Modeling of 4G coverage using Matlab and validation with real measurements obtained through G-NetTrack

Modelado de la cobertura 4G mediante Matlab y validación con mediciones reales obtenidas a través de G-NetTrack

Modelagem da cobertura 4G utilizando Matlab e validação com medidas reais obtidas através do G-NetTrack

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Summary. - The purpose of this work is to model and validate 4G LTE coverage in "Las Villas," a residential area of Babahoyo, to determine the actual quality of service compared to theoretical propagation models. The method used was descriptive-comparative, non-experimental, and quantitative. It was based on the collection of real-world data obtained through Drive Tests and Walk Tests, using the G-NetTrack Lite app on Android devices. The acquired data were exported in .csv format and processed in MATLAB. In this software, the LTE Toolbox library and the COST-231 Hata propagation model were used to simulate the signal and create coverage maps. Consequently. The comparison between measured and simulated values showed acceptable agreement according to MAE and RMSE metrics. The findings allow us to conclude that the COST-231 Hata model provides an appropriate approximation of the actual 4G signal behavior in the studied area, thus validating its use for planning and analyzing LTE mobile networks.

Keywords: *G-NetTrack Lite; RSRP; Drive test; Propagation model; COST-231 Hata.*

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Resumen. - *El objetivo de este trabajo es modelar y validar la cobertura 4G LTE en "Las Villas", una zona residencial de Babahoyo, para determinar la calidad de servicio actual en comparación con modelos de propagación teóricos. El método empleado fue descriptivo-comparativo, no experimental y cuantitativo. Se basó en la recopilación de datos reales obtenidos mediante Drive Tests y Walk Tests, utilizando la aplicación G-NetTrack Lite en dispositivos Android. Los datos adquiridos se exportaron en formato .csv y se procesaron en MATLAB. En este software, se utilizó la biblioteca LTE Toolbox y el modelo de propagación COST-231 Hata para simular la señal y crear mapas de cobertura. La comparación entre los valores medidos y simulados mostró una concordancia aceptable según las métricas MAE y RMSE. Los resultados permiten concluir que el modelo COST-231 Hata proporciona una aproximación adecuada del comportamiento actual de la señal 4G en la zona estudiada, validando así su uso para la planificación y el análisis de redes móviles LTE.*

Palabras clave: *G-NetTrack Lite; RSRP; Drive test; Propagation model; COST-231 Hata.*

***Resumo**. -* *O objetivo deste trabalho é modelar e validar a cobertura 4G LTE em "Las Villas", uma área residencial de Babahoyo, para determinar a qualidade de serviço atual em comparação com modelos teóricos de propagação. O método utilizado foi descritivo-comparativo, não experimental e quantitativo. Baseou-se na coleta de dados reais obtidos por meio de testes de campo e testes de caminhada, utilizando o aplicativo G-NetTrack Lite em dispositivos Android. Os dados adquiridos foram exportados em formato .csv e processados no MATLAB. Neste software, a biblioteca LTE Toolbox e o modelo de propagação COST-231 Hata foram utilizados para simular o sinal e criar mapas de cobertura. A comparação entre os valores medidos e simulados mostrou concordância aceitável de acordo com as métricas MAE e RMSE. Os resultados permitem concluir que o modelo COST-231 Hata fornece uma aproximação adequada do comportamento atual do sinal 4G na área estudada, validando assim seu uso para o planejamento e análise de redes móveis LTE.*

Palavras-chave: *G-NetTrack Lite; RSRP; Drive test; Modelo de propagação; COST-231 Hata.*

1. Introduction. - Modeling 4G coverage networks in Ecuador has been of paramount importance for optimizing current coverage and ensuring service quality, as seen in the city of Babahoyo. By 2025, national coverage had reached just over 80.58%, encompassing urban and rural areas in more than 3,000 locations [1]. This achievement is due to investment by public and private institutions in telecommunications infrastructure, which have incorporated technologies and tools to conduct various studies, including the design, testing, and validation of 4G LTE network coverage systems, this study specifically focuses on validating the COST-231 Hata empirical propagation model using field RSRP measurements.

Globally, several studies conducted in technologically advanced countries have examined the coverage and performance of 4G LTE mobile networks in urban and residential areas, using propagation models and real-world field measurements. By comparing signal quality parameters, such as RSRP, acquired through Walk Tests and Drive Tests, these studies have allowed for the evaluation of the accuracy of theoretical models like COST-231 Hata. The reported results agree that propagation models provide satisfactory estimates of actual signal behavior. However, differences exist regarding urban morphology, building density, and environmental conditions, which emphasizes the importance of validating these models in specific contexts.

Cellular devices have been updated over time, requiring higher data transmission rates. Therefore, a network with excellent performance is necessary for end-user satisfaction. The implementation of new mobile telecommunications technologies has allowed users to experience service improvements, such as greater coverage capacity on these devices and higher transmission speeds [2].

In the province of Los Ríos, connectivity projects have been integrated to optimize 4G coverage, especially to support higher network traffic during peak hours, thus improving the user experience. These projects are supported by research and simulations that anticipate network behavior in various situations, optimizing resources so that a future migration to the technology can be achieved 5G. 4G modeling in the city of Babahoyo contributes to technological and digital development, strengthening sectors such as education, commerce, health, and other areas where the canton's 4G network has become essential.

This research seeks to examine and diagnose the quality of 4G coverage in Babahoyo, where population growth could worsen mobile network connectivity for end users.
Despite advances in upgrading 4G infrastructure and local conditions, there have been signal variations and inconsistencies that are not always reflected in aggregated official data, such as national coverage maps. This creates problems for users, causing interruptions in voice calls, data usage for browsing, and slow speeds during peak hours.

Modeling 4G systems in MATLAB is justified because it is a very useful tool for the design, simulation, and optimization of LTE systems. This is because MATLAB can handle the complexity of 4G and improve simulations [3]. Therefore, it is essential to understand, test, and optimize system performance before a concrete implementation, considering elements such as latency, throughput, and parameters that can optimize the quality of mobile communication.

The research is limited to the analysis of 4G coverage in Babahoyo, specifically in the residential area where "Las Villas" is located. This area comprises five housing developments on the outskirts of the city (with approximately 3,600 to 3,900 people), along the road connecting Babahoyo with the Mata de Cacao Road. Real-world measurements will be taken using G-NetTrack software and coverage maps published by CONECEL (Claro) to evaluate the accuracy of the information provided by the operator. The study is limited solely to the defined urban area, 4G technology, and the selected models, excluding other cities, technologies, or simulation methods. This area was chosen because Claro's coverage map shows an irregular signal and it is considered a less risky zone due to the country's security situation.

1.1 Related jobs. -The performance of LTE cellular networks in various environmental settings has been examined in a few studies. In [4], thorough research was carried out to compare signal quality characteristics supplied by local mobile providers in order to assess LTE network performance in residential and high-rise commercial regions.

According to the data, Digi had the best coverage, with 66% in commercial zones and 83% in residential areas (RSRP > −100 dBm). Celcom and Maxis performed worse. The investigation confirmed the agreement between provider data and actual measurements by reporting notable signal abnormalities, particularly in coverage gap areas found in operator maps. Due to things like wall attenuation and decreased internal interference, signal degradation was mostly seen in residential areas far from base stations and at higher building altitudes.
To increase coverage in remote and high-altitude locations, the authors suggested deploying repeaters.

A comparison of 4G network propagation models in Riobamba, Ecuador's private and urban regions was carried out in [5]. RSRP data obtained with Network Cell Info software were used to assess models including Log-Normal, Okumura-Hata, COST-231, and SUI. The average RSRP values within 200 meters of base stations ranged from −80 to −106 dBm, according to the data. While COST-231 worked well in densely populated regions and the Log-Normal model was better suited for urban microcells beyond 200 meters, the SUI model demonstrated greater performance in dense urban environments with diverse topography and vegetation.

Unlike earlier research, the current study focuses on a thorough analysis employing RSRP measurements that were acquired using the G-NetTrack program and analyzed in MATLAB using.txt data files. A single propagation model, COST-231 Hata, was chosen because it works well in moderately congested urban settings, which is appropriate for the chosen residential region outside of Babahoyo's center zone. In order to provide a more accurate validation of the model and offer useful suggestions for network improvement, comparative assessments were focused exclusively on measured RSRP values and theoretical RSRP predictions derived from the COST-231 Hata model used.

2. Materials and methods. - The research will have a quantitative scientific approach, this will be based on data collection, analysis and mathematical modeling of technical parameters used in the validation of 4G networks. The study adopts a hypothetical-deductive method, because how the signal behaves at different strategic points will be analyzed, then a hypothesis is formulated on the data taken and evaluated with computer simulations. The methodological design is non-experimental and descriptive-correlational, because we are not going to manipulate the signal parameters, but rather the real values are going to be analyzed. Our study incorporates a comparative validation method, which will allow us to relate the values measured with G-NetTrack and the theoretical values that Matlab will generate, to compare the precision and effectiveness of coverage modeling.

The phases of the suggested methodology are shown in Figure I, which structurally and sequentially depicts the major steps used in this investigation, from data processing and signal collecting to propagation modeling and outcomes interpretation. The method used to assess network performance and verify the results is clearly shown in this diagram.

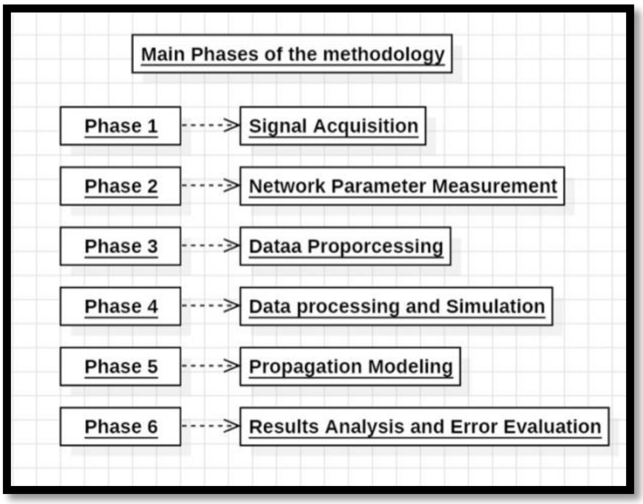


Figure I. Main phases of the methodology.

Signal Acquisition: This phase involves capturing the LTE signal in the field within the "Las Villas" study area in the city of Babahoyo. Signal acquisition is performed using Android mobile devices with the G-NetTrack Lite application, which allows for real-time recording of network parameters. Measurements are conducted through Walk Tests and Drive Tests to represent both pedestrian and vehicular mobility scenarios, ensuring adequate spatial coverage of the analyzed area. This phase forms the experimental basis of the study, providing the real-world data necessary for subsequent validation.

Network Parameter Measurement: In this stage, the technical parameters of the 4G LTE network are measured and recorded, extracted directly from the G-NetTrack application. The main indicators analyzed are the received reference signal strength (RSRP), signal quality (RSRQ), and signal-to-noise ratio (SNR), which allow for the evaluation of network performance and service quality. Additionally, data associated with the base station is recorded, such as the cell identifier, mobile operator, and frequency band, which facilitates the proper contextualization of the measurements taken.

Data Preprocessing: Once the measurements are obtained, the collected data is exported in .csv format for further processing. This phase involves data preprocessing, which includes cleaning up erroneous data, removing outliers, and organizing the samples according to their geographic and temporal location. This process ensures that the information used in MATLAB is consistent and reliable, reducing errors in simulation and comparative analysis. The distances between the base station and each measurement point were computed from the WGS84 geographic coordinates recorded by G-NetTrack Lite, using the Haversine formula to account for earth's curvature. The base station coordinates used correspond to the CLARO_EC cell consistently serving the study area, identified through the cell ID field in the G-NetTrack logs. The data generated by the software were preprocessed and filtered before analysis. Samples not corresponding to 4G technology (2G and 3G technology) were discarded. Missing or incomplete sample values were also eliminated. Infrequent or atypical values, such as deviations observed in the graphs generated by the MATLAB software, were identified and excluded from the validation set. Furthermore, the number of segments affected by service cell changes was minimized by selecting stable LTE service cell intervals, provided the requirements were met.

The simulation's base station parameters are compiled in Table I. To ensure that all comparable samples correspond to a single serving cell, segments from the G-NetTrack logs where the serving cell identifier changed between subsequent samples were identified and removed from the validation dataset.

Parameter	**Value**
Operator	CLARO_EC
Technology	4G LTE
Frequency band	1900 MHz (Band 2)
Antenna height	30 m
Coordinates	As recorded in G-NetTrack logs

Table I. BS & handovers.

Data Processing and Simulation: In this phase, the preprocessed data is imported into MATLAB, where numerical processing and LTE network simulation are performed. The LTE Toolbox is used to facilitate the manipulation of 4G system parameters and enable the analysis of radio link behavior. Furthermore, spatial interpolation techniques are applied to generate continuous coverage maps from discrete measurements, allowing for a clear visual representation of signal behavior in the study area.

Propagation Modeling: This stage focuses on applying the COST-231 Hata propagation model, selected for its suitability in urban and suburban environments. The model allows for estimating propagation loss and calculating theoretical RSRP values based on parameters such as distance, frequency, and antenna heights. The results obtained using the theoretical model are compared with measured data, generating simulated coverage maps that represent the expected LTE signal behavior in the analyzed area.

Results Analysis and Error Evaluation: Finally, a comparative analysis is performed between the measured and simulated values. To quantify the model's accuracy, standard validation metrics such as MAE, RMSE and mean bias are calculated, which allows for evaluating the difference between the actual network performance and the theoretical estimate. This phase validates the effectiveness of the COST-231 Hata model and determines whether the simulation adequately represents real 4G coverage, considering factors such as attenuation, urban environment, and propagation conditions.

2.1 Flowchart. - Figure II, illustrate the sequential workflow of the proposed methodology for modeling and validating 4G LTE coverage in the residential area of "Las Villas" in Babahoyo. The diagram provides a clear overview of the main stages involved in the study, from field data acquisition to the final validation of the propagation model.

The process begins with the signal acquisition phase, where real-world measurements are collected using the G-NetTrack Lite application through Walk Test and Drive Test procedures. These tests allow the characterization of LTE signal behavior under both pedestrian and vehicular mobility conditions.

Next, the network parameter measurement phase focuses on the extraction of key LTE performance indicators, including the Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), and Signal-to-Noise Ratio (SNR). These parameters are essential for assessing the quality of service and network performance.

The collected data are then subjected to data preprocessing, where the measurements are exported in CSV format, filtered, and organized. This phase ensures data consistency by removing outliers and invalid samples, thereby improving the reliability of the subsequent analysis.

Measurements were collected periodically using G-NetTrack Lite software, employing parameters such as radio frequency and GPS, and using different mobile device positions. This can generate various geolocation errors depending on satellite visibility and obstructions caused by urban infrastructure. Changes in speed during the drive test can also affect the spatial sample density. However, these limitations are quite common in LTE measurements.A predetermined synchronization between GPS coordinates and radio measurements was assumed; this was based on the times established by the software.

In the data processing and simulation phase, the preprocessed data are imported into MATLAB. Using the LTE Toolbox, numerical processing and spatial interpolation techniques are applied to generate continuous coverage representations and preliminary signal maps for the study area.

Subsequently, propagation modeling is performed using the COST-231 Hata model, selected for its suitability in urban and suburban environments. This model enables the estimation of theoretical RSRP values based on propagation conditions, which are later compared with measured data.

Finally, the methodology concludes with the results analysis and error evaluation phase, where measured and simulated RSRP values are compared. MAE, RMSE and bias metrics are calculated to quantify the accuracy of the model and validate its applicability for real 4G LTE coverage analysis.

Overall, the flowchart summarizes the logical and systematic approach adopted in this research, highlighting the integration of empirical measurements and theoretical modeling to achieve reliable coverage validation results.

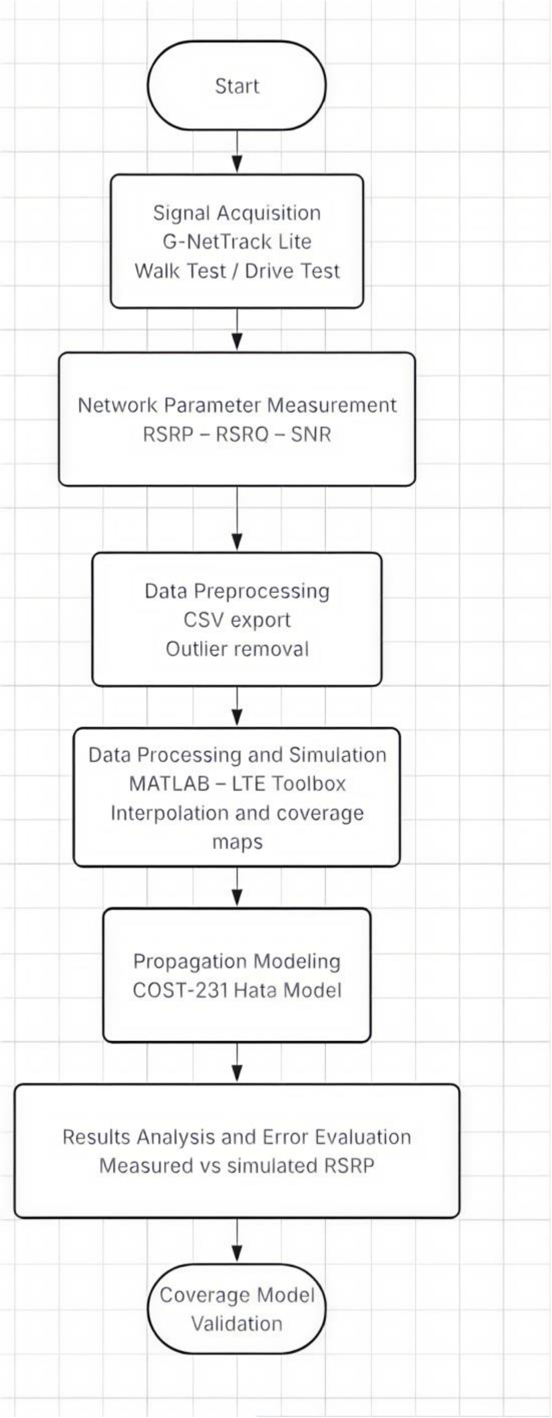


Figure II. Project planning flowchart

2.2. Schematic circuit. -

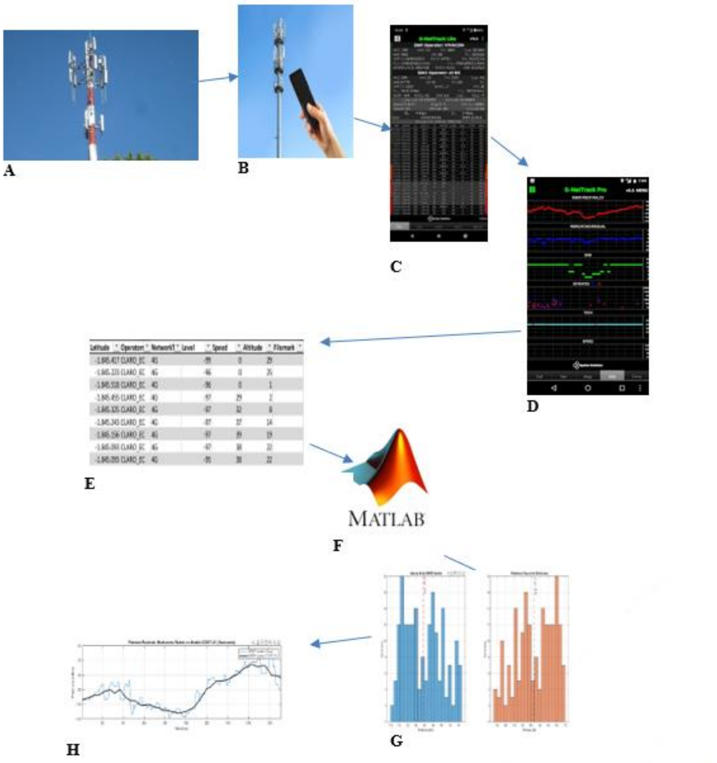


Figure III. Schematic Circuit Example

A: Illustration of the base station.
B: Telephone for receiving the signal.
C: Obtaining signal parameters using G-NetTrack.
D: Comparative analysis of the signal graphs.
E: .csv file of the obtained data.
F: Exporting the file to Matlab software.
G: Using propagation models to obtain simulated values.
H: Comparative graphs between measured and simulated values.

3. Development. –

Figure IV. The drive test route was taken using the G NetTrack application.

As shown in Figure IV, when the respective measurement was performed, the application provided a .kml file containing all the data collected by the G-NetTrack Lite application. The signal quality is represented by colors along different sections of the route: green indicates very good signal strength, dark green indicates good signal strength, and yellow indicates fair signal strength. The image shows that the signal from the base station is generally good, as the signal strength is quite clear. In the yellow areas, there is some attenuation due to obstructions in some residential areas, such as large trees or buildings, which interfere with the signal path, making it difficult for the mobile device to receive it.

Sample	Timestamp	Longitude	Latitude	Operator name	Network Tech	Level (dB)	Speed (km/h)	Altitude
1	2025.12.06_ 15.49.41	-7.952.464	-1.845.417	CLARO_EC	4G	-99	0	29
10	2025.12.06_ 15.49.55	-7.952.547	-1.845.040	CLARO_EC	4G	-95	38	24
20	2025.12.06_ 15.50.05	-7.952.650	-1.844.558	CLARO_EC	4G	-86	41	25
30	2025.12.06_ 15.50.15	-7.952.744	-1.844.056	CLARO_EC	4G	-85	42	26
40	2025.12.06_ 15.50.25	-7.952.851	-1.843.510	CLARO_EC	4G	-97	46	26
50	2025.12.06_ 15.51.37	-7.952.919	-1.843.175	CLARO_EC	4G	-107	11	23
60	2025.12.06_ 15.51.57	-7.953.027	-1.842.643	CLARO_EC	4G	-101	39	24
70	2025.12.06_ 15.52.11	-7.953.137	-1.842.068	CLARO_EC	4G	-102	40	23
80	2025.12.06_ 15.52.21	-7.953.245	-1.841.533	CLARO_EC	4G	-105	54	23
90	2025.12.06_ 15.52.31	-7.953.379	-1.840.848	CLARO_EC	4G	-105	62	21
100	2025.12.06_ 15.52.41	-7.953.495	-1.840.246	CLARO_EC	2G	-113	30	23

Table II. Results obtained from the drive test.

As can be seen in Table II, these are the parameters obtained when performing measurements with the G-NetTrack software. These values are summarized for the purpose of explanation, taking a sample of every 10 data points obtained. The values shown in the application's .txt file include the exact date and time the measurement was taken, the exact coordinates of the site (Altitude/Latitude), the operator of the SIM card used for the measurement, which in this case was Claro_EC, the technology, which in this case was 4G-LTE as it is the most common in the area, the Level, which is the signal strength received at different distances between the device and the base station, and the latitude of the base station, which is located at an average height of 30 meters, although this varies due to the irregularities of the terrain.

The relationship between transmitted and received power under ideal free-space conditions was only demonstrated using a simplified link-budget analysis based on the Friis transmission concept as a preliminary theoretical reference. The COST-231 Hata empirical propagation model, which is more suited for urban residential settings, is the primary validation target of this study.

$$\mathrm{Pr(db)} = \mathrm{Pt(db)} + Gt(\mathrm{dbi}) + Gr(\mathrm{dbi}) + 20log_{10}\left(\frac{\lambda}{4\pi d}\right) \qquad (1)$$

Equation I. Friis equation

Where:
Pr (db) = It is the power received from the antenna expressed in decibels.
Pt (db) = It is the power radiated from the antenna, expressed in decibels.
Gt (dbi) = It is the gain emitted by the antenna when transmitting, expressed in decibels.
Gr (dbi) = Es la ganancia que se recibe de la antena, expresada en decibelios.
$20log_{10}(\frac{\lambda}{4\pi d})$ = This term represents the loss in the air.

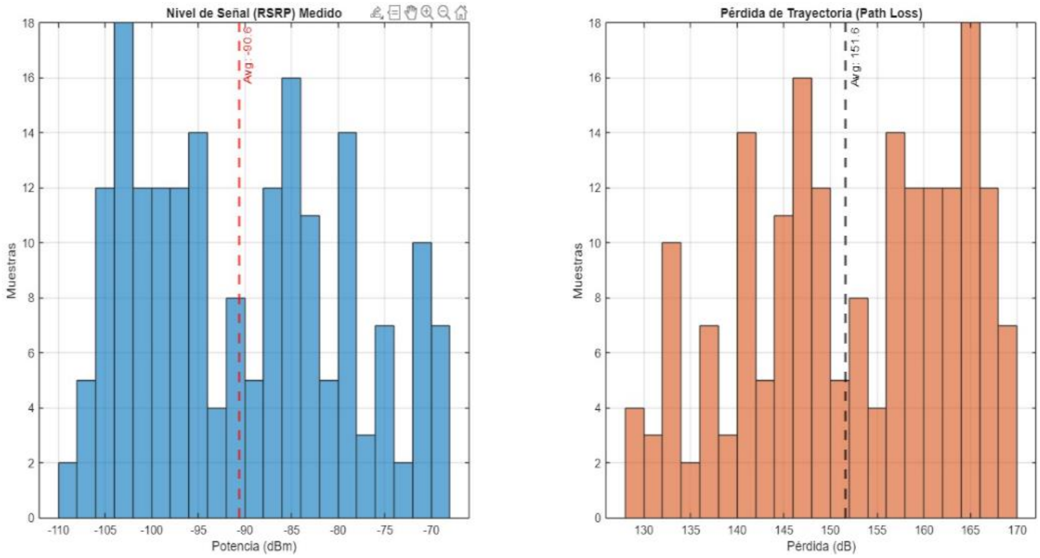


Figure V. Preliminary link-budget reference analysis under idealized conditions

Figure V shows a simplified theoretical reference based on free-space propagation assumptions. These results are presented only for conceptual comparison and are not used as the primary validation model.
The main validation stage of this study employed the COST-231 Hata propagation model to compare theoretical LTE RSRP predictions with measured field values obtained through G-NetTrack.

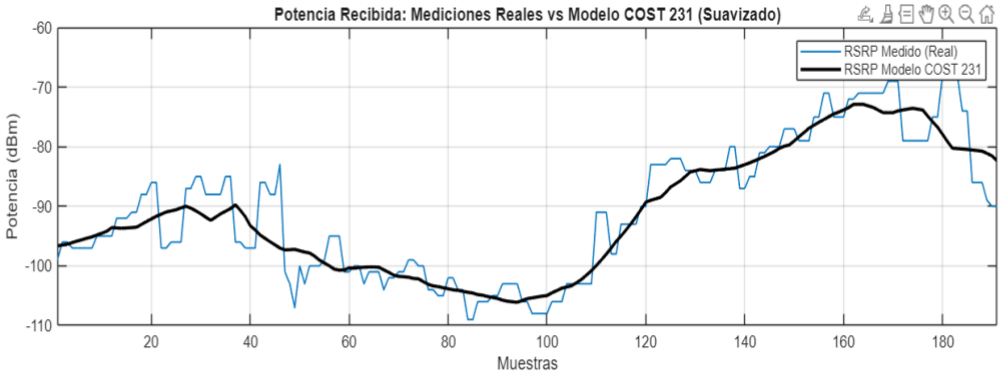


Figure VI, Received Power: Actual Measurements vs. Cost 231 Models (Smoothed)

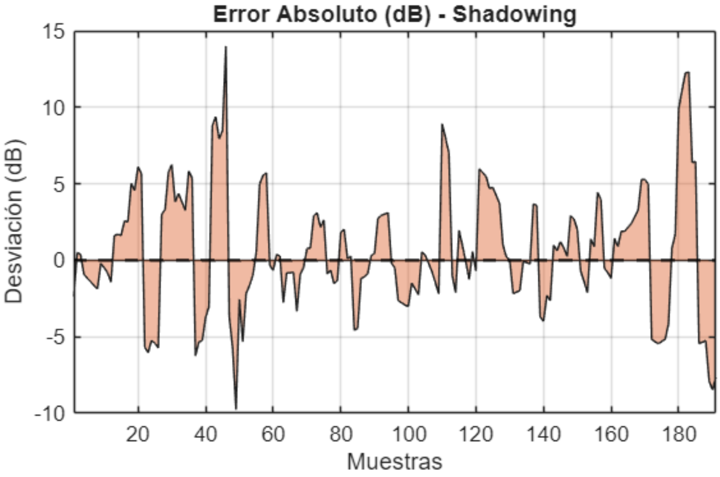


Figure VII, Absolute Error (dB) – Shadowing

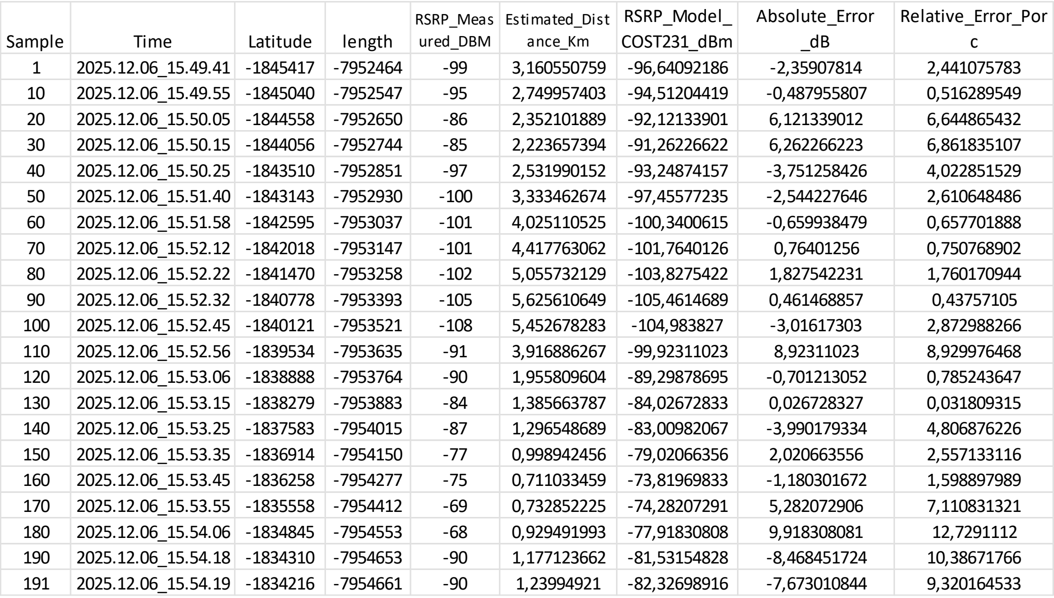
MAE	3.64 dB
RMSE	4.76 dB
Mean Bias	-0.32 dB

Table III. Statistical Validation Metrics

These results indicate that the model provides an acceptable prediction accuracy for LTE signal coverage in the studied residential urban environment. In the Figure VI, a comparison is shown between the ideal behavior of an average signal, calculated using the Cost-231 Hata propagation model, and the signal measured in different samples. As can be seen, there are values with very irregular peaks, but these are far from the ideal value that an antenna should radiate. This indicates that the power is not constant but varies depending on how far we deviate from the ideal or if there is any interference in the transmission channel.

In the Figure VII the absolute error is shown, comparing the actual signal error with the simulated error of the propagation model. As shown in the image, the values do not exceed 15 dB, which can be interpreted as a correct application of the model and that the percentage error of the measurement is acceptable. In the Table II presents the statistical validation metrics of the COST-231 Hata model. Instead of percentage relative error, standard propagation-model metrics were used, including Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and mean bias. These metrics provide a more rigorous assessment of model performance when comparing measured and predicted RSRP values expressed in dBm.

Model validation was performed using standard propagation metrics based on representative measurement samples. The COST-231 Hata model achieved a Mean Absolute Error (MAE) of 3.64 dB, a Root Mean Square Error (RMSE) of 4.76 dB, and a mean bias of -0.32 dB.



Sample	Time	Latitude	length	RSRP_Measured_DBM	Estimated_Distance_Km	RSRP_Model_COST231_dBm	Absolute_Error_dB	Relative_Error_Porc
1	2025.12.06_15.49.41	-1845417	-7952464	-99	3,160550759	-96,64092186	-2,35907814	2,441075783
10	2025.12.06_15.49.55	-1845040	-7952547	-95	2,749957403	-94,51204419	-0,487955807	0,516289549
20	2025.12.06_15.50.05	-1844558	-7952650	-86	2,352101889	-92,12133901	6,121339012	6,644865432
30	2025.12.06_15.50.15	-1844056	-7952744	-85	2,223657394	-91,26226622	6,262266223	6,861835107
40	2025.12.06_15.50.25	-1843510	-7952851	-97	2,531990152	-93,24874157	-3,751258426	4,022851529
50	2025.12.06_15.51.40	-1843143	-7952930	-100	3,333462674	-97,45577235	-2,544227646	2,610648486
60	2025.12.06_15.51.58	-1842595	-7953037	-101	4,025110525	-100,3400615	-0,659938479	0,657701888
70	2025.12.06_15.52.12	-1842018	-7953147	-101	4,417763062	-101,7640126	0,76401256	0,750768902
80	2025.12.06_15.52.22	-1841470	-7953258	-102	5,055732129	-103,8275422	1,827542231	1,760170944
90	2025.12.06_15.52.32	-1840778	-7953393	-105	5,625610649	-105,4614689	0,461468857	0,43757105
100	2025.12.06_15.52.45	-1840121	-7953521	-108	5,452678283	-104,983827	-3,01617303	2,872988266
110	2025.12.06_15.52.56	-1839534	-7953635	-91	3,916886267	-99,92311023	8,92311023	8,929976468
120	2025.12.06_15.53.06	-1838888	-7953764	-90	1,955809604	-89,29878695	-0,701213052	0,785243647
130	2025.12.06_15.53.15	-1838279	-7953883	-84	1,385663787	-84,02672833	0,026728327	0,031809315
140	2025.12.06_15.53.25	-1837583	-7954015	-87	1,296548689	-83,00982067	-3,990179334	4,806876226
150	2025.12.06_15.53.35	-1836914	-7954150	-77	0,998942456	-79,02066356	2,020663556	2,557133116
160	2025.12.06_15.53.45	-1836258	-7954277	-75	0,711033459	-73,81969833	-1,180301672	1,598897989
170	2025.12.06_15.53.55	-1835558	-7954412	-69	0,732852225	-74,28207291	5,282072906	7,110831321
180	2025.12.06_15.54.06	-1834845	-7954553	-68	0,929491993	-77,91830808	9,918308081	12,7291112
190	2025.12.06_15.54.18	-1834310	-7954653	-90	1,177123662	-81,53154828	-8,468451724	10,38671766
191	2025.12.06_15.54.19	-1834216	-7954661	-90	1,23994921	-82,32698916	-7,673010844	9,320164533

Table IV, Drive Test Results.

Table IV shows the values obtained in the Drive Test. Among the grouped parameters are the time intervals for recording the measurements. This table includes data for every 10 samples out of the 191 total samples taken. The table shows the latitude and longitude coordinates of each sample, the measured RSRP, an estimate of the distance from the mobile device to the base station, and the RSRP modeled with COST-231 Hata. These values allow us to calculate the percentage error, expressed in decibels (dB), These values allow the calculation of absolute prediction errors expressed in dB. The errors are not consistent but vary along the route, which aligns with the signal irregularity shown in the previously presented graphs. These variations are caused by different phenomena that affect the transmission channel, such as shadow fading, multipath fading, and obstructions like trees, buildings, and terrain irregularities.

We can conclude that the absolute error values are within an acceptable range for propagation studies in real-world environments, allowing us to affirm that the COST-231 Hata model provides a fairly accurate representation of signal behavior over a given distance. The relative percentage error shown in the third graph is very low, indicating that the theoretical model and experimental values agree.

To complement the information provided by the Matlab code, we will verify the accuracy of the displayed data using formulas and calculations.

In this case, we used the COST-231 Hata formula for path loss.

$$L(dB) = 46.3 + 33.9log10(f) - 13.82log10(hb) - a(hm) + \left(44.9 \; - 6.55log10(hb)\right)log10(d) + Cm. \quad (2)$$

Equation II. COST-231 Hata formula for path loss.

This equation yields the average journey loss in the urban environment.
The parameters to be used are as follows:

Parameter	**Value**	**Meaning**
f	1900 MHz	PCS / LTE Band
hb	30 m	Tower height
hm	1.5 m	Mobile height

Cm	3 dB	Metropolitan city, Metropolitan correction factor, applied based on the urban morphology of "Las Villas," which presents continuous building coverage, paved streets, and infrastructure density consistent with the metropolitan environment category defined in the COST-231 Hata model.
d	km	Distance BS–UE

Table V, Parameters Used for Path Loss.

In this case, we will use this formula because we aim to estimate the path loss that the signal experiences as it propagates from the base station to the cellular device in environments with significant obstructions, such as urban areas. This model is primarily used to design and plan cellular networks with technologies like GSM, UMTS, and LTE, as it allows us to predict signal transmission levels, map coverage, locate base stations, and, most importantly, evaluate quality of service before taking actual measurements. The metropolitan correction factor (Cm = 3 dB) was selected because the 'Las Villas' residential area presents urban characteristics, including paved roads, continuous building facades, and proximity to the city of Babahoyo consistent with the metropolitan environment category established in the COST-231 Hata model.

The formula relates to several parameters mentioned above and previously measured with the G-NetTrack Lite software, such as the operating frequency. In this case, the frequency is relevant because higher frequencies are directly proportional to signal attenuation, which explains why higher frequency bands have lower coverage. The height of the base station is also a factor, and in this case, it has an inverse effect. Antennas with greater height significantly reduce signal loss because they improve line of sight and decrease obstruction from urban infrastructure. These parameters include the height of the mobile device and the distance between the base station and the user. This distance increases logarithmically as the user moves further from the antenna.

Next, we will calculate whether the user's actual height influences signal loss within the COST-231 Hata model. Although this condition is evaluated within the formula, in real-world mobile networks, users typically hold their phones at an average height of 1.5 meters. Therefore, this value is substituted into the equation to determine how much it corrects signal loss.

As the next point, the calculation will be carried out to verify if the real height of the user influences the path loss within the COST-231 Hata model. Although this condition is evaluated within the formula. In real mobile networks, the user usually holds the phone at an average height of 1.5m, so this value is substituted into the equation to check how much it really corrects the signal loss.

$$
\begin{gathered}
a(hm) = 3{,}2(log10(11{,}75hm))^2 - 4{,}97 \\
a(hm) = 3{,}2(log10(11{,}75 \times 1{,}5))^2 - 4{,}97 \\
a(hm) = 3{,}2(log10(17{,}625))^2 - 4{,}97 \\
a(hm) = 3{,}2(1{,}246)^2 - 4{,}97 \\
a(hm) = 3{,}2(1{,}553) - 4{,}97 \\
a(hm) \approx 0{,}0\ dB
\end{gathered}
$$

Equation III. Trip loss calculation based on height.

The value of 0.0 dB was obtained, this means that for a typical user, the height at which the mobile phone is located does not cause any difference in the total link loss. This allows us to validate that the power delivered by the base station depends mostly on the distance, frequency and height of the base station, while the height of the user only acts as a fine adjustment of the model.

To simplify the analysis and facilitate calculations, graphs and comparisons, we will rewrite the equation as follows:

$$L(dB) = A + B\ log10(d) + Cm. \quad (4)$$

Equation IV. Simplified Path Loss Formula.

Standard part A:

$$A = 46.3 + 33.9\ log10(1900) - 13.82\ log10(30) - a(hm)$$
$$A = 46.3 + 33.9(3.279) - 13.82(1.477) - 0$$
$$A = 46.3 + 111.17 - 20.41$$
$$A = 137.06\ dB$$

Equation V. System base loss calculation.

Slope B:

$$B = 44.9 - 6.55\ log10(30)$$
$$B = 44.9 - 6.55(1.477)$$
$$B = 35.23$$

Equation VI. Path loss, logarithmic form.

This value indicates that the path loss grows logarithmically with distance, its magnitude being dependent on the height of the base station antenna.

Once constants A and B have been determined, they are substituted into the simplified formula to obtain the value for the path loss calculation.

$$L(dB) = A + B\ log10(d) + Cm$$
$$log10(3.16) = 0.5$$
$$L = A + B\ log10(d) + Cm$$
$$L = 137.06 + 35.23(0.5) + 3$$
$$L = 137.06 + 17.62 + 3$$
$$L = 157.68\ dB$$

Equation VII. Trip loss calculation.

This result represents the average path loss that the signal experiences when propagating from the base radio to a mobile device, located at an average distance of 3.16 km away. This information is pre-established by the conditions provided by the Cost-231 Hata model.

To determine theoretical RSRP values related to the COST-231 Hata path-loss model, the EIRP value was evaluated as a supplementary engineering reference. Typically published in the technical literature for this kind of infrastructure, the transmitted power (Ptx = 46 dBm), antenna gain (Gtx = 17 dBi), and feeder losses (Ltx = 2 dB) are indicative values for urban LTE macro deployments running at 1900 MHz. These factors do not serve as the study's major validation inputs; rather, they are only used as a reference.

Ptx	Power transmitted by the base station.
Gtx	Gain of the transmitting antenna.
Ltx	Losses in cables and connectors.

Table VI. EIRP parameters

$$PIRE = 46 + 17 - 2 = 61\ dBm$$
$$RSRP = PIRE - L$$
$$RSRP = 61 - 157.68$$
$$RSRP = -96.7\ dBm$$

Equation VIII. RSRP calculation.

In this case, the value that Matlab gives us of the modeled RSRP is -96.64 dBm and the value that it gives us using the established formulas is - 96.7 dBm.

A comparison between the results computed using the theoretical COST-231 Hata propagation model and those derived using the MATLAB code is shown in Table 8. The first ten samples were used for this study.

The propagation loss, which is the radio channel's attenuation determined by the propagation model, the RSRP derived from the theoretical relationship RSRP = PIRE−L, the RSRP values produced by MATLAB (which directly incorporates the propagation model), and the absolute difference between the two results are all included in the table.

Both unprocessed and smoothed samples were examined. To lessen the impact of short-term fading and enhance the readability of large-scale behavior, a moving average filter was only used for the visual depiction of signal trends in Figure VI. The three main validation metrics, MAE, RMSE, and bias were only computed using the raw measured data; no smoothing was used.

The close agreement between the analytical calculations and MATLAB outputs confirms the correct implementation of the COST-231 Hata model equations within the simulation environment.

Sample	**PIRE (dBm)**	**Propagation losses L (dB)**	**RSRP Calculated (dBm)**	**RSRP MATLAB (dBm)**	**Diference (dB)**
1	61	157.68	-96.70	-96.64	0.06
2	61	158.12	-97.12	-97.05	0.07
3	61	158.95	-97.95	-97.88	0.07
4	61	159.40	-98.40	-98.32	0.08
5	61	160.10	-99.10	-99.02	0.08
6	61	160.85	-99.85	-99.78	0.07
7	61	161.50	-100.50	-100.43	0.07
8	61	162.20	-101.20	-101.12	0.08
9	61	162.95	-101.95	-101.88	0.07
10	61	163.60	-102.60	-102.54	0.06

Table VII. Consistency Check Between Analytical COST-231 Formulation and MATLAB Implementation

As shown in Figure VIII, a comparison of the RSRP values is established as a function of the distance between the radio base and the receiver, the curves corresponding to the calculated RSRP and the RSRP obtained in MATLAB overlap throughout the range of distances analyzed. This indicates that the mathematical formulation has been correctly applied and that the propagation model has been implemented appropriately at the time of performing the simulation. The observed differences are minimal and can be verified by numerical rounding, so they are considered negligible from an engineering point of view.

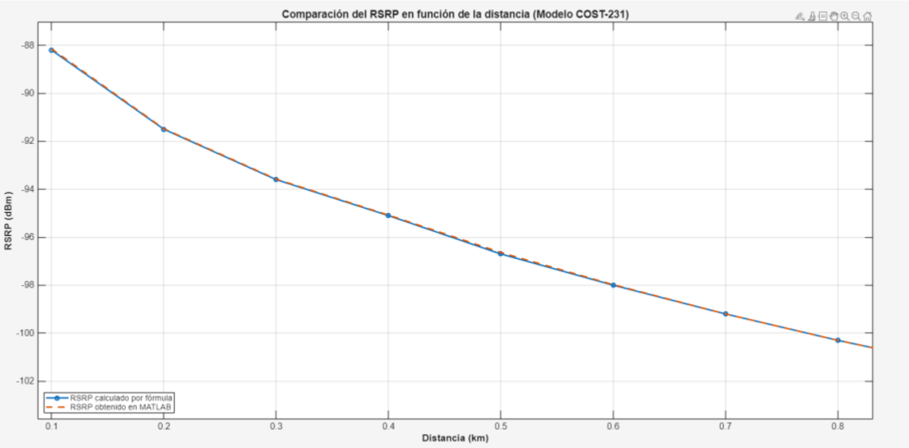


Figure VIII. Analytical vs MATLAB COST-231 RSRP Consistency Check

4. Conclusions.- The COST-231 Hata model was chosen as the most appropriate for examining signal propagation in the city of Babahoyo, particularly in the residential sector "Las Villas," after a strong conceptual foundation on 4G LTE coverage and urban propagation models was built.

The G-NetTrack Lite application was used to gather genuine field measurements using the Walk Test and Drive Test techniques, yielding RSRP values that accurately depict the behavior of the 4G LTE signal. The findings demonstrated that the received power level progressively changes with both urban ambient conditions and distance from the base station, making it possible to determine the actual coverage in the research region.

The COST-231 Hata model was used in MATLAB to simulate theoretical 4G LTE coverage, yielding received power values that were in line with those seen in an urban residential setting. Good agreement was found between the simulated and measured RSRP values, The comparison between measured and simulated RSRP values showed acceptable prediction accuracy according to MAE and RMSE metrics, confirming that the COST-231 Hata model is suitable for preliminary LTE coverage estimation in the studied area.

Ultimately, the COST-231 Hata model was successfully validated through comparison between COST-231 MATLAB predictions and actual field measurements. Furthermore, despite local variations brought on by distance and urban morphology, the comparison with the coverage data supplied by the mobile operator demonstrated general consistency with field measurements, confirming the accuracy of the operator's coverage information within typical urban error margins.

The results indicate that the COST-231 Hata model provides a very reasonable approximation of the signal coverage established by the operator's maps. The field measurements comprised RSRQ and SNR values that were noted along the study path in addition to RSRP. The presence of these indicators in the dataset indicates that the G-NetTrack measurements captured a complete picture of link quality, and they may serve as the foundation for future QoS-oriented analyses in the same area, even though a full quantitative analysis of these indicators is outside the main purview of this validation study. While local deviations were observed due to factors such as attenuation, obstruction, and measurement uncertainty, the model achieved considerably good agreement with field measurements according to the MAE and RMSE metrics.

The final validation results correspond exclusively to the COST-231 Hata model, while the Friis-based link budget was included only as a theoretical reference.

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Author contribution:
1. Conception and design of the study
2. Data acquisition
3. Data analysis
4. Discussion of the results
5. Writing of the manuscript
6. Approval of the last version of the manuscript

JATP has contributed to: 1, 2, 3, 4, 5 and 6.
RGCA has contributed to: 1, 2, 3, 4, 5 and 6.
DHCV has contributed to: 1, 2, 3, 4, 5 and 6.

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