

Determination of Indoor Wireless Network Design Based on Artificial Intelligence Heatmap Using Measurable Efficiency Indicators, a Weighted Decision Matrix, and Segmented Quality of Experience Validation

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ABSTRACT

Uneven wireless signal distribution and inefficient device deployment remain common problems in multi-storey school buildings. This study proposes a traceable design selection procedure for indoor wireless networks that integrates AI Heatmap predictive simulation, a weighted decision matrix with a measurement-based scoring rubric, and segmented Quality of Experience (QoE) validation. Two scenarios were defined and simulated on the same blueprint at 2.4 GHz and 5 GHz: an efficient design with 11 access points and an ideal design with 26. Five quantitative indicators were formulated, namely coverage efficiency, marginal coverage, cost per coverage point, marginal cost per coverage point, and capacity utilisation ratio, and were converted into 1–5 scores through an explicit rubric. The efficient design achieved a coverage efficiency of 11.00–12.80 points per access point against 5.93–6.42 for the ideal design, while the marginal cost of upgrading reached IDR 1,354,736–1,560,000 per coverage point, six times the average cost, and capacity utilisation fell from 72.7% to 30.8%. The efficient design obtained a weighted score of 4.30 (Highly Feasible) against 4.05 (Feasible), and QoE testing with 128 respondents yielded 4.26 (Very Satisfied). Per-band simulation shows zero poor-category area on 2.4 GHz for both scenarios, whereas on 5 GHz 21–22% of the area falls into the Poor class, still within the coverage footprint but below the usable threshold, a shortfall absorbed by fallback to 2.4 GHz within the same service set and corroborated by client side measurements showing a mean RSSI of –61 dBm on 2.4 GHz against –74 dBm on 5 GHz. Sensitivity analysis shows that this ranking holds only while investment efficiency carries a weight above 0.182; below that threshold the ideal design prevails. The contribution therefore lies not in declaring one design universally superior, but in providing a procedure that makes design decisions traceable to measurement data and states explicitly the conditions under which each design is preferable.



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I. INTRODUCTION

Technology-based learning requires a stable and evenly distributed wireless network in schools. In multi-storey buildings, meeting this requirement is not straightforward because of the many partitions and walls that weaken signals, together with potential interference between rooms and between floors. Unplanned access point placement results in areas of weak signal, excessive coverage overlap, and wasted devices [1], [2].

Predictive planning based on building floor plans has proven effective in anticipating these problems. Floor plans

are used as the basis for simulation with building materials entered as parameters, so that signal distribution can be predicted before installation [1]. Several studies show that optimisation algorithms can improve coverage quality with a smaller number of access points [3], while three-dimensional modelling helps suppress interference while maintaining signal quality throughout rooms [1]. Recent developments also employ machine learning for radio map estimation to improve coverage prediction accuracy [4]. Current Wi-Fi standards are even moving towards inter-access-point coordination to improve spectrum efficiency in dense environments [5].

Nevertheless, most previous studies stop at presenting the optimal configuration produced by simulation. Planning software generally recommends the number of access points that maximises coverage without considering institutional budget constraints. Yet in engineering practice, design decisions must balance user benefit against device investment value. This gap forms the focus of the present study: how to select among several design alternatives in a measurable and traceable manner, rather than simply following the maximum recommendation of the software.

In addition, service quality evaluation in similar studies is generally performed in aggregate. In reality, school network users consist of groups with different usage patterns. Teaching and educational staff prioritise stability and security for administration and video conferencing, whereas students are more sensitive to access speed and ease of use. Previous work has emphasised that QoE management requires an understanding of user diversity and service context [6], and that a single average value such as the Mean Opinion Score does not always adequately represent the distribution of user perception [7]. Structured QoE measurement frameworks have also been developed for various types of services [8]. Combining assessments without segment separation therefore risks producing conclusions that are unrepresentative of one of the groups.

The novelty of this study does not lie in any of the three components individually, since predictive heat mapping, weighted decision matrices, and QoE surveys are each well established. It lies in the chain that links them: measurement data are first converted into quantitative indicators, the indicators are then mapped onto scores through an explicit rubric, and only afterwards are the scores aggregated into a decision. This chain makes every element of the final decision traceable backwards to a measured quantity, which addresses the most frequent criticism of additive weighting methods, namely that scores are assigned without a stated basis. The procedure additionally reports the conditions under which the resulting ranking changes, so that the decision is presented together with its domain of validity rather than as an absolute claim.

This study aims to propose and test a selection procedure for indoor wireless network design that integrates three components: AI Heatmap predictive simulation, a weighted decision matrix with a measurement-based scoring rubric, and Quality of Experience (QoE) validation analysed per user segment. Its main contribution lies in providing a mechanism that makes every decision score traceable back to measurement data, so that the design justification is not subjective. This approach complements network topology design practices widely reported in the context of educational institutions in Indonesia [9].

II. METHOD

The study employs a Research and Development approach integrated with the Network Development Life Cycle (NDLC) framework. The stages carried out comprise

requirement analysis, topology design, signal distribution simulation, device implementation, and monitoring and evaluation.

A. Location and Research Object

The study was conducted on the second and third floors of a learning building at a state vocational high school in Semarang, Central Java. Both floors contain classrooms, laboratories, a hall, and corridors with high user density. Internet connectivity is provided by two service providers, namely a 1 Gbps primary connection and a 50 Mbps backup connection. The devices used are dual-band RG-AP720-L access points mounted on the ceiling, together with Power over Ethernet switches and Category 6 cabling. This study limits its scope to the 11 access points serving the second and third floors, which form part of a total of 13 access points installed in the building; the remaining two units serve the first and fourth floors and fall outside the scope of this study. The design refers to the IEEE 802.11 [10] and IEEE 802.3 [11] standards for wireless and Ethernet systems, the ISO/IEC 11801 [12] and ANSI/TIA-568 [13] cabling standards, and national regulations on telecommunications provision [14] and technical requirements for devices in the 2.4 GHz and 5 GHz bands [15], [16].

B. Design Scenario Definition

Two design scenarios were defined explicitly before the simulation was run so that the comparison would be fair and replicable. The definitions of both scenarios are presented in Table I.

TABLE I
DEFINITION OF DESIGN SCENARIO PARAMETERS

Parameter	Efficient Design	Ideal Design
Determination basis	Minimum number of APs meeting actual needs	Adding APs until the entire area is covered, without resource constraints
Coverage threshold	$\geq 60\%$ area in the Good category; 0% Poor	$\geq 75\%$ area in the Good category; 0% Poor
Capacity per AP	± 50 active users	± 30 active users
Orientation	Device investment efficiency	Maximum signal quality

C. Testing Parameters and Criteria

All testing thresholds refer to prevailing industry standards and technical recommendations, as summarised in Table II. These thresholds were established so that the assessment is objective and verifiable.

TABLE II
TESTING PARAMETERS AND CRITERIA

Parameter	Threshold	Source
RSSI for real-time services	≥ -67 dBm	[17], [18]
RSSI for basic data services	≥ -70 dBm	[17]
Unserved area	< -75 dBm	[17]

Throughput per user	≥ 5 Mbps down; ≥ 3 Mbps up	[19]
Design capacity per radio	25–30 active clients	[20]
Highest QoE category	≥ 4.21 (MOS ≥ 4.2)	[21], [22]

D. Simulation Input Parameters

The accuracy of predictive simulation depends heavily on the input parameters used. These parameters cover the radio specifications of the device, the physical characteristics of the building, the channel plan for suppressing interference, and user density assumptions. All input parameters used are summarised in Table III so that the simulation can be replicated.

TABLE III
AI HEATMAP SIMULATION INPUT PARAMETERS

Group	Parameter	Value
Software	Simulation platform	Ruijie Reyee Cloud, AI Heatmap feature
Software	Access period	2026
Device	Access point model	Ruijie RG-AP720-L (indoor)
Device	Wireless standard	IEEE 802.11a/b/g/n/ac (Wi-Fi 5)
Device	Frequency bands	2.4 GHz and 5 GHz (simultaneous dual-band)
Device	Antenna type	Internal, omnidirectional
Device	Maximum throughput	1,167 Mbps (300 Mbps 2.4 GHz + 867 Mbps 5 GHz)
Device	Transmit power	Automatic (automatic transmit power control)
Device	Mounting method	Ceiling mount, height ± 3 m
Building	Floor plan source	Architectural blueprint of floors 2 and 3
Building	Material attenuation model	Software material library (Table IV)
Interference	Channel plan 2.4 GHz	1, 6, 11 (non-overlapping)
Interference	Channel width 2.4 GHz	20 MHz
Interference	Channel plan 5 GHz	Automatically assigned by cloud controller
Users	SSID configuration	Two segmented SSIDs (students and staff), each dual-band
Users	Density per access point	50–80 active clients per band
Users	Total actual users	± 430 users (47 staff; 383 students)
Threshold	Good / Fair / Poor category	≥ -60 / -75 to -60 / < -75 dBm

Physical obstruction modelling was performed by redrawing every wall, door, and partition on the floor plan and then assigning its material type. The software provides a material library with default attenuation values as presented in Table IV. These attenuation values serve as the signal loss parameter when computing the received power distribution at every point on the plan.

TABLE IV
BUILDING MATERIAL ATTENUATION MODEL USED IN THE SIMULATION

Group	Material Type	Attenuation (dB)
Common	Thin wall	5
Common	Medium wall	12
Common	Thick wall	28
Material	Concrete wall	6
Material	Brick wall	5
Material	Metal wall	10
Material	Elevator shaft wall	14
Material	Solid wooden door	3
Material	Office door	2
Material	Thin door	1
Material	Metal door	10
Material	Thick glass	1
Material	Workstation partition	1
Material	Warehouse shelf	13
Material	Window	1

The attenuation range in the material library spans from 1 dB for light obstructions such as windows, thick glass, and partitions, up to 28 dB for thick walls. This spread shows that the accuracy of material type assignment substantially affects the prediction, since misclassifying a single wall type can alter the estimated received power by tens of decibels.

The attenuation values in Table IV are software defaults and therefore require verification against scientific references so that the simulation results can be defended. Modelling signal loss based on the number and type of walls traversed is a well-established approach known as the multi-wall model, formulated in the final report of COST Action 231 [23] and further developed for multi-storey environments [24]. The same approach underlies indoor radio system planning in ITU-R Recommendation P.1238 [25], while the electrical characteristics of building materials and their effect on wave propagation are addressed in ITU-R Recommendation P.2040 [26].

The attenuation range in the software library, from 1 dB for light obstructions to 28 dB for thick walls, falls within the range reported in studies of multi-wall and multi-frequency modelling for indoor environments [27]. Nevertheless, these default values are generic and have not been calibrated against the building materials at the study site. Empirical calibration through received power measurement at several reference points would improve prediction accuracy, and this constitutes one limitation of the present study.

Access points were mounted on the ceiling at a height of approximately 3 m above the floor, a position that provides an even radiation pattern throughout the room while reducing obstruction by furniture. Transmit power was not fixed but delegated to the automatic power control mechanism, so that each access point adjusts its power level to the radio conditions of its neighbours. In the 2.4 GHz band, a channel plan of 1, 6, and 11 with a 20 MHz channel width was applied, a combination of three non-overlapping channels that

suppresses co-channel interference between neighbouring access points, while channel assignment in the 5 GHz band is performed automatically by the cloud controller.

The network broadcasts two SSIDs separated by user segment, namely one SSID for students and one for teaching and educational staff. Each SSID is published on both frequency bands with band steering, so that devices supporting 5 GHz are directed to that band while legacy devices remain served on 2.4 GHz. This SSID separation also forms the basis for applying different bandwidth and security policies across segments. Documenting all these parameters is important because differences in wall material, mounting height, or channel plan can significantly alter the predicted coverage, and without such documentation the simulation cannot be reproduced. A consequence of using automatic power and channel assignment is that the actual values adapt to the environment, so replication requires recording the configuration output at the time of measurement.

E. Characteristics of the AI Heatmap Feature

The term AI Heatmap refers to a predictive planning feature embedded in the vendor cloud platform. Functionally it can be described through its inputs, processing, and outputs. The inputs are a scaled floor plan, the type and position of every obstruction with its attenuation value, the radio specifications of the device, and the target number and position of access points. The processing estimates the received power at every grid point on the plan by combining free space loss with the cumulative attenuation of the obstructions traversed, which is the working principle of the multi-wall model [23], [24]. The outputs are a colour map of predicted received power, the percentage of area in each signal category, and an automatic recommendation of candidate access point positions.

Two characteristics distinguish this feature from a conventional deterministic radio-frequency propagation simulation. First, the tool operates on an empirical model with a preset material library rather than on ray tracing or full-wave electromagnetic solving, so its computation is far lighter but its spatial resolution is coarser. Second, the automatic placement recommendation function is what the vendor labels as artificial intelligence, in the sense of a search procedure that proposes candidate positions from the plan geometry and the coverage target. The vendor does not publish the algorithm, the objective function, or the search parameters underlying this recommendation. Consequently the present study treats the feature as a black box whose outputs are used as data, and does not claim any contribution regarding the algorithm itself. This lack of algorithmic transparency is stated openly as a limitation, and it also motivated the decision to determine access point placement manually rather than to accept the automatic recommendation, so that both scenarios rest on criteria that are explicit and replicable.

F. Signal Distribution Simulation Procedure

The first stage is floor plan preparation. The architectural plan of each floor was uploaded to the platform and then

scaled by defining a reference distance of known length so that the dimensions in the drawing correspond to actual measurements. All walls, doors, and partitions were subsequently retraced on the plan and assigned material types according to the library in Table IV. Precision at this stage determines prediction accuracy, because the position and type of obstructions are the primary inputs to the signal loss computation.

Access point placement in both scenarios was determined by the researchers rather than generated automatically by the software. In the efficient scenario, the number and position of access points were set as the minimum configuration that still meets the actual user capacity requirement. In the ideal scenario, access points were added incrementally until the entire area on the plan was covered by an adequate signal category according to the heat map, without considering budget constraints. The stopping criterion for the ideal scenario is full area coverage, so that the resulting number of access points represents the maximum requirement according to the simulation.

The simulation was run using the AI Heatmap feature on the Ruijie Reyee Cloud cloud-based network management platform, accessed through its web interface in 2026. This platform was not selected through a comparison of planning tools; it is the network management system already in operation at the site, so the same environment that manages the installed devices also provides the predictive planning feature. Using it therefore keeps the device inventory, the material model, and the monitoring data within a single environment, at the cost of tying the prediction to one vendor propagation implementation, which is stated among the limitations of this study. Because the platform is software as a service that is updated periodically without a public version number, the access period is recorded as a marker of the software configuration in effect at the time of the study. The simulation was executed twice on the same blueprint for each floor, at 2.4 GHz and 5 GHz. The recorded outputs comprise the percentage of area by signal strength category, the number and position of access points, and areas potentially becoming blind spots. The reported coverage percentage refers to the Good category, namely areas with RSSI ≥ -60 dBm, which represents the optimal signal level for real-time services.

G. Weighted Decision Matrix

The final design was selected using a weighted decision matrix with the Simple Additive Weighting approach. The value of each dimension is computed as the product of weight and score, then summed as expressed in equation (1).

$$S = \sum (w_i \times s_i), \quad \sum w_i = 1 \quad (1)$$

where S is the total weighted score, w_i the weight of the i -th dimension, and s_i the score of the i -th dimension on a 1–5 scale. The weights were assigned by the researchers as expert judgement aligned with the stated objectives of the study, not derived from a formal weighting method such as the Analytic Hierarchy Process, nor elicited from a stakeholder panel. The user benefit dimensions of coverage, capacity, and service

quality were given a combined weight of 0.65 because the primary objective is to guarantee adequate service for all users on the two floors, while device investment and ease of implementation received a combined weight of 0.35 to represent the engineering-economics constraint faced by the institution. Because this assignment is a judgement rather than a measurement, its influence on the final ranking is examined explicitly through the sensitivity analysis reported in Section III.D.

So that scoring is not subjective, every dimension is equipped with a rubric that converts measurement data into a 1–5 scale as presented in Table V. With this rubric, all scores can be traced back to measured data.

TABLE V
SCORING RUBRIC FOR THE DECISION DIMENSIONS

Dimension	Measurement Basis	5	4	3	2	1
Coverage	Mean area in the Good category	≥80%	70–79%	60–69%	50–59%	<50%
Capacity	Ratio of installed capacity to requirement	≥2.00	1.20–1.99	1.00–1.19	0.80–0.99	<0.80
Quality	QoE value and blind spot condition	≥4.21 ; 0% Poor	3.41–4.20	2.61–3.40	1.81–2.60	<1.81
Investment	Ratio of cost to the cheapest option	1.00–1.25	1.26–1.50	1.51–1.75	1.76–2.50	>2.50
Installation	Number of devices managed	≤15	16–20	21–30	31–40	>40

The class boundaries in the rubric were derived from the thresholds already established in Table II and from the design references used in this study. The coverage boundaries follow the coverage targets defined for both scenarios in Table I; the capacity boundaries express the ratio of installed capacity to actual requirement, with a ratio below unity meaning that demand is not met; the quality boundaries reuse the QoE interpretation classes; the investment boundaries express the cost ratio relative to the cheapest option, so that the cheapest option always receives the highest score; and the installation boundaries follow the number of devices to be managed. The final matrix value is interpreted using feasibility criteria constructed with a class interval width of $(5 - 1) \div 5 = 0.8$ [22], namely 1.00–1.80 Highly Infeasible; 1.81–2.60 Infeasible; 2.61–3.40 Moderately Feasible; 3.41–4.20 Feasible; and 4.21–5.00 Highly Feasible.

H. Quantitative Decision Indicators

So that the comparison of both scenarios can be expressed in measurable quantities, five decision indicators were formulated as follows. Coverage efficiency (CE) expresses the average contribution of each access point unit to the served area, as in equation (2).

$$CE = C \div N \quad (2)$$

Marginal coverage (MC) expresses the additional coverage obtained from each additional access point unit in equation (3).

$$MC = \Delta C \div \Delta N \quad (3)$$

Cost per coverage point (CCP) and marginal cost per coverage point (MCC) express the investment required to obtain one percentage point of coverage, in equations (4) and (5) respectively.

$$CCP = (N \times P) \div C \quad (4)$$

$$MCC = (\Delta N \times P) \div \Delta C \quad (5)$$

Capacity utilisation ratio (CUR) expresses the proportion of installed capacity actually used at peak load, as in equation (6).

$$CUR = B \div K \quad (6)$$

All symbols and units used in equations (1) to (7), together with their data sources, are summarised in Table VI. Units and data sources are stated so that every indicator can be recomputed independently by the reader.

TABLE VI
NOTATION, UNITS, AND DATA SOURCES OF THE INDICATORS

Symbol	Description	Unit	Data Source
S	Total weighted design score	—	Computation
w_i	Weight of the i-th assessment dimension	—	Objective setting
s_i	Score of the i-th dimension (1–5 scale)	—	Rubric, Table V
Q_1, Q_2	QoE value of the staff and student segments	1–5 scale	Questionnaire
n_1, n_2	Number of respondents per segment	persons	Questionnaire
C	Area in the Good category ($RSSI \geq -60$ dBm)	%	AI Heatmap simulation
N	Number of access points installed	units	Design configuration
P	Unit price of an access point	IDR/unit	Procurement data
B	Peak concurrent user load	clients	Cloud controller
K	Installed service capacity	clients	$N \times 50$ clients/AP
CE	Coverage efficiency	points/unit	Equation (2)
MC	Marginal coverage	points/unit	Equation (3)
CCP	Cost per coverage point	IDR/point	Equation (4)
MCC	Marginal cost per coverage point	IDR/point	Equation (5)
CUR	Capacity utilisation ratio	%	Equation (6)

The five indicators CE, MC, CCP, MCC, and CUR are objective because all their variables originate from simulation results, network monitoring, and procurement data, so that the computation can be verified independently.

The overall research stages and the interrelationships among the components of the procedure are shown in Figure 1. The procedure is arranged in three sequential phases so that every design decision has a traceable basis.

The design phase prepares all required inputs, ranging from user requirements and building plans to the definition of both scenarios and the radio and material attenuation parameters. Establishing all parameters at the outset is important so that both scenarios are compared under equivalent conditions, ensuring that differences in results genuinely arise from differences in the number and position of access points rather than from differing assumptions.

The simulation and decision phase constitutes the core of the procedure. Simulation outputs are not interpreted directly but are first converted into quantitative indicators, then into scores through the rubric, and finally aggregated in the decision matrix. This three-step sequence is what makes the final decision traceable back to measurement data.

The implementation and validation phase tests whether the selected design actually performs under real conditions. Validation is carried out from two perspectives, namely technical performance through network monitoring and user perception through segmented QoE testing, so that the conclusion does not rest on simulation results alone.

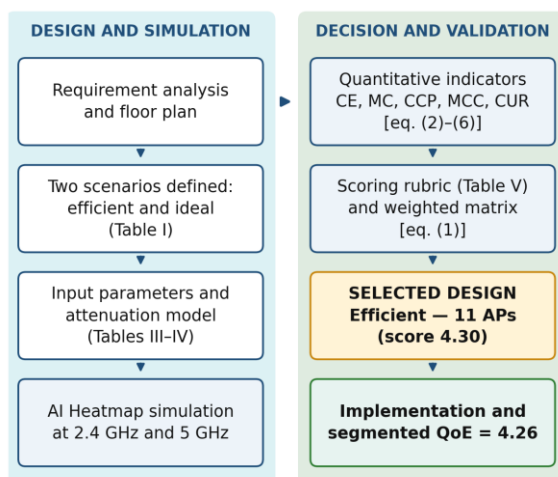


Figure 1. Research flow and design determination procedure

I. QoE Instrument and Analysis

Service quality evaluation was conducted using a 1–5 Likert questionnaire comprising 12 indicators grouped into three aspects, namely technical network quality, user experience, and general satisfaction. The instrument was designed taking into account that perceived quality is influenced by the usage context of each group [28], consistent with service-based QoE assessment approaches [29]. Respondents numbered 128, consisting of 47 teaching and educational staff (36.72%) and 81 students (63.28%). Sampling was voluntary: questionnaires were distributed to all network users on the second and third floors and completed by those willing to participate. This number corresponds to

approximately 30% of the active user population, with the inter-segment composition preserved in the computation of the combined value through proportional weighting.

Analysis was performed separately for each segment and then combined using a weighted average based on respondent proportions, as expressed in equation (7).

$$QoE = (Q_1 n_1 + Q_2 n_2) \div (n_1 + n_2) \quad (7)$$

where Q_1 and Q_2 are the QoE values of the staff and student segments respectively, and n_1 and n_2 the number of respondents in each segment. A weighted average was chosen so that the actual user composition is reflected in the final value.

III. RESULTS AND DISCUSSION

A. Signal Distribution Simulation Results

The simulation results for both scenarios on the second floor are shown in Figure 2, while those for the third floor are shown in Figure 3. Green indicates areas in the Good category, yellow the Fair category, and red the Poor category.

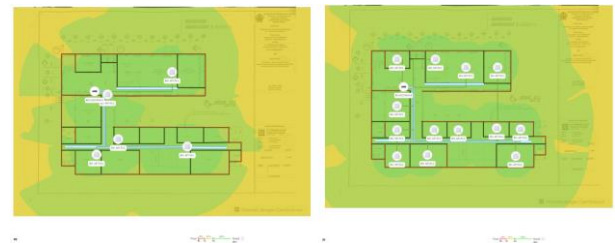


Figure 2. Second floor coverage comparison: efficient design with 5 APs (left) and ideal design with 14 APs (right)



Figure 3. Third floor coverage comparison: efficient design with 6 APs (left) and ideal design with 12 APs (right)

A quantitative summary of both scenarios is presented in Table VII. Investment values are computed using a unit device price of IDR 2,860,000 including the Power over Ethernet adapter.

TABLE VII
COMPARISON OF RESULTS FOR THE TWO DESIGN SCENARIOS

Parameter	Efficient	Ideal	Difference
Number of APs, floor 2	5 units	14 units	+9 units
Number of APs, floor 3	6 units	12 units	+6 units
Total APs	11 units	26 units	+15 units
Good coverage, floor 2	64%	83%	+19%

Good coverage, floor 3	66%	77%	+11%
Poor category area	0%	0%	equal
Service capacity	± 550	± 1,300	+750
Investment value	IDR 31.46 m	IDR 74.36 m	+136%

The coverage figures in Table VII refer to the 2.4 GHz band, which is the band that determines whether an area is served at all, because every client in the deployment can associate on it whereas only part of the population can associate on 5 GHz. On this band both scenarios yield a Poor category of 0%. The three categories are received power classes within the predicted coverage footprint rather than a distinction between covered and uncovered space: every point on the plan lies inside the footprint of at least one access point, and the category records how strong the signal is there. A Poor share of 0% on 2.4 GHz therefore means that no part of either floor is predicted to fall below the usable threshold of -75 dBm, so that the whole floor area is not merely reached by signal but reached at a level sufficient for service. This is an area based result computed for a reference receiver on the floor plan and should be distinguished from the instantaneous received power recorded at individual client devices, which additionally depends on device orientation, antenna quality, body shadowing, and the access point to which a client happens to remain associated. The main difference between the scenarios lies in the extent of the Good category area, where the ideal design leads by 19 percentage points on the second floor and 11 percentage points on the third floor.

Because the network publishes both bands under the same service set, the simulation was also run separately for each band so that the difference in propagation behaviour would be visible rather than assumed. The results for all eight combinations of band, floor, and scenario are presented in Table VIII.

TABLE VIII
SIMULATED COVERAGE DISTRIBUTION PER FREQUENCY BAND

Band	Floor	Scenario	Poor	Fair	Good
2.4 GHz	2	Efficient	0%	36%	64%
2.4 GHz	2	Ideal	0%	17%	83%
2.4 GHz	3	Efficient	0%	34%	66%
2.4 GHz	3	Ideal	0%	23%	77%
5 GHz	2	Efficient	22%	54%	24%
5 GHz	2	Ideal	5%	68%	27%
5 GHz	3	Efficient	21%	55%	24%
5 GHz	3	Ideal	13%	60%	27%

Note: Poor < -75 dBm; Fair -75 to -60 dBm; Good ≥ -60 dBm.

Table VIII makes explicit a property that an aggregate figure would conceal. The 0% Poor result holds on 2.4 GHz for both scenarios and both floors, but not on 5 GHz, where the efficient design places 22% of the second floor and 21% of the third floor in the Poor class, and even the ideal design

places 5% and 13% respectively. These areas are still inside the 5 GHz coverage footprint; what the classification records is that the predicted received power there falls below -75 dBm and is therefore too weak to be relied upon on that band alone. The pattern is consistent with the higher free space path loss of the shorter wavelength and with the greater attenuation of building materials at 5 GHz reported in the propagation literature [26], [27], noting that the material library in Table IV assigns a single attenuation value per material and therefore does not itself represent this frequency dependence. It also shows that adding access points reduces but does not eliminate 5 GHz shadow zones within the same building geometry.

This difference does not translate into unserved area. The two bands are published under a single service set, so a client whose 5 GHz signal weakens falls back to 2.4 GHz without changing network, and on that band the whole floor area remains above the usable threshold. The consequence is therefore one of throughput rather than availability: in those zones the client is served at the lower capacity of the 2.4 GHz band. Reporting the two bands separately states the limitation of the selected design precisely, namely that the efficient design guarantees availability across the whole floor area but guarantees high band throughput over roughly three quarters of it.

B. Quantitative Decision Indicators

Applying equations (2) to (6) to the data in Table VII produces the indicators presented in Table IX. The computation uses a unit device price P of IDR 2,860,000.

TABLE IX
QUANTITATIVE DECISION INDICATORS FOR BOTH SCENARIOS

Indicator	Fl. 2 Efficient	Fl. 2 Ideal	Fl. 3 Efficient	Fl. 3 Ideal
Number of APs (N)	5	14	6	12
Coverage C (%)	64	83	66	77
CE (points/AP)	12.80	5.93	11.00	6.42
CCP (IDR/point)	223,437	482,409	260,000	445,714
MC (points/AP)	—	2.11	—	1.83
MCC (IDR/point)	—	1,354,736	—	1,560,000

Note: MC and MCC are transition values from the efficient to the ideal design and are therefore listed in the ideal design column for each floor.

The coverage efficiency of the efficient design reaches 12.80 points per access point on the second floor and 11.00 points on the third floor, roughly twice that of the ideal design at 5.93 and 6.42 points per unit. A similar pattern appears in the cost per coverage point, where the efficient design requires IDR 223,437 to 260,000 per point while the ideal design requires IDR 445,714 to 482,409 per point.

The most decisive finding concerns marginal cost. Each additional percentage point of coverage in the transition to the

ideal design requires IDR 1,354,736 on the second floor and IDR 1,560,000 on the third floor. These values amount to approximately six times the average cost per coverage point in the efficient design, quantitatively confirming diminishing returns.

In terms of capacity utilisation, a peak load of 400 clients against the installed capacity of the efficient design yields a utilisation ratio of 72.7%, whereas for the ideal design this ratio falls to 30.8%. This indicates that the ideal design exhibits installed capacity in excess of actual requirements. Expressed per actual user, the investment value of the efficient design is IDR 73,162 per user compared with IDR 172,930 per user for the ideal design.

C. Decision Matrix Results

Converting the data in Table VII into scores through the rubric in Table V produces the assessment presented in Table X. As an illustration, the coverage dimension in the efficient design receives a score of 3 because the mean Good category area of 65% falls within the 60–69% range, whereas the ideal design receives a score of 5 because its mean reaches 80%.

TABLE X
WEIGHTED DECISION MATRIX

Dimension	Weight	Score E	Score I	Value E	Value I
Signal coverage	0.25	3	5	0.75	1.25
Service capacity	0.20	4	5	0.80	1.00
Service quality	0.20	5	5	1.00	1.00
Investment efficiency	0.25	5	2	1.25	0.50
Ease of implementation	0.10	5	3	0.50	0.30
Total	1.00	—	—	4.30	4.05
Category	—	—	—	Highly Feasible	Feasible

Based on the decision matrix in Table X, the efficient design obtains a weighted score of 4.30 and falls into the Highly Feasible category, while the ideal design obtains 4.05 in the Feasible category. Although the ideal design leads in the coverage and capacity dimensions, this advantage is insufficient to offset its weakness in the investment efficiency dimension, which carries a large weight. In the service quality dimension, both designs are at an equivalent level.

D. Sensitivity Analysis

Because the weights are an expert judgement rather than a measured quantity, their influence on the ranking was examined by varying the weights and the scoring thresholds while holding the dimension scores fixed, since the scores originate from measured data. Six weighting scenarios were tested, as presented in Table XI.

TABLE XI
RANKING STABILITY UNDER DIFFERENT WEIGHTING SCENARIOS

Weighting scenario	Efficient	Ideal	Preferred design
Baseline (0.25/0.20/0.20/0.25/0.10)	4.30	4.05	Efficient
Equal weights (0.20 each)	4.40	4.00	Efficient
Investment-dominant (0.40)	4.55	3.60	Efficient
Coverage-dominant (0.40)	4.00	4.45	Ideal
User benefit enlarged (0.80)	4.15	4.45	Ideal
Zero investment weight	4.07	4.74	Ideal

The ranking reverses at an investment weight of 0.182. As long as investment efficiency is given a weight above this value, the efficient design prevails; below it, the ideal design prevails. In a one-at-a-time test in which each weight was varied by $\pm 50\%$ and the remainder renormalised, the ranking was stable in nine of ten combinations, the single reversal occurring when the investment weight was halved to 0.125.

The scoring thresholds were examined in the same way by shifting the coverage class boundaries so that the efficient design would receive an adjacent score, as presented in Table XII.

TABLE XII
RANKING STABILITY UNDER DIFFERENT COVERAGE SCORE THRESHOLDS

Coverage score, efficient design	Efficient	Ideal	Outcome
2 (boundary raised)	4.05	4.05	Tie
3 (present rubric)	4.30	4.05	Efficient
4 (boundary lowered)	4.55	4.05	Efficient

These results indicate that the advantage of the efficient design is conditional rather than universal. It holds whenever investment efficiency is treated as a substantive criterion, and it disappears when cost is disregarded or when coverage alone dominates the decision. Rather than weakening the finding, this delimitation is itself an outcome of the procedure: the method reports not only which design is preferable but also the range of preferences within which that conclusion remains valid, which is information that a single aggregate score cannot convey.

E. Performance of the Implemented Network

The efficient design with 11 APs was implemented and monitored through the same Ruijie Reyee Cloud platform. During the monitoring period, all 14 network devices comprising 11 APs and 3 switches remained online without connectivity disruption. The network served up to approximately 380 to 400 concurrent active clients, with 6,119 client sessions recorded over a full month of operation and traffic distributed across the 2.4 GHz and 5 GHz bands. The number of concurrent clients fluctuates with the academic calendar, so the figure of 400 clients is used as the reference peak load in computing the capacity utilisation ratio.

Throughput measurement results at four test points are presented in Table XIII. All test points achieved throughput well above the minimum service requirement for high-quality

video conferencing, namely 5 Mbps download and 3 Mbps upload per user.

TABLE XIII
THROUGHPUT MEASUREMENT RESULTS

Test Point	Download (Mbps)	Upload (Mbps)	Latency (ms)
Floor 2 — classroom	85	42	12
Floor 2 — corridor	72	38	15
Floor 3 — hall	68	35	18
Floor 3 — classroom	80	40	13

Capacity adequacy cannot be judged from the number of access points alone, and was therefore examined against the available backhaul bandwidth and the observed traffic profile. Dividing the 1 Gbps primary connection by a reference peak of 400 concurrent clients yields a nominal share of approximately 2.5 Mbps per user, which falls below the 5 Mbps per user associated with high-definition video conferencing [19]. Taken in isolation, this figure would suggest that the backhaul is a binding constraint.

Measured traffic, however, does not support that reading. Over a representative 24-hour period the two service sets together carried 44.19 GB, of which 22.63 GB belonged to the staff segment and 21.56 GB to the student segment. Averaged over ten active hours this corresponds to approximately 9.8 Mbps, or about 1% of the installed link. On the busiest day of the monthly reporting period the combined volume reached roughly 140 GB, equivalent to about 31 Mbps averaged over active hours and an estimated 78 Mbps during the busiest hour, or approximately 8% of the installed capacity. Client activity classification reinforces this picture: the overwhelming majority of clients fell into the lowest activity category throughout the month rather than into the high or extreme categories.

The reconciliation is therefore straightforward. The 5 Mbps per user guideline represents a worst case in which every concurrent client simultaneously sustains high-definition video conferencing, a condition that does not arise in this deployment, where usage is dominated by intermittent retrieval of learning material. This explains why a nominal share of 2.5 Mbps per user coexists with a measured QoE of 4.26, and it indicates that neither the backhaul nor the number of access points is currently the limiting factor. The practical implication is that bandwidth expansion should be treated as a contingency against future growth in usage intensity rather than as an immediate requirement, a conclusion that could not have been reached from the nominal per-user calculation alone.

The monthly report further shows a highest daily peak of approximately 380 concurrent clients, with 200 to 260 clients on ordinary teaching days, and 6,119 client sessions over the month. Client load is not evenly distributed across access points: the six busiest units accounted for the majority of associations, with those serving the second floor collectively carrying about 65% of clients. Traffic was almost evenly split between the two service sets at 51.2% for the staff segment

and 48.8% for the student segment, even though student clients formed the larger group at 53.2%, which indicates a higher per-user consumption in the staff segment and provides an additional empirical basis for the segment-specific bandwidth policy recommended in this study.

With respect to the risk of congestion as the user population grows, the efficient design retains headroom of roughly 150 concurrent clients before reaching its installed capacity, while measured backhaul utilisation leaves substantial margin. Congestion would therefore be expected to arise first from a change in usage intensity, such as widespread simultaneous video streaming, rather than from the number of clients as such. Monitoring the activity category distribution offers an earlier warning of this transition than monitoring client counts alone.

F. Client-Level Validation of the Capacity and Band Assumptions

Two assumptions underlying the design were tested against the client association log exported from the cloud controller, covering 1,226 sessions from 175 unique clients over a 35-hour period spanning two consecutive teaching days. The first assumption is that a per-radio design reference of 25 to 30 active clients [20] is adequate for the room types on these floors; the second is that band steering shifts most of the load to 5 GHz, which is the premise under which the 5 GHz coverage gaps identified in Table VIII were judged tolerable. Of the 829 sessions recorded on the second and third floors, the per-access-point figures are presented in Table XIV.

TABLE XIV
OBSERVED CLIENT LOAD PER ACCESS POINT ON FLOORS 2 AND 3

Access point	Unique clients	Peak clients	Traffic (GB)
Fl. 2 — Normada room	62	20	10.94
Fl. 2 — corridor	64	9	3.96
Fl. 2 — classroom 8	38	14	2.03
Fl. 2 — electrical lab	42	5	0.47
Fl. 3 — classroom 2	45	16	4.76
Fl. 3 — accreditation room	31	7	2.65
Fl. 3 — classroom 3	32	5	1.64
Fl. 3 — classroom 4	16	3	0.12
Fl. 3 — hall, rear	27	7	0.31
Fl. 3 — hall, front	29	5	0.14

The highest peak recorded on any single access point is 20 concurrent clients, at the busiest unit on the second floor, and only two units exceed 15. Every unit therefore remains below the 25 to 30 client design reference, which confirms that the 11 access points of the efficient design are not capacity limited under present usage. The margin is not uniform: the busiest unit operates at roughly 70% of the lower design reference while four units remain below 25% of it, so the constraint that would appear first is the concentration of load

on a small number of rooms rather than the aggregate number of access points.

Load is likewise unevenly distributed across floors. The second floor recorded a peak of 44 concurrent clients against 19 on the third floor, and carried 17.8 GB of the 27.0 GB total for the two floors, consistent with the room functions and occupancy patterns of each floor. This asymmetry matters for any future expansion, since it indicates that additional capacity would be better directed at specific second floor rooms than distributed evenly.

On the band assumption, 128 of the 175 clients, or 73%, associated on 5 GHz at least once, while 47 clients associated exclusively on 2.4 GHz. The traffic split is more pronounced than the client split, with 39.6 GB of the 47.7 GB total, or 83%, carried on 5 GHz. Band steering therefore operates as intended, and the 5 GHz shadow zones reported in Table VIII affect throughput at a minority of positions rather than availability. At the same time, the 27% of clients that never reach 5 GHz confirm that 2.4 GHz cannot be treated as a legacy band in this deployment, which is the reason it remains the band against which the coverage criterion is assessed.

A separate client list snapshot taken during a teaching morning provides the received power that the association log omits. Across 36 associated clients the mean RSSI is -69 dBm, but the two bands differ sharply: clients associated on 2.4 GHz average -61 dBm with 15% below -75 dBm, whereas clients associated on 5 GHz average -74 dBm with 52% below that level. The direction and approximate magnitude of this gap match the simulated per band distribution in Table VIII, which strengthens the interpretation that the 5 GHz Poor areas are a genuine propagation effect rather than an artefact of the prediction model. Restricted to the second and third floors the sample comprises 22 clients, with 21% and 12% of them below -75 dBm respectively.

These figures are drawn from a two day association window and a single client snapshot rather than a full academic term, and neither constitutes a planned site survey at predetermined measurement points. They therefore validate the capacity and band assumptions and corroborate the per band prediction, but they do not substitute for the systematic client side RSSI survey identified as a limitation of this study.

G. QoE Evaluation Results

The mean score of each indicator for both segments together with their differences is presented in Table XV.

TABLE XV
QOE RESULTS PER INDICATOR BY USER SEGMENT

No	Indicator	Staff	Students	Diff.
1	Access speed is adequate	4.15	4.42	+0.27
2	Connection rarely drops	4.38	4.15	-0.23
3	Response time is fast	4.20	4.28	+0.08
4	Signal is strong throughout the area	4.10	4.22	+0.12
5	Network is easy to access	4.35	4.25	-0.10

6	Connecting is straightforward	4.25	4.45	+0.20
7	Content runs smoothly	3.98	4.35	+0.37
8	Online meeting quality	4.30	4.12	-0.18
9	Sense of security when using the network	4.28	3.98	-0.30
10	Overall performance satisfaction	4.22	4.40	+0.18
11	Conformity with expectations	4.18	4.35	+0.17
12	Willingness to recommend	4.20	4.38	+0.18
	Mean	4.22	4.28	0.06

A recapitulation of the values per segment and the weighted combined value is presented in Table XVI.

TABLE XVI
RECAPITULATION OF WEIGHTED COMBINED QOE

Segment	n	Proportion	QoE	Category
Teaching staff	47	36.72%	4.22	Very Satisfied
Students	81	63.28%	4.28	Very Satisfied
Combined	128	100%	4.26	Very Satisfied

Table XVI shows that the weighted combined QoE value of 4.26 falls into the Very Satisfied category. The combined value is closer to the student segment because its respondent proportion is larger, which confirms that a weighted average is more representative than a simple average.

The weighted combined QoE value of 4.26 exceeds the Mean Opinion Score threshold of 4.2, which indicates a high level of satisfaction [21].

H. Discussion

The principal finding of this study is that adding devices does not always deliver proportionate benefit, and this can be expressed quantitatively. Increasing from 11 to 26 access points raises device investment by 136%, yet the marginal coverage obtained is only 2.11 points per unit on the second floor and 1.83 points per unit on the third floor. By comparison, the coverage efficiency of the efficient design reaches 12.80 and 11.00 points per unit, so each additional access point contributes only about 17% of what an access point in the initial configuration contributes. The marginal cost per coverage point, at six times the average cost, reinforces this conclusion. Given that full area coverage above the minimum threshold has already been achieved on 2.4 GHz in both scenarios, adding devices no longer resolves availability gaps but merely strengthens the signal in areas already served; the residual 5 GHz shadow zones are likewise only partly recovered by densification, falling from 21 to 22% down to 5 to 13% while the device count more than doubles.

Segmented QoE analysis provides information not visible in aggregate analysis. The staff segment gives a higher score for connection stability (4.38 against 4.15), whereas the student segment leads in access speed and ease of connection.

The lowest scores are recorded for the security indicator among students and content smoothness among staff, both at 3.98. These findings form the basis for a technical recommendation to apply Quality of Service policies per VLAN segment, prioritising stability and security in the staff segment and access capacity in the student segment. Such application is feasible because both segments have been separated at the SSID level, so that the results of segmented QoE analysis can be translated directly into distinct configuration policies without altering the network architecture. This result reinforces earlier findings that perceived quality on wireless networks is influenced by the type of activity performed [25], and that QoE assessment must consider user context rather than technical parameters alone [26].

Compared with previous studies that focus on optimising access point placement to maximise coverage [2], [3], the proposed procedure adds a decision layer that explicitly accounts for resource constraints. The use of a scoring rubric together with five quantitative indicators also addresses a common weakness of the Simple Additive Weighting method, namely its dependence on subjective judgement, by tying every score to quantities that can be recomputed from simulation, monitoring, and procurement data. The cloud controller based approach employed here is likewise consistent with the trend towards centralised network management [30] and the need for load optimisation that accounts for user priorities [31].

The limitations of this study lie in the weight assignment, which remains a researcher judgement even though it is aligned with the study objectives. The material attenuation values used are also software defaults and have not been calibrated against local building materials. In addition, the simulation was run on a single software package, so the results have not been compared with other planning tools using different propagation models. The two scenarios were likewise determined by the researchers according to criteria set at the outset rather than through an automatic placement optimisation algorithm, so the possibility remains that other configurations outperform the two compared here. The reliability of the questionnaire instrument was not tested statistically, because only the per-indicator means were retained rather than the individual responses, so that Cronbach's alpha and construct validity could not be computed; this should be regarded as a limitation of the instrument reporting rather than of the instrument design. Field validation of the simulation was likewise not performed: predicted received power was not compared against measured RSSI or SNR at surveyed points, so the prediction error of the heat map remains unquantified. Network testing was confined to throughput and latency at four points and did not include packet loss, jitter, per-user throughput, or measurement under controlled variations of load, and channel utilisation and signal-to-noise ratio were not recorded. QoE testing is also cross-sectional and does not cover sustained peak load conditions or long-term inter-floor interference analysis.

Future work may formalise weight assignment using the Analytic Hierarchy Process or stakeholder elicitation, retain individual questionnaire responses so that instrument reliability can be established, validate the heat map against surveyed RSSI and SNR measurements to quantify prediction error, extend network testing to packet loss, jitter, and controlled load variation, and test the procedure against comparison configurations generated by placement optimisation algorithms.

IV. CONCLUSION

This study proposes a selection procedure for indoor wireless network design that integrates AI Heatmap simulation, a rubric-based weighted decision matrix, and segmented QoE validation. Applying the procedure to a multi-storey school building resulted in the selection of an efficient design with 11 access points, obtaining a weighted score of 4.30 in the Highly Feasible category and outperforming the ideal design with 26 access points, which obtained 4.05 in the Feasible category.

The selected design places the entire floor area above the minimum signal threshold on the 2.4 GHz band, with no predicted Poor category on that band, while on 5 GHz 21 to 22% of the area is predicted to fall into the Poor class, still within the coverage footprint but below the usable threshold, a shortfall absorbed by fallback to 2.4 GHz within the same service set. It serves approximately 400 concurrent active clients with measured throughput of 68 to 85 Mbps at a capacity utilisation ratio of 72.7%, and achieves a weighted combined QoE of 4.26 in the Very Satisfied category. Quantitatively, the efficient design attains a coverage efficiency of 11.00 to 12.80 points per access point at a cost of IDR 223,437 to 260,000 per coverage point, whereas upgrading to the ideal design requires a marginal cost of IDR 1,354,736 to 1,560,000 per point, roughly six times the average cost, with the capacity utilisation ratio falling to 30.8%.

Sensitivity analysis shows that this ranking is conditional rather than absolute: it holds while investment efficiency carries a weight above 0.182 and reverses when cost is disregarded or when coverage alone dominates the decision. The main contribution of this study is therefore twofold. First, it provides a mechanism that renders network design decisions traceable back to measurement data. Second, it reports the range of decision preferences within which the resulting recommendation remains valid, so that the justification for design selection can be defended both scientifically and practically without overstating its generality.

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