Comparative Analysis Between LTE RSRP Measurements and Propagation Models in Open Area over 2800 m.a.s.l in Riobamba-Ecuador

Anthony Gualli, Lessly Borja, Anderson Yanqui and Alexis Leon

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Anthony Gualli[1[https://orcid.org/0009-0006-0164-757X]], Lessly Borja[2[https://orcid.org/0009-0000-4805-361X]], Anderson Yanqui[3[https://orcid.org/0009-0001-0727-8609]], and Alexis Leon[4[https://orcid.org/0009-0006-5665-6414]]

[1] Escuela Superior Politécnica de Chimborazo University, Panamericana Sur km 1 1/2, Riobamba-Ecuador
[2] https://historicoweb.espoch.edu.ec/

Abstract. In this work, three measurement campaigns have been carried out under similar environmental conditions for a comparative analysis of the received power intensity (RSRP using the Network Cell Info Lite application) in band 4 (2140 Mhz) of Claro (Mobile Telecom Service) LTE at different points in open areas of the Faculty of Medicine at ESPOCH, with five propagation models (Log-Distance, Extended Hata or COST-231, SUI, Walfish - Bertoni and Erceg). The best fitting model for the received power range (-60 dBm to -100 dBm) in the Medicine cell is Walfish - Bertoni.

Keywords: LTE · power · propagation · model · mobile

1 Introduction

Mobile communications use radio technologies to transmit information through the air. The first mobile network was 2G which was limited to internet browsing. The 3G network had much higher speeds than the 2G network (internet browsing with real-time images, video and audio). The 4G network allowed for high quality video streaming and a much faster and smoother online browsing experience. And the latest evolution in 5G mobile networks will provide even higher speeds than 4G offering new services such as augmented and virtual reality, autonomous driving, the internet of things (IoT), etc. [1], [2].

Currently, the increase in internet usage and the proliferation of wireless data networks are forcing operators to implement new technologies such as LTE (Long Term Evolution), which is a standard for high-speed wireless data communications, low latency and packet optimisation with a flexible bandwidth (1.4MHz-20MHz). Its architecture is called Evolved Packet System (EPS), which is: user

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equipment (accessing the network), access network (base stations for connectivity to the backbone network) and backbone network (access control to the cellular network) [3].

A propagation model is a mathematical expression that aims to predict the received power of the electromagnetic signal as a function of frequency, distance and other factors. There are empirical (various measurements in a particular environment), semi-empirical (measurements that fit a certain model) and deterministic (based on propagation theory) models [4].

The most commonly used propagation models are: Okumura-Hata propagation model for signals in the VHF and UHF frequency range in urban environments, considering BS distance, antenna height and frequency [5].

The Cost 231 model is used for signals in suburban and rural environments, taking into account operating frequency, antenna height, terrain height and terrain roughness, and considering scattering losses [6].

And the Stanford University Interim (SUI) model with corrections for frequencies above 1900MHz, includes the path loss exponent and proposes three different terrain types: urban, suburban and rural [7].

To accurately determine the RSRP (reference received signal power) in mobile systems, specialised equipment such as the Narda SRM-3006 is needed, or free or paid software can be used from our mobile device. For the analysis, RSRP power measurements were made at approximately 436 points in the open spaces of the Faculty of Medicine with regard to the nearest BS working in Claro LTE band 4 (2140 MHz) using the software "Network Cell Info Lite" which gives detailed information about the mobile network and the quality of the signal [8]. Taking into account the gain of high-end mobile phones (2dB) and performing at least three measurement campaigns in the same environment conditions so that the best fitting propagation model can be predicted (Walfish - Bertoni and COST-231).

2 Theoretical Framework

2.1 Log-Distance Propagation Model

The Log Distance model is a technique used to estimate the signal loss that occurs in the propagation of electromagnetic waves as they move away from a transmitting antenna. This model is based on the idea that the signal strength decreases with distance travelled, but in a non-linear fashion [9]. The Log Distance model equation is expressed in (1).

$$P_r(dB) = P_r(d_o) + 10nlog(\frac{d}{d_o}) \tag{1}$$

Where:

- Pr (dB) = is the power loss in dB at distance d.
- Pr (do) = is the power loss in dB at reference distance do.

- n = is the attenuation exponent to be adjusted for each environment and frequency.
- d = is the distance at which the power loss is to be estimated.

Table 1. Loss exponent (n) values for reference only

Environment	Path loss Exponent (n)
Free Space	2
Urban area cellular radio	2.7-3.5
Shadowed urban cellular radio	3-5
Inside a building-line of sight	1.6-1.8
Obstructed in building	4-6
Obstructed in factory	2-3

The values of the loss exponent (n) given in the Table 1. [10] are for reference only. Care should be taken to estimate the value of n, for the given environment prior to design and modelling.

2.2 Extended Hata or COST-231 Propagation Model

The European Co-operative for Scientific and Technical research (EUROCOST) formed the COST-231 working committee to develop an extended version of the Hata model. COST-231 proposed the following formula to extend Hata's model to 2 GHz. [11] The proposed model for path loss is shown in (2).

$$\begin{aligned} P_L &= 46,3 + 33,9log(f) - 13,82log(h_b) \\ &\quad - a(h_r) + [44,9 - 6,55log(h_b)]log(d) + C_M \end{aligned} \tag{2}$$

Here, f represents the frequency in MHz, d denotes the distance between the transmitter and receiver, hb and hr the correction factors for BS height and receiver height respectively. The parameter CM is zero for suburban and rural environments while it has a value of 3 for urban area. The function a(hr) for urban area is defined in (3).

$$a(h_r) = 1,1log(f) - 0,7h_r - [1,58(f) - 0,8] \tag{3}$$

Model constraints:

- f = 1500MHz to 2000 MHz
- hb = 30 m to 200 m
- hr = 1 m to 10 m
- d = 1 km to 20 km

And the receiving power is calculated with equation(4).

$$P_r = P_t + G_r - P_L \tag{4}$$

2.3 SUI Propagation Model

The SUI models are divided into three types of terrains, namely A, B and C. Type A is associated with maximum path loss and is appropriate for hilly terrain with moderate to heavy foliage densities. Type C is associated with minimum path loss and applies to flat terrain with light tree densities. Type B is characterised with either mostly flat terrains with moderate to heavy tree densities or hilly terrains with light tree densities. [12] The basic path loss equation with correction factors is presented in (5).

$$PL = A + 10\gamma * log(\frac{d}{d_0}) + X_f + X_h + s \quad for \quad d > d_0 \tag{5}$$

Where:

$$d_0 = 100m \tag{6}$$

$$A = 20log(\frac{4\pi d_0}{\lambda}) \tag{7}$$

$$\gamma = a - b * h_b + \frac{c}{h_b} \tag{8}$$

Where, the parameter hb is the BS height above ground in metres and should be between 10 m and 80 m.The constants used for a, b and c are given in Table 2. [12]

Table 2. Numerical Values for the SUI Model Parameters

Model Parameter	Terrain A	Terrain B	Terrain C
a	4,6	4,0	3,6
b	0,0075	0,0065	0,005
c	12,6	17,1	20

Correction factors:

$$X_f = 6log(\frac{f}{2000}) \tag{9}$$

$$X_h = -10,8log(\frac{h_r}{2000}) \quad for \quad Terrain \quad A, B \tag{10}$$

$$X_h = -20log(\frac{h_r}{2000}) \quad for \quad Terrain \quad C \tag{11}$$

$$s = 0,65log(f)^2 - 1,3log(f) + \alpha \tag{12}$$

Here alpha = 5.2 dB for rural and suburban environments (Terrain A and B) and 6.6 dB for urban environment (Terrain C).

And the receiving power is calculated with equation(4).

$$P_r = P_t + G_r - PL \tag{13}$$

2.4 Walfish - Bertoni Propagation Model

It considers the number of buildings between the two antennas as a fundamental factor, it is applied in PCS (Personal Communications Service) cellular systems with a shorter range which operate in UHF/SHF frequency bands. [13] The loss equation expressed in (14).

$$L_p = 89,5 + A + 21log(f) + 38log(d) - 18log(H) - 18log(1 - \frac{d^2}{17H}) \quad (14)$$

$$A = 5log[(\frac{b}{2})^2 + (h_b - h_r)^2] - 9log(b) + 20log[\arctan(\frac{2(h_b - h_r)}{b})] \quad (15)$$

Where:

- A = loss factor for nearby buildings
- d = distance to the BS
- hb = height of the BS
- H = average value between hb and building height
- hr = receiver height
- b = distance between buildings

And the receiving power is calculated with equation(4).

$$P_r = P_t + G_r - L_p \quad (16)$$

2.5 Erceg Propagation Model

Erceg 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. [14] The model was in particular adopted in the 802.16 study group and is popular with WiMAX suppliers for 2.5 GHz products, and even 3.5 GHz fixed WiMAX. The path loss is described in (17).

$$L = L_0 + 10\gamma log(\frac{d}{d_0}) + s \quad for \quad d > d_0 \quad (17)$$

Where:

$$L_0 = 20log(\frac{4\pi d_0}{\lambda}) \quad (18)$$

$$d_0 = 100m \quad (19)$$

$$\gamma = (a - b * h_b + \frac{c}{h_b}) + x\sigma_\gamma \quad (20)$$

$$s = y\sigma \quad (21)$$

$$\sigma = \mu_\sigma + z\sigma_\sigma \quad (22)$$

$$x, y, z = Gaussian\ random\ variables\ N(0,1) \quad (23)$$

The parameter values are presented in Table 3. [14] for the different terrain categories.

Table 3. Parameter values in different terrain categories.

Parameter	Terrain Category		
	A	B	C
a	4,6	4	3,6
b	0,0075	0,0065	0,0050
c	12,6	17,1	20
σ_γ	0,57	0,75	0,59
μ_σ	10,6	9,6	8,2
σ_σ	2,3	3	1,6

- A = Hilly / moderate to heavy tree density
- B = Hilly / light tree density or flat / moderate to heavy tree density
- C = Flat / light tree density

Model constraints:

- f = 800 to 3700 MHz
- hb = 10 to 80 m
- hr = around 2 m
- d = 0.1 to 8 km

And the receiving power is calculated with equation(4).

$$P_r = P_t + G_r - L \tag{24}$$

3 Methodology

In order to obtain the desired results, a flow chart was designed detailing the steps to be followed Fig. 1.

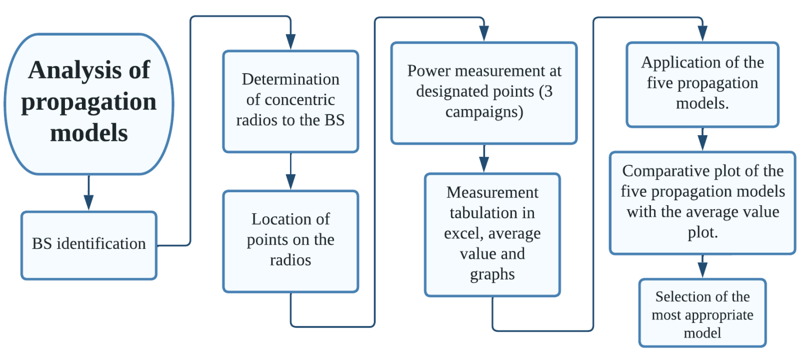

Fig. 1. Comparative analysis flowchart.

Using Google Maps software, the BS is identified for RSRP power measurements for the Faculty of Medicine cell.

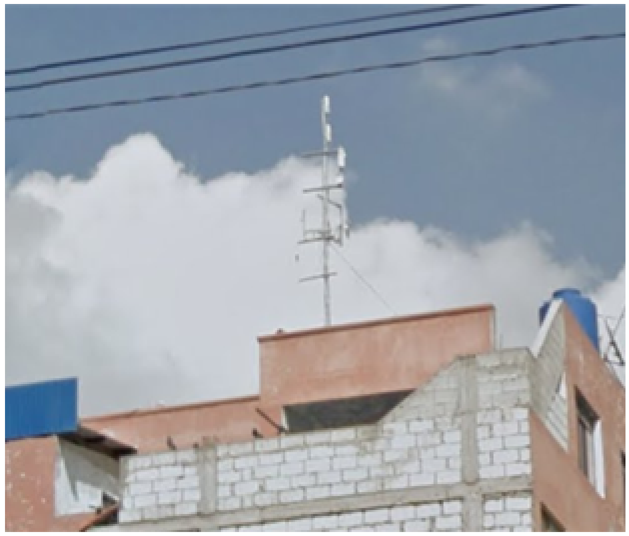

Fig. 2. BS of the faculty of Medicine.

Fig. 2. show the Claro BS for the cell of the Faculty of Medicine, located at Avenida Canónigo Ramos and Nicolás Delgado. At a height of 15 metres and working in the band 4 at a frequency of 2140 MHz. In summary, the location and height of the BS are shown in Table 4.

Table 4. BS Information

Base Station	Latitude	Length	Height (m.a.s.l)	Height (hb)
BS	1°39'08.46"S	78°40'28.51"O	2820	15

Once the BS was identified, Google Earth was used to plot radios concentric to it, passing through the gridded area (1x1)m of the Faculty of Medicine cell. This gives a total of 36 radios between distances of 236.51 m to 369.49 m as shown in Fig. 3.

Subsequently, Fig. 4. shows the placement of the points to be measured (with position marks) obtained at the intersections of the concentric radios with the straight lines separated by 5 m in the gridded area of the Faculty of Medicine, obtaining a total of 398 points.

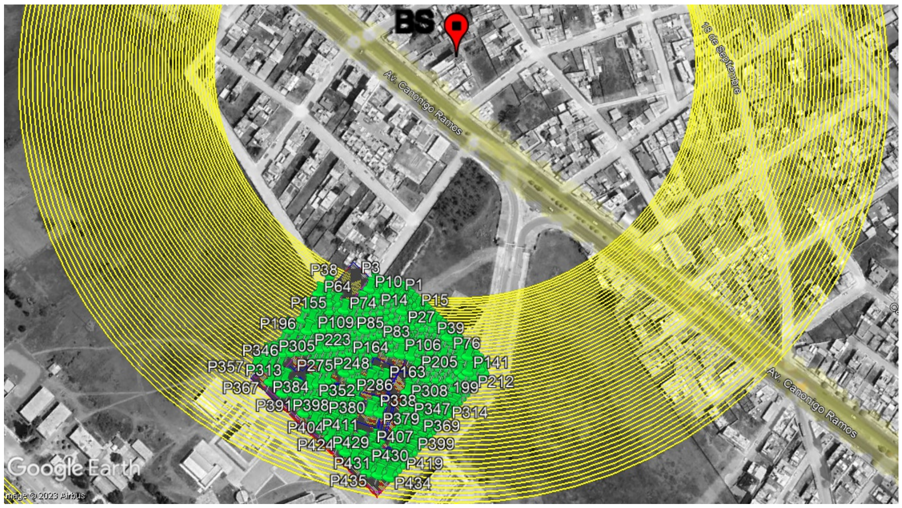

Fig. 3. Concentric radios of the BS of the Faculty of Medicine.

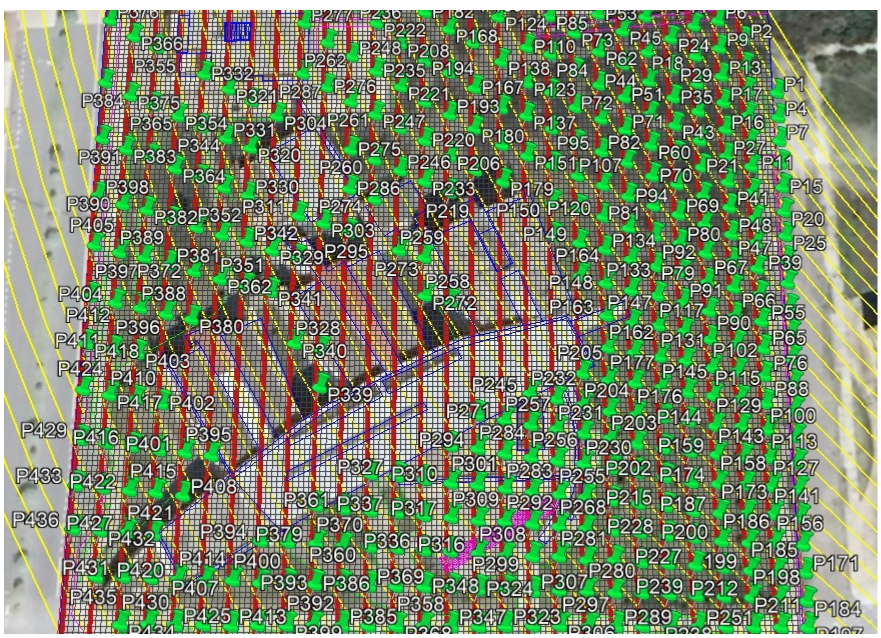

Fig. 4. Obtaining points from the Faculty of Medicine.

Fig. 5. shows the Narda SRM-3006 (ESPOCH) equipment used to obtain the value of the effective electric field strength [15] at the nearest point of the BS from the bandwidth and centre frequency.

Fig. 5. Narda SRM-3006 Device

Giving a value of E = 1 V for the Medicine cell. The ITU-525 recommendation is used to obtain the equivalent isotropically radiated power EIRP (24).

$$e = \frac{\sqrt{30EIRP}}{d} \tag{25}$$

$$EIRP = \frac{(d * e)^2}{30} \tag{26}$$

Replacing the known data in equation (24) gives the approximate result of 46 dBm for the Medicine cell.

Fig. 6. was performed using SPSS software and shows the RSRP powers measured at each distance of the 398 points of the Faculty of Medicine during three different two-hour campaigns from 14:00 pm to 16:00 pm on a sunny day, which allowed to obtain similar power values in the mentioned campaigns.

For the comparative analysis, SPSS software is also used to obtain the average RSRP power of the three campaigns carried out, whose values range from -60 dBm to -100 dBm at the Faculty of Medicine as shown in Fig. 7.

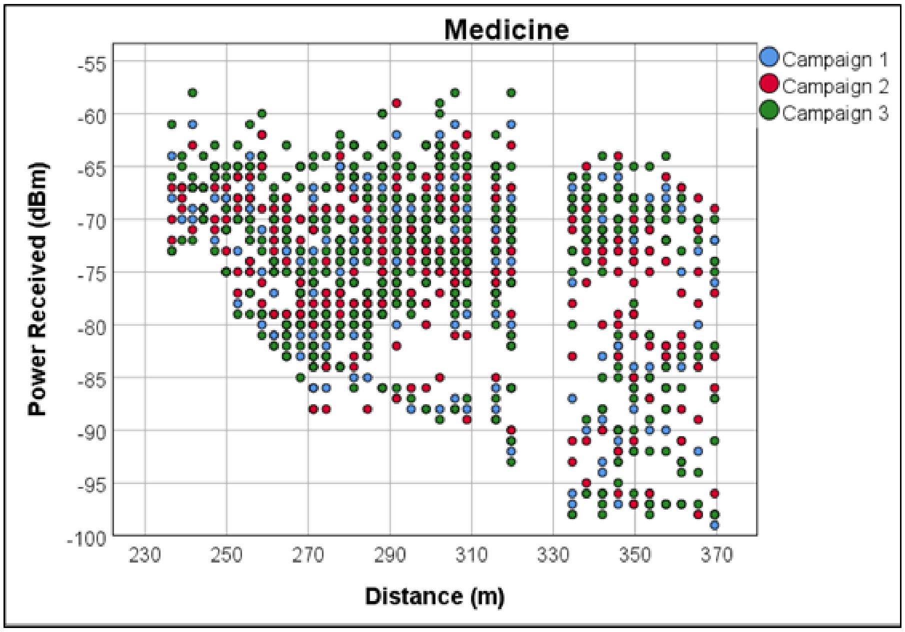

Fig. 6. Medicine Faculty Power-Distance Graph

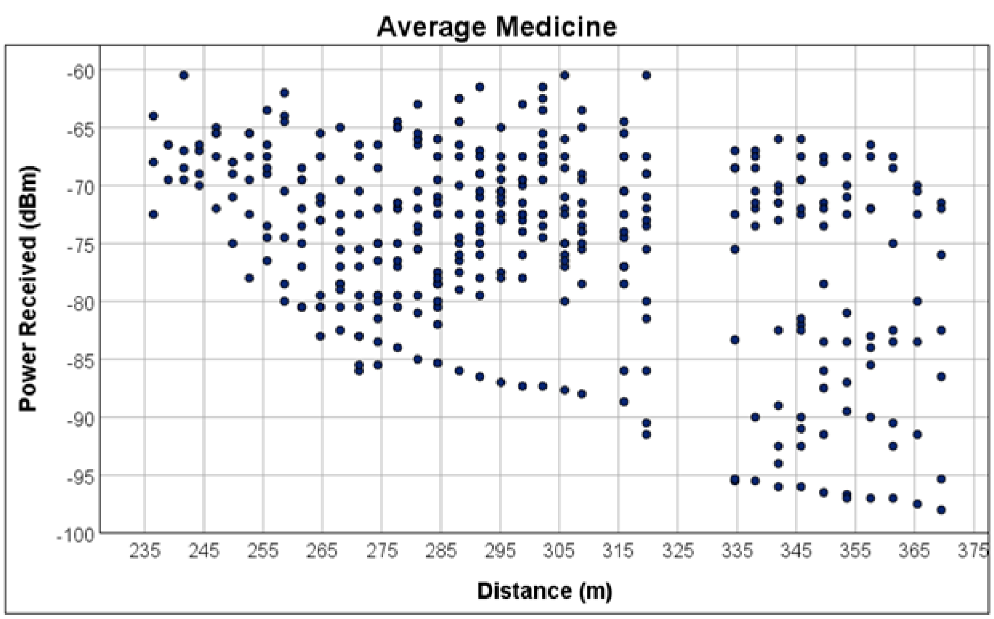

Fig. 7. Average power in the Faculty of Medicine

To find the propagation model that best fits the RSRP powers of the 398 points shown in Fig. 8, a single point with its respective RSRP (in the range of -68 dBm to -76 dBm) is selected from the 36 distances to perform the analysis of the five propagation models under study in the Faculty of Medicine.

3.1 Log-Distance Model

In this model, the first of the 36 RSRP measurements is chosen as the known power [Pr(do)=-68 dBm]. To find the value of n, the squared error of the 36 RSRP measurements is calculated and the values of a and b are obtained and substituted into equation (27).

$$n = \frac{b}{a} \tag{27}$$

$$n = 7,49901 \tag{28}$$

Since n is greater than two, it is possible to substitute the data into equation (1) to find the 36 RSRP measurements at the different radius points of the Faculty of Medicine.

3.2 Extended Hata or Cost 231 Model

For this model we start by finding the value of a(hr) by replacing the frequency of 2140 Mhz and the height of the mobile (1.5 m) in equation (3) given by the Okumura Hata propagation model for an urban environment. With the value of a(hr), the basic losses of the model can now be calculated using equation (2) for the 36 distances where CM is zero for suburban areas. These are subtracted in equation (4).

3.3 SUI Model

The 36 points of each radius must be classified according to the type of terrain present in them. Obtaining that the first 24 points are of terrain C and the remaining 12 of terrain B. The correction factors are found using equations (9), (10), (11) and (12) according to the type of terrain and the values of a, b and c are shown in Table 2, both for terrain B and C, and are replaced in equation (8), and the basic losses of the Free-Space model are calculated with equation (7). With these values found, the losses of this model can be calculated with equation (5) and in turn the RSRP of the 36 points using equation (13).

3.4 Walfish-Bertoni Model

In the Medicine cell, an analysis scenario where the average distance between buildings is 75.33 m is chosen to replace in equation (15) and obtain the value of A used in equation (14) for the basic losses of this model. It is now possible to calculate the RSRP of the 36 points with equation (16).

3.5 Erceg Model

For this model we apply the values from Table 3. for a category C terrain present in the Medicine cell and give random Gaussian values of x = 0.2, y = 0.4 and z = 0.6 , necessary to find the values to replace in equation (17) for the basic losses of this model. Consequently, the 36 RSRP measurements of the Faculty of Medicine can now be found with equation (24).

4 Results

In this section, the results of the received powers of the proposed propagation models are analyzed with respect to the value of the received power at each point using the Network Cell Info software for the cell under study in the Faculty of Medicine. As shown in Fig. 8. the received powers decrease with increasing distance with the exception of specific points where environmental conditions cause higher or lower propagation losses.

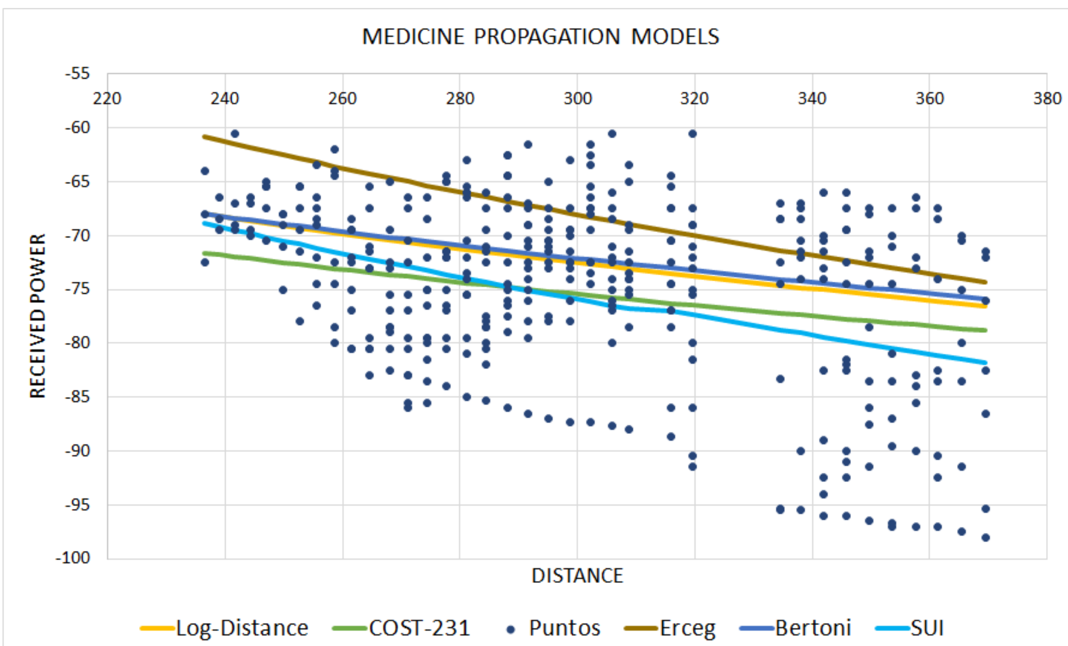

Fig. 8. Comparative graph of the propagation models

In order to find the propagation model that best fits the 398 RSRP measurements, the mean square error of each model is calculated, the value of which is shown in Table 5.

Table 5. Mean Square Error of each Model

Model	Mean Square Error
Log-Distance Model	2,33698
COST-231 Model	6,65415
SUI Model	11,72926
Walfish-Bertoni Model	2,59443
Erceg Model	36,49632

These values are compared and the model with the lowest mean square error is chosen, except for the basic model (Log-distance). That is, the Walfish-Bertoni model with a mean square error of 2.59443 is chosen as the best fit to the RSRP measurements.

5 Conclusions

- Propagation models are essential tools for predicting and understanding how waves propagate in various environments. However, it is important to take into account limitations, validate the models experimentally and consider knowledge of the environment to obtain accurate and reliable results.
- There are several propagation models used in the field of wireless communications to predict attenuation and received power in different types of environments such as urban, suburban and rural. LOG DISTANCE, SUI, ERCEG and EURO-COST are used for this comparative analysis. Each model has its own conditions depending on factors such as frequency and antenna height.
- To obtain the received powers of each model, the specialised Narda SRM-3006 (ESPOH) equipment is used to obtain the EIRP of the Faculty of Medicine more accurately from the total effective electric field strength at a point close to the base radio, giving a value of 46 dBm in this cell.
- Mean square error (MSE) is a commonly used metric to assess the accuracy of propagation models in various fields, such as wireless communications and wave propagation.
- The results from the Faculty of Medicine show that the model with the lowest mean square error is the Walfish-Bertoni model with a value of 2.59443, therefore this propagation model is the best fit to the 398 RSRP measurements measured with Network Cell Info is the Walfish-Bertoni model, which is in the range of -67 dBm to -76 dBm.

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