Improving the Treatment of Mixed-Terrain Paths of the Recommendation ITU-R P.1546 for the Path-Loss Prediction of Short UHF Links

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***Abstract*— The Recommendation ITU-R P.1546 provides a "method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz" and has been proposed to mitigate known limitations associated to distance and frequency ranges, combining several existent methods in one. In the present work, we suggest an improvement in the Recommendation for the treatment of mixed-terrain paths, based on the intersection of the Fresnel's ellipsoid with the terrain profile. Preliminary results (measured and theoretical) are presented and discussed.**

***Index Terms*— Methods of coverage prediction for radio-mobile services, critical communication systems, mixed paths approach.**

I. Introduction

Empirical and semi-empirical methods for the prediction of radio coverage are extremely important for designing and implementing wireless networks. In general, empirical methods are established from observations of the signal strength, measured for several locations throughout the environment of the radiowave propagation (radio channel). In turn, semi-empirical methods are established from the physics of the propagation phenomenon, generally combined with empirical adjustments. The ITU (International Telecommunication Union) recommendations are fine examples of such methods.

In the present work, our aim is to apply the Recommendation ITU-R P.1546 for the coverage prediction of UHF wireless systems over relatively short distances. However, it is known that such recommendation provides a questionable treatment of mixed-terrain paths, specifically those involving (dry) ground and water. So, our objective is to present an improvement for such treatment based on physical insights (precisely, the intersection of the Fresnel's ellipsoid with the terrain profile). The results obtained from this improved model is compared against those of the usual Recommendation ITU-R P.1546, the Okumura-Hata model, and measurements conducted around the Pampulha lagoon in Belo Horizonte, MG, Brazil, at 1809.2 MHz.

II. Recommendation ITU-R P.1546

The recommendations published by the ITU supply effective techniques for wireless coverage and power-budget planning. Specifically, the Recommendation ITU-R P.1546 extends the applicability of the well-known ITU-R P.370. It is a point-to-area method for frequencies ranging from 30 MHz up to 3 GHz, embracing distances from 1 to 1000 km. Its propagation curves represent the field-strength values exceeded for 1% to 50% of time. The recommendation also presents curves of the effective height of transmission from 10 m up to 1200 m and corrections for mixed-terrain paths, among other peculiarities [1].

III. Mixed-Terrain Paths

The Recommendation ITU-R P.1546 provides corrections for the treatment of a radiowave propagation over mixed-terrain paths; i.e., terrain profiles partially composed of (dry) ground and partially covered by water [1]. Such corrections are given in terms of the percentages of terrain corresponding to ground or water. In turn, the corresponding percentages are calculated by taking into account the whole path (i.e., from the transmitting antenna up to the receiving one). Such procedure arouses several questions, as for relatively short radio links without obstructions it is well known that the larger contributions associated with the terrain scattering come from the *specular region*, and not from the whole path. The specular region is generally defined by the intersection of the first Fresnel's ellipsoid with the terrain's profile, where for the present scenario the ellipsoid corresponds to the radiation of the transmitting antenna toward the image of the receiving antenna (as illustrated in Fig. 1).

IV. A New Approach for the Mixed-Path Treatment

For relatively short radio links (i.e., with distances up to about 10 km) and with a clear line-of-sight, the adopted approach is quite simple. Instead of considering the complete terrain profile between the antennas, only that portion corresponding to the intersection between the first Fresnel's ellipsoid and the terrain profile is considered for the calculation of the percentages mentioned in Sect. III. For that, the ground is approximated by its equivalent plane and the ellipsoid is defined by the transmitting antenna (at one of the focus) and the image of the receiving antenna (at the other focus), as depicted in Fig. 1. The relative positions (with respect to the transmitting antenna) of the

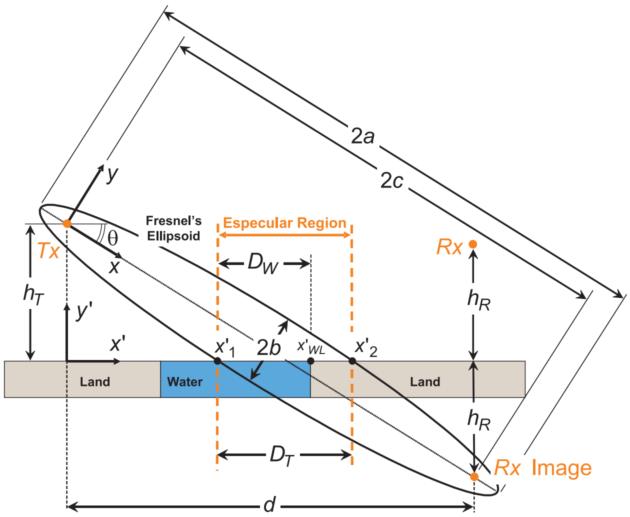


Fig. 1. Mixed path geometry.

ground-water interfaces must be known (for example, x'_{WL} in Fig. 1).

From Fig. 1 and from the first Fresnel's ellipsoid properties one can show that [2]

$$
\begin{aligned}
a &= \sqrt{b^2 + c^2} \\
b &= \sqrt{\frac{\lambda\, c}{2}} \\
2c &= \sqrt{d^2 + (h_T + h_R)^2}
\end{aligned} \tag{1}
$$

where λ is the wavelength, $2a$ and $2b$ are the major and minor axial lengths of the ellipsoid, respectively, $2c$ is the inter-focal distance of the ellipsoid, and h_T and h_R are the heights of the transmitting and receiving antennas, respectively. From Fig. 1 one also observes that the desired percentage of water (P), just considering the terrain profile intersected by the Fresnel's ellipsoid, is given by the ratio

$$
P = \frac{D_W}{D_T} \;, \tag{2}
$$

where D_T is the terrain-profile length intersected by the ellipsoid and D_W is that portion of D_T corresponding to water (if any).

The lengths D_T and D_W can be calculated with the help of the ellipse equation, given by

$$
\frac{(x-c)^2}{a^2} + \frac{y^2}{b^2} = 1 \;, \tag{3}
$$

where the pertinent parameters are as illustrated in Fig. 1. However, the coordinate system x, y is not appropriate to define the lengths D_T and D_W of (2). Instead, we use the auxiliary coordinate system x', y', related to x, y by

$$
\begin{aligned}
x &= x' \cos\theta - (y' - h_T) \sin\theta \\
y &= x' \sin\theta + (y' - h_T) \cos\theta
\end{aligned} \tag{4}
$$

where

$$
\begin{aligned}
\cos\theta &= d/(2c) \\
\sin\theta &= (h_T + h_R)/(2c)
\end{aligned} \tag{5}
$$

and the other pertinent parameters are as illustrated in Fig. 1. Substituting (1) and (4) into (3), the ellipsoid equation can be rewritten as:

$$
\frac{\left[x' \cos\theta - (y' - h_T)\sin\theta - c\right]^2}{c(c+\lambda/2)} + \frac{\left[x' \sin\theta + (y' - h_T)\cos\theta\right]^2}{(\lambda\, c/2)} = 1 \;. \tag{6}
$$

Finally, from Fig. 1 one observes that the x' coordinates corresponding to the intersection of the Fresnel's ellipsoid with the terrain profile are given by setting $y' = 0$ in (6):

$$
\frac{(x' \cos\theta + h_T \sin\theta - c)^2}{c(c+\lambda/2)} + \frac{(x' \sin\theta - h_T \cos\theta)^2}{(\lambda\, c/2)} = 1. \tag{7}
$$

Solving for x' in (7):

$$
\begin{aligned}
x'_1 &= \Big[c(\lambda + 2h_T \sin\theta)\cos\theta \\
&\quad - \sqrt{\lambda(2c+\lambda)(2c\, h_T \sin\theta + \lambda c/2 - h_T^2)}\Big] \\
&\quad \div \left(\lambda + 2c\, \sin^2\theta\right) \\
x'_2 &= \Big[c(\lambda + 2h_T \sin\theta)\cos\theta \\
&\quad + \sqrt{\lambda(2c+\lambda)(2c\, h_T \sin\theta + \lambda c/2 - h_T^2)}\Big] \\
&\quad \div \left(\lambda + 2c\, \sin^2\theta\right)
\end{aligned} \tag{8}
$$

and, consequently,

$$
\begin{aligned}
D_T = x'_2 - x'_1 &= \frac{2\sqrt{\lambda(2c+\lambda)(2c\, h_T \sin\theta + \lambda c/2 - h_T^2)}}{\lambda + 2c\, \sin^2\theta} \\
&\approx \frac{2\sqrt{\lambda c(4c\, h_T \sin\theta + \lambda c - 2h_T^2)}}{\lambda + 2c\, \sin^2\theta} \;,
\end{aligned} \tag{9}
$$

as, in practice, $c >> \lambda$. Once the coordinates x'_1 and x'_2 are known, together with the terrain profile, the calculation of D_W and, consequently, P is trivial.

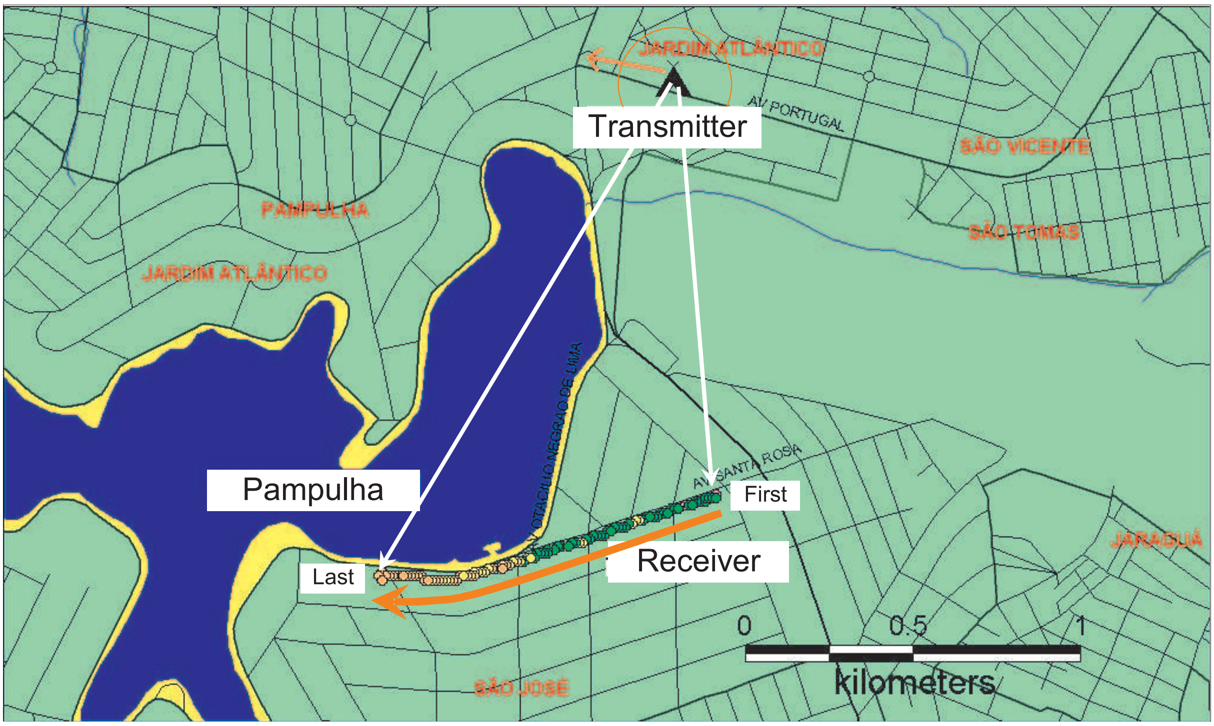
Afterwards, the field strength at the receiving antenna location is calculated by:

$$
E = (1-P)\, E_{land} + P\, E_{sea} \tag{10}
$$

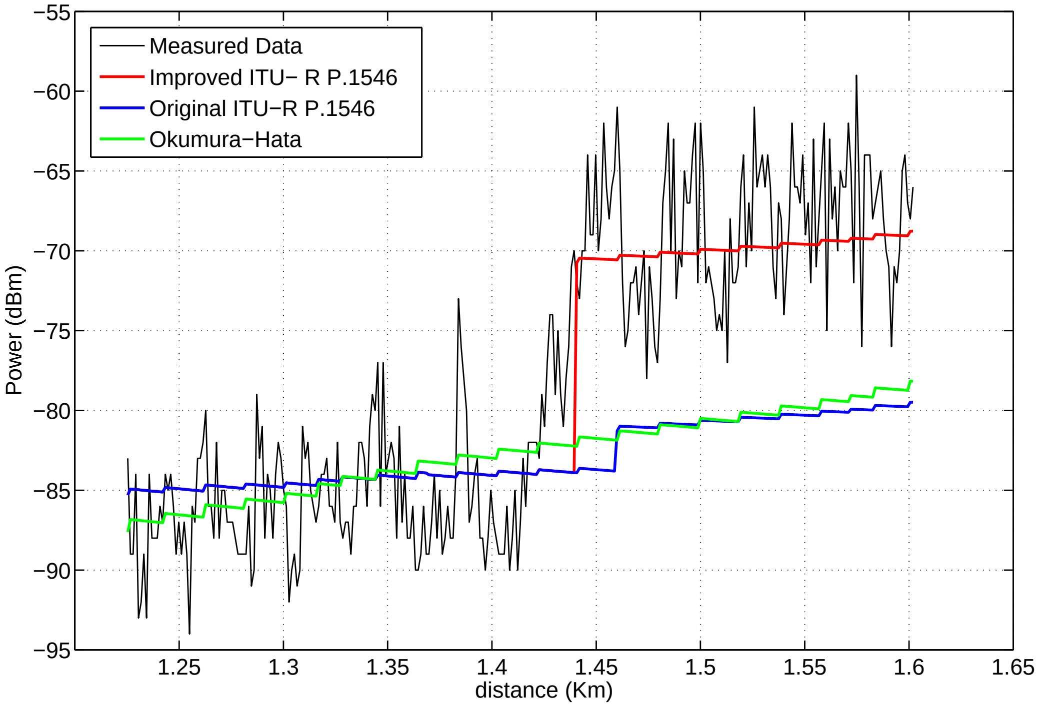
where E_{land} and E_{sea} are calculated accordingly to [1] while P is that of (2). From the equation above one can notice that, as $P \leq 1$ and $E_{land} < E_{sea}$, $E_{land} \leq E \leq E_{sea}$.

V. Case Study

The improvement presented in Sect. IV is now applied to predict the coverage offered by a radio-base station at the neighborhood of the Pampulha lagoon, in the city of Belo Horizonte, MG, Brazil. The operating frequency is



(a)



(b)

Fig. 2. Measurements conducted around the Pampulha lagoon in the city of Belo Horizonte, MG, Brazil: (a) measurement area and (b) measured received power together with coverage predictions provided by the Recommendation ITU-R P.1546 (with and without the improvement) and the Okumura-Hata model.

1809.2 MHz. Measurements were conducted around the lagoon and the results are to be compared against the predictions provided by the Recommendation ITU-R P.1546 (with and without the previously discussed improvement) and by the Okumura-Hata model [3].

The measurement area is depicted in Fig. 2(a). The transmitting and receiving antenna heights are $h_T = 18.9$ m and $h_R = 2.0$ m, respectively. The distance between the antenna masts, d, varies according to the receiver's location, being $d \approx 1225$ m for the initial point and $d \approx 1600$ m for the last one [see Fig. 2(a)]. As one can observe from Fig. 2(a), initially the link is completely over ground. The path is mixed (i.e., with part of the radio link over the lagoon) from $d \approx 1440$ m up to 1600 m.

The received power (in dBm) obtained from the measurements and those yield by the three coverage-prediction models are shown in Fig. 2(b) as functions of d. Taking into account all data points, the average of the measured power is about -70.8 dBm with a standard deviation of 9.2 dB. Such results can be associated to several characteristics, as multipath components, inhomogeneous terrain morphology, among many others. One can clearly observe from Fig. 2(b) the increase of the measured signal level (about 15 dB) for $d > 1440$ m, which is obviously due to the scattering over the lagoon's surface.

From Fig. 2(b) one also observes that for $d < 1440$ m the ITU-R P.1546 recommendation and the Okumura-Hata model basically provide the same predictions, which are approximately equal to the average of the measured data. However, for $d > 1440$ m, the improvement discussed in Sect. IV starts to play, providing distinct results from those of the original ITU-R P.1546 and Okumura-Hata models. Actually, the proposed model provides very accurate predictions for the average power level, differently from the original ITU-R P.1546 and Okumura-Hata models.

Obviously, the single case presented here is not sufficient to completely assure the usefulness of the proposed model; many test cases are still needed. But one clearly observes from Fig. 2(b) that the mixed-path treatment suggested in the original Recommendation ITU-R P.1546 may not be appropriate for scenarios similar to that of Fig. 2(a).

VI. Conclusions

We presented an improvement for the treatment of mixed-paths (i.e., with ground and water) in the Recommendation ITU-R P.1546, suited for relatively short UHF radio links with a clear line-of-sight. Measurements were conducted around the Pampulha lagoon in Belo Horizonte, MG, Brazil, at 1809.2 MHz, and the results were compared against those provided by the Recommendation ITU-R P.1546 (with and without the above mentioned improvement) and the Okumura-Hata models.

The improved Recommendation ITU-R P.1546 was capable of predicting with good accuracy the average power level obtained from the measured data, while the usual ITU-R P.1546 and Okumura-Hata predictions were off by approximately 15 dB.

Acknowledgment

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