

PROPAGATION MODELS APPLIED IN OPEN AREAS UNDER LTE TECHNOLOGIES AND FITTING WITH MEASUREMENTS

Luis Javier Sefla Urquizo ¹	luis.sefla@esPOCH.edu.ec
Daniel Alejandro Basantes Cherrez ¹	daniel.basantes@esPOCH.edu.ec
Erick Alexander Tintin Sanchez ²	erick.tintin@esPOCH.edu.ec
Joseph Alexander Aguilar Bonilla ³	joseph.aguilar@esPOCH.edu.ec

¹ Telecomunicaciones Riobamba, Ecuador

² Telecomunicaciones Banos, Ecuador

³ Telecomunicaciones Ambato, Ecuador

ABSTRACT

This paper presents an analysis of propagation models used to measure power intensity levels in the Department of Informatics and Electronics Sciences of ESPOCH University, using Movistar's LTE technology. Using the Cell Info Lite application and Google Earth software, the base radio was precisely located and concentric circles were drawn covering 145 points outside the department, covering an area of 36400 m². Three measurement campaigns were carried out at each point on different days and similar schedules, with the objective of comparing the propagation models and observing the variations in losses in the proposed scenario. The results indicate a close alignment between the Erceg model and the measured values obtained from Cell Info Lite, suggesting that this model is the most suitable for this specific scenario. These results have important implications for LTE technology planning and optimization, especially in environments similar to the Department of Informatics and Electronics Sciences at ESPOCH University, since the selection of an appropriate propagation model, such as the Erceg model, can significantly improve coverage and network performance for Movistar users..

Palabras Clave: Propagation Model, LTE, Movistar.

➤ I. Introduction

Mobile communication technology has evolved tremendously in recent decades, going through various generations that have significantly

improved the connectivity and data transmission speed. The first generation of mobile cellular technology, 1G, was characterized by limited voice quality and network capacity. Subsequently, 2G technology improved voice quality and added features such as text messaging and international roaming. 3G technology added data capabilities and enabled simultaneous voice and data transmission. 4G technology offered faster data speeds and improved data handling capacity for high-demand applications such as video conferencing and online video streaming. [1]

Long Term Evolution (LTE) technology is a mobile communication technology that has had a significant impact on how people communicate and access information. LTE is considered like an advanced version of 4G technology and has significantly improved data transmission speeds, mobile network capacity, and energy efficiency of mobile devices. [2] It has enabled the transmission of high-definition services and fast downloading of large files. Additionally, its ability to support multiple users simultaneously has enhanced the capacity of mobile networks, allowing more users to connect and enjoy advanced services without affecting connection stability. LTE is a wireless broadband technology capable of reaching speeds of up to 300 Mbps. [3]

Presently, Propagation models are used to predict the strength of signal power between a base and a receiver. These models consider various factors, such as distance, frequency, and environmental conditions. Among the most used models are the renowned Ericsson 999 model, [4] which stands out for its precision in urban environments when

considering the presence of buildings and artificial obstacles. On the other hand, the Erceg model specializes in estimating attenuation in microcell and macrocell scenarios, taking into account the density of buildings and surrounding vegetation. Furthermore, the Walfisch-Ikegami model focuses on propagation prediction in urban and suburban environments, considering diffraction and reflection in the presence of natural and artificial obstacles. The SIU model is relevant in path loss estimation and signal power adjustment in various communication environments. This model considers factors such as path loss, attenuation, and interference effects to calculate the expected signal power at a given point. For its part, the Log-Distance model is a widely used basic reference model that is based on the assumption that path loss increases logarithmically with distance. [5]

In this research, the Network Cell Info Lite application was used to measure the power intensity of Movistar’s LTE technology. The base station was located using Google Earth to place the analysis areas and to place 145 points covering the Faculty of Informatics and Electronics. Three measurement campaigns were carried out at similar times to evaluate variations in signal strength due to environmental factors such as weather and vegetation, among others. Subsequently, a more detailed comparative analysis was performed using the propagation models to evaluate the average results obtained. [6]

► II. Theoretical Framework

Propagation Models

A. Log-Distance Model

A radio propagation model that predicts the path loss encountered by a signal within a building or in densely populated areas over distance. In many cases, empirical results agree with Friis on a logarithmic decay with distance, however, the quadratic exponent is not the best fit to the data in many real propagation environments. Path loss is generally expressed as a function of distance by an exponent n according to: [7]

$$Pr(d) = Pr(d_0) + 10n \log \left(\frac{d}{d_0} \right) \quad (1)$$

Where:

$Pr(d)$: The signal propagation power loss at a distance d .

$Pr(d_0)$: The signal propagation power loss at a distance d_0 .

d : Distance between transmitter and receiver [m].

n : Is the attenuation exponent.

d_0 : First distance measurement performed.

B. Cost 231 Walfish-Ikegami Model

The COST 231 model is a semi-empirical path loss prediction model. It is recommended for macro-cells in urban and sub-urban scenarios, with good path loss results for transmitting antennas located above average rooftop height. However, the error in the predictions increases considerably as the transmitter height approaches rooftop height, leading to very poor performance for transmitters below that level. Compared to previous models such as Okumura-Hata, the COST 231 model includes a series of additional parameters to the calculation process, in addition to expanding the frequency range in which it can be used (800 - 2000 MHz). The model performs a more detailed calculation of the attenuation, based on four additional parameters. [8] [9]

- Height of buildings.
- Width of streets.
- Separation between buildings.
- Orientation of the street concerning the direction of propagation.

For LOS scenarios, the propagation loss considers only the free space loss, $L_b = LO(los)$

$$LO(los) = 42.6 + 26 \log(d) + 20 \log(f) \quad (2)$$

Where:

d : Is expressed in km.

f : is expressed in MHz.

The typical NLOS path described in the COST 231 model is shown in Figure 1 and Figure 2.

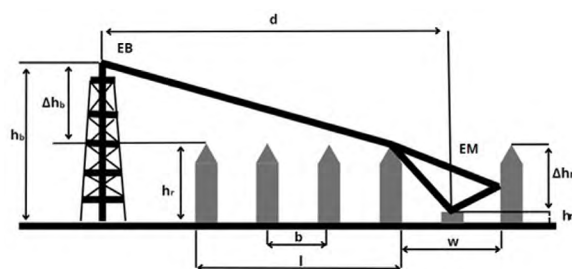


Fig. 1. Typical NLOS Propagation Scenario Profile view [8].

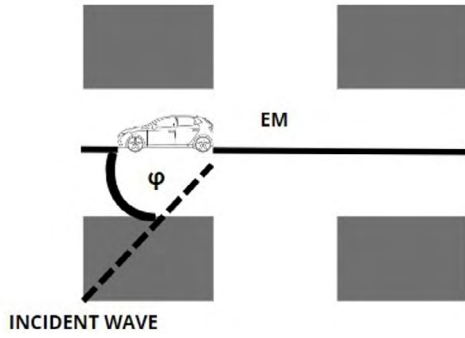


Fig. 2. Typical NLOS Propagation Scenario Top view [8]

The parameters defined in the COST 231 model (Figure 2) are the following:

- hr : Average height of the buildings (m).
- w : Street width (m).
- bl : Average spacing between buildings (m).
- ϕ : Angle formed by the direction of propagation and the axis of the street.
- hb : Height of the base station antenna (m).
- hm : Height of mobile device antenna (m).
- $(\Delta h_m = h_r - h_m)$ (m).
- $(\Delta h_b = h_b - h_r)$ (m).
- l : Total distance between the first and last building (m).
- d_r : Distance between base station and mobile device (km).
- f : Frequency of operation of the MOVISTAR cellular network (MHz).

When there is no line of sight, the propagation losses are determined by:

$$L_{NLOS} = \begin{cases} L_0 + L_{rst} + L_{msd} & , \text{ for } L_{rst} + L_{msd} > 0 \\ L_0 & , \text{ for } L_{rst} + L_{msd} \leq 0 \end{cases}$$

The propagation loss in free space conditions, L_0 , is obtained according to the expression:

$$L_0 = 32.4 + 20\log(d) + 20\log(f) \quad (3)$$

The term L_{rst} considers the width of the street and its orientation concerning the direction of ray propagation.

The expression for the calculation of L_{rst} is given by:

$$L_{rst} = -8.2 - 10\log(w) + 10\log(f) + 20\log(\Delta h_m) + L_{ori} \quad (4)$$

Where:

$$L_{ori} = \begin{cases} -10 + 0.35\phi, & \text{For } 0^\circ \leq \phi < 35^\circ \\ 2.5 + 0.007(\phi - 35), & \text{For } 35^\circ \leq \phi < 55^\circ \\ 4.0 + 0.11(\phi - 35), & \text{For } 55^\circ \leq \phi \leq 90^\circ \end{cases}$$

“The L_{ori} term is a correction factor that quantifies losses due to street orientation. If the value of L_{rst} is 0, it should be considered as $L_{rst} = 0$.

The multiscreen diffraction loss, L_{msd} , is a function of the frequency, the distance between the mobile device and the base station, as well as the height of the base station and the height of buildings. Similar to L_{rst} , if L_{msd} is negative, it is considered as $L_{msd} = 0$. Its value is calculated using the following expression:”

$$L_{msd} = L_{bsh} + k_a + k_d \log(d) + k_f \log(f) - 9\log(b) \quad (5)$$

Where:

$$L_{bsh} = \begin{cases} -18 \log(1 + \Delta h_b) \phi & , \text{ For } h_r > h_b \\ 0 & , \text{ For } h_r \leq h_b \end{cases}$$

Is a term that depends on the height of the base station.

In addition, the following parameters are defined:

$$K_a = \begin{cases} 54, & \text{For } h_b > h_r \\ 54 - 0.8 \Delta h_b, & \text{For } h_b \leq h_r \text{ and } d \geq 0.5 \text{ Km} \\ 54 - \frac{0.8 \Delta h_b d}{0.5}, & \text{For } h_b \leq h_r \text{ and } d < 0.5 \text{ Km} \end{cases}$$

$$K_d = \begin{cases} 18, & \text{For } h_b > h_r \\ 18 - 15 \frac{\Delta h_b}{h_r}, & \text{For } h_b \leq h_r \end{cases}$$

$$K_f = \begin{cases} -4 + 0.7 \frac{f}{925 - 1}, & \text{For medium - sized cities} \\ -4 + 1.5 \frac{f}{925 - 1}, & \text{For metropolitan centers} \end{cases}$$

The k_a term presents the increase in path loss for the case of base stations located below the average height of the buildings. The terms k_d and k_f control the dependence of L_{msd} on distance and frequency, respectively. If there is no data on the buildings on the route, the COST 231 model recommends using the following values [10]:

$$hr = 3m * (\text{No. of Floors}) + \text{ceiling height} \quad (6)$$

$$\text{ceiling height} = \begin{cases} 3m, & \text{sloping roof} \\ -0m, & \text{flat roof} \end{cases}$$

C. Ericsson 9999 Model

The Ericsson 9999 model, developed by the company Ericsson, is used for network addressing. It is an extension of the Hata model. The advantage of this model is that it allows for parameter adjustments according to the specific scenery in which the model is being applied. [11]

The mathematical expression that describes the loss predicted by this model is as follows:

$$L = a_0 + a_1 \log(d) + a_2 \log(h_b) + a_3 (h_b) \log(d) - 3.2(\log(11.75h_r))^2 + g(f) \quad (7)$$

Considering that:

$$g(f) = 44.43\log(f) - 4.78(\log(f))^2 \quad (8)$$

Where:

- f : Frequency (GHz)
- d : Distance between transmitter and receiver (m).
- h_b : Height of buildings (m).
- h_r : Receiver height (m).

The TABLE 1 below shows the correction factor values for different sectors:

TABLE 1: Factor of correction for different sectors

Factor	Urban	Suburban	a
a_0	36.2	43.20	45.95
a_1	30.2	68.93	100.6
a_2	-12.0	-12.0	-12.0
a_3	0.1	0.1	0.1

D. Erceg Model

Erceg et al. [12] proposed a model derived from a vast amount of data at 1.9 GHz, which makes it a preferred model for PCS and higher frequencies. The model was in particular adopted in the 802.16 [13] study group and is popular with WiMAX suppliers for 2.5 GHz products, and even 3.5 GHz fixed WiMAX.

$$l = l_0 + 10\gamma \log\left(\frac{d}{d_0}\right) + s \quad \text{For } d \geq d_0 \quad (9)$$

where free space approximation is used $d < d_0$ for. Values for l_0 , γ , and s are defined in tables 2 and 3.

TABLE 2: Values for Erceg model.

Parameter	Value (dB)
L_0	$20 \log \frac{4\pi d_0}{\lambda}$
d_0	100 (m)
γ	$(a - bh_B + c/h_B) + \phi_\gamma$
s	$\gamma\phi$
ϕ	$\mu_\phi + z\phi_\phi$
x, y, z	Gaussian random variables $N(0, 1)$

TABLE 3: Values for Erceg model parameters in various terrain categories.

Parameter	Terrain Category		
	A (Hilly/moderate to heavy tree density)	B (Hilly/light tree density or flat)	C (Flat/light tree density)
a	4.6	4.0	3.6
b	0.0076	0.0065	0.0050
c	12.6	17.1	20.0
ϕ_γ	0.57	0.75	0.59
μ_ϕ	10.6	9.6	8.2
ϕ_ϕ	2.3	3.0	1.6

E. SUI Model

Stanford University Interim (SUI) model is developed for IEEE 802.16 by Stanford University. It is used for frequencies above 1900 MH. In this propagation model, three different types of terrains or areas are considered. These are called terrain A, B, and C. Terrain A represents an area with the highest path loss, it can be a very densely populated region while terrain B represents an area with moderate path loss, a suburban environment. Terrain C has the least path loss which describes a rural or flat area. In Table 4, these different terrains and different factors used in the SUI model are described [8] (Table 4).

TABLE 4: Different terrains and their parameters.

Parameter	Terrain A	Terrain B	Terrain C
a	4.6	4.0	3.6
$b(1/m)$	0.0076	0.0065	0.0050
$c(m)$	12.6	17.1	20.0

The path loss in the SUI model can be described as:

$$PL = A + 10\gamma \log \left(\frac{d}{d_0} \right) + X_f + X_h + S \quad (10)$$

Where PL represents Path Loss in DBS, d is the distance between the transmitter and receiver, d_0 is the reference distance, X_f is the frequency correction factor, X_h is the correction factor for base station height, S is shadowing and γ is the path loss component and it is described as [14]:

$$\gamma = A - bh_b + \frac{c}{h_b} \quad (11)$$

where h_b is the height of the base station and a, b and c represent the terrain for which the values are selected from the above table.

$$A = 20 \log \left(\frac{4\pi d_0}{\lambda} \right) \quad (12)$$

where A is free space path loss while d_0 is the distance between Tx and Rx and λ is the wavelength. The correction factor for frequency and base station height are as follows:

$$X_f = 6 \log \left(\frac{f}{2000} \right) \quad (13)$$

$$X_b = -10,8 \log \left(\frac{h_r}{2000} \right) \quad (14)$$

where f is the frequency in MHz, and h_r is the height of the receiver antenna. This expression is used for terrain types A and B. For terrain C, the blow expression is used.

$$X_h = -20 \log \left(\frac{h_r}{2000} \right) \quad (15)$$

$$S = 0.65 (\log(f))^2 - 1.3\log(f) + \alpha \quad (16)$$

For rural and suburban environments (Terrain A and B):

$$\alpha = 5.2 \text{ dB.}$$

For urban environments (Terrain C): $\alpha = 6.6 \text{ dB.}$ [15]

» III. Metodología

Shown in Figure 3 is the block diagram in which the steps that were carried out to perform the power intensity measurements outside the Computer and Electronics Department were specified in order to later compare them with the propagation models.

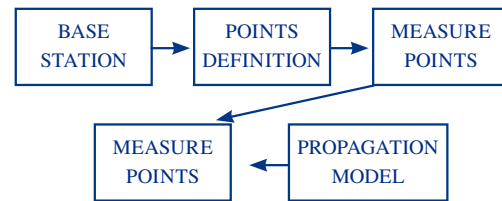


Fig. 3. Process Block Diagram

The Figure 4 shows the Movistar LTE base station located next to ESPOCH, with an EIRP of 46 dBm at coordinates -1.656432, -78.680327. The location is determined by the Network Cell Info Lite application, which allows you to identify it based on power intensity levels, taking as reference the criteria of shortest distance and highest power level. [16]



Fig. 4. Figure 4 Base Station

Show in Figure 5 the device used to measure the field strength (NARDA), obtaining a result of 0.5 v/m at a distance of 142 meters from the radio base, with the recommendation ITU-R P.525-4 the EIRP was determined from the electric field obtaining an EIRP of 52dBm.



Fig. 5. NARDA

The parameters of the transmitting antenna are shown in Table 5, where a frequency of 1940MHz.

TABLE 5: Base Station Parameters.

Parameter	Value
Operator	Movistar
Frequency	1940 MHz
Band	2
Latitude	1°39'23.2"S
Length	78°40'49.2"W
Height	20 m

Knowing the location of the base radio, 14 radios were plotted obtaining a total of 145 points covering all the exteriors of the Department of Informatics and Electronics in which the measurements of the receiving power were taken, Google Earth was used to mark the 14 radios shown in Figure 6 .



Figure 7. LOCATION OF POINTS

The distances of the radios are shown in Table 6. The distance from the transmitting antenna to the outer space of the Department of Computer Science and Electronics was considered. The number of radios was determined to cover all this area, obtaining a total of 14 radios.

TABLE 6: SPOKE DISTANCES

Radios	Distance (m)	Average power measured (dBm)
1	284.25	-89
2	303.98	-90
3	324.35	-91.33333
4	344.09	-92.33333
5	364.30	-93
6	384.81	-95
7	403.93	-97
8	423.67	-96
9	443.88	-96.33333
10	463.77	-96.33333
11	483.67	-96.66666
12	503.72	-97
13	523.61	-67.66666
14	543.83	-99.33333

To obtain the measurements of the power intensity levels at each point, the Network Cell Info Lite application was used. Three measurement campaigns were carried out at similar times and in similar scenarios to analyze the power variations in each campaign. This allowed obtaining an average value of the power intensity at each point. Figure 7 shows the results of the three measurement campaigns carried out on different days of the week in the Computer and Electronics Department. In the campaigns, the relationship between power and distance is observed without the presence of factors affecting the measurements in open spaces. In each of the campaigns it was analyzed how the power varies as the distance increases.

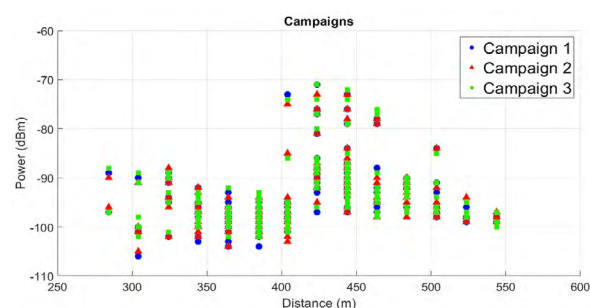


Figure 6. Results Campaigns

A. Log-distance Model

In this propagation model, equation 1 was used, which depends on data shown in Table 6. Substituting the values in the equation, the results in terms of n could be obtained. This process was applied to the 14 radii, then the mean square error was calculated, which is the sum of squared errors divided by the number of measurements. Once this process was completed, an equation was obtained for the mean squared error which is a function of n to minimize the mean squared error, the mean squared error was derived and equaled to zero, resulting in the optimum value of n, which in this case is n = 3.6395. And with this value determine the powers calculated for each radius.

B. Cost 231 Walfish-Ikegami Model

The Cost 231 Ikegami model was designed using a frequency of 1940 MHz, with a transmitting antenna located at a height of 20 meters and a receiving antenna at a height of 1.5 meters. To obtain more accurate data, the IT and Electronics department was divided into two scenarios, and measurements were taken to determine the

average width of the streets and the average height of the buildings. These additional parameters were considered in order to improve the accuracy of the results and allow a more appropriate comparison with other available models. In the model, an Equivalent Isotropic Radiated Equivalent Radiated Power (EIRP) of 52 dBm was used, while the receiver gain was estimated at 2 dBi. Taking into account these additional parameters and performing measurements in the two scenarios mentioned above, a higher accuracy in the results and a better application in similar scenarios is achieved. I am sorry for the above confusion and hope this answer is clearer and more accurate.

C. Ericsson 9999 Model

The current model was developed using a frequency of 1940 MHz, with a transmit antenna height of 20 m and a receive antenna height of 1.5 m. In addition, an EIRP (Equivalent Isotropic Radiated Power) of 52 dBm and a receiver gain of 2 dBi were found. It is important to highlight that in this model the specific parameters of a suburban environment that are shown in the table 1 have been taken into account.

D. Erceg Model

This model was developed using a frequency of 1940 MHz, with a transmitting antenna height of 20 m and a receiving antenna height of 1.5 meters. The effective isotropically radiated power (EIRP) has a value of 52 dBm and the receiver gain is 2 dBi. It should be noted that this model takes into account the parameters established in Table 2 and Table 3, specifically in Table 3, For the Faculty of Computer Science and Electronics it was ruled that it is a suburban environment, based on that category C is used (density of light trees and flat terrain).

E. SUI Model

The model developed was based on a frequency of 1940 MHz, with a transmitting antenna located at a height of 20 meters and a receiving antenna at a height of 1.5 meters. The EIRP used was 52 dBm and the receiver gain was set to 2 dBi. It is important to note that additional parameters specific to a suburban environment were considered in this model, such as the 5.2 dB attenuation due to the presence of obstacles and other factors. These additional considerations may affect the results

obtained, which explains the differences with the initial expectations.

» IV. Analysis of Results

A comparison between different propagation models, including Log-Distance, Erceg, Ericsson 9999, SUI and the Walfish-Ikegami model, along with the average measured values, is presented in Figure 8. The figure is divided into two categories: points with direct line of sight and points without direct line of sight.

The results reveal that generally points with direct line of sight present better average power values compared to points without line of sight. It is observed that the maximum value recorded is -104 dBm, while the minimum value is -71.7 dBm.

In terms of the fit of the models to the scenario, it was determined that the Erceg model fits more accurately to the measurements made. The mean square error (MSE) was used to evaluate the quality of the models' fit, and the Erceg model obtained the lowest MSE, with a value of 3.62, compared to the other models.

On the other hand, the Ericsson 9999 model tends to overestimate the values in relation to the measurements made, which implies that it predicts mean powers higher than those observed. In contrast, the SUI model underestimates the values, i.e., it predicts mean powers lower than those observed. The Walfish-Ikegami model also shows some degree of fit to the scenario, although not as accurate as the Erceg model.

These results emphasize the importance of selecting an appropriate propagation model to improve accuracy in the planning and optimization of telecommunication networks. In this case, the Erceg model proved to be the most suitable for the evaluated scenario due to its adjustment capacity and accuracy in predicting propagation losses.

In summary, the Erceg model more accurately fits the measured data in this scenario, showing better agreement with the observed mean powers. This indicates that the Erceg model is able to more accurately capture the propagation characteristics in the specific environment evaluated. On the other hand, both the SUI model and the Ericsson 9999 model show discrepancies compared to the measured mean powers. These discrepancies can be attributed to the limitations and simplifications inherent in these models. The SUI model, despite its versatility and adaptability, may overlook environment-specific

factors and oversimplify certain propagation effects, resulting in less accurate predictions. In addition, the Ericsson 9999 model may have limited accuracy in scenarios with variable terrain, dense vegetation, or natural obstacles, leading to less accurate estimates, especially in suburban environments similar to the present study.

► V. References

- [1] J. Gallagher, «Fifth-Generation (5G) Telecommunications Technologies: Issues for Congress,» Congressional Research Service, 2019.
- [2] G. González, D. Prado, F. Marante y A. Ledesma, «Analysis of LTE and LTE-Advanced system features through simulation processes,» *Ingeniare. Revista chilena de ingeniería*, vol. 25, n° 3, 2017.
- [3] A. Gillis, «LTE (Long-Term Evolution),» TechTarget, 2023.
- [4] J. Gomez y J. Zorro, «Unbosque,» Mayo 2019. [En línea]. Available: <https://repositorio.unbosque.edu.co/bitstream/handle/20.500.12495/10265/Estudio%20comparativo%20entre%205%20modelos%20de%20propagaci%C3%B3n%20de%20la%20red%204g%20Lte-A%20en%20diferentes%20ambientes%20de%20la%20ciudad%20de%20Bogot%C3%A1?sequence=1>. [Último acceso: julio 2023].
- [5] H. Moreno, D. Moreno, A. Flores y J. Ribadeneira, «Análisis comparativo de modelos de propagación en la telefonía móvil en la banda de 1900 MHz (LTE) a través de mediciones de campo eléctrico en la ciudad de Ambato,» *MAskay*, vol. 13, n° 2, pp. 1-8, 2023.
- [6] E. Ponce, J. Ledesma, R. Puchaicela y K. Miraba, «Estudio comparativo de modelos de propagación con el análisis de la intensidad de la señal LTE de las estaciones base con el área de cobertura en Riobamba -Ecuador,» *Coinciencia Digital*, vol. 5, n° 3, 2022.
- [7] J. Torres, Á. Pinto-Mangones, M. Macea, N. A. Pérez y L. Rujano, «MODELO PARA LA ESTIMACIÓN DE LAS PÉRDIDAS,» *UNIVERSIDAD, CIENCIA y TECNOLOGÍA V*, vol. 20, n° 78, pp. 1-12, 2016.
- [8] B. Vique, M. Escobar, A. Proaño, C. Bayas y A. Infante, «Comparación de modelos de propagación de radio en cinco celdas de cobertura LTE de Riobamba - Ecuador,» *Revista Tecnológica Espol*, vol. 34, n° 3, pp. 171-190, 2022.
- [9] J. d. C. V. Calero, «Universidad Tecnica de Amabto,» 12 2015. [En línea]. Available: https://repositorio.uta.edu.ec/bitstream/123456789/19382/1/Tesis_t1094ec.pdf. [Último acceso: junio 2023].
- [10] L. Aguilar, «Walfisch Bertoni model,» 7 septiembre 2010. [En línea]. Available: <https://pt.slideshare.net/eliche04/modelo-de-walfisch-bertoni>. [Último acceso: junio 2023].
- [11] K. M. R. Jiménez, «ESCUELA SUPERIOR POLITÉCNICA DEL,» 2018. [En línea]. Available: <https://www.dspace.espol.edu.ec/retrieve/132244/D-CD106670.pdf>. [Último acceso: mayo 2023].
- [12] Erceg, Greenstein y Tjandra, «An Empirically Based Path Loss Model for Wireless Channels in Suburban Environments,» *IEEE Journal on Selected Areas in Communications*, vol. 17, n° 12, pp. 1205--1211, 1999.
- [13] IEEE 802.16 Broadband Wireless Access Working Group, «Channel Models for Fixed Wireless Applications,» Contribution to 802.16a, 2003. [En línea]. Available: http://wirelessman.org/tga/docs/80216a-03_01.pdf. [Último acceso: mayo 2023].
- [14] A. Barrios, R. Arjona y R. Alvarez, «COMPARISON OF RADIO PROPAGATION MODELS IN THE SUBURBAN,» *Revista Colombiana de*, vol. 32, n° 32, 2018.
- [15] N. Shabbir, M. T. Sadiq, H. Kashif y R. Ullah, «Comparison of radio propagation models for long term evolution (LTE) network,» 2011. [En línea]. Available: https://elearning.esPOCH.edu.ec/pluginfile.php/1518137/mod_resource/content/1/1110.1519.pdf. [Último acceso: junio 2023].
- [16] N. Shabbir, «Comparison of radio propagation models for long term evolution (LTE) network - Ecuador,» *International Journal of Next-Generation Network*, 2011.
- [17] L. Yopez y M. Gragirena, «Corroboración del modelo de propagación “indoor”,» X

- JORNADAS DE INVESTIGACION , pp. 64-67, 2012.
- [18] C. Valero, «adslzone.net,» 21 04 2016. [En línea]. Available: <https://www.adslzone.net/2016/04/21/la-tecnologia-lte-pro-nos-hara-mas-corta-la-espera-del-5g-volando-1-gbps-movil/>. [Último acceso: 15 06 2023].
- [19] A. Galo, J. Gusñay , M. Ovaco, A. Puma y A. Uvidia, «Comparative analysis of propagation path loss models,» MASKAY, vol. 13, n° 1, 2022.
- [20] D. Curipoma y C. Macas, «UNIVERSIDAD TÉCNICA PARTICULAR DE LOJA,» enero 2019. [En línea]. Available: <https://dspace.utpl.edu.ec/bitstream/20.500.11962/23844/1/Curipoma%20Hernandez%20Danny%20Fabian%20y%20Macas%20Malan%20Carlos%20Andr%C3%A9.pdf>. [Último acceso: 06 2023].

