Flat Terrain Measurements and Path Loss Models at 1.0 and 1.5 GHz

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Abstract

In this paper an outdoor measurement campaign for almost flat terrain environment is undertaken for wireless mobile applications at frequencies 1.0 GHz and 1.5 GHz. The measured results are compared here both with the well – known in the literature "Two–Ray" (TR) model of wave propagation, as well as with the also well – known "Extended Hata" (EH) model. As a result, it is found here that under the conditions of this outdoor experiment the TR model is much more accurate, as compared to the measured results of ours. It is intended that further research by our research group will be conducted by our research group in the direction of comparison of our measured results with alternative analytical results which have been produced by us in previous publications of ours, in the "high frequency" regime.

1. Introduction

The problem of electromagnetic (EM) wave propagation over the flat terrain (or over a lossy medium with flat interface) is well – known in the literature as the *"Sommerfeld antenna radiation problem"*, where the interest here is for observation points over the flat interface [1-23]. However, in this paper we concentrate in comparing our outdoor experimental measurements in "high frequency" regime (here for frequencies 1.0 GHz and 1.5 GHz), which are obtained here by our research group, with approximate or empirical models of electromagnetic (EM) wave propagation [24-30]. In near future proposed research by our group, we intend to compare our outdoor experimental results measured by us here with alternative analytical results which have been produced by our research group in previous publications of ours (always in the "high frequency" regime).

This paper is organized as following: Section 2 describes the measurement equipment, as well as the procedure followed during our outdoor measurement campaign. Candidate path loss models to characterize the measured path loss are introduced and discussed in Section 3. Finally, conclusions and future research are presented in Section 4.

2. Measurement campaign

The measurements were carried out in a football (soccer) field inside our University (NTUA) campus, in order to represent a near flat earth scenario. The field was partially covered with grass, whereas it was surrounded by tall trees. Fig. 1 illustrates the measurement environment, as well as the transmit (Tx) and receive (Rx) locations. The red circles denote the two different Tx locations, being separated about 5 m, which concurrently transmit a continuous wave (CW) signal at 1.0 GHz (Tx1), and 1.5 GHz (Tx2), respectively. It is worth noticing that under such conditions no wave interference between the two transmitted EM waves, i.e., from the two transmitting antennas, is observed, because of the fact that both transmitted waves are very narrowband, since they are CW signals.

The two (2) antennas were both mounted at a height of 2.7 m about the field surface. Two signal generators were utilized to produce the transmitted signals, which were fed, through similar 3-m low loss cables, to similar *vertically polarized* omnidirectional antennas. They both have a half power beamwidth (HPBW) of 45° in the elevation plane and a constant gain of about 0.20 dBi in the azimuth plane at the selected frequencies. The transmitted effective isotropic radiated power (e.i.r.p.), was 16.1 dBm and 18.8 dBm, at 1.0 and 1.5 GHz, respectively.

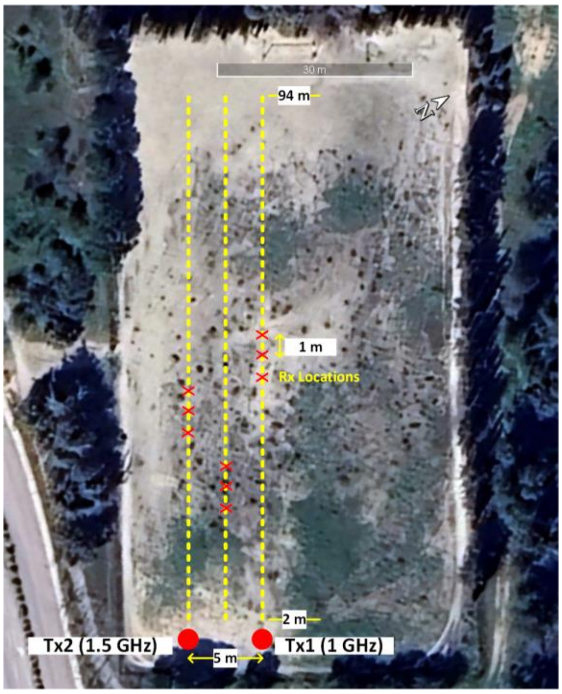


Figure 1. Measurement environment and locations.

An SRM-3006 frequency selective field meter by Narda GmbH (Pfullingen, Germany) in spectrum analysis mode was employed as the receiving unit. An electric field isotropic probe was used (420 MHz -- 6 GHz with a 0 dBi gain), connected to the main control unit through a 1.5-m cable. The Rx sensor was mounted on a wooden tripod at 1.7 m above the field surface. The Rx unit recorded the power samples in dBm, using a time average of 2 minutes. The Rx sensitivity was -120 dBm. The utilized Rx equipment was calibrated according to the ISO/IEC 17025:2017 standard [24]. Table I summarizes the Tx and Rx characteristics adopted in the launched measurement campaign.

TABLE I. Transmitter and receiver characteristics during the measurement campaign at each selected frequency scenario

	1.0 GHz	1.5 GHz
Tx power	17 dBm	20 dBm
Tx gain	0.20 dBi	
Cable loss	1.14 dB	1.42 dB
EIRP	16.1 dBm	18.8 dBm
Rx gain	0 dBi	
Rx sensitivity	-120 dBm	

The Rx recorded the signal at distinct positions from 2 m up to 94 m in three (3) parallel routes, as also shown in Fig. 1, in steps of 1 m. At each measurement position the Rx was stationary, having a line-of-sight (LOS) condition with the Tx. This entails a total number of 279 collected power samples at each frequency band.
Based on the received signal power the measured path loss *PL*, in decibels, at each Rx location can be described by:

$$PL = \mathrm{P}_{\mathrm{Tx}} - L_{\mathrm{c}} + G_{\mathrm{Tx}} + G_{\mathrm{Rx}} - P_r \qquad (1)$$

where P_{Tx} denotes the Tx power in dBm, L_{c} indicates the cable losses, G_{Tx}, G_{Rx} stands for the Tx and Rx gains, respectively, in dBi, and P_r is the received signal power in dBm. Therefore, from (1), 279 path loss samples are resolved at each examined frequency scenario at a specific distance d_D, in meters, between Tx and Rx (length of the direct ray) that is given by:

$$d_D = \sqrt{d^2 + (h_t - h_r)^2} \qquad (2)$$

where d indicates the horizontal (ground) distance, in meters, between Tx and Rx, and h_t, h_r designate the Tx and Rx heights (2.7 and 1.7 m), respectively.

The raw data for both scenarios are shown in Fig. 2, where the received power versus distance is depicted. It should be pointed out that the distance from Tx in logarithmic scale, in meters, represents the direct distance (d_D) between Tx and Rx.

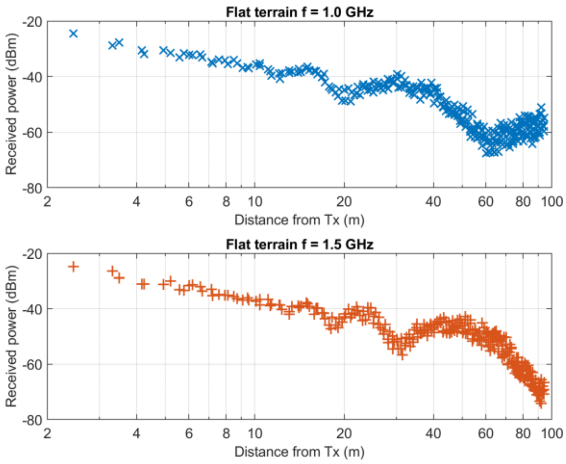


Figure 2. Received signal power at each measured location at 1 and 1.5 GHz.

Clearly the power samples imply a flat terrain pattern, where power drops are encountered at specific distances. This resembles to a *two-ray pattern model*, which will be examined for its appropriateness to model the measured path loss in Section 3, below, along with appropriate Extended Hata model, as well, for comparison purposes.

3. Path loss models, results and discussion

The two-ray model describes the signal propagation using two components. The direct ray between Tx and Rx and a ground reflected path ray. The path loss, in decibels, based on the two-ray model is given by [25]:

$$PL = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) - 20\log_{10}\left|1+\Gamma_V\, e^{j\Delta\varphi}\right| \quad (3)$$

where λ is the wavelength, in meters, at each selected frequency, and d is the ground (horizontal) distance between Tx and Rx, as previously mentioned. Furthermore, Γ_V denotes the vertical polarization reflection coefficient of the ground reflected path, and $\Delta\varphi$ stands for the phase difference between the direct and the ground paths. The reflection coefficient is described by:

$$\Gamma_V = \frac{-\varepsilon_r \sin\theta_i + \sqrt{\varepsilon_r - (\cos\theta_i)^2}}{\varepsilon_r \sin\theta_i + \sqrt{\varepsilon_r - (\cos\theta_i)^2}} \quad (4)$$

where θ_i, is the *"grazing angle"* of the incident wave (i.e., the angle between the incident EM wave and the flat terrain), and ε_r is the relative permittivity of the ground. Assuming a very dry ground, $\varepsilon_r = 3$ according to [26]. Furthermore, the grazing angle in (4), is related to the geometrical propagation characteristics according to:

$$\sin\theta_i = \left(\frac{h_t + h_r}{d_G}\right)$$
$$\cos\theta_i = \left(\frac{d}{d_G}\right) \quad (5)$$

where d_G denotes the length of the ground reflected ray, in meters, which can be calculated by:

$$d_G = \sqrt{d^2 + (h_t + h_r)^2} \quad (6)$$

Finally, the phase difference between of the path lengths between the direct and the ground reflected rays are given by:

$$\Delta\varphi = \frac{2\pi}{\lambda}(d_D - d_G) \quad (7)$$

where d_D and d_G are provided by (2) and (6), respectively.

Apart from the two-ray path loss model, the measured path loss is also compared with the *"Extended Hata"* model [27]. A rural/open area environment is assumed in this case; therefore, the path loss is given by:

$$\begin{aligned} PL = PL_U &- 4.78(\log_{10}[\min\{\max\{150, f\}, 2000\}])^2 \\ &+ 18.33\log_{10}[\min\{\max\{150, f\}, 2000\}] - 40.94 \end{aligned} \quad (8)$$

where f is the operating frequency in MHz, and PL_U the path loss considering the urban environment. The latter parameter can be calculated according to:

$$\begin{aligned} PL_U &= 46.3 + 33.9\log_{10}(2000) + 10\log_{10}(f/2000) \\ &-13.82\log_{10}(\max\{30, h_t\}) \\ &+(44.9 - 6.55\log_{10}(\max\{30, h_t\}))\log_{10}(d_D) - a(h_r) - b(h_t) \end{aligned} \quad (9)$$

where d_D is the direct ray distance, converted in kilometres, between Tx and Rx, and f the operating frequency in MHz. Further, $a(h_r)$ and $b(h_t)$, are the correction factors for the Rx and Tx, respectively, taking into account their specific heights h_r and h_t in meters. The correction factors are adopted for the rural/open area locations and can be calculated by:

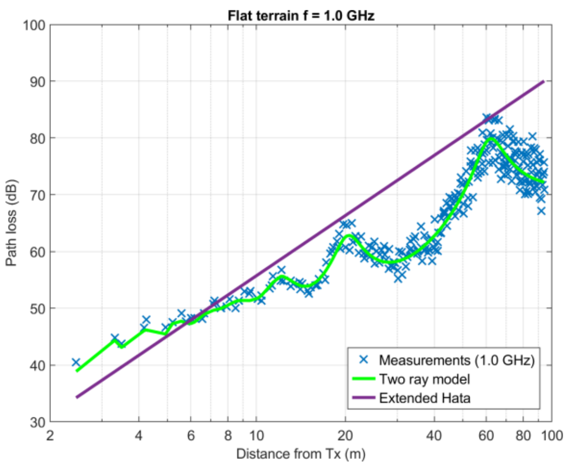
$$b(h_t) = \min\{0, 20\log_{10}(h_t/30)\} \quad (10)$$

and

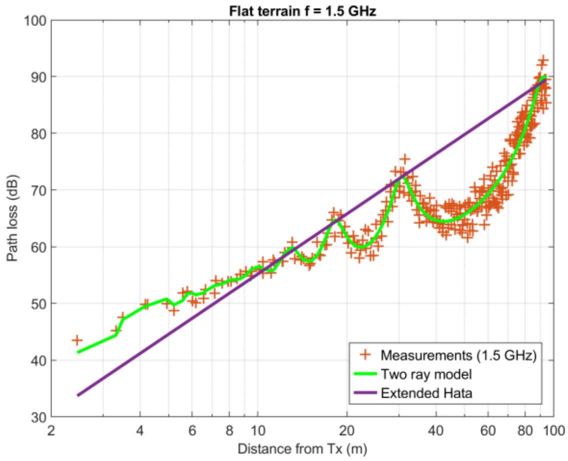
$$\begin{aligned} a(h_r) &= (1.1\log_{10}(f) - 0.7)\min\{10, h_r\} \\ &-(1.56\log_{10}(f) - 0.8) + \max\{0, 20\log_{10}(h_r/10)\} \end{aligned} \quad (11)$$

This model is widely used and is applicable for frequencies up to 3 GHz, and distances up to 40 km, respectively.

The results are presented in Fig. 3 where the path loss versus distance (in logarithmic scale) is provided along with the two different empirical models for comparison.



(a)



(b)

Figure 3. Path loss results versus distance. (a) 1.0 GHz. and (b) 1.5 GHz.

It is evident that "two-ray model" adapts better to the measured path loss, as it takes into account the geometrical characteristics of the propagating signal in the specific flat-terrain environment. On the other hand, the "Extended Hata model", predicts well the path loss in the first few meters (about 10 m for 1.0 GHz measurements, or about 15 m, for 1.0 GHz measurements), but diverges afterwards compared to the measured samples.

To compare quantitatively and validate the realized outcome, appropriate error metrics are applied, in order to analyze the statistical error of each model [28], [29]. The mean absolute error (MAE), in decibels, is given by:

$$\mathrm{MAE} = \frac{1}{N}\sum_{i=1}^{N}\left|PL_i^{meas} - PL_i^{pred}\right| \quad (12)$$

where PL_i^{meas} and PL_i^{meas} stand for the measured and predicted path loss values, respectively, and i is the index of the measured sample. Finally, N is the total number of path loss samples (279 at each frequency scenario). The mean absolute percentage error (MAPE) is calculated according to:

$$\text{MAPE} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{PL_i^{meas} - PL_i^{pred}}{PL_i^{meas}}\right| \times 100\% \quad (13)$$

Finally, the root mean square (RMS) error, which actually represents the shadow factor is given, in decibels, by:

$$\text{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(PL_i^{meas} - PL_i^{pred}\right)^2} \quad (14)$$

The prediction errors are computed in the following applying (12)-(14), for each assessed path loss model. An acceptable RMS error for a path loss model is 6-7 dB for urban locations, and higher than 10 up to 15 dB, for suburban and rural/open areas [30].

Table II summarizes the numerical results of the obtained error metrics for each model and frequency scenario.

TABLE II. Statistical results between measured and predicted path loss for Two-Ray (TR) and Extended Hata (EH) models at each frequency scenario

Model	Metric	1.0 GHz	1.5 GHz
TR	MAE [dB]	**1.8**	**1.7**
	MAPE [%]	**2.6**	**2.4**
	RMS [dB]	**2.3**	**2.1**
EH	MAE [dB]	**9.6**	**7.6**
	MAPE [%]	**14.4**	**11.3**
	RMS [dB]	**10.8**	**9.1**

The results in Table II reveal that "Two-Ray" (TR) model is better applicable in a near flat-terrain environment, that is much lower errors are obtained, as compared with the "Extended Hata" (EH) model. In terms of RMS error, TR model adjusts slightly better at 1.0 GHz, nevertheless the error values between the two frequency scenarios are comparable. On the other hand, despite the high errors, EH model adapts better at 1.5 GHz, which implies that is more suitable at higher frequency applications over flat-terrain. However, at 1.0 GHz the results are discouraging, delivering an RMS error of 10.8 dB, which is higher that the acceptable value of 10 dB for rural/open areas, as suggested in [30]. Therefore, based on the above analysis, EH empirical model is not recommended for accurate path loss predictions in flat-terrain scenarios. Instead, geometrical optics (GO) models, such as "TR model", are better applicable, providing accurate path loss predictions, thus being recommendable for such flat-terrain applications.

4. Conclusion

In this paper we presented an outdoor experimental measurement campaign of our research group from propagation of EM waves over flat terrain (at 1.0 GHz and 1.5 GHz) and compared the experimental results with the "two – ray" model, as well as with the "Extended Hata" propagation model. It was found that the former model ("two – ray" propagation model) provides very good accuracy to the measured data (as this might be expected in the "high frequency regime", examined here).

As future work, the authors intend to assess additional path loss models of theirs (obtained by them through their previous research experience on EM propagation problems over the terrain), and validate their suitability to predict accurately the path loss in near flat-terrain scenarios.

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