Lee's Model

By
W. C. Y. Lee
PacTel Corporation
Walnut Creek, CA

Abstract

Lee's Model [1] is used to predict the local-mean of a received signal along a mobile path where the mobile unit travels. The standard derivation of prediction error by comparing the predicted values with the measured data is approximately 2-3 dB. The model is simple to implement and has a theory to back it.

I. Introduction

Most prediction models are used to predict the pathloss along the radio path. The radio path is the path from the base-station antenna to the mobile-station antenna. The pathloss curve is generated from the measured data received along the mobile path and plotted along the radio path. The standard deviation is about 6-8 dB. Since a large standard deviation from the prediction is hard to use to design a cellular system, Lee's Model[1] is used to predict the local mean along the mobile path.

II. The Philosophy of Forming Lee' Model

In a mobile radio environment, due to the fact that the mobile antenna height is very close to the ground, the mobile signal received from the base station is affected by two factors. One is due to the strong ground reflection which depends on the natural terrain contour along the radio path. The other is due to the different human-made structures which result in different excessive loss in different geographical areas.

These two causing factors are imbedded in the received signal. In this model we try to predict two factors separately:

A. Caused by the human-made structures only

The human-made structures are different in different cities and the terrain contours are not flat and vary from area to area. If we try to obtain the received signal attenuation only caused by the human-made structures, then the terrain contour in the area has to be flat which is impossible in reality. However, the average process of elevations at different spots but at the same radio-path distance would wipe out the terrain variation. Therefore, a pathloss curve with a careful averaging process on the elevations would provide the signal attenuation caused by the human-made structures only as shown in Fig. 1.

$$P_r = p_{ro}\left(\frac{d}{d_o}\right)^{-\gamma}\alpha_o \qquad \text{(in milliwatts)}$$

$$= p_{ro} - 10\gamma\log\left(d/d_o\right) + \alpha_o \qquad \text{(in dBm)} \quad (1)$$

where P_{ro} is the received power in milliwatts at the distance of d_o which can be 1 mile or 1 km, d is the distance with the same unit as d_o and γ is the slope of the pathloss in mobile radio environment. 10γ represents the dB value per decade. α_o is the connection factor when the actual condition is different from the reference conditions which are specified as:

h_1 - antenna height at the cell site - 100 ft (or 30 m)
G_t - antenna gain at the cell site - 6 dBd
P_t - transmission power - 10w
h_2- antenna height at the mobile unit - 10 ft (or 3 m)
G_m - antenna gain at the mobile unit - 0 dBd

The pathloss curve of the suburban areas can be expressed as:

$$p_r = (P-46) - 61.7\ \text{dBm} - 38.4\log d + 20\log\left(\frac{h_1}{100}\right) + 10\log\frac{h_2}{10} + G_m \qquad (2)$$

where P is the ERP in dBm, d in miles, h_1 and h_2 in feet and G_m in dBd. By setting G_m = 0 dBd, Eq (2) can be simplified as follows:

$$p_r = p\cdot 10^{-14.77}\cdot d^{3.84}\cdot h_1^2 \quad \text{(milliwatts)} \quad (3)$$

$$d = \left[\frac{P}{P_r}\cdot 10^{-14.77}\cdot h_1^2\right]^{\frac{1}{3.84}} \quad \text{(in miles)} \quad (4)$$

If P_r of 32 dBu is received, then use the conversion between dBu and dBm at 850 MHz, dBm (=) dBu - 132, the value of 32 dBu converts to -100 dBm.

Substituting P_r = 100 dBm into Eq (4) yields

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$$d = 0.348\left(h_1^{0.5208} \times P^{0.2604}\right) \text{ (in miles)} \quad (5)$$

Eq (5) is the contour for a received power P_r equals 32 dBu.

B. Adding the cause of terrain contour

For calculating the additional changes in the received signal due to the terrain contour, we need an accurate terrain data base. There are four conditions based on the terrain contour situations which can be stated.

1. In a non-obstructive condition

First we have to find the specular reflection point (see Fig. 2) at which the tangential line of that ground curvature is intercepting at the cell-site antenna location. Then the effective antenna height is obtained by measuring the height from the intercepting point to the antenna.

The antenna-height-gain factor is G_e

$$G_e = 20\log\frac{h_e}{h_1} \quad (6)$$

2. In an obstructive condition

We can find the knife-edge diffraction loss which is illustrated in Fig. 3 with a parameter v

$$v = -h_p\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1} + \frac{1}{d_2}\right)} \quad (7)$$

3. The condition of land-to-mobile over water

In this condition, there are two specular reflected waves as shown in Fig. 4. The three waves, one direct wave and two reflected waves added at the mobile receiver, results in a free space loss(2).

4. The condition of land-to-boat over water

In this condition (see Fig. 5), there is only one strong specular reflected wave over the water, the result is the same as open-area pathloss curve.

III. A Normal-cell Model

The normal-cell model is used for a cell greater than 1 km in diameter and can be formed as shown in Table 1.

VII. Microcell Model

When the size of the cells is small, less than 1 Km, the street orientation and individual blocks of buildings make a difference in signal reception, as mentioned previously. Those street orientations and individual blocks of buildings do not make any noticeable difference in reception when this signal is well attenuated at a distance over 1 Km. Over a large distance, the relatively great mobile radio propagation loss of 40 dB/dec is due to the situation that two waves, direct and reflected, are more or less equal in strength. The local scatterers, i.e., buildings surrounding the mobile unit, reflect this signal causing only the multipath fading not the pathloss at the mobile unit. When the cells are small, the signal arriving at the mobile unit is blocked by the individual buildings which weakens the signal strength and is considered as part of the pathloss. Therefore we have to take another approach in our prediction, to be described in this section. In small cells we are calculating the loss based on the dimensions of the building blocks. Since the ground incident angles of the waves are, in general, small due to the low antenna heights used in small cells, the exact height of buildings in the middle of the propagation paths is not important, as shown in Fig. 6. Therefore, only a top-view aerial photo map is used. We can use air photos to calculate the proportional length of the direct wave path being attenuated by the building blocks. When the wave is not being blocked by the building it is a line-of-sight condition. From the measurement data along the streets in an open line-of-sight condition we find the line-of-sight signal reception P_{los}. Also, from the measured signal P_{os} along the streets in out-of-sight conditions within the cells, we find the additional signal attenuation a_B formula due to the portion of building blocks over the direct path by subtracting the received signal from P_{los}. The steps for forming an additional signal attenuation formula a_B are as follows:

1. Calculate the total blockage length B by adding the individual building blocks. For example, B = a + b + c at point A shown in Fig. 7.

2. Calculate the signal strength P_{los} for line-of-sight conditions.

3. Measure the signal strength P_{os} for out-of-sight conditions.

4. The local mean at point A is P_{os} (at A). The distance from the base to the mobile unit is d_A. The blockage length B at point A is B = a + b + c. Then the value of a_B for a blockage of B can be expressed as:

$$a_B\,(B = a + b + c) = P_{los}\,(d = d_A) - P_{os}\,(\text{at } d_A)$$

Then the additional signal attenuation curve based on the building blockage is found experimentally as shown in Fig. 8. The a_B curve was obtained at Irvine, California. The curve shows the rapid attenuation occurred while B is less than 500 ft. When B is greater than 1,000 ft., a nearly constant value of 20 dB attenuation is observed. It can be explained by the street corner phenomenon as shown in Fig. 9. The rapid attenuation was seen on the mobile signal during the turning from one street to another as B starting from 0' and increasing. After B reaches 500' the received signal strength P_{os} will remain 18 dB below the P_{los} as the distance d increases. The path losses due to a line-of-sight condition for a series of antenna heights have been measured along many streets. The 9 dB/oct (or 30 dB/dec) antenna height gain over an antenna height change is usually observed in a small cell, as shown in Fig. 10. It is due to the fact that the incident angle in the small cell is usually larger than 10°. In the small-cell prediction model we use the two curves, P_{los} and a_B to predict the received signal strength. Therefore, the Microcell (small cell) model can be formed as:

$$P_r = P_{los} - a_B \tag{8}$$

Where P_{los} is the line-of-sight pathloss (measured) and a_B is the additional loss due to the length of the total building blocks B along the paths.

The expression to be evaluated is:

$$P_{los} = P_o + 10(\gamma_o)\log\frac{d_1}{d_o} \quad \text{(From Fig. 9)} \tag{9}$$

$$\alpha_B = 10(\gamma_1)\log B \quad \text{(From Fig. 9)} \tag{10}$$

Where P_o is the intercept point at a distance d_o, d_1 is the total distance. Usually d_1 is smaller than d_o in the small cell prediction. γ_o is the line-of-sight pathloss slope. B is the length of blocking. γ_1 is the slope due to blocking.

$$P_r = P_o + 10(\gamma_o)\log\frac{d_1}{d_o} - 10(\gamma_1)\log B \tag{11}$$

This Microcell model has been verified in the areas of Irvine and San Diego, California with good results, as shown in Figs. 11 and 12.

In a hilly area, Eq (8) can be modified by adding the term antenna height gain obtained from Fig. 10 as:

$$P_r = P_{los} - \alpha_B + 30\log\frac{h_e}{h_e} \tag{12}$$

The prediction from the Microcell model is not as accurate as that from the normal-cell model. This is due to the fact that we are using a statistical prediction tool to predict the signal in more or less deterministic conditions where the propagation distance is short.

VIII. Full Prediction Model

A full prediction model will be superimposed on the normal-cell model and the Microcell model to predict the received signal strength in a range up to 15 miles. Beyond this distance, the radio horizon may be considered. The interfering signal is always weaker when it is coming from beyond the radio horizon. It can be neglected in most cases in the mobile radio system design.

Table I. Conditions of the normal-cell model

Conditions	Received Power	Effected By		Correction Factor
		Human-made Structures	Natural Terrain	
Non-obstructive	P_r =	$P_{r_o} - 10(\gamma)\log\frac{d}{d_o}$	$+ 20\log\frac{h_e}{h_1}$	$+\alpha_o$
Obstructive	P_r =	$P_{r_o} - 10(\gamma)\log\frac{d}{d_o}$	$+ L$	$+\alpha_o$
Land-to-Mobile over water	P_r =	$P - 20\log(4\pi d/\lambda)$		$+\alpha_o$
Land-to-Boat	P_r =	$-49 - 43.5\log\frac{d}{d_o}$		$+\alpha_o$

References

1. W. C. Y. Lee "Lee's Model," a condensed version shown in Appendix II, written by the Propagation Ad Hoc Committee of IEEE Vehicular Technology Society appeared in a special issue of IEEE Transactions on Vehicular Technology, February 1988, pp. 68-70.

2. W. C. Y. Lee "Mobile Cellular Telecommunications Systems," McGraw Hill Co., Chapter 4.

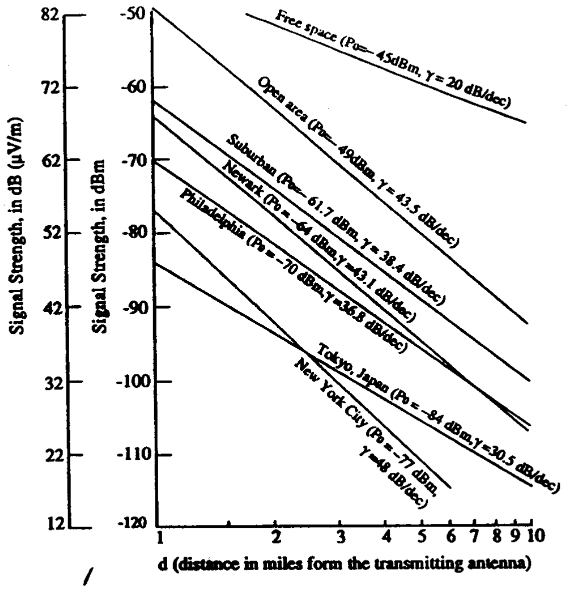

Figure 1 Propagation Pathloss In Different Areas

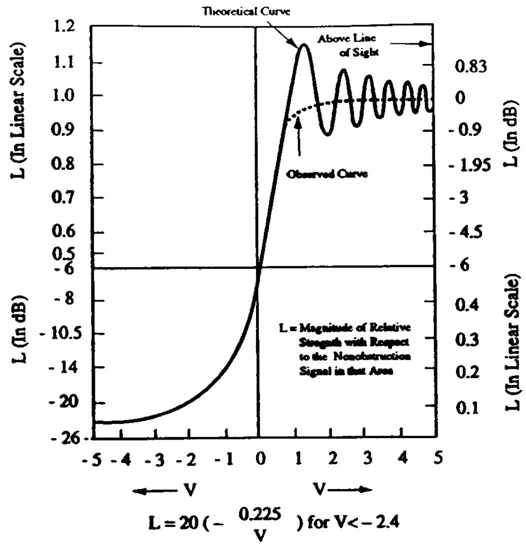

Figure 3 Shadow-Loss Prediction

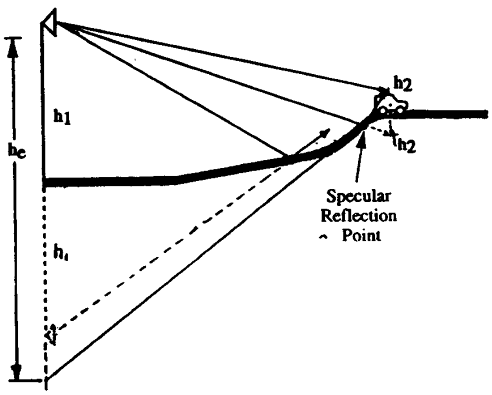

Figure 2 Effective Antenna Height Calculation

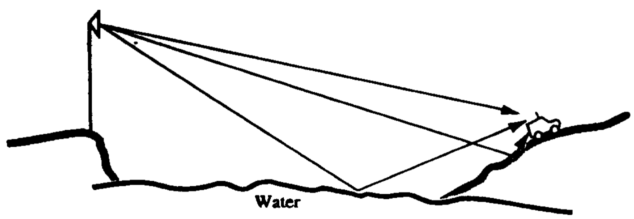

Figure 4 Land-To-Boat Over Water

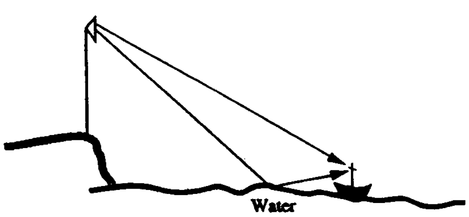

Figure 5 Land-To-Boat Over Water

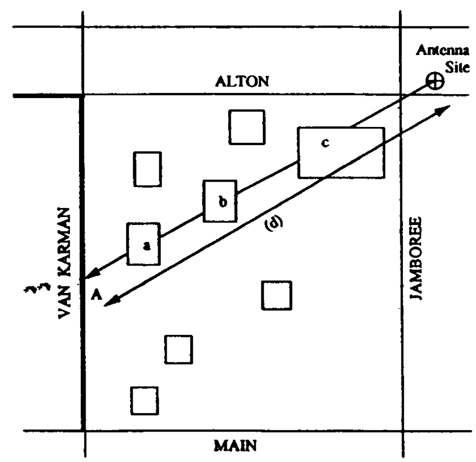

Figure 7 Building Block Occupancy At Location A
B = a + b + c

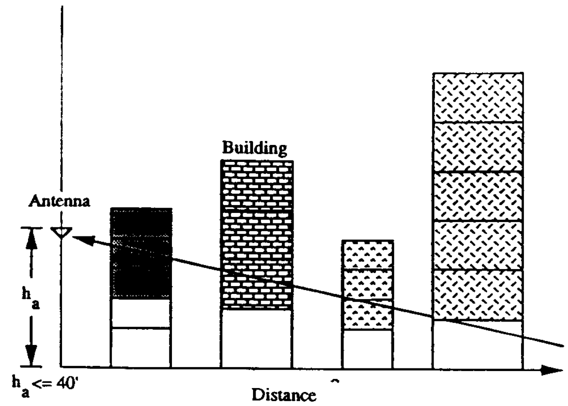

Figure 6 The Propagation Mechanics Of Low-Antenna Height At The Cell Sites

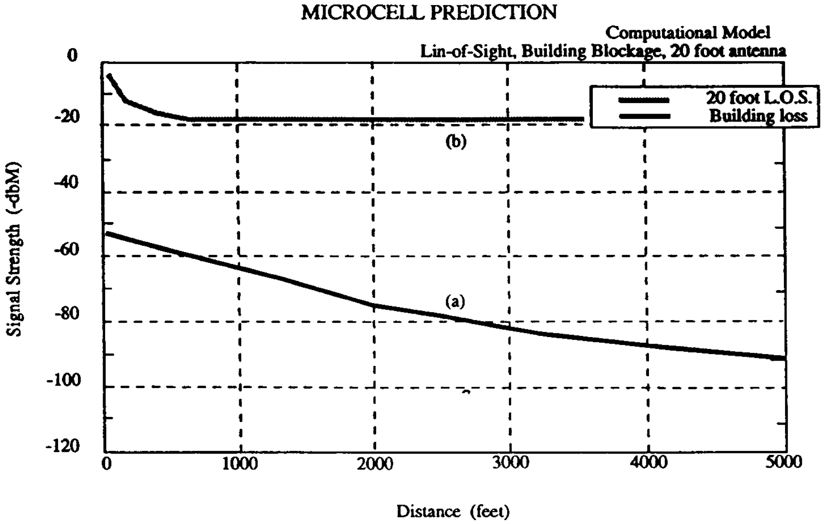

Figure 8 Microcell Prediction Parameters
(a) Line-Of-Sight P_{los} (b) The L_B Due To Building Blockage

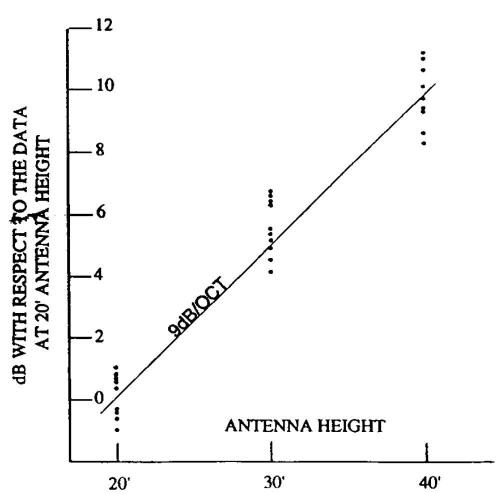

Figure 10 Antenna Height Effect In Microcell Systems

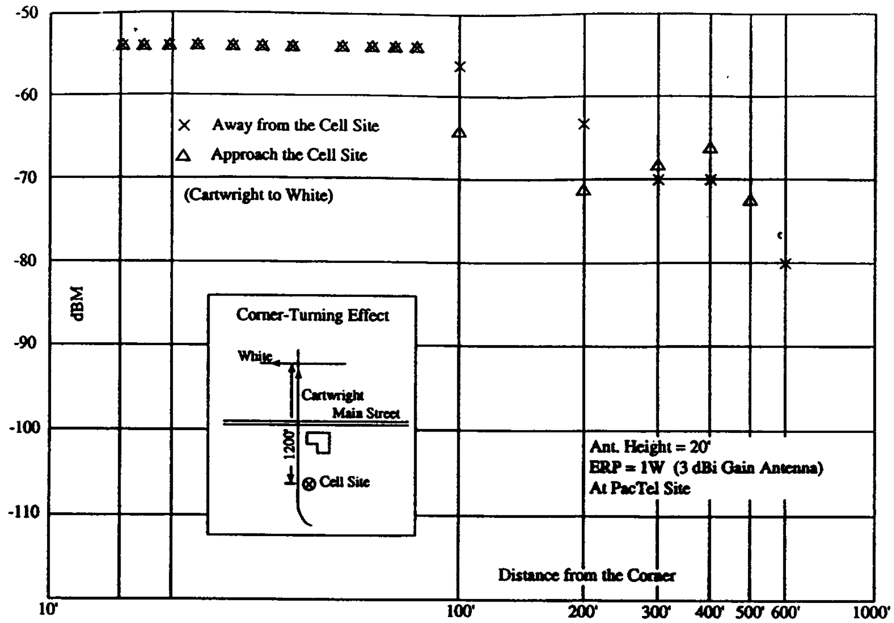

Figure 9 Corner Turning Effect Tested In Irvine, CA

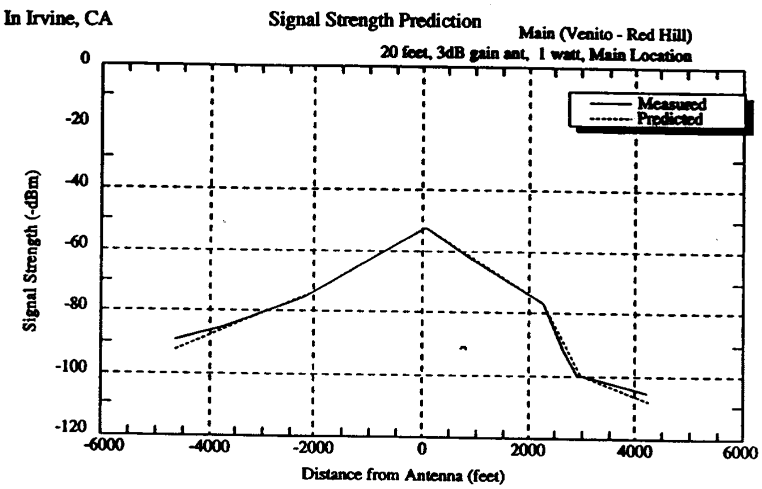

Figure 11 Comparison Of The Measured Data And The Predicted Curve At Main Street, Irvine, CA

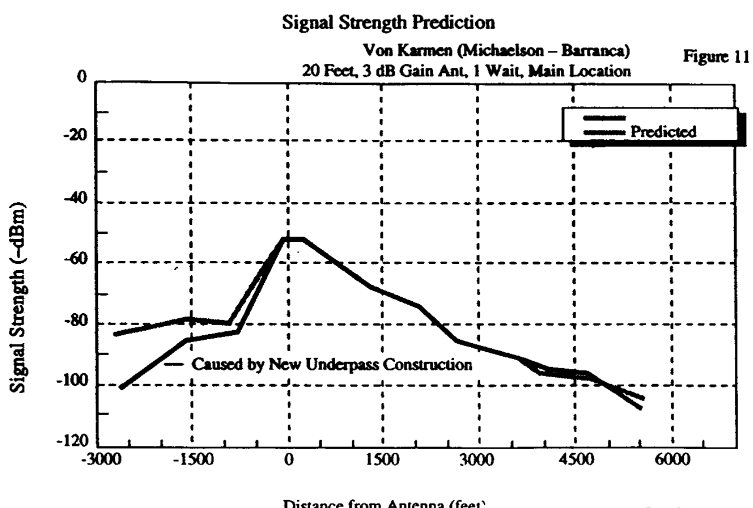

Figure 12 Comparison Of The Measured Data And The Predicted Curve At Von Karmen, Irvine, CA