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Propagation models applied to LTE technologies in residential areas in Riobamba – Ecuador

Modelos de propagación aplicados a tecnologías LTE en zonas residenciales de Riobamba – Ecuador

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Palabras claves: modelos de propagación, tecnología LTE, software, potencia de recepción.

Resumen

Introducción. Se sabe que en cualquier sistema de transmisión lo que se propaga son ondas electromagnéticas que se transmiten y reciben y conocer la tendencia en la que varía con la distancia es uno de los requisitos fundamentales para un sistema de transmisión celular confiable y eficiente. **Objetivos:** Realizar un estudio comparativo de cinco modelos de propagación en diferentes escenarios en la zona norte de la ciudad de Riobamba; determinar cuál de los cinco modelos incluidos en el estudio es el más aplicable en cada caso. **Metodología:** Realizar un diagrama comparativo mediante gráficos que muestren la tendencia de cada uno de los modelos de propagación con respecto a las mediciones obtenidas mediante el software. **Resultados:** El modelo de propagación SUI es el que se adaptó a los escenarios propuestos porque sus cálculos para determinar las pérdidas de trayectoria incluyen datos más específicos dentro de un área suburbana. **Conclusiones:** Tras las respectivas investigaciones y los resultados obtenidos, se determinó que a una distancia considerable entre la estación base y el receptor móvil, la potencia de recepción disminuye.

Keywords: propagation models, LTE technology, software, receiving power.

Abstract

Introduction. It is known that in any transmission system what propagates are electromagnetic waves which are transmitted and received and knowing the trend in which it varies with distance is one of the fundamental requirements for a reliable and efficient cellular transmission system. **Objectives:** To conduct a comparative study of five propagation models in different scenarios in the northern area of the city of Riobamba; to determine which of the five models included in the study is the most applicable in each case. **Methodology:** To make a comparative diagram by means of graphs showing the trend of each of the propagation models with respect to the measurements obtained by means of the software. **Results:** The SUI propagation model is the one that was adapted to the scenarios proposed because its calculations to determine path losses include more specific data within a suburban area. **Conclusions:** After the respective investigations and the results obtained, it was determined that from a considerable distance between the base station and the mobile receiver, the reception power decreases.

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Introduction

Communication is understood as the process by which information is transmitted and received, the same that has evolved over time creating new methods so that data reception is as optimal as possible, 4G technology can reach 300 Mbps, reducing the waiting time to a small part of generation number 3 (3G) (Maldonado et al., 2010). Each of them have advantages in different types of applications, 3G networks are good for voice and data, and in terms of Internet This generation was a pioneer in high speed, however, today it is no longer the fastest network with the arrival of the 4G network, which is normally LTE technology, the same one that adapts in the propagation models for the calculation of losses in cell reception (Alonso et al., 2013).

Knowing the received signal and the trend in which it varies with distance is one of the fundamental requirements for a reliable and efficient cellular transmission system. It is known that in any transmission system what propagates are electromagnetic waves and these, being propagating in free space, are vulnerable to the different attenuations that the environment in which it is located may present, which causes the power received at the mobile station to be less than that originally emitted by the base station, this effect is also called propagation loss (path loss); the propagation loss is an aspect that directly influences the received signal strength, affecting the optimization of the transmission system (Akinwole, 2013).

There are several applications with which the power in- tensity of a base radio can be obtained such as “Best Signal Finder” or “Netmonitor Cell Signal Logging”; A software with a simple and efficient interface is the “Network Cell Info Lite” application, which is described as a cellular network monitor and measurement recording tool (4G +, LTE, CDMA, WCDMA, GSM) (Akinwole, 2013). It also provides WiFi information (beta) and is a network monitor in the Network and manager category. This application can be very useful to check the mobile network coverage that exists at a certain moment where it provides the information about the power intensity to the nearest base radio and showing the technology, whether 4G or 3G, to which the device is connected (Akinwole, 2013).

Propagation models make it easier to obtain the value of losses in space produced by the different attenuation factors, or the area in which the transmission system is located. A propagation model with mathematical expressions and algorithms simulates the scenario in which our transmission system could be found, that is, with the help of a propagation model it is easy to predict the path loss of a radio frequency signal that is commonly composed of a base station and a mobile receiver

Empirical propagation models are generally used to calculate path loss in wireless channels under different types of scenarios, and their results are taken into account when choosing the location of base stations and planning activities in the coverage area where The models used to obtain the different power levels of the different localities in the northern sector of the city of Riobamba are the Log-Normal model, the Hata Okumura model, the COST 231 model, the Walfisch-Bertoni model and the SUI model.

Objectives

- To conduct a comparative study of five propagation models in different scenarios in the northern area of the city of Riobamba; to determine which of the five models included in the study is the most applicable in each case.
- Differentiate the most relevant aspects of each propagation model, to optimize the greatest number of resources when applying them in practice.
- Inquire about software or applications that facilitate the collection of data on the powers captured by the mobile receiver with reference to a base station.
- Apply the Log-Normal propagation model in each scenario to define the range in which the losses received by the mobile receiver will oscillate.
- To make a comparative diagram where the trend of each propagation model is visualized with respect to the measurements obtained by the software, to know which model is more like the trend and to define the reason for the possible attenuations presented in the different propagation models in each scenario.

Methodology

To perform the comparative analysis of the propagation models applied at each base station, the following procedure was conducted:

1. Research on the most relevant aspects to apply each of the models presented as detailed below:

   - Log-Normal Model

   With the Log-Normal propagation model it is possible to describe the shading effects that can occur in the different measurement scenarios that contain a transmitter and a re- ceiver. In this propagation model the distance is variable and by this can be obtained the losses of the trajectory (*Log Normal Shadowing*, s.f.).

   The basic path loss equation detailing the Log-Normal propagation model starts from the first measurement, that is, the power received by the mobile receiver at the nearest distance from the base station; from this measurement and with the help of the Log-Normal model values of the optimal N are obtained which is a fundamental factor to plot the trend curve that will present the losses produced in the free space in the different environments

After having found the value of n, it is already possible to know the correction factor σ; adding and subtracting the value of sigma to the equation posed by the Log-Normal propagation model is known the range in which the powers captured by the mobile receiver will oscillate, is that the Log-Normal model presents an easy and effective way to predict the power that will be obtained at a certain distance (Some Empirical Models, s.f.).

$$PL(d) = PL(d) + 10n\log(\frac{d}{d_o}) + X_\sigma \quad (1)$$

- X_σ Fading component

- Okumura – Hata Model

In 1980 Hata released an expression for the correction factor based on the realized curves of the Okumura model, which is the most cited macroscopic dispersion model. With this correction factor it was possible to include to the Okumura model effects present in the environment such as diffraction, scattering and reflection that are present in most transmitted signals (Mathuranathan, 2019).

The general equation for the free-space propagation losses presented by the model is:

$$PL(d) = A + \mathrm{Blog(d)} + \mathrm{C} \quad (2)$$

Where (d) is the distance between Tx and Rx given by a range of 1-20kim. The variables A, B, C depend on factors such a frequency, type of environment and antenna height as detailed in the equations described below. (Pinto et al., 2016)

$$A = 69.55 + 26.26\log(f) - 13.82\log(h_b) - a(h_m) \quad (3)$$

$$B = 44.9 - 6.55\log(h_b) \quad (4)$$

Where:

f_c: Transmitting frequency described by the model from a range of 150 MHz to 1500 MHz

h_b: Transmitting antenna height (30m-200m)

h_m: Receiving antenna height (1m-10m)

$a(h_m)$: Receiving antenna height correction factor that varies according to the environment in which it is located.

C: Correction factor for rural and open suburban areas (Mathuranathan, 2019).

- COST-231 Model

This model is an extension of the COST Hata model (European Commission & Directorate-General for the Information Society and Media, 1999; Amarasinghe et al., 2009). It is used for frequencies over 2000MHz. For the line-of-sight (LOS) between the transmitter and receiver, the path loss is given by:

$$P_L = 42.64 + 26\log(d) + 20\log(f) \quad (5)$$

Under no-line-of-sight (NLOS) conditions, the path loss is as follows:

$$P_L = L_o + L_{RTS} + L_{MSD} \quad (6)$$

L_o represents the free space decay, described as:

$$L_o = 32.45 + 20\log(\mathrm{d}) + 20\log(\mathrm{f}) \quad (7)$$

L_{RTS} is referred to as the diffraction from the roof to the street, and can be calculated as follows:

$$L_{RTS} = -16.9 - 10\log(w) + 10\log(f) + 20\log(h_b - h_r) + L_{ORI} \quad (8)$$

The unit of L_{ORI} is given in degrees and this is referred to as the orientation of the antenna relative to the street, and can be calculated by (Calero, 2015):

$$-10 + 0.354\mathrm{a} \;\; \text{for} \;\; 0 < \mathrm{a} < 35$$

$$2.5 + 0.075(a - 35) \;\; \text{for} \;\; 35 < \mathrm{a} < 55$$

$$4 - 0.114(a - 55) \;\; \text{for} \;\; 55 < \mathrm{a} < 90$$

- Walfisch-Bertoni Model

In this model, it takes into account the heights of the buildings in relation to street level to draw diffraction models that predict the average power of the signal at pavement level (Alqudah, 2013).

The path losses are represented as:

$$L = L_0 + L_{ex} \quad (9)$$

Where L_0 is the free space loss and is defined as:

$$L_0(dB) = 32.44 + 20logf_c(MHz) + 20logR(km) \quad (10)$$

L_{ex} is the loss of the signal at roof level due to the shadow cast by roofs on the receiver, combined with is the diffraction loss in the signal from the roof to street level (Walfisch & Bertoni, 1988).

$$L_{ex}(dB) = 57.1 + A + logf_c + 18logR - 18log(h_t - h) - 18log\left(1 - \frac{R^2}{17(h_t - h)}\right) \quad (11)$$

Where:

R : distance (transmitter - receiver) [kilometers].

f_c : operating frequency [MHz].

h_t : effective height (transmitting antenna) [meters].

h_r : effective height (receiving antenna) [meters].

h : average building height [meters].

- SUI model

This model was developed by Stanford University for IEEE 802.16, its acronym SUI stands for Stanford University Interim (Ghz et al., s.f.; Abhayawardhana et al., 2005). The SUI model works for frequencies above 1900 MHz. This model takes into consideration three diverse types of terrain, which are Terrain A for a higher path loss area (densely populated region), Terrain B for a moderate path loss area (suburban environment) and Terrain C for a lower path loss (rural or flat area). The following table shows the values taken by plots A, B and C for their different parameters.

Table 1

Different terrains & their parameters

Parameters	Terrain A	Terrain B	Terrain C
a	4.6	4	3.6
b(1/m)	0.0075	0.0065	0.005
c(m)	12.6	17.1	20

To calculate the basic propagation loss, the SUI model proposes to group the propagation scenarios into three distinct categories, each with its own characteristics:

- Category A: Mountainous terrain with medium and elevated levels of vegetation, corresponding to high loss conditions.
- Category B: Mountainous terrain with low levels of vegetation, or flat areas with medium and elevated levels of vegetation. Average level of losses.
- Category C: Flat areas with extremely low or no density of vegetation. Corresponds to paths where losses are low (Chisab, 2014).

The following equation is used to calculate the path loss in this propagation model:

$$P_L = A + 10\gamma \log\left(\frac{d}{d_0}\right) + X_f + X_h + S \qquad (12)$$

PL is the path loss [dB], d represents the distance between the transmitting antenna and the receiving antenna [kilometers], d0 is the reference distance (in this case it takes the value of 100) [meters], Xf represents the frequency correction factor, Xh is referred to as the base station (BS) height correction factor, s is shadowing and γ represents the path loss component and is described as (Chisab, 2014):

$$\gamma = a - bh_b + \left(\frac{c}{h_b}\right) \qquad (13)$$

hb represents the height of the base station, a, b, and c the terrain types which are selected from the table noted above.

$$A = 20log(\frac{4\pi d_0}{\lambda})$$
(14)

A is the free space path loss, d0 represents the distance between the transmitting antenna and the receiving antenna, λ as the wavelength. The correction factors for frequency and base station height are detailed below:

$$X_f = 6\log(\frac{f}{2000})$$
(15)

$$X_h = -10.8\log\left(\frac{h_r}{2000}\right)$$
(16)

As seen above, f is the frequency [MHz], hr the receiver height [meters]. This expression is used for terrain types A and B. For terrain type C, the following expression is used:

$$X_h = -20\log(\frac{h_r}{2000})$$
(17)

$$s = 0.65(\log f)^2 - 1.3\log(f) + \alpha$$
(18)

α takes the value of 5.2 dB which is for terrain A and B (rural and suburban respectively), and for terrain type C (urban environment) α is equal to 6.6 dB (Navarro & Andredy, 2012).

The signal strength measurements for this project were collected in 5 different base stations in the northern part of Riobamba with the Network Cell Info Lite application.

The number of data collected per antenna was 50 measurements in 3 contrasting times of the day in which different values were obtained according to different conditions presented for the collection, such as sector, weather condition, traffic, users, cellular technology, region and the distance between sender and receiver. To know the distance between the point where the measurements were made and the position of the antenna, the google earth tool was used.

The data table II provides detailed information on each of the base stations, describing the value of the calculated isotropic radiated power (EIRP), the maximum and minimum distance at which the measurements were taken and the respective height of the transmitting antenna at each base station.

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Figure 1

Location of base stations

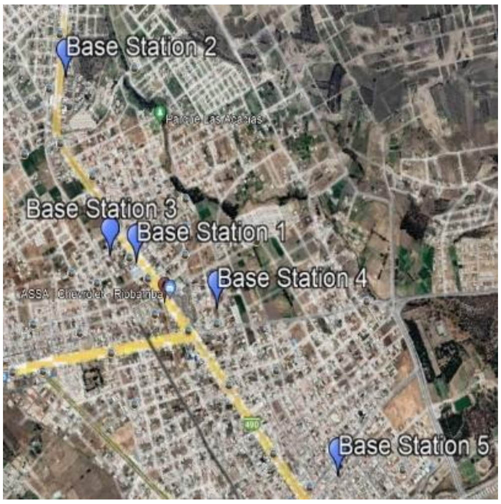

Table 2

Different terrains & their parameters

Base	EIRP	Maximum Distance	Maximum Distance	Height of base stations
BS1	26,4345 dBm	60 m	252 m	24 m
BS2	18,9563 dBm	40 m	168 m	30 m
BS3	23,4760 dBm	67 m	431 m	25 m
BS4	29,2909 dBm	61 m	316 m	15 m
BS5	27,0181 dBm	50 m	200 m	24

Once the data was obtained, an average power value was obtained to which the normal log model was subsequently applied using all the processes mentioned above, to know the range in which the values were displayed. Once this is done, the rest of the models to be studied are applied using the equations mentioned above. Then the measurements were figure, and the respective models were made in MATLAB to compare and observe which would be the best model that fits our measurements.

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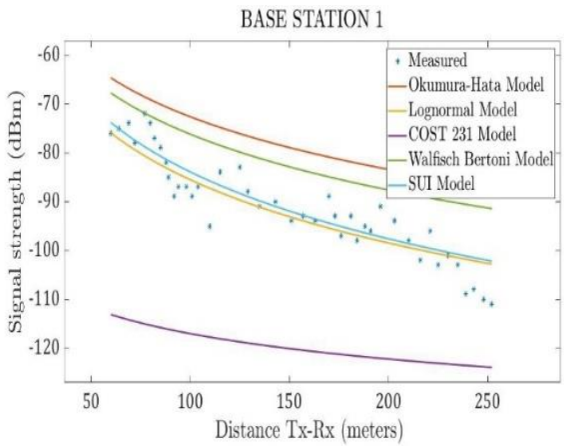
Results:

A. Base Station 1 (BS1)

Figure 2

Comparison of propagation models in BS-1

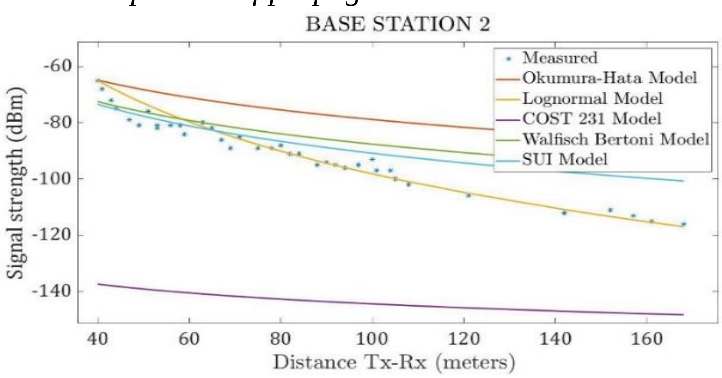


The figure shows the calculation of 50 measurements in five different propagation models, this calculation was carried out in the urban sector of the city of Riobamba-Norte, the image shows the comparison of each propagation model with respect to the measurements, in the case in this sector, the best model is the SUI because they are closer to the values of the measured powers, which implies that there is better efficiency. However, the Walfisch-Bertoni model can be considered efficient but on a smaller scale because few points are close. which shows that up to a certain distance this model provides superior results. Similarly, the models that show the least efficiency in this sector are the normal Log and the COST 231 and Okumura Hata models, which are the furthest from the points taken in the area.

B. Base Station 2 (BS2)

Figure 3

Comparison of propagation models in BS-2

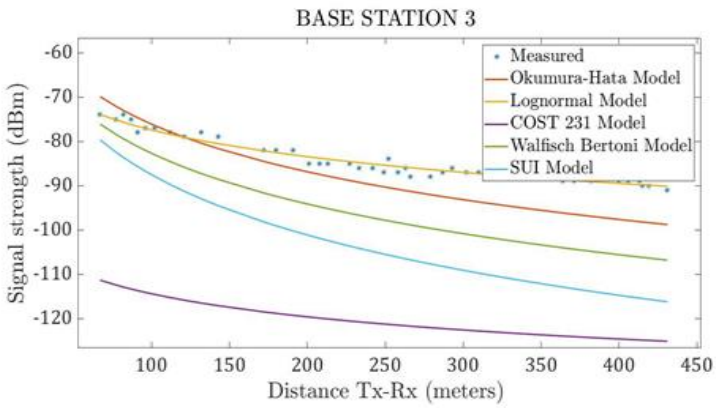


The previous figure shows the comparison of the 5 propagation models together with the curve of the 50 average power values based on different distances, this event was conducted in the Santa Ana neighborhood, north sector of the city of Riobamba, this sector is considered a suburban area. It could be seen in the graph that the curve that best fits our measurements is that of the Log Normal model because our measurement points tend to center around this model, it was also observed that the SUI and Walfish-Bertoni models as the distance increases, the power decrease does not vary much with respect to the model that was coupled to our measurements, that is, the Log Normal model tends to drastically decrease the power as the receiver moves away from the transmitting antenna.

C. Base Station 3 (BS3)

Figure 4

Comparison of propagation models in BS-3

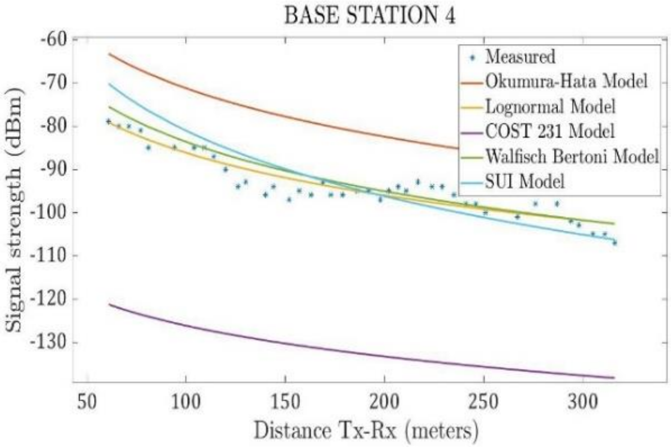


The figure shows the calculation of 50 measurements in five different propagation models, this calculation was performed in the urban sector of the city of Riobamba-North, the image shows the comparison of each propagation model with respect to the measurements, in the case of this sector the best models are the Walfisch-Bertoni and Okumura Hata, because they present a greater proximity to the values of the measured powers implying that there is better efficiency, However, the SUI model can be considered efficient but on a smaller scale because few points are close, showing that up to a certain distance this model provides good results. Similarly, the models that have lower efficiency in this sector are the Log normal and the COST 231 models, which are the furthest away from the points taken in the area.

D. Base Station 4 (BS4)

Figure 5

Comparison of propagation models in BS-4

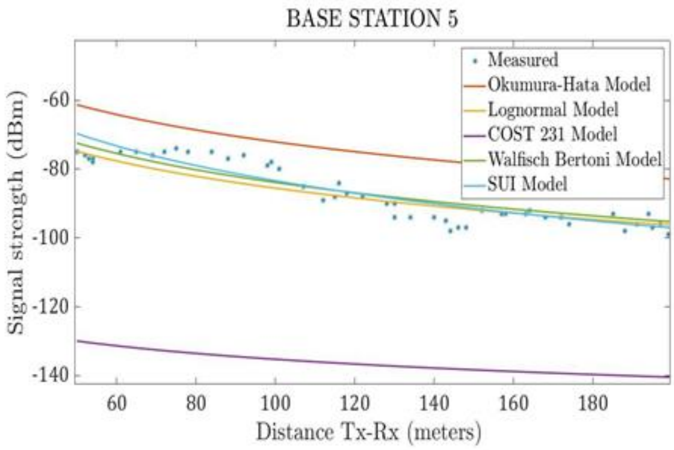


The models that were applied at base station 4 are plotted in "Fig. 7". Each of these models was calculated by means of their respective formulas, which differ in the selection of required variables; it is also possible to visualize and make the respective comparison according to the model that best fits the measurements previously made. This comparison is made with respect to the measurements previously made using the Network Cell Info Lite application, thus allowing to verify which of the five models is the most applicable to this base station.

E. Base Station 5 (BS5)

Figure 6

Comparison of propagation models in BS-5



The figure shows the comparison between propagation models applied in 50 average measurements in the north of Riobamba in Ernesto Noboa and Sangay streets. In this case, the models that best adapt to the measurement are Bertoni and Sui. This is because, as can be seen in the graph, the measurement points are close to the straight lines that represent the models. On the contrary, the less adequate models for the measurements are the Log normal and the COST 231 models, which are the furthest away from the points taken in the area.

Calculation of the root mean square error

In the following section a comparative table of the mean square error is made for each of the propagation models, where each model will have a respective enumeration that allows to identify it in the table III, where a respective analysis of which is the best model applicable to each of the studied zones will be made, it is worth mentioning that the values inserted in the table are given in dB.

1. Cost 231 Model
2. Okumura Hata Model
3. Walfish Bertoni Model
4. Sui Model
5. Log Normal Model

Table 3

Mean square error

Base	1	2	3	4	5
BS1	8,30	5,25	4,89	3,35	3,12
BS2	8,57	5,12	3,95	3,71	3,09
BS3	7,85	3,53	4,27	4,81	3,16
BS4.	8,80	5,47	3,19	3,41	3,05
BS5	9,05	4,91	3,20	3,34	3,15

In base station 1 the model that is coupled is the SUI and Log-Normal model, in base station 2 the Sui model and the Walfish Bertoni model were coupled, in the base station 3 the Okumura Hata model is coupled, in the base station 4 the Walfish Bertoni model and the SUI were coupled, and in the last base station the Walfish Bertoni model and the SUI model were coupled.

Conclusions

- In the project presented, it has been shown that the simulation of the mobile channel for 4G-LTE bands ob-tained acceptable results in the prediction of path loss in urban environments based on the Log-normal propagation model, Okumura Hata, Walfisch-Bertoni, COST 231 and SUI.

- We were able to assess the losses in each base station and determine the best model for each one with respect to the measurements. Each of the formulas in the propagation models and their different parameters were considered to perform the respective calculations. It was satisfactory to conduct the programming in MATLAB and verify which model is closest to the measured and calculated points.
- From the comparison made with respect to the propagation models evaluated at base station 4, it can see at a glance that the most applicable propagation models are the Walfisch Bertonni Model and the SUI model, which keeps its data in the same trend as the measurements obtained by the software; there were data that were disregarded because they were significantly dispersed from the trend. To make corrections to the model so that it more closely resembles the measurements made, it is possible to calculate the root mean square value and evaluate the data that are closest.
- After the analysis conducted in the various locations of the city, it was possible to demonstrate that although the idea that the shorter the distance the better the signal reception, the analogy is not always true, because there are factors that influence the quality of the signal that a user can receive on his mobile device. It was determined that the maximum range of each base antenna in the different sectors is different because these are more populated areas than others where interference will occur in diverse ways.
- With the comparative analysis of each model used in the different base stations located north of the city of Riobamba, it is possible to deduce that the most optimal model to use in this type of residential areas is the SUI model due to the short distances and frequencies in which it operates.

References

Abhayawardhana, V. S., Wassell, I. J., Crosby, D., Sellars, M., & Brown, M. G. (2005). *Comparison of empirical propagation path loss models for fixed wireless access systems*. *1*, 73-77 Vol. 1. https://doi.org/10.1109/VETECS.2005.1543252

Akinwole, B. O. H. (2013). Comparative Analysis of Empirical Path Loss Model for Cellular Transmission in Rivers State. *American Journal of Engineering Research*, 8.

Alonso Quintana, R., Bordón López, R., & Montejo Sánchez, S. (2013). Estudio comparativo de los modelos de propagación de canal inalámbrico. *Ingeniería Electrónica, Automática y Comunicaciones*, *34*(1), 12–26.

Alqudah, Y. (2013). *On the Performance of Cost 231 Walfish Ikegami Model in Deployed 3.5 GHz Network*. 524–527. https://doi.org/10.1109/TAEECE.2013.6557329

Amarasinghe, K., Peiris, K. G. A. B., Thelisinghe, L. A. D. M. D., Warnakulasuriya, G. M., & Samarasinghe, A. T. L. K. (2009). Comparison of propagation models for Fixed WiMAX system based on IEEE 802.16-2004. In *ICIIS 2009—4th International Conference on Industrial and Information Systems 2009, Conference Proceedings* (p. 129). https://doi.org/10.1109/ICIINFS.2009.5429880

Calero, C. V. (2015). S*imulación del modelo de propagación cost 231 walfisch- ikegami para el canal móvil de bandas 4G. https://repositorio.uta.edu.ec/jspui/handle/123456789/19382*

Chisab, R. (2014). Performance Evaluation of 4G-LTE-SCFDMA Scheme under SUI and ITU Channel Models. https://www.researchgate.net/publication/262373991_42101-7474-IJET-IJENS_C_February_2014_IJENS

European Commission & Directorate-General for the Information Society and Media. (1999). *COST Action 231: Digital mobile radio towards future generation systems: Final Report*. Publications Office.

Ghz, W. O., Milanovic, J., & Bejuk, K. (s.f.). *Comparison of Propagation Models Accuracy for* WiMAX on 3.5 GHz. https://www.researchgate.net/publication/4321213_Comparison_of_Propagation_Models_Accuracy_for_WiMAX_on_35_GHz

Log normal Shadowing. (s.f.). Retrieved May 17, 2022, from https://www.ques10.com/p/47939/log-normal-shadowing-1/

Maldonado, C., Perez García, N., Uzcátegui, J., & Malaver, E. (2010). Nuevo modelo de propagación para redes WLAN operando en 2.4 Ghz, en ambientes interiores. *Télématique*, *9*, 1–22.

Mathuranathan. (2019, March 27). Hata Okumura model for outdoor propagation. *GaussianWaves*. https://www.gaussianwaves.com/2019/03/hata-okumura-model-for-outdoor-propagation/

Navarro Cadavid, A., & Andredy Ardila, C. (2012). Ajuste estadístico de modelos de propagación de señal usando medidas de la ciudad de Cali. *Ingenium*, *6*(11), 11. https://doi.org/10.21774/ing.v6i11.58

Some Empirical Models. (s.f.). Retrieved May 17, 2022, from https://www.ques10.com/p/48583/some-empirical-models/

Walfisch, J., & Bertoni, H. L. (1988). A theoretical model of UHF propagation in urban environments. *IEEE Transactions on Antennas and Propagation*, *36*(12), 1788–1796. https://doi.org/10.1109/8.14401

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