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MACRO-CELL PATH LOSS PREDICTION, CALIBRATION, AND OPTIMIZATION BY LEE'S MODEL FOR SOUTH OF AMMAN CITY, JORDAN AT 900, AND 1800 MHZ

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ABSTRACT

This paper addresses a path loss prediction and optimization by means of Lee's model for Jiza town, south of Amman city, Jordan. Data were collected from mobile companies in Jordan in the frequency band of 900, and 1800 MHz. The calibrated Lee's, Hata, and Egli's path loss models were compared with respect to the original collected data. It is found that for the 900 MHz Lee's prediction model has the least RMSE among other compared models, and thus is best fit such areas. On the other hand, the 1800 MHz has higher RMSE deviation compared to Egli's model. Therefore, to realize least RMSE, an optimization factor is proposed. A new frequency reliance of the optimization factor is reported; so as a frequency dependent relation is proposed. The new factor is justified in accordance with physical differences between the 1800 MHz and the 900 MHz propagation mechanism. After optimization, minimal RMSE value is obtained for Lee's model, and examples are given for comparison.

Keywords: *Path Loss Models, Optimization Parameters, Macro Cell Propagation*

1. INTRODUCTION

Minimum power prediction for the transmission of microwave mobile systems is one of the essential factors researchers are aiming. Such need is of great concern to achieve higher quality standards, lower over all running cost, minimize transmit power, better covering of different areas with different environmental situations.

Propagation path loss models are proposed in different area criteria's such as in macro cells, micro cells, and none the less inside buildings. These models are based on observations and measurements of power loss in different areas. all of the models depend on many parameters such as distance range, building criteria, terrain landscape, operating frequency, transmit and receive antenna heights [1]. However, most models are not efficiently suitable for all study cases. As an example, different cases are noted in Amman city, Jordan [2].

In this paper, a calibration and optimization parameter for Lee's macro-cell model is proposed for Jiza town south of Amman city. This area is considered an open area with flat landscape distribution. This calibration is compared with Hata and Egli's model for the purpose of evaluation completeness. A new optimization parameter is proposed in order to achieve minimum RMSE between the new proposed and the actual calculated path loss. In the following section a brief introduction of these models are given for reference.

2. PROPAGATION MODELS

In wireless channels, path loss prediction is a critical stage of planning enables the effective tuning of transmitted power, maximize coverage area and obtain highest quality of service in addition to considerable cut in over all plan cost. In this section, a number of propagation models are presented for reference

A. HATA'S MODEL

Originally, this model was introduced to urban areas. Correction factors were introduced to account for suburban and rural areas. It is valid for the range of distances from 1 – 100 km [3, 4].

The main equation of path loss urban relation is given as

$$L_{(urban)}(dB) = 69.55 + 26.16\log(f_c) - 13.82\log(h_r) - a(h_r) + (44.9 - 6.55\log(h_t))\log(d) \quad (1)$$

The expression of suburban areas is

$$L_{(suburban)}(dB) = L_{(urban)} - 2\left[\log\left({f_c}/{28}\right)\right]^2 - 5.4 \quad (2)$$

And for open rural areas, it is as

$$L_{(open)}(dB) = L_{(urban)} - 4.78(\log(f_c))^2 + 18.33\log(f_c) - 40.94 \quad (3)$$

The correction factor, $(a(h_r))$, in the basic equation, differs as a function of the size of the coverage area.

For small and medium areas, it is

$$a(h_r) = (1.1\log(f_c) - 0.7)h_r - (1.56\log(f_c) - 0.8) \quad (4)$$

For large area, it is

for $f_c < 300$MHz

$$a(h_r) = 8.29(\log(1.54h_r))^2 - 1.1dB \quad (5.a)$$

and

for $f_c > 300$MHz

$$a(h_r) = 3.2(\log(11.75h_r))^2 - 4.97\,dB \quad (5.b)$$

In the above equations, d is the distance between transmit and receive antennas, f_c represents the operating frequency from 150MHz to 1500MHz. h_t, the transmit antenna height from 30m to 200 m, and h_r the receive antenna height from 1m to 10m [4].

B. EGLI'S MODEL

This model is introduced by John Egli in 1957, and is assumed a terrain dependent model and it is based originally on the free space propagation model [5]. It is applicable for frequency range of 40 – 900 MHz and for distance ranges less than 60 km. The propagation path loss relations are given as follows

for $h_m \leq 10$ meter

$$L_t(dB) = 76.3 + 40\log(d) - 20\log(h_b) - 10\log(h_m) + 20\log(f_c) \quad (6.a)$$

for $h_m > 10$ meter

$$L_t(dB) = 85.9 + 40\log(d) - 20\log(h_b) - 10\log(h_m) + 20\log(f_c) \quad (6.b)$$

where, h_b is the height of the base station antenna. h_m is the height of the mobile station antenna. d is the Distance from base station antenna, where all distances are ranged in meter, and f_c is the frequency of transmission in megahertz [5].

C. LEE'S MODEL

The original Lee's model is proposed for flat terrain areas. The path loss relation depends on two main factors mainly P_{r0}, the power received at the intercept point, and γ, the path loss slope. General Lee's equation is given a

$$L_t = P_t - P_r \quad (7)$$

Or as

$$L_t = P_t - P_{ro} + 10\gamma\log\left(\frac{d}{d_o}\right) + 10n\log\left(\frac{f}{f_o}\right) - 10\log(\alpha_o) \quad (8)$$

where P_t is the transmit power signal. P_r is the received power at linkage distance d. P_{r0} is the received power at the intercept point, γ the path loss slope, f is the actual carrier frequency, f_0 is the reference carrier frequency which is 900 MHz, d is the travelled distance in kilometer, and d_0 is the distance to the intercept point [6,7]. In the original Lee's model the intercept point is chosen to be 1.6 km, but it could be chosen with another value. if another point is chosen, a correction factor should be taken in to account. n is the frequency exponent, and is usually equals 2 if $f \leq 450$ MHz in open or suburban areas, and equals 3 for urban areas for $f \geq$

450 MHz. The correction factor α_0 is used if antennas height and gain, and transmit power are different than the nominal values. The transmit antenna height nominal value is given as 30 meters with 6 dB gain, and transmit power of 10 W. The receiver antenna height nominal value is 3 meters with 0 dB gain [8]. The correction factor α_0 is expressed as

$$\alpha_o = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 \tag{9}$$

where

$$\alpha_1 = \left(\frac{h_{nb}}{30.84}\right)^2 \qquad \alpha_2 = \left(\frac{h_{nm}}{3}\right)^v \tag{10.a}$$

$$\alpha_3 = \left(\frac{P_{nt}}{10}\right) \qquad \alpha_4 = \left(\frac{G_{nm}}{4}\right) \tag{10.b}$$

$$\alpha_5 = \text{Different mobile antenna gain factor.} \tag{10.c}$$

where h_{nb} and h_{nm} are the new base antenna and new mobile antenna heights respectively, in meter, P_{nt} is the new transmission power in watts, *Gnm* is the new mobile antenna gain in dB. The exponent *v* values are defined as [8]

values are defined as [5].

$v = 2$ if $h_{nm} > 10$ meters (11.a)

$v = 1$ if $h_{nm} < 3$ meters (11.b)

3. DATA COLLECTION, CALIBRATION AND VERIFICATION

A. Data Collection and Calibration

This study was carried out for different routes in Jiza town, south of Amman city, Jordan. The areas, where the data has been collected, are considered rural areas with scattered buildings of mostly 1 level, 4 - 5 meters above ground level. Green landscape is not common to be seen in such areas. Data has been collected by ERICSSON TEMS (Test Mobile Systems) Cell-Planner tool with an antenna mounted on a moving vehicle 1.5 meter above ground level. Average height of transmit antenna is about 30 – 32 meter above ground level, with different transmit power. Sampling rate of the collected data, in an average, is about 2 – 3 samples per meter. The number of collected data points varies from one route to another with an average of 1000 points with distance ranges from 1 – 3 km, at the frequency bands of 900, 1800 MHz.

Lee's equation has been calibrated to suit the area of Jiza. Five different areas are used to calibrate both the intercept point path loss, P_t-P_{r0}, and the slope, γ, in the main Lee equation for the 900 MHz band. Table 1 shows different values of P_t-P_{ro} and γ, calculated for different cities used in the calibration of the original Lee's model [9], and are compared with the calibrated values at Jiza town.

B. Data Verification

To verify the calibrated Lee's model for the 900 MHz, and for the 1800 MHz, one route at Jiza town is used and shown in Figure 1. The area is considered an open area with quasi-flat landscaping. The path of the collected data for the 900 MHz (right line), and for the 1800 MHz (left line). The positions of the transmitters of both the 900 MHz and the 1800 MHz are also shown on Figure 1.

Table 1: Comparison P_t-P_{ro} and γ for different locations compared to calibrated values in Jiza town

	P_t-P_{ro} (dB)	γ slope
Suburban areas in USA	53.9	3.84
Philadelphia city	62.5	3.68
Newark city	55.2	4.31
Tokyo city	77.8	3.05
Calibrated for Jiza town (900 MHz)	120.85	2.65

Figure 1: Measured data paths. Right is for 900MHz of distance 1 – 3.5 km. Left is for 1800 MHz of distance 1 – 2 km.[Google Earth].

C. Evaluation of 900 and 1800 MHz Data

Figure 2 shows the calibrated Lee’s model, for the 900 MHz, at one route in Jiza town compared to the original Lee’s model calculated at different locations in USA and Japan. Originally Lee has data collected at different suburban areas in USA, Philadelphia city, Newark city, and Tokyo city [8]. From Figure 2 it is clear that the calibrated Lee’s model has predicted path loss better than the original Lee’s model used in different areas than Amman.

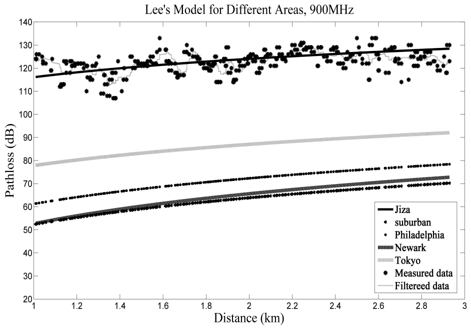

Figure 2: Calibrated Lee’s model in Jiza town, for 900 MHz, compared to calibrated Lee’s model of USA and Japan.

This would show the need for a calibration to suit different environments. RMSE values are used to compare these models and are given in Table 2 for the frequency band of 900 and 1800 MHz. As shown in Table 2, it is noted that Lee’s model has the lowest RMSE value compared to other models regarding the 900 MHz band. As the 1800 MHz is the concern, Egli’s model has shown better RMSE value with a deviation of 2.6 dB from calibrated Lee’s model. This would suggest that the calibration used is still not efficient for the 1800 MHz. thus an optimization procedure is proposed in this paper to obtain better RMSE values.

Table 2: RMSE values for Hata, Egli, and calibrated Lee’s models at 900MHz.

RMSE (dB)	Hata Open Area Model	Egli’s Model	Calibrated Lee’s Model
900 MHz	14.34	7.29	7.20
1800 MHz	15.07	6.13	8.76

D. RMSE Optimization

Optimization of the 1800 MHz for better RMSE value requires revisiting Lee’s model again. This equation (8) would be divided into 3 main parts. The first part is the original path loss relation given as

$$P_t - P_{ro} + 10\gamma \log\left(\frac{d}{d_o}\right) \qquad (12)$$

The second part is a frequency dependent part given in the form

$$10n\log\left(\frac{f}{f_o}\right) \qquad (13)$$

The third is the calibration dependent part to suit for different scales of parameters, and was calibrated for Jiza town region for the 900 MHz. This part is given by

$$10\log(\alpha_o) \qquad (14)$$

Neither (12) nor (13) can be optimized since they are calibration dependent and frequency dependent factors. The part of great concern in this optimization would be the third part given in (14). In this part calibration is obtained for the 900 MHz band, and used for the 1800 MHz band. So as we suggest an optimization of the form

$$10k\log(\alpha_o) \qquad (15)$$

A regression analysis is utilized to maintain best value of k that would give minimum RMSE as shown in Figure 3. Ten different routes, of each frequency band, have been used to check for the optimum value and k is normalized for the 10 areas under study. As it is implied from Figure 3, it is found that, for the 900 MHz, the minimum value is at k = 0.1, and k = 0.4 for the 1800 MHz. This difference in the value of k would imply its dependency on operating frequency f. In addition to that as the curve would suggest the relation between normalized cumulative RMSE and k is not linear, thus it is suggested that k may be represented as of the form

$$k = m\left(\frac{f}{f_0}\right)^2 \qquad (16)$$

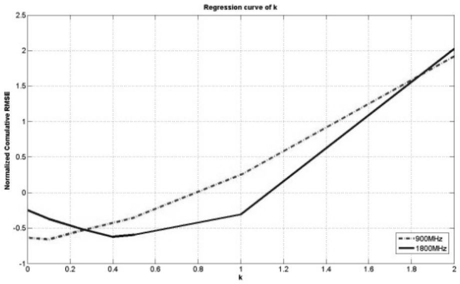

Figure 3: optimized value of correction factor k for the 900 MHz (Points) and 1800 MHz (Line).

Assuming such values of optimization factor k, and regarding the minimum RMSE values it would be inferred that m should be m = 0.1.

Thus the final Lee's model is proposed to be of the form

$$L_t = P_t - P_{ro} + 10\gamma\log\left(\frac{d}{d_o}\right) + 10n\log\left(\frac{f}{f_o}\right) - 10\,m\left(\frac{f}{f_0}\right)^2\log(\alpha_o) \qquad (17)$$

To physically justify this difference in the value of k, by using the obtained calibrated value in Jiza town for Lee's model given in Table 1. This value would be the same for both the 900 MHz and the 1800 MHz. Also, a 6 dB difference would rise from the relation in (13), for open area criteria. Normalizing the same parameters of both frequency bands given in (15), it would be clear that a 4 dB additive value in favor of the 1800 MHz band. This would show that path loss differences between the 1800 MHz and the 900 MHz is added to up to 10 dB. Thus, such value is within accepted range of path loss difference between the 900 MHz band and the 1800 MHz as given in [10].

To verify the suitability of the optimized values of m, Figure 4 and Figure 5 show path loss relation before and after the optimization for route 1, of each frequency band, in airport road, Jiza town. RMSE values before and after optimization with Least square method (LSM) best fitting path loss line are also given in Table 3 for comparison.

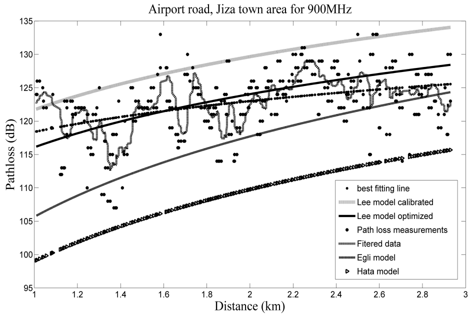

Figure 4: Comparison of calibrated and optimized Lee's model with best fitting path loss for the 900 MHz.

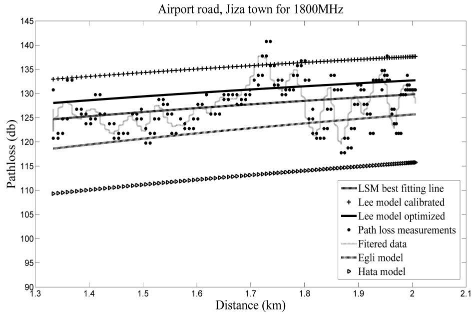

Figure 5: Comparison of calibrated and optimized Lee's model with best fitting path loss for the 1800 MHz.

Table 3: RMSE Values for Calibrated Optimized Lee's Model and Best Fitting Path Loss for The 900 and the 1800 MHz bands

	Route1 , 900 MHz	Route2 , 900 MHz	Route1 , 1800 MHz	Route2 , 1800 MHz
Calibrated Lee's Model	7.2	10.8	8.76	6.95
Optimized Lee's Model	3.22	5.97	3.65	6.22
LSM best Fitting Line	2.8	4.1	3.59	5.00

4. CONCLUSIONS

In the above study it is found that Lee's model and his proposed procedure is well suited open area categories, for the 900 MHz band, in south of

Amman city (Jiza town). The calibrated results were compared to both Egli's and Hata's model as they represent other types of statistical path loss prediction models. It is found that for the 900 MHz, Lee's model performed well and has the least RMSE value, compared to the other two models. The suitability of the procedure for other frequency bands was not confirmed such that for the 1800 MHz Egli's model has the least RMSE value compared to the other models. This shows that the correction proposed by Lee's to include other frequencies needs more optimization. The optimization process was achieved through curve fitting procedure and as a result a new frequency dependent parameter is suggested to be added to optimize the final relation. The new proposed optimization has achieved best RMSE value compared to other models. Other frequency analysis is needed as to optimize the new parameter to account for a wide range of frequency bands. In addition to that, other area categories are to be analyzed to study the need and the effect of the new proposed parameter.

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