POLYKASTRO<br>(141.7Km/146.0degs)                                                                                                                                                                          | 40.795220<br>22.681800 | 2+                  | 52.8                  | 38.2                         | 48.4<br>48.5<br>48.5                     |
| 7   | PROFITIS ELIAS<br>(173.1Km/140.8degs)                                                                                                                                                                      | 40.640320<br>23.040200 | 2+                  | 64.3                  | 42.3                         | 56.9<br>57.3<br>51.3                     |

TABLE VI. Differences between measurements and propagation models.

| No. | Measurements Points<br>CRN VRV ATV VHF<br>CH 6 (182.25MHz) ,<br>P = 10 kW (40 dBW)<br>Antenna Gain = 8.5dBd<br>Altitude = 772m,<br>Ht = 80m<br><br>ERP = 70 kW (48.5 dBW)<br>LAT: 41.85931<br>LONG: 21.73846 | Differences (dB) between |                       |                                   |                         |
|-----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|-----------------------|-----------------------------------|-------------------------|
|     |                                                                                                                                                                                                              | FSH-3<br>&<br>L-R        | FSH-3<br>&<br>Deygout | FSH-3<br>&<br>Epstein<br>Peterson | FSH-3<br>&<br>Giovaneli |
| 1   | VODNO 1051m<br>(30.8Km/292.6degs)                                                                                                                                                                            | -0.1                     | 0.1                   | 0.1                               | 0.1                     |
| 2   | PETROVEC 1<br>(15.8Km/311.3degs)                                                                                                                                                                             | -9.3                     | -4.5                  | -4.5                              | -4.5                    |
| 3   | VELES<br>(18.1Km/158.0degs)                                                                                                                                                                                  | -1.8                     | -4.8                  | -4.8                              | -4.8                    |
| 4   | NEGOTINO<br>(52.5Km/144.0degs)                                                                                                                                                                               | -14.0                    | -14.3                 | -14.3                             | -15.3                   |
| 5   | BOSKILJA<br>(86.9Km/134.0degs)                                                                                                                                                                               | 7.5                      | -1.9                  | -6.8                              | -6.8                    |
| 6   | POLYKASTRO<br>(141.7Km/146.0degs)                                                                                                                                                                            | 14.6                     | 4.4                   | 4.3                               | 4.3                     |
| 7   | PROFITIS ELIAS<br>(173.1Km/140.8degs)                                                                                                                                                                        | 22.0                     | 7.4                   | 7.0                               | 13.0                    |
|     | Average                                                                                                                                                                                                      | 2.7                      | -1.9                  | -2.7                              | -2.0                    |
|     | Standard Deviation                                                                                                                                                                                           | 12.8                     | 7.1                   | 7.2                               | 9.0                     |

where the differences are larger than 10 dB). Generally speaking, diffraction attenuation is mostly overestimated by the Longley-Rice model, especially at very large distances, and this can be easily seen at measurement points 6 and 7, where the three other models used in this study are nearer to the measured result. In this case study in the VHF-TV Band, the classical multiple diffraction models of Deygout, Epstein-

Peterson, and Giovaneli, are more accurate than the Longley-Rice model, especially at very large distances from the transmitter.

### III. CONCLUSIONS

Classical propagation prediction models have been compared in this study for the VHF and UHF TV broadcasting frequencies. This study was focused on propagation in mountainous terrain, and in long propagation paths. Four different broadcasting sites have been used: Hortiat, Boskija, Turtel, and Crn-Vrv that cover neighboring geographical areas. The Longley-Rice model (ITM) with worldwide SRTM 3-arc-second data, incorporates single knife-edge and double knife-edge models, and produces satisfactory results in comparison to measurements in most cases. However, the Longley-Rice model is overestimating diffraction attenuation at very large distances from the transmitter, especially in the VHF TV Band. Deygout, Epstein-Peterson and Giovaneli approaches are approximating multiple knife-edge diffraction using geometrical constructions. All the three of them give satisfactory results, and they are classic well established models, [18-19]. Their relative accuracy was found to be comparable in the case studies of this paper. They proved to be more accurate than the Longley-Rice model over long paths including diffracting obstacles in the VHF-TV Band. A further improvement in diffracting loss calculation accuracy is expected from Vogler's rigorous method, [10].

### ACKNOWLEDGMENT

Parts of this work were performed within the NATO SfP-984409 project "Optimization and Rational Use of Wireless Communications Bands" (ORCA). The authors would like to thank everyone involved.

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