Study of DVB-T2 Broadcasting in Tropical Environments: Comparative Empirical Propagation and QoS-QoE Spatial Analysis

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ABSTRACT

This study analyzes the performance of DVB-T2 broadcasting in tropical urban environments by comparing propagation models and examining the relationships between Quality of Service (QoS) and Quality of Experience (QoE). Field strength data from Okumura-Hatta, Longley-Rice, and ITU-R P.1546 models were assessed across 52 locations in Semarang, Indonesia. Statistical analysis shows that ITU-R P.1546 provides the highest average signal strength, while Okumura-Hatta exhibits the lowest variability, indicating more stable predictions. The results show that the ITU-R P.1546 model produces the highest average field strength (88.32 dBμV/m), while the Okumura-Hatta model demonstrates the lowest variability, indicating more consistent predictions. Geographic Information System (GIS)-based analysis reveals that the spatial distribution of field strength and QoE is positively correlated between field strength and MOS, with 52 respondents. Areas with strong signal levels (>120 dBμV/m) exhibit high Mean Opinion Score (MOS) values (>4.5). GIS-based spatial analysis further confirms that areas with higher signal levels correspond to higher user-perceived quality. These findings highlight the importance of integrating statistical and spatial analysis for DVB-T2 network evaluation and optimization in tropical environments.

Keywords-DVB-T2; GIS; propagation models; QoS; QoE

I. INTRODUCTION

The transition from analog to digital broadcasting systems has driven technological advancements toward more efficient digital standards. One of the most widely adopted standards is Digital Video Broadcasting–Second Generation Terrestrial (DVB-T2). DVB-T2 is chosen for its high spectral efficiency, robustness against multipath interference, and ability to deliver high-quality video and audio [1, 2]. However, implementing DVB-T2 presents significant challenges, particularly regarding broadcast coverage and service quality in regions with tropical climates, such as Semarang City, Indonesia. The performance of the DVB-T2 system in tropical regions poses unique challenges. Environmental factors such as high humidity, heavy rainfall, dense vegetation, and irregular terrain morphology can cause signal attenuation, multipath fading, and reduced coverage quality compared to temperate regions.

Signal propagation in digital television broadcasting is influenced by factors such as topography, population density, air humidity, and rainfall. Path loss calculation in propagation models plays a crucial role in DVB-T2 network planning [3-6]. Therefore, it is essential to validate empirical propagation models such as Okumura-Hatta, Longley-Rice, COST-231, and ITU-R P.1546, which were generally developed under non-tropical environmental conditions. This highlights the importance of field measurement-based studies and comprehensive analyses comparing theoretical model predictions with actual measurements. Furthermore, the quality of digital TV broadcasting is determined not only by technical Quality of Service (QoS) indicators but also by Quality of Experience (QoE). QoE represents the perceived QoS. Authors in [7] demonstrated that increases in field strength and Carrier-to-Noise ratio (C/N) positively influence users' perceived quality. Comparative studies on suitable propagation models for DVB-T2, such as those presented in [8-11], have been conducted; however, only a few have explored the relationship between propagation models, QoS, and QoE.

However, QoE measurements are still rarely integrated with QoS assessments, even though this integration is crucial for understanding the relationship between QoS and QoE parameters within a given area. The integration of QoS and QoE measurements can be achieved through a spatial analysis approach based on the Geographic Information System (GIS), enabling a better understanding of coverage reliability and the optimization of DVB-T2 implementation strategies in tropical environments [7, 12].

The novelty of this work lies in the simultaneous integration of three analytical dimensions: a comparative statistical evaluation of propagation models (Okumura-Hatta, Longley-Rice, and ITU-R P.1546) using measurement data obtained in tropical environments to evaluate the prediction accuracy of DVB-T2 broadcast coverage; an assessment of the accuracy and suitability of each empirical propagation model using measurement data specific to tropical regions; and quantitative QoS–QoE correlation modeling and GIS-based spatial analysis to capture the geographical dependency of user experience.

Furthermore, this study provides new insights into DVB-T2 performance in tropical environments, which are often characterized by complex terrain, high humidity, and dense urban structures, conditions that are not fully represented in conventional propagation model studies.

II. QUALITY OF SERVICE PARAMETERS

The performance of the DVB-T2 digital broadcasting system is influenced by the quality of technical parameters that represent signal propagation conditions. In the DVB-T2 system, QoS parameters play a crucial role in ensuring stable reception, image clarity, and overall service quality [13]. In this study, QoS is evaluated based on field strength values. Field strength refers to the intensity of the electric field of electromagnetic waves received by the receiving antenna at a specific point. The higher the field strength value, the stronger the received signal power. Field strength measurements were conducted using a field strength meter, and the collected data were then used to validate the applied propagation models. In addition, these data served as the basis for GIS-based signal coverage analysis (coverage mapping). Propagation models for broadcasting are generally categorized into three types: empirical, semi-empirical, and deterministic methods [14].

A. Okumura-Hatta Propagation Model

The Okumura-Hatta model is an empirical propagation model used to estimate path loss at frequencies ranging from 150 to 1500 MHz over distances of 1-20 km [15, 16]. Although this model does not account for environmental parameters in detail, it provides a reasonably accurate estimation of path loss.

The Okumura-Hatta method is given by :

$$E = 69.82 - 6.16 log f + 13.82 \log H_1 + a(H_2) - (44.9 - 6.55 \log H_1) * (\log d)^2 \quad (1)$$

where E is the field strength (dB(μV/m)) for 1 kW transmission, H_1 is the effective base station antenna height above ground (30-200 m), and H_2 is the mobile station antenna height above ground (1-10 m).

$$a(H_2): (1.1\ log\, f - 0.7)H_2 - (1.56 \log f - 0.8) \quad (2)$$

This recommendation provides results comparable to the Okumura–Hatta method for distances up to 10 km, $h_2 = H_2 = 1.5\ m, R = 1.5$.

B. Longley-Rice Propagation Model

The Longley-Rice propagation model is one of the propagation models commonly applied in terrestrial communication systems such as DVB-T2 due to its ability to account for the effects of topography, atmospheric conditions, and ground surface characteristics. This model is designed to predict path loss within the frequency range of 20 MHz-20 GHz and for transmission distances between 1 and 2000 km [17, 18]. Total pathloss pada Longley-Rice is given by:

$$L_t = L_b + A_t + A_s + A_g \quad (3)$$

and free space loss is given by:

$$L_b = 32.45 + 20\ log\, f + 20\ log\, d \quad (4)$$

Longley-Rice to calculate field strength predictions in the receiver is given by:

$$E = 106.9 - L_t + G_t + G_r \quad (5)$$

where :

L_t : Total path-loss (dB)
L_b : Free space basic transmission loss (dB)
A_t :Terrain-dependent loss (dB)
A_s : Scattering loss (dB)
A_g : Anomalous propagation (dB)
f : Frequency (MHz)
d : distance of transmitter to receiver (km)
G_t : Gain antenna TX(dBi)
G_r : Gain antenna RX (dBi)

C. ITU-R P.1546 Propagation Model

The ITU-R P.1546 model, proposed by ITU-R, is an empirical propagation model for radio and television broadcasting systems operating in the 30–3,000 MHz range and distances up to 1,000 km [1, 19]. It estimates the median field strength at the receiver location. Unlike the Longley–Rice model, which is based on terrain analysis, P.1546 is derived from extensive field measurements across various regions, making it suitable for broadcast coverage planning and macro-scale telecommunication design. The median field strength *(E)* at a given distance is calculated using the ITU-R P.1546 propagation model, as expressed in:

$$E = E_{50,50}(d, f, h_t, h_r) + \Delta E_{env} + \Delta E_{time} + \Delta E_{location} \quad (6)$$

The path loss can be calculated using the equation relating the Effective Isotropic Radiated Power (EIRP) to the electric field strength:

$$L_p = 139.3 + 20\log f - E + 10\log P_t + G_t \quad (7)$$

$$L_p = EIRP + 106.9 - E \quad (8)$$

where L_p is the pathloss (dB) and E is the field strength (dBμV/m).

D. Quality of Experience and Mean Opinion Score

QoE is a parameter that describes the level of user satisfaction with a communication service. A total of 52 respondents participated in the study, with each respondent corresponding to one measurement point. Respondents were asked to evaluate the perceived quality of DVB-T2 reception, including image clarity, signal stability, and overall viewing experience. In this study, the factors influencing QoE are divided into three main aspects: the Mean Opinion Score (MOS), the audio quality score, and the user experience aspect. MOS is a quantitative method for measuring QoE based on users' subjective assessments of service quality. The MOS scale used in this study consists of five levels: bad, poor, fair, good, and excellent.

The MOS value is obtained by involving the number of respondents, with the average score calculated using:

$$MOS = \frac{1}{N}\sum_{i=1}^{N} S_i \quad (9)$$

where N represents the total number of respondents, and S_i denotes the individual score assigned by the i-th respondent. This research proposes and evaluates the most suitable radio wave propagation model for tropical and high-humidity environments, where signal attenuation and multipath effects are significantly pronounced. Three widely used propagation models, namely Okumura-Hata, Longley-Rice, and ITU-R P.1546, are systematically compared to assess their applicability and predictive accuracy under the environmental conditions considered.

In addition to the physical-layer evaluation, user satisfaction, expressed as QoE, is quantified through structured questionnaires and direct surveys conducted with end-users on perceived signal quality, stability, and overall service reliability. The measured QoS parameters are then statistically correlated with the corresponding QoE results to investigate and validate the relationship between objective network performance metrics and subjective user perception.

The combined analysis of QoS and QoE provides a comprehensive framework for assessing overall service quality and identifying the most appropriate propagation model for realistic deployment scenarios. The measurement parameters and evaluation metrics used in this study are summarized in Table I, which serves as the basis for subsequent comparative analysis and model validation.

TABLE I. ENVIRONMENTAL PARAMETERS

Variable	Value
	Parameter of the transmitter and receiver
Coordinate	-7.0455 LS, 110.4259 BT
Address	Jl. Bukit Puncak No.1, Ngesrep, Kec. Banyumanik, Kota Semarang, Jawa Tengah 50261
TX tower high	125 m
Frequency	570 MHz
Power transmitter	7, 25 KWatt
Panel antenna	8 panel
TX antenna gain	17 dBi
TX loss feeder	1.7 dB
Antenna polarisation	Horizontal
Feeder cable	70 m
RX antenna gain	12 dB
RX loss feeder	2 dB
RX C/N ratio	20 dB
RX tower high	3 m

III. SYSTEM MODEL OF RESEARCH

The DVB-T2 system model analyzed in this research is based on a Single Frequency Network (SFN) architecture operating in the UHF band. The propagation channel in tropical regions is influenced by high humidity, heavy rainfall, dense vegetation, irregular topography, and urban building structures. The QoS parameter analyzed is field strength, while the QoE parameter is derived from survey results using the MOS scale. The mapping function is illustrated using a GIS to visualize the spatial relationship between QoS and QoE. The research stages are presented in Figure 1. The study was carried out in a structured manner to evaluate the performance of a DVB-T2 digital broadcasting system. Field strength data were collected at 52 measurement locations and analyzed using three commonly used empirical propagation models: Okumura-Hatta, Longley-Rice, and ITU-R P.1546. These models were compared based on their ability to represent actual field conditions through field strength analysis. In addition, QoE was assessed through user surveys involving questionnaires, interviews, and direct observations. The results from signal measurements and user evaluations were jointly analyzed to identify the relationship between signal quality and user experience. The findings provide technical insights into the most appropriate empirical propagation model for tropical environments and contribute to a better understanding of DVB-T2 performance from both technical and user perspectives.

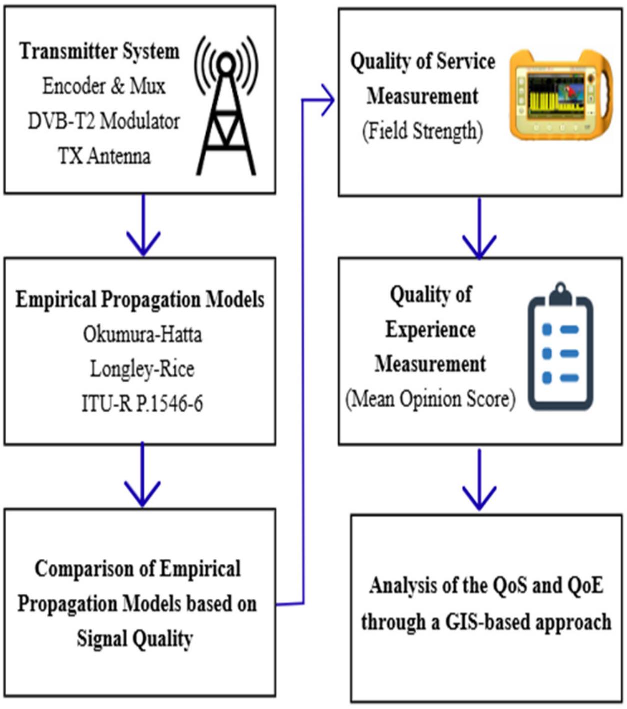

Fig. 1. System model.

IV. PERFORMANCE EVALUATION AND EMPIRICAL RESULTS

This section presents a comparative statistical analysis of the propagation models to evaluate their performance characteristics in predicting DVB-T2 field strength in tropical urban environments. The analysis focuses on key statistical indicators, including mean, standard deviation, and coefficient of variation, to assess both the central tendency and variability of each model.

A. Comparative Statistical Analysis of Propagation Models

A comparative statistical analysis was conducted to evaluate the characteristics of the three propagation models, namely ITU-R P.1546, Okumura-Hatta, and Longley-Rice, based on predicted field strength values across 52 sampling locations. The analysis focuses on the mean, standard deviation, and Coefficient of Variation (CV) to assess the general behavior, stability, and relative dispersion of each model, as presented in Table II.

TABLE II. AVERAGE SIGNAL QUALITY VALUE FOR EMPIRICAL PROPAGATION MODELS

	Okumura-Hatta	**ITU-R P.1546-6**	**Longley-Rice**
Field strength (dBµV/m)	75,603	88,317	86,944
Attenuation (dB)	142,042	17,796	19,97
Free space loss (dB)	-	108,134	108,134

TABLE III. STATISTICAL COMPARISON OF PROPAGATION MODELS USING STANDARD DEVIATION AND CV

Model	**Mean (dBµV/m)**	**Std Dev (dBµV/m)**	**CV**
ITU-R P.1546	88,32	17,88	0,2024
Okumura Hatta	75,60	11,42	0,1510
Longley-Rice	86,94	24,76	0,2848

The results show that the ITU-R P.1546 model yields the highest average field strength of 88.32 dBµV/m, followed by the Longley-Rice model at 86.94 dBµV/m and the Okumura-Hatta model at 75.60 dBµV/m. This indicates that the ITU-R and Longley-Rice models tend to provide more optimistic predictions of signal coverage, whereas the Okumura-Hatta model yields more conservative estimates.

A comparative statistical analysis was conducted to evaluate the characteristics of the three propagation models. The mean field strength values indicate that the ITU-R P.1546 model tends to produce higher signal predictions than the Okumura-Hatta and Longley-Rice models, suggesting a more optimistic estimate of coverage. The standard deviation was used to assess the variability of each model. The results show that the Okumura-Hatta model exhibits lower standard deviation, indicating more stable predictions across different measurement locations. In contrast, the Longley-Rice model demonstrates higher variability, reflecting its sensitivity to environmental and terrain conditions.

To further evaluate the relative dispersion, the CV was calculated. The results indicate that the ITU-R model achieves a balanced trade-off between signal strength and variability, while Okumura-Hatta provides the most consistent predictions. Spatial analysis reveals that the distribution pattern of ITU-R predictions aligns more closely with the observed QoE (MOS) distribution, suggesting that this model better captures the spatial behavior of signal propagation in tropical urban environments.

In terms of variability, the Okumura-Hatta model exhibits the lowest standard deviation (11.42 dBµV/m), indicating more consistent predictions across different locations. In contrast, the Longley-Rice model shows the highest variability (24.76 dBµV/m), suggesting higher sensitivity to environmental factors such as terrain irregularities and propagation conditions. The ITU-R model presents moderate variability with a standard deviation of 17.88 dBµV/m. In terms of variability, the Okumura-Hatta model exhibits the lowest standard deviation (11.42 dBµV/m), indicating more consistent predictions across different locations. In contrast, the Longley-Rice model shows the highest variability (24.76 dBµV/m), suggesting higher sensitivity to environmental factors such as terrain irregularities and propagation conditions. The ITU-R model presents moderate variability with a standard deviation of 17.88 dBµV/m.

B. Field Strength Distribution

Based on the measurement data from 52 test points, the distribution results are illustrated in Figure 2. The color of each point represents the field strength value, with purple indicating the lowest field strength and yellow representing the highest. Additionally, the size of each circle is proportional to the field strength; the larger the circle, the stronger the signal. The highest signal strength is observed around the coordinates of longitude 110.4 and latitude –7.05. Moving away from this central point, the colors transition to green and blue, indicating a gradual decrease in field strength. This reduction suggests that the transmitter station is located near the center of the distribution. The lowest field strength values are likely due to topographical obstructions, such as hilly terrain, which affect signal propagation.

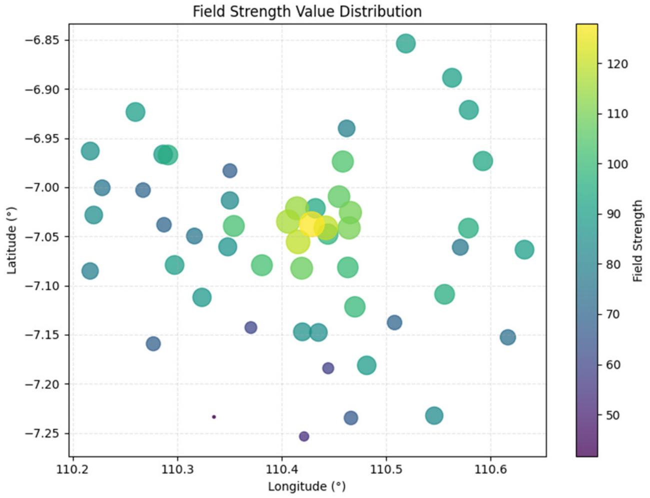

Fig. 2. Field strength distribution.

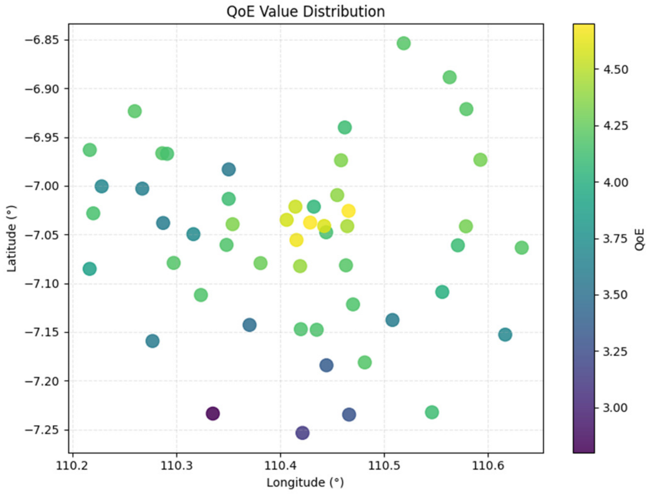

Fig. 3. QoE distribution.

C. Quality of Experience Distribution

QoE represents the spatial distribution pattern of user satisfaction levels with the service in each area. The distribution illustrates the spread of MOS values across various measurement points, reflecting users' perceived quality of the service they received. Figure 3 illustrates a GIS-based map showing the spatial distribution of QoE values, with yellow indicating the highest QoE levels and purple the lowest. The highest QoE values are observed around the coordinates of longitude 110.4 and latitude –7.05, which correspond to the area with the highest field strength. This indicates that higher signal strength leads to better QoE. Compared with the field strength map, the QoE distribution pattern shows strong similarity. The QoE values are the highest in the central region and decrease with distance from the center, indicating that QoE is directly proportional to signal quality.

D. QoS-QoE Spatial Correlation

The QoS–QoE spatial correlation represents the relationship between the technical parameters of a digital television broadcasting system and the level of user perception within a specific area. To investigate the relationship between QoS and QoE, a combined spatial and statistical analysis was conducted using field strength as the QoS parameter and MOS as the QoE indicator. To quantitatively validate this relationship, Pearson correlation analysis was performed between field strength and MOS values across all sampling points. The result shows a strong positive correlation, with an R coefficient of 0.942, indicating a high degree of linear dependence between QoS and QoE. This implies that improvements in signal strength are strongly associated with enhanced user experience in DVB-T2 broadcasting systems.

This analysis aims to determine the extent to which the physical network parameters influence the MOS, as illustrated geographically.

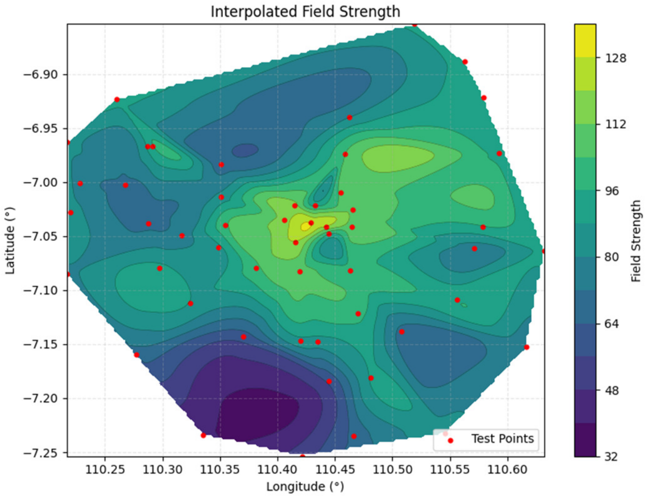

Fig. 4. Interpolated field strength.

Figure 4 displays the interpolated distribution of field strength values across the measurement area, providing a visualization of signal propagation and coverage quality. The red points represent the measurement locations, while the color gradient illustrates the field strength values in dBμV/m. The interpolation results reveal a signal distribution pattern, in which the highest field strength, 125 dBμV/m, is located at coordinates 110.4° longitude and –7.05° latitude.

As the distance from the central area increases, the field strength gradually decreases to approximately 80–100 dBμV/m, indicated by green coloration. In this region, the coverage quality remains relatively good, although signal stability is slightly lower. The results demonstrate that field strength can serve as a reliable technical indicator for predicting QoE. However, environmental propagation factors and channel quality continue to play a significant role in determining overall service quality.

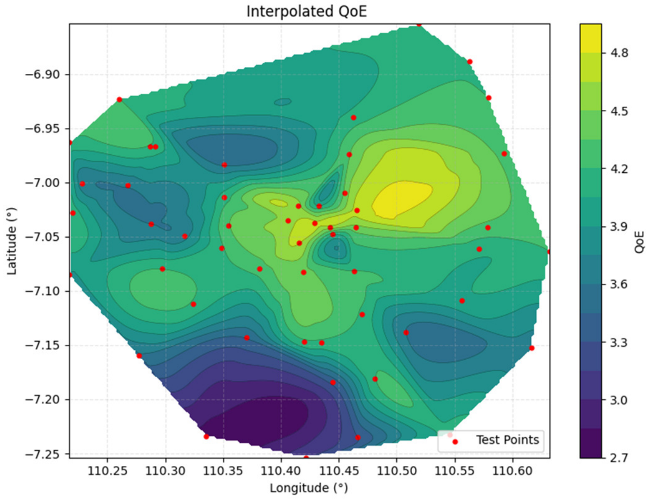

Fig. 5. Interpolated QoE.

Figure 5 presents the spatial interpolation of QoE values. The results are generally consistent with the field strength interpolation pattern. Areas with strong signal strength exhibit QoE values above 4.5, whereas southern regions experience the weakest signal, with QoE values being below 3 and field strength levels under 68 dBμV/m. This indicates that a decrease in signal power directly affects user service quality. However, some locations still demonstrate good QoE values (>4) despite having moderate field strength levels.

The interpolation results reveal that the QoE distribution across the study area exhibits heterogeneous characteristics. Regions close to the transmitter show very high user experience quality, whereas peripheral areas (particularly the southern side) display lower QoE levels. Technical parameters do not solely determine QoE values but are also influenced by environmental propagation conditions. Spatial analysis is based on interpolation results; thus, it serves as an essential tool for network planning and developing strategies to improve service quality.

From a spatial perspective, the GIS-based visualization reveals a consistent clustering pattern, with areas of high field strength spatially aligned with regions of high MOS values. This spatial agreement further reinforces the statistical findings and confirms a strong QoS–QoE dependency in the observed DVB-T2 network.

V. CONCLUSION

This study presents an empirical investigation of DVB-T2 broadcasting performance in tropical environments by integrating analyses of various propagation models to identify the most suitable one. Field measurement results indicate that the distribution of field strength in tropical regions is strongly influenced by environmental factors such as high humidity, dense vegetation, and complex topography. Among the three propagation models evaluated, the ITU-R P.1546 model demonstrated the best predictive performance with the highest agreement to field measurement data, making it the most appropriate model for estimating DVB-T2 coverage in tropical regions. The Geographic Information System (GIS)-based spatial analysis provides a visualization of the spatial correlation between Quality of Service (QoS) and Quality of Experience (QoE). Areas with strong signal strength exhibit high Mean Opinion Score (MOS) values. In contrast, southern regions with weaker signal levels show lower QoE, emphasizing the direct relationship between technical parameters and user-perceived service quality.

DECLARATION OF COMPETING INTERESTS

The authors declare no competing interests.

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DATA AVAILABILITY

The data used in this study were obtained from original simulations, analytical calculations, and direct surveys conducted with respondents.

AI USE AND DECLARATION OF GENERATIVE AI USE

In this research, AI was only utilized to explore several correlation algorithms between variables and to learn the fundamentals of programming. AI was not used in the writing process of this article.

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