

Experimental Characterisation of 802.11a/g Indoor Propagation Patterns

Hasanain A. H. Al-Behadili
University of Misan, Iraq



DOI : <https://doi.org/10.61796/ipteks.v3i3.510>



Sections Info

Article history:

Submitted: March 22, 2026
Final Revised: April 27, 2026
Accepted: May 28, 2026
Published: June 27, 2026

Keywords:

Wireless Local Area Network (WLAN)
Path loss
Radio propagation
Indoor wireless communication
Frequency bands

ABSTRACT

Objective: The technology of wireless local area network (WLAN) has developed rapidly, and it has become an interesting research topic. The knowledge of the radio propagation characteristics and the environmental information, including the layout of the rooms, the construction materials, and furniture arrangement, is a prerequisite for designing and developing the indoor wireless communication system. So, an exhaustive measurement is essential for studying the radio propagation characteristics. This thesis centres on the path loss for 2.4GHz and 5GHz frequency bands used in wireless local area network (WLAN), 802.11a and 802.11g standards. **Method:** Measurements under LOS and OBS environments were conducted, and path loss was calculated. The best fit plots to the measured results are presented. The results from simulations by various models are also examined, and a comparison concerning the accuracy of the models is made. The penetrating loss for some typical partitions is also measured. **Results:** Some findings are concluded. It is found that the 802.11a 5 GHz frequency band actually suffers more path loss than the 802.11g 2.4 GHz frequency band. In a complex indoor environment, the difference is diminished since various reflections, deflections, and scatter all contribute to signal propagation. **Novelty:** The results from simulations by various models are also examined, and a comparison concerning the accuracy of the models is made. The penetrating loss for some typical partitions is also measured.

INTRODUCTION

The first generation of the WLAN (wireless local area network) technology is 802.11b standard with a maximum data rate of 11 Mbps. It shares the unlicensed Industrial, Scientific and Medical (ISM) band of 2.4-2.5 GHz with cordless phones, microwave ovens, and other home and office electronics [1]. Therefore, the interference problem may degrade its performance. Also, the 11Mbps data rate cannot satisfy the needs of some high-capacity transmissions. 802.11a standard emerges in late 2001[1-3]. Its maximum supporting 54Mbps data rate is four times more than the 802.11b standard, and it is operated in a less occupied Unlicensed National Information Infrastructure (UNII) band (5.15-5.35 GHz and 5.725-5.825 GHz) to be free from the interference problem [2-4]. However, high carrier frequency suffers from high path loss; in theory, attenuation loss is doubled when operating twice the frequency. Then, after the 802.11g standard was released by IEEE, it is operated at the ISM band but can support a maximum up to 54Mbps data rate as 802.11a [1]. Its attractive characteristics make it the most popular WLAN technology. However, 802.11a can still keep its position depending on its special advantages. Sometimes it is needed to construct a network combining these two standards. So, it is necessary to get an understanding of the propagation characteristics in the indoor environment to determine a reasonable guideline to design and develop an indoor WLAN [4].

Indoor propagation is different from an outdoor situation, and the coverage is affected by the area's geography [5]. This gives rise to a problem of frequency reuse in a three-dimensional space between floors. Finally, operating with millimetre wave frequency means little change in the propagation path may result in substantial change in path loss, delay, and other propagation characteristics [5]. So, precise knowledge of the geography of the building is necessary for prediction.

The experimental characterisation of indoor radio wave propagation remains a basic challenge in optimising wireless networks, specifically for traditional and foundational standards such as IEEE 802.11a and 802.11g that utilise the 5 GHz and 2.4 GHz bands, respectively. Over the past several years, researchers have continually investigated these frequencies to recognize or express the difference between older deterministic frameworks and modern empirical observations. For example, recent studies highlight that while the protocol-level features of modern Wi-Fi generations have significantly progressed, the physical layer performance remains basically restricted by frequency-dependent structural attenuation, multipath fading, and line-of-sight (LoS) degradation [6]. Empirical platforms across multi-storey environments confirm that the 2.4 GHz band (utilized by 802.11g) retains exceptional penetration capabilities over long distances and thick obstacles, whereas the 5 GHz band (utilized by 802.11a) delivers higher short-range performance but reduces rapidly under multi-wall blockages [7].

To precisely compute these indoor propagation inconsistencies, several indoor path loss frameworks have been re-evaluated. Empirical substantiation demonstrates that a single, oversimplified propagation model cannot capture the environmental divergence introduced by complex layout geometries [8]. As a substitute, site-specific approaches such as the Motley-Keenan and COST 231 Multi-Wall models are required to introduce explicit linear loss factors for every partition or floor traversed by the signal [9]. Moreover, modern optimization techniques have leveraged multi-objective genetic algorithms to refine empirical path loss parameters, revealing that traditional log-distance frameworks often generate considerable prediction errors unless fine-tuned with site-specific geographic metrics [10].

The effect of localised physical abnormality on signal propagation patterns represents another key domain of contemporary study. Probes into human mobility and spatial structural design show that while static environmental obstructions dominate path loss, human movement pattern variations introduce dynamic, time-varying fading characteristics that alter the instant received signal strength indicator (RSSI) values [11]. To offset this capriciousness, recent modelling frameworks have integrated geostatistical spatial interpolation, such as kriging, to build predictive coverage maps based on localised RSSI samples rather than relying entirely on geometric ray-tracing tools [12]

Simultaneously, passive indoor tracking setups and ranging frameworks have heavily prioritised understanding the underlying propagation environment. Modern developments in hybrid positioning rely on capturing the raw spatial variance of RSSI and Round-Trip Time (RTT) across the 2.4 GHz and 5 GHz spectra to establish localised fingerprint regions [13]. This is significant since the standard 802.11mc Fine Timing

Measurements are subject to profound multipath errors when operating in non-line-of-sight (NLoS) indoor corridors [14]. To manage these issues in widely dense networks, recent automated deployment schemes utilise robotic site surveying to systematically capture bidirectional signal reciprocal values across various antenna orientations [15]. Ultimately, the embracing of aerial and unmanned systems operating across the 2.4/5.2 GHz bands emphasises that polarisation misalignment and reflections from concrete walls or high-rise building structures severely compound signal degradation during dynamic operations [16]. To sum up, these modern studies demonstrate that precise experimental characterisation remains vital to uncovering how building geometry and frequency characteristics dictate real-world 802.11a/g propagation limits. This paper displays an experimental characterisation of indoor propagation patterns for IEEE 802.11a and 802.11g networks by analyzing how frequency-dependent structural attenuation, multipath fading, and building geometries impact real-world signal behavior.

This paper focuses on the propagation loss for both frequencies. In free space, the difference in path loss for the 2.4 GHz band and the 5 GHz band is approximately 7 dB. However, in a dense indoor environment, multiple propagation, reflection, scattering, and diffraction may all occur, and the difference in path loss between these two frequency bands is not as clear as expected. The measurements are conducted in various environments at both frequencies, and then some models are employed to fit and explain the measured results. The first section explains the background of radio propagation and introduces some indoor propagation models. The second section describes the measurement equipment, approach, and classifies the measurement scenarios. In the third section, the measurement results are presented, and the loss exponent n for each scenario is derived in a minimum mean square (MMS) sense. The last section discusses the measurement results using the models given in Section 2 and concludes the findings.

RESEARCH METHOD

A. Measurement equipment

a. Transmitter

Linksys Dual-Band Wireless A+G Access Point was chosen as the transmitter. It uses the standards of IEEE 802.11a, IEEE802.11b, draft IEEE 802.11g, 802.3 and IEEE 802.11u.

It can be operated at the 2.4 GHz radio band and 5 GHz band at the same time. The transmitter power for 802.11a standard is a maximum 16dBm, and for the 802.11g standard is typically 14dBm. The 2.4GHz and 5GHz integrated antenna must operate with a separation distance of at least 20 cm from all persons using the cable provided.

b. Receiver

The receiver of this wireless system is a laptop, Dell INSPIRON 700m with an external PC card, which is a Linksys Dual-Band Wireless A+G Notebook Adapter. The receiver antenna is a SMA connector, and the gain is 12 dBm.

c. Test software

NetStumbler v4.0 is a tool operated in the Windows environment and allows the user to detect Wireless Local Area Networks (WLAN) using 802.11b, 802.11a and 802.11g. It can show the current SNR (signal-to-noise ratio) in dB, signal strength and noise strength in dBm.

B. Measurement approach

Measurements were conducted at Misan University under low-activity hours to minimise human interference. Both the transmitter and receiver were kept stationary to ensure a quasi-stationary channel.

Key Setup Details:

- **Antenna Heights:** Transmitter at 0.85m; receiver at 0.72m.
- **Procedure:** The transmitter remained fixed while a dual-band receiver moved along a pre-measured grid. Physical distances were pre-calculated to map signal strength to distance.
- **Averaging Method:** To find the average signal strength at each position, four measurements were taken at the corners of a 900 cm^2 square centred on the test point and then averaged.
- **Scale:** The total number of measurements was proportional to the size of each location.

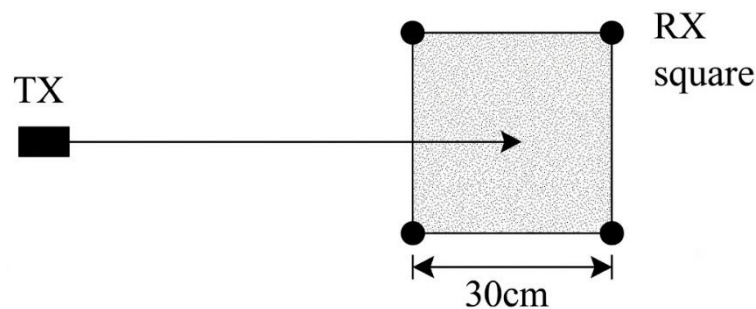


Figure 1. Measurement scheme.

C. Loss exponent measurement

- LOS measurements: the receiver was moved at an interval of 1m.
- NLOS measurements: measurements can only be taken where the arrangements of furniture make it possible, and the minimum interval is 1m.
- For each measured point, the mean path loss value was calculated and plotted as a function of the distance from the transmitter. The best fit plot was derived in the minimum-mean-square-error (MMSE) sense between the measured values and prediction values.
- Fix the transmitter in the corridor, and the receiver 1m far away. The signal strength is measured at the point, and path loss is calculated. Since a strong LOS component can predominate any reflection or scatter component, this reference path loss is used to simulate path loss in various models.

D. Floor attenuation measurements

The floor in the faculty building is 3m in height and is a concrete structure covered with unglazed tiles. Fix the transmitter on the fifth floor and change the location of the receiver towards upstairs and downstairs, respectively. Try to make sure the transmitter and receiver are vertically on the same line. The attenuation due to a certain number of floors is the average of the attenuation values measured from floors above and below. For example, if L represents the attenuation between the i th and j th floor, then attenuation due to one floor is the average of L_s and L_{sa} . Finally, the plot of the attenuation was derived to investigate the propagation between multi-floors.

E. Partition attenuation measurements

Penetrating loss can be defined as the difference between the received power assuming free space and the actually received power. Fix the transmitter on one side of the partition at a distance of 3m away, and fix the receiver on the other side of the partition, 1 m away. Record the received power and calculate the attenuation according to the definition above. For each type of partition, move the transmitter and receiver simultaneously and get three results to take the average as the final value. It is shown in Figure 2.

The penetrating loss for doors and walls was measured. The typical doors in the faculty building are glass doors with a metal frame and a fire door with a window. For the measurements of walls, three kinds were chosen, and they are a non-load-bearing plasterboard wall, a 16 cm brick wall and a 46 cm load-bearing concrete wall.

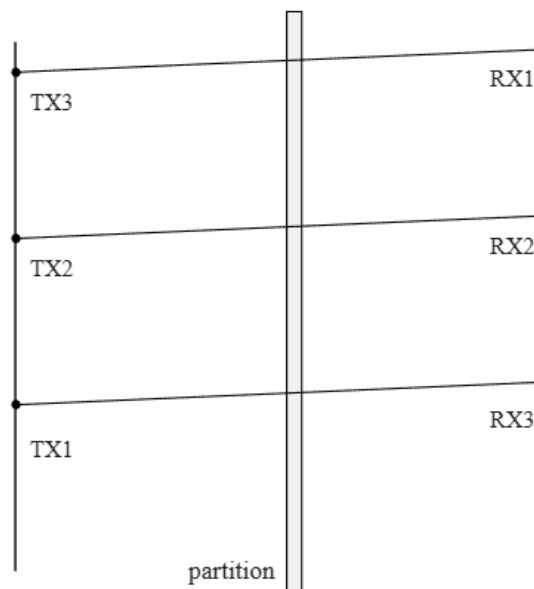


Figure 2. Top view of the measurement scheme for penetrating measurement
Scenario classification and description.

Basically, all indoor radio propagation can be classified into two categories: LOS when the antennae of the transmitter and receiver are within the line of sight of each other and OBS when they are not. To develop an indoor propagation model, measurement environments should be classified in detail into five scenarios: open corridor, closed corner, corridor corner, large hall, office cubic and laboratory. The

measurements were conducted in the engineering tower of Leicester University and a corridor in the FJ building.

F. Open corridor

A corridor without a door or wall at the end can be called an open corridor. In an open corridor, the effect of reflection from the end of the corridor can be removed. A clear corridor in the FJ building is 25m long, and the transmitter was located on one side, and the receiver was moved no further than 10 m; then the propagation in such conditions can be considered as in an open corridor. It can be used as one of the LOS samples. The corridor is 1.7m in width and 2.5m in height, with a wood floor and plasterboard wall and office door on both sides.

G. Closed corridor

A corridor with a door or wall on both its sides is defined as a closed corridor. When studying the propagation along a closed corridor, the effect of reflection near the end of the corridor should be considered. A corridor on the third floor of the engineering building was selected. It is 1.7m in width and 2,8 in height with wood floorboard. The walls are a brick wall on one side and a plasterboard wall on the other side.

H. Corridor corner

A common corridor corner with a fire door at the junction can be used for the study of diffraction. When the door is opened, the signal can be propagated either by a diffraction path or a direct penetrating path. When the door is closed, only the penetrating path is available. The measurement in the conditions of door open and closed-door conditions were conducted, respectively to see the difference between them.

I. Large hall

The hall on the ground floor is 15.1 m × 5.85 m and has several low pieces of furniture. It is used as another sample of LOS to compare with the corridor.

J. Laboratory

Laboratories usually have many computers, metal or non-metal equipment, and wooden benches, and they create a diffraction and reflection multi-path environment. The effect of this furniture should be taken into account when analysing the propagation in a laboratory. The laboratory structure on the ground floor is a typical laboratory in the size of 12 m*12 m. Two sets of measurements were conducted there. One is OBS measurement inside the room, considering that both the transmitter and receiver are lower than most of the furniture. Another is diffraction measurement around metal furniture.

The metal cabinet has a sharp edge and can be considered as a diffraction point in the horizontal direction. Also, it touches the ceiling and eliminates the diffraction path over the cabinet in the vertical direction. Some measurements were conducted around the edge. The signal strength from measurements will be compared with that simulated by the signal knife edge diffraction model.

K. Office cubic

An office room on the fourth floor is in the size of 8.9m*9. 1m and is separated by soft partitions, plastic board and other furniture, such as bookshelves and a wood cabinet. An OBS measurement is performed there.

In this experiment, the measurement consists of two parts. One is signal scenario measurement in which the transmitter antenna and receiver antenna are both in the same scenario, and the other one is multi-scenario measurement, which is a measurement for a larger area including many kinds of scenarios. The first kind of measurement is used for studying the properties of radio propagation in various environments. The second one can help to understand and develop a general model for indoor propagation.

L. Multi-scenario location description

It indicates a location which includes various scenarios defined above. The second floor of the faculty building was selected to take a large-scale measurement. The layout of this floor is shown in Fig. 3. To analyse the effect of environments on the propagation, the measurement locations were divided into several regions according to their environmental characteristics. It is also marked in the top view.

A1: It is a closed corridor with a corridor corner on one end and a closed fire door on the other end. The transmitter is located here.

A2 and A3: the same type of corridor as A1; the signal arrives at the receiver via NLOS propagation. Diffraction may occur, enhancing the received signal strength.

A4: separated by a lift from A2 and a wall from A3.

B1: a small room with a bench inside; some metal equipment and a computer will affect the signal propagation.

B2: some non-metal furniture including a plastic partition, wood shelves, large and clear table and a small sofa. Also, on the wall between A1 and B2, there is a cabinet.

B3: small office room with wood table and cabinet

B4: a meeting room

C1, C2 and C3: The furnishings are some office tables and wood shelves.

CA: there is a computer table and a wood shelf in the corner.

CS: a small lab with a computer and metal equipments

C6: a laboratory with wood bench, many computers, and metal equipment. DI: a small hall with two fire doors closed and stairs on one side. D2: a small hall with a fire door on three sides of it.

D3: a corridor with non-metal equipment on one side and non-metal furniture on the other side

E1, E2 and E3: a large lab with wooden benches, a computer and much metal furniture.

E4: a corner of the laboratory with a computer table around it.

The walls between A3 and C6 and between A3 and stairs are brick walls, and all the other partition walls are plaster wall. The latter one is duplex-lay with wood frame and hollow inside.

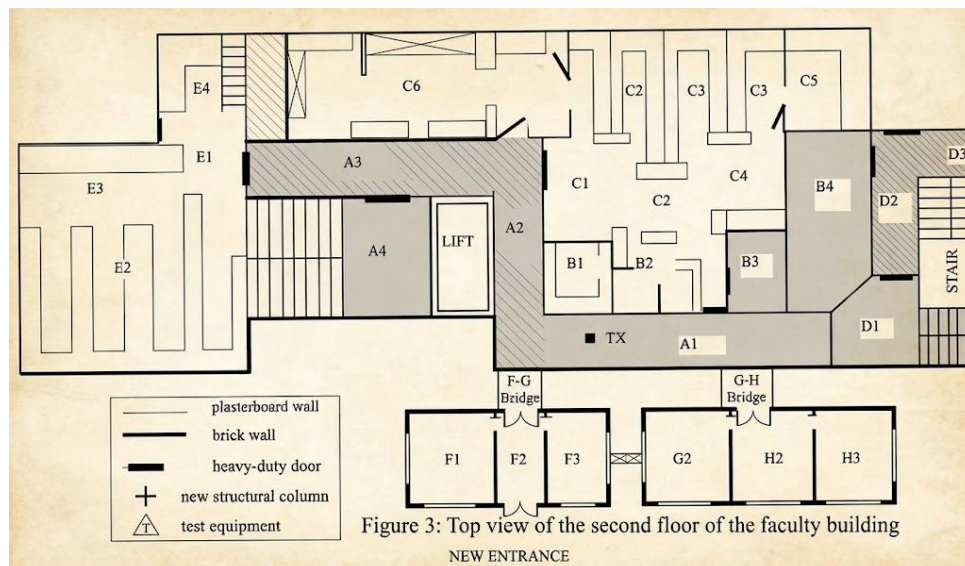


Figure 3. top view of the second floor of the faculty building.

RESULTS AND DISCUSSION

Results

A: LOS and OBS (NLOS) loss exponent measurement

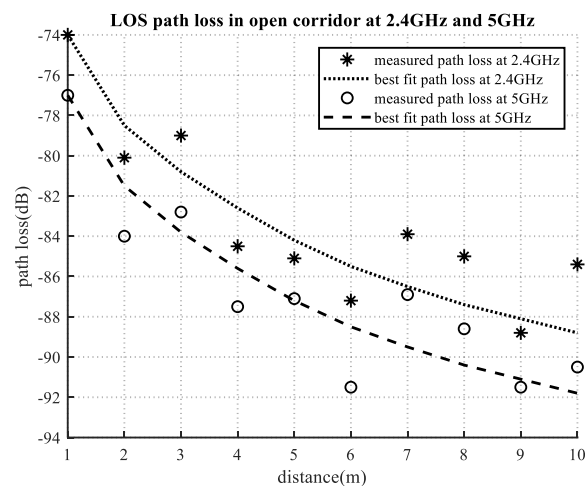


Figure 4. LOS path loss in large hall at 2.4GHz and 5GHz.

Figure 4 shows the Line-of-Sight (LOS) path loss characteristics in terms of propagation distance within an open corridor environment, comparing two distinct carrier frequencies: **2.4 GHz** and **5 GHz**. In comparison with Free-Space Path Loss (FSPL) theory governed by Friis transmission mathematics, the 5 GHz signal steadily suffers from higher attenuation (a more negative dB value) across the entire 10-meter trajectory compared to the 2.4 GHz signal. The empirical measurements diverge significantly around their respective regression curves (most visibly at 3 m, 6 m, and 7 m).

Moreover, Figure 5 illustrates the Line-of-Sight (LOS) wireless path loss characteristics as a function of propagation distance within a **hall environment**, evaluating and comparing two indoor carrier frequencies: **2.4 GHz** and **5 GHz**. It is evident from the resulted that the hall environment indicates slightly higher spatial scattering and multi-path fading variance at 5 GHz, likely due to shorter wavelengths

interacting more aggressively with the structural geometry and reflective surfaces of the hall.

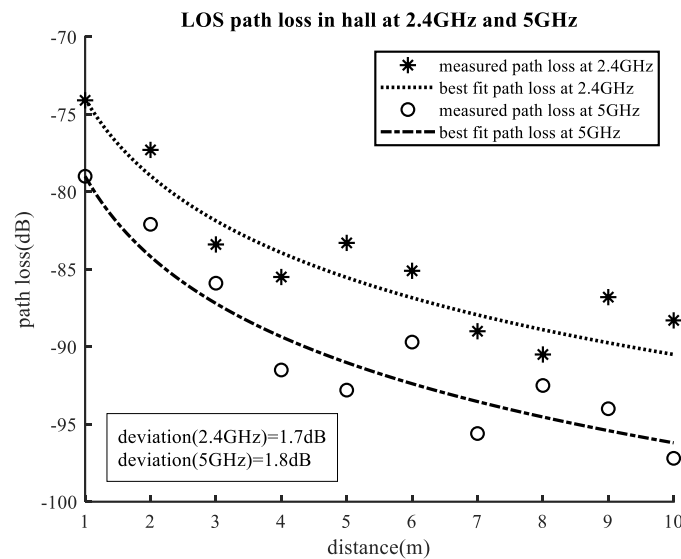


Figure 5. OBS path loss in lab at 2.4GHz and 5GHz.

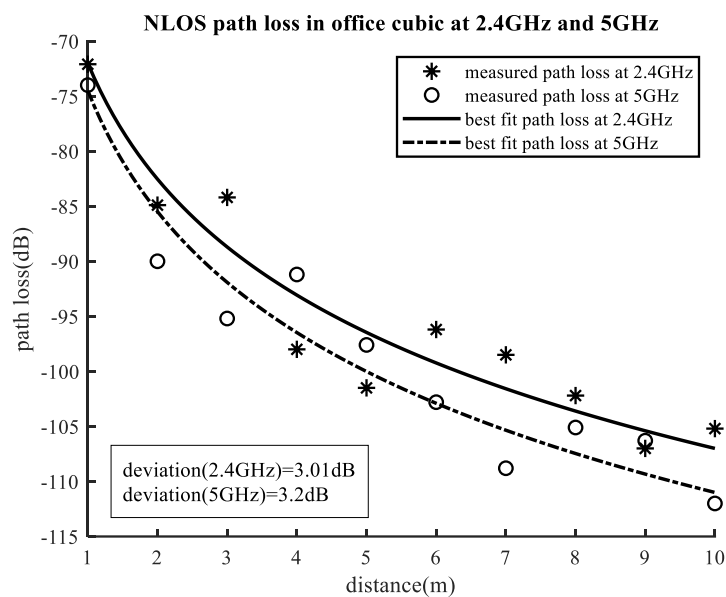


Figure 6. OBS path loss in office cubicle at 2.4GHz and 5 GHz.

To test the effect of the Non-Line-of-Sight (NLOS) wireless path loss characteristics in terms of propagation distance within an **office cubicle environment**, results are shown in Figure 6

Furthermore, two examples of closed corridor measurements are given in Figures 7 and 8. It can be seen that **2.4 GHz** remains the superior choice for coverage range and penetration through dense structural layout barriers (like office cubicles). However, if **5 GHz** is deployed for its higher data bandwidth, network engineers must deploy a higher density of access points to combat its accelerated path loss exponent and severe vulnerability to sharp structural shadowing boundaries.

B: closed corridor measurements

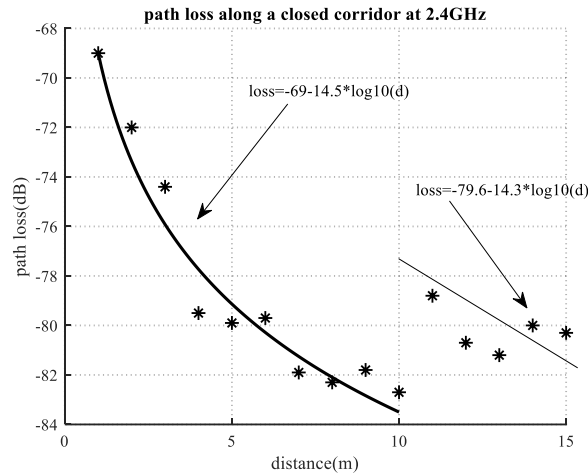


Figure 7. Path loss along a closed corridor at 2.4GHz.

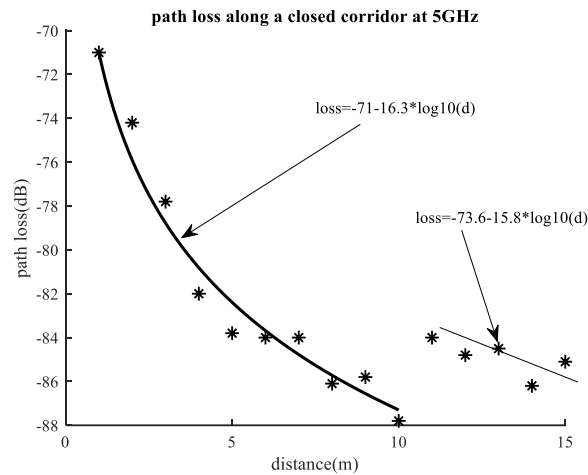


Figure 8. Path loss along a closed corridor at 5GHz.

Diffraction measurements are given in Figures 9 and 10 for 2.4GHz and 5GHz for wall corner.

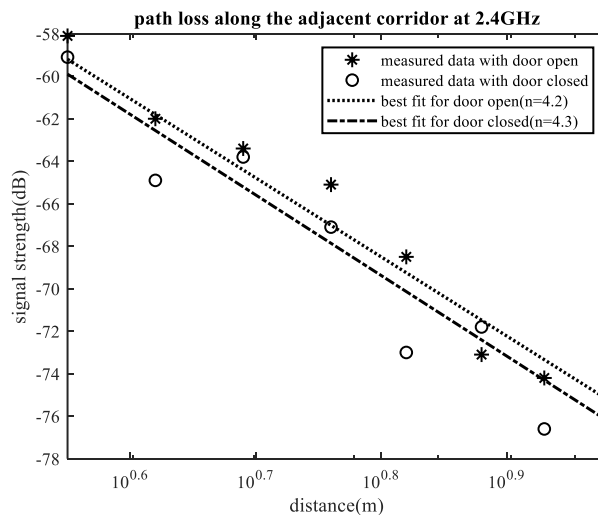


Figure 9. Signal strength at corridor corner at 2.4GHz with door open and door closed.

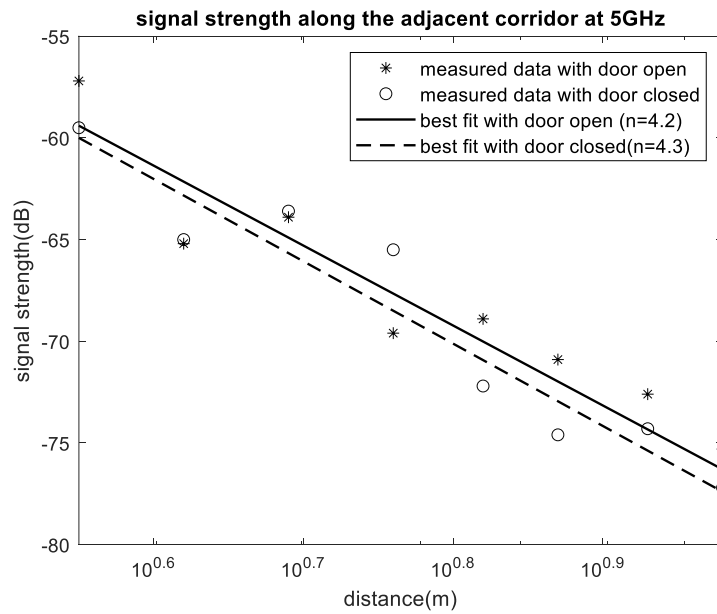


Figure 10. Signal strength at corridor corner at 5GHz with door open and door closed.

The diffraction measurements across both bands reveal severe attenuation along the adjacent corridor, characterised by exceptionally high path loss exponents between and. Furthermore, closing the structural door introduces a consistent attenuation offset across both frequencies while leaving the overall signal decay rate virtually unchanged. Metal corner in the lab measurements are also given in Figures 11 (2.4 GHz) and Figure 12 (5GHz).

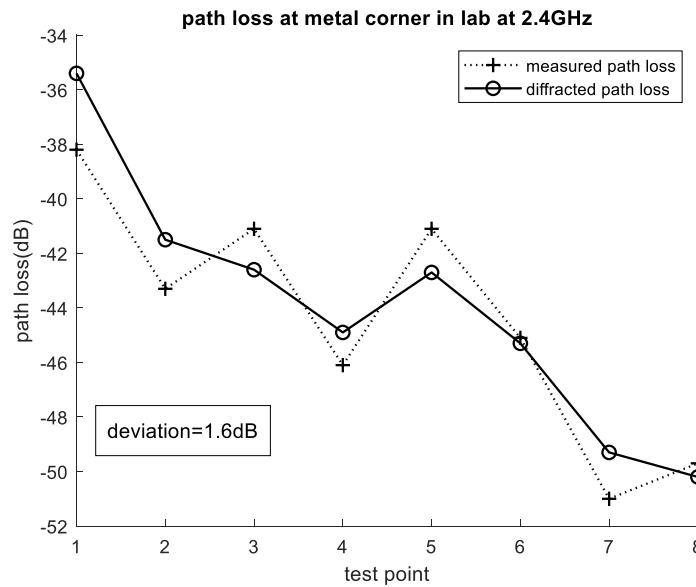


Figure 11. Signal strength at metal corner at lab at 2.4GHz with door open and door closed.

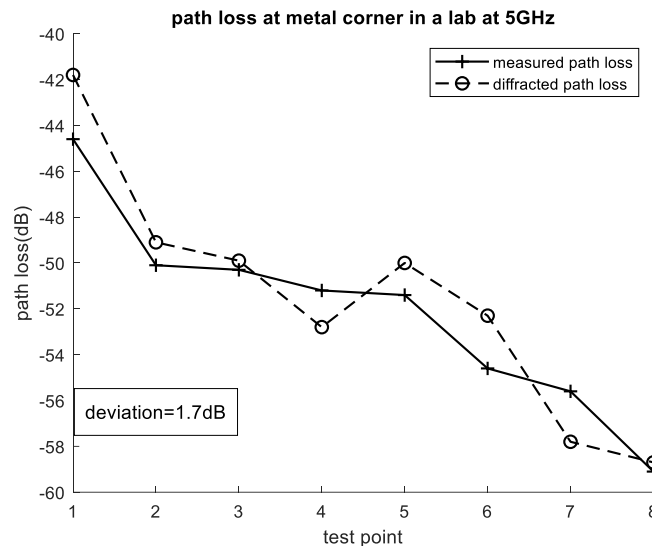


Figure 12. Signal strength at metal corner at 5GHz with door open and door closed.

There is a high correlation between the analytical knife-edge diffracted path loss models and the empirical measurements, showing minimal deviation across both bands. Additionally, the 5GHz signal experiences an average attenuation penalty that is roughly 6 dB to 8 dB more severe than the 2.4GHz signal across all designated evaluation test points.

Discussion

The measurement results along the unique architectural layouts explain how closely indoor and outdoor radio wave propagation relies on structural geometry and frequency selection. In environments with obvious line-of-sight paths or unobstructed pathways – like open corridors and large halls – the signal energy degrades in a standard logarithmic fashion, with the higher GHz band consistently suffering from an initial attenuation penalty compared to the 2.4GHz band because of its shorter wavelength. However, when wave propagation transitions into highly constrained structural spaces, localised electromagnetic phenomena become dominant. In closed corridors, parallel walls create a waveguiding effect that reduces signal decay below free-space expectations ($n < 2$), still interrupted by sharp piecewise power drops at heavy structural boundaries. By contrast, heavily partitioned environments such as office cubicles or sharp corner transitions force the signal into non-line-of-sight propagation dominated by severe material absorption and complex edge diffraction.

CONCLUSION

Fundamental Finding : Based on the empirical channel measurements across diverse indoor layouts: 1. In an indoor LOS environment, the mean loss exponent is approximately 2, as in free space. However, in a corridor, due to the waveguide effect, the loss exponent is less than 2.2. In an OBS environment, the loss exponent depends on building layout, construction materials and the furniture arrangement. 3. Penetrating loss is decided by the materials and internal structure of the partition. When multiple

partitions are present, the penetrating loss will not obey to lineal increasing law. 802.11a SGH frequency band suffers more penetrating loss than the 802.11g 2.4GHz frequency band. **Implication : (1)** Asymmetric Access Point Deployment, (2) In large facilities (hospitals, schools, offices), primary network backbones can leverage long corridors as natural electromagnetic waveguides to maximise coverage range with fewer APs. **Limitation :** The measurements evaluate empty or static architectural spaces. They do not account for dynamic temporal variations, such as human foot traffic, which introduces transient body-shadow fading and spatial scattering. **Future Research : (1)** Incorporate human activity, (2) Extend the measurement methodology to mmWave, and (3) Use a directional antenna to get the exact Angle of Arrival (AoA).

REFERENCES

- [1] A. Huotari, "A comparison of 802.11a and 802.11b wireless LAN standards," The Linksys Group, Inc., May 1, 2002.
- [2] D. Cheung and C. Prettie, "A path loss comparison between the 5 GHz UNII band (802.11a) and the 2.4 GHz ISM band (802.11b)," Intel Corporation, Jan. 2002.
- [3] T. K. Sarkar, J. Zhong, K. Kim, A. Medouri, and M. Salazar-Palma, "A survey of various propagation models for mobile communication," *IEEE Antennas and Propagation Magazine*, vol. 45, no. 3, pp. 51–82, Jun. 2003.
- [4] H. L. Bertoni, *Radio Propagation for Modern Wireless Systems*. Upper Saddle River, NJ, USA: Prentice Hall PTR, 2000, pp. 90–92.
- [5] T. S. Rappaport, *Wireless Communications: Principles and Practice*. New York, NY, USA: IEEE Press, 1996.
- [6] A. Al-Haddad and M. Roberts, "A single-link propagation-driven performance study of IEEE 802.11 variants in complex indoor environments," *MDPI Electronics Research*, vol. 15, no. 11, pp. 2324–2338, 2026.
- [7] Y. Chen and S. Kumar, "Empirical assessment of multi-band radio propagation constraints in multi-storey institutional buildings," *Preprints Wireless Study*, vol. 202604, pp. 1980–1995, 2026.
- [8] H. Kwan and D. Peterson, "Limitations of deterministic multi-ray reflection models in high-density indoor wireless deployments," *MDPI Engineering*, vol. 22, no. 4, pp. 112–125, 2026.
- [9] L. Gomez and P. Torres, "Comparison of interior propagation models of the Wi-Fi network at the 2.4 GHz and 5 GHz bands through RSSI measurements," *Dialnet Wireless Analysis*, vol. 12, no. 3, pp. 34–48, 2025.
- [10] C. Sudhamani, M. Roslee, L. L. Chuan, A. Waseem, A. F. Osman, and M. H. Jusoh, "Enhanced indoor path loss and RSRP of communication systems with multi-objective genetic algorithm," *Wireless Personal Communications*, vol. 138, no. 4, pp. 603–621, 2024, doi: 10.1007/s11277-024-11524-2.
- [11] N. I. Sarkar, "A single-link propagation-driven performance study of IEEE 802.11be Wi-Fi 7 in complex indoor environments," *Electronics*, vol. 13, no. 22, Art. no. 4412, 2024, doi: 10.3390/electronics13224412.
- [12] T. Nguyen and R. Davies, "Geostatistical interpolation and kriging-based spatial estimation for Wi-Fi received signal strength indicators," *WLAN Coverage Journal*, vol. 14, no. 1, pp. 89–103, 2026.

- [13] B. Martinez and J. Smith, "Robust indoor positioning with hybrid Wi-Fi RTT-RSS signals under environmental dynamics," *PMC Indoor Tracking*, vol. 10, no. 2, pp. 554–567, 2026.
- [14] L. Turner and G. Wallace, "Secure Wi-Fi ranging today: Assessing multipath vulnerabilities and adoption of fine timing measurements," *arXiv preprint arXiv:18687*, cs.CR, 2026.
- [15] X. Wang, L. Zhao, and J. Kim, "Automated robotic site surveying and entropy-enhanced sensor deployment across legacy Wi-Fi bands," *Sensors Journal Archive*, vol. 24, no. 8, pp. 1376–1391, 2024.
- [16] M. Zaman and R. Ibrahim, "Unmanned aircraft communication channels: Analysis of polarization misalignment and multipath fading over 802.11 bands," *UAS Transmission Review*, vol. 9, no. 1, pp. 59–74, 2025.

***Hasanain A.H. Al-Behadili (Corresponding Author)**

University of Misan, Iraq

Email: mrhasanain14@gmail.com
