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# TUNING OF THE PROPAGATION MODEL ITU-R P.1546 RECOMMENDATION

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**Abstract**—In the present work, a precise optimization method is proposed for tuning the parameters of ITU-R P.1546 recommendation to improve its accuracy in VHF and UHF propagation prediction. In this optimization method, the genetic algorithm is used to tune the model parameters. The predictions of the tuned model are compared with those of the ITU-R P.1546 recommendation and verified in comparison with some electric field strength measurements obtained by utilizing the IS-95 pilot signal in a commercial CDMA network in rural Australia.

## 1. INTRODUCTION

With the rapid development of wireless communication at VHF and UHF bands, there is an increasing need for reliable point-to-area prediction tools in the planning of radiocommunication services. These prediction tools must include the characteristics of the particular zone in which the system is intended to be used. A semi-empirical method has been proposed in ITU-R P.1546 recommendation for reliable prediction of radio propagation at VHF and UHF bands [1]. This method can include the effects of terrain, scattering objects of the environment and other propagation conditions, among various factors and corrections.

The aim of this paper is to present an optimization algorithm which can improve the accuracy of ITU-R P.1546 recommendation for propagation modeling. Tuning of the empirical propagation models has been widely used to increase the accuracy of predictions [2–4], but, to the authors' best knowledge, optimization and tuning of ITU-R P.1546 model in particular is completely original. There are 21 tuneable parameters in the point-to-area prediction method of ITU-R P.1546 which provide a high degree of freedom for tuning the model.

On the other hand, this high degree of freedom and the complexity of the model formulas may cause divergence and instability in the tuning process. Therefore, some considerations should be addressed. Based on these considerations, we propose an optimization algorithm to tune the model parameters. In this algorithm, the genetic optimization technique [5–14] is used to perform a global search for the best set of parameters. The resulting tuned model is compared with the common ITU-R P.1546 model via some electric field measurements obtained by utilizing the IS-95 pilot signal in a commercial CDMA network in rural Australia. It should be noted that this comparison is presented to show the efficiency of the proposed algorithm in reduction of the prediction error. In practice, the algorithm can be used as a professional tool to obtain the tuned model parameters in every propagation zone, if a comprehensive set of measurement data is available.

## 2. MEASUREMENTS

The radio wave propagation measurements have been performed at 881.52 MHz by cooperation of the Commonwealth Scientific & Industrial Research Organization (CSIRO) and the Australian Telecommunications Cooperative Research Center (ATcrc), using a CDMA Pilot Scanner. The scanner, which is controlled by a laptop PC, is equipped with a global positioning system (GPS) and an omni-directional antenna at the height of 1.7 m above ground [15–17]. The collected test data have been originated from two measurement campaigns performed in rural Western Australia in June 2003 and May 2004 [16, 17] along a wide variety of measurement paths in macrocellular environment with different rural terrain. Only one pilot channel was received in these rural areas, limiting the effect of inter-cell interference [17]. The omni-directional transmitter antenna of the selected macrocell with the effective radiated power of 44.6 dBm, is located at the height of 30.5 m above ground.

## 3. PROCESSING OF THE MEASURED DATA

Before starting the optimization algorithm, the raw measured electric field must be processed. The resulted field strength is used as the processed measured field strength for comparison with the simulation results.

### 3.1. Extraction of the Field Strength for a Given Percentage of Time

According to ITU-R P.1546 recommendation [1], the field strength at each measurement point is calculated for a given percentage of time inside the range from 1% to 50%. This is done by fitting a normal distribution to the different electric field strengths which are measured at one measurement point. Thus, the field strength which will be exceeded for $t$% of times at each receiver location can be given by:

$$E(t) = E_T(median) + Q_i(t/100)\sigma_T \text{ dB}(\mu\text{V/m}) \quad (1)$$

where $E_T(median)$ is the median field strength with respect to the time at the receiver location, $Q_i(x)$ is the inverse complementary cumulative normal distribution as a function of probability and $\sigma_T$ is the standard deviation of normal distribution of the field strength at the receiver location.

### 3.2. Extraction of the Field Strength for a Given Percentage of Locations

According to ITU-R P.1546 recommendation [1], in area-coverage prediction methods, it is intended to provide the statistics of reception conditions over a given area, rather than at any particular point. The field strength value at $q$% of locations within an area represented by a square with a side of 200 m is given by:

$$E(q) = E_L(median) + Q_i(q/100)\sigma_L \text{ dB}(\mu\text{V/m}) \quad (2)$$

where $E_L(median)$ and $\sigma_L$ are the median and standard deviation of field strength over the defined area, respectively. It should be noted that $q$ can vary between 1 and 99.

## 4. DETERMINATION OF TRANSMITTING/BASE ANTENNA HEIGHT

As the terrain information is available, the transmitting/base antenna height, $h_1$, should be obtained as follow [1]:

For land paths shorter than 15 km, $h_1$ is equal to $h_b$, where $h_b$ is the height of the antenna above terrain height averaged between $0.2\,d$ and $d$ km where $d$ is the distance between the transmitter and the receiver.

For land paths of 15 km or longer, $h_1$ is equal to $h_{eff}$, where $h_{eff}$ is defined as the transmitter height in meters over the average level of the ground between distances of 3 and 15 km from the transmitting/base antenna in the direction of the receiving/mobile antenna.

## 5. THE FIELD STRENGTH PREDICTION FORMULAS

The following formulas are used according to the recommendation for field strength prediction:

$$l_d = \log_{10}(d) \tag{3}$$

$$k = \frac{\log_{10}\left(\frac{h_1}{9.375}\right)}{\log_{10} 2} \tag{4}$$

$$E_1 = \left(a_0k^2+a_1k+a_2\right) l_d+\left(0.1995k^2+1.8671k+a_3\right) \tag{5}$$

$$E_{ref1} = b_0\left[\exp\left(-b_4 10^{l_d^{b_5}}\right)-1\right]+b_1\cdot\exp\left[-\left(\frac{l_d-b_2}{b_3}\right)^2\right] \tag{6}$$

$$E_{ref2} = -b_6 l_d + b_7 \tag{7}$$

$$E_{ref} = E_{ref1} + E_{ref2} \tag{8}$$

$$E_{off} = c_5 k^{c_6} + \frac{c_0}{2}k\left\{1-\tan h\left[c_1\left(l_d-\left(c_2+\frac{{c_3}^k}{c_4}\right)\right)\right]\right\} \tag{9}$$

$$E_2 = E_{ref} + E_{off} \tag{10}$$

$$p_b = d_0 + d_1\sqrt{k} \tag{11}$$

$$E_u = \min\left(E_1, E_2\right) - p_b\log_{10}\left(1+10^{-\frac{|E_1-E_2|}{p_b}}\right) \tag{12}$$

$$E_{fs} = 106.9 - 20l_d \tag{13}$$

$$E_b = \min\left(E_u, E_{fs}\right) - 8\log_{10}\left(1+10^{-\frac{\left|E_u-E_{fs}\right|}{8}}\right) \tag{14}$$

$$Corrections = C_{e.r.p.} + C_{h_2} + C_{urban} + C_{t.c.a.} + C_{h_1<0} \tag{15}$$

$$E_c = E_b + Corrections \ \mathrm{dB}(\mu\mathrm{V/m}). \tag{16}$$

In the above equations, $d$ and $h_1$ are in km and m, respectively. $E_{fs}$ is the free space field strength and $E_b$ is the propagating field strength without considering the corrections (both for 1 kW effective radiated power). The parameters $a_0$, $a_1$, $\ldots$, $a_3$, $b_0$, $b_1$, $\ldots$, $b_7$, $c_0$, $c_1$, $\ldots$, $c_6$, $d_0$ and $d_1$ are given for nominal frequencies and time percentage in the recommendation. These coefficients are defined as the optimization parameters in the optimization algorithm. $C_{e.r.p.}$, $C_{h_2}$, $C_{urban}$, $C_{t.c.a.}$ and $C_{h_1<0}$ are the corrections for effective radiated power, receiving/mobile antenna height, short urban/suburban paths, terrain clearance angle and negative values of $h_1$, respectively. The related formulas for calculation of $C_{h_2}$, $C_{urban}$, $C_{t.c.a.}$ and $C_{h_1<0}$ can be found in [1]. The correction $C_{e.r.p.}$ must be added to $E_b$, if the effective radiated power of the transmitter antenna is not equal to the nominal value of 1 kW:

$$C_{e.r.p} = 10\log_{10}\left(\frac{ERP}{1000}\right) \tag{17}$$

To prevent any divergence of the optimization algorithm, Equations (34) and (41) of [1] have been rewritten in the form of (12) and (14), respectively.

## 6. OPTIMIZATION ALGORITHM

In the optimization algorithm, the parameters $a_0$, $a_1$, ..., $d_0$ and $d_1$ must be tuned to minimize difference between the predicted and measured electric field strengths:

$$\begin{aligned}\min_P MSE &= \min_P \frac{1}{n_m}\sum_{i=1}^{n_m}\left(E_{m_i} - E_{c_i}(P)\right)^2 \\ &= \min_P \frac{1}{n_m}\sum_{i=1}^{n_m}\left(E_{m_i} - E_c\left(P, d_i, h_{1_i}, \ldots\right)\right)^2\end{aligned} \tag{18}$$

where $n_m$ is the number of measurement points, $E_{m_i}$ is the processed measured electric field strength at the $i$th measurement point, $d_i$ and $h_{1_i}$ are the values of $d$ and $h_1$ in the $i$th measurement point, respectively and $E_{c_i}$ is the predicted field strength at that point using the set of model parameters, $P$:

$$P = (a_0, \ldots, a_3, b_0, \ldots, b_7, c_0, \ldots, c_6, d_0, d_1) \tag{19}$$

The corrections obtained by (15) do not depend on the optimization parameters and can be omitted from the optimization algorithm. Therefore, (18) can be rewritten as:

$$\begin{aligned}\min_P MSE &= \min_P \frac{1}{n_m}\sum_{i=1}^{n_m}\left(E_{bm_i} - E_{b_i}(P)\right)^2 \\ &= \min_P \frac{1}{n_m}\sum_{i=1}^{n_m}\left(E_{bm_i} - E_b\left(P, d_i, h_{1_i}\right)\right)^2\end{aligned} \tag{20}$$

where, $E_{bm_i} = E_{m_i} - Correction\,s_i$.

Table 1 shows that by using the tabulated model parameters, for distances up to 35 km, the value of $E_{ref1}$ is much lower than $E_{ref}$, and has negligible effect on the predicted field strength. Considering a wide variation range for those parameters which appear in $E_{ref1}$, $(b_0, b_1, \ldots, b_5)$, will cause an unacceptable increase in $E_{ref1}$ during the tuning process. This may cause a decrease in $E_{ref2}$ or $E_{off}$ which makes the optimization process unstable. To overcome this difficulty, the variation range of these parameters should be limited during the optimization process, especially when most of the measurement points are at distances less than 35 km from transmitter.

**Table 1.** $|E_{ref1}/E_{ref}|$ for different distances from 1 km to 35 km at 100 MHz, 600 MHz and 2000 MHz for $t = 50\%$.

| | $d$(km) | 1 | 5 | 10 | 15 | 25 | 35 |
|---|---|---|---|---|---|---|---|
| $\left\lvert\frac{E_{ref1}}{E_{ref}}\right\rvert$ | 100 MHz | $4.1\times 10^{-8}$ | $9.9\times 10^{-9}$ | $2.3\times 10^{-5}$ | $2.7\times 10^{-4}$ | $3.7\times 10^{-3}$ | $1.7\times 10^{-2}$ |
| | 600 MHz | $2.2\times 10^{-6}$ | $5.2\times 10^{-5}$ | $1.4\times 10^{-3}$ | $6.8\times 10^{-3}$ | $3.8\times 10^{-2}$ | $1.0\times 10^{-1}$ |
| | 2000 MHz | $4.9\times 10^{-8}$ | $7.6\times 10^{-6}$ | $3.6\times 10^{-4}$ | $2.6\times 10^{-3}$ | $2.3\times 10^{-2}$ | $8.5\times 10^{-2}$ |

As it is mentioned, the high number of tuning parameters and the complexity of the model formulas may cause divergence and instability in the algorithm. In order to tune the model parameters, a global optimization method must be applied to the problem. Among these methods, the genetic algorithm [18] may be a superior option. Applying this algorithm, one should obtain the values of the model parameters in such a way that the following objective function becomes minimum:

$$objFun(P) = \frac{1}{n_m}\sum_{i=1}^{n_m} t\left(E_{bm_i} - E_b\left(P, l_{d_i}, k_i, E_{fs_i}\right)\right)^2 \qquad (21)$$

By knowing $l_{d_i}$, $k_i$, $E_{fs_i}$ and $E_{bm_i}$ for all the measurement points, the objective function is obtained for each set of the model parameters, $P$, during the optimization process. Applying the genetic algorithm results in the vector $P_{1opt}$, which contains the optimum values for the parameters $a_0$, $a_1$, …, $a_3$, $b_0$, $b_1$, …, $b_7$, $c_0$, $c_1$, …, $c_6$, $d_0$ and $d_1$.

## 7. EVALUATION OF THE TUNED MODEL

In order to compare the predictions with the measurements, the electric field strength in the measurement points is computed by both ITU-R P.1546 and tuned model parameters. Two sets of field strengths are resulted from these computations. To evaluate these predictions, we compare them with the measurements by defining the prediction error at each measurement point as follows:

$$Error_{i\,\substack{P.1546\\opt}} = \left| E_{m_i} - E_{c_i}\left(P_{\substack{P.1546\\opt}}\right)\right|. \qquad (22)$$

where, $P_{P.1546}$ and $P_{opt}$ are ITU-R P.1546 and tuned model parameters, respectively.

The maximum and mean prediction errors are obtained by:

$$MaxError_{\substack{P.1546\\opt}} = \max_i \left(Error_{i\,\substack{P.1546\\opt}}\right) \qquad (23)$$

$$MeanError_{\substack{P.1546\\opt}} = \frac{1}{n_m}\sum_{i=1}^{n_m} Error_{i\,\substack{P.1546\\opt}}. \qquad (24)$$

The prediction error's standard deviation is obtained by:

$$StDError_{\substack{P.1546\\opt}} = \sqrt{\frac{1}{n_m}\sum\left(Error_{i\,\substack{P.1546\\opt}} - MeanError_{\substack{P.1546\\opt}}\right)^2} \qquad (25)$$

In the above equations, the subscripts $P.1546$ and *opt* are referred to the values obtained by the ITU-R P.1546 and tuned model parameters, respectively.

## 8. SIMULATION RESULTS

In order to investigate the efficiency of the mentioned tuning algorithm, five measurement paths are selected. Fig. 1 shows these measurement paths and the transmitting antenna location in the longitude-latitude plane. The measured electric field strengths are processed for 50% time and 50% locations according to ITU-R P.1546. We divide the total measurement points of these paths into two equal parts. This is down by completely random selection of half of the points and put them in one part and set the others in another part. The first part is applied in the optimization algorithm to obtain the tuned parameters. The second part is taken away from this algorithm and just used for

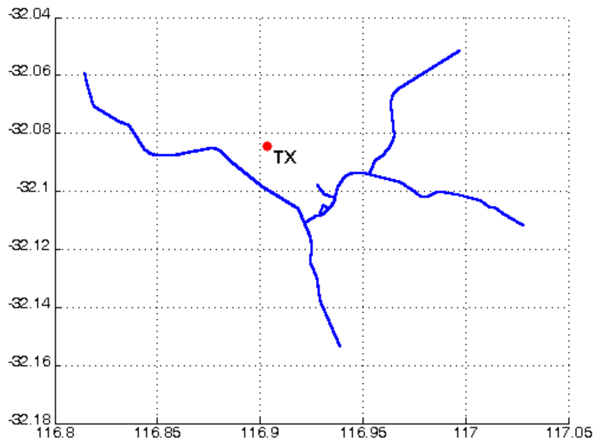


**Figure 1.** Measurement paths and transmitting antenna location in the longitude-latitude plane.

verification. Then, the predictions of the tuned model are compared with the measurements and ITU-R P.1546 recommendation results at those measurement points which are chosen for verification.

Actually, in the recommendation, the parameter values are given just for nominal frequency values of 100, 600 and 2000 MHz. Based on the recommendation, the field strength values for a given frequency should be obtained by interpolation between the values for the nominal frequencies or in the case of frequencies below 100 MHz or above 2000 MHz, by extrapolation from the two nearer nominal frequency values. Therefore, we have to obtain ITU-R P.1564 field values at the operating frequency of 881.52 MHz by interpolation between the field values for the nominal frequencies of 600 and 2000 MHz.

By using the first part of the measurement points, the tuned parameters are obtained at 881.52 MHz and compared with the original parameters of the recommendation model in Table 2. As can be seen in Table 3, the maximum and mean prediction errors and the prediction error's standard deviation of ITU-R P.1546 recommendation are 55.63 dB, 13.22 dB and 11.32 dB, while these values are reduced to 35.81 dB, 7.74 dB and 6.50 dB, respectively for the tuned model. In Fig. 2, a comparison is made between the predicted and measured electric field strengths of path1 to path5. It should be noted that the prediction error of the tuned model can be more reduced if the tuned parameters are obtained based on the comprehensive measurements for different transmitter-receiver distances in the whole propagation zone.

**Table 2.** Comparison between the parameters of ITU-R P.1546 recommendation and tuned model for 50% time.

| | 600 MHz | 2000 MHz | Tuned(881.52 MHz) |
|---|---|---|---|
| $a_0$ | 0.0946 | 0.0946 | 0.0196 |
| $a_1$ | 0.8849 | 0.8849 | 0.1098 |
| $a_2$ | −35.399 | −35.399 | −11.183 |
| $a_3$ | 92.778 | 94.493 | 78.162 |
| $b_0$ | 51.6386 | 30.0051 | 31.6071 |
| $b_1$ | 10.9877 | 15.4202 | 17.9832 |
| $b_2$ | 2.2113 | 2.2978 | 2.3371 |
| $b_3$ | 0.5384 | 0.4971 | 0.5080 |
| $b_4$ | $4.323 \times 10^{-6}$ | $1.677 \times 10^{-7}$ | $3.1538 \times 10^{-6}$ |
| $b_5$ | 1.52 | 1.762 | 1.736 |
| $b_6$ | 49.52 | 55.21 | 29.86 |
| $b_7$ | 97.28 | 101.89 | 105.95 |
| $c_0$ | 6.4701 | 6.9657 | 7.0786 |
| $c_1$ | 2.9820 | 3.6532 | 4.8087 |
| $c_2$ | 1.7604 | 1.7658 | 2.7312 |
| $c_3$ | 1.7508 | 1.6268 | 1.4085 |
| $c_4$ | 198.33 | 114.39 | 311.11 |
| $c_5$ | 0.1432 | 0.1309 | 0.7798 |
| $c_6$ | 2.2690 | 2.3286 | 1.9407 |
| $d_0$ | 5 | 8 | 5.1049 |
| $d_1$ | 1.2 | 0 | 1.2230 |

**Table 3.** Comparison between ITU-R P.1546 recommendation and tuned model.

| Error | ITU-R P.1546(dB) | Tuned model(dB) |
|---|---|---|
| Maximum error | 55.63 | 35.81 |
| Mean error | 13.22 | 7.74 |
| Error's standard deviation | 11.32 | 6.50 |

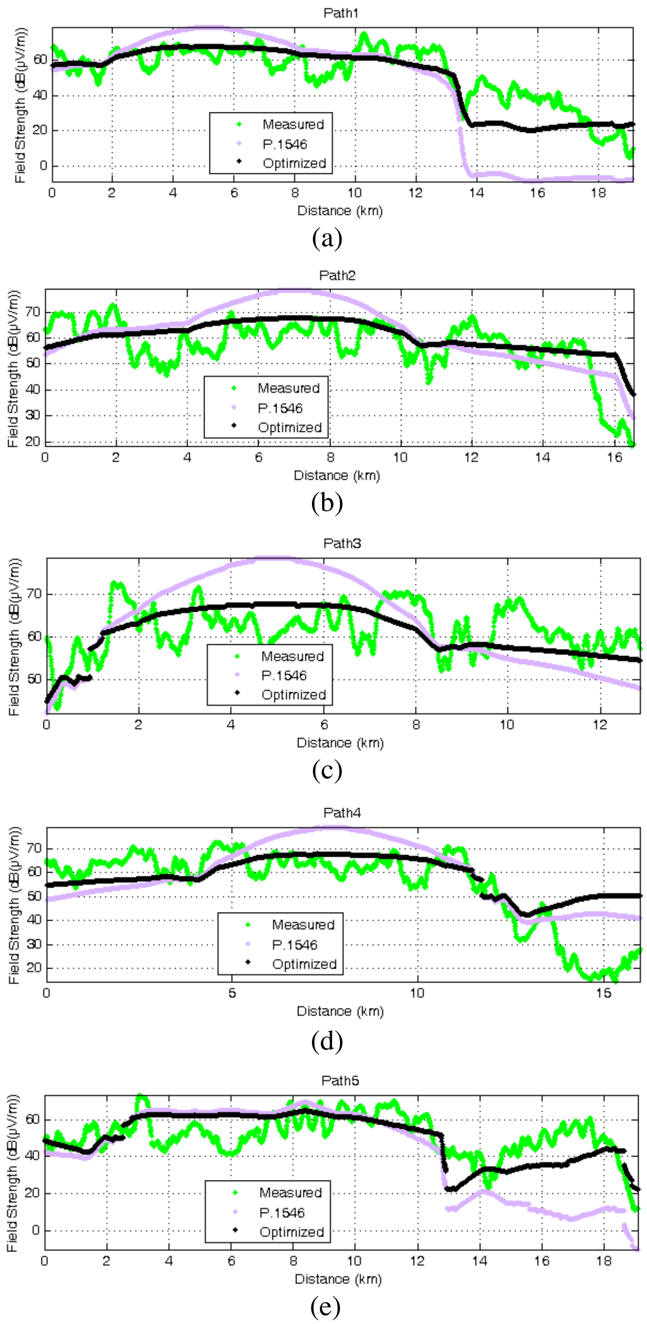


**Figure 2.** Comparison of the tuned model with the measurements and ITU-R P.1546 for measurement paths.

## 9. CONCLUSION

An optimization algorithm was proposed and illustrated in this paper to tune the parameters of ITU-R P.1564. This tuning method was verified in comparison with the measurements performed by utilizing the IS-95 pilot signal of a commercial CDMA mobile network in the rural environment. The comparison results show a high degree of reduction in the prediction error.

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