Research Journal of Applied Sciences, Engineering and Technology 8(13): 1578-1584, 2014
DOI:10.19026/rjaset.8.1136
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: June 20, 2014 Accepted: August 03, 2014 Published: October 05, 2014

Research Article

A New Statistical Algorithm Based on the Conventional Lee's Path Loss Model for the 900 and 1800 MHz

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Abstract: The aim of this proposed technique is to optimize the prediction quality and to minimize the overall measured RMSE error of the original Lee's path loss model. The new technique is a statistical algorithm based on the concept of mean value normalization that has a wide range of applications. Statistical path loss models, such as Lee's model, are assumed as major prediction models used primarily in the pre-planning procedures to pre-estimate losses and minimize the overall cost. Lee's model as a major prediction model is well known to accurately predict such losses in diverse landscape criteria's. As compared to the original model, the new proposed technique has demonstrated better RMSE accuracy. Less RMSE, of an average of 3-4 dB's is obtained in most macro-cell open areas in the area of Jiza town, south of Amman city, Jordan. Examples are provided in both the 900 MHz and the 1800 MHz to signify the enhancement of the prediction accuracy of the new proposed algorithm.

Keywords: Large scale path loss models, model optimization, statistical parameters

INTRODUCTION

Lee's model is one of the major prediction models that are widely accepted as an accurate statistically based model. It was proposed in 1982 by Lee (1985) after conducting extensive experimental measurements in different USA cities with diverse variation in landscape structures. The model was originally proposed for the 850 MHz band by inserting the local averages for a stream of received signal strengths known as bins. Corrections for other bands were made possible by inserting a relative frequency modification fraction. Real collected received power data are used in order to fine tune the Lee's model and to establish the required training procedure based on the provided original set. The general proposed model by Lee is of the form:

$$Pl = L_0 + \alpha\ log\left(\frac{R}{R_{ref}}\right) - 10\ log(F_1F_2F_3F_4F_5) + 10\log\left(\frac{P_{tx}}{P_{txREF}}\right) \tag{1}$$

where,

$$F_1 = \left(\frac{h_b}{30.48}\right)^2 \tag{2}$$

$$F_2 = \left(\frac{G_b}{4}\right) \tag{3}$$

$$F_3 = \begin{cases} \left(\frac{h_m}{3}\right)^2 \text{for } h_m > 3 \\ \left(\frac{h_m}{3}\right) \text{for } h_m < 3 \end{cases} \tag{4}$$

$$F_4 = G_m \tag{5}$$

$$F_5 = \left(\frac{f}{900}\right)^{-n} \tag{6}$$

The variables are as given in Table 1.

The set of data used in Lee's experiments ranges from basic suburban areas into dense metropolitan areas in USA and other some major cities worldwide as shown in Table 2. For the case of the suburban areas a Path loss slope of 38.4 dB/dec. and an intercept point of 53.9 dB (or with the A parameter of 99.86 dB) were reported. Other city structure category embodies intense metropolitan areas such as the Tokyo city which was represented by a slope of 30.5 dB/dec. and an intercept point of 77.8 dB (or with the A parameter of 123.77 dB). The difference in these two parameters, the slope and the intercept point, between disparate areas landscape was related to the different impact of two major factors that would affect the propagation of signals (Lee, 1985, 1992, 1993, 1997; Lee and Lee, 2000):

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Table 1: List of the variables used in Lee's conventional model

Pl	Received signal level, the mean signal level received at the distance R from the transmitter (dB)
L_0	The signal strength expected for reference conditions $R_{REF}h_{bREF}P_{txREF}h_{mREF}$
α	The slope, the rate of decay in signal strength (dB/decade)
R	The distance from the transmitter
R_{REF}	The reference distance
h_b	The height of the base transmit antenna
h_m	The height of the mobile receive antenna
h_{mREF}	The reference height of the mobile receive antenna
f	Operating frequency
G_b and G_m	Base antenna and mobile antenna gains, respectively
n	Frequency adjustment factor takes values between 2 and 3
P_{tx}	P_{tx} the transmit ERP
P_{txREF}	The reference transmit ERP

Table 2: Lee's model parameters for different areas

Area and type	A	B
Tokyo (urban)	123.77	30.5
New work (urban)	101.20	43.1
Philadelphia (urban)	108.49	36.8
Sub-urban	99.86	38.4
Rural	86.12	43.5
Free space	96.92	20.0

- Manmade structures and clutters
- Natural terrain

Thus in the original Lee's model the effect of each of the above mentioned factors were dealt with separately (Lee and Lee, 2000).

In Lee and Lee (2000) claimed that the careful averaging process of path losses through the radio-path would wipe out terrain variations and thus would reveal the losses due to manmade structures. The drawback of this averaging process is that it would produce an area path loss pattern that may be assumed not desirable if the detailed effect of the terrain is preferred.

To accommodate the effect of the natural terrain, the normalization process described in Lee and Lee (1997) may be implemented to eliminate the effect of terrain landscape on the received signal. Though may be considered accurate as has been claimed, the insertion of the mentioned normalization process on each measured point is not an easy task. In addition, high resolution terrain data is required to perform such a procedure that may complicate the calculation process, if such data is assumed to be obtained.

In his basic suggestion of the model, Lee's claimed that the proposed mathematical procedure would convey prediction accuracy within a ±3 dB. Major studies, though, revealed that the prediction accuracy of lee's model lay below the expected level of precision in different landscape structures and in different frequency ranges (Xu *et al*., 2010; Evans *et al*., 1997). This may be attributed to different reasons. Among them is the terrain roughness extent that may cause additional losses and has been covered in later extension of the model as proposed in Lee and Lee (2000). The second cause is the manmade structure effect. The extent of such structures differs significantly from the areas where the original Lee's model was conducted. Finally, the correction provided by Lee for different frequency ranges was also proved to be not as accurate as expected (Evans *et al*., 1997). Therefore many proposed studies have adopted different scale of optimization to suit Lee's model in their area of measurements. The deviation of Lee's model in the given area of studies has been reported in the range of 5-10 dB (Xu *et al*., 2010; Evans *et al*., 1997; Nissirat *et al*., 2012). Optimization of Lee's model is managed through different mathematical or statistical techniques to minimize the overall RMSE error and to obtain a more accurate prediction level.

The optimization process proposed in Evans *et al*. (1997) may be found less complex. The technique proposed was meant to test the validity of Lee's model for the 1900 MHz prediction. Results showed that predicted losses in flat areas deviates in an average of 5-6 dB from the actual measured losses. More deviation in the range of 9-10 dB is calculated for areas of more rough terrain topology. Concluded remarks signify the validity of Lee's model in the given range.

The objective of this study is to introduce a new statistical algorithm, which relies on the original Lee's path loss model and is based on data normalization over the mean (average) value. This new proposed technique uses the same mathematical structure originated by Lee; though depart from the original model by the statistical management used to perform the path loss calculations. Followed sections would first introduce the specifications of the measurement campaign along with the details of the area under test. Then the new statistical method of conduction is proposed and mathematically derived. Finally, examples are presented to verify the accuracy of the proposed model as compared to the original Lee's model.

DATA SET AND MEASUREMENT CAMPAIGN

Principally, statistical analysis relies heavily on available data. Such data either be collected by the researchers in the field or obtained from original sources for analytical study. In this study, received power data obtained from mobile service providers working in the Hashemite Kingdom of Jordan. These data where obtained from two companies, as a result of

Fig. 1: Route of data collection through the airport road to Jiza town. Length of about 35 km. Dimensions 40×35 km. Google earth (2012)

Table 3: Classification of the open area category compared to other area categories

Area category	Urban	Suburban	Open
Building levels	Beyond 4 levels	2-4 levels	2 levels and less
Heights meters	Beyond 15 m	10-15 m	7-10 m

a drive test campaign, the first named Umniah, working in the frequency band of 1800 MHz and the second called Zain working in the frequency band of 900 MHz. Data collected with the aid of a Global Positioning System (GPS) device contained among others, longitude, latitude and altitude readings of both of the transmitter and the route taken by the receiver. The set of data used in this study where mainly from two locations. The first location is through the airport road and had collected path-loss readings starting from the west of Amman city down to Jiza town of a length of about 30-40 km as shown in Fig. 1.

The data that suit the class of an open area was extracted, were the open area category was assumed as per the classification given in Table 3. The second location was around the center of Jiza town which was considered also as an open area as shown in Fig. 2. Scattered building of a single to two floors, 8-12 m of altitude is the most prevailed structures in the open area case.

The transmitters are mainly of omni-directional Kathrein antennas and are mounted on towers of about 20-30 m above ground levels as shown in Fig. 3. During the drive test campaign, the calculated average speed of the car was 30-40 km with an average measuring sample rate of 3-4 samples/m.

METHODOLOGY

The measurements are conducted for macro-cell scenarios in open areas with almost flat landscape profile. Using datasets collected from open areas facilitates focusing on the effect of the natural terrain variation on the accuracy of estimating the path-loss parameters. The need of terrain normalization described in Lee (1992) and Lee and Lee (1997) is not needed in such a case were the effect of the buildings and manmade structures is assumed minimum. Assuming an n of statistically independent path-loss datasets arranged as columns of the matrix $\overline{Y} = [Y_1 Y_2 \dots Y_n]$, where each dataset Y_i contains r number of samples, hence $\overline{Y}$ is $r \times n$ matrix. The path-loss is measured with respect to the travelled distance x producing a pair of data for each point (x_m, Y_i^m), $m = 1 \dots r$ and $i = 1 \dots n$.

In the conventional Lee's model, the intercept and the slope of the path-loss curve are calculated for each dataset Y_i using the least square method (Lee, 1985, 1992; Lee and Lee, 2000; Alotaibi *et al*., 2008). Therefore, each pair of data (x_m, Y_i^m) is related according to the linear fitting:

$$Y_i^m \cong C_i + D_i x_m \tag{7}$$

Fig. 2: Routes of Jiza town south of Amman city. Dimensions 8×8 km, Google Earth (2010)

Fig. 3: Picture of the transmitter used for the 900 MHz, airport road, Jiza town, Amman, Jordan

where, C_i and D_i, are the intercept and the slope, respectively for the dataset Y_i. Then the intercept and the slope in Lee's model would be calculated as the average of the intercept and the slope of every dataset:

$$C = \frac{\sum_{k=1}^{n} C_i}{n} \; and \; D = \frac{\sum_{k=1}^{n} D_i}{n} \quad (8)$$

In the proposed method, each dataset is first statistically scaled and shifted producing a transformed dataset Y_i^* presented as (Lee, 1985, 1992; Lee and Lee, 2000):

$$Y_i^* = \frac{K_i Y_i - \mu_{Yi}}{\sigma_{Yi}} \text{ for i =1,...n} \quad (9)$$

where,

K_i : A scaling factor for the dataset Y_i

μ_{Yi} and σ_{Yi} : The mean and the standard deviation of the dataset Y_i

The average of the scaled and shifted datasets is then fitted using the least square method to calculate the normalized intercept and slope (Liping *et al*., 2009). For each point in the scaled and shifted dataset Y_1^{*m}:

$$\frac{Y_1^{*m} + Y_2^{*m} + \cdots + Y_n^{*m}}{n} \cong C_{norm} + D_{norm} x_m, \text{ for } m = 1\ldots r \quad (10)$$

Which is equivalent to:

$$\frac{\frac{K_1 Y_1^m - \mu_{Y1}}{\sigma_{Y1}} + \frac{K_2 Y_2^m - \mu_{Y2}}{\sigma_{Y2}} + \cdots + \frac{K_n Y_n^m - \mu_{Yn}}{\sigma_{Yn}}}{n} \cong C_{norm} + D_{norm} x_m \quad (11)$$

Rearranging (11) we would have:

$$\frac{K_1 \prod_{j=2}^{n} \sigma_j Y_1^m + K2 \prod_{\substack{j=1 \\ j\neq 2}}^{n} \sigma_j Y_2^m + \cdots + K_n \prod_{\substack{j=1 \\ j\neq n}}^{n-1} \sigma_j Y_n^m}{n} \cong C_{norm} \prod_{j=1}^{n} \sigma_j + D_{norm} \prod_{j=1}^{n} \sigma_j \, x_m + \left(\frac{\left(\prod_{j=2}^{n} \sigma_j \mu_1 + \prod_{\substack{j=1 \\ j\neq 2}}^{n} \sigma_j \mu_2 + \cdots + \prod_{\substack{j=1 \\ j\neq n}}^{n-1} \sigma_j \mu_n \right)}{n} \right) \quad (12)$$

For the fitting line to represent the datasets Y_i, the scaling factors should be:

$$K_i = \frac{1}{\prod_{\substack{j=1 \\ j\neq i}}^{n} \sigma_j} \quad (13)$$

For each dataset Y_i, nullify the effects of antenna heights and gain.

$$Y_i' = Y_i - 10\log\left(\frac{h_b}{h_{bref}}\right) - 10\log\left(\frac{h_m}{h_{mref}}\right)$$

↓

Calculate the standard deviation and mean of each dataset Y_i'.

↓

Scale and shift each dataset Y_i' as follows:

$$Y_i^* = \frac{Y_i}{\prod_{j=1}^{n}\sigma_j} - \frac{\mu_i}{\sigma_i}$$

↓

Compute the average of the scaled and shifted dataset:

$$Y_{mean} = \frac{Y_1^* + Y_2^* + \cdots + Y_n^*}{n}$$

↓

Fit the averaged dataset Y_{mean} to linear relation using least square method:

$$Y_{mean} = C_{norm} + D_{norm}\log(distance\ in\ km)$$

↓

Lee's path-loss intercept point and slope are:

$$intercept = C_{norm}\prod_{j=1}^{n}\sigma_j + \left(\frac{\left(\prod_{j=2}^{n}\sigma_j\mu_1 + \prod_{\substack{j=1\\j\neq 2}}^{n}\sigma_j\mu_2 + \cdots + \prod_{\substack{j=1\\j\neq n}}^{n-1}\sigma_j\mu_n\right)}{n}\right)$$

$$slope = D_{norm}\prod_{j=1}^{n}\sigma_j$$

Fig. 4: Flow chart of the proposed procedure

Substituting K_i into Eq. (9), the scaled and shifted data can be written as:

$$Y_i^* = \frac{Y_i}{\prod_{j=1}^{n}\sigma_j} - \frac{\mu_i}{\sigma_i} \tag{14}$$

This procedure is summarized in the following flowchart given in Fig. 4.

RESULTS AND EXAMPLES

Two locations, one is for the 900 MHz band and the other is for the 1800 MHz were used as examples to demonstrate the validity of this proposed method. The first location was through the airport road crossing the Jiza town with a measured length of about 3 km as shown in Fig. 5.

The calculated intercept value and slope applying Lee's conventional path-loss method were 121 dB and 26.5 dB/dec, respectively. The calculated values obtained by the proposed method were 115.6 dB for the intercept value and 32.9 dB/dec for the slope. Obtained RMSE of 3.83 dB is calculated for the conventional method as compared to 6 dB for the Lee's conventional method. The best fitting line RMSE was measured with a deviation of 3.35 dB as shown in Fig. 6.

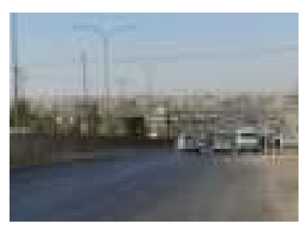

Fig. 5: The route taken for the example of the 900 MHz band, airport road, Jiza town

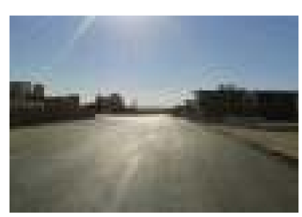

Fig. 6: The route taken for the 1800 MHz example

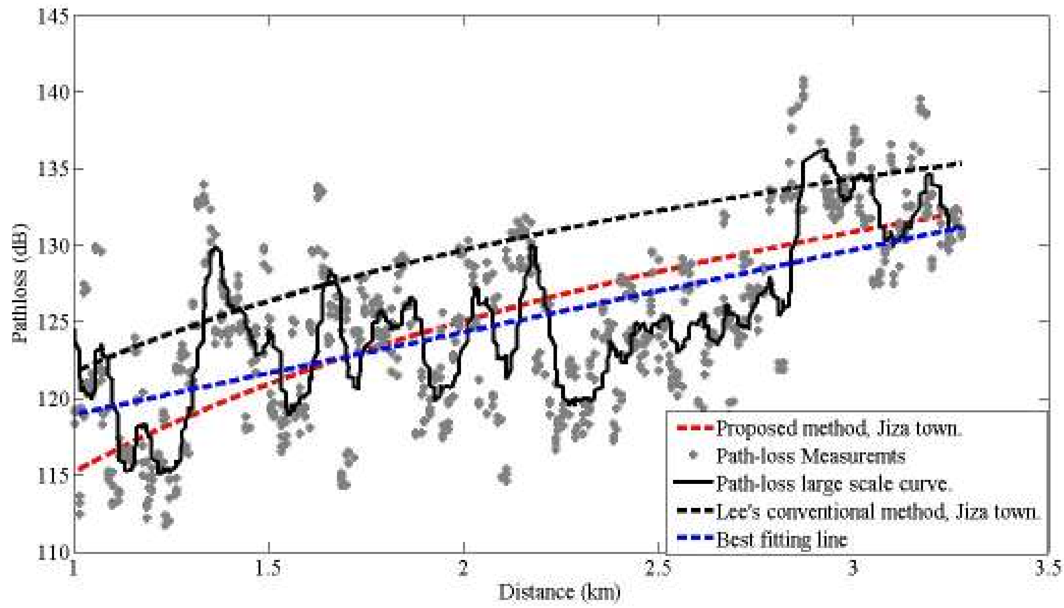

Fig. 7: Path-loss prediction curve using the proposed method as compared to Lee's conventional method and the best fitting line

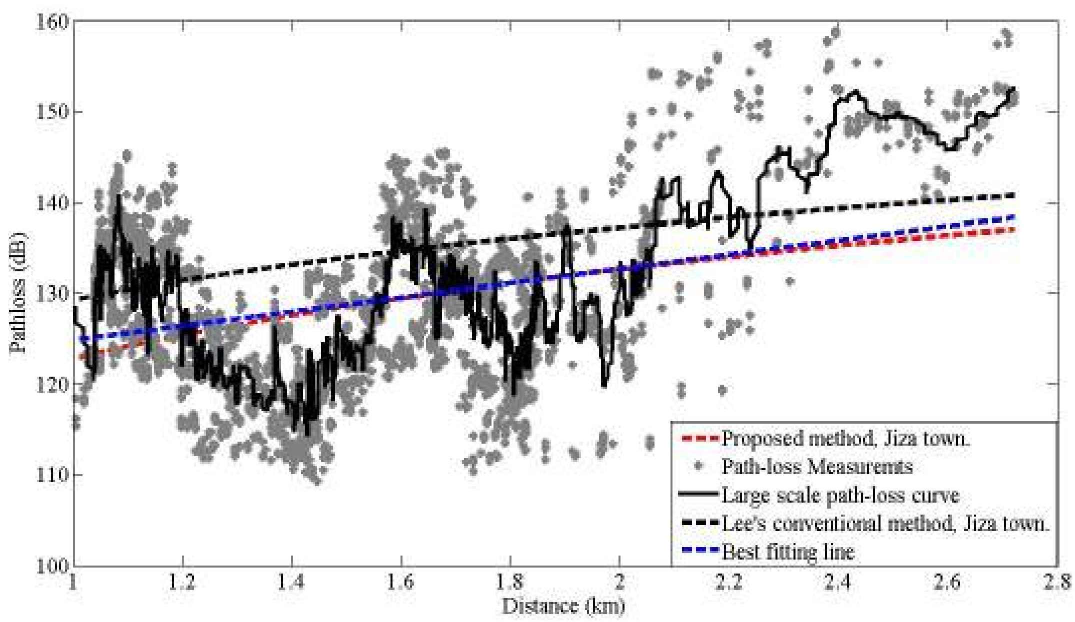

Fig. 8: Path-loss prediction curve of the proposed method 1800 MHz, as compared to Lee's conventional method and the best fitting line

Table 4: RMSE comparison values for different routes in Jiza town

Area	Proposed method RMSE	Conventional method RMSE	Best fitting line RMSE
Jiza town route 2 900 MHz	3.90	7.09	2.80
Jiza area route 3 900 MHz	3.99	8.54	3.79
Jiza town route 2 1800 MHz	3.80	6.59	3.42
Jiza town route 3 1800 MHz	5.91	9.76	4.89

The 1800 MHz route is located in the suburb of Jiza town. The drive test was along a road of 3 km length where scattered buildings not more than 10 m of altitude were present as shown in Fig. 7. An RMSE of 3.8 dB is measured for the proposed method as compared to 6.6 dB for the original Lee model as shown in Fig. 8. The improved RMSE values obtained signifies the importance and advantages of the proposed method as compared to the original Lee model.

Table 4 summarizes the obtained RMSE, of some other routes taken in this study, for both the 900 and 1800 MHz bands as compared to the conventional Lee model.

CONCLUSION

This paper emphasizes the effect of statistically scaling and shifting the obtained path-loss datasets on improving the estimation of Lee's path-loss parameters. Statistical Scaling and shifting brought datasets collected from different areas into an absolute common average and deviation values. Such procedure would rather reduce the effects of terrain variations on the collected datasets. The proposed method has been applied on datasets collected from 20 different sites for both the 900 and 1800 MHz bands. In both frequency ranges the proposed method predicted the path-loss more accurately as compared to the conventional method. It is worth to note that the maximum obtained deviation of the proposed method prediction from the best fitting line is about 1 dB. Moreover, the proposed method prediction accuracy outperformed the conventional method by up to 4-5 dB.

ACKNOWLEDGMENT

The authors would express their appreciation to the support of this study under the governmental grant number Oup-2014-182.

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