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Original articles

Comparison of radio propagation models in five LTE coverage cells in Riobamba

Comparación de modelos de propagación de radio en cinco celdas de cobertura LTE de Riobamba

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Abstract

This article performs a comparative analysis of the power intensity levels measured with the Network Cell Info Lite application and the performance of the different propagation models: Log-Normal, Okumura Hata, COST 231, Walfish Bertoni, and SUI in the 4G LTE Frequency Band. The study was conducted in five LTE coverage cells located in the southern area of the city of Riobamba. The model that best fits each cell was chosen by means of absolute error analysis, thus obtaining an empirical correction factor for the proposed models. For the analysis of the absolute error, three measurement campaigns were carried out with 50 samples where the mean value was obtained. After applying the aforementioned models, the Log-Normal model yielded the most favorable results, being the one that achieved the best adaptation in Riobamba, since the power levels vary in the range (-80; -106) dBm at a coverage area not exceeding 200m.

Keywords: Coverage cells, frequency band, multiscreen diffraction loss, cells and open spatial propagation model, Friis.

Summary: Introduction, Theoretical Framework, Methodology, Results and Conclusions.

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Resumen

Este artículo realiza un análisis comparativo de los niveles de intensidad de potencia medidos con la aplicación Network Cell Info Lite y el desempeño de los diferentes modelos de propagación: Log-Normal, Okumura Hata, COST 231, Walfish Bertoni y SUI, en la Banda de Frecuencia 4G LTE. El estudio se realizó en cinco celdas de cobertura LTE ubicadas en la zona sur de la ciudad de Riobamba. Se eligió el modelo que mejor se ajusta a cada celda mediante el análisis de error absoluto, con ello se obtuvo un factor empírico de corrección para los modelos propuestos. Para el análisis del error absoluto se realizaron tres campañas de medición con 50 muestras donde se consiguió el valor medio. Después de aplicar los modelos antes mencionados, el modelo Log-Normal arrojó los resultados más favorables siendo este, el que logró una mejor adaptación en Riobamba ya que los niveles de potencia varían en el rango (-80; -106) dBm a una zona de cobertura no superior a los 200m.

Palabras clave: Celdas de cobertura, banda de frecuencia, pérdida de difracción multipantalla, celdas y modelo de propagación espacial abierta, Friis.

Introduction

The growing demands on mobile services have encouraged many researchers toward achieving multi- services with low latency. To illustrate that, Zhang (2012) pointed out that LTE (Long Term Evolution) is a standard for high-speed wireless data communications which is maintained as a project of the 3rd Generation Partnership Project (3GPP). In addition, to cover the requirements of the mobile migrations of Internet applications, such as VOIP, video streaming, music downloading, and mobile TV, LTE networks offer the capacity to tolerate the throughput explosion for the connection from mobile devices customized to those new mobile applications. A propagation model is a set of mathematical expressions, diagrams, and algorithms used to represent the radio characteristics of a given environment (Bekele, 2017).

In 2004, an initial study of long-term evolution (LTE) was introduced and viewed as a path for migration to 4G networks (Rao, 2009). With the rapid development of LTE (4G) technology in recent years, 4G terminals like mobile phones have been widely used for communication. LTE (4G) signals have covered indoor and outdoor environments in modern cities. Inspired by the advances in wireless sensing that have enabled a large variety of new applications such as indoor localization (Li, 2016).

LTE aims to increase the speed and capacity of wireless networks by utilizing signal processing techniques and modulations (Hadi, 2015). 4G technology is supported by the 3GPP (third generation) standard, which bases its system on IP, that is, it is a system of systems and a network of networks, and is subsequently overcome in the convergence between cable networks or wireless networks, computers, electrical devices -electronic, ICT among others to provide access speeds between 100Mbps in movement and 1Gbps at rest, but the most important thing is to maintain the quality of service (QoS) from point to point (end-to-end), with high security to massify the number of additional services in any place betting on having the lowest possible cost (Tomažič, 2009).

Path loss models are sophisticated tools for predicting coverage area, interference analysis, frequency assignments, and cell parameters which are the basic elements for the network planning process in mobile radio systems (Blaunstein, 2006).

The Okumura-Hata model is the most widely used empirical propagation prediction model. In 1980, Hata introduced an empirical formula for propagation loss that was derived from Okumura's report to put the propagation prediction method into computational use in system planning software. The propagation loss is presented in the simple form A + B log(R), where A and B are functions of frequency and height of the antenna and R is the distance (Y., 1967). This simplicity of the model has made it the most widely used propagation prediction model and it is even standardized for international use (Union, 1995).

The European Cooperative for Scientific and Technical Research (Euro-Cost) developed the Cost 231 model, in which the Hata model is extended to the 2 GHz range, covering the VHF and UHF bands. CM is a correction factor to fit the model by extending the frequency range for which the Hata model operates; CM (0 dB) for medium cities and suburban areas; CM (3 dB) for metropolitan centers; and that corresponds to the equations presented in the Hata model. One of the contributions of this model is to consider losses due to dispersion (Garcia, 2004).

Stanford University Interim (SUI) model derived from Hata, with corrections for frequencies above 1900MHz. It includes the path loss exponent, it proposes three different types of terrain: urban, suburban, and rural. The height of the antenna of the proposed base station is between 10 and 80 meters, that of the mobile from 2 to 10 meters, and the extension of the cell from 0.1 to 8 km (Shahajahan, 2009).

The model, proposed by Joram Walfisch and Henri Bertoni, considers the losses produced by the diffractions that occur on the roofs of buildings (Walfish, 1988). It is a model that does not consider the existence of a line of sight between the transmitter and the receiver, it uses the phenomenon of diffraction to describe the losses suffered by the signal before reaching the receiver located low above the street. The contribution of the rays that penetrate the buildings and of those that suffer multiple diffractions is neglected. The separation between the buildings must be less than their height and they are supposed to be arranged in parallel rows. The frequency range in which this model applies is from 300 to 3,000 MHz, with a separation between transmitter and receiver of 200 to 5,000 m. It is not applicable when the base station antenna is below the average height of buildings (Hernando, 2013).

The log-normal distribution is a function distributing a dependent variable in a normal or Gaussian fashion on a logarithmic scale of the independent variable. This function has been used for a long time to describe size distributions of particle properties in atmospheric aerosols. Foitzik (1964) used this functional relationship for the description of optical aerosol properties. Later, Whitby (1974) built a general concept for the multimodal nature of the atmospheric aerosol on this approach by fitting measured particle size distributions in a combination of three log-normal distributions (Heintzenberg, 1994).

To determine the performance of the previously proposed propagation models, a comparative analysis of the power intensity levels measured with the Network Cell Info Lite application in the 4G Frequency Band was carried out at 5 LTE coverage cells located in the southern zone of the Riobamba city and the model that best adapts to the conditions of the area will be extinguished by applying an empirical correction factor to the proposed models. The document details the absolute error for the calculation of this correction factor, considering three measurement campaigns with 50 samples where the mean value was obtained. From the study carried out, it was concluded that the model Log-Normal is the best estimator of power levels considering the environment of the city, which is a residential area.

Theoretical Framework

Log-Normal Model

It is an empirical model based on a reference of the losses at a pre-established distance, and applicable in closed environments by factors of correction. It is expressed in an equation as a function of the distance between transmitter and receiver as:

$$PL(d) = PL(d_0) + 10n\,log\left(\frac{d}{do}\right) + X_\sigma \tag{1}$$

Where is the path loss variable due to the multiple trajectories; $PL(d_0)$ is the- loss to one near reference distance d_0 and it is calculated using the space propagation model open, Friis formula, or taking measurements field; X_σ is a random variable expressed in dB and experimentally validated and statistically. The model is simple but absorbs the random effects of shadows and multipath that occur for different measurement locations with the same distance between the Tx-Rx, but with different obstructions in the path of propagation comparing with a reference value (Yepez, 2012).

Okumura Hata Model

The Hata model is an empirical formulation of the graphical path loss data provided by Okumura and is valid from 150 MHz to 1500 MHz. Hata presented the urban area propagation loss as a standard formula and supplied correction equations for application to other situations. The standard formula for median path loss in an urban area is given:

$$L_{50}(dB) = 69.55 + 26.16logf_c - 13.82logh_{te} - a(h_{re}) + (44.9 - 6.55logh_{te})logd \tag{2}$$

Where f_c is the frequency (MHz) from 150 MHz to 1500 MHz, $h_{te}$is the effective transmitter (base station) antenna height (meters) ranging from 30 m to 200 m, h_{re} is the effective receiver (mobile) antenna height (meters) ranging from 1 m to 10 m, d is the T-R separation distance (km), and $a(h_{re})$ is the correction factor for effective mobile antenna height which is a function of the size of the coverage area. For a small to medium-sized city, the mobile antenna correction factor is given by:

$$a(h_{re}) = (1.1logf_c - 0.7)h_{re} - (1.56logf_c - 0.8)\ dB \tag{3}$$

and for a large city, it is given by:

$$a(h_{re}) = 8.29(log1.54h_{re})^2 - 1.1\ dB \text{for } f_c \leq 300 \text{ MHz} \tag{4}$$

$$a(h_{re}) = 3.2(log11.75h_{re})^2 - 4.97\ dB\ \ \text{for } f_c \geq 300 \text{ MHz} \tag{5}$$

The predictions of the Hata model compare very closely with the original Okumura model if d exceeds 1 km. This model is well suited for large cell mobile systems, but not personal communications systems (PCS) which have cells on the order of a 1km radius (Anonymous, 1968).

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:

- 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, $L_b = L_{0(LOS)}$ where:

$$L_{0(LOS)} = 42.6 + 26\,log(d) + 20log\,(f) \tag{6}$$

d is expressed in km and f in MHz.

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

Figure 1

Typical NLOS Propagation Scenario Profile view

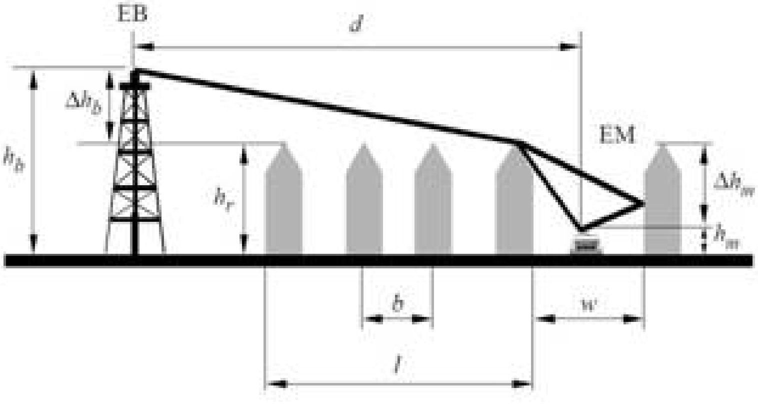
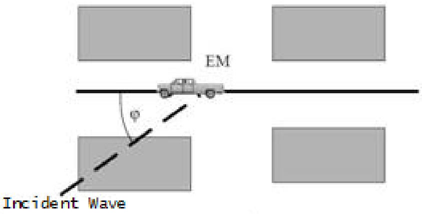


Figure 2

Typical NLOS Propagation Scenario Top view



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

- h_r: average height of buildings (meters)
- w: width of the street (meters)
- b: average distance between buildings (meters)

- φ: angle formed by the direction of propagation and the axis of the street.
- h_b: base station antenna height (meters)
- h_m: height of the mobile device antenna (meters)
- $\Delta h_m = h_r - h_m$ (meters)
- $\Delta h_b = h_b - h_r$ (meters)
- l: total distance between the first and the last building on the path (meters)
- d: distance between the base station and mobile device (km)
- f: frequency (MHz)

The basic propagation loss for the NLOS scenario is given by:

$$L_b = \begin{cases} L_0 + L_{rts} + L_{msd} & for\ L_{rts} + L_{msd} > 0 \\ L_0 & for\ L_{rts} + L_{msd} \leq 0 \end{cases} \tag{7}$$

The propagation loss in free space conditions, L0, is obtained according to the expression:

$$L_0 = 32.4 + 20\,log(d) + 20 log\,(f) \tag{8}$$

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

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

$$L_{rts} = -8.2 - 10\,log(w) + 10\,log(f) + 20\,log(\Delta h_m) + L_{ori} \tag{9}$$

where:

$$L_{ori} = \begin{cases} -10 + 0.35\varphi & for\ 0^0 \leq \varphi < 35^o \\ 2.5 + 0.07(\varphi - 35) & for\ 35^o \leq \varphi < 55^o \\ 4.0 - 0.11(\varphi - 35) & for\ 55^o \leq \varphi \leq 90^o \end{cases} \tag{10}$$

The L_{ori} term is a correction factor that quantifies losses due to street orientation. In case the value of $L_{rts} < 0$, $L_{rts} = 0$ should be considered.

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. Like L_{rts}, if L_{msd} is negative, $L_{msd} = 0$ is considered. Its value is calculated using the expression:

$$L_{msd} = L_{bsh} + k_a + k_d\,log(d) + k_f\,log(f) - 9 log\,(b) \tag{11}$$

where:

$$L_{bsh} = \begin{cases} -18\,log(1 + \Delta h_b) & for\ h_b > h_r \\ 0 & for\ h_b \leq h_r \end{cases} \tag{12}$$

Is a term that depends on the height of the base station. In addition, the following parameters are defined:

$$k_a = \begin{cases} 54 & for\ h_b > h_r \\ 54 - 0.8\Delta h_b & for\ h_b \leq h_r\ y\ d \geq 0.5\ km \\ 54 - \dfrac{0.8\Delta h_b d}{0.5} & for\ h_b \leq h_r y\ d < 0.5km \end{cases} \tag{13}$$

$$k_d = \begin{cases} 18 & for\ h_b > h_r \\ 18 - 15\dfrac{\Delta h_b}{h_r} & for\ h_b \leq h_r \end{cases} \tag{14}$$

$$k_f = \begin{cases} -4 + 0.7\left(\dfrac{f}{925 - 1}\right) & for\ medium - sized\ cities \\ -4 + 1.5\left(\dfrac{f}{925 - 1}\right) & for\ metropolitan\ centers \end{cases} \tag{15}$$

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: (Aguilar, 2010).

$$h_r = 3\,m * (No.of\ floors) + ceiling\ height \tag{16}$$

$$ceiling\ height = \begin{cases} 3\,m & sloping\ roof \\ 0\,m & flat\ roof \end{cases} \tag{17}$$

Walfish-Bertoni Model

It is valid when there is no line of sight between the base station and the mobile. Buildings are modeled as a set of diffraction and absorption screens buildings of a uniform height and width are considered, require that the transmitting antenna is above the highest ceiling.

The path loss is given by:

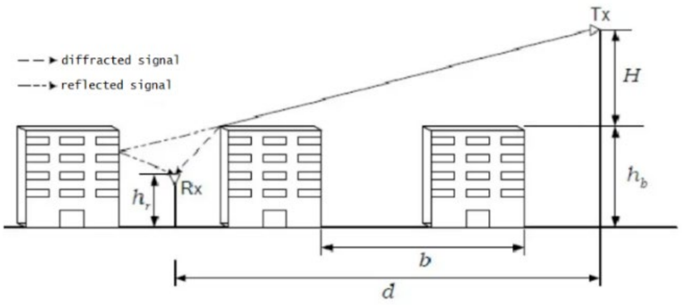
$$L_p = 89.55 + 21logf + 38logd - 18logH + A - 18log\left(1 - \frac{d^2}{17H}\right) \tag{18}$$

where:

- f: frequency (MHz)
- d: distance between transmitter and receiver (km)
- H: average height of the antenna concerning the height of the buildings (m)
- A: variable that expresses the influence of buildings on the signal

Figure 3

Typical propagation Scenario



The influence of buildings on the signal (Figure 3).

$$A = 5log\left[\left(\frac{b}{2}\right)^2 + (h_b - h_r)^2\right] - 9logb + 20log\left\{tan^{-1}\left[\frac{2(h_b - h_r)}{b}\right]\right\} \tag{19}$$

where:

- h_b: height of buildings (m)
- h_r: receiver height (m)
- b: distance between buildings (m)

In a real environment, the geometry of the buildings is irregular, causing this model to have less certainty in predicting the received power; however, this model is applicable in radio propagation simulation software (Cell View) if adaptations are made to the equations or if an average density and height of buildings are obtained (Shabbir, 2011).

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 1, these different terrains and different factors used in the SUI model are described (Table 1).

Table 1

Different terrains and 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

The path loss in the SUI model can be described as

$$PL = A + 10\gamma\ log\left(\frac{d}{d_0}\right) + X_f + X_h + S \tag{20}$$

where PL represents Path Loss in DBS, d is the distance between the transmitter and receiver, do 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

$$\gamma = a - bh_b + \frac{c}{h_b} \tag{21}$$

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.

$$A = 20log\left(\frac{4\pi d_0}{\lambda}\right) \tag{22}$$

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

$$X_f = 6log\left(\frac{f}{2000}\right) \tag{23}$$

$$X_h = -10.8log\left(\frac{h_r}{2000}\right) \tag{24}$$

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.

$$X_h = -20log\left(\frac{h_r}{2000}\right) \tag{25}$$

$$S = 0{,}65(logf)^2 - 1.3\,log(f) + \alpha \tag{26}$$

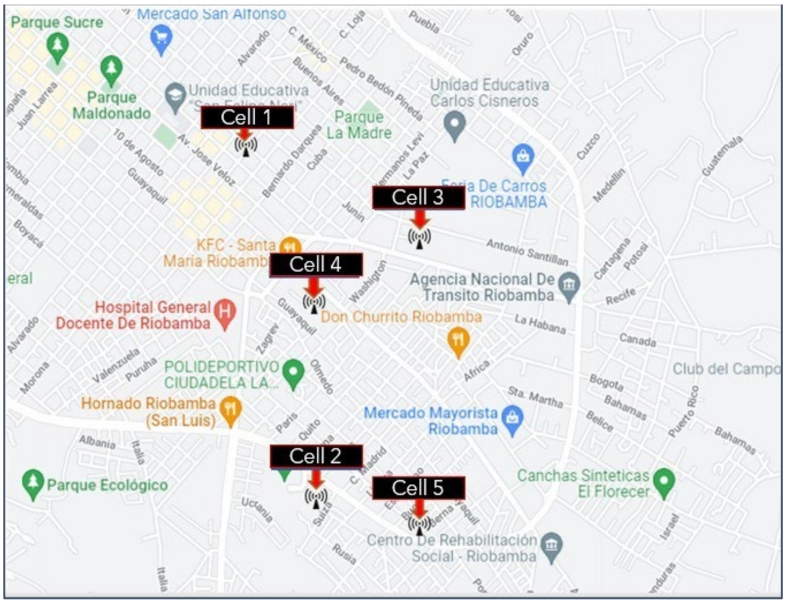
Here, $\alpha = 5.2$dB for rural and suburban environments (Terrain A & B) and 6.6 dB for urban environments (Terrain C) (Shabbir, 2011).

Methodology

The comparative analysis was carried out on 5 LTE coverage cells in the South Zone of the city of Riobamba in 3 different campaigns, taking 50 reference samples from which, the arithmetic means of said measurements were taken to have an estimate of the reception power of each cell.

Figure 4

Location of LTE coverage cells



The southern area of the city of Riobamba was taken by the Google Maps application where the 5 cells were located, and the power data was collected for the study of the propagation models that can be applied in said area. Each antenna works with different operators (Figure 4).

The applicability of this document was carried out using 2 software programs: Microsoft Excel for the development of mathematical operations and obtaining numerical data, and MATLAB for the management of graphs and the statistical study of results.

To determine which model best fits, we apply the equations of the different propagation models considering the correction factor and the parameters that each model requires.

Coverage Cell 1

The first cell is located on José Orozco and Bernardo Darquéa streets from Riobamba City it belongs to the Tuenti operator and works with an operating frequency of 1900MHz. Next, the considerations for the use of propagation models are detailed (Table 2).

Table 2

Parameters Cell 1

PARAMETERS	VALUE
Base station antenna height (m)	30
Mobile device height (m)	1.5
Distance (m)	47–170
Street width (m)	4
Elevation angle	14.47°-40.79°
Buildings height (m)	9
Distance between buildings (m)	4

Fuente: https://www2.ulpgc.es/hege/almacen/download/27/27199/propagacion.pdf

Coverage Cell 2

The second cell is in the Sabún Sports Complex, located on Av. October 9 and Atenas street from the Riobamba city, it belongs to Tuenti operator and works with an operating frequency of 1900MHz. Next, the considerations for the use of propagation models are detailed (Table 3).

Table 3

Parameters Cell 2

PARAMETERS	VALUE
Base station antenna height (m)	32
Mobile device height (m)	1.5
Distance (m)	48.62 – 205.02
Street width (m)	4
Elevation angle	20° - 63°
Buildings height (m)	9
Distance between buildings (m)	3.5

Coverage Cell 3

The third cell is located at Celso Rodríguez Avenue and París street from Riobamba city, it belongs to the Tuenti operator and works with an operating frequency of 1900MHz. Next, the considerations for the use of propagation models are detailed (Table 4).

Table 4

Parameters Cell 3

PARAMETERS	VALUE
Base station antenna height (m)	18
Mobile device height (m)	1.5
Distance (m)	49 – 211
Street width (m)	4
Elevation angle	25° - 63°
Buildings height (m)	9
Distance between buildings (m)	4.5

Coverage Cell 4

The fourth cell is located at Leopoldo Freire Avenue and Lisboa Street from Riobamba city, it belongs to the CNT operator and works with an operating frequency of 1900MHz. Next, the considerations for the use of propagation models are detailed (Table 5).

Table 5

Parameters Cell 4

PARAMETERS	VALUE
Base station antenna height (m)	30
Mobile device height (m)	1.5
Distance (m)	49 – 226
Street width (m)	4
Elevation angle	25°-72°
Buildings height (m)	9
Distance between buildings (m)	3.5

Coverage Cell 5

The fifth cell is located at 9 de Octubre avenue and Noruega street from Riobamba city, it belongs to the Claro operator and works with an operating frequency of 1700MHz. Next, the considerations for the use of propagation models are detailed (Table 6).

Table 6

Parameters Cell 5

PARAMETERS	VALUE
Base station antenna height (m)	25
Mobile device height (m)	1.5
Distance (m)	48.62 – 205.02
Street width (m)	4
Elevation angle	17° - 70°
Buildings height (m)	9
Distance between buildings (m)	4

Finally, the losses obtained by each of the models mentioned above are replaced in the general formula that is given by:

$$Pr(dBm) = Pt + Gt + Gr - L_{pm} \tag{27}$$

where:

- Pt: transmission potency
- Gt: transmission gain
- Gr: reception gain
- L_{pm}: propagation models lost

The received power obtained was plotted against the distance around each of the base stations for each propagation model and compared to the measured field average power value.

Adjusting the Propagation Model

Since the propagation models were taken in cities whose conditions are very different from the study area, it is necessary to adjust the model. For this, the absolute error that will represent the empirical correction factor was used to determine with what range of power the values are far from the real ones measured. To do this, the average of the measured values and the average of each of the propagation models that required adjustment is used.

$$\varepsilon_{abs} = |v_{real} - v_{measured}| \tag{28}$$

where:

- ε_{abs}: absolut mistake
- v_{real}: average power value
- $v_{measured}$: power value for each propagation model

Results

The following graphs obtained show the approximate curves of the propagation models without a correction factor in each of the five LTE coverage cells concerning the average power whose data was collected in the southern zone of the city of Riobamba.

Figure 5

Coverage cell 1 without correction factor

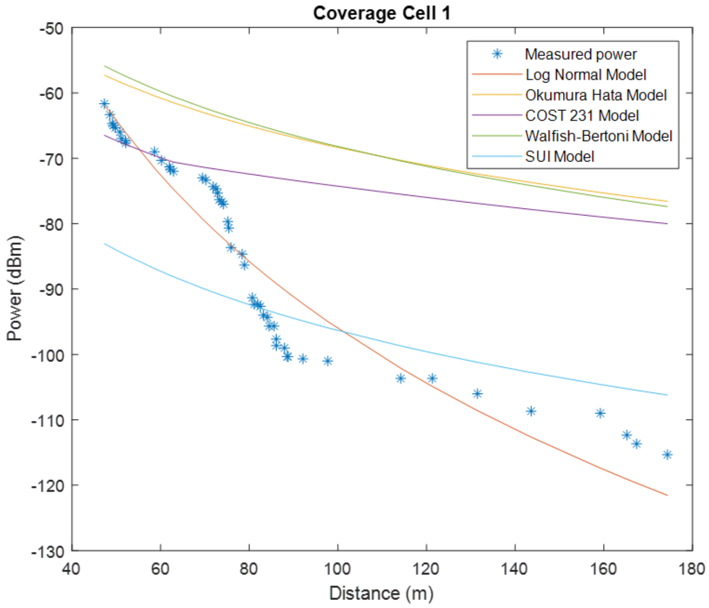
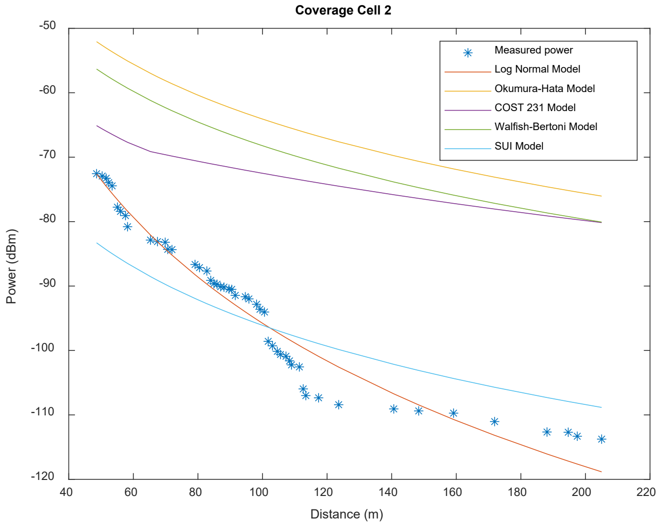


Figure 5In cell 1 (Figure 5). It is possible to observe that without the corrections to the different propagation models, the samples obtained resemble the Log Normal model, in addition to the other models such as Okumura-Hata and the Walfish-Bertoni model, giving results very far from the values measured.

Figure 6

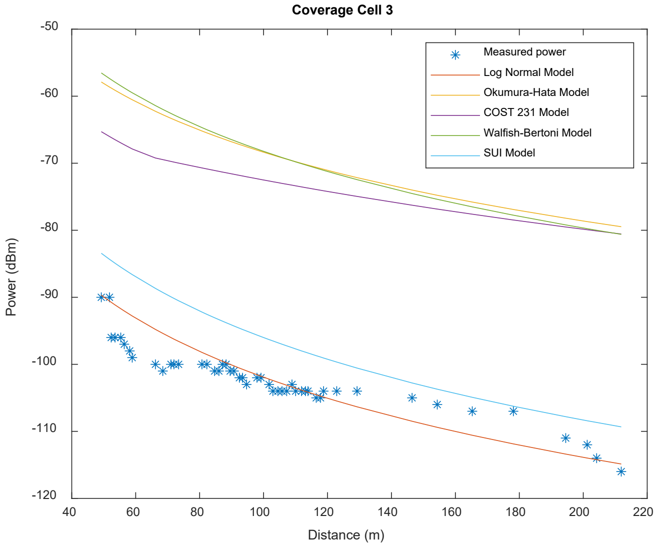
Coverage cell 2 without correction factor



In cell 2 (Figure 6) it is possible to observe that the samples obtained are similar to the Log Normal model within 100 meters, which is where there is a great concentration of powers, so it can be said that it is where it is best has been coupled to the prediction model, considering that the different attenuations are due to being in an area full of vegetation. On the other hand, the other models do not coincide with the powers collected because the area where the samples were taken does not meet the characteristics of the different models, which is why it is seen that both the Okumura-Hata, Cost 231 and Walfish-Bertoni are far apart with respect to the powers obtained and compared with the data obtained in the other radio bases, it is observed that these 3 models are much further away from each other.

Figure 7

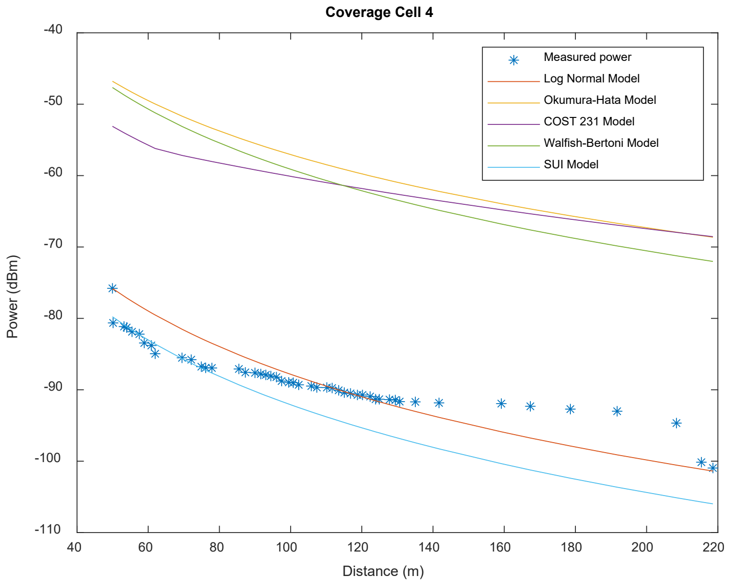
Coverage cell 3 without correction factor



In cell 3 (Figure 7) it is observed that the data collected is very similar to the Log Normal model, especially between 80 and 118 meters there is coupling with respect to this model, but at the same time, it is possible to observe that the powers collected at from 130 to 190 meters they resemble the SUI model, these power losses are because the area where the data was collected was an area where there are many houses between 2 and 3 floors.

Figure 8

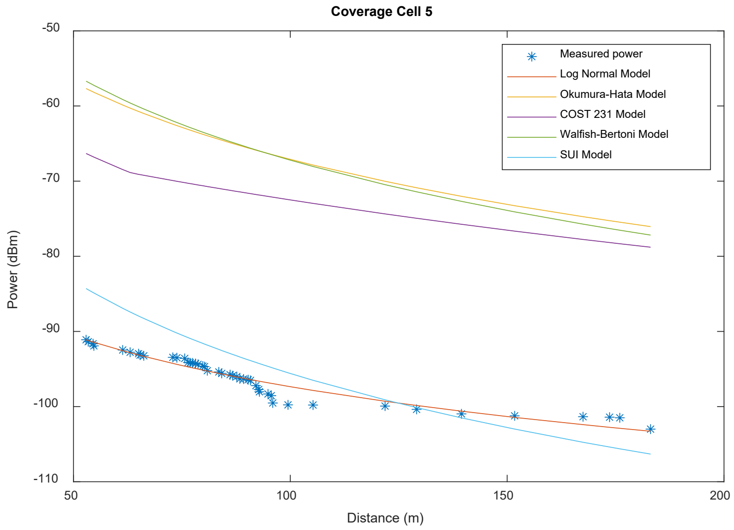
Coverage cell 4 without correction factor



In cell 4 (Figure 8) where it is observed that it resembles two models, firstly, the collected data tend to have a coupling with the SUI model between 47 to 78 meters, and from 83 to 140 meters they are coupled to the model. Log Normal, considering that from 140 meters these tend to suffer more attenuations, therefore they move away from the results of the models, this is because the data obtained were in a place full of buildings within the main street.

Figure 9

Coverage cell 5 without empirical correction factor

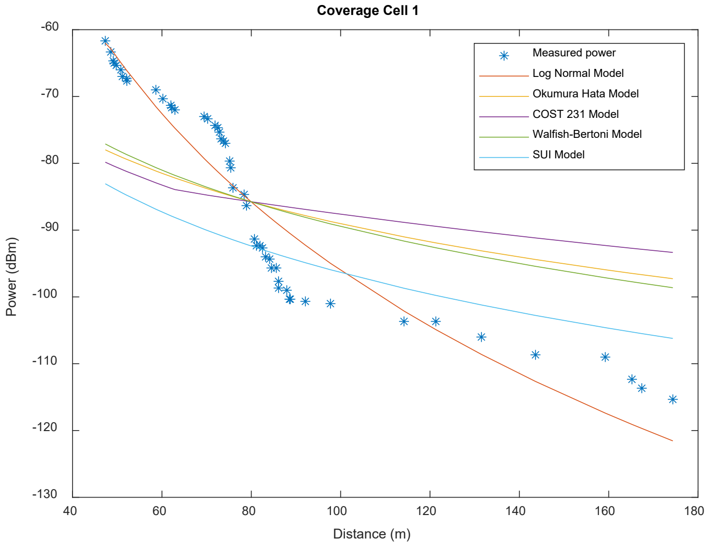


In cell 5 (Figure 9) it is observed that it resembles the Log Normal model within 50 to 96 meters of distance, where there is a great concentration of powers between 70 to 94 meters, in addition to that manages to observe that there is an intersection between the SUI model and Log Normal, so that within 130 to 135 meters the data collected resembles the SUI model.

Next, the graphs of the propagation models are presented with a correction factor so that they are coupled to the power measurements of the 5 different LTE coverage cells located in the southern zone of the city of Riobamba, in this way having a prediction of attenuation in that area.

Figure 10

Coverage cell 1 with correction factor



In cell 1 shown in (Figure 10) the correction factor was applied to 3 propagation models: Okumura-Hata, Cos 231, and the Walfish-Bertoni model, the correction values were: -20.69 dBm, -13.34 dBm, -21.23 dBm respectively. When applying the correction factor, the graphs of the propagation models are better coupled to the power samples taken with the mobile, however, the model that is more coupled in cell 1 is the Log-normal model.

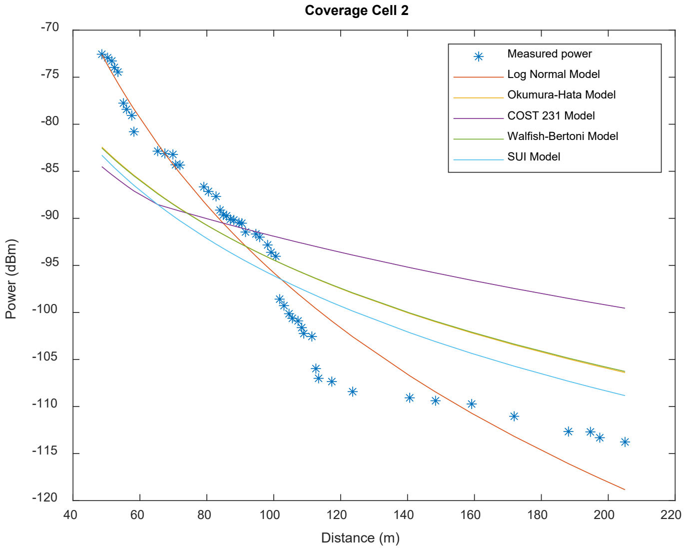
In the first 100 meters, many powers were collected, finally, it was visualized that at a greater distance the samples suffer an attenuation that is caused by the presence of different infrastructures. It is possible to observe that, without the corrections to the different propagation models, the samples obtained are similar to the Log Normal model, in addition to other models such as the Okumura-Hata model and the Walfish-Bertoni model, giving results very far from those obtained. measured values. According to Pérez, within his investigation he affirms the following:

> Attenuation as a result of energy absorption by the medium occurs as a consequence of the electromagnetic characteristics of the material through which the wave propagates and is the fundamental cause of energy losses in the case of material media. (p. 111). Pérez (2001)

That is why within the first 100 meters different powers were collected, finally it was visualized that at a greater distance the samples suffer an attenuation that is caused by the presence of different infrastructures.

Figure 11

Coverage cell 2 with correction factor



In cell 2 shown in (Figure 11) the correction factor was applied to 3 propagation models: Okumura-Hata, Cos 231, and the Walfish-Bertoni model, the correction values were: -30.35 dBm, -19.40 dBm, - 26.20 dBm respectively. When applying the correction factor, the graphs of the propagation models performed better than the power samples taken with the mobile, however, the model that best fits cell 2 is the Log-Normal with variations less than 5dBm.

In cell 2 (Figure 6) it can be seen that the samples obtained are similar to the Log Normal model within 100 meters, which is where there is a large concentration of powers, so it can be said that it is where there is a better coupling to the prediction model, considering that the different attenuations are due to being in an area full of vegetation. According to Recommendation ITU-R P.833-3, it states:

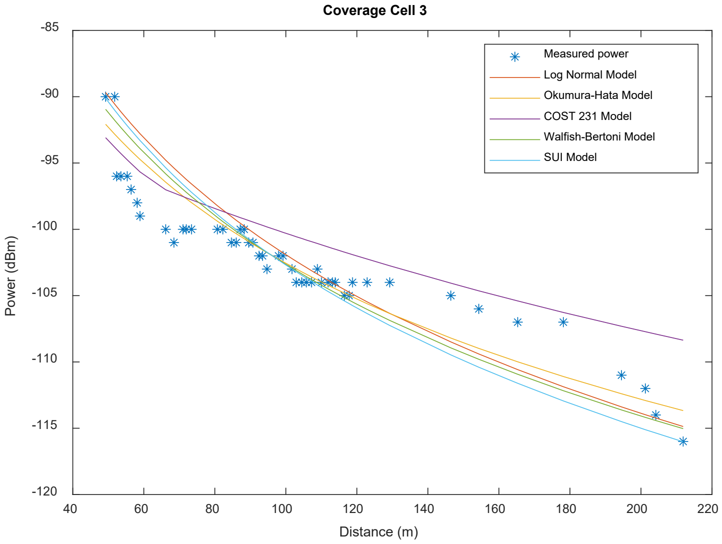
> In certain cases, vegetation attenuation may be important, both for terrestrial systems and for Earth-to-space systems. But the great diversity of conditions and types of foliage makes it difficult to develop a general prediction procedure. In addition, there is a lack of adequately verified experimental data. (p.1). Recommendation UIT-R P.833-3 (2001)

On the other hand, the other models do not coincide with the powers collected because the area where the samples were taken does not meet the characteristics of the different models, so it is seen that both the Okumura-Hata, Cost 231, and Walfish- Bertoni are very far apart concerning the powers obtained and comparing with the data obtained in the other radio bases, it is observed that these 3 models are much further away from each other.

In cell 3 shown in (Figure 12) correction factor was applied to 4 propagation models: Okumura-Hata, Cos 231, the Walfish-Bertoni model, and the SUI model, the correction values were -34.20 dBm, - 27.28 dBm, -34.42 dBm, and -6.69 dBm respectively. When applying the correction factor, the graphs of the propagation models performed better than the power samples taken by the mobile, however, we see that almost all the models fit correctly, being the one that stands out the most are the Cos 231 model and the Cos 231 model. Log-Normal with differentiation between the measured value and that of the power of the models not greater than 6 dBm.

Figure 12

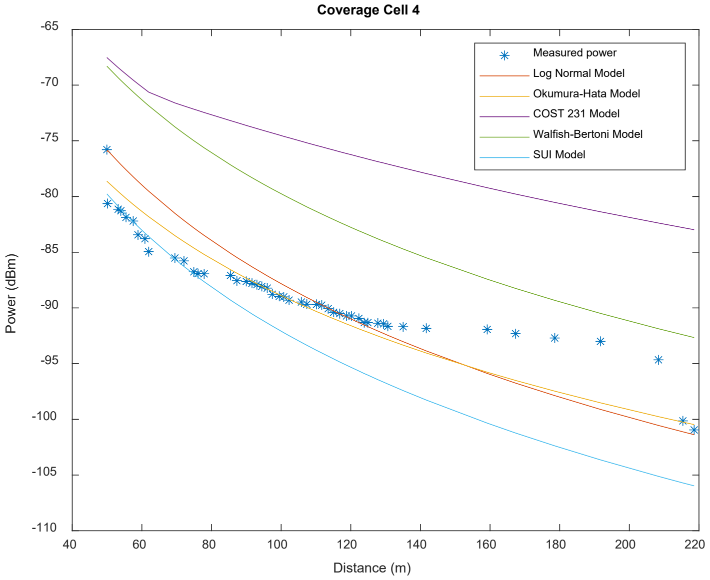
Coverage cell 3 with correction factor



In cell 3 (Figure 7) it is observed that the collected data are very similar to the Log Normal model, especially between 80 and 118 meters there is coupling concerning this model, but at the same time it is possible to observe that the powers captured from 130 to 190 meters are similar to the SUI model, these power losses are because the area where the data was collected is an area where there are many houses between 2 and 3 floors. For this reason, Anonymous (2019), suggests that "whenever there is a refraction of the electromagnetic wave, we will have a reflection of energy on the separation surface, for which the energy of the refracted wave will be less than that of the incident" (p.2). Anonymous (2019).

Figure 13

Coverage cell 4 with correction factor



In cell 4 shown in (Figure 13) the correction factor was applied to 3 propagation models: Okumura-Hata, Cos 231, the Walfish-Bertoni model, the correction values were: -31.84 dBm, -14.43 dBm, -20.64 dBm, respectively. When applying the repair factor, the graphs of the propagation models are better coupled to the power samples taken by the mobile, however, the curve of the Okumura-Hata model, together with the normal Log model, was the most adapted, even though between 140m and 200m there is a significant dispersion in the measurements whose differentiation is less than 8 dBm.

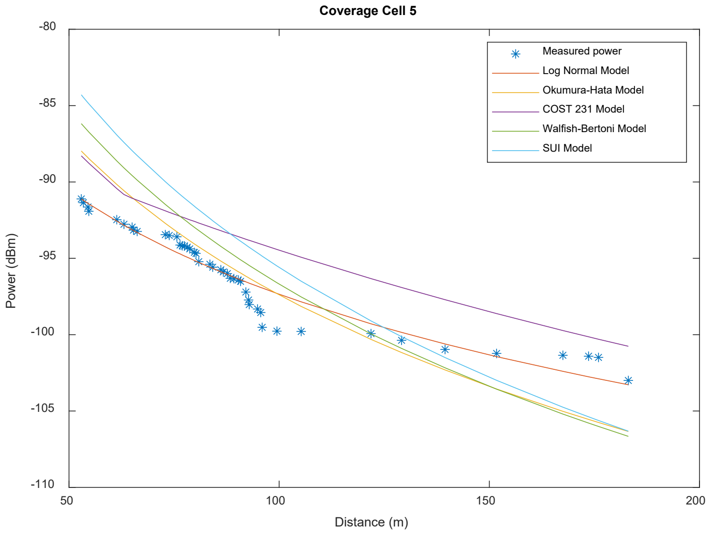
In cell 4 (Figure 8) where it is observed that it resembles two models, first of all, the collected data tend to have a coupling with the SUI model between 47 to 78 meters, and from 83 to 140 meters are coupled with the Log Normal model, considering that from 140 meters these tend to suffer more attenuation, according to Recommendation ITU-R P.1407-1, states:

> In radio systems with low antenna heights, there are often multiple indirect paths between the transmitter and receiver due to reflection from surrounding objects, in addition to the direct path when there is a line of sight. This multipath propagation is particularly important in urban environments where building walls and paved surfaces generate strong reflections. (p.1). Recommendation UIT-R P.1407-1 (2003)

Therefore, they are far from the results of the models, this is because the data obtained was in a place full of buildings within the main street.

Figure 14

Coverage cell 5 with correction factor



In cell 5 shown in (Figure 14) correction factor was applied to 3 propagation models: Okumura-Hata, Cos 231, and the Walfish-Bertoni model, the correction values were: -30.29 dBm, -21.97 dBm, -29.48 dBm, respectively. When applying the correction factor, the graphs of the propagation models are better coupled to the power samples taken by the mobile, however, the one that best fits is the normal Log model curve with a differentiation between the measurements taken and the model less than 5dBm.

> One of the technologies and methods used is the repeater or signal amplifier. In this case, the signal received from a cellular operator is amplified to provide coverage inside a building. The building or area to be covered can be any building, house, garage, or factory where the mobile phone signal is weak, and we want to amplify it. (p.n). Ubierna (2018)

In addition to the fact that it is possible to observe that there is an intersection between the SUI model and Log Normal, this is because these models do not consider losses due to reflection from different infrastructures, and within 130 to 135 meters the data collected resembles the SUI model.

Conclusions

- The use of these models and the application of the correction factor allowed us to analyze the values of reception power and real propagation losses in particular environments of the southern zone of Riobamba city.
- The samples obtained show a significant improvement with the use of the Correction Factor, thus increasing the accuracy of predicting power levels.
- In the southern part of Riobamba city, as it is a residential area without the existence of large buildings, the signal loss does not exceed -106 dBm. Despite also the existence of natural topographic factors that influence it.
- According to the results obtained, it was concluded that the Log-Normal model is the best predictor of power in the southern area of the city of Riobamba considering the different scenarios where there were propagation losses.
- In the case of using these prediction models in practice, the data must be modeled by software to determine the coverage and power of the signal that the physical equipment must emit.

References

Anonymous. (1968). *Okumura model*. Mobile Radio Propagation: Large-Scale Path Loss. https://elearning.espoch.edu.ec/pluginfile.php/1518133/mod_resource/content/1/sysc5608-AntProp-A21-A25.pdf

Aguilar, L. (2010). *Walfisch bertoni model*. Share and Discover Knowledge on SlideShare. https://pt.slideshare.net/eliche04/modelo-de-walfisch-bertoni

A. (2019). Broadcast and TV reception. Spread, from https://www2.ulpgc.es/hege/almacen/download/27/27199/propagacion.pdf

Bekele, N., & Demissie, B. (2017). *Analyzing and modeling of geo spatial effect on radio wave propagation system using geospatial technologies*. SCIRP Open Access. https://www.scirp.org/journal/paperinformation.aspx?paperid=81536

Blaunstein, N., Toeltsch, M., Laurila, J., Bonek, E., Katz, D., Vainikainen, P., Tsouri, N., Kalliola, K. & Laitinen, H. (2006). *Signal power distribution in the azimuth, elevation and time delay domains in urban environments for various elevations of base station antenna*. https://publik.tuwien.ac.at/files/pub-et_11863.pdf

Garcia, A., Ortega, H., Navarro, A. & Rodriguez, A. (2004*). Effect of terrain on electromagnetic propagation in urban environments on the Andean region, using the COST231-Walfisch-Ikegami model and GIS planning tools*. IEEE Xplore. https://ieeexplore.ieee.org/document/1353626

Hadi, S. & Tiong, T. (2015). *Adaptive modulation and coding for LTE wireless communication*. IOP Conf. Ser.: Mater. Sci. Eng. 78 012016. https://iopscience.iop.org/article/10.1088/1757-899X/78/1/012016/pdf

Heintzenberg, J. (1994). *Properties of the log-normal particle size distribution, Leipzig, Germany*. https://www.researchgate.net/publication/233157378_Properties_of_the_Log-Normal_Particle_Size_Distribution

Hernando, J., Riera, J., & Mendo, T. (2013). Radio transmission: Vol. 7. Radio transmission (7a ed.). Ramon Areces University Publishing House.

ITU-R P.833-3, R. (2001). Attenuation due to vegetation. International Telecommunications Union. Retrieved August 11, 2022, from https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.833-3-200102-S!!PDF-S.pdf

ITU-R P.1407-1, R. (2003). Multipath propagation and parameterization of its characteristics. Multipath propagation and parameterization of its characteristics. from https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.1407-1-200304-S!!PDF-S.pdf

Li, X., Li, S., Zhang, D., Xiong, J. & Wang, Y. (2016). *Dynamic-MUSIC: Accurate device-free indoor localization*. Heidelberg, Germany. https://ink.library.smu.edu.sg/cgi/viewcontent.cgi?article=4391&context=sis_research

Pérez Gracia, M. (2001, October 26). underground radar. Evaluation for applications in archeology and historical-artistic heritage. Retrieved on August 11, 2022, from https://www.tdx.cat/bitstream/handle/10803/6216/13capitulo04.pdf?sequence#:~:text=La%20atenuaci%C3%B3n%20como%20resultado% 20of ,the%20case%20of%20means%20materials.

Rao, A., Weber, A., Gollamudi. S. & Soni, R. (2009). *LTE and HSPA+: Revolutionary and evolutionary solutions for global mobile broadband | Semantic Scholar. Semantic Scholar | AI-Powered Research Tool*. https://www.semanticscholar.org/paper/LTE-and-HSPA+:-Revolutionary-and-evolutionary-for-Rao-Weber/c489aee76072912ed14804d439719cb5ef0d0b23

Shabbir, N., Sadiq, M. T., Kashif, H. y Ullah, R. (2011). *Comparison of radio propagation models for long term evolution (LTE) network.* https://elearning.espoch.edu.ec/pluginfile.php/1518137/mod_resource/content/1/1110.1519.pdf

Shahajahan, M. & Abdulla Hes-Shafi, A. Q. M. (2009) *Analysis of propagation models for wimax at 3.5 GHz.* http://www.diva-portal.org/smash/get/diva2:830403/FULLTEXT01.pdf

Tomažič, S. & Jakuš, G. (2009). *Long term evolution: Towards 4th generation of mobile telephony and beyond. IEEE Xplore.* https://ieeexplore.ieee.org/document/5339397

Union, I. T. (1995). Recommendation ITU-R p.529-2 *prediction methods for the terrestrial land mobile service in the vhf and UHF bands*. https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.529-2-199510-S!!PDF-E.pdf#:~:text=Rec.%20ITU-R%20P.529-2%201%20RECOMMENDATION%20ITU-R%20P.529-2%20PREDICTION,BANDS%20(Question%20ITU-R%20203/3)%20(1978-1990-1995)%20Rec.%20ITU-R%20P.529-2

Ubierna, O. (2018). Cellular repeaters and distributed antenna systems DAS. Wireless technology blog., from https://www.comunicacionesinalambricashoy.com/wireless/repetidores-moviles-y-sistemas-de-antenas-distribuidos-das/

Walfish, J. & Bertoni, H. L. (1988). *A theoretical model of UHF propagation in urban environments.* https://www.researchgate.net/publication/3007907_A_Theoretical_Model_of_UHF_Propagation_in_Urban_Environments

Y., Okumura. (1967). *Field strength and its variability in VHF and UHF land-mobile radio service.* 16:825-873.

Yepez, L. & Gragirena, M. (2012). *Corroboration of the "indoor" propagation model log-normal shadowing path loss model and characterization of buildings electrical/electronic and classrooms*. http://www.usfx.bo/nueva/vicerrectorado/citas/TECNOLOGICAS_20/Ingenieria%20Electrica/78.pdf

Zhang, L., Xia, L., Liu, Z., Jing, J. & Ma, Y. (2012). *Evaluating the Optimized Implementations of SNOW3G and ZUC on FPGA*. IEEE Xplore. https://ieeexplore.ieee.org/document/6296005