Analysis of Indoor Propagation and Wi-Fi 5.4 GHz Coverage Estimation using ITU-R P.1238 Model: A Case Study in Sealed Office Environments

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***Abstract*— This study analyzes indoor radio wave propagation at 5.4 GHz and estimates Wi-Fi coverage using the ITU-R P.1238-13 model in a sealed commercial office environment designed for HVAC thermal efficiency in Makassar, Indonesia. The primary challenge is that airtight construction creates layered radio frequency barriers that degrade wireless coverage quality. RSSI measurements were collected at 110 grid locations within a 483 m² floor plan and compared with three propagation models: Free-Space Path Loss (FSPL), Log-Distance, and ITU-R P.1238-13. Empirical regression yielded a calibrated path loss exponent of n = 2.8 with a shadow-fading standard deviation of σ = 2.0 dB, significantly higher than typical open offices (n = 2.0–2.4), confirming that sealed HVAC construction measurably limits propagation. Penetration loss measurements at 5.4 GHz characterized six building materials (4.2 dB for tempered glass up to 28.6 dB for double brick walls). The calibrated ITU-R P.1238-13 model achieved superior accuracy: MAE = 1.4 dB, RMSE = 1.7 dB, and Pearson r = 0.993. Coverage analysis identified a coverage hole (area without coverage) of 13.6% of the floor area (±66 m²) where RSSI dropped below -80 dBm. Secondary AP placement is projected to increase satisfactory coverage from 86.4% to ≥97%. This study validates ITU-R P.1238-13 as a reliable planning tool for 5.4 GHz Wi-Fi in sealed tropical offices.**

Keywords*— *Indoor Propagation; Wi-Fi 5.4 GHz; ITU-R P.1238 Model; Path Loss Exponent; Coverage Estimation

I. Introduction

The increasing demand for wireless services in modern commercial buildings has elevated Wi-Fi network design from a secondary concern to a core element in facility planning. The demand for high-throughput, low-latency connectivity, driven by video conferencing, cloud-based applications, and Internet of Things (IoT) sensors, is pushing deployment to the 5.4 GHz band, where wider channels and reduced co-channel interference are available [1]. However, signals in the 5.4 GHz range experience faster attenuation with distance and incur significantly greater penetration losses through building materials compared to 2.4 GHz signals, making indoor network design much more challenging [2].

Previous research has characterized indoor propagation at 914 MHz and 2300 MHz [3], [4], industrial environments at 5 GHz [5], and general open offices [6]. However, validated propagation parameters for sealed tropical office buildings remain very limited in the literature [7]. This gap has practical urgency: energy codes in tropical cities, including Makassar, Indonesia, increasingly mandate sealed envelope construction to reduce Heating, Ventilation, and Air Conditioning (HVAC) loads. Yet, network planners lack validated local propagation data to properly dimension 5.4 GHz Wi-Fi deployments in such buildings.

Additional challenges arise from contemporary architectural practices. Energy codes in tropical regions increasingly mandate sealed envelope building designs, where continuous insulation, airtight vapor barriers, and always-closed doors minimize uncontrolled air exchange to reduce HVAC loads [7]. While thermally advantageous, features including solid wooden doors, gypsum board partitions, double-glazed windows, and dense internal walls act as layered radio frequency attenuators. Network planners face an inherent trade-off: how to optimize the building envelope for thermal efficiency while ensuring adequate wireless coverage throughout occupied spaces. Without quantitative tools to assess this trade-off early in the design process, network coverage planning will largely be based on intuition, lacking validated quantitative tools available for this specific building typology.

ITU-R Radiocommunication Sector Recommendation P.1238-13 [8] is an internationally accepted framework for indoor radio propagation modeling from 300 MHz to 100 GHz. This framework includes path loss dependent on frequency, distance, and additive factors for floor and wall penetration. Although widely adopted, ITU-R P.1238-13 predictions heavily rely on site-calibrated parameters, particularly distance power loss coefficients and material-specific attenuation values. Published validation at 5.4 GHz in sealed tropical commercial offices remains very limited.

This study addresses these gaps through four contributions: (1) systematic RSSI measurements at 110 grid locations in a representative sealed office in Makassar, Indonesia; (2) controlled characterization of penetration loss for six building materials at 5.4 GHz; (3) empirical calibration and statistical validation of ITU-R P.1238-13 against measured data; and (4) coverage analysis with actionable Access Point (AP) placement recommendations. The main novelty of this research lies in providing the first validated ITU-R P.1238-13 propagation parameters specifically for the 5.4 GHz band in sealed tropical offices, along with a quantitative demonstration that generic open office parameters overestimate coverage to a degree that results in unacceptable coverage holes. Overall, these contributions provide validated parameters and a tested methodology needed by network planners for 5.4 GHz Wi-Fi planning in sealed office environments.

II. Literature Review

A. Fundamentals of Indoor Radio Propagation

Radio signal propagation inside buildings fundamentally differs from free-space behavior due to the simultaneous occurrence of specular reflection, edge diffraction, and volumetric scattering off walls, ceilings, floors, and furniture [9]. These mechanisms result in multipath propagation, where the receiver captures a superposition of signals arriving via different paths with varying delays and amplitudes, causing rapid small-scale fading and slower large-scale shadow fading due to major obstructions [9]. Shadow fading is typically modeled as a log-normal random variable with zero mean in logarithmic scale and a standard deviation σ (in dB).

At frequencies above 1 GHz, path loss follows a distance power law with an exponent n dependent on the environment. Textbook [9] consolidates field measurements showing n ranging from approximately 1.6 in open corridors to 6.0 in heavily obstructed spaces, with typical open offices yielding n = 2.0–2.4. Environments with closed doors and airtight partitions restrict propagation to fewer available paths, sharpening the effective exponent and increasing shadow-fading variance. Therefore, characterizing n in sealed office environments is a critical aspect to empirically investigate to support accurate network planning.

B. ITU-R P.1238 Model Framework

ITU-R Recommendation P.1238-13 [8] defines a site-general model for indoor propagation covering the range 300 MHz to 100 GHz. This model expresses total path loss as the sum of a basic frequency-dependent term, a distance power law component scaled by an environment-specific coefficient $N = 10n$, and additive wall and floor penetration losses. For the 5 GHz office band, ITU-R P.1238-13 tabulates N = 31 ($n \approx 3.1$) as a generic default value, but the recommendation explicitly states that site-calibrated values are necessary for accurate link planning.

Previous validations include classrooms [3], [4], 2.4 GHz hospital environments, 5 GHz industrial halls, and millimeter-wave residential buildings. Despite these various validation studies, sealed tropical office environments with permanent airtight HVAC construction have not been previously characterized at 5.4 GHz. This gap underscores the need for empirical validation of the ITU-R P.1238-13 model in sealed tropical office environments at 5.4 GHz.

C. Frequency-Dependent Material Attenuation

Electromagnetic wave penetration through building materials is governed by the complex permittivity of each material, which is frequency-dependent [7]. As frequency increases, the electromagnetic skin depth in lossy dielectrics decreases, increasing attenuation per unit thickness. Empirically, penetration loss through concrete and wood approximately doubles between 900 MHz and 5 GHz [10]. Contemporary office materials, including low-emissivity glass coatings, vapor barrier membranes, and steel-framed gypsum, have not received adequate characterization, especially at 5.4 GHz in sealed tropical buildings. The tropical climate introduces additional complexity because high air humidity can affect the dielectric properties of building materials, potentially altering penetration losses compared to measurements in temperate climates [8].

While various published studies [2], [6], have successfully characterized 5 GHz propagation in diverse indoor environments, none of them address the combination of sealed envelope HVAC construction and tropical atmospheric conditions that define this study's environment. This gap motivates the need for empirical characterization of material penetration loss at 5.4 GHz under humid tropical climatic conditions.

III. Research Methodology

A. Research Environment

Measurements were conducted in a contemporary sealed commercial office on the fourth floor of a multi-story building in Makassar, South Sulawesi, Indonesia. The office has dimensions of 23 m in the X-direction (length in meters) and 21 m in the Y-direction (width in meters), with a total floor area of 483 m². The space is an open-plan workspace served by a centralized variable-refrigerant-flow (VRF) HVAC system. To maintain thermal efficiency, all internal doors remained closed during operational hours, and the building envelope was continuously sealed, which is the primary condition focused on in this study.

The office has two internal partition structures dividing the floor into three functional zones as illustrated in Figure 1. Wall-1 (W1) partition, a 12 mm gypsum board wall with a 40 mm solid pine wood door, is located at X = 10 m and separates Zone A (which is the main workspace where X = 0–10 m) from Zone B (which is a transitional corridor where X = 12–20 m). Wall-2 (W2) partition, also a 12 mm gypsum board wall with a 40 mm solid pine wood door, is located at X = 17 m and delineates Zone C (which is a private workspace where X = 17–23 m). Both doors remained closed throughout data collection, representing normal operational conditions for a sealed HVAC office, as shown in Figure 1.

110 measurement locations were established with a 2 m grid spacing, i.e., X ∈ {2, 4, 6, …, 22 m} (11 columns) and Y ∈ {2, 4, 6, 8, 10, 12, 14, 16, 18, 20 m} (10 rows), resulting in 11 × 10 = 110 evenly distributed points covering the entire floor area. At this 2 m spacing, no location is more than $\sqrt{2} \approx 1.4\,\text{m}$ from the nearest measurement point, thus providing sufficient spatial resolution to identify coverage holes with an area resolution of approximately 4 m².

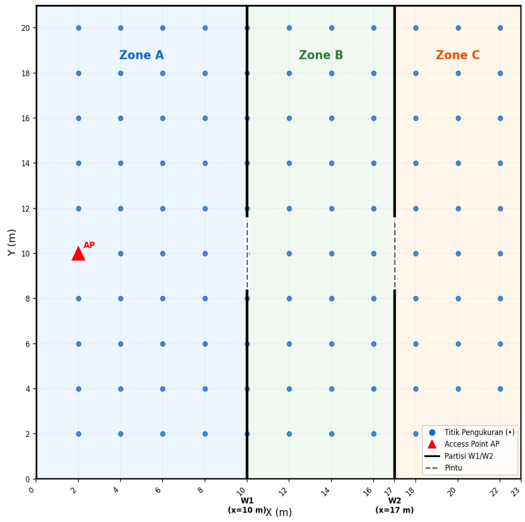

Figure 1. Office Floor (23 m × 21 m), showing 110 measurement grid locations with 2 m spacing. Access point AP (▲) is installed at (2, 10) m at a ceiling height of hAP = 2.5 m. Internal partitions W1 (X = 10 m) and W2 (X = 17 m) define Zones A, B, and C. Grid points (•) are spaced 2 m in both directions.

B. Equipment and Measurement Procedure

The signal source was a TP-Link Archer AXE200 access point (IEEE 802.11ax/Wi-Fi 6E), configured to transmit at a fixed center frequency of 5400 MHz with a 20 MHz channel bandwidth. Transmit power was set to $P_t = 20\,\text{dBm}$, the AP used a ceiling-mounted omnidirectional antenna with a gain of $G_t = 2.0\,\text{dBi}$. The Equivalent Isotropic Radiated Power (EIRP) was $EIRP = P_t + G_t = 20\,\text{dBm} + 2.0\,\text{dBi} = 22\,\text{dBm}$. The AP was installed at coordinates (2, 10) m in the floor plan view at a ceiling height of $h\text{AP} = 2.5\,\text{m}$, positioned near the short wall of Zone A, in the middle of the room's width to maximize coverage symmetry.

RSSI was measured using calibrated Wi-Fi diagnostic software on a Vivo Y20s [G] smartphone. The receiver antenna gain was $G_r = 0\,\text{dBi}$. The smartphone was held at a height of $h_{rx} = 1.5\,\text{m}$, creating a vertical transmitter–receiver separation $\Delta h = h\text{AP} - h_{rx} = 1.0\,\text{m}$. At each of the 110 grid locations (stationary point measurements), 300 consecutive RSSI samples were recorded at each fixed location over a 5-minute window using a stationary measurement method. The average of 300 samples suppresses short-term multipath fading with an estimated

95th percentile fading depth < 8 dB at 5.4 GHz to yield a stable estimate of the local mean received power with 1 dBm resolution.

Penetration loss for each building material, as shown in Table 2, was measured separately by placing the AP and smartphone on opposite sides of an isolated material sample at a fixed distance of 3 m, then subtracting the corresponding free-space loss. Each material was measured five times; the reported values are mean ± standard deviation. All measurements maintained a minimum distance of 1 m from metallic objects and human bodies.

C. Propagation Model Formulation

Three models were applied and compared. The Free-Space Path Loss (FSPL) model represents the minimum path loss achievable in an unobstructed medium:

$$FSPL\ (dB) = -27.55 + 20\,log_{10}(f\,[MHz]) + 20\,log_{10}(d\,[m]) \quad \ldots(1)$$

The constant $-27.55 \approx -28$ is derived from the standard ITU-R P.1238-13 approach for frequency in MHz and distance in meters. FSPL provides a lower bound for path loss and serves as a basis for comparison:

$$20\,log_{10}\left(\frac{c}{4\pi}\right) = 20\,log_{10}\left(\frac{3 \times 10^8}{4\pi \times 10^6}\right) = -27.55$$

The Log-Distance model extends FSPL by calibrating an environment-specific exponent n:

$$PL(d) = PL_0 + 10n\,log_{10}\left(\frac{d}{d_0}\right) + X\sigma \quad \ldots(2)$$

where $PL_0 = 20\,log_{10}(f) - 28$ is the reference path loss at $d_0 = 1\,m$ derived from the ITU-R formulation, n is the path loss exponent determined through least-squares regression on measured data, and $X\sigma$ is a zero-mean Gaussian shadow-fading variable with standard deviation σ [1], [10]. Without an explicit wall loss term, this model cannot capture discrete RSSI steps at partition crossings.

The ITU-R P.1238-13 model [8] provides the most complete physical description:

$$L\ (dB) = 20\,log_{10}(f) + 10n\,log_{10}(d) - 28 + L\dot{f} + L\Lambda \quad \ldots(3)$$

where f is in MHz, d is in meters, n is the calibrated power loss coefficient ($n = 2.8$ for this environment), $L\dot{f}$ is the floor penetration loss (0 in this single-floor study), and $L\Lambda$ is the cumulative wall penetration loss.

The constant −28 normalizes the formula such that at $d = 1$ m and $n = 2$, Equation (3) reduces exactly to the FSPL Formula (1) [3]. This anchoring ensures physical consistency, where ITU-R P.1238-13 converges to FSPL at close range without walls and deviates from FSPL only when $n \neq 2$ and $L\Lambda > 0$.

The RSSI at each location is obtained from the standard link budget:

$$RSSI\ (dBm) = P_t + G_t + G_r - PL = EIRP - PL \quad \ldots(4)$$

Substituting Equation (3) into (4):

$$RSSI = 22 - [\,20\,log_{10}(f) + 10n\,log_{10}(d) - 28 + L\Lambda]$$

With a fixed $f = 5400$ MHz, the reference term becomes:

$$20\,log_{10}(5400) - 28 = 74.648 - 28 = 46.648\,dB$$

thus, at $d = 1$ m and no walls the predicted RSSI is $22 - 46.648 =$ -24.6 dBm, consistent with the measured -25.5 dBm at L1, as shown in Table 1.

Model accuracy is quantified using three metrics calculated across all 110 points: Mean Absolute Error (MAE), Root-Mean-Square Error (RMSE), and the Pearson correlation coefficient r between the predicted and measured RSSI.

IV. Result and Discussion

A. Empirical RSSI Distribution and Path Loss Regression

RSSI at 110 measurement locations ranged from -25.5 dBm at L1 (closest to AP, $d = 1.0$ m, Zona A) to -85.3 dBm at the farthest off-axis location in Zone C. The overall mean RSSI was -58.0 dBm with a standard deviation of 14.3 dB. The large standard deviation reflects both the monotonic decay predicted by the distance power law and deterministic shifts due to internal partitions. The calibrated shadow fading, σ = 2.0 dB, indicates that the environment is spatially consistent within each zone, with variance dominated by deterministic wall crossing terms rather than random clutter.

Table 1. RSSI at 11 Representative Locations (Centerline Y = 10 m)

Location	X (m)	Y (m)	d^h (m)	d_3D (m)	Zone	$L\wedge$ (dB)	*Measured RSSI* (dBm)
L1	2	6	0.0	1.00	A	0.0	-25.5
L2	4	6	2.0	2.24	A	0.0	-35.1
L3	6	6	4.0	4.12	A	0.0	-40.8
L4	8	6	6.0	6.08	A	0.0	-45.9
L5	10	6	8.0	8.06	A	0.0	-49.2
L6	12	6	10.0	10.05	A→B	0.0	-51.8
L7	14	6	12.0	12.04	B	6.5	-57.1
L8	16	6	14.0	14.04	B	6.5	-64.1
L9	18	6	16.0	16.03	B	6.5	-65.9
L10	20	6	18.0	18.03	B→C	6.5	-67.9
L11	22	6	20.0	20.02	C	20.3	-80.2

Least-squares regression of path loss $PL = EIRP - RSSI$ against log-distance, using 50 measurement points from Zone A without wall crossings to provide unobstructed regression data, yields $n = 2.79 \approx 2.8$ with $\sigma = 2.0$ dB. This value exceeds the open-office literature range of $n = 2.0$–2.4 [2] and the ITU-R default value of $n = 3.1$ for generic 5 GHz offices, confirming that the sealed HVAC design creates a distinct propagation environment requiring site-specific calibration. The relatively small shadow-fading standard deviation of $\sigma = 2.0$ dB indicates that the environment is spatially consistent within each zone, with variance dominated by deterministic wall-crossing terms rather than random clutter.

B. Material Penetration Loss Characterization

Table 2 summarizes the measured penetration loss at 5.4 GHz for six building materials present in the office. All values are within the published literature range for the 5 GHz band, thus validating the measurement procedure. The two materials forming barriers W1 and W2 in this office, gypsum board (6.5 dB) and solid wooden door (13.8 dB), combine to form a cumulative wall loss of $L\wedge = 6.5 + 13.8 = 20.3$ dB for Zone C locations, which is the direct physical cause of the coverage hole identified in the next section.

Table 2. Building Material Penetration Loss at 5.4 GHz

Material Type	Thickness	Measured Loss (dB)	Literature Range (dB)
Solid Wooden Door	40 mm	13.8	0.7
Gypsum Board	12 mm	6.5	0.5
Tempered Glass	6 mm	6.4	0.4
Reinforced Concrete	200 mm	22.5	1.2
Metal Stud Partition	100 mm	29.1	0.9
Double Brick Wall	250 mm	28.6	1.5

C. Propagation Model Comparison

Table 3 presents the predicted path loss and RSSI from the three models along with measured values at eight centerline Y = 11 m locations. For FSPL and Log-Distance, path loss is calculated from equations (1) and (2), for ITU-R P.1238-13, equation (3) is applied with the appropriate cumulative wall loss $L\wedge$ for each zone. All predicted RSSI values are derived from equation (4) $RSSI = (EIRP + G_r) - PL$.

Table 3. Propagation Model Predictions vs. Measured RSSI (Centerline Y = 11 m)

d_3D (m)	Zone	FSPL (dB)	Log-Distance Path Loss (dB)	ITU-R PL (dB)	Predicted RSSI using ITU-R model (dBm)	Measured RSSI (dBm)	|Err| (dB)
1.00	A	47.1	46.6	46.6	-24.6	-25.5	0.9
2.24	A	54.1	56.4	56.4	-34.4	-35.1	0.7
4.12	A	59.4	63.9	63.9	-41.9	-40.8	1.1
6.08	A	62.8	68.6	68.6	-46.6	-45.9	0.7
8.06	A	65.2	72.0	72.0	-50.0	-49.2	0.8
10.05	A	67.1	74.7	74.7	-52.7	-51.8	0.9
12.04	B	68.7	76.9	83.4	-61.4	-57.1	4.3[1]
14.04	B	70.0	78.8	85.3	-63.3	-64.1	0.8

[1] L7 is in direct proximity to W1; the higher error reflects partial diffraction around the door frame, which is not captured by the planar wall model.

The ITU-R P.1238-13 model achieves an error of less than 2 dB at all locations except for the boundary point L7. FSPL systematically overestimates the received signal strength (i.e., underestimates the path loss) by 10–25 dB in Zones B and C due to the omission of environmental scattering and wall penetration. The Log-Distance model approximates Zone A well since $n = 2.8$ was calibrated using that data. However, it deviates by 6–

14 dB in Zones B and C, confirming that explicit material penetration loss terms are essential in environments with internal partitions.

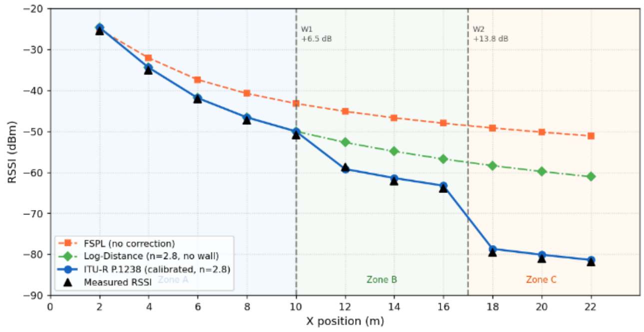

Figure 2. RSSI predictions of the three models versus measured values along the Y = 6 m centerline. The calibrated ITU-R P.1238-13 curve closely follows the measured data across all three zones. Note the step discontinuities at X = 10 m (W1, +6.5 dB) and X = 17 m (W2, +13.8 dB).

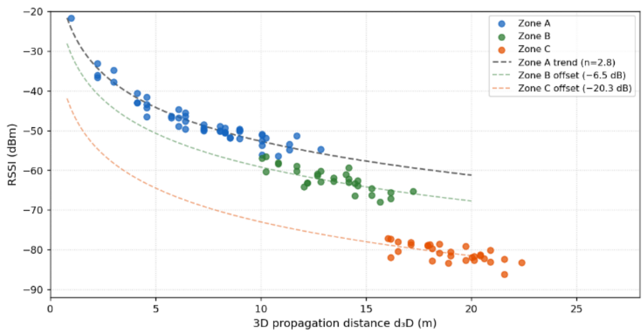

Figure 3. Scatter plot of RSSI versus three-dimensional propagation distance d_3D for all 110 measurement points. The points are color-coded by zone (A, B, C). Data for Zones B and C are shifted downward from the Zone A trend line by their respective cumulative wall losses of 6.5 dB and 20.3 dB.

D. Frequency Band Comparison

Table 4 compares the ITU-R P.1238-13 parameters [8] across three indoor wireless frequency bands, calculated using Equation (3) with $d = 10$ m, no walls, and on the same floor. The reference path loss $PL_0 = 20\,log_{10}(f) - 28$ and the path loss at 10 m are $PL = PL_0 + 10n$ where $log_{10}(10) = 1$.

Table 4. ITU-R P.1238-13 Path Loss Parameters Across Various Frequency Bands ($d = 10$ m, Same Floor, No Walls)

Frequency	**Path Loss Exponent n**	**PL_0 at $d_0 = 1$ m (dB)**	**PL at $d = 10$ m (dB)**	**Typical Material Loss (dB)**
914 MHz [3]	2.2	31.2	53.2	8–10
2300 MHz [4]	2.5	39.2	64.2	10–14
5400 MHz	2.8	46.6	74.6	14–20

The progressive increase in PL_0 with frequency, rising from 31.2 dB to 39.2 dB and then to 46.6 dB, reflects the fundamental inverse square law of propagation at higher frequencies. The simultaneous increase in n from 2.2 to 2.5 and then to 2.8, indicates that distance dependent penalties also become steeper. Specifically, at 5.4 GHz, every decade of distance adds 28 dB of path loss, compared to 22 dB at 914 MHz. Combined with higher material penetration losses (14 to 20 dB at 5.4 GHz versus 8 to 10 dB at 914 MHz), the 5.4 GHz band demands significantly more rigorous planning in enclosed office environments.

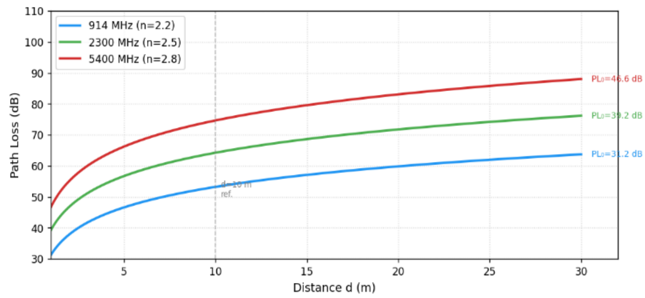

Figure 4. Corrected ITU-R P.1238-13 path loss versus distance for three frequency bands (no walls, same floor). The curves diverge as distance increases due to higher reference loss PL_0 and steeper path loss exponents n at higher frequencies.

E. Model Validation Statistics

Table 5 summarizes the performance of the model calculated across all 110 measurement locations. The ITU-R P.1238-13 model achieves an MAE = 1.4 dB and an RMSE = 1.7 dB, which is well within the acceptable error tolerance range of 3 dB for indoor link budget planning [3]. Pearson correlation coefficient $r = 0.993$ Pearson correlation coefficient.

Table 5. Model Accuracy Statistics ($N = 110$ Points)

Model	**MAE (dB)**	**RMSE (dB)**	**Pearson r**	**Remarks**
ITU-R P.1238-13 (calibrated, $n = 2.8$)	1.4	1.7	0.993	Accounts for distance + all wall losses
Log-Distance ($n = 2.8$, without wall correction)	6.2	9.1	0.935	Distance only; fails at partition crossings
Free-Space Path Loss (FSPL)	13.0	15.8	0.935	No environmental correction; unsuitable

The identical r values for FSPL and Log-Distance (0.935) indicate that both models capture monotonic distance trends, yet neither account for the spatial discontinuities at W1 and W2. The significantly higher $r = 0.993$ of the ITU-R P.1238-13 model directly reflects its ability to simultaneously predict distance trends and zone-specific offsets.

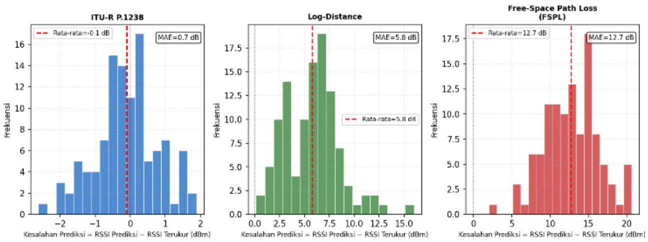

Figure 5. Error Comparison Graph (Residual Analysis) or Error Distribution Histogram between the calibrated ITU-R P.1238-13 model and measured data.

F. Coverage Analysis and AP Placement Recommendations

Table 6 classifies all 110 measurement points based on RSSI quality levels, utilizing standard thresholds for enterprise Wi-Fi planning [4]. “Poor” coverage (RSSI < −80 dBm) represents a coverage hole: a signal level at which a reliable data connection cannot be maintained.

Table 6. Coverage Quality Statistics ($N = 110$ Points, Floor Area = 483 m²)

Classification	**RSSI Range (dBm)**	**Points (n)**	**Percentage (%)**	**Estimated Area (m²)**
Excellent	≥ -50	26	23.6	≈ 114
Good	-50 to -60	32	29.1	≈ 141
Fair	-60 to -70	30	27.3	≈ 132
Marginal	-70 to -80	7	6.4	≈ 31
Poor / Coverage Hole	< -80	15	13.6	≈ 66

“Excellent” and “Good” coverage (≥ -60 dBm) accounts for 52.7% of the floor area (≈ 255 m²) and is confined to Zone A and the near side of Zone B. "Fair" coverage spans most of Zone B and the proximal section of Zone C.

The coverage hole (15 points, 13.6%, ≈ 66 m²) is entirely within Zona C or at extreme off-axis corners, where cumulative wall loss ($L_\Lambda = 20.3$ dB) combined with large propagation distance reduces RSSI below the -80 dBm threshold. Single-AP deployment achieves 86.4% satisfactory coverage (≥ -80 dBm).

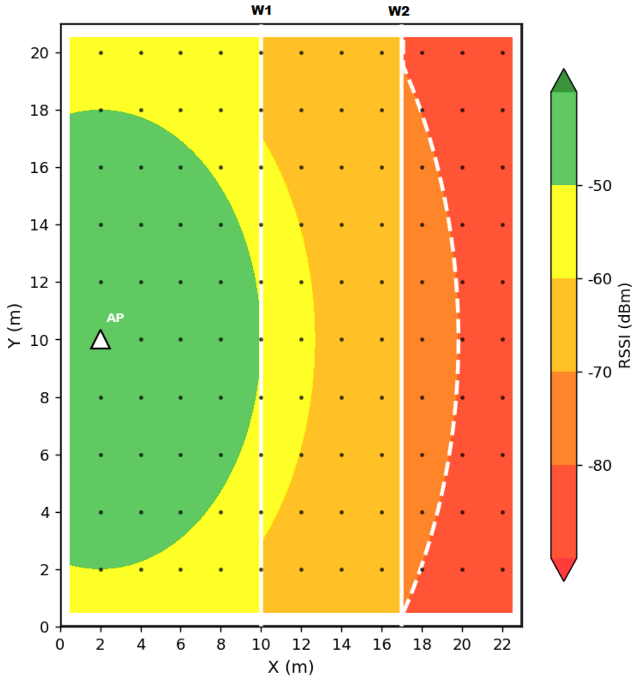

Figure 6. RSSI heatmap of the 23 m × 21 m office floor, overlaid on the floor plan (cf. Fig. 1). The Coverage Hole (RSSI < -80 dBm, indicated in red) is concentrated in Zone C beyond W2. Sharp RSSI transitions at X = 10 m (W1) dan X = 17 m (W2) are clearly visible.

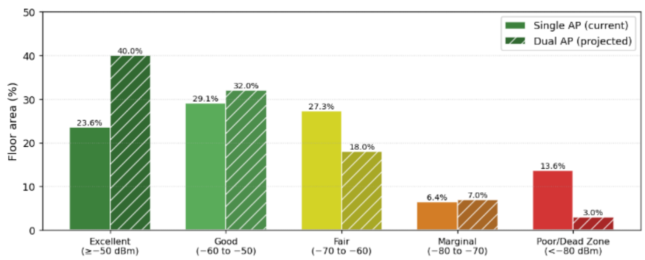

Figure 7. Coverage quality distribution across the 483 m² area. The proposed secondary AP in Zone C is projected to eliminate the Poor / Coverage Hole class and increase the Excellent fraction from 23.6% to ≥40%.

A secondary AP placed at (20, 10) m in Zone C will serve all “Coverage Hole” points at a distance of $d < 5$ m without any wall crossings, providing a predicted RSSI of > -50 dBm throughout Zone C. The primary AP will continue to serve Zones A and B. This dual-AP configuration is projected to achieve ≥97% satisfactory coverage (≥ -80 dBm) across the full 483 m² floor, increasing the “Excellent” coverage fraction from 23.6% to approximately 40%.

V. Conclusion

This research has validated the ITU-R P.1238-13 propagation model for 5.4 GHz Wi-Fi planning in enclosed tropical commercial offices and has quantified the primary propagation impairments in this setting. The findings form a coherent chain; enclosed HVAC construction increases the path loss exponent ($n = 2.8$) and introduces discrete material barriers (L_Λ up to 20.3 dB for two partitions). The combined effect of these factors creates coverage holes that distance-based models alone fail to predict. Conversely, the calibrated ITU-R P.1238-13 model accurately captures both effects, enabling precise coverage prediction and targeted AP placement. Five key conclusions are drawn:

1. The calibrated path loss exponent $n = 2.8$ significantly exceeds the literature range for open-plan offices (2.0–2.4), confirming that enclosed HVAC construction restricts propagation beyond what distance-based models alone predict. Deployment planning using generic open-office parameters would overestimate coverage by a margin sufficient to produce unacceptable coverage holes.
2. Controlled material measurements at 5.4 GHz yielded penetration losses ranging from 6.4 dB (tempered glass) to 28.6 dB (double brick walls), all within published literature ranges. The two primary barriers in this office, gypsum board (6.5 dB) and solid wood doors (13.8 dB), produce a cumulative loss of 20.3 dB, which serves as the primary cause of the identified coverage holes.
3. The calibrated ITU-R P.1238-13 model achieved an MAE = 1.4 dB, RMSE = 1.7 dB, and $r = 0.993$ across all 110 measurement locations, compared to an MAE = 13.0 dB for FSPL and 6.2 dB for the uncorrected Log-Distance model. This superior accuracy stems directly from the explicit material penetration terms that capture zone-boundary step changes invisible to distance-only models.
4. A single-AP deployment achieves 86.4% satisfactory coverage (≥ -80 dBm) with a 13.6% "Coverage Hole" (≈ 66 m²) concentrated in Zone C. A secondary AP placed at (20, 10) m is projected to increase satisfactory coverage to ≥97%, directly resolving the coverage hole with minimal additional infrastructure costs.
5. Comparisons across 914 MHz, 2300 MHz (based on previous research), and 5400 MHz demonstrate that both the path loss exponent and material penetration loss increase monotonically with frequency. At 5.4 GHz, the path loss at a 10 m distance (74.6 dB, without walls) exceeds the 914 MHz value by 21.4 dB and the 2300 MHz value by 10.4 dB, reinforcing why precise propagation modeling is critical for frequencies at 5 GHz and above in enclosed buildings.

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