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OPTIMAL COVERAGE FOR INDOOR COMMUNICATIONS BASED ON 5G WI-FI DEVICES

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ABSTRACT

To achieve optimal wireless fidelity (Wi-Fi) coverage, start by assessing the location and evaluating the needs of users and devices. This study compares various UniFi devices (Mesh, Lite, Pro, and HD) to identify which one can provide free Wi-Fi coverage throughout Najaf International Airport. To cover the passenger terminals, 19 UniFi Mesh or UniFi Lite devices, 12 UniFi Pro devices, and 8 UniFi HD devices are needed. It was observed that the UniFi HD device provides extensive coverage and supports over 500 users. It delivers high-speed data transmission, reaching 800 Mbps on the 2.4 GHz band and 1733 Mbps on the 5 GHz band.

Additionally, it used UniFi HD devices to enhance coverage, reduce costs, and minimize signal interference, aligning with recent research objectives. Furthermore, it was observed that the coverage rate is 60% with UniFi Mesh or UniFi Lite devices, 72% with UniFi Pro devices, and increases to 92%-100% with UniFi HD devices. It was concluded that increasing the number of devices in airport terminals can hinder signal transmission due to varied operating ranges and obstacles, particularly in Non-Line-of-Sight (NLoS) regions. Materials like concrete can obstruct signals, while wood and iron scatter them, and bricks may absorb them.

KEYWORDS

MU-MIMO Antenna, Optimal Coverage, 5G Communications, Wi-Fi Networks, NLoS Regions, Radiation Pattern.

1. INTRODUCTION

The growing demand for more serviceable and competent wireless network architecture has led to continuous investigation into all possible methods to achieve the desired result (Muttair et al., 2021; Haban and Waddy, 2025; Iavich et al., 2021). It is very necessary to identify the weaknesses and limitations of modern digital wireless systems. These limitations contain factors such as communication strategies, network design, speed, signal analysis, signal processing rate, and others (Muttair et al., 2023; Shehab and Yonis, 2025; Muttair et al., 2021). Nonetheless, the problem lies not in the design of the multipurpose Wi-Fi wireless network; rather, it is that a network framework and digital system with functions have more significant demands on the processing that comprises this system (Solmaz et al., 2022; Zhou et al., 2021; Muttair et al., 2024). If the system is not sufficiently fast, speed turns into a severe problem (Pahlavan & Krishnamurthy, 2021; Muttair et al., 2022).

Additionally, the requirement for high-speed network configuration is increasing daily, yet there is a limited understanding of how these networks are established (Gavriluţ et al., 2022; Jagannath et al., 2022). This era has witnessed a massive demand for fast information technology and digital systems. As a result, academic studies are performed frequently to develop methods and algorithms that meet the increasing expectations of digital system users. Implementing and evaluating social network design behaviour is much more comfortable without disproportionate design time (Muttair et al., 2019; Azizi & Talatahari, 2022). Software tools enable straightforward prototyping and modeling of practical systems, facilitating experimentation, customization, and a range of applications (Guo et al., 2022; Muttair et al., 2022). Therefore, the proposal of the optimal network structure depends on two points: the first point is the efficiency of the devices used, and this efficiency depends on the ability of the device's antenna to direct signals, as well as the data transfer rate between transmitting devices and receiving points (Lee et al., 2022; Al-Asadi et al., 2022). The second point addresses the design scenario, which serves as the main framework for organizing information exchange among the components of the network architecture (Shinde & Vijayabaskar, 2022; Arshad et al., 2021). Additionally, the main concern for researchers in network design is identifying the optimal locations for transmitters, as these stations are the most fundamental and crucial components of wireless network architecture (Kiaksar & Shahriar, 2021; Muttair et al., 2022; Aletri et al., 2020). All researchers in the field of communication and networks suggested several algorithms to identify the best positions for base transmission stations. Despite their claims, these algorithms did not meet their aims, resulting in drastically erroneous outcomes (Mushatet et al., 2025; Muttair & Mosleh, 2023; Bencak et al., 2022).

This study will assess the Wi-Fi availability at Najaf International Airport to determine whether it meets the needs of travelers. It will focus on two main principles: the first principle is to propose a network structure that minimizes the number of Wi-Fi devices. This approach aims to reduce costs and decrease noise and interference from signals transmitted between routers and receiving points. The second principle focuses on utilizing multiple routers to determine optimal coverage for each device, ensuring the best fit within the proposed network architecture.

The other sections are organized as follows: Section 2 presents the case study, the proposed network architecture, and the specifications of the devices used in this paper. Section 3 will present the results and a detailed discussion of all the scenarios proposed in this study. Section 4 will provide conclusions and recommendations for future work.

2. CASE STUDY AND PROPOSED NETWORK ARCHITECTURE

The UniFi device operates as an access point (AP) that broadcasts on separate frequency bands, allowing simultaneous transmission without interference (Muttair et al., 2019). The 2.4 GHz band can be set for VHT20 and VHT40 with channels between 1 and 11 and transmit power up to 18 dBm, and the 5 GHz band can be set for VHT20, VHT40, and VHT80 with channels between 36 and 165 with Dynamic Frequency Selection (DFS) and transmit power up to 18 dBm (Azizi & Talatahari, 2022). DFS was designed to prevent electromagnetic interference with other uses of the C-band frequency band that predate Wi-Fi, such as military radar, satellite communication, and radar (Guo et al., 2022; Muttair et al., 2022).

The study in this paper focused on the environment of the passenger terminals at Najaf International Airport. The choice of traveler places aims to provide a reliable Wi-Fi connection, enhancing the experience and enabling comfortable communication without additional charges. The suggested basic network framework for enabling wireless coverage in an airport interior environment is shown in Fig. 1. A network comprises three Cisco switches, a Cloud Core Router (MikroTik RB), and a UniFi controller. It depends on establishing four UniFi devices: Mesh, Lite, Pro, and HD. The aim is to determine which device provides the best coverage and delivers a strong Wi-Fi signal to all users, regardless of whether there are few or many travelers. The airport reception hall was created using precise measurements with UniFi V6.2.26 software and the UniFi Pro V2.1.11 integrated console. Fig. 2(a) displays a two-dimensional (2D) illustration, whereas Fig. 2(b) shows a three-dimensional (3D) representation. The airport departure halls were constructed using materials such as drywall, brick, carbide, wood, concrete, glass, double-pane coated glass, bulletproof glass, and steel, among other elements utilized in the interior of the UniFi controller. The material height and thickness can be determined and modified, and the range of a band in dB that can be set for it is between 3 dB and 28.5 dB, as listed in Table 1. The material properties determine the reflection and transmission coefficients directly, as listed in Table 1, whereas the diffraction coefficients are determined indirectly by their dependence on the reflection and transmission coefficients. The thickness of certain materials is necessary to calculate reflection and transmission coefficients, and the UniFi controller makes assigning construction materials easy.

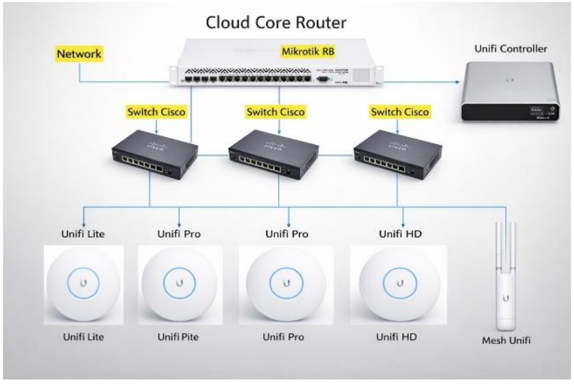


Fig. 1. The proposed network design for the Najaf International Airport environment.

(a) **(b)**

Fig. 2. The structure of the airport terminal building was designed using UniFi software for (a) 2D and (b) 3D designs.

Table 1. Properties of materials used in the construction of the airport terminal structure.

Material Color	Types of Materials	Thickness (m)	Reflection & Transmission Coefficients (dB)
●	Drywall	0.35	3 to 4
●	Cubicle	0.28	3.5 to 7.5
●	Wood	0.045	3.5 to 6.5
●	Brick	0.28	12 to 20
●	Concrete	0.30	12 to 20
●	Glass	0.003	2.5 to 7
●	Glass Double Pane Coated	0.004	13 to 20
●	Glass Bulletproof	0.005	10 to 20
●	Steel	0.0625	16 to 28.5

The UniFi device utilizes an omnidirectional antenna designed for high-density applications, enhanced by MU-MIMO technology. 802.11ac Wave 2 MU-MIMO (multi-user, multiple-input, multiple-output) technologies, as shown in Fig. 3, enable a Wave 2 AP to communicate with multiple clients simultaneously – significantly increasing multi-user throughput and overall user experience.

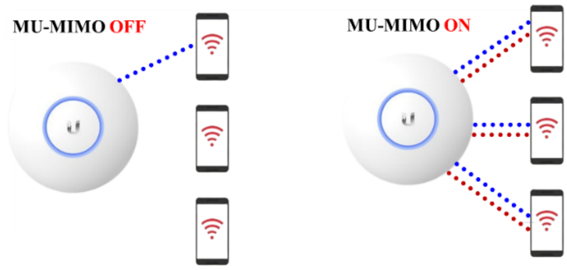


Fig. 3. The difference between UniFi devices for single-user (SU) MIMO and multi-user (MU) MIMO.

This article provides a comprehensive comparison of the characteristics of the various UniFi devices. Table 2 lists diverse comparison characteristics, including dimensions, types of planned deployment, data transfer speeds for both 2.4 GHz and 5 GHz bands, unrestricted ports, Power over Ethernet (PoE) mode, and additional characteristics. A primary purpose was to discover which frequency offered suitable wireless coverage in airport interior terminals. This is especially important since the signal path from the Wi-Fi routers to the users may be blocked by various barriers and impediments. Finding the optimal wireless coverage for the interior environment of an airport requires careful consideration of several bands.

Table 2. Comprehensive comparison of UniFi devices used in this study.

Device Shape			
Device Name	UAP-AC-Lite & Mesh	UAP-AC-PRO	UAP-AC-HD
Dimensions	160 × 31.45 mm	196.7 × 35 mm	220 × 48.1 mm
Environment	Indoor	Indoor/Outdoor	Indoor/Outdoor
2.4 GHz Radio Rate	300 Mbps	450 Mbps	800 Mbps
5 GHz Radio Rate	867 Mbps	1300 Mbps	1733 Mbps
PoE Mode	802.3af/A PoE & 24v PoE	802.3af PoE/802.3at PoE+	802.3at PoE+
Ports	10/100/1000 Ethernet	10/100/1000 Ethernet	10/100/1000 Ethernet
Wi-Fi Users	100 Users	200 Users	+500 Users

Fig. 4 depicts the UniFi devices deployed in airport terminals, which were installed at various heights ranging from 5 to 8 meters to determine the optimal height for effective coverage of the airport's interior environment.

Fig. 4. The UniFi devices have been installed in real practice in the passenger terminals at various heights.

3. DISCUSSION OF RESULTS

This section presents the efficiency results of the devices selected in the simulation and installation sections within the passenger terminals. Consequently, the results of UAP-AC-Mesh UniFi devices, UAP-AC-Lite UniFi devices, UAP-AC-PRO UniFi devices, and UAP-AC-HD UniFi devices will be presented.

3.1. UAP-AC-Mesh UniFi Devices Results

The results of the antenna broadcast capacity of the unified network device at various heights are shown in Fig. 5. To assess the accuracy and efficiency of the Wi-Fi routers, the device will be tested at heights ranging from 5 to 8 meters. This method determines the optimal height for effective coverage in passenger terminals. The UAP-AC-Mesh UniFi device was found to achieve perfect coverage at a height of 8 meters. In contrast, at lower altitudes, specifically 5 meters, refraction, reflection, and diffraction increase in the signal path from the signal router to the receiving devices. As a result, these obstacles will cause a decline in the device's performance when accurately covering the passenger terminals.

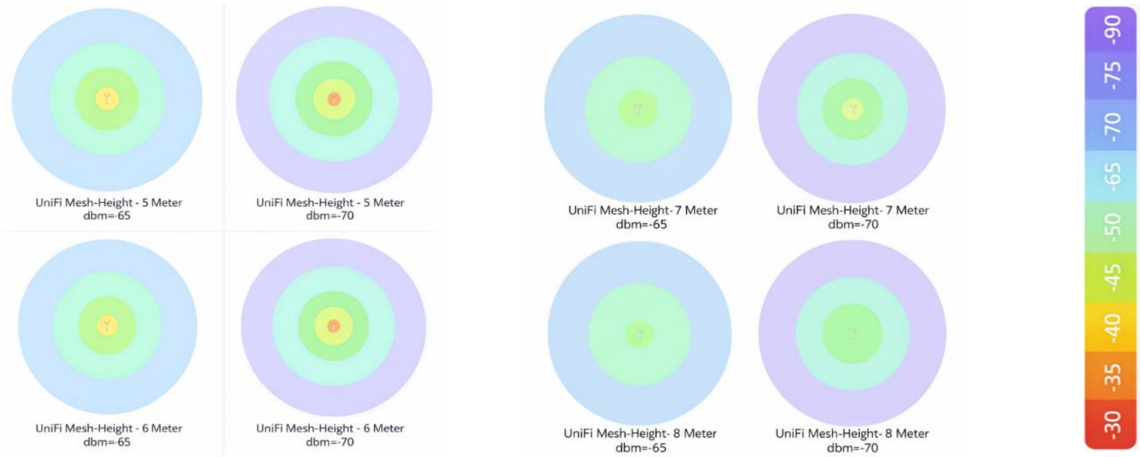


Fig. 5. The radiation patterns of the UniFi Mesh antenna at various heights with power levels of -65 dBm and -70 dBm.

3.2. UAP-AC-Lite UniFi Devices Results

The radiation patterns of the antenna for the UniFi Lite device at various heights are illustrated in Fig. 6. In all cases, the focus was on adjusting the receiving power between -65 and -70 dBm. This range is beneficial in NLoS conditions, where the signal paths are subject to numerous refractions, reflections, and collisions.

The coverage capacity of the UniFi Lite devices when the received power is -65 dBm, as shown in Fig. 7(a), and when the received power is -70 dBm, as shown in Fig. 7(b). Figs. 7(a) and (b) demonstrate the optimal Wi-Fi coverage at 8 meters height. To greatly expand wireless coverage and improve connection in the airport's interior, 19 devices are required, since each UniFi Lite can support up to 100 users.

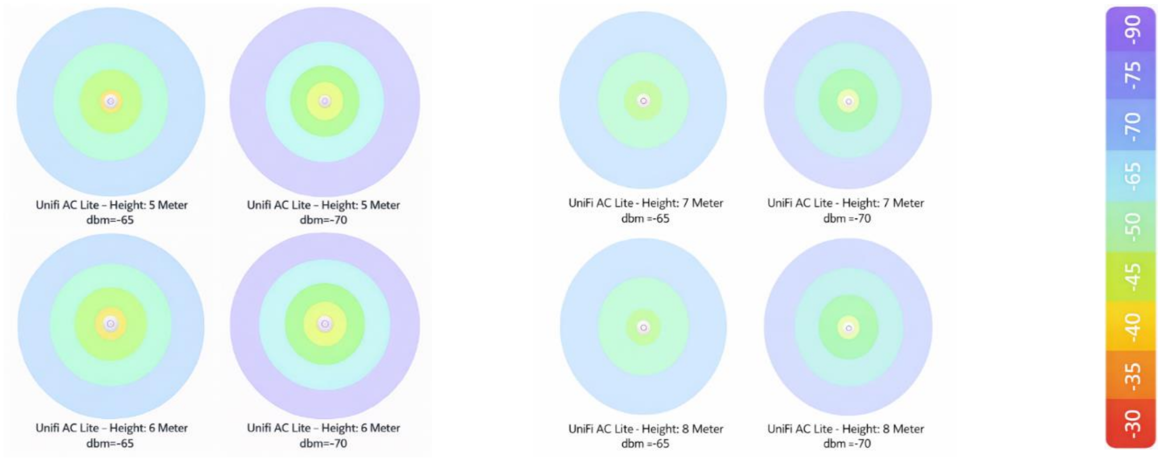


Fig. 6. The radiation pattern strength of the UniFi Lite antenna is measured at different heights with received power levels of -65 dBm and -70 dBm.

(a) **(b)**

Fig. 7. The coverage rate in the passenger terminals using the UniFi Lite device at a height of 8 meters is measured when the received power is -65 dBm and -70 dBm.

3.3. UAP-AC-PRO UniFi Devices Results

The radiation pattern results for the UniFi Pro antenna at various heights and received power levels are shown in Fig. 8. It was observed that the radiation pattern results at a height of 8 meters were optimal, regardless of whether the received energy was -65 dBm or -70 dBm. A height of 8 meters was found to be optimal for the device due to different considerations. Building materials might block the signal route, which is one of the primary causes. The Wi-Fi signal may be reflected, refracted, absorbed, diffracted, or dispersed as a result of this impediment. The signal will reach the recipient very weakly, gradually weakening the proposed network.

At a height of 8 meters using the PRO device, the coverage field is described as follows: Fig. 9(a) offers the received power of -65 dBm, and Fig. 9(b) displays a received power of -70 dBm. The results show that the coverage of the UniFi PRO device is significantly better than that of the Mesh and Lite devices. The increased data transmission capability of UniFi Pro is responsible for the improvement. A new approach now needs only 12 devices to cover the hallways, compared to 19 devices needed for the UniFi Mesh and Lite. Its decrease in the total number of devices has resulted in reduced costs and decreased noise levels, which are the primary focuses of this study. While Mesh and Lite devices may support 100 users, a UniFi Pro can support up to 200; the Pro's superior performance allows for higher coverage.

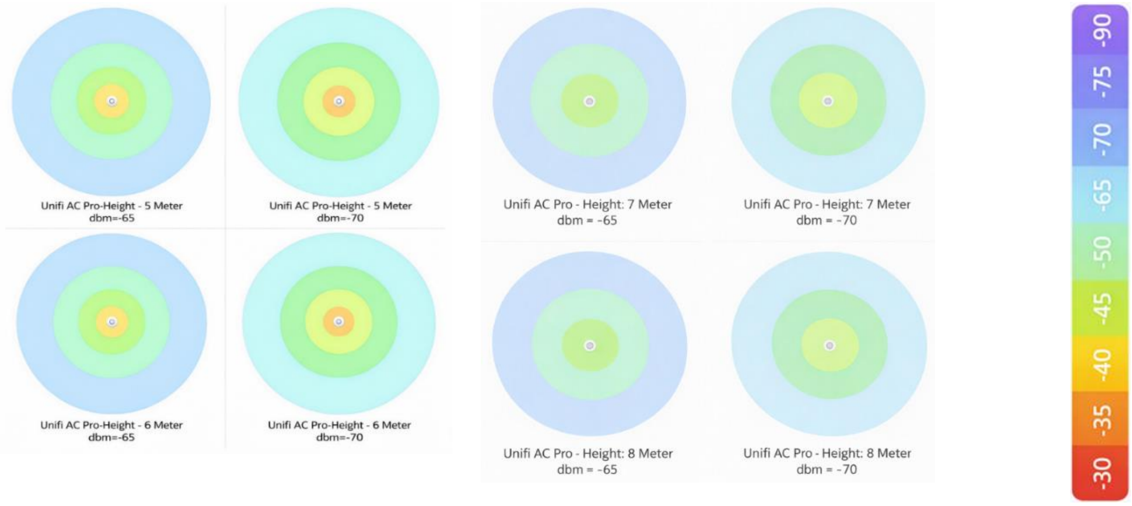
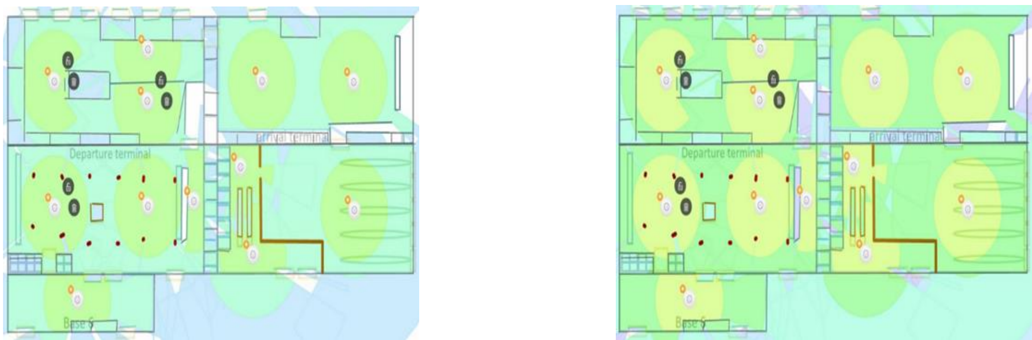


Fig. 8. The radiation pattern strength of the UniFi Pro antenna at various heights and received power levels.



(a) **(b)**

Fig. 9. The radiation pattern strength of the UniFi Pro antenna at different received powers and heights.

3.4. UAP-AC-HD UniFi Devices Results

Fig. 10 illustrates the strength levels of the electromagnetic radiation patterns for UniFi HD at different powers and heights. The recommendations demonstrate that the UniFi HD device has a considerably better radiation pattern and radio capabilities than other devices. It operates at 2.4 GHz and 5 GHz with speeds of 800 Mbps and 1,733 Mbps, respectively. These higher speeds significantly increase its transfer capacity.

Area of coverage levels when using the UniFi HD device at -65 dBm are shown in Fig. 11(a), while those at -70 dBm are illustrated in Fig. 11(b). All passenger terminals were covered using only 8 UniFi HD devices, which is half the total number of Mesh and Lite devices required. Hence, this approach was capable of reducing the interference among signals and noise that dispersed the received power, especially in regions with NLoS. Each UniFi HD device is capable of accommodating over 500 people due to its significant transmission capacity. In comparison, the Mesh and Lite devices can serve up to 100 people, while the Pro device can support up to 200 people on the Wi-Fi network.

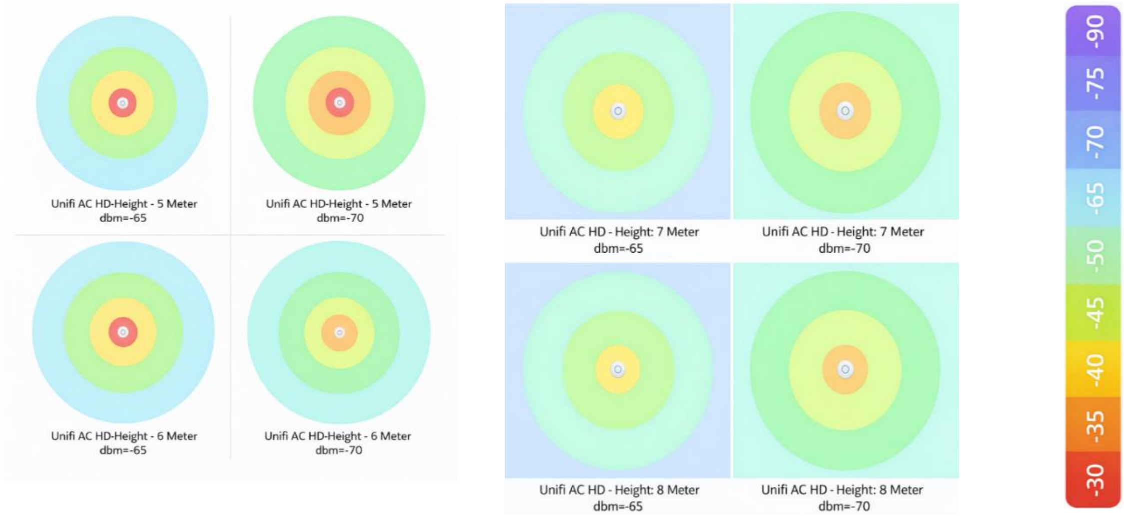
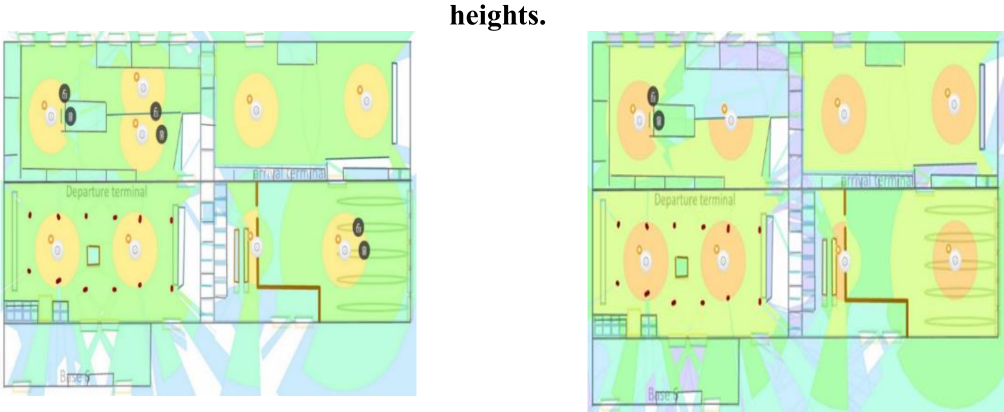


Fig. 10. The intensity level of the radiation patterns for the UniFi HD at different powers and heights.



(a) **(b)**

Fig. 11. A coverage level for a UniFi HD device at (a) -65 dBm and (b) -70 dBm received power.

The findings from every device show that the optimal installation height for coverage range and signal quality is 8 meters. This result is based on measurements made at signal levels of -65 dBm and -70 dBm in various locations' units. This conclusion is based on measurements taken at signal strengths of -65 dBm and -70 dBm across different units of the locations. Fig. 12 displays the connection statistics of UniFi devices, including central processing unit (CPU) and memory usage, user count, and usage of 2G and 5G channels. The Wi-Fi experience of users with signal-strength ratios and coverage rates ranging from 60% to 100% is demonstrated in Fig. 13. The signal strength ratio is 60% when using UniFi Lite or Mesh devices, 72% when using UniFi Pro devices, and 92% to 100% when using UniFi HD devices.

To mathematically calculate the CPU and memory usage based on Eq.1 and Eq. 2, the channel utilization is calculated using Eq.3.

$$C(t) = \frac{\text{CPU time used}}{\text{CPU time available}} * 100 \tag{1}$$

$$M(t) = \frac{\text{RAM used}}{\text{Total RAM}} * 100 \tag{2}$$

$$U(t) = \frac{\text{time the channel is busy}}{\text{total observation time}} * 100 \tag{3}$$

Where $C(t)$ represents CPU usage at time (t), $M(t)$ is memory usage at time (t), and $U(t)$ represents channel utilization at time (t).

Fig. 12. Statistics on UniFi device connections for the 2G and 5G bands, including usage percentage, channel utilization, and number of users.

Fig. 13. Wi-Fi clients experience coverage and transfer rates for four UniFi devices: Mesh, Lite, Pro, and HD.

Furthermore, the standard curves for the Signal-to-Noise Ratio (SNR) measurement of different UniFi devices at various momentum times are presented in Fig. 14. It was observed that the SNR performance of the HD device was the best compared to the Mesh, Lite, and Pro devices. These measurements were taken at different times to determine the accuracy of the performance, and the SNR value remained better for the HD device at all times from 1 to 24 hours. To mathematically calculate the SNR value based on Eq.4.

$$SNR(dB) = 10 * \log_{10}\left(\frac{P_{signal}}{P_{noise}}\right) \quad (4)$$

Where P_{signal} represents signal power and P_{noise} is noise power.

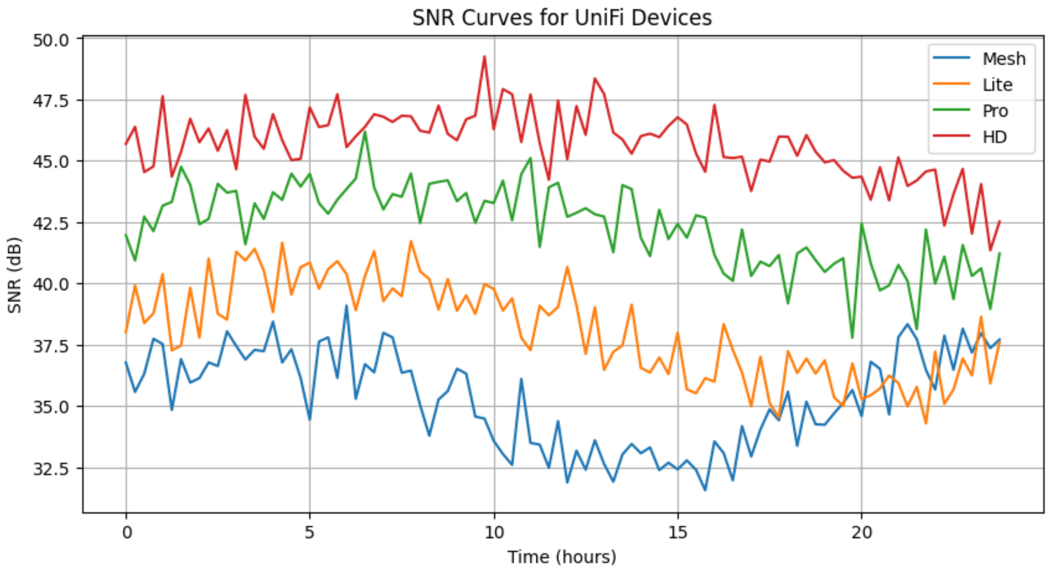


Fig. 14. SNR curves for the proposed UniFi devices at different times.

3.5. Comparison with Recent Studies

A comprehensive comparison was conducted between the work presented in this article and recent studies proposed by other researchers, as shown in Table 3. This comparison focused on several characteristics, including the type of study (applied or simulated), the UniFi devices used, the target environment, the number of communication devices used, the type of coverage (indoor or outdoor), and coverage efficiency. It was observed that the proposed study is comprehensive in all aspects, as it was applied both practically and theoretically, utilizing diverse devices at varying heights and areas to achieve optimal coverage. As a result, the coverage efficiency ranged from 92% to 100% using HD devices. In contrast, other studies lacked several important practical factors. These studies were unable to implement their work practically. They lacked the capacity to conduct diverse studies using devices at varying heights and areas, thus failing to achieve optimal coverage for the target environment.

Table 3. Comprehensive comparison between the proposed study and other recent academic works.

Reference	Study Type (Applied/ Simulation)	Devices Used (UniFi)	Target Environment	No. of Devices Used	Coverage (Indoor/ Outdoor)	Coverage Efficiency (%)
(Naman et al., 2020)	Simulation	HD	Multi-floor building	NA*	Indoor	NA*
(Ashaari et al., 2021)	Simulation	Generic UniFi setup (unspecified models)	SOHO (Small Office/ Home Office)	12	Indoor	NA*
(Dong et al., 2025)	Simulation	NA*	Experimental setups (lab)	NA*	Indoor	NA*
This Study	Applied and Simulation	Mesh, Lite, Pro, and HD	Najaf International Airport	19 Mesh 19 Lite 12 Pro 8 HD	Indoor	Mesh = 60 Lite = 60 Pro = 72 HD=92–100

*Not Available

4. CONCLUSION

In this paper, optimal coverage of the passenger terminal at Najaf International Airport was achieved using various modern UniFi devices, including Mesh, Lite, Pro, and HD models. A comprehensive comparison of the proposed devices was conducted to determine the best option for passenger terminal coverage. The UniFi HD device achieves optimal coverage rates ranging from 92% to 100%, while the Pro, Mesh, and Lite devices achieve coverage rates of 72% and 60%, respectively. This study successfully reduced the cost, noise, and signal interference by using the minimum number of devices necessary to cover the passenger terminal. Specifically, 8 UniFi HD devices were used, which provided optimal coverage for the area. To achieve optimal coverage, 12 devices using a UniFi Pro and 19 devices using UniFi Mesh or Lite are required in the passenger terminals. It has been observed that increasing the number of devices in airport terminals causes a deterioration in the transmitted signals to users because each device will operate in a different range, and this will lead to many obstacles in the signal path, especially in NLoS areas, the most important of which are building materials, some of which act to reflect or break the signal path, such as concrete. Some other materials, such as wood and iron, can scatter signals, while others, like bricks, may absorb them.

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