

Optimization of Access Point Location Using an Integer Programming Model

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Abstract—To address the increasing demand for reliable connectivity in educational environments, strategic access point (AP) placement is necessary to support coverage and bandwidth requirements while controlling installation cost. This study applies a binary integer programming model to the third floor of the College of Technologies at Bukidnon State University in order to determine a feasible minimum-cost AP configuration under site-specific conditions. The model incorporates coverage, bandwidth, range, and AP-count constraints, together with demand estimates based on expected simultaneous network use. Results show that the optimization framework can identify a feasible AP-to-area assignment that satisfies the imposed constraints within the study site. Because the nominal AP ranges are large relative to the dimensions of the floor, the resulting configuration is influenced more strongly by installation cost and bandwidth feasibility than by range limitation alone. The findings show the practical value of binary integer programming as a structured planning tool for access point placement in bounded indoor environments. While the resulting configuration is specific to the physical, technical, and cost conditions of the study area, the modeling approach may be applied to other institutional settings through appropriate parameter recalibration. A post-deployment wireless site survey is recommended to verify actual field performance and identify any remaining coverage gaps.

Keywords—Access points (APs); optimization; wireless network; coverage; integer programming

I. INTRODUCTION

Reliable Wi-Fi service in educational buildings depends on effective access point placement that can satisfy coverage and bandwidth needs without unnecessary installation cost. Bukidnon State University's College of Technologies Annex B Campus already has a documented network design proposal, which establishes the institutional context for wireless planning in the same setting [1], [2].

In [1], the authors discuss wireless propagation across diverse environments and explain how physical barriers affect signal attenuation. In [3] and [4], the authors also examine the effects of buildings, vegetation, and terrain on signal strength and coverage, while [5] analyzes diffraction, reflection, and scattering in obstacle-rich environments. In [6], [7], and [8], the authors discuss applications of linear programming and the simplex algorithm in optimization, while [9] and [10] address path loss modeling. In [11], the authors examine user density in wireless mesh networks, [12] compares propagation across the 2.4 GHz and 5 GHz bands, [13] and [14] analyze broader coverage models, and [15] and [16] discuss deployment cost considerations.

Designing a network requires careful consideration of several factors. In [17], the authors emphasize the importance of determining the optimum number of APs for reliable performance in wireless communication systems. Indoor studies and optimization work show that adequate WLAN coverage can be achieved with a minimal number of strategically placed APs ([18]; [19]). However, determining the number and optimal placement of APs in indoor or outdoor environments is challenging. Effective design must account for adequate coverage, minimum signal strength at all nodes, required bandwidth, and the presence of obstructions, reflections, and signal interference. Such a design demands proper modeling and formulation of the problem as an optimization task with multiple constraints.

Recent WLAN planning continues to treat AP deployment as a constrained optimization problem where placement and configuration determine coverage quality, interference risk, and total deployment cost [20].

Genetic Algorithms (GA) remain used in Wi-Fi AP deployment problems because they can search large, discrete location spaces using fitness-driven evolution [22]. However, GA can be computationally demanding because it repeatedly evaluates a population of candidate solutions across many generations [23].

Particle Swarm Optimization (PSO) is also applied to indoor AP placement, including binary PSO variants that select AP locations under deployment constraints [24]. PSO is often preferred for its simple implementation and relatively few parameters to tune ([25]; [26]). Despite this, PSO can suffer from local-optima trapping and loss of swarm diversity, which can reduce solution quality on complex search spaces [25].

Integer programming remains a strong method for AP placement because it supports binary site-selection decisions and explicit constraints for coverage, bandwidth, and cost [27]. Recent work also combines placement with configuration decisions such as channel assignment and transmit power within ILP-based formulations [29]. Although the solve time increases as problem size grows, integer programming can produce optimal solutions for moderate-sized deployment instances [27].

This study applies a binary integer programming model to the third floor of the College of Technologies at Bukidnon State University. The resulting AP configuration is specific to the floor layout, candidate installation sites, AP specifications, user-demand assumptions, and installation costs used in the model.

Recent WLAN planning research formulates indoor AP deployment as a binary linear program that jointly selects AP count, candidate locations, and emission channels to satisfy coverage requirements while controlling infrastructure cost [21]. Joint AP placement and channel assignment can also be expressed as an integer linear program that incorporates power tuning and partially overlapping channels to manage interference and avoid costly post-deployment adjustments [29]. Wireless Internet access planning on campuses also fits classic facility-location structure, with maximal covering models used to reconfigure access point sites to improve service quality and reduce operating costs [30].

Related router siting problems in mesh networks use mixed-integer linear programming variants of the p-median model to minimize the number of deployed routers under coverage-radius constraints [31]. Cellular network design similarly applies mixed-integer programming to choose base-station locations that minimize installation and operating costs under capacity and QoS constraints while computing path loss via propagation modeling [32]. These recent formulations support integer programming as a defensible core method for selecting AP locations under explicit coverage, cost, and propagation constraints [21].

Existing studies have examined AP placement through integer programming, genetic algorithms, particle swarm optimization, and hybrid methods under various coverage and configuration constraints. The present study focuses more narrowly on a site-specific minimum-cost formulation for a bounded university floor, using explicit coverage, bandwidth, range, and AP-count constraints.

A. Basic Concepts

- Wi-Fi refers to a family of wireless local area network (WLAN) technologies defined by the IEEE 802.11 standards. It enables devices such as desktop and laptop computers, smartphones, wearables, printers, and cameras to connect to a local network and access the Internet without physical cabling, typically within a limited coverage area.
- Wide area network (WAN) is a telecommunications network that links servers and end-user devices across large geographic distances, ranging from hundreds to thousands of kilometers, often by interconnecting multiple local or metropolitan networks.
- Local area network (LAN) is a telecommunications network that connects servers and end-user devices within a limited geographic area, typically within a room, building, or campus, and usually within about one kilometer.
- Access point (AP) is a network device that provides Wi-Fi connectivity, allowing wireless clients to join a wired network. In many deployments, the AP connects by Ethernet to upstream equipment such as a switch and router, which then provides access to local network services and the Internet. Some products combine AP and router functions in a single unit, and some broadband gateways (modem-router devices) also include built-in Wi-Fi, effectively serving as the access point. In larger

organizations, multiple APs are installed across the site to extend coverage so users can connect to the same network from different areas.

- Routers receive and transmit data through computer networks. By sending data packets to their intended IP addresses, it manages traffic between different networks and permits several devices to share an Internet connection.
- Bandwidth is the maximum data speed that a network connection can support. Greater bandwidth suggests a higher capacity, but it doesn't always translate into better performance.

II. OBJECTIVES OF THE STUDY

The study aims to determine an access point configuration for the third floor of the College of Technologies that satisfies coverage and bandwidth requirements while minimizing installation cost under defined constraints. Specifically, it seeks to:

- 1) Assess the existing AP locations of a given network in terms of:
 - a) Coverage quality (minimal path loss)
 - b) Model type (number of users, bandwidth (2.4 or 5G, area of coverage), Environment type (indoor or outdoor), Obstacle type, and
 - c) Cost metrics (installation cost per unit, fiber optic cable length cost).
- 2) Design an integer programming model to identify optimal AP locations, specifically addressing:
 - a) Coverage satisfaction
 - b) Cost minimization
 - c) Bandwidth feasibility

III. METHODOLOGY

This study is based on the existing access point (AP) locations on the third floor of the College of Technologies (COT) at Bukidnon State University, as reflected in Fig. 1.

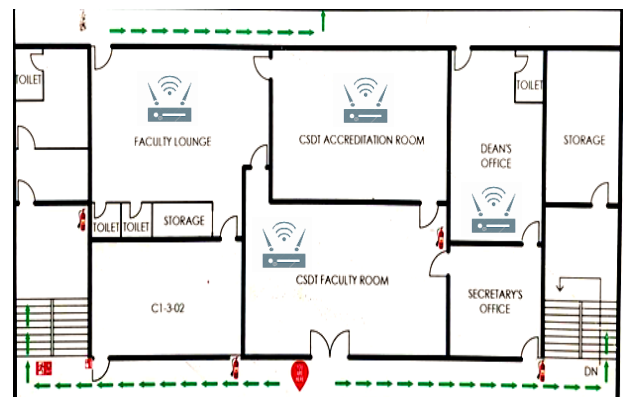


Fig. 1. Floor plan of the COT 3rd floor.

Fig. 1 presents the third-floor layout of the College of Technologies, which served as the spatial basis for identifying candidate AP locations, service areas, and AP-to-area distances

used in the optimization model. Because the floor layout, AP specifications, demand assumptions, and installation costs are site-specific, the resulting configuration should also be interpreted as site-specific.

Fig. 2 shows the existing network topology of the COT 3rd floor, indicating the current access points and the offices they serve within the study site. Together, Fig. 1 and Fig. 2 provide the spatial and network context used in formulating the optimization model.

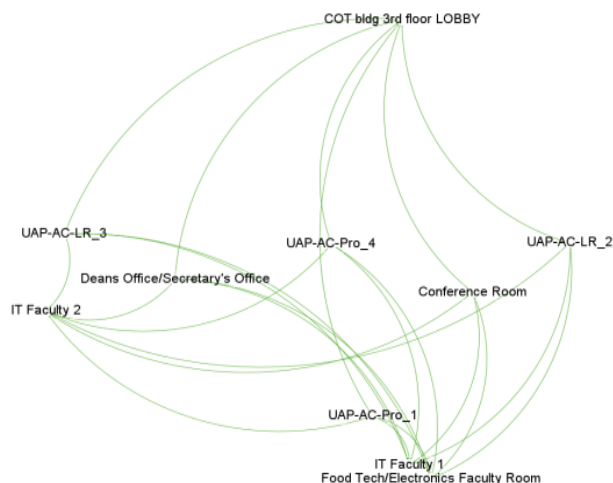


Fig. 2. COT 3rd floor offices served by 4 APs.

Table I provides an overview of four APs at the COT, detailing their locations, user coverage, specifications, unit costs, and cable distances from the switch used in the computation of installation cost. The network infrastructure utilizes Cat 6 cables, priced at Php 35 per meter, to support data transmission rates of up to 10 Gbps from the switch, with 1 Gbps allocated per access point (AP). Each AP offers dual-band operation with maximum data rates of 450 Mbps on the 2.4 GHz frequency and 867 Mbps on the 5 GHz frequency. Faculty, personnel, and students are limited to 60 Mbps, 40 Mbps, and 20 Mbps per user per device, respectively, with each AP capable of handling up to 175 connections simultaneously (70% of 250).

A. Optimization Method

This study formulates the access point placement problem as a binary integer programming model. The model determines which access points should be installed and which service areas should be assigned to the installed access points, subject to coverage, bandwidth, range, and installation limits. The

objective is to minimize the total installation cost while ensuring that all required service areas are served within the defined constraints.

Let $i \in I$ denote the set of candidate access points and $j \in J$ denote the set of service areas.

B. Objective Function

The objective of the model is to minimize the total installation cost of the selected access points:

$$\text{Minimize } z = \sum_{i \in I} C_i x_i \quad (1)$$

1) Decision Variables

$$X_i = \begin{cases} 1, & \text{if access point } i \text{ is installed} \\ 0, & \text{otherwise} \end{cases}$$

$$Y_{ij} = \begin{cases} 1, & \text{if area } j \text{ is served by access point } i \\ 0, & \text{otherwise} \end{cases}$$

2) Parameters

C_i : total installation cost of access point i , consisting of the unit cost of the AP and the cable cost from the switch to the AP location

r_i : coverage range of access point i

d_{ij} : distance between access point i and area j

B_i : maximum bandwidth capacity of access point i

U_j : total bandwidth demand of users in area j

L : maximum number of access points allowed for installation

$$a_{ij} = \begin{cases} 1, & \text{if } d_{ij} \leq r_i \\ 0, & \text{otherwise} \end{cases}$$

where,

a_{ij} indicates whether service area j lies within the allowable range of access point i .

The attenuation-adjusted broadcast value for each AP-to-area pair was computed by combining the nominal broadcast value of the access point with an attenuation term based on distance and wall barriers:

$$P_{ij}^{(2.4)} = B_i^{(2.4)} + \left[L_0^{(2.4)} + 10n \log_{10} \left(\frac{d_{ij}}{d_0} \right) + N_{ij} W_{2.4} \right] \quad (2)$$

$$P_{ij}^{(5)} = B_i^{(5)} + \left[L_0^{(5)} + 10n \log_{10} \left(\frac{d_{ij}}{d_0} \right) + N_{ij} W_5 \right] \quad (3)$$

TABLE I. EXISTING AP LOCATIONS

AP	AP Current Location	Network Connected	AP Model/Type	Transmission Frequency	Range	Environment Type	Cost of AP	Distance of AP from switch(m)
1	COT 3rd Floor Lobby	Student, Faculty, Personnel	UAP-AC-Pro	5 GHz and 2.4GHz	up to 122m	Indoor	Php 12,100.00	20.92
2	COT Conference Room	Student, Faculty	UAP-AC-Lite	5 GHz and 2.4GHz	up to 91 m	Indoor	Php 9,000.00	43.6
3	COT Food Tech Faculty	Student, Faculty, Personnel	UAP-AC-LR	5 GHz and 2.4GHz	up to 183 m	Indoor	Php 14,000.00	32.75
4	COT IT Faculty	Faculty	UAP-AC-LR	5 GHz and 2.4GHz	up to 183 m	Indoor	Php 14,000.00	24.49

where, $B_i^{(2.4)}$ and $B_i^{(5)}$ are the nominal broadcast values of access point i for the 2.4 GHz and 5 GHz bands, $L_0^{(2.4)}$ and $L_0^{(5)}$ are the reference-loss constants, n is the path-loss exponent, d_{ij} is the distance between access point i and service area j , d_0 is the reference distance, N_{ij} is the number of wall barriers between access point i and service area j , and $W_{2.4}$ and W_5 are the attenuation values assigned per wall barrier for the 2.4 GHz and 5 GHz bands, respectively.

The attenuation-related calculations followed standard indoor radio-planning principles, with Recommendation ITU-R P.1238 included as a relevant reference for indoor radiocommunication system planning [28]. The propagation analysis incorporated both distance-related attenuation and barrier-related attenuation between each access point and service area. The resulting attenuation-adjusted values were used as supporting indicators in interpreting AP-to-area relationships within the study site.

The total bandwidth demand for each service area was estimated from the number of students, faculty members, and personnel assigned to the area, their corresponding per-user bandwidth allowances, and a simultaneous-use factor representing the proportion of users expected to be active on the network at the same time. Thus:

$$U_j = \tau_j(20S_j + 60F_j + 40P_j) \quad (4)$$

where, S_j , F_j , and P_j represent the number of students, faculty members, and personnel in service area j , respectively; and τ_j denotes the simultaneous-use factor for area j .

The simultaneous-use factor τ_j represents the proportion of users in service area j expected to be active on the network at the same time. This factor was used to estimate concurrent service demand rather than assuming that all assigned users would simultaneously consume their full bandwidth allowance. In this study, τ_j was assigned according to the expected activity level of each area, with lower values used for transitional or administrative spaces and higher values used for high-concurrency spaces such as the Conference Room. This approach is consistent with WLAN capacity-planning guidance that bases demand on expected active users and connections rather than total assigned occupancy.

For the present study, the simultaneous-use factor was set at 0.30 for the lobby, 0.80 for the Conference Room, 0.50 for faculty rooms, and 0.40 for the Dean's Office/Secretary's Office.

The total installation cost for each access point was computed as the sum of the AP unit cost and the cable cost from the switch to the AP location. Thus:

$$C_i = A_i + 35L_i \quad (5)$$

where, A_i is the unit cost of access point i , L_i is the cable length in meters from the switch to the AP location, and 35 represents the cable cost per meter in Philippine pesos at the time of the conduct of this study.

3) *Constraints*: The following constraints are imposed in minimizing access point placement.

a) *Coverage constraint*: Each area j must be assigned to at least one access point within its range:

$$\sum_{i \in I} Y_{ij} \geq 1, \forall j \in J \quad (6)$$

b) *AP selection constraint*: An area j can only be served by access point i if access point i is installed:

$$Y_{ij} \leq X_i, \forall i \in I, \forall j \in J \quad (7)$$

c) *Bandwidth constraint*: The total bandwidth demand assigned to access point i must not exceed its bandwidth capacity:

$$\sum_{(j \in J)} U_j Y_{ij} \leq B_i X_i, \forall i \in I \quad (8)$$

d) *Range constraint*: Access point i can only serve area j if area j lies within its coverage range:

$$Y_{ij} \leq a_{ij}, \forall i \in I, \forall j \in J \quad (9)$$

e) *AP count constraint*: The total number of installed access points must not exceed the allowable limit:

$$\sum_{i \in I} X_i \leq L \quad (10)$$

f) *Binary restriction*:

$$X_i \in \{0,1\}, Y_{ij} \in \{0,1\} \quad (11)$$

This formulation provides the basis for selecting access point locations that satisfy the required service coverage and bandwidth demand while minimizing total installation cost within the defined study constraints.

C. Solution Procedure

The integer programming model was implemented in Microsoft Excel Solver. The objective cell was set to minimize the total installation cost, and the changing variable cells corresponded to the binary decision variables for AP installation and AP-to-area assignment. The model was solved using the Simplex LP method with binary restrictions imposed on X_i and Y_{ij} .

IV. RESULTS

Under the formulated binary integer programming model and the specified Excel Solver settings, Microsoft Excel Solver produced a feasible minimum-cost AP assignment for the evaluated service areas of the COT third floor. The final Solver run required 2.35 seconds, and the resulting solution was accepted in this study as the optimal solution for the study instance. The evaluated service areas included the COT third-floor lobby, Conference Room, Food Tech/Electronics Faculty Room, IT Faculty 1, IT Faculty 2, and the Dean's Office/Secretary's Office.

The final solution assigns binary values to the decision variables X_i and Y_{ij} , consistent with the binary integer programming formulation of the study. In this model, $X_i=1$ indicates that access point i is selected in the final solution, whereas $X_i=0$ indicates that it is not selected. Similarly, $Y_{ij}=1$ indicates that service area j is assigned to access point i , whereas $Y_{ij}=0$ indicates that no such assignment is made. These values were generated by the Solver and form the basis for interpreting the final AP-selection and AP-assignment pattern.

Table II presents the evaluated AP-to-area assignments under the optimization model. The table shows that all evaluated AP-area pairs satisfy the coverage-feasibility condition. This indicates that, for the present study site, all candidate access points are within the allowable range of the evaluated service areas under the specified model assumptions. As a result, the range condition operates as a general feasibility requirement rather than as the principal factor distinguishing selected from unselected AP-area pairings.

Because all candidate AP-area relationships are feasible in terms of range, the differentiating output of the model is reflected in the Solver-generated binary variables X_i and Y_{ij} . The values of these variables identify which access points were retained in the final solution and which AP-area assignments were selected after the cost, bandwidth, and AP-count constraints were applied. In this sense, Table II reports not only physical feasibility but also the discrete decisions made by the optimization model under the imposed constraints.

TABLE II. EVALUATION OF AP-TO-AREA ASSIGNMENTS UNDER THE OPTIMIZATION MODEL

Area	Access Point AP_i	Distance between AP i and area j (m) d_{ij}		Maximum data rate broadcast B_i		Attenuation-adjusted broadcast values P_{ij}		Total cost per AP c_i	AP range (m) r_i	Total bandwidth demand of users in area j u_j	x_i	y_{ij}	Coverage feasibility $d_{ij} \leq r_i$
				2.4 Ghz	5Ghz	2.4 Ghz	5Ghz						
COT bldg 3rd floor	UAP-AC-Pro	d1,1	8	450	1300	450.00	1300.00	13,007.20	122	180	1	1	1
	UAP-AC-Lite	d2,1	15	300	867	300.00	867.00	9,907.20	91	180	1	1	1
	UAP-AC-LR	d3,1	6	450	867	450.00	867.00	14,907.20	183	180	0	0	1
	UAP-AC-LR	d4,1	10.4	450	867	450.00	867.00	14,907.20	183	180	0	0	1
Conference Room	UAP-AC-Pro	d1,2	11	450	1300	450	1300	13,801.00	122	1160	0	0	1
	UAP-AC-Lite	d2,2	3.4	300	867	300	867	10,701.00	91	1160	0	0	1
	UAP-AC-LR	d3,2	9	450	867	450	867	15,701.00	183	1160	0	0	1
	UAP-AC-LR	d4,2	10	450	867	450	867	15,701.00	183	1160	0	0	1
Food Tech/Electronics Faculty Room	UAP-AC-Pro	d1,3	7	450	1300	450	1300	13,421.25	122	474	0	0	1
	UAP-AC-Lite	d2,3	10	300	867	300	867	10,321.25	91	474	0	0	1
	UAP-AC-LR	d3,3	3.4	450	867	450	867	15,321.25	183	474	0	0	1
	UAP-AC-LR	d4,3	9	450	867	450	867	15,321.25	183	474	0	0	1
IT Faculty 1	UAP-AC-Pro	d1,4	17	450	1300	450	1300	13,132.15	122	420	1	1	1
	UAP-AC-Lite	d2,4	13	300	867	300	867	10,032.15	91	420	0	0	1
	UAP-AC-LR	d3,4	14	450	867	450	867	15,032.15	183	420	0	0	1
	UAP-AC-LR	d4,4	2.8	450	867	450	867	15,032.15	183	420	0	0	1
IT Faculty 2	UAP-AC-Pro	d1,5	15	450	1300	450	1300	13,272.50	122	294	0	0	1
	UAP-AC-Lite	d2,5	15.2	300	867	300	867	10,172.50	91	294	0	0	1
	UAP-AC-LR	d3,5	11	450	867	450	867	15,172.50	183	294	0	0	1
	UAP-AC-LR	d4,5	5	450	867	450	867	15,172.50	183	294	0	0	1
Deans Office/Secretary's Office	UAP-AC-Pro	d1,6	10	450	1300	450	1300	13,850.00	122	104	0	0	1
	UAP-AC-Lite	d2,6	5	300	867	300.00	867.00	10,750.00	91	104	0	0	1
	UAP-AC-LR	d3,6	11	450	867	450.00	867.00	15,750.00	183	104	0	0	1
	UAP-AC-LR	d4,6	16.6	450	867	450.00	867.00	15,750.00	183	104	0	0	1

V. DISCUSSION

The results show that the final AP configuration must be interpreted mainly through the Solver-generated binary variables X_i and Y_{ij} . Since all evaluated AP-area pairs satisfy the coverage-feasibility condition, the selected pattern of X_i and Y_{ij} values should be interpreted as the result of constrained optimization among feasible alternatives rather than as a consequence of range exclusion.

Table II shows that all evaluated AP-to-area pairs satisfy the coverage-feasibility condition. This indicates that the candidate access points are within the allowable range of the evaluated service areas under the assumptions of the study. Under this condition, range functions mainly as a feasibility requirement and does not strongly differentiate among candidate assignments. The final configuration should therefore be interpreted as a constrained selection among feasible alternatives rather than as an outcome driven primarily by distance exclusion.

The selected pattern of X_i and Y_{ij} values further indicates that the optimization process filtered feasible options and retained only those selections and assignments that satisfied the imposed constraints at minimum total installation cost. In this way, a value of 1 reflects a selected decision in the final solution, while a value of 0 reflects a feasible option that was not retained by the Solver under the defined optimization criteria.

Because the nominal AP ranges are large relative to the dimensions of the study site, installation cost and bandwidth feasibility exert a stronger influence on the final AP assignment pattern than range limitation alone. This supports the interpretation that the binary integer programming model is useful as a structured planning tool for identifying a feasible minimum-cost AP configuration in a bounded indoor environment. At the same time, the findings should be read within the limits of the present formulation and site conditions.

The present study applies the binary integer programming model under a single set of site-specific assumptions for user demand, AP range, and installation cost. Accordingly, the resulting configuration should be interpreted as the optimal solution for the defined study instance rather than as a robustness-tested solution across multiple scenarios. This study does not include scenario-based analysis under varying user density, coverage-radius assumptions, or budget constraints. As a result, the discussion of model sensitivity is limited to literature-supported expectations and to the recognition that different parameter settings may produce different feasible configurations in future applications of the model.

VI. CONCLUSION

The study shows that binary integer programming can be applied as a structured approach to access point placement on the third floor of the College of Technologies at Bukidnon State University. Under the defined assumptions and constraints, the model identified a feasible minimum-cost AP configuration that satisfied the required coverage and bandwidth conditions of the study area.

The results indicate that all evaluated AP-to-area pairs were range-feasible under the specified model assumptions. Consequently, the final configuration was influenced more strongly by installation cost and bandwidth feasibility than by range limitation alone. This highlights the value of binary integer programming as a method for selecting among multiple feasible alternatives under explicit operational constraints.

Because the study is based on site-specific physical, technical, and cost parameters, the resulting AP configuration should be interpreted as specific to the modeled environment. The same formulation may still be applied to other indoor settings, provided that the relevant floor layout, access point specifications, demand assumptions, and installation costs are recalibrated to reflect the target context. A post-deployment wireless site survey is recommended to verify actual field performance and identify any remaining coverage gaps.

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