Lee Microcell Propagation Model: A Complex Case Empirical Study

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Abstract: - Power propagation model construction for mobile communications is very important in order to assure the quality of physical communication. The Lee model allows predicting the path loss in different scenarios: terrain, suburban, urban, over-aquatic, among others. It has been used to model the communications in several scenarios around the world. It also can be used to model the communication at different frequencies and transmission power. Other derived models have also been published recently. In this paper we present a new usage of this model to predict the path loss in a complex scenario. Recent case study works apply this model to a specific scenario that only considers problems with one kind of transmission media. We consider different kind of environments present in our scenario. We have done an analysis that includes a deep insight on obstruction phenomenon caused by buildings and how they impact signal propagation. We also analyze a microcell in which vegetation is present. The novelty is that the two above environments are present in our case study and show that the Lee's model is very appropriated in both cases. This complex scenario (living lab) allows us to design an academic realistic learning tool for some key concepts about signal propagation theory and practice.

Key-Words: - Lee propagation model, campus environment, fading, learning tool.

1 Introduction

Mobile communications have evolved tremendously in the last 20 years. Several generations of technologies have appeared and every year some new improvements in mobile communications is achieved. Mobile services are attracting new users around the world day by day. These mobile services are a key factor of the new Information Society of XXI century. A key factor to make possible these mobile services was the definition of early models of wireless signal propagation [1] in the last century (around the 1990 decade). These communication models allow predicting the path loss of wireless signal propagation in the free space (air) when obstacles are encountered between the antenna and the receiver. The prediction of path loss is very important due to several mobile services use it to efficiently implement services like Location Base Services, Handoff and Handover and others. Mobile Web and mobile Cloud services need the efficient implementation of the above services. The key success of Mobile communications is the efficient implementation of such last services.

We center our attention on modeling the path loss in physical mobile communications. There exist several models dedicated to the estimation of received power that include the effect of obstacles on propagation of wireless signal in the air between the wireless antenna and the wireless receiver. The authors in [2] compared results from Lee's, Hata's and Egli's models considering an open area with flat landscape distribution at 900 and 1800 MHz frequency bands. They conclude that only Lee's model was the best compared to the other two models at the 900 MHz but correction proposed by Lee’s model to include other frequencies such as 1800 MHz needs more optimization. Another work [3] compared the propagation performance for Lee's, Okumura's and Hata's models at 900 MHz varying mobile and base station antenna heights, and transmitter-receiver distance. In [4] is reviewed several radio propagation models for LTE including the Okumura's model and one extension of Hata’s model. Lee's model was not considered for the authors in the comparison. Another work to compare several propagation models at 940 MHz GSM frequency for urban, rural and suburban areas in India was presented in [5]. The authors did not consider Lee's model in the comparison. They were planning to extend the study for *Worldwide Interoperability for Microwave Access* (*WiMAX*) technology. The work [6] focused on the comparison of radio propagation models indoor and out of a building and not as usual other works did that focused the comparison for radio technologies operating outdoors. Other models (Bertoni-Walfish, Hat, Walfisch-Ikegami and the standard macrocell) were proposed in the study done in [7]. They show that Bertoni-Walfish was the best appropriated for the scenario they studied.

The nature of the obstacles is very important and it has produced a lot of papers that study the influence of these obstacles in particular scenarios. A typical obstacle was a set of buildings in a semi-urban or urban scenario, trees in a forest, the surface of Water when mobile communications were used in the border or inside a lake (for example)...The importance of these obstacles was that each kind of obstacle influences the path loss in a different way. For example in [1] a novel radio propagation model for microcellular environments was presented. They considered the creation of many different virtual sources and used ray-tracing to consider trees and buildings.

We have considered a complex scenario (case study) that integrates two different kinds of obstacles. For this scenario we have considered the Lee model for assigning the fading generated by the obstruction of buildings located in the straight propagation path between the transmitter antenna and the mobile receiver (the semi-urban part of our scenario). We did a deep analysis which included a deep insight on obstruction phenomenon caused by buildings and how they impact signal propagation. We first modeled the propagation phenomenon, then we did several experimental measurements in the coverage zone of the antenna and finally we validated the theoretical model with the experimental measurements. The importance of this work is that we were able to apply the Lee’s original model developed to urban areas to our complex scenario by adjusting the distance-power gradient corresponding to the LOS loss, in order to account for the additional power losses caused by the vegetation found in our complex setting. We also considered other parts of our complex scenario and made some measurements in order to complete the study and go beyond other previous works that only present simple scenarios. The lessons learned aimed us to build an academic learning tool.

The rest of the paper is as follows. In Section 2 we present some related work reviewing the Lee model and its application to different scenarios. In Section 3 we define our complex scenario. In Section 4 we present the modeling process of our complex scenario and its empirical evaluation, and the reasons our scenario is much appropriated to build a realistic tool for a living lab in which our students can experiment with Lee model in theory and practice. Finally we sum up some conclusions and present future work.

2 Lee Model and Obstruction Modeling

It is well known that obstacles directly affect propagation of wireless signals. We might tend to think that power received by a mobile receptor comes from waves crossing through obstacles along a propagation path but reality is all power comes from reflected waves which is commonly called multipath reflection phenomenon. Despite the fact of multipath reflection phenomenon, there is a relation between received power and the number of obstacles in the propagation path. When the number of obstacles between a transmitter and a receiver increases, signal power perceived by a receptor decreases as a result. Certainly, obstacles play a big role in signal propagation modeling and it is necessary to include them as part of the analysis.

Lee's microcell propagation model is a power prediction technique that includes the effect of obstacles on propagation analysis. It is widely applied to mobile cellular systems with cell coverage radius less than 1 Km. Lee's methodology is very easy to implement and provides faster and more accurate results in terms of signal power prediction when compared to other generic propagation models. In fact it was recommended by the *International Telecommunications Union (ITU)* and the *European Conference of Postal and Telecommunications Administrations (CEPT)* to obtain the local mean values of the received signal along a route. It was developed for a Rayleigh distribution in the ultra-high frequency (UHF) band. We think it can be used in complex scenarios and moreover it is the model the Telecommunications operators prefer to use in practice. We in [8] did some measurements in the same scenario in response to an official request of Ecuadorian Telecommunication operators. For these reasons we evaluated the empirical measurements for validating the Lee’s model.

The original Lee microcell model considered terrain and buildings as obstacles [9] [10] [11] located at urban and semi urban environments. The model presented a power prediction equation and a methodology for detailed analysis of building obstruction using the help of empiric characteristics curves based upon field measurements. It also addressed some interesting and useful concepts such as block building density, obstruction distance and equivalent obstruction distance.

Lee's microcell model is presented in the following equation.

$$P_r(A) = P_t - L_{los}(d_A, h_1) - L_b(B) \tag{1}$$

Where $P_r(A)$ is received power at a random A point within the coverage area, P_t is the *Effective Radiated Power (ERP)*, $L_{los}(d_A)$ is line of sight loss at d_A distance from the source. The last parameter is L_b that represents any loss mainly associated to buildings obstruction along the propagation path and it normally depends on the buildings obstruction distance denoted as B.

This model was enhanced in order to be applied to other kind of obstacles. In [12] and [13] Lee considered different databases for characterizing streets in urban zones and the extension of the basic model for macrocells.

Other authors have extended this model to consider complex scenarios. In [14] the generalization of Lee’s model to any propagation channel and frequency band was presented. It also described the methodology to obtain the parameters involved in the model.

The Lee’s model or extensions of this model have been also applied to several scenarios recently. A good point of start to understand Lee's model and an example of application is shown in [15]. The authors explain the model and apply it to a non-homogeneous environment considering the environment divided in different variable density buildings (dense urban, urban, suburban...). They apply the model after deriving from field strength measurements the 1 mile intercept and the path loss slope parameters for each type of environment. The authors consider that building a database with pairs of known intercept and slope parameters let apply the Lee's model to different environments to perform propagation predictions. The work in [2] is also a case study in the city of Amman. With experimentation we tried to verify if Lee's model will behave well at the 1800 MHz band at our complex scenario. In [3] are obtained simulations using Matlab software, low power loss levels for Okumura's model. Practical experimentation is not made as we propose in our contribution. In [16] the application of Lee’s model at Nigeria is compared with others models for *Code Division Multiple Access* (*CDMA*) system operating in 800MHz UHF. As the conclusion of this comparison, the authors chose Hata’s model for their target environment. A similar conclusion is presented in [17] for Irbid town in Jordan. The work in [18] presents a method for path loss prediction that is based on Lee's model that takes into account the effects of buildings in radio signal propagation. It is applied at 850 MHz in urban and dense urban environments of Miami. The work in [19] presented a detailed formulation to model radio transmission among multi-story buildings and within buildings at 900, 1800 and 2300 MHz. Lee model has been also studied for *Wireless Sensor Networks* (*WSN*) in a Smart City scenario [20] (urban). Also vegetation and forest are other obstacles studied, for example in [21] the Lee’s model is studied for a WSN and in [22] a Case study in Thailand was presented. Recently, software that implements the Okumura-Hata’s propagation model is presented in [23].

In this paper we will apply the Lee’s model to a complex scenario that can be easily used by university students to learn about propagation of radio signals. The interest of this scenario is that it includes several interesting cases to apply the Lee’s model. In addition, previous propagation models developed for a university campus environment or as part of a laboratory inside a research institute were not aimed to provide a hands-on learning tool where the students or researchers would experiment with real signals from real telecom operators [24, 25]. Moreover the Ecuadorian mobile operators use this model in practice for network planning and design since it is suggested by ITU. For these reasons the students will benefit using a simple but practical model in a complex scenario.

3 The Complex Scenario

In this Section we present the complex scenario in which we implemented the experimentation of the Lee's model. The scenario is located at the Engineering area of the *Escuela Superior Politécnica del Litoral* (*ESPOL*) campus in the city of Guayaquil, Ecuador, which is located in the tropical part of South America. In this scenario, we have identified two microzones as indicated in Figure 1.

The first microzone was nearby to the *Base Station* (*BS*), just below the antenna, which was represented as a rectangle box in Figure 1. The first microzone was also shown in Figure 2, where we showed at the left the BS considered in our analysis, which had twenty seven meters of height. In this microzone, there were no buildings obstructing the line of sight between the BS and the receiver, and reached about seventy five meters from the BS; this area could be considered as a little forest, which has a considerable level of vegetation mainly composed by trees of ten meters of height in average. Therefore, in this scenario we had to consider the fading caused by the trees in the signal propagation between the BS and the receiver, so we did not have free space nor the obstruction of buildings as the initial conditions required for the Lee´s original model.

On the other hand we had the second microzone, which corresponded to the part where the Engineering buildings are located. As is shown in Figure 3, the type of edifications found in this part of our scenario corresponded mainly to two-floor buildings, which were mostly made of concrete. These buildings expanded from about 75 m with respect to the BS and reached up to about two hundred meters of coverage, where there were no more Engineering buildings to consider in this research. In this area, the level of vegetation was reduced with respect to the first microzone, which was mainly composed by smaller trees and grass.

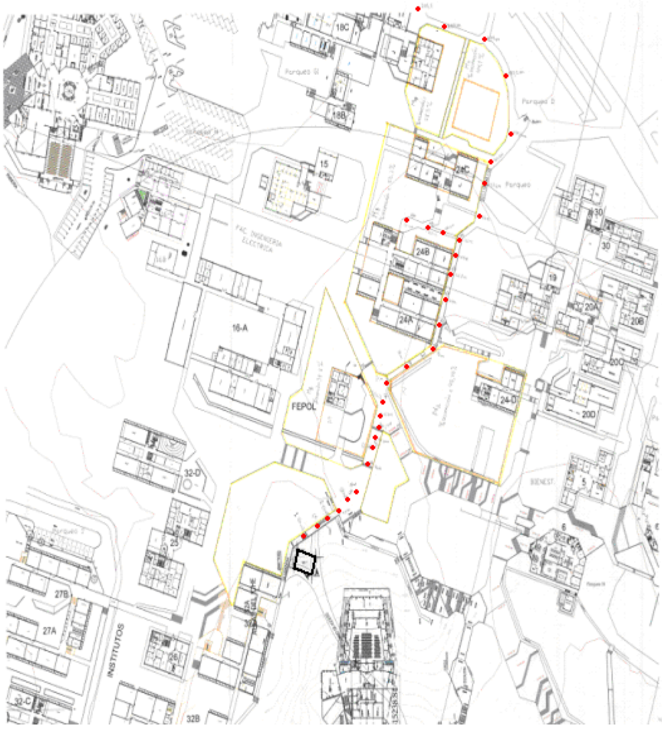

Fig. 1: ESPOL campus engineering area.


Fig. 2: ESPOL engineering forest.


Fig. 3: ESPOL engineering buildings.

4 Empirical Study and Validation

As stated before, our area of study was divided in two microzones, the first one considered the forest part nearby the BS and the second one covered the Engineering buildings next to the forest microzone. We argue that the second microzone could be modeled using the Lee's model for urban areas, where the building obstructions are the main cause of signal fading.

On the other hand, we argue the first microzone can be modeled adjusting the *Line of Sight* (*LOS*) *Loss* in the Lee's equation in order to incorporate a higher distance-power gradient related to the presence of vegetation in the surroundings of the BS. The presence of different environments in the same investigated scenario has been previously addressed by the use of different distance-power gradients, which were customized to propagation characteristics of each particular environment [26]. The approach for modeling this microzone will be described in Section 4.2.

Table 1 shows the different values of average received power measured at different distances from the BS, and the type of microzone related to the corresponding measurement point. The forest area or first microzone, where there are no buildings obstructing the propagation of the signal, expands from the point located at 10 m of distance from the base station to the one located at 75 m. The remaining points correspond to the second microzone, where there is a prevalence of buildings over the vegetation.

TABLE 1

MEASUREMENT POINTS FOR OUR LEE'S MODEL.

Distance (m)	Average Received Power [dBm]	Microzone
10	-20,17	Forest
15	-16,19	Forest
20	-21,4	Forest
25	-27,78	Forest
30	-23,52	Forest
35	-22,52	Forest
46	-20,16	Forest
52	-23,01	Forest
55	-25,57	Forest
59	-28,71	Forest
63,6	-27,31	Forest
67,6	-26,51	Forest
75	-23,59	Forest
84	-23,28	Buildings
96	-26,84	Buildings
104	-28,78	Buildings
114	-28,67	Buildings
122,8	-31,34	Buildings
129	-32,54	Buildings
131,2	-35,07	Buildings
132,4	-32,81	Buildings
133,6	-33,09	Buildings
135	-28,36	Buildings
146	-28,36	Buildings
157,2	-28,3	Buildings
166	-32,78	Buildings
179,6	-31,88	Buildings
197,2	-37,22	Buildings
202	-40,99	Buildings
204	-43,31	Buildings
205,2	-47,81	Buildings

We applied the Lee's modeling approach to urban areas from the measurement point located at 84 m of distance from the BS to the last point located at 205,2 m. In this case, we considered the fading caused by the building obstructions and the LOS loss as defined in the Section 4.1.

4.1 Model Construction, Case Study: GSM Antenna at ESPOL Engineering Campus

The coverage limit in the second microzone, were within the *Global System for Mobile (GSM)* communications 850 MHz microcell BS antenna shown in Figure 2. In Figure 1 is shown ESPOL campus engineering area mapping. The black box is the antenna's location and red points are to be considered for model construction that will be explained in more detail later in this section.

The Lee's Equation 1 is made out of four terms: received power, effective radiated power, LOS and environmental losses mainly caused by surrounding buildings. At first glance, three out of four terms are either known or can be easily calculated. $P_r(A)$ is obtained by measuring using in this case the NARDA SRM 3000 spectrum analyzer, P_t is a transmission system's constant, and LOS loss is calculated using the following equation as follows [7].

$$L_{los} = 20 \log \frac{4\pi d_A}{\lambda} \quad (2)$$

The value of twenty in Equation 2 was related to a distance-power gradient of 2 corresponding to the propagation in free space or unobstructed LOS. Later we will propose a tiny change to this gradient due to the presence of vegetation in this area of analysis.

Given that only L_b is unknown and everything else can be obtained in one way or another, Lee's equation can be solved for L_b. Part of the analysis consists on measuring signal power from source antenna at every point in the sample propagation path (red points depicted at Figure 1). In the second column of Table 2, it can be seen the average received power of the measurements realized at different distances from base station.

The *ERP* was a generally known transmission system constant; in this case, it was 58 dBm. The LOS loss -as stated before- was to be determined using Equation 2. At this point, three out of four Lee's equation terms were known and it could be effectively solved for L_b. Table II shows a summary of result values.

TABLE 2

SUMMARY OF LEE'S MODEL RESULT VALUES.

Distance (m)	Average Received Power [dBm]	ERP [dBm]	Llos [dB]	Lb [dB]
84	-23,28	58	69,72	11,56
96	-26,84	58	70,88	13,96
104	-28,78	58	71,58	15,20
114	-28,67	58	72,38	14,29
122,8	-31,34	58	73,02	16,32
129	-32,54	58	73,45	17,09
131,2	-35,07	58	73,60	19,47
132,4	-32,81	58	73,68	17,13
133,6	-33,09	58	73,75	17,34
135	-28,36	58	73,84	12,52
146	-28,36	58	74,53	11,83
157,2	-28,3	58	75,17	11,13
166	-32,78	58	75,64	15,14
179,6	-31,88	58	76,32	13,56
197,2	-37,22	58	77,14	18,08
202	-40,99	58	77,35	21,64
204	-43,31	58	77,43	23,88
205,2	-47,81	58	77,48	28,33

The environmental obstruction at ESPOL engineering area mainly consists on mid-size buildings and its obstruction length calculation was not an easy endeavor. In some cases, it got really hard to accurately figure out what this value was; therefore it was necessary to present a practical and very useful concept: the equivalent obstruction length B_{eq}, which estimated the B value by using block occupation density. The Figure 4 illustrates this concept.

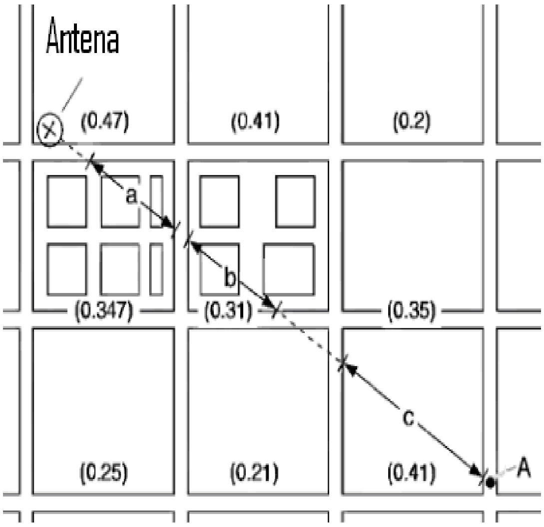

Fig. 4. Equivalent obstruction length concept illustration [1]

The Figure 5 shows three blocks named M_a, M_b and M_c between the transmitter antenna and a sample point A. M_a is the block crossed by the line with distance a, M_b is the block crossed by the line with distance b, and M_c is the block crossed by the line with distance c. In this case, B would be the result of calculating every single obstruction caused by buildings along an imaginary straight propagation path between the transmitter antenna and point A. In order to simplify this process, Lee suggested the following [2]:

First, calculate building occupation density of a block using the following equation.

$$P_i = \frac{A_e}{A_t} \quad (3)$$

In this case, P_i represented i-th block's occupation density, A_e the buildings occupation area, and A_t the total area in the corresponding block. In the example shown in Figure 5, we had that P_a, P_b, and P_c are the corresponding occupation densities of blocks M_a, M_b and M_c respectively.

Second, we calculated the total obstruction length of every block along the propagation path between the transmitter and the receiver, which in our referred example corresponded to obtain the distances *a, b,* and *c*.

Finally, the equivalent obstruction length B_{eq} at point A was calculated as follows:

$$B_{eq}(A) = a.P_a + b.P_b + c.P_c \quad (4)$$

In this equation, B_{eq} estimated the actual obstruction length value notated as B, being B_{eq} much easier and faster to compute than actual B.

Then, Lee's equation was rewritten as follows:

$$P_r(A) = ERP - L_{los}(d_A) - L_b(B_{eq}(A)) \quad (5)$$

In summary, the values of L_b and B_{eq} were found for every point in the sample propagation using the procedure described above. The relation between these values was presented as a plot of L_b versus B_{eq} and was usually known as the characteristic empiric curve of the model, and in this particular case the curve was associated to ESPOL engineering campus area. The Table 3 shows L_b and B_{eq} values.

TABLE 3

Lb and Beq.

BEQ (m)	Lb [dB]
11,41	11,56
22,82	13,96
19,02	15,20
24,99	14,29
18,41	16,32
20,58	17,09
28,55	19,47
30,54	17,13
27,89	17,34
21,91	12,52
24,87	11,83
25,23	11,13
34,53	15,14
25,90	13,56
51,74	18,08
48,77	21,64
53,51	23,88
44,69	28,33

The equation that results after the application of a linear adjustment procedure of L_b and *Beq* was:

$$L_b = 0.2751 B_{eq} + 5 \quad (6)$$

The value of 5 in Equation 6 can be regarded as a referential initial loss related to the propagation of the signal over a new environment composed by buildings. At this point, after finding an approximate relation between L_b and B_{eq}, the model construction process was finished. Therefore, the model was entirely described in terms of the transmission system's characteristics and its surroundings configuration. After replacing all the parameters described above, the Lee's customized equation was:

$$P_r(A) = 58 - \left(20{,}5 \log \frac{4\pi d_A}{\lambda}\right) - \left(0.2751 B_{eq} + 5\right) \quad (7)$$

Equation 7 shows that the distance-power gradient of the LOS expression corresponding the Lee's model was slightly modified from 2,00 to 2,05. This change was related to the presence of vegetation (smaller trees) in this complex contour.

4.2 Lee Model Adjustment to Simulate Performance in Forest Area Underneath the Base Station

In Section 4.1 we presented the empirical study we performed in the second microzone of our scenario, which corresponded to the part where the Engineering buildings were located. In this Section we present the modeling analysis we did to the first microzone, where a high level of vegetation surrounds the BS antenna.

We modified the Lee's model in order to incorporate a higher distance-power gradient due to significant presence of trees of ten meters of height in average, as shown in Figure 2. Specifically, we increased the distance-power gradient corresponding to the LOS expression described in Equation 2, from a value of 2,0 to 2,6 as follows.

$$L_{los} = 26 \log \frac{4\pi d_A}{\lambda} \quad (8)$$

Therefore the modeled received power for the first microzone or forest area, which goes from underneath the BS to a distance of 75 meters from this, will depend only on the effective radiated power and the adjusted LOS loss, as described in Equation 8. The final expression of the received power for this microzone is described in the following equation.

$$P_r(A) = 58 - \left(26 \log \frac{4\pi d_A}{\lambda}\right) \quad (9)$$

Finally, our model will be composed of two parts: The first one corresponding to Equation 9 for the forest area nearby the BS, which reaches up to 75 m from this, and the second one corresponding to Equation 7, which applies to the area where the buildings are located and expands from 84 m to 205 m from the BS.

Table 4 shows the summary of predicted received power using our constructed model for this complex scenario, as described before, and the actual measured values. In addition, it can also be seen the values of the equivalent obstruction length B_{eq} and the building obstruction loss L_b corresponding to the second microzone.

4.3 Model Validation

The ultimate outcome of this work can be summarized into the customized Lee's Equations 7 and 9. It presented ESPOL Engineering GSM antenna's propagation model explained in terms of particular parameters related to the transmission system's characteristics and surroundings configuration.

Lee's procedure for model validation consists of the following steps, which applies to the first and second microzones defined in our complex scenario:

1. To map the coverage area clearly and identifying building blocks and streets, or forest.
2. To calculate the occupation ratio of every building block.
3. To choose a random sample point within the coverage area.
4. To identify building blocks between the source antenna and the sample point.
5. To calculate equivalent building obstruction length (B_{eq}) along the straight propagation path between the source antenna and the sample point.
6. To estimate building obstruction loss (L_b) by evaluating the characteristic curve of the coverage area (L_b vs B) using an equivalent building obstruction length (B_{eq}), previously calculated in step 5.
7. To calculate the received signal power at sample points using Equation 7 or 9.
8. To measure actual received power at sample point.
9. To compare the two values obtained in the two previous points.

It is important to note that the procedure to validate our model in the forest area, or first microzone, includes only the steps 1, 3, 7, 8, and 9.

The Figure 5 shows the plot of the Table 5 data: the blue line corresponds to the estimated values calculated using Lee's model equation, and the green line depicts the actual power measurements.

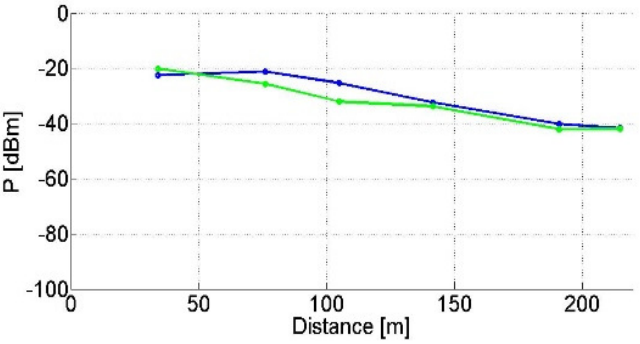

Fig. 5. Comparison between Lee customized prediction model (blue curve) and field measurements (green curve) values.

The result observed in Figure 5 indicates a good match between the predicted simulated values and the measured values, which validates our modeling effort realized in this investigation.

TABLE 4

MEASURED AND PREDICTED VALUES

DISTANCE (M)	AVERAGE RECEIVED POWER (DBM)	PREDICTED POWER (DBM)	ERP (DBM)	LB (DB)	BEQ (M)
10	-20.17	-8.6018	58	0	0
15	-16.19	-13.1802	58	0	0
20	-21.4	-16.4286	58	0	0
25	-27.78	-18.9482	58	0	0
30	-23.52	-21.007	58	0	0
35	-22.52	-22.7476	58	0	0
46	-20.16	-25.8335	58	0	0
52	-23.01	-27.2179	58	0	0
55	-25.57	-27.8512	58	0	0
59	-28.71	-28.644	58	0	0
63.6	-27.31	-29.4917	58	0	0
67.6	-26.51	-30.1804	58	0	0
75	-23.59	-31.3534	58	0	0
84	-23.28	-21.5996	58	8.138891	11.4
96	-26.84	-25.9273	58	11.277782	22.8
104	-28.78	-25.5945	58	10.232402	19
114	-28.67	-28.0543	58	11.874749	25
122.8	-31.34	-26.9061	58	10.064591	18.4
129	-32.54	-27.9416	58	10.661558	20.6
131.2	-35.07	-30.2847	58	12.854105	28.6
132.4	-32.81	-30.9132	58	13.401554	30.5
133.6	-33.09	-30.2645	58	12.672539	27.9
135	-28.36	-28.7122	58	11.027441	21.9
146	-28.36	-30.2239	58	11.841737	24.9
157.2	-28.3	-30.981	58	11.940773	25.2
166	-32.78	-34.0244	58	14.499203	34.5
179.6	-31.88	-32.3513	58	12.12509	25.9
197.2	-37.22	-40.2922	58	19.233674	51.7
202	-40.99	-39.6893	58	18.416627	48.8
204	-43.31	-41.081	58	19.720601	53.5
205.2	-47.81	-38.7068	58	17.294219	44.7

Table 5 shows a comparison between the expected values calculated using Lee's customized Equations 7 and 9, and the actual power measurements at six randomly selected sample points within the antenna's coverage area at ESPOL engineering campus.

TABLE 5

LEE'S MODEL PREDICTION VERSUS ACTUAL MEASUREMENTS

Asessment Point	Power Prediction [dBm]	Actual Power Measurement [dBm]
P1	-22,43	-20,07
P2	-21,16	-25,63
P3	-25,28	-32,06
P4	-32,33	-33,75
P5	-40,10	-42,05
P6	-41,67	-41,88

4 Conclusion

Lee's model is used by mobile telecommunication operators to plan its mobile networks due to it is an ITU standard. The planning of mobile networks in microcells that include several kind of media transmission (vegetation, buildings…) is very important because each scenario is unique. In this sense we have studied a complex case study that includes vegetation and buildings and previously was an experimentation area requested by Ecuadorian mobile operators. In this paper we have experimentally validated the Lee's model in our complex case study. The results are very interesting for mobile telecommunications operators and Academia.

Even though the studied area could not be exactly considered as urban, which is a Lee's model requirement, the outcome of the customized Lee model based upon real measurements happens to be a very good estimation for the received power prediction in a university campus environment.

The signal power behaves differently as expected in some examined points along the coverage area, such as the case of P3 observed in Table V. This behavior could be explained as unusual power variations produced by refraction and superposition of diffracted signals.

The procedure for model customization and validation process described in this research effort will be used as a learning tool, in a wireless communications or propagation class in the form of laboratory experience. The tool is thought to give students a hands-on learning experience with an overview of some key concepts on propagation theory.

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