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Quality Analysis of Signal and Attenuation of Outdoor Wi-Fi in Dynamic Weather Conditions

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Abstract

This paper analyzes the quality of outdoor Wi-Fi signals and rain attenuation under dynamic weather conditions using UniFi 6 Mesh and UniFi 7 Pro devices at 2.4 GHz and 5 GHz frequencies. Our proposed method evaluates network performance using QoS parameters, RSSI measurements, and theoretical rain attenuation analysis based on ITU-R propagation models. The experiments were conducted under sunny, light rain, and heavy rain conditions in a real outdoor environment at Ayana Resort Bali Hotel. The QoS results achieved excellent performance with throughput of 22.17 Mbps, packet loss of 0.015%, delay of 0.41 ms, and jitter of 0.000 ms, producing a TIPHON index value of 4 categorized as "Very Satisfactory." The RSSI analysis showed that increasing rainfall intensity significantly reduced signal strength, especially at the 5 GHz frequency. The highest degradation occurred at the UniFi 7 Pro 5 GHz channel, where RSSI decreased from -40.80 dBm during sunny weather to -62.61 dBm during heavy rain. The results also demonstrated that actual attenuation values were much higher than theoretical attenuation due to environmental factors such as humidity, wet surfaces, and multipath propagation. This study confirms that weather conditions strongly influence outdoor Wi-Fi performance and highlights the importance of empirical field testing for reliable outdoor wireless network deployment.

Keywords:
Quality Analysis, Signal, Attenuation, QoS, Wi-Fi

1. Introduction

Wireless communication technology continues to evolve rapidly and becomes an essential infrastructure in modern digital society. Outdoor Wi-Fi networks now support various activities such as smart campus systems, public internet services, surveillance systems, IoT communication, and real-time data transmission. The increasing demand for stable outdoor wireless connectivity requires networks that can maintain reliable signal quality under different environmental conditions. However, outdoor wireless propagation faces more complex challenges than indoor communication because the signal directly interacts with atmospheric conditions, environmental obstacles, and dynamic weather variations. Rainfall, humidity, wind, and temperature changes influence signal propagation characteristics and cause attenuation that reduces communication performance. Therefore, understanding the relationship between weather conditions and outdoor Wi-Fi signal quality becomes increasingly important for improving network reliability and optimization strategies [1]–[3].

Signal attenuation represents one of the most critical issues in outdoor wireless communication systems. Rainfall intensity particularly affects radio wave propagation because water droplets absorb and scatter electromagnetic signals during transmission. Previous studies show that rain attenuation significantly degrades signal strength and

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communication quality, especially in tropical regions with high rainfall intensity [4]. Riyawan and Effendi analyze rain attenuation in satellite communication systems and demonstrate that rainfall directly reduces received signal quality. Similarly, Amrullah et al. explain that tropical rain characteristics produce severe attenuation due to multiple scattering and absorption effects. These conditions create instability in wireless communication performance and increase transmission losses during heavy rain periods. Since outdoor Wi-Fi networks operate continuously in open environments, they become highly vulnerable to environmental interference and atmospheric attenuation effects [2], [5].

Several studies investigate the influence of weather conditions on outdoor wireless local area networks and confirm that meteorological variables strongly affect network performance. Bri et al. analyze outdoor WLAN systems and report that rain, humidity, and temperature variations reduce signal quality and communication stability. Their findings indicate that environmental conditions produce fluctuations in RSSI values, packet loss, and throughput degradation during adverse weather situations. Yoo et al. also observe that rain and wind significantly influence RSSI measurements in wireless sensor networks, especially over long-distance outdoor communication links. These studies confirm that weather-related attenuation does not only affect high-frequency satellite systems but also impacts common wireless communication technologies such as Wi-Fi networks. Nevertheless, many previous studies focus only on general WLAN behavior without specifically analyzing signal attenuation characteristics in dynamic outdoor Wi-Fi environments [6], [7], [20].

The development of modern Wi-Fi technologies such as Wi-Fi 6 and Wi-Fi 7 introduces higher transmission capacity, lower latency, and wider channel bandwidths for outdoor deployments. Adame et al. evaluate Wi-Fi 6/7 performance in high-density outdoor environments and demonstrate significant improvements in network efficiency and throughput. However, the increasing use of higher frequencies also introduces stronger susceptibility to attenuation and propagation losses under dynamic weather conditions. Millimeter-wave communication studies conducted by Samimi and Rappaport reveal that higher-frequency wireless systems experience substantial path loss and environmental sensitivity during outdoor propagation. Al-Hourani and Kandeepan further demonstrate that weather conditions severely affect millimeter-wave propagation performance, especially under rainfall and atmospheric disturbances. These findings indicate that future outdoor Wi-Fi deployments require more detailed attenuation analysis to ensure communication stability and service quality [11], [18], [19], [24].

Recent advancements in wireless network analysis increasingly integrate machine learning, digital twins, and predictive modeling techniques to optimize communication systems. Trînc proposes a transformer-based surrogate modeling approach for outdoor Wi-Fi 7 network planning using ray-tracing and machine learning methods. Konak also applies deep learning models for wireless signal prediction in Wi-Fi positioning systems and demonstrates improved signal estimation capability. These studies indicate that intelligent prediction systems can improve network planning and signal optimization under complex propagation environments. However, many predictive approaches still prioritize spatial modeling and positioning accuracy rather than analyzing the direct influence of dynamic weather conditions on outdoor Wi-Fi attenuation. As environmental variability continues to increase, integrating weather-based signal analysis into wireless prediction models becomes an important research direction [12], [16].

The growing adoption of IoT and smart monitoring systems also increases the need for reliable outdoor wireless communication. Setiawan et al. develop an IoT-based rainfall monitoring system that depends heavily on stable wireless data transmission for real-time environmental observation. In practical deployment, unstable outdoor wireless communication can reduce monitoring accuracy and increase data transmission delays. Furthermore, wireless sensor networks require energy-efficient communication strategies because unstable signal conditions increase retransmission rates and energy consumption. Sendra et al. explain that wireless sensor network optimization strongly depends on communication stability and transmission efficiency. Therefore, analyzing the relationship between signal attenuation and dynamic weather conditions becomes important not only for Wi-Fi communication quality but also for maintaining efficient IoT-based environmental monitoring systems [1], [8].

In addition to weather-related interference, outdoor wireless communication systems also encounter challenges related to spectrum coexistence and signal competition. Kim and Dietrich analyze the coexistence between outdoor Wi-Fi and radar systems at the 3.5 GHz band and reveal that external interference significantly affects signal reliability. Similarly, Yang et al. develop passive client density mapping methods for outdoor Wi-Fi environments and demonstrate the complexity of signal behavior in dense outdoor deployments. These findings indicate that outdoor Wi-Fi quality depends on multiple interacting variables, including environmental conditions, propagation loss, interference, and user density. Although several studies analyze specific propagation factors individually, comprehensive research that simultaneously examines outdoor Wi-Fi signal quality and attenuation behavior under dynamic weather conditions remains limited [10], [15].

Based on these challenges, this study focuses on analyzing the quality of outdoor Wi-Fi signals and attenuation characteristics under dynamic weather conditions. This study investigates how environmental variables such as rainfall, humidity, and atmospheric changes influence RSSI, signal stability, and attenuation levels in outdoor wireless communication systems. Unlike previous studies that mainly focus on satellite communication, millimeter-wave systems, or general WLAN performance, this research specifically evaluates outdoor Wi-Fi propagation behavior in realistic environmental conditions. The results of this study are expected to provide a deeper understanding of weather-induced attenuation patterns and contribute to the development of more adaptive, reliable, and efficient outdoor wireless communication systems for future smart environments [4], [6], [18], [21],[22], [23].

2. Related Works

Rappaport established one of the fundamental theoretical frameworks for wireless communication propagation and signal behavior in outdoor environments. The study explained how free-space loss, multipath fading, diffraction, scattering, and atmospheric absorption significantly influenced wireless signal quality. The work also described how environmental conditions altered propagation characteristics and affected communication reliability. This contribution became an important reference for later wireless network studies because it provided strong mathematical and conceptual models for signal attenuation analysis. However, the study mainly focused on general wireless propagation principles and did not specifically evaluate modern outdoor Wi-Fi performance under dynamic weather conditions such as rain intensity variation or humidity fluctuation. [3]

Bri et al. investigated the influence of weather conditions on outdoor WLAN performance through experimental measurements. The study analyzed parameters such as temperature, humidity, wind, and rainfall to determine their effects on wireless throughput and signal strength. The results showed that rainfall and humidity reduced network stability and caused fluctuations in received signal levels. The strength of this study lay in its real-world outdoor WLAN experimentation and direct performance measurements. The work successfully demonstrated that environmental variables significantly affected communication quality. However, the study focused on conventional WLAN systems and did not explore newer Wi-Fi technologies such as Wi-Fi 6 or Wi-Fi 7. The analysis also remained limited to short-term observations without integrating predictive modeling approaches. [6]

Bri, Ramos, Lloret, and Garcia-Pineda further expanded outdoor wireless studies by analyzing meteorological variables and their relationship with WLAN performance. The researchers found that humidity and rain intensity directly influenced packet loss and network degradation. Their work provided quantitative observations that linked environmental changes with signal attenuation. The study contributed important evidence that outdoor wireless networks required adaptive management under unstable weather conditions. The experimental approach improved understanding of practical network behavior in real environments. Nevertheless, the research did not investigate attenuation modeling in tropical regions where rainfall intensity is typically higher and more variable. The study also did not incorporate advanced signal prediction or machine learning methods for dynamic adaptation. [7]

Islam, Rahman, and Farid specifically evaluated outdoor Wi-Fi links under different weather conditions. The researchers measured throughput, latency, packet delivery, and signal strength during clear and rainy conditions. Their findings showed that rainfall significantly degraded Wi-Fi performance and reduced communication reliability. The study directly related to outdoor Wi-Fi quality assessment because it focused on practical network performance evaluation in varying environmental conditions. The researchers successfully demonstrated the relationship between weather variability and network instability. However, the study only analyzed conventional Wi-Fi infrastructure and limited environmental parameters. It also lacked deeper attenuation analysis and did not investigate the influence of future high-frequency outdoor Wi-Fi technologies. [4]

Amrullah, Setijadi, and Hendrantoro analyzed rain attenuation in tropical regions using multiple scattering and absorption effects. The study provided an important propagation model for understanding how heavy rainfall degraded wireless communication signals. The researchers demonstrated that tropical rain conditions produced significant attenuation, especially at higher frequencies. This work became highly relevant for outdoor wireless communication studies in tropical countries because it emphasized realistic environmental propagation effects. The study also strengthened attenuation modeling by integrating exponential drop size distribution analysis. However, the research concentrated mainly on theoretical propagation computation and satellite communication scenarios rather than practical outdoor Wi-Fi deployment measurements. [5]

Yoo, Cotton, and Scanlon experimentally examined the effects of rain and wind on RSSI performance in wireless sensor networks. Their results showed that environmental disturbances caused measurable signal degradation and unstable received signal strength. The study provided valuable empirical evidence regarding the sensitivity of wireless systems to dynamic outdoor conditions. One major strength of this work was the use of direct experimental observations that reflected real environmental interference. The research also highlighted that wireless communication systems required more adaptive mechanisms to maintain stable connectivity. Nevertheless, the work focused on wireless sensor networks instead of outdoor Wi-Fi systems and did not evaluate modern high-bandwidth communication standards. [20]

Al-Hourani and Kandeepan investigated the effect of weather on millimeter-wave propagation through experimental analysis. The researchers observed that rain and atmospheric conditions significantly increased propagation loss at higher frequencies. Their findings became increasingly important because modern Wi-Fi technologies continue to move toward higher-frequency communication systems that are more sensitive to environmental attenuation[24]. The study provided strong experimental validation of weather-related propagation challenges in outdoor communication networks. However, the research concentrated on millimeter-wave communication and did not specifically evaluate outdoor Wi-Fi quality metrics such as throughput, latency, or packet loss. The study also did not examine tropical climate behavior, which often presents more severe rainfall conditions. [18]

Recent studies by Adame, Bel, and Barceló explored Wi-Fi 6 and Wi-Fi 7 deployment performance in high-density outdoor environments. The researchers showed that modern Wi-Fi technologies improved throughput capacity, channel efficiency, and user connectivity. The study demonstrated the growing importance of advanced outdoor wireless infrastructure for public communication systems. Similarly, Trînc introduced machine learning and ray-tracing approaches for outdoor Wi-Fi 7 network planning and digital twin modeling. These studies provided significant advancements in outdoor wireless optimization and predictive analysis. However, both works mainly focused on network planning, deployment efficiency, and capacity enhancement rather than weather-induced attenuation analysis. The studies also provided limited investigation into how dynamic environmental conditions directly affected outdoor Wi-Fi signal quality and reliability [12], [25].

3. Proposed Method

1. Received Signal Strength Indicator (RSSI)

The proposed method in this study evaluates the quality of outdoor Wi-Fi signals under dynamic weather conditions using the Received Signal Strength Indicator (RSSI). RSSI represents the received power level from the access point to the client device and is measured in decibel-milliwatts (dBm). The received signal strength can be expressed as:

$$RSSI = P_t + G_t + G_r - L_p - L_w \quad (1)$$

where P_t denotes the transmitter power, G_t represents the transmitter antenna gain, G_r indicates the receiver antenna gain, L_p is the free-space path loss, and L_w represents additional attenuation caused by environmental and weather factors such as rain, humidity, and wind. Higher RSSI values approaching $0dBm$ indicate stronger received signals, while lower negative values indicate weaker signal quality.

The free-space propagation loss used in this study is calculated using the logarithmic propagation model:

$$L_p = 32.44 + 20\log_{10}(f) + 20\log_{10}(d) \quad (2)$$

where L_p is the path loss in dB, f is the transmission frequency in MHz, and d is the transmission distance in kilometers. To analyze weather influence, this study incorporates rain attenuation into the propagation model using:

$$A_r = kR^{\alpha}d \quad (3)$$

where A_r denotes rain attenuation (dB), R represents rainfall intensity (mm/h), d is the link distance, and k and α are frequency-dependent coefficients based on ITU-R propagation standards. This approach allows the study to quantitatively analyze the relationship between weather variations and outdoor Wi-Fi signal degradation.

2. Quality of Service (QoS)

Quality of Service (QoS) is the ability of a particular network to provide optimal service according to standards in relation to network capacity, overcoming jitter and delay. QoS refers to the network's capability to provide better service to certain network traffic through various technologies. The purpose of QoS is to meet the needs of different services, which use the same infrastructure [7].

Table 1 QoS Values and Percentages

Mark	Percentage (%)	Index
3,8-4	95-100	Very satisfactory
3-3,79	75-94,75	Satisfying
2-2,99	50-74,75	Less satisfactory
1-1,99	25-49,75	Signs

The QoS parameters used in measuring a network are as follows:

a. Throughput, namely speed (rate) effective data transfer, which is measured in bps (bit per second). Throughput is the total number of successful packet arrivals observed at a destination during a given time interval divided by the duration of that time interval [8].

Table 2. Value Categories Throughput

Category	Throughput (bps)	Index
Very good	100	4
Good	75	3
Currently	50	2
Signs	< 25	1

b. Packet Loss is a parameter that describes a condition that shows the total number of lost packets that can occur due to collision and congestion on the network [8].

Table 3. Value Categories Packet Loss

Category	Packet Loss (%)	Index
Very good	0	4
Good	3	3
Currently	15	2
Signs	25	1

c. Delay (Latency) is the time required for data to travel the distance from origin to destination. Delay can be influenced by distance, physical media, I have accumulated also long processing time [8].

Table 4. Value Categories Delay

Category	Delay (ms)	Index
Very good	< 150	4
Good	150 - 300	3
Currently	300 - 450	2
Signs	> 450	1

d. Jitter is the variation in packet arrival, this is caused by variations in queue length, in data processing time, and also in the time of reassembling packets at the end of the journey [8].

Table 5. Value Categories Jitter

Category	Jitter (ms)	Index
Very good	0	4
Good	0 - 75	3
Currently	75 - 125	2
Signs	125 - 225	1

3. Rain Attenuation

Rain attenuation is a phenomenon of decreasing the strength of radio wave signals when propagating through an atmosphere containing water particles. The interaction between radio waves and water droplets causes absorption and scattering processes, so that the signal energy received by the receiving device is reduced [23]. Rain attenuation is calculated using a discrete rain attenuation model expressed by equation [22].

$$A(n) = \sum_{m=0}^{N-1} (a\, R_{(m)}^{b}) * \Delta L_m \quad (4)$$

Where:

- A(n) : total rain attenuation (dB)
- a and b : damping coefficients
- R : rainfall intensity (mm/hour)
- ΔLm : length of the signal path on the m-th segment.

4. Experimental Setup

This paper conducted the experimental study at the Ayana Resort Bali Hotel located in the Jimbaran coastal area, Bali, where the UniFi Outdoor Wi-Fi network has been widely deployed to provide internet access in public outdoor environments. Unlike previous laboratory-based studies that only analyzed indoor scenarios with limited distance variations, our proposed method evaluated outdoor Wi-Fi performance in real environmental conditions with dynamic weather changes. The selected location provides representative environmental characteristics, including open-space propagation, coastal atmospheric conditions, and relatively high rainfall intensity. These conditions allowed us to analyze the influence of weather attenuation on outdoor wireless communication more realistically. Our proposed method utilized RSSI measurements to evaluate signal quality under varying environmental conditions and to investigate how modern outdoor Wi-Fi equipment adapts to rain attenuation according to the ITU-R P.838-3 propagation model [21].

We performed data collection under three different weather scenarios consisting of sunny conditions, light rain, and heavy rain. We conducted all measurements at identical observation points to ensure consistent comparisons and to minimize bias caused by location differences. Our proposed method measured RSSI degradation caused by rain attenuation and environmental interference during each weather condition. The experimental setup also supports the integration of outdoor Wi-Fi as User Equipment (UE) within future 5G communication environments by evaluating signal stability in real deployment scenarios. The obtained results demonstrate that weather intensity significantly affects outdoor Wi-Fi signal quality, where increasing rainfall produces higher attenuation and lower RSSI values. Table 6 presents the experimental setup used in this study.

Table 6. Experimental Setup of Outdoor Wi-Fi Measurements

Parameter	Description
Research Location	Ayana Resort Bali Hotel, Jimbaran, Bali
Network Type	UniFi Outdoor Wi-Fi
Environment	Outdoor coastal public area
Weather Conditions	Sunny, Light Rain, Heavy Rain
Measurement Parameter	RSSI (dBm)
Measurement Points	Fixed observation points
Objective	Analyze signal attenuation under dynamic weather
Communication Scenario	Outdoor Wi-Fi / 5G UE support
Measurement Method	Repeated real-time RSSI monitoring

5. Results and Analysis

1. Network Topology

The network topology in this study was designed using UniFi Outdoor Access Points (UAPs) placed in public areas of the Ayana Resort Hotel, Bali. The WiFi devices used consisted of several access points with 2.4 GHz and 5 GHz frequency configurations, connected to the backbone system via a switch and a main router.

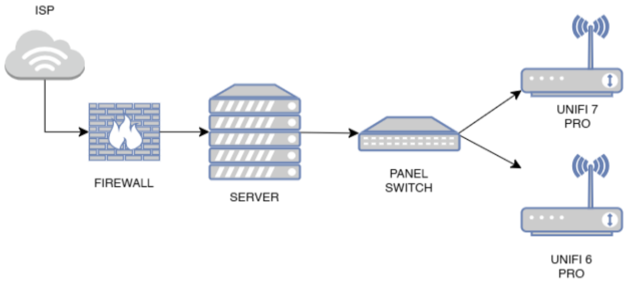
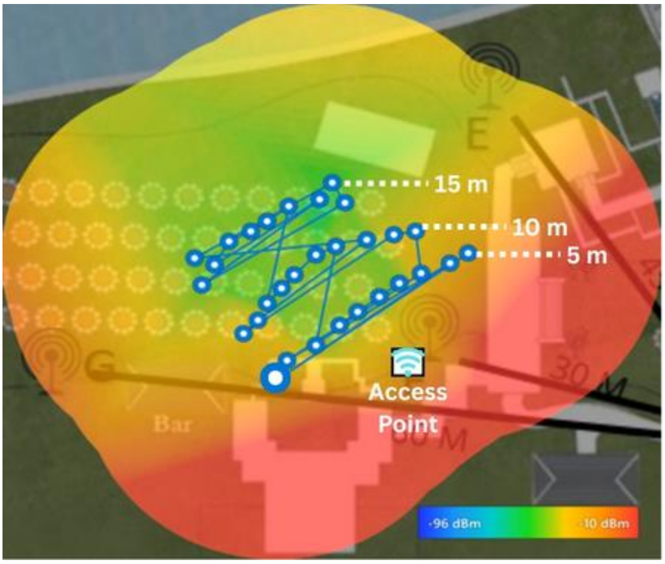


Figure 1. WiFi Network Topology

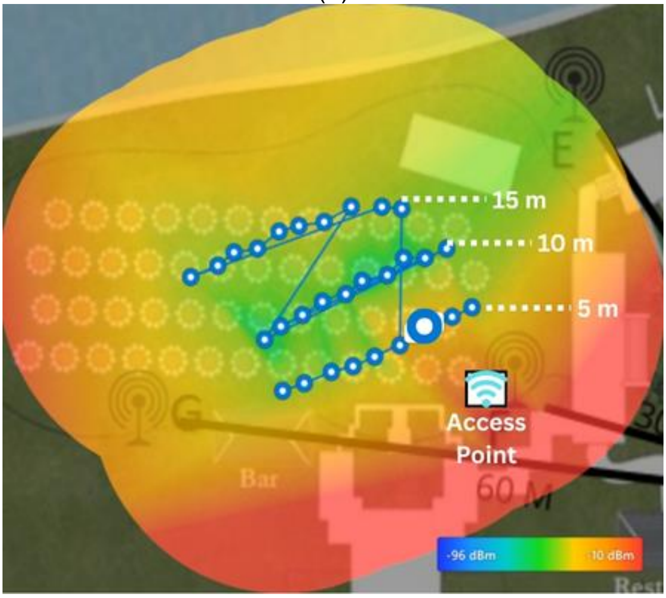
The ISP's internet connection passes through a firewall for security, then is routed to a server serving as a management center, and then to a switch panel that manages distribution to two primary access points (Unifi 6 Pro and Unifi 7 Pro) on the 2.4 GHz and 5 GHz frequencies. Both APs are strategically placed in the hotel's public areas.

2. Map *Heatmap*

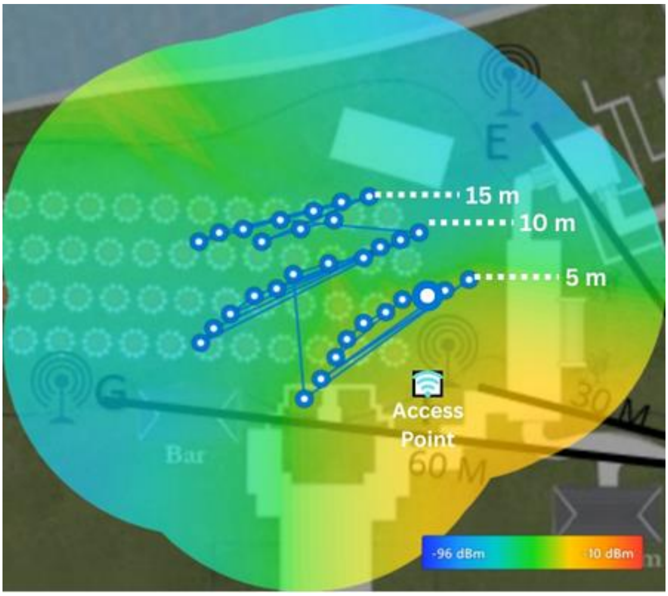
Map making *heatmap* NetSpot aims to visualize the spatial distribution of WiFi signal strength (RSSI) under various weather conditions. This color gradient visualization helps identify areas with good signal quality and those experiencing significant attenuation, as well as compare the performance of UniFi 6 Mesh and UniFi 7 Pro devices in different environments.


15 m
10 m
5 m
Access Point
Bar
-96 dBm
-10 dBm

(a)

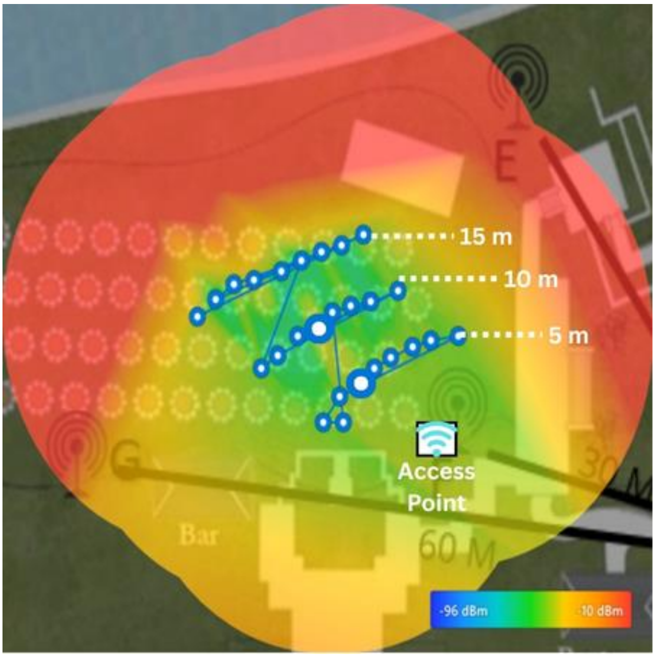

15 m
10 m
5 m
Access Point
Bar
-96 dBm
-10 dBm

(b)

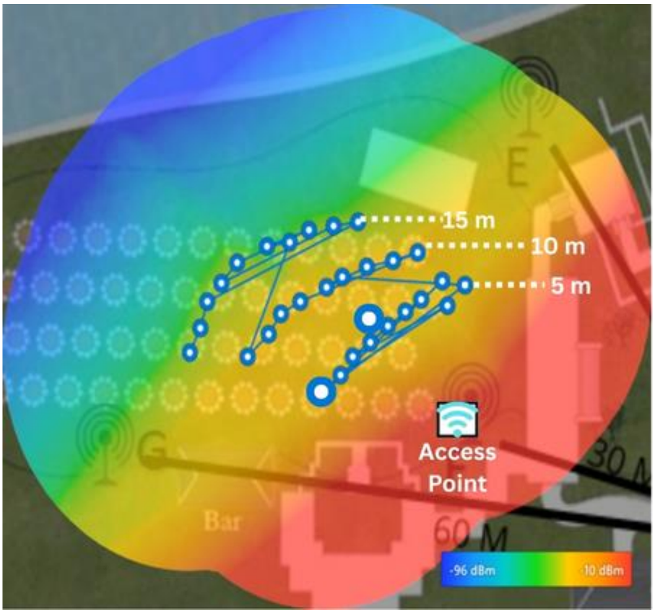


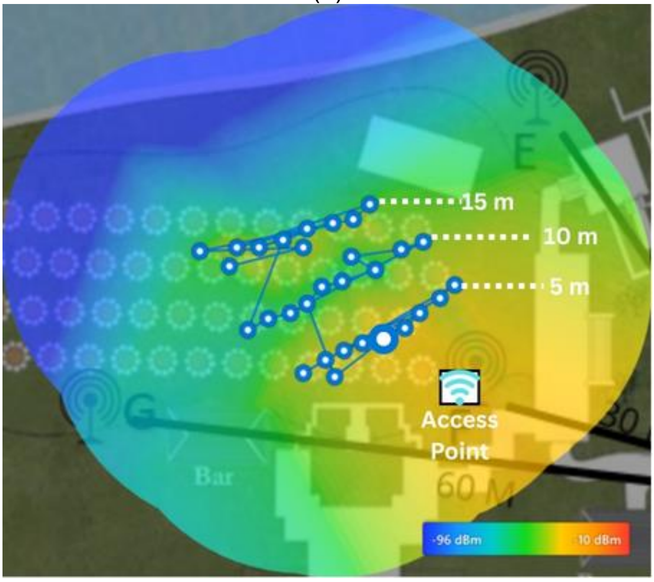
(c)

Figure 2. UniFi U6 Mesh Heatmaps of Sunny Weather (a), Light Rainy Weather (b), and Heavy Rainy Weather (c).



(a)



(b)


(c)

Figure 3. UniFi U7 Pro Heatmaps of Sunny Weather (a), Light Rainy Weather (b), and Heavy Rainy Weather (c).

3. QoS measurement

The QoS parameter measurement results showed an index value of 4 for each parameter based on the TIPHON standard. Thus, the average QoS index value at the Ayana Resort Hotel is 4, which is included in the "Very Satisfactory" category.

Table 7. QoS Parameter Value Results

Parameter	Mark	Index	Information
Throughput	22.17 Mbps	4	Very good
Packet Loss	0.015%	4	Very good
Delay	0.41 ms	4	Very good
Jitter	0.000 ms	4	Very good
Average		**4**	**Very satisfactory**

4. RSSI Value Analysis

Data collection was carried out in three weather conditions, namely sunny, light rain, and heavy rain. The results of RSSI measurements at two points with a frequency of 2.4 GHz and 5 GHz showed the highest value during sunny weather at U7 2.4 GHz reaching -39.32 dBm. During light rain there was a decrease in RSSI, and the decrease was more significant during heavy rain, such as at U6 5 GHz dropping from -49.22 dBm during sunny weather to -54.77 dBm during light rain and then -60.42 dBm during heavy rain.

Table 8. RSSI Value Results Based on Weather Conditions

Weather Conditions	Date	Average RSSI Value			
		U6 (dBm)		U7 (dBm)	
		2,4 GHz	5 GHz	2,4 GHz	5 GHz
Sunny Weather	5/11/2025	-50.58	-49.22	-39.32	-40.80
Light Rain Weather (<20mm)	6/11/2025	-59.86	-54.77	-54.80	-47.92
Heavy Rain Weather (>20mm)	8/01/2026	-62.94	-60.42	-55.25	-62.61

Increasing rainfall intensity is directly proportional to a decrease in RSSI values. The 5 GHz frequency experiences greater attenuation than the 2.4 GHz frequency, especially during heavy rain. This is consistent with radio wave propagation theory and the ITU-R P.838-3 recommendation that attenuation due to absorption and scattering by raindrops increases at higher frequencies. Thus, the measurement results demonstrate that rainy weather conditions, especially high intensity, significantly impact the performance of outdoor WiFi networks.

4. Rain Attenuation Analysis

Signal attenuation measurements on UniFi 6 Mesh (U6) and UniFi 7 Pro (U7) devices at 2.4 GHz and 5 GHz frequencies were carried out under light rain (<20 mm/hour) and heavy rain (>20 mm/hour) conditions. The results show that increasing rain intensity causes greater attenuation, with the 5 GHz frequency being more susceptible than 2.4 GHz. In heavy rain, the highest attenuation occurs at the U7 5 GHz frequency, which jumps drastically from -7.12 dB (light rain) to -21.81 dB. Meanwhile, at the U6 5 GHz frequency, the attenuation increases from -5.54 dB to -11.20 dB. This indicates that different devices and frequencies have different levels of resistance to rain attenuation.

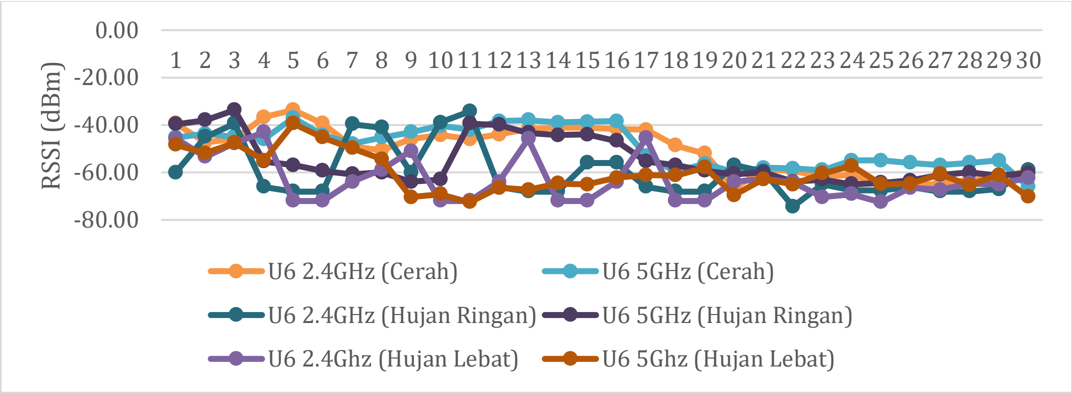


Figure 4. UniFi 6 Mesh Signal Strength Graph

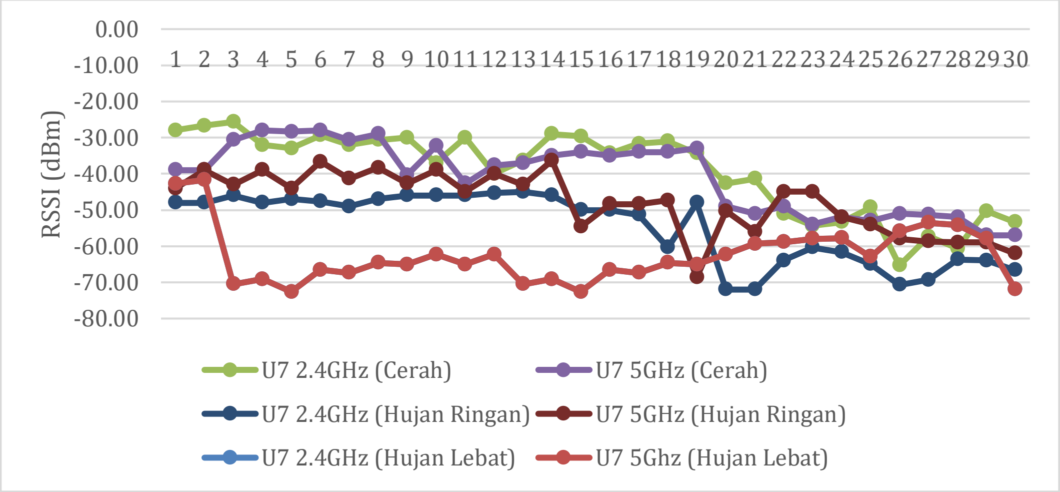


Figure 5. UniFi 7 Pro Signal Strength Graph

The signal strength graphs confirm that both devices experience RSSI degradation during rain compared to sunny weather. The UniFi 6 Mesh exhibits a more extreme and fluctuating degradation, particularly at 5 GHz, while the UniFi 7 Pro has a more stable trend with better overall RSSI values. This aligns with ITU-R P.838-3 theory that attenuation increases with rain intensity, particularly at high frequencies. The study also strengthens the possibility that devices with advanced antennas, beamforming, and adaptive protocols, such as the UniFi 7 Pro, can minimize the impact of rain attenuation, particularly at 5 GHz, making them more robust for outdoor WiFi network deployments.

5. Comparison of Actual and Theoretical Rain Attenuation

Rain attenuation was calculated using the model with parameters of rainfall, frequency, and path length of 30 meters [23]. In light rain, the theoretical attenuation is 0.000013 dBm at 2.4 GHz and 0.00012 dBm at 5 GHz. In heavy rain, the attenuation increases to 0.000046 dBm at 2.4 GHz and 0.00042 dBm at 5 GHz. These results indicate that the theoretical attenuation is very small due to the short path length, but the 5 GHz frequency is still more vulnerable than 2.4 GHz according to propagation theory.

Table 9. Results of Theoretical Rain Attenuation Analysis

Weather	Frequency (GHz)	Rainfall (mm/hour)	k (a)	a (b)	Specific Attenuation (dBm/km)	Track Length (km)	Rain Attenuation (dBm)
Light rain	2,4 GHz	5	0,0001	0,91	0,00043	0,03	0,000013
	5 GHz	5	0,001	0,88	0,0041	0,03	0,00012
Heavy Rain	2,4 GHz	20	0,0001	0,91	0,00153	0,03	0,000046
	5 GHz	20	0,001	0,88	0,01393	0,03	0,00042

Table 10. Comparison of Actual and Theoretical Damping

Weather	Frequency (GHz)	Actual Rain Attenuation (dBm)		Theoretical Rain Attenuation (dBm)
		U6	U7	
Light rain	2,4 GHz	-9.28	-15.48	0,000013
	5 GHz	-5.54	-7.12	0,00012
Heavy Rain	2,4 GHz	-12.36	-15.93	0,000046
	5 GHz	-11.20	-21.81	0,00042

The actual attenuation measured in the field is much greater than the theoretical attenuation. In light rain, the actual attenuation of U6 ranges from -12.33 dBm to -15.67 dBm, while U7 ranges from -13.33 dBm to -13.67 dBm. In heavy rain, the actual attenuation reaches -20 dBm to -29 dBm. Meanwhile, the maximum theoretical attenuation is only 0.00042 dBm. This significant difference indicates that the RSSI decrease cannot be explained by purely atmospheric rain attenuation. According to Amrullah et al., significant rain attenuation occurs at frequencies >10 GHz, while at WiFi frequencies (<10 GHz) the contribution is small [15]. However, a study by Bri et al., proves that outdoor WLAN performance is still influenced by meteorological factors. The large RSSI decrease during rain is more due to non-atmospheric factors such as wet antennas (*rain wetting*), change *multipath*, high humidity, wet surface reflection, and device characteristics [16]. Therefore, the resilience of outdoor WiFi devices to rain must be tested empirically in the field, not only based on operating frequency.

6. Conclusion

This study successfully analyzed the quality of outdoor Wi-Fi networks under dynamic weather conditions using QoS, RSSI, and rain attenuation measurements on UniFi 6 Mesh and UniFi 7 Pro devices. Our proposed method can produce comprehensive evaluations of outdoor wireless network performance by combining network quality parameters with environmental propagation analysis. The QoS results demonstrated excellent network performance, where throughput reached 22.17 Mbps with packet loss of 0.015%, delay of 0.41 ms, and jitter of 0.000 ms. Based on the TIPHON standard, all parameters achieved an index value of 4 and were categorized as “Very Satisfactory.” These findings indicate that the deployed outdoor Wi-Fi infrastructure can maintain stable communication quality despite environmental variations and outdoor operational challenges.

This paper also demonstrated that rainfall intensity significantly affects outdoor Wi-Fi signal quality and attenuation characteristics. We observed that increasing rain intensity consistently reduced RSSI values at both 2.4 GHz and 5 GHz frequencies. Our proposed method can harvest real environmental measurements showing that the 5 GHz frequency experiences more severe attenuation than 2.4 GHz during heavy rain conditions. The highest RSSI degradation occurred at the U7 5 GHz channel, which decreased from -40.80 dBm during sunny weather to -62.61 dBm during heavy rain. Similarly, rain attenuation increased substantially during high rainfall intensity, where the U7 5 GHz experienced attenuation up to -21.81 dB. These findings are consistent with radio propagation theory and ITU-R P.838-3 recommendations, which explain that higher frequencies are more vulnerable to absorption and scattering effects caused by rain droplets. Furthermore, this study confirmed that advanced outdoor Wi-Fi devices equipped with adaptive antennas and beamforming technologies can provide better signal stability under challenging weather conditions.

Our proposed method further revealed that actual field attenuation values were significantly higher than theoretical attenuation values calculated using the propagation model. The theoretical attenuation remained extremely small because of the short transmission path length, while actual attenuation reached more than -20 dBm during heavy rain. This study can produce important evidence that outdoor Wi-Fi degradation is not solely caused by atmospheric rain attenuation, but is also strongly influenced by non-atmospheric factors such as wet antenna surfaces, humidity, multipath changes, reflection from wet objects, and device hardware characteristics. Therefore, this paper emphasizes that empirical outdoor testing is essential for evaluating the real robustness of Wi-Fi systems in dynamic weather environments. The findings of this study can support the development of more reliable outdoor wireless infrastructures, particularly for smart tourism, public hotspot deployment, and future 5G-integrated outdoor communication systems.

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