

Evaluation of the Recommendation ITU-R P.1546-2 for UHF Field-Strength Prediction over Fresh-Water Mixed Paths

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Abstract—In this paper, the principal objective is to validate a new approach for the field-strength estimate in VHF and UHF radio links partially over water. The method is compared with measurements conducted in the cities of Belo Horizonte, MG, and Brasília, DF, Brazil. The approach is based on physical insights applied in the Recommendation ITU-R P.1546-2 mixed path treatment. The results show good agreement with the measured data.

Index Terms—Propagation models, Recommendation ITU-R P.1546-2, Propagation over Mixed Paths.

I. INTRODUCTION

The Recommendation ITU-R P.1546-2 provides a "method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz". Specifically, it is a step-by-step method for predicting field strengths in VHF and UHF point-to-area terrestrial radio links based on propagation curves (measured data). The recently updated version (august 2005) provides a new approach to estimate field strengths over mixed paths, i.e., radio paths over both land and sea [1]. However, the recommendation does not deal with radio links partially over fresh water (e.g., lakes, rivers, etc.). It has been agreed, in the context of international planning, that such fresh-water mixed paths are to be treated as completely over land. So, radio links over, for example, the Victoria Sea in Africa or even over the Amazon River should be considered and treated as if over land paths. This treatment may lead to over estimations of the path loss in situations where significant bodies of fresh water are present between transmitter and receiver. As a direct consequence, interference levels may be underestimated in such scenarios.

To overcome this drawback, in this work an approach previously derived in [2] is applied to improve the field-

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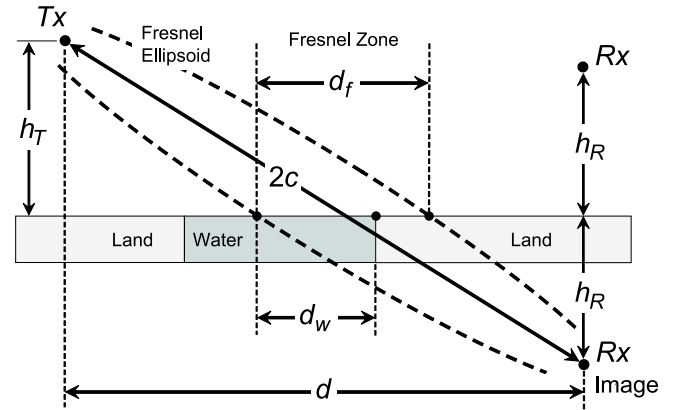


Fig. 1. Equivalent mixed path profile and first Fresnel's ellipsoid.

strength estimates of the updated Recommendation ITU-R P.1546-2. The improvement is valid for relatively short radio links partially over fresh water [3]. To validate the approach, path loss measurements were conducted around the Pampulha Lagoon in the city of Belo Horizonte, MG, and the Paranoa Lake in Brasília, DF, both in Brazil. The measured data were further compared against estimates provided by the official Recommendation ITU-R P.1546-2 and by the proposed procedure.

II. APPROACH FOR THE MIXED PATH TREATMENT

The proposed approach attempts to improve the field-strength prediction of the updated Recommendation ITU-R P.1546-2 for relatively short VHF and UHF radio links over mixed paths specifically composed by fresh water and land. The method is based on the interception of the first Fresnel's ellipsoid and the terrain profile, as depicted in Fig. 1. Due to the application of the Fresnel's ellipsoid concept, the method is valid for relatively short radio links, i.e., links comprising

distances not far beyond 10 km. To use the Fresnel's ellipsoid approach, the ground is approximated by its equivalent plane and the ellipsoid is defined by the transmitting antenna at one focus and the image of the receiving antenna at the other focus of the ellipsoid, as illustrated in Fig. 1. The main concept is to find the percentage of water that lies inside the intersection of the ellipsoid with the equivalent plane profile (i.e., the Fresnel zone around the specular point), instead of using the whole profile between transmitter and receiver, as suggested by the official Recommendation ITU-R P.1546-2. Such percentage is then applied to calculate the weights of the contributions due to all-water and all-land field strengths provided by the recommendation curves, in order to estimate the actual mixed path field strength. Furthermore, the all-water data provided by the recommendation, originally acquired for radio links over sea water, is applied as valid for fresh water as well.

Based on the theory discussed in [2] and [4] and with the help of Fig. 1, the percentage (p_w) of fresh water inside the specular Fresnel zone is given by

$$p_w = \frac{d_w}{d_f}, \quad (1)$$

where d_f is the length of the Fresnel zone around the specular point and d_w is the portion of d_f that lies over fresh water, if any. With the help of the ellipsoid equation and Fig. 1, one can show that [2]:

$$d_f \approx \frac{2c\sqrt{\lambda(2c+\lambda)(4h_T h_R + 2c\lambda)}}{(h_T + h_R)^2 + 2c\lambda}, \quad (2)$$

where λ is the wavelength, h_T and h_R are the heights of the transmitting and receiving antennas with respect to the equivalent plane, respectively, and $2c$ is the inter-focal distance of the ellipsoid, given by

$$2c = \sqrt{d^2 + (h_T + h_R)^2}, \quad (3)$$

where d is the length of the radio link. Once the ellipsoid equation is known, the attainment of d_w in (1) depends only on the knowledge of the mixed path profile.

With p_w given by (1), the field strength is calculated as in the Annex 5 of [1]:

$$E = (1 - p_w) E_{land}(d) + p_w E_{sea}(d), \quad (4)$$

where $E_{land}(d)$ and $E_{sea}(d)$ are the field strengths at distance d obtained from the all-land and all-sea recommendation curves, respectively, in spite of the fact that the water under the radio link is fresh.

III. CASE STUDIES

A. Case I - Pampulha

To evaluate the new approach, narrow-band measurements have been carried on the surroundings of the Pampulha Lagoon in Belo Horizonte (19 56' S; 43 57' W), Brazil, at 1809 MHz, in a predominantly suburban environment. The results will be presented in comparison with the ITU-R P.1546-2 (with and without the approach discussed in Sect. II) and the Okumura-Hata method [5].

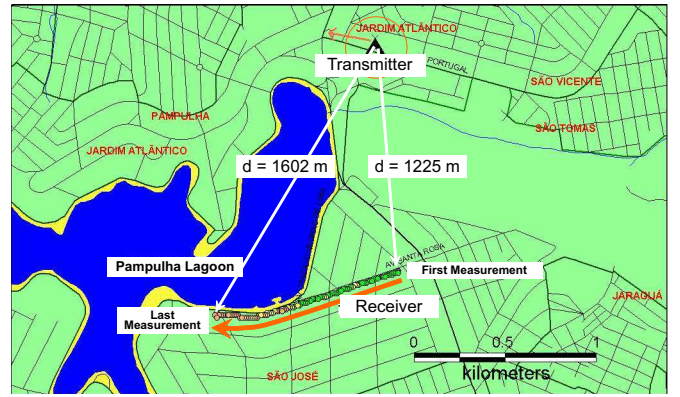


Fig. 2. The measurement site around the Pampulha Lagoon.

The measurement site is illustrated in Fig. 2. The transmitting base station has an EIRP of 57.5 dBm and $h_T \approx 19$ m. The receiving antenna is a half-dipole with $h_R \approx 2$ m. From Fig. 2, one observes that the avenue where the measurements were conducted is almost straight, which enables the results to be given in terms of the distance d between the transmitter and receiver. Measurements were recorded with intervals of 1m, starting with $d \approx 1225$ m up to $d \approx 1602$ m (see Fig. 2). The mixed path starts at $d \approx 1440$ m up to the last measurement point.

A total of 293 measurements were conducted and properly stored. Local mean values were further obtained by averaging the data for each 10 m, in order to remove short-term fading effects. These mean values were then compared against the predictions provided by the Okumura-Hata model (for a suburban environment), Recommendation ITU-R P.1546-2 assuming all-land paths (the usual assumption of the recommendation for such in land scenario), mixed paths (adopting the recommendation algorithm for calculating p_w), and mixed paths together with the new approach of calculating p_w from (1). The results are shown in Fig. 3 as function of d , noting that for $d < 1440$ m the radio link is over all-land paths and for $d > 1440$ m it is partially over the lagoon (i.e., mixed path). In Table I, the mean value error (MVE) and the standard deviation (STD) of the estimates provided by the Okumura-Hata and ITU-based models with respect to the measured mean values are presented. The results were obtained considering only the mixed path situations (i.e., for $d > 1440$ m), for which the method discussed in Sect. II is devoted.

TABLE I
MEAN VALUE ERROR (MVE) AND STANDARD DEVIATION (STD) FOR THE MIXED PATH ($d > 1440$ M) ESTIMATES PROVIDED BY THE SEVERAL MODELS IN THE PAMPULHA'S CASE STUDY.

Propagation Model	MVE(dB)	STD(dB)
Okumura-Hata	-14.59	2.28
All-land ITU-R P.1546-2	-14.93	2.28
Mixed Path ITU-R P.1546-2	-8.72	2.95
Mixed path ITU-R P.1546-2 with new approach	-1.40	2.26

From Fig. 3 and Table I, it can be observed that for $d > 1440$ m the discrepancies among the methods appear

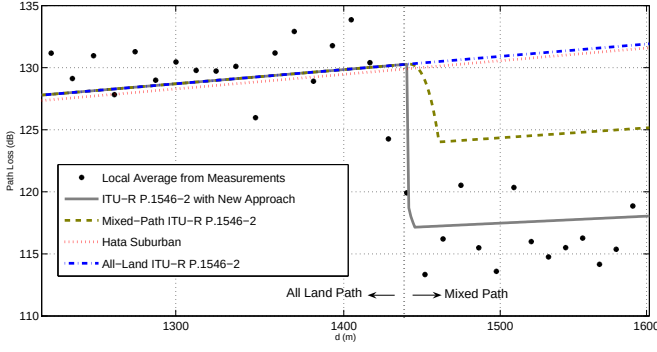


Fig. 3. Path loss results (estimated and measured) at 1809 MHz for the suburban environment depicted in Fig. 2.

significantly. The official Recommendation ITU-R P.1546-2, considering all-land paths, provides $MVE = -14.93$ dB and $STD = 2.28$ dB, which are basically the values obtained by the Okumura-Hata model. The recommendations with the mixed path treatment present improved results. The official ITU-R P.1546-2 using the mixedpath correction presents a still large $MVE = -8.72$ dB, with $STD = 2.95$ dB. However, the new approach of Sect. II drastically reduces the MVE to -1.40 dB, with $STD = 2.26$ dB.

Figure 4 shows the scatter plot of the path loss estimates provided by the Recommendation ITU-R P.1546-2 with the mixed path treatment and with the new approach, as functions of the measured path loss at the points where $d > 1440$ m. Results at the diagonal line indicate a perfect agreement between the prediction provided by a model and the measured data value. Once more, one can observe that the proposed method provides better estimates than the official ITU recommendation, even when the mixed path treatment is adopted.

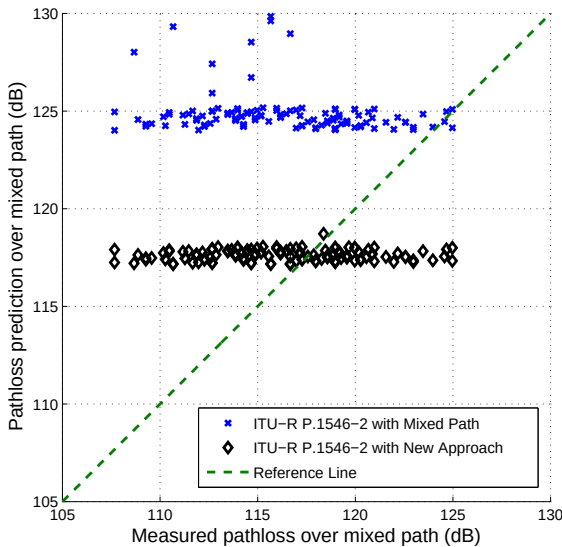


Fig. 4. Scatter plot of the path loss estimated by the Mixed Path ITU-R P.1546-2 and by the new approach, with respect to the mixed path measured data for the Pampulha's case study.

Figures 5 and 6 present the distribution histograms of

the MVE for the mixed path ITU-R P.1546-2 and the new approach, respectively. The solid line is the probability density function of a Gaussian (normal) random variable. From these figures one can observe that the MVE provided by the new approach has an almost normal distribution, indicating a better prediction of the path loss behavior.

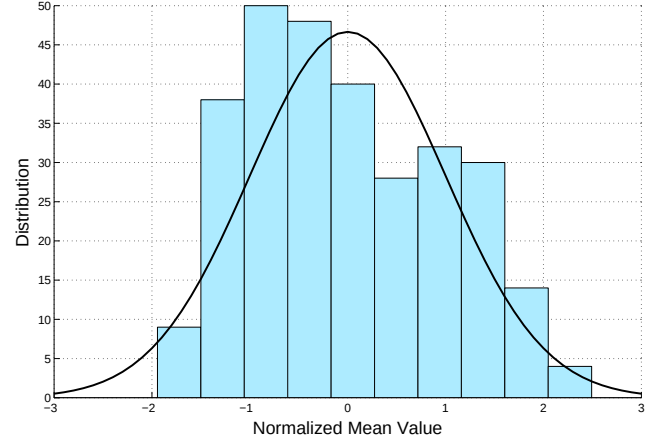


Fig. 5. MVE distribution histogram of the mixed path ITU-R P.1546-2 for the Pampulha's case study.

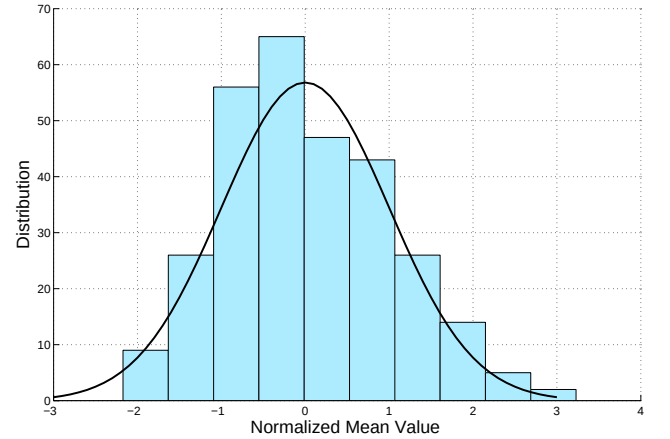


Fig. 6. MVE distribution histogram of the new approach for the Pampulha's case study.

B. Case II - Paranoa

The second case study was performed around the Paranoa Lake, in Brasilia (15 50' S, 47 42' W), Brazil, at 856.039 MHz. The environment is typically suburban, similar to that found in the Pampulha's case study, and is illustrated in Fig. 7. The transmitting antenna is omnidirectional, with a directivity of 8.14 dB and $h_T \approx 30$ m. The receiving antenna is an ASP 1897T, with a directivity of 3 dB and $h_R \approx 1.5$ m. The transmitting base station has an EIRP of 60.26 dBm. The measurements were conducted in the streets around the lake, following a quite irregular path, as depicted in Fig. 7. The distance d between transmitter and receiver varies irregularly with the receiver position, varying from 1.5 km up to 5 km. For this reason, the results to be shown are given with respect

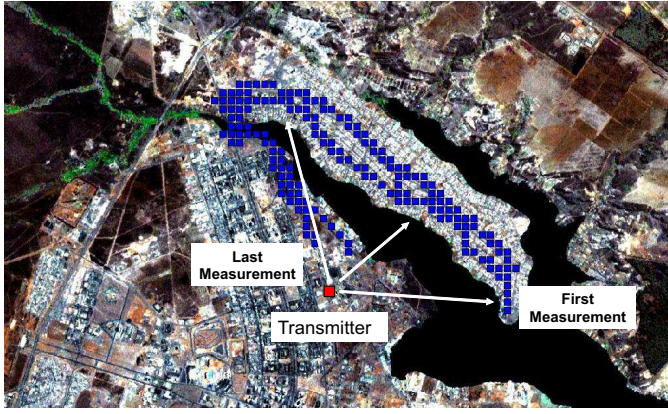


Fig. 7. Measurement site around Paranoa Lake in Brasilia, DF, Brazil.

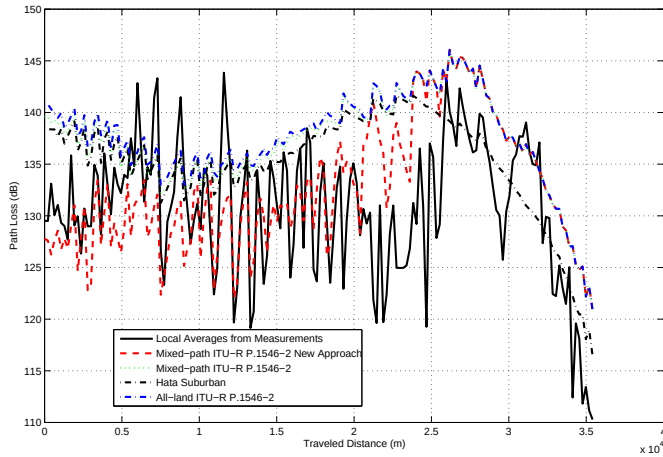


Fig. 8. Path loss results (estimated and measured) at 856 MHz for the suburban environment depicted in Fig. 7.

to the distance measured along the receiver's path, reaching 35 km. The measured data was stored, yielding a total 166 local mean values.

Initially, the radio link is over a mixed path, which lasts until the distance of 24 km. After that, the link is practically over land. The path loss results with respect to the traveled distance is shown in the Fig. 8. As in the Pampulha's case study, one can observe from Fig. 8 that the predicted path loss given by the all-land ITU-R P.1546-2 generally overestimates the measured data for radio links over mixed paths, while the new approach discussed in Sect. II) provides the best overall agreement, when compared against the other models. Table II presents the MVE and STD values with respect to the measured path loss local means. Such values were obtained considering only the cases over mixed paths.

Figure 9 shows the scatter plot of the path loss estimates provided by the Recommendation ITU-R P.1546-2 with the mixed path treatment and with the new approach, as functions of the measured path loss at locations where mixed paths are present. The results demonstrate that the proposed method provides better estimates than the other models. Figures 10 and 11 present the distribution histograms of the MVE for the mixed path ITU-R P.1546-2 and the new approach, re-

TABLE II
MEAN VALUE ERROR (MVE) AND STANDARD DEVIATION (STD) FOR THE MIXED PATH ESTIMATES PROVIDED BY THE SEVERAL MODELS IN THE PARANOIA'S CASE STUDY.

Propagation Model	MVE (dB)	STD (dB)
Okumura-Hata	-5.83	6.20
All-land ITU-R P.1546	-7.03	6.23
Mixed Path ITU-R P.1546	-6.49	6.36
Mixed Path ITU-R P.1546-2 with new approach	0.15	6.15

spectively. Again, one can observe from the figures that the MVE provided by the new approach has an almost normal distribution, indicating a non-tendentious behavior.

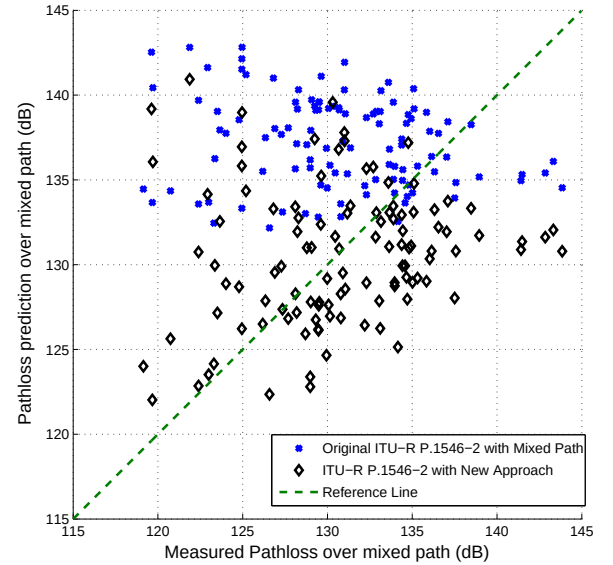


Fig. 9. Scatter plot of the path loss estimated by the mixed path ITU-R P.1546-2 and by the new approach, with respect to the mixed path measured data for the Paranoia's case study.

IV. CONCLUSIONS

A new approach for the use of the Recommendation ITU-R P.1546-2 in mixed paths partially over fresh water was applied in the prediction of two study cases. The approach is based on calculating the mixed path interpolation factor just considering the terrain features located inside the Fresnel zone around the specular point. The estimates provided by the new procedure were compared against narrow-band measurements performed around two lagoons (the Pampulha Lagoon, in Belo Horizonte, and the Paranoa Lake, in Brasilia, Brazil) in typically suburban residential areas. For the two cases, the new approach provided a better mean value of errors (MVE) than the official Recommendation ITU-R P.1546-2 and Okumura-Hata models.

V. ACKNOWLEDGMENT

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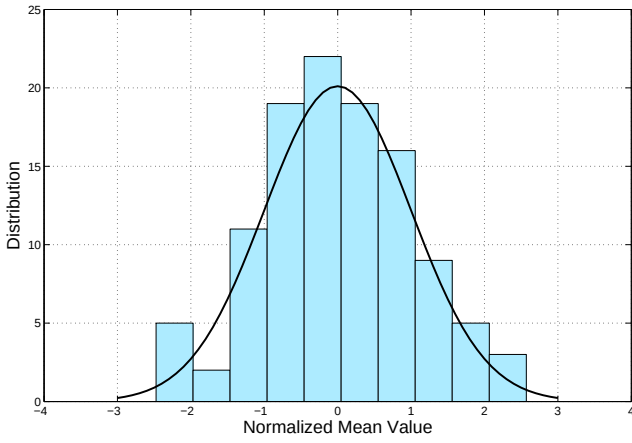


Fig. 10. MVE distribution histogram of the mixed path ITU-R P.1546-2 for the Paranoa's case study.

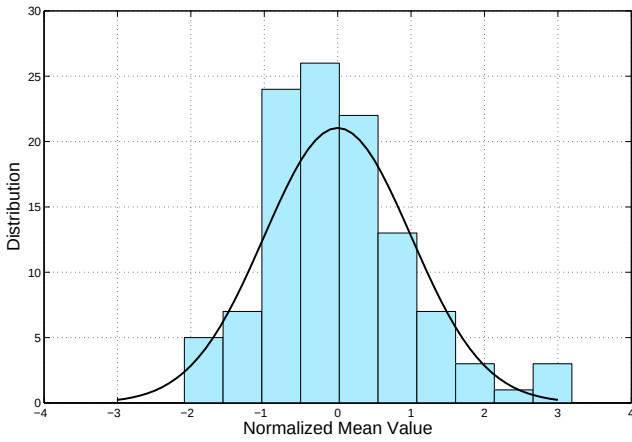


Fig. 11. MVE distribution histogram of the new approach for the Paranoa's case study.

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