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RESEARCH ARTICLE

Experimental Visualization of the LoRaWAN Variable Correlation in Jakarta

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ABSTRACT This work presents empirical research into the efficacy of LoRaWAN, a wireless communication protocol that enables data transmission over extensive distances while minimizing power consumption and cost. This research aims to understand the correlation between transmission and connectivity within the LoRaWAN framework. Prior research on LoRaWAN has not investigated the influence of factors such as building height above sea level (MASL), elevation coordinate during the driving test, elevation gateway position coordinate point, distance from transmission transmitter to receiver, Signal-to-Noise Ratio (SNR), and Received Signal Strength Indicator (RSSI) on coverage status about environmental complexity. Hence, this study gathered data through a driving test utilizing a GlobalSat tracker with the identification numbers (K02188, K02204, and K02205) to examine these variables' impact on LoRaWAN performance. The trial results consist of logarithmic and historical data collected at specific gateway locations in Jakarta. The RSSI measurements, which indicate the strength of the signal, varied from -127 dB to 60 dB, with an average Signal-to-Noise Ratio (SNR) of 7 dB. The coverage status is classified into different categories, including Excellent (12.55%), Acceptable (16.57%), Good (19.86%), Poor (23.98%), and Very Poor (27.01%). The correlation variable analysis reveals that the coverage status is highly correlated with the independent variables. Provides useful insight into the areas available for LoRaWAN performance and reliability as a technology that will support digital smart meter deployment in challenging and complex environments. Correlation variables provide information about the elements that influence coverage status.

INDEX TERMS LoRaWAN, free space loss, height building, elevation, distance, correlation variable.

I. INTRODUCTION

The categories obtained based on RSSI used to find out whether they can become experimental coefficients, and the correlated variables that affect the independent and dependent variables. The variable consists of several as follows: longitude latitude drive test (dt) coordinates, longitude latitude gateway (gt) coordinates, RSSI, Signal to Noise Ratio (SNR), altitude (alt), distance (d), elevation_dt, elevation_gt, and building height above 15 meters (HB). Based on these variables, the capacity calculation is also used to examine the effect of the distribution of building height and elevation based on the drive test and gateway data, then generates the coverage status of the LoRaWAN gateway [33]. Areas that are the location of the LoRaWAN device drive test have different signal strength intensities depending on the results obtained, which are then categorized based on the level of coverage. Through the coverage status of the LoRaWAN gateway, research has examined the relationship between the independent and dependent variables in the form

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of the elevation of the drive test point and the elevation of the installed gateway position with the distribution of building heights using regression testing. This test was conducted on the LoRaWAN gateway with IoT technology specifications that excel in battery saving. In addition, this test was also carried out to support the digitalization of technological innovation where the research conducted was within the frequency radius of 920 - 923 MHz [12].

The development of LoRaWAN technology is very important for consideration in planning and implementing IoT (Internet of Things) applications based on several reasons, such as the main advantages of LoRaWAN (Long Range Wide Area Network), which are simple devices that have a long battery life [1], range, gateway position, signal quality, and signal interference [2], [3]. IoT technology can revolutionize the global world because the objects used are equipped with an internet connection, which allows connected devices to collect and exchange information [3], [8]. The scope of urban planning on the surrounding conditions affects the propagation of LoRaWAN ability to reflect signals between buildings, one of which is physical barriers in this case affecting signal strength [4], [5]. In transmitting the signal that is transmitted, it reflects the optimization of the LoRaWAN network, which is also taken into account as a data packet delivery medium for the effective received signal strength based on the distribution as measured using effective signal power (ESP) [6], [9]. One of the mega cities used in this study is Jakarta, which has 44 sub-districts, many tall buildings, and a projected population of more than 12 million people.This will impact how use and access communication, specifically the digital transformation that telecommunications companies (PT.Y) are supporting digital smart meters for households in Jakarta This will have an impact on how people use and access communication, specifically the digital transformation that telecommunications companies are supporting. The needs of big cities regarding connectivity between infrastructure have increased intelligence, business insight, efficiency, and innovation to improve mobility performance in the urban environment [7], [8], [15], [16]. Jakarta, as an urban area, has a distribution of high-rise buildings, which can cause blank spots, namely areas where the signal is uncovered. The Received Strength Signal Indicator (RSSI) has a provision that states that the higher the RSSI value received, the stronger the signal strength. Besides, the lower the RSSI value received, the weaker the signal strength [9], [10], [11]. LoRaWAN gateways are not currently spread out well, especially in the Jakarta area. This is because coverage planning for Free Space Loss (FSL), which is calculated over a distance of 8.76 km, is not well done, and previous studies have not calculated the capacity for correlation variables [11].

Based on the previous research, the researcher has developed an ongoing study by carrying out a LoRaWAN drive test, which is performed experimentally towards the Gambir district in Jakarta under the name of Menteng Drive Test-Path. A total of 23 gateway sites, or 28.04% of the 645 gateway sites, have been spread widely across various districts throughout Indonesia. Otherwise, the quality of the LoRaWAN gateway signal is defined into five categories based on each performance: Excellent with a status category of 5, good with a status category of 4, acceptable with a status category of 3, poor with a status category of 2, and very poor with a status category of 1.

This study formulation of the problem in this study aims to determine the relationship between variables that affect coverage status. The study utilizes the regression method to analyze the data obtained from the driving test conducted using three trackers. Researchers analyze the acquired data to examine the correlation between variables such as RSSI, elevation, and related factors. They specifically investigate the impact of the distance between gateways and LoRaWAN devices on signal quality, as it can diminish when the distance is too great. Is it essential to install a directional antenna in locations classified as uncovered (red line) due to numerous barriers and significant signal gaps? There is significant potential for implementing digital smart meter events in houses in Jakarta, given the installation of 3,381,100 meters for heads of households in 2022, as reported by the Central Statistics Agency (BPK) of Jakarta Province. The pilot project for digital smart meters in Indonesia is taking place in Jakarta, with significant involvement from state-owned enterprises in the telecommunications and power sectors. The implementation of digital smart meters is being carried out utilizing LoRaWAN technology. Researchers analyze the acquired data to examine the correlation between variables such as RSSI, elevation, and related factors. They specifically investigate the impact of the distance between gateways and LoRaWAN devices on signal quality, as it can diminish when the distance is too great. Is it essential to install a directional antenna in locations classified as uncovered (red line) due to numerous barriers and significant signal gaps? There is significant potential for implementing digital smart meter events in houses in Jakarta, given the installation of 3,381,100 meters for heads of households in 2022, as reported by the Central Statistics Agency (BPK) of Jakarta Province. The pilot project for digital smart meters in Indonesia is taking place in Jakarta, with significant involvement from state-owned enterprises in the telecommunications and power sectors. The implementation of digital smart meters is being carried out utilizing LoRaWAN technology. By examining the response variable and predictor variables, predictions can be formulated. This paper makes the following contributions: The main contribution of this research is to serve as an exemplar in demonstrating comprehensive policies and procedures that facilitate industrialization and digital transformation. Additionally, it aims to implement digital smart meters in Jakarta, specifically between PT. Y and PT. P, which are industry companies in their respective countries.

This research is organized as follows: Section I discusses the basic problem of signal strength in LoRaWAN, highlighting the importance of understanding and addressing this issue. Section II provides the research background, presenting the context and relevance of the study. Section III it outlines the methodology employed to conduct the drive test investigation, describing the approach and techniques used to fulfill the research objectives. Section IV presents the verified proposed solution, showcasing the findings and outcomes of the research. Section V concludes the research, summarizing the key findings, implications, and potential future directions.

II. RELATED WORKS

LoRaWAN, as a technology that supports the development of the Internet of Things (IoT), has garnered significant attention from researchers worldwide. In previous studies, researchers have analyzed LoRaWAN in Jakarta, Indonesia, specifically focusing on the application of LoRaWAN in path loss and obtaining information about signal coverage and quality based on drive test data from 2020. However, these studies did not take into account the height of buildings or the elevation of gateway locations above sea level [4]. In this section, we will briefly review the existing studies on LoRaWAN performance, specifically referring to studies [4], [13], [14].

A. FREE SPACE LOSS

The path loss (PL) model focuses on the large-scale average received signal strength based on variations in the distance between the receiver and transmitter. PL models are designed to predict specific environments. The most straightforward path loss model is free space loss (FSL), which is the condition of LoRaWAN that is adaptable in an open space or obstacle-free environment where there is no interference from an object that can block or weaken the signal, thus affecting the transmission of radio signals between LoRaWAN devices [15], [16], according to the characteristics of the environment in urban Area 2 was implemented in LoRaWAN devices [17], [18]. FSL focuses on the distance between the sender (T_x) and receiver (R_x) signals, which is inversely proportional to the square of the distance between the receiver and transmitter, such as the height of the antenna in the category of open space height, or in urban environments with many buildings that have a building height above 15 meters. Therefore, the city of Jakarta in Indonesia is suitable as a research role model in identifying the performance of the LoRaWAN gateway [19], [24].

$$L = 20\log 10(d) + 20\log 10(f) + 20\log 10\left(\frac{4\pi}{c}\right). \quad (1)$$

where:
L = free space loss in decibels (dB)
d = distance between transmitter and receiver (km)
f = operational frequency in hertz (Hz)
c = constant

B. RECEIVED SIGNAL STRENGTH INDICATOR (RSSI)

Measuring signal strength in a cellular network is used to test signal strength in radio frequency to optimize network or device performance or receiver, and signal inference can affect signal quality [20], [27]. RSSI can show that the technology of LoRaWAN can have a large misplacement due to frequency distortion in the carrier signal or random frequency ranges that jump to pseudorandom sequences in terms of spread spectrum techniques [26], [32], or gateways that experience interference so that they have a large SNR. LoRaWAN is able to show the impact of frequency hopping on placement accuracy, which is also known by observing the RSSI of a frequency [9], [21].

$$RSSI(dBm) = P - A. \quad (2)$$

where:
$RSSI$ = Received Signal Strength Indicator, measured in decibel milliwatts (dBm) P = Received Signal Strength in dBm A = Reference Level or Signal Loss in dBm

C. SIGNAL TO NOISE RATIO AND BIT RATE ERROR

The signal-to-noise ratio (SNR) is an important parameter in LoRaWAN, alongside RSSI. SNR is measured in decibels. (dB) and represent the ratio between the strength of the signal and the strength of the noise. A higher SNR value indicates better signal quality [20], [27]. In other words, while RSSI provides information about the overall strength of the received signal, and SNR represents the quality of the signal. of the device. In this context, RSSI describes the level of total signal strength [4], [22].

$$SNR(dB) = P\_signal - P\_noise. \quad (3)$$

where:
SNR = signal-to-noise ratio, measured in decibels (dB). P_signal = desired signal strength measured inappropriate units (e.g., dBm) P_noise = Noise Level in the Communication Environment, measured in appropriate units (e.g., dBm).

Higher SNR indicates better performance than lower BER. High SNR is essential in wireless communication systems like OFDM to reduce the Bit Error Rate (BER) and improve transmission reliability [36]. Transmission line interference can modify signal amplitude, phase, or frequency, lowering SNR and fading. Modulation schemes, error coding, and diversity reception must be used to reduce the bit error rate. Poor signal-to-noise ratio (SNR) can increase bit error rate (BER), indicating more erroneously received bits. A communications system with a high SNR and low BER performs well. Increased signal-to-noise ratio (SNR) reduces bit error rate (BER), improving data transmission quality and reliability. The relationship between signal-to-noise ratio (SNR) and Bit Error Rate (BER) is significant in studying LoRaWAN, an LPWAN technology for IoT communication. This link is essential for urban study. Urban signal quality and noise are affected by high-rise buildings, electronic device interference, and population density. These factors affect SNR and BER. A higher signal-to-noise ratio (SNR) indicates a stronger signal than background noise, lowering bit error rate (BER) and data transmission errors.

However, physical obstacles and other noise sources might change metropolitan areas' signal-to-noise ratio (SNR), affecting the bit error rate (BER). LoRaWAN uses Chirp Spread Spectrum (CSS), a modulation method that resists interference and allows reliable transmission at low SNR. Despite these issues, LoRaWAN operates well in metropolitan areas with an acceptable Bit Error Rate (BER). Urban research may also find that diversity tactics, such as using many LoRaWAN gateways to receive the same messages, can improve SNR and BER due to various autonomous signal transmission routes. LoRaWAN investigations in urban environments should consider density, topography, and infrastructure.

D. GATEWAY

LoRaWAN, specifically designed for IoT applications, is required.as a medium for long-distance communication with low power consumption [28]. The gateway serves the purpose.of receiving and forwarding data to various LoRaWAN devices within its range [2], [31]. In the process of forwarding and receiving data, the gateway's performance is closely related to RSSI. Because RSSI is a parameter that measures the strength of the signal, the quality of the connection, the communication range, and the impact of environmental factors on the signal received by the gateway. A stronger RSSI indicates a higher signal strength, implying good signal quality. On the on the other hand, a weakly received signal may suggest the possibility of interference caused by limitations in the communication range or environment factor [23], [24], [29], [30].

E. LINEAR REGRESSION

Linear regression is a statistical method that can be applied.Such as businesses to help forecast events based on a linear relationship between dependent and independent variables. Find the relationship between the dependent variables and the independent variables and predict the path loss model. This model is based on an equation that describes how the signal gets weaker when it crosses a free-space area. This equation is made by measuring the signal strength at a certain distance from the gateway performance. Linear regression models the relationship between variables affecting RSSI, gateways, building distribution, SNR, and distance to increase the number of gateways or rearrange the frequency of data transmission [25], [34].

$$y = b_0 + b_1x_1 + b_2x_2 + \ldots + b_px_p. \tag{4}$$

where:

y = dependent or independent variables that you want to predict

b_0 = intercept or constant

b_1, b_2, b_p = slope associated with each Independent Variables

x_1, x_2, x_p = explanatory variables (subdistrict ID = district)

F. BINARY LOGISTIC REGRESSION

Regression logistic is a statistical method that extends linear regression to analyze the relationship between a dependent variable (Y) and one or more independent variables (X1, X2). etc). It allows us to assess the impact of each independent variable on the dependent variable, while assuming other variables as constants, using the following equation:

$$P(Y = \left(1|X = \frac{1}{(1 + exp\,(-z))}\right). \tag{5}$$

where:

$P(Y = (1|X)$ = the probability of the LoRaWAN coverage state event occurring, containing the values of features X

z = linear combination of the corresponding features

The features used need to be represented using a X factor feature, namely as follows.

$$X = [x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8]. \tag{6}$$

where:

x_1 = signal strength (RSSI)
x_2 = distance from the gateway
x_3 = obstacles
x_4 = height of building
x_5 = coverage status
x_6 = elevation
x_7 = altitude
x_8 = Signal-to-Noise Ratio (SNR)

III. EXPERIMENT PLATFORM METHOD

Before making predictions for the performance of the LoRaWAN network, it is essential to identify and prepare variables that affect the network's performance. These variables include the transmitting power of devices and gateways, elevation information, and the height of buildings. Initiate the prediction of the LoRaWAN network; testing data is collected from the already installed LoRaWAN network. Data collection helps identify the values and variables relevant to the network's performance. By analyzing and understanding these variables, predictions can be made to assess and improve the performance of the LoRaWAN network. Testing data is collected based on the LoRaWAN network that has been installed to identify the values and variables. A statistical test data analysis is performed to describe the relationship between these variables. The testing data that has gone through the testing stage needs to be validated before entering the modelbuilding stage to test the reliability of the resulting model and help predict the performance of the LoRaWAN network. In addition, collecting data based on spatial data related to the location of LoRaWAN gateways using tools such as digital maps and GlobalSat GPS trackers is very important in supporting the prediction. Spatial data has a significant role in analyzing the LoRaWAN device network from a spatial perspective. Spatial analysis involving spatial data manipulation can describe information about the geographic environment and the spatial relationship between one gateway and the surrounding environment. In this case, the understanding has to do with spatial analysis. Then, the distance between two gateways is calculated based on a driving test or the search for the best place to put a LoRaWAN gateway, considering things like elevation and population density and the location of the LoRaWAN gateway being sent. Test data that has been collected can be processed first to clean the data from noise and invalid data. Data that can be used for testing has gone through the data cleaning process to be ready to be tested.

In this experiment, the researcher divides it into several steps of a structured process study, which are represented in Figure 1.

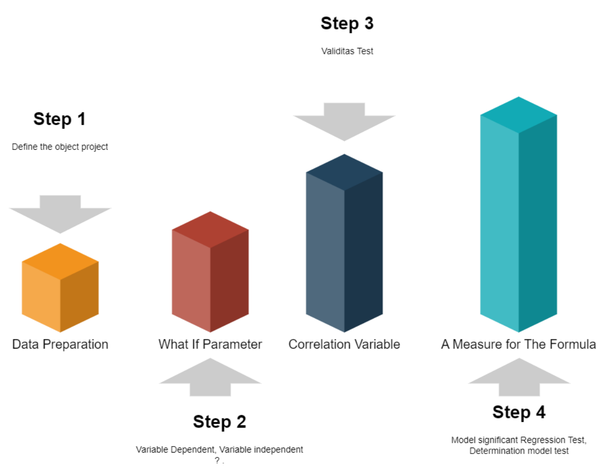

FIGURE 1. LoRaWAN drive test experiment step process flow.

The flow of the stages of this research, which is attached in Figure 1, consists of four structured steps that are useful in investigating the experiment drive test in the Jakarta area. The RSSI investigation acts as a point in the coverage area to determine the resulting distribution under the condition of random data collection with radio frequency transmitter coverage elements based on the three GlobalSat ID devices used, as shown in Table 1.

TABLE 1. The result of ID tools drive test device.

Device ID	GPS Tracker Code	History Data	Log Data
DEV63a404df6ac7136747	K02188	Available	Available
DEV6380f441614a447478	K02204	Available	Available
DEV63810d9a62e1181941	K02205	Available	Available

Table 1 lists the device IDs from using the GlobalSat device ID to conduct a driving test for signal strength tracking in Jakarta. Based on the LoRaWAN drive test stages shown in Figure 1, the next step after preparing the drive test device is to determine the spatial point of the drive test tracking path based on the longitude and latitude points of the location gateway, as shown in Figure 2. Table 2 lists the specifications from GlobalSat LT501E to track a driving test for signal strength tracking in Jakarta.

TABLE 2. Specification GlobalSat LT501E.

SPECIFICATION: GlobalSat LT501E GPS Tracker
Sensitivity: -128 dBm
Interface: LED Indicator
Antenna: Internal
Operating Temperature: -20^{o}C -60^{o}C
Power supply : Rechargeable Li-Polymer battery 500mAh
Sensor: 3 - Axis Accelerometer
Communication: LoRaWAN Class A & Class C
Protection Class: IPX7
Operating Humidity: 5% - 95% RH

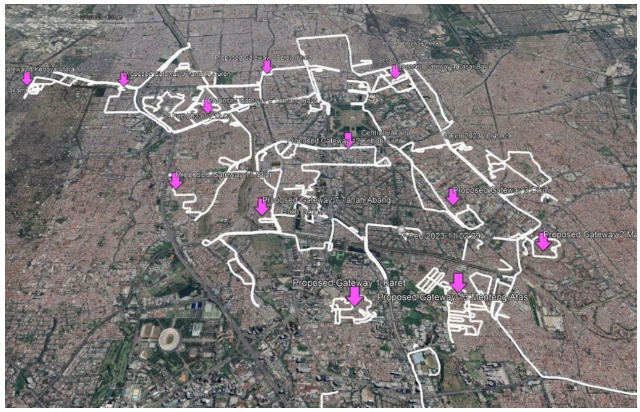

FIGURE 2. LoRaWAN drive test path.

In Figure 2, the route of the data collection stages through the drive test with purple arrows is a gateway that can receive and send signals so that RSSI and SNR can be known at that location point from a total of 23 gateway locations, as shown in Figure 2, as follows:

1) LoRaWAN gateway mapping, with the help of Quantum GIS (QGIS) tools, which are geographic information system (GIS) software, is carried out by entering the gateway coordinate points, namely latitude_dt and longitude_dt, coordinate points obtained from changes in the position of the data retrieval drive test and coordinates latitude_gt and longitude_gt, namely the position of the existing LoRaWAN gateway.
2) Network coverage analysis, using data from drive test results related to RSSI and SNR to understand the extent of the coverage of the covered gateway.
3) Deployment modeling is reviewed with QGIS to determine the distance and elevation of the elevasi_dt coordinates, changes in the data retrieval position of the test drive, and the elevation position of the existing LoRaWAN gateway.

After determining the three criteria above, an illustration was designed that illustrates the placement of the LoRaWAN gateway to identify the signal reception coverage in accordance with the radio frequency signal emission achieved in order to examine in depth the variable correlation based on the RSSI value obtained.

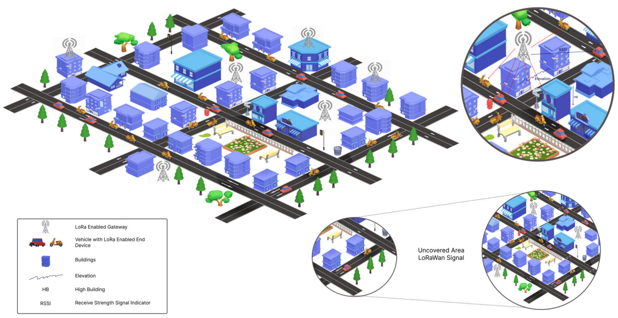

FIGURE 3. A sketch of LoRaWAN positioning system with signal reception from end-device, ranging on a gateway, elevation, and high building.

Figure 3 shows the LoRaWAN gateway system's position modeling, which was based on installed gateway mapping and case studies in the Jakarta area. The mapping depicted in the illustration is arranged based on several factors, such as the LoRaWAN gateway, a vehicle that supports the running of the drive test process to calculate the distance of the current position of the drive test device from the central gateway, buildings consisting mostly of tall buildings, as well as the RSSI value recorded when conducting a drive test on the LoRaWAN gateway with multimedia building in Gambir sub-district in Jakarta, which became the test point.

Then, still in Step 2, the next process in this research stage focuses on researchers studying other parameters by paying attention to attribute variables, including those presented in Table 3. Therefore, to predict status_co, several parameters need to be defined, as shown in Table 4.

TABLE 3. Research parameters.

ID	Remarks	Status
Status_co	Status coverage	Dependent Variable
latitude_dt	Latitude from Drive Test Tracker (decimal)	Independent Variable
longitude_dt	Longitude from Drive Test Tracker (decimal)	Independent Variable
SNR	Signal-to-Noise Ratio	Independent Variable
latitude_gt	Latitude Gateway (decimal)	Independent Variable
longitude_gt	Longitude Gateway (decimal)	Independent Variable
RSSI	Received Signal Strength Indication	Independent Variable
alt	Level of Ground Truth (meter)	Independent Variable
distance	Distance between Tracker and Gateway (meter)	Independent Variable
elevasi_dt	Height of Tracker (meter)	Independent Variable
elevasi_gt	Height of gateway (feet)	Independent Variable
HB	Height of Building (meter)	Independent Variable

In this study, experimental analysis is supported by the impact of transmission using several parameters, as shown in Table 4. These include bandwidth, SF, frequency, duty cycle, and payload for the appropriate transmission configuration.

TABLE 4. Parameters for LoRaWAN.

No.	Parameter	Value
1	Bandwith	125 kHz
2	Spreading Factor (SF)	10
3	Duty Cycle	4/5
4	Frequency	920 - 933 MHz
5	Payload	16 Byte

IV. EXPERIMENTAL RESULT

Before carrying out experimental results, a comparison is first carried out from previous research with the existing works from the literature, with the comparison results as follows:

The initial study utilized for comparison was conducted in urban areas in Indonesia, particularly in close proximity to Jakarta, and was published in 2019 under the title "Coverage and Capacity Analysis of LoRaWAN Deployment for Massive IoT in Urban and Suburban Scenario" [35]. However, this research did not incorporate building height, a crucial characteristic of urban areas, as a variable. Instead, it solely considered the elevation height of the ground contour. The study found that the minimum RSSI receive sensitivity at SF 12 was -137 dBm, which means that weak signal levels happened in 0.58% of the areas that were looked at. The optimal signal strength ranged from -115 to -135 dBm. Moreover, the transmission distance to the received signal was measured at approximately 6.07165 km. It's important to note that this particular research did not include a calculation of the correlation between variables.

The second comparative research was conducted in the urban area of Beirut, Lebanon, and was published in 2019 under the title "LoRaWAN Network: Radio Propagation Modes and Performance Evaluation in Various Environments in Lebanon" [2]. Unlike the previous study, this research incorporated building height as a variable, explicitly focusing on buildings with a height of 12 meters. The study involved measuring two gateways positioned at 260 meters above sea level. It determined that a good RSSI, capable of reception at SF 12, was at −108 dBm within the transmission distance range of 8.5 to 9 km for the received signals. Similar to the previous research, this study did not calculate the correlation between variables.

The next thing is to determine the experimental results of this study. The stages begin in Steps 3 and 4. The allocation of the Menteng drive test for LoRaWAN optimization involves considering various factors and conducting an outdoor drive test in the urban area, specifically in the Gambir District. The gateway site at Menara Multimedia, Jakarta, is visualized in figure 5. However, this research did not incorporate building height, a crucial characteristic of urban areas, as a variable. Instead, it solely considered the elevation height of the ground contour. The study found that the minimum RSSI sensitivity at SF 12 was -137 dBm, which means that weak signal levels happened in 0.58% of the areas looked at. The optimal signal strength ranged from -115 to -135 dBm. Moreover, the transmission distance to the received signal was approximately 6.07165 km. It is important to note that

TABLE 5. Comparison result between this research and other research.

Compare	Area $(\mathrm{Km})^2$	Population	Method	Strength
Our Result	664.01	10.06 million	HB : 15 Meter (minim) Elevasi_dt : Yes Elevasi_gt : Yes Frequency:920 MHz distance DT from Transmitter or Receiver: Yes SF: 10 BW: 125KHz	This research demonstrates robustness by using mathematical analysis to examine the interplay of factors in a multifaceted setting. This study analyses the practical application of digital household smart meters using LoRaWAN technology. An inherent limitation of this work is its reliance solely on SF, BW, and frequency parameters derived from the telecommunications industry standards employed in Indonesia during the specific timeframe of the experiment.
[35]	167.67	unknown	HB meter: - (Max) Elevation_dt; Yes Elevation_gt - Frequency: 923MHz distance DT from Transmitter or Receiver: Yes SF: 10 BW: 125KHz	The strength of this paper is that it examines both urban and rural areas, helping decision-makers in vertical industries to carry out network planning and optimization for mass IoT applications, which is very important for successful implementation: insufficient methodology, unrepresentative sample, insufficient data analysis depth, or inappropriate interpretation of results.
[2]	10.452	6.8 million	HB meter: 12 meters (Max) Elevation_dt; No Elevation_gt No Frequency: 868MHz Latency (distance): Yes SF ; 10 BW : 125KHz, 250KHz, 500KHz	The strength of this paper measures the underground signal but does not provide a comprehensive measure of its resistance. This research was experimental but not long-term.

this research did not include a calculation of the correlation between variables. The historical data and log files consist of primary data sets in Jakarta, characterized by its lack of hills and mountains. This is due to Jakarta's geographical location in the lowlands and the presence of islands. Jakarta, the nation's capital, is a metropolis as the hub for government, economy, and commerce. Jakarta serves as the official capital of Indonesia and acts as a pioneering hub for technical advancements, setting an example for other cities in the country

The outcome of this study is a dataset that can contribute to optimizing LoRaWAN gateway placement. This dataset includes the historical and logs file datasets, device configuration, and desktop connection. Researchers can use this dataset directly, accessing the history and log files while choosing a dedicated test drive category to record the data.

TABLE 6. Result of drive test path Menteng based on Figure 1.

Site Gateway Name	Excellent	Good	Acceptable	Poor	Very Poor	Dominan Signal status_co
Menara Multimedia	4.51	5.24	5.78	6.41	6.40	6.41
Rasuna Tower 9	7.38	6.82	16.73	8.22	16.88	16.88
Slipi Test Gateway	5.54	6.69	7.28	7.67	7.28	7.67
Tower STO Cempaka Putih (Baru)	7.32	5.92	9.06	9.05	7.31	9.06
Tower STO Cengkareng (BARU)	14.19	15.60	15.54	15.80	15.39	15.80
Tower STO Kota 2 (baru)	5.26	7.96	7.00	9.58	6.74	9.58
Tower STO Pasar Minggu (2)				6.60		6.60
Tower STO Tebet (Test Antena Baru)	8.34	9.78	8.24	10.76	8.41	10.76
TR2 - TNG - Tower STO Pondok Aren					14.23	14.23
TR2-BKS-Tower STO Pondok Gede (2)				11.64	12.24	12.24
TR2-JKB-Tower STO Kedoya (2)	9.75	10.72	9.74	10.19	9.83	10.72
TR2-JKB-Tower STO Slipi	6.63	7.38	7.66	7.62	7.56	7.66
TR2-JKB-Tower STO Taman Duta Mas	9.97	10.22	10.22	10.76	10.71	10.76
TR2-JKP-Tower STO Kemayoran	7.20	12.08	8.92	23.94	19.18	23.94
TR2-JKS-Tower STO Cipete				10.75	8.57	10.75
TR2-JKS-Tower Sto Jagakarsa		17.16	12.83	17.15	13.11	17.16
TR2-JKS-Tower STO Kalibata	9.18	9.19	6.15	10.84	8.74	10.84
TR2-JKS-Tower STO Palmerah (4)				4.40	6.39	6.39
TR2-JKS-Tower STO Tebet (2)	8.34	9.00	16.32	4.78	16.45	16.45
TR2-JKT-Tower STO Klender			12.70	8.57		12.70
TR2-JKT-Tower STO Kranggan (2)					8.61	8.61
TR2-JKT-Tower STO Penggilingan (2)					11.01	11.01
TR2-JKU-Tower STO Pademangan/ANC 2.2 (2)		3.00	9.70	3.16	7.84	9.70

Table 6 presents the result of the Menteng drive test path against the 23 gateway sites in Jakarta, considering the RSSI values. The table provides the distribution of coverage status based on the RSSI values at each gateway site. Here are the Coverage status values for the Menteng drive test path: Excellent: The highest at 13.80%, observed at Tower STO Cengkareng, Baru, Good: 17.16% observed at TR2-JKS-Tower Jagakarsa, Acceptable: 12.70% observer at Rasuna Tower 9, Poor: 17.17% observed at TR2-JKS-Tower Jagakarsa, and Very Poor: 19.18% observed at TR2-JKP-Tower STO Kemayoran.These values represent the distribution of coverage status based on the RSSI values recorded at each gateway site during the Menteng drive test path. Additionally, Figure 4 provides tabulated data related to the distribution of RSSI values at the gateway site in each sub-district of Jakarta. This data offers further insights into the RSSI distribution across various city areas.

This research was designed to use a bandwidth of 125 KHz, a spreading factor (SF) of 10, and operate at a frequency of 920 MHz, which aligns with the prevailing standard utilized by the Indonesian telecommunications sector. Using these specific criteria, we evaluate the efficiency of LoRaWAN in highly populated metropolitan areas characterized by towering structures. The reduction in received power and excessive bit errors are influenced by the height of the building and elevation, as they produce interference from reflected signals. The research findings indicate that LoRaWAN is capable of satisfying the data rate and latency prerequisites for transmission applications.

Nevertheless, according to the findings of empirical measurements, as depicted in figure 5, specific locations or regions exhibit uncovered status, indicating a significant weakness in the signal inside those areas. This demonstrates the necessity for enhancing the dependability of LoRaWAN to meet the requirements of mission-critical applications.

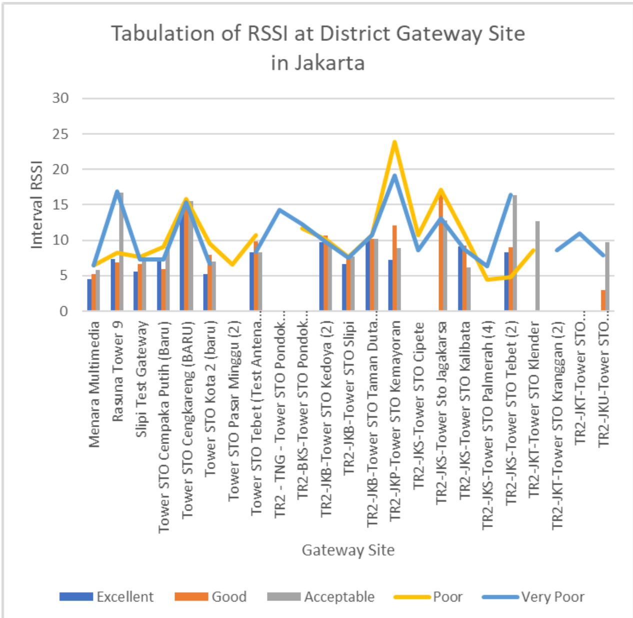

FIGURE 4. Tabulation of status coverage and RSSI towards gateway site.

A tabulation pattern can be seen through a histogram plot that shows the number of observations in each category of "status" variables in the data frame df_gateway the LoRaWAN. This plot is created using the Seaborn library with the countplot() function, which counts the number of occurrences of each category value in the "status" variable and returns its histogram. The df_gatewayLoRaWAN ['status'] argument gives the data the variable "status" in the data frame df_gatewayLoRaWAN. The label="Count" argument sets the y-axis label to "Count" on the plot. Thus, this plot shows the number of observations in each value of the variable category "status" in the data frame df_gatewayloRaWAN. There is still a LoRaWAN gateway with the following results: excellent 12.55%, acceptable 16.57%, good 19.86%, poor 23.98%, and very poor 27.01%.

In the drive test path from a sub-district in Jakarta, the site gateway that is the point center of the Menteng test path is the side gateway of Menara Multimedia. The multimedia building is located in Gambir District, which in Figure 6 is a sample barometer of other districts in Jakarta. Of course, the placement of the gateway site in the Gambir District area affects the quality of RSSI and coverage status (status_co), so that the RSSI recorded on the Multimedia Tower gateway site with a 360° rotation as seen in the visualization in Figure 5. Then, the elevation of Gambir District, in this case, Multimedia Building, is at 5.6 masl, which shows that the elevation of the gateway in this area is considered stable with an average alt of 90.39%. Judging from the tabulation of HB distribution, Gambir District has HB above 15 m with an HB percentage of 64.09% based on HB distribution in sub-districts in Jakarta, which is one of the considerations considering the coordinate point of the Multimedia Building visualized in this study is also the largest telecommunications provider office in Indonesia. This study focuses on determining the quality of the signal emitted from the Multimedia Tower gateway site.

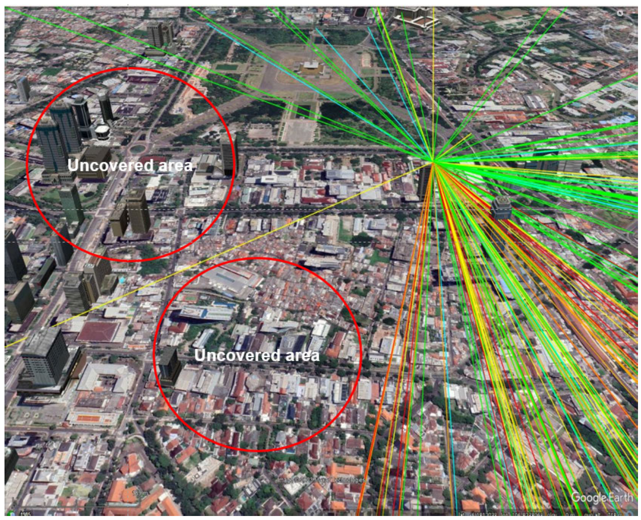

FIGURE 5. Menara multimedia gateway.

Figure 5 displays drive test results from the Menara Multimedia site gateway, shown with radiant lines spread 360° to the surrounding environment. The signal quality is then categorized based on the color of the signal beam line shown in Figure 5 above. The blue line defines the Excellent signal status at 4.51%, the green line defines the Good signal status at 5.24%, the yellow line defines the Acceptable signal status at 5.76%, the orange line defines the Poor signal status at 6.41%, and the red line defines the Very Poor signal status at 6.40%. In addition, some areas are not covered by signals from the gateway site, as indicated by areas that are not covered or crossed by the transmit line, which is caused by obstacles in the related area. If you look at the dataset collected based on record file history and log files spatially related to LoRaWAN gateways from each sub-district in Jakarta, which is then shown in Figure 6 (a case study of Multimedia Building),

The spatial layout in Figure 6 shows the distribution of tall buildings around the multimedia building. The spatial layout is presented based on the parameters contained in the dataset, namely: elevasi_dt, elevasi_gt, RSSI, SNR, and the position of the building around the Menara Multimedia gateway site in Gambir sub-district in Jakarta. Drive tests in this region help in visualizing how a building's height and elevation affect RSSI and SNR over distance. The signal range is based on the visualized spatial layout, among others: Excellent with RSSI > −100 dBm, Good with RSSI <= −100 dBm and

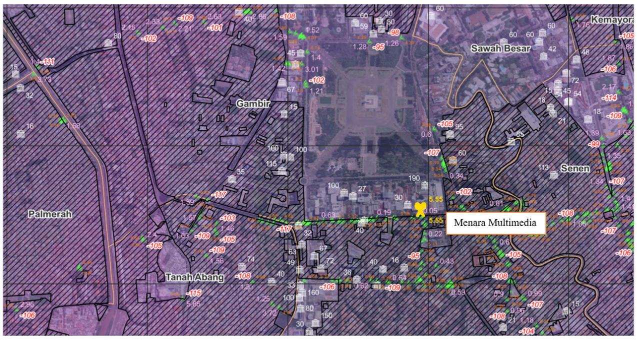

FIGURE 6. Spatial layout of high buildings around the menara multimedia.

RSSI >= −109 dBm, Acceptable with RSSI <= −110 dBm and RSSI >= −113 dBm, Poor with RSSI <= −114 dBm and RSSI >= −116 dBm, and Very Poor with RSSI <= −117 dBm. Each sub-district visualized in the spatial layout has a boundary or sub-district boundary based on latitude and longitude coordinates, as well as the distribution of the height of each building presented in Figure 7.

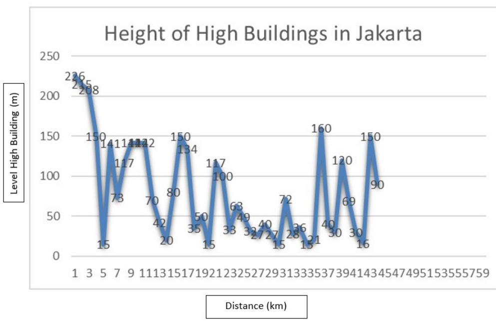

FIGURE 7. Height distribution of high buildings in Jakarta.

Figure 7 visualizes the height range of buildings in 44 sub-districts in Jakarta, with a minimum height of 15 m and a maximum above 200 m, which affects the distribution of LoRaWAN gateway signals. The height level of the building is high compared to the elevation found in the Jakarta area, as shown in Figure 8.

The distribution of coordinate points from the location of the LoRaWAN gateway with the case study of Menara Multimedia based on data from latitude_dt parameters and longtitude_dt taken during the driving test in the Gambir sub-district in Jakarta is shown in Figure 8. At the time of the driving test with the Multimedia Tower as the LoRaWAN gateway center, several parameters were generated to support further research, such as RSSI, SNR, and altitude. These parameters greatly affect the quality of the coverage status recorded on the test drive device. Signal strength based on the coverage status of the LoRaWAN gateway can also be identified through the RSSI value generated. The correlation between each variable that affects the signal strength of the LoRaWAN gateway is presented in Figure 9 in the form of a heat map.

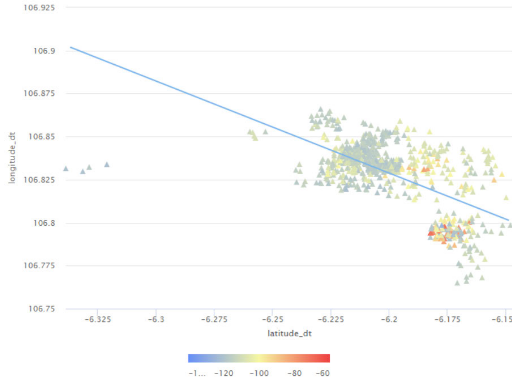

FIGURE 8. Gateway locations.

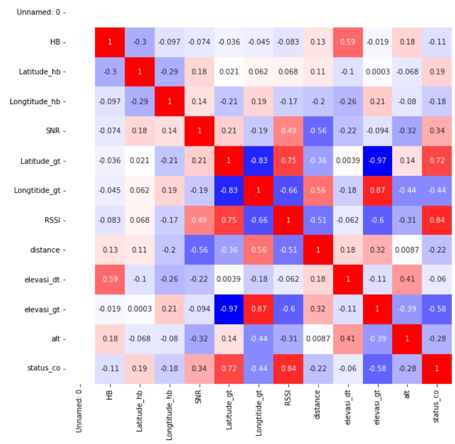

FIGURE 9. Correlation variable.

Figure 9 depicts a heatmap that illustrates the correlation of dependent and independent variables based on the outcomes of drive tests conducted in the vicinity of the multimedia building. The correlation of variables generated through the heatmap shows that the RSSI value that is highly related to the status of coverage (status_co parameter in the dataset) has a value of 0.84%. The dataset related to the LoRaWAN gateway site was re-studied in order to find the right method to optimize the placement of the LoRaWAN gateway with a case study in this Jakarta area. Based on the testing process by implementing the linear regression method, it is known that the height level of buildings in the Jakarta area that became a case study in this study was directly proportional to the RSSI and elevation of the LoRaWAN gateway. The results of testing with the linear regression method are represented in Figure 10.

Tests that implement the linear regression method against datasets related to LoRaWAN drive test gateway results with the test center located in the multimedia building can be seen in 10. Based on 10, it can be stated that the height of the building is directly proportional to the RSSI value along with

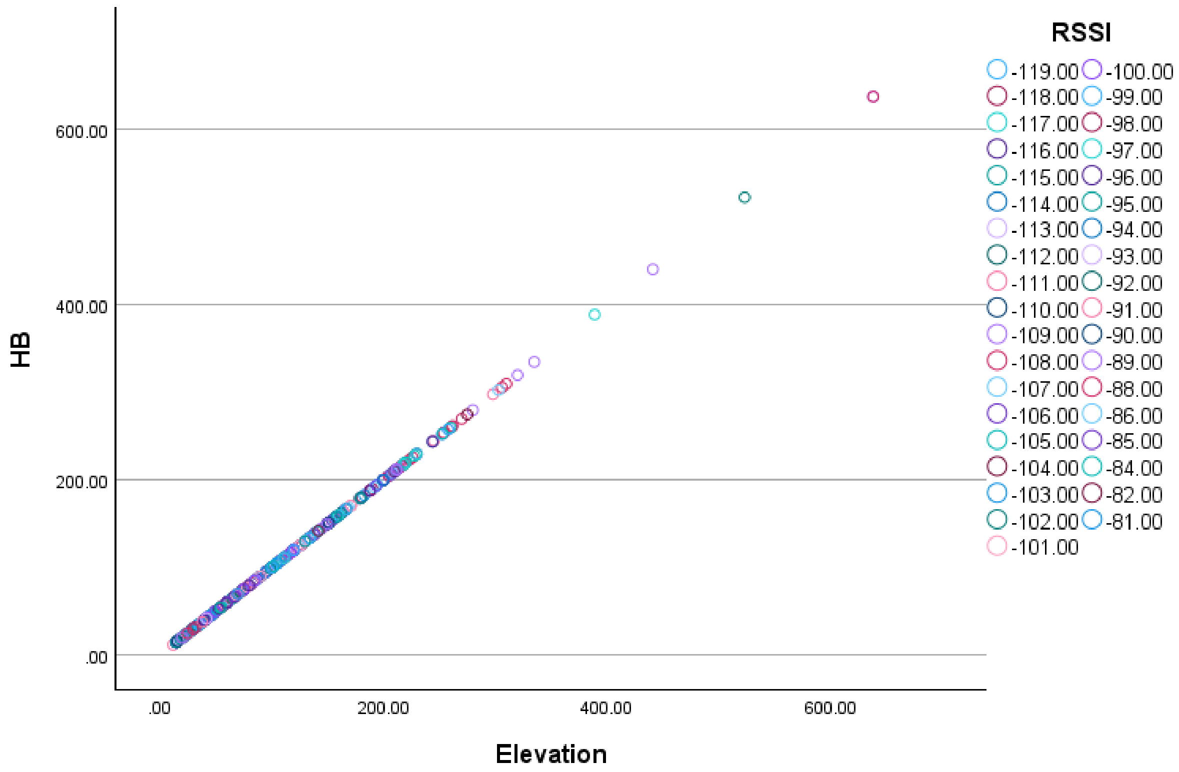

FIGURE 10. Dataset test result with linear regression method.

the elevation of the LoRaWAN gateway. The signal quality of the LoRaWAN gateway also depends on the environmental conditions around the gateway site. The more obstacles there are in an area, the signal quality will decrease. Conversely, the fewer or no obstacles in an area, the better the signal quality it has. There are many factors that contribute to the signal quality of the LoRaWAN gateway, as well as the tests carried out in this study. Therefore, this study again conducted testing by implementing other methods in order to provide good prediction and accuracy results from the tests run.

Based on data related point gateway in Jakarta more than 100 points. More than 100 gateway points in Jakarta, this study took 23 gateway points corresponding to the Menteng path area visualized in figure 2. In 44 sub-districts, in Step 4, data analysis was carried out on as many as 753 records for samples of Gambir District, in Jakarta, with the binary logistic regression method, which produced a formula to determine the correlation between variables (in this research, they are referred to as predictors) [8], such as RSSI, SNR, alt, distance (d), elevasi_gt, and building height above 15 meters (HB). So based on a study for capacity calculation to determine the correlation of new variables in this study, the effect of building height distribution and gt elevation on the LoRAWAN status coverage (status_co) category is studied to determine whether it has a relationship with independent variables in the form of elevation from the drive test point and elevation from the gateway position, as well as the distribution of the height of the building where the LoRaWAN gateway is installed at the location. The first step to executing test data is to implement the binary logistic regression method with the six continuous predictors. This study tests the probability of signal coverage based on the dominant signal coverage status, which is then categorized based on the level of RSSI signal status_co (code 0 = very poor and poor and code 1 = excellent, good, and acceptable).

Y	X1	X2	X3	X4	X5	X6	X7
4.00	-104.00	-10.50	60.00	60.00	5.60	60.00	1.00
4.00	-107.00	-.20	45.00	45.00	5.60	45.00	1.00
4.00	-106.00	-6.50	90.00	90.00	5.60	90.00	1.00
4.00	-101.00	-3.50	78.00	78.00	5.60	78.00	1.00
4.00	-102.00	-3.50	99.00	99.00	5.60	99.00	1.00
4.00	-109.00	-2.50	97.00	97.00	5.60	97.00	1.00
4.00	-109.00	-14.00	84.00	84.00	5.60	84.00	1.00
4.00	-109.00	-12.80	30.00	30.00	5.60	30.00	1.00
3.00	-111.00	-13.00	59.00	59.00	5.60	59.00	1.00

FIGURE 11. Testing of LoRaWAN dataset on SPSS.

In Figure 11, a sample record of LoRaWAN test data used in this study is presented. The sample data contains Y (status_co), X1 (RSSI), X2 (SNR), X3 (alt), X4 (distance), X5 (elevation), X6 (height building), and X7 (code coverage). The binary logistic regression method used in this study produces various models that can be used for consideration in research results, namely omnibus tests of model coefficients and model summaries with Hosmer and Lemeshow tests.

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	977.853	46	<.001
	Block	977.853	46	<.001
	Model	977.853	46	<.001

FIGURE 12. **Omnibus test results based on LoRaWAN test data.**

The model used in this study produces omnibus tests of model coefficients, which test the suitability of relatively significant models. The results of this Chi-square test resulted in an intercept of X2(46) = 977.853, p <.001. The results of the Chi-square test can be seen in Figure 12. Then, in Figure 13, a regression model with a -2 log-likelihood is explained, which is used to assess the suitability of the model carried out by the hypothesis and whether it is appropriate or not following the test data used with a coefficient value of −2 log-likelihood of 36.348a, Cox & Snell Square 0.727, and Nagelkerje R Square 0.983.

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	36.348[a]	.727	.983

FIGURE 13. **Results of the LoRaWAN testing data model summary.**

A second fit test is conducted based on the Hosmer and Lemeshow tests to evaluate whether the model has achieved the best goodness of fit. This test helps determine the extent to which the data model is matched. The results of the Hosmer and Lemeshow tests produce statistical values and p-values that are interrelated. If the p-value is greater than the specified significant level, then there is no evidence to reject the hypothesis, which means that the model has a match with the test data and the opposite is true. So the results of Figure 14 state whether the research matched the test data.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	.519	8	1.000

FIGURE 14. **Hosmer and Lemeshor testing results based on LoRaWAN test data.**

Tests that implement the Binary Logistic Regression method also show contingencies from the Hosmer and Lemeshow Test on the categorized status_co parameter (code 0 = very poor and poor and code 1 = excellent, good, and acceptable) to provide evidence of errors that may occur during model specification (see Figure 15).

Contingency Table for Hosmer and Lemeshow Test

		Code Coverage = .00		Code Coverage = 1.00		
		Observed	Expected	Observed	Expected	Total
Step 1	1	75	75.000	0	.000	75
	2	75	75.000	0	.000	75
	3	75	74.998	0	.002	75
	4	72	72.806	3	2.194	75
	5	5	4.162	70	70.838	75
	6	0	.034	75	74.966	75
	7	0	.000	75	75.000	75
	8	0	.000	75	75.000	75
	9	0	.000	75	75.000	75
	10	0	.000	78	78.000	78

FIGURE 15. **Contingency Table for Hosmer and Lemeshow test.**

Based on the contingency values shown in Figure 15, the classification of test data that provides additional information to assess how well the model formulation fits is shown in Figure 16. The classification results obtained can help in determining how far predictions can be observed to review correlation variables, and the overall percentage obtained based on this model is 99.3%. Thus, the percentage result shows that the result of the observed correlation variable is predicted correctly. Conducting experiments with LoRaWAN in intricate settings necessitates the widespread adoption of digital smart meters in every household. Examples of such environments may encompass areas characterized by skyscrapers, undulating topography, or significant levels of electromagnetic interference for improvement in future research quality.

Classification Table[a]

			Predicted		
			Code Coverage		Percentage Correct
	Observed		.00	1.00	
Step 1	Code Coverage	.00	300	2	99.3
		1.00	3	448	99.3
	Overall Percentage				99.3

a. The cut value is .500

FIGURE 16. **Classification table results.**

V. CONCLUSION

Using the Multimedia scenario from many gateways in Jakarta because Multimedia buildings have many obstacles to this visualization, this research develops a formula for analyzing the correlation between LoRaWAN data variables (RSSI, SNR, altitude, distance, gateway, and so on) in Jakarta, emphasizing Gambir. The LoRaWAN connection and coverage in open spaces are the primary focus areas for this investigation. A transportable measurement equipment showed an average RSSI performance of -127 dB to 60 dB with a signal-to-noise ratio of 7 dB, according to the data acquired by the instrument. The status categories of Excellent, Acceptable, Good, Fair, and Very Poor are decided when the signal strength is considered. The constructed model has an accuracy of 99.3 % with an error rate of 0.7% for status prediction, and it can serve as a reference for the development of urban LoRaWAN. The potential limitations of the experimental research in this study pertain to generalization. The researchers conducted drive tests at more than 100 gateway points in Jakarta, which varied in elevation and exhibited high complexity. However, this study primarily focuses on the Menteng area, precisely 23 LoRaWAN gateway points. This is because of time limitations associated with deploying a pilot project involving digital smart meters for households between PT. Y and PT. P, both industrial companies in their respective fields are controlled by the same parent company that uses LoRaWAN technologies. These outcomes will serve as a benchmark for implementation in Jakarta and other regions. This research can be a significant policy guide for infrastructure development in urban areas beyond the particularÂ locale.

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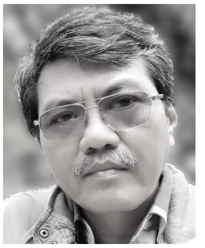

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