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# A Single-Link Propagation-Driven Performance Study of IEEE 802.11be Wi-Fi 7 in Complex Indoor Environments

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**Abstract**

IEEE 802.11be, commercially known as Wi-Fi 7, extends wireless local area network (WLAN) capability through wider channel bandwidths, higher-order modulation, and tri-band operation. However, realised indoor performance is still strongly affected by radio propagation conditions. This study presents a controlled empirical assessment of Wi-Fi 7 behaviour in a multi-storey university building by examining throughput and received signal strength (RSS) across the 2.4 GHz, 5 GHz, and 6 GHz bands using a single-link measurement setup. Six experimental scenarios were used to examine distance variation, wall penetration, line-of-sight (LOS) obstruction, floor separation, antenna orientation, and microwave interference. The measured RSS values were compared with the free-space, two-ray ground reflection, and log-distance shadowing models using mean absolute error (MAE). Six experimental scenarios were designed to isolate dominant indoor impairments, including distance variation, wall penetration, line-of-sight obstruction, floor separation, antenna orientation, and microwave interference. Measured RSS values were evaluated against free-space, two-ray, and log-distance shadowing models using mean absolute error as the comparison metric. Results show that 2.4 GHz retains greater penetration at lesser capacity, while 6 GHz offers the maximum short-range throughput under clear line-of-sight conditionsbut rapidly deteriorates with structural attenuation. Performance in all bands is greatly diminished by multi-wall blockage and line-of-sight loss. A single propagation model cannot adequately capture the divergence introduced by increasing distance and indoor attenuation, while short-range line-of-sight conditions more closely resemble deterministic predictions in terms of measured RSS alignment. Overall, the results highlight the trade-off between Wi-Fi 7's capacity and coverage, and provide helpful advice for choosing frequencies, positioning access points, and organizing indoor coverage. The research findings provide insights into the practical deployment of next-generation Wi-Fi in multi-story buildings and residential houses.

**Keywords:** IEEE 802.11be; indoor radio propagation; received signal strength; throughput; path loss; empirical performance evaluation



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## 1. Introduction and Background

Wireless local area networks (WLANs) continue to evolve in response to the demand for higher data rates, lower latency, and more reliable indoor connectivity. The latest generation, IEEE 802.11be, commercially referred to as Wi-Fi 7, extends previous WLAN standards through wider channel bandwidths; higher-order modulation; and operation across the 2.4 GHz, 5 GHz, and 6 GHz frequency bands. While the protocol-level features of Wi-Fi 7 are well defined in the standard, its practical performance is fundamentally constrained by indoor radio propagation conditions. Signal attenuation caused by walls, floors, furniture, and structural materials, as well as multipath fading and interference from co-located devices, often leads to substantial deviation from idealised theoretical behaviour. Propagation challenges become increasingly pronounced at higher frequencies, particularly in the newly allocated 6 GHz band, where penetration losses and line-of-sight dependency can significantly influence link stability and throughput. As a result, empirical measurement of Wi-Fi 7 performance in realistic indoor environments is essential for understanding its true operational characteristics. Existing indoor WLAN studies have largely focused on earlier IEEE 802.11 variants or on simulation-based evaluation of emerging standards. Although these works provide valuable insight into general propagation trends, they do not adequately capture the combined effects of modern hardware, contemporary building structures, and multi-band operation introduced with 802.11be. In particular, there is a lack of publicly available measurement campaigns that systematically compare throughput and received signal strength across the 2.4 GHz, 5 GHz, and 6 GHz bands under controlled yet realistic indoor conditions. This gap limits the ability to validate analytical propagation models and to inform effective deployment strategies for next-generation WLANs.

This study investigates single-link IEEE 802.11be Wi-Fi 7 behaviour in a multi-storey university building using a controlled measurement approach. The experiments were arranged to examine how practical indoor conditions affect link performance, including transmitter–receiver distance, device orientation, wall penetration, floor separation, line-of-sight obstruction, and nearby appliance operation. Throughput and received signal strength (RSS) were measured with commercial Wi-Fi 7 hardware across the 2.4 GHz, 5 GHz, and 6 GHz bands.

This study contributes measured evidence on how each band responds to common indoor propagation constraints. It also shows the trade-off between short-range capacity and coverage robustness, particularly when higher-frequency links are exposed to obstruction or vertical separation. In addition, measured RSS values were compared with established propagation models to determine where these models remained useful and where they diverged from practical Wi-Fi 7 measurements. These findings provide site-specific evidence for the tested building and offer guidance for Wi-Fi 7 planning in comparable indoor environments.

Understanding performance and reliability in modern Wi-Fi systems requires the examination of both environmental influences and protocol-level mechanisms. An empirical investigation reported in [1] evaluated how human mobility alters indoor link throughput across different floors and room configurations. The study distinguishes between static, periodic, and random movement patterns, showing that while fluctuations are observable, throughput degradation caused solely by the movement of people is often less dominant than structural attenuation or placement effects. These findings highlight that environmental geometry and obstruction characteristics remain primary determinants of sustained throughput. Performance prediction in dense next-generation WLANs has increasingly moved toward data-driven modelling. The ATARI framework proposed in [2] formulates throughput estimation as a graph learning problem, where device relationships and channel interactions are preserved through convolutional layers. By embedding topology-aware features into the prediction process, the model demonstrates improved accuracy compared to independent-feature baselines, particularly under channel bonding and high-density conditions. This approach underscores the value of relational modelling when interference coupling cannot be approximated as independent noise.

Industrial adoption of Wi-Fi technologies demands consistent performance under heterogeneous interference and deployment conditions. A comparative experimental assessment reported in [3] evaluated multiple IEEE 802.11 generations across residential, laboratory, and industrial environments. The study reveals that band selection—particularly operation in the 6 GHz spectrum—significantly influences throughput stability and latency metrics. However, early Wi-Fi 7 implementations do not uniformly outperform mature Wi-Fi 6/6E systems, emphasizing that practical gains depend on hardware optimization and firmware maturity rather than the specification alone. Low-latency deterministic communication over WLANs has been explored through the integration of time-sensitive networking principles. The analysis presented in [4] examines how 802.11be features such as multi-link operation and coordinated scheduling may support bounded-latency traffic. While contention-based channel access inherently introduces randomness, the paper outlines architectural adaptations capable of narrowing delay variance. This work bridges wired Time-Sensitive Networking (TSN) concepts with wireless evolution toward Wi-Fi 7. A broader technical consolidation of IEEE 802.11ax advancements is provided in [5], which categorizes improvements across PHY and MAC dimensions, including Orthogonal Frequency Division Multiple Access (OFDMA), spatial reuse, target wake time, and uplink multi-user transmission. The survey clarifies how these mechanisms interact under dense deployments and identifies unresolved challenges in scheduling fairness and cross-feature optimization. Such structured analysis provides context for evaluating incremental improvements against system-level performance objectives.

One of the key MAC-layer characteristics of IEEE 802.11be [6] is multi-link operation; however, in this study, it was purposefully turned off so that throughput and RSS variations could be attributed to a single propagation path rather than link aggregation or traffic distribution across multiple bands. The empirical analysis presented in [7] evaluates bidirectional Wi-Fi communication between mobile robots and access points under varying placements and frequency bands. Experimental results show that throughput stability and retransmission rates are highly sensitive to AP positioning and band selection. The study highlights that infrastructure placement decisions directly influence latency-sensitive robotic operations. Despite its theoretical advantages, Wi-Fi 7 performance in indoor environments remains constrained by propagation loss, structural attenuation, and interference. Existing studies often focus either on protocol-level enhancements or simplified propagation assumptions, leaving a gap in experimentally validated, scenario-driven analysis. Although Bartolín et al. [3] present a valuable comparative performance study of Wi-Fi standards from IEEE 802.11n to IEEE 802.11be, its primary focus is on the benchmarking of network-level Quality of Service (QoS) metrics, including throughput, round-trip time, jitter, and packet loss, across residential, laboratory, and industrial environments. In contrast, the present work adopts a propagation-driven experimental methodology that specifically isolates the influence of indoor radio propagation phenomena on Wi-Fi 7 performance. The study systematically examines the impact of distance, wall penetration, floor separation, line-of-sight obstruction, antenna orientation, and microwave interference on both throughput and received signal strength (RSS). Furthermore, measured RSS values are validated against classical analytical propagation models—namely, the free-space, two-ray ground reflection, and log-distance shadowing models—using mean absolute error (MAE). To the best of the authors' knowledge, this is one of the first controlled, single-link experimental studies that combines tri-band Wi-Fi 7 measurements with analytical propagation model validation in a complex multi-storey indoor environment. The reviewed studies show that Wi-Fi 7 performance has often been examined from the viewpoint of standard evolution, protocol capability, or general quality-of-service benchmarking. Less attention has been given to controlled, single-link measurements that separate the effects of specific indoor propagation conditions on IEEE 802.11be performance. In particular, there remains limited experimental evidence showing how throughput and received signal strength (RSS) vary across the 2.4 GHz, 5 GHz, and 6 GHz bands when the same link is exposed to distance variation, wall penetration, floor separation, line-of-sight obstruction, device orientation, and nearby appliance operation.

This study addresses that gap through a controlled measurement campaign in a multi-storey university building. The work is not intended to represent every indoor building or a full-scale multi-user network. Instead, it provides a focused, propagation-driven evaluation of single-link Wi-Fi 7 behaviour under repeatable indoor conditions.

The main contributions are summarized as follows:

1. A single-link IEEE 802.11be Wi-Fi 7 testbed was configured to measure throughput and RSS across the 2.4 GHz, 5 GHz, and 6 GHz bands under consistent physical and medium-access control settings.
2. Six indoor propagation conditions were examined: transmitter–receiver separation, wall penetration, floor separation, line-of-sight obstruction, antenna orientation, and nearby appliance operation.
3. The measured results were used to explain band-dependent behaviour, including the trade-off between short-range capacity at higher frequencies and stronger penetration at lower frequencies.
4. Established propagation models were used as reference tools to interpret the measured RSS behaviour and to identify where simplified model assumptions diverged from practical Wi-Fi 7 measurements.
5. The findings provide site-specific evidence from a multi-storey indoor environment and support practical guidance for access-point placement, band selection, and coverage planning in comparable buildings.

## 2. Related Work

Beyond enterprise applications, industrial deployment limits add more latency and reliability requirements. In [3], a multi-environment experimental campaign examined 802.11n through 802.11be in industrial, laboratory, and residential contexts. Wi-Fi 6/6E offers greater stability, especially in the 6 GHz band under controlled interference settings, according to measured round-trip time (RTT), jitter, throughput, and packet-loss data. Nevertheless, the gap between specification promise and practical execution is highlighted by the fact that early Wi-Fi 7 hardware does not routinely beat mature Wi-Fi 6 implementations. Signal modelling, mobility-aware experimentation, protocol-level efficiency enhancements, and decentralised learning paradigms have all been covered in previous research. It is still difficult to combine mobility dynamics, multi-band operation, federated multi-agent coordination, and spatial signal estimation into a single experimental framework. The industrial measurement campaign described by Bartolín et al. [3] compares several IEEE 802.11 generations using network-level QoS metrics, but it neither verifies measured RSS against analytical propagation models nor looks into the propagation mechanisms causing observed performance differences. This encourages more cross-layer research for next-generation Wi-Fi systems that integrate collaborative learning and propagation awareness. Their results show that kriging reduces modelling complexity in multi-floor and interference-rich office settings while providing statistically reliable RSSI prediction. Static coverage models are unable to account for the added variability that wireless performance during mobility introduces. A robot operating system-based framework for measuring throughput, latency, retransmissions, and RSSI in bidirectional communication between mobile robots and base stations was proposed in [7]. By comparing the 2.4 GHz and 5 GHz bands for various access point locations, the study demonstrated how robot motion, channel selection, and AP positioning jointly affect stability and latency. The results show that the physical placement of networking infrastructure has a significant influence on real-time robotic operations. One of 802.11be's key features is Enhanced Multi-Link Operation (MLO), the actual behaviour of which varies significantly across multi-radio and single-radio implementations. In their analysis of the enhanced multi-link single-radio feature, Avallone and Imputato explain how switching limits and coordination affect actual throughput and latency results [8]. Their explanation highlights that performance gains depend on how the MAC arranges connection usage during traffic spikes and congestion, not merely on peak PHY rates. This perspective is helpful for indoor assessment studies, since it promotes the evaluation of link-level utilisation and access dynamics in addition to end-to-end throughput [8]. Data-driven control has also been proposed for adjusting MLO parameters when analytical optimisation is not practical. Wu et al. [9] constructed multi-link frame aggregation length selection as a learning problem and proposed a deep reinforcement learning approach to adapt aggregation under changing link circumstances. The method aims to achieve stable goodputimprovements without having set heuristics per band or channel state by modelling the interplay among numerous links and the aggregation decision. According to the study, next-generation WLAN performance may depend more on adaptive, policy-based control rather than static configuration [9]. Since Wi-Fi 6E and Wi-Fi 7 primarily rely on 6 GHz functioning, it is now critical to comprehend the actual deployment interference characteristics. Dogan-Tusha et al. quantified building entry loss, leakage to outdoor reception, and the visibility of indoor BSSIDs outside buildings in a comprehensive dense indoor measurement campaign in 6 GHz [10]. Their results show that under typical conditions, only a tiny portion of interior deployments are visible outdoors, which raises concerns about coexistence for incumbents and policy design. These results explain why 6 GHz frequently seems "cleaner" in practice for indoor throughput investigations and why interference conclusions should be connected to measurement scale and environmental density [10]. In addition to improving system-level protocols, learning can be applied to quantise or compress feedback. By mapping reports to a bounded candidate set, Deshmukh et al. introduced iFOR, which uses unsupervised learning (K-means) to reduce compressed beamforming feedback [11]. According to their calculations, goodputin high-SNR regimes can be greatly increased by reducing feedback bits; however, as payload length grows, trade-offs become apparent. The findings encourage a measuring mindset in which feedback/control cost and goodputmust be examined simultaneously, particularly for EHT-era WLAN links [11]. Previous research has included industrial benchmarking, protocol-level standard evolution, mobility-aware performance analysis, and spatial interpolation. Nevertheless, an integrated framework that combines mobility-induced dynamics, multi-band experimental validation, and environmental propagation models is still lacking. This encourages a cross-layer experimental approach that connects next-generation Wi-Fi performance evaluation with geostatistical signal modelling.

Liu et al. [12] summarised the main IEEE 802.11be techniques, including improved channel bandwidth, multi-link operation, and latency-oriented enhancements. However, rather than being an indoor propagation measurement study, their work was mainly standards-oriented and simulation-based. Similarly, research on smartphone localisation indicates that calibration should not be viewed as a one-time event. It tends to more accurately reflect real signal behaviour and produce more stable positioning results when it changes in tandem with user movement [13]. Since UWB and Wi-Fi RTT offer distinct advantages that can be integrated rather than directly compared, broader survey research has begun to examine positioning technologies collectively rather than individually [14]. However, research utilising Wi-Fi CSI adopts a different approach, viewing signal variation as valuable data, particularly when deep learning is applied to decipher minute alterations brought about by human activity in communal areas [15]. Comparing Wi-Fi generations from a networking standpoint reveals steady increases in responsiveness and stability; these advances are not always constant when actual environmental interference is considered [3]. With self-supervised techniques demonstrating that significant spatial patterns may be directly learned from signal behaviour without substantial manual input, more recent methods shift away from densely labelled datasets [16]. Despite the range of approaches available, review studies continue to highlight that typical problems like scalability and multipath effects are still challenging to handle in practice [17]. This is especially evident in RSSI-based systems, where shifting surroundings can rapidly impair signal consistency and lower positioning accuracy in unpredictable ways [18]. In order to overcome these constraints, some research has integrated Wi-Fi with other sensing techniques, demonstrating that combining sources can assist in sustaining dependability in more difficult circumstances, such as cases of blocked surroundings [19]. When multiple links are available, Carrascosa-Zamacois et al. [20] experimentally demonstrated that MLO can reduce latency and increase throughput. Using adaptive path-loss exponents, floor attenuation effects, and calibrated RSSI behaviour, Poolsawasd et al. [21] created empirical LoRa path-loss models for 433 MHz interior corridor environments. According to their findings, LoRa propagation is considerably altered by lengthy corridors and multi-floor constructions, and the suggested models offer more accurate prediction than standard ITU, LoRa, and 3GPP models. However, their focus was on multi-link scheduling rather than the propagation response of a single controlled Wi-Fi 7 link in the presence of indoor obstruction. The current work, on the other hand, solely concentrates on IEEE 802.11be and uses a propagation-driven approach that blends model-based analysis with controlled single-link observations. This makes it possible to analyse in depth how interference, blockage, and indoor attenuation affect tri-band Wi-Fi 7 performance. When considered collectively, the literature points to a slow shift. While more recent work tends to combine methods and make systems more flexible, earlier attempts mostly attempted to improve specific metrics. Nevertheless, unpredictable signal behaviour and environmental changes continue to pose challenges for indoor positioning. This suggests that methods that can adapt over time are needed instead of relying on rigid presumptions about how signals behave in a particular location. Table 1 summarises the key industrial Wi-Fi studies and highlights their main evaluation focus, methodologies, and limitations.

**Table 1.** Summary of industrial Wi-Fi studies and recent advancements.

| Ref. | Problem | Approach | Testbed | 802.11be | RSS M/M | Focus |
|---|---|---|---|---|---|---|
| [3] | Industrial WLAN reliability | Multi-env. evaluation (802.11n–be) | (Y) | (N) | (Y) | RTT/QoS |
| [6] | IEEE 802.11be MLO behaviour | MAC-layer analysis of multi-link operation | (N) | (Y) | (N) | MLO/latency |
| [7] | Mobility impact | ROS-based measurements | (Y) | (N) | (Y) | Throughput |
| [8] | Multi-link behaviour | Protocol analysis (802.11be) | (N) | (Y) | (Y) | Latency |
| [9] | Link aggregation control | DRL-based optimisation | (N) | (Y) | (Y) | Goodput |
| [10] | 6 GHz interference | Dense measurement campaign | (Y) | (N) | (N) | Interference |
| [11] | Feedback overhead | K-means compression | (N) | (Y) | (Y) | Efficiency |
| – | This work | 802.11be Wi-Fi 7 in complex indoor environments | (Y) | (Y) | (Y) | Integrated |

Note: Y = evaluated; N = not evaluated. Multi-band refers to operation across the 2.4, 5, and 6 GHz bands. RSS M/M = RSS model versus measurement analysis. QoS = Quality of Service.

## 3. PHY/MAC Configuration and Experimental Parameters

To support reproducibility and clearer interpretation of the results, the physical layer (PHY) and medium access control (MAC) configuration of the Wi-Fi 7 testbed is stated explicitly (Table 2).

**Table 2.** Wi-Fi 7 PHY/MAC configuration.

| Parameter | Configuration |
|---|---|
| Standard | IEEE 802.11be (Wi-Fi 7) |
| Channel Bandwidth | 80 MHz (2.4/5 GHz), 160 MHz (6 GHz) |
| Modulation (MCS) | Adaptive (auto-rate) |
| Spatial Streams | 2 × 2 MIMO |
| Guard Interval | 0.8 µs |
| Multi-Link Operation (MLO) | Disabled (single-link operation) |
| Traffic Type | TCP (SMB file transfer) |
| Payload Size | 1.17 GB file transfer |
| Operating Mode | Infrastructure (AP–Client) |
| Channel Selection | Manual selection after spectrum scan |
| Selected Channels | Non-overlapping channels with low background utilisation |
| MLO Status | Disabled |
| 320 MHz Support | Not enabled |
| Rationale | Controlled single-link propagation analysis |

Multi-Link Operation (MLO) and 320 MHz channel bandwidth were intentionally disabled in this study to maintain a controlled single-link experimental framework. The objective was to isolate the influence of indoor propagation phenomena on throughput and received signal strength (RSS) without the additional variability introduced by simultaneous multi-link transmission and dynamic link aggregation. Although these features are important components of the IEEE 802.11be standard, their use would complicate attribution of performance changes to specific propagation mechanisms. Table 3 compares the present work with closely related studies in terms of evaluated performance parameters, main contributions, and remaining research gaps.

**Table 3.** Comparison of related Wi-Fi studies with the present work.

| Ref. | Performance Parameters | Main Contribution | Gap Addressed by This Work |
|---|---|---|---|
| [3] | Throughput, RTT, jitter, and packet loss | Provides a practical comparison of IEEE 802.11n wtih IEEE 802.11be across residential, laboratory, and industrial environments. | Does not isolate propagation effects such as distance, walls, floors, LOS obstruction, antenna orientation, or microwave interference. The present work focuses on controlled single-link Wi-Fi 7 propagation behaviour. |
| [6] | Link coordination, throughput potential, and latency behaviour | Explains multi-link operation as a key IEEE 802.11be mechanism for improving link use and traffic distribution. | Focuses on MAC-layer multi-link operation rather than measured indoor RSS and throughput under specific propagation impairments. |
| [8] | Throughput and latency behaviour | Analyses the enhanced multi-link single-radio feature of IEEE 802.11be and explains how link switching and coordination affect practical performance. | Relevant to Wi-Fi 7 MLO design, but it is protocol-focused and does not measure single-link indoor RSS or propagation effects under distance, wall, floor, LOS, orientation, or microwave interference scenarios. |

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**Table 3.** *Cont.*

| Ref. | Performance Parameters | Main Contribution | Gap Addressed by This Work |
|---|---|---|---|
| [12] | Peak throughput, bandwidth, latency, modulation, and protocol features | Summarises IEEE 802.11be features such as 320 MHz channels, 4096-QAM, and MLO. | Does not provide a real indoor measurement campaign covering tri-band RSS, throughput, or obstruction-driven propagation behaviour. |
| [20] | Throughput and latency | Experimentally evaluates Wi-Fi multi-link operation and shows its benefit for delay and throughput improvement. | Studies multi-link behaviour, while the present work disables MLO to isolate single-link propagation effects across the 2.4, 5, and 6 GHz bands. |
| This work | Throughput, RSS, throughput degradation, and RSS model deviation | Presents a controlled tri-band IEEE 802.11be Wi-Fi 7 measurement study in a multi-storey indoor building. | Evaluates distance, wall penetration, floor separation, LOS obstruction, antenna orientation, and microwave interference using a controlled single-link setup across the 2.4, 5, and 6 GHz bands. |

The experiments were therefore conducted using a single active link with fixed channel bandwidths supported by the test hardware. In the 6 GHz band, a 160 MHz channel was used, while 80 MHz channels were selected for the 5 GHz and 2.4 GHz measurements to ensure stable operation across all scenarios. Channel selection was performed manually following a preliminary spectrum scan to identify non-overlapping channels with minimal background activity. The same channel configuration was retained throughout the measurement campaign to ensure consistency and repeatability.

### *3.1. Measurement Testbed and Resources Used*

All measurements were conducted using commercially available 802.11be hardware operating in the 2.4 GHz, 5 GHz, and 6 GHz bands (wireless card: Intel AX1775; access point: ASUS BE9700 RT-BE92U). IEEE 802.11be introduces Extremely High Throughput (EHT) mechanisms [22]. A fixed access point was positioned at a predefined reference location within the indoor test environment, while the receiver was relocated according to the experimental scenario under investigation.

For each scenario, including orientation change, wall penetration, distance variation, line-of-sight obstruction, and floor separation, three independent trials were conducted for each frequency band. The average throughput $T$ for each configuration was computed as

$$T = \frac{1}{N} \sum_{i=1}^{N} T_i, \tag{1}$$

where $T_i$ is the throughput measured in trial $i$ and $N = 3$ is the number of repeated trials. Similarly, the average received signal strength ($P_r$) was calculated as

$$P_r = \frac{1}{N} \sum_{i=1}^{N} P_{r,i}, \tag{2}$$

where $P_{r,i}$ is the RSS value recorded in trial $i$ and $N = 3$. Each measurement condition was repeated three times per frequency band, and the values reported in the results are the arithmetic means of the three trials.

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### *3.2. Propagation Model Formulation*

To interpret the measured RSS behaviour, three propagation models were used for comparison: the free-space model, the two-ray ground reflection model, and the log-distance shadowing model.

#### 3.2.1. Free-Space Model

The free-space model assumes unobstructed propagation and represents the received power ($P_r(d)$) at distance $d$ as

$$P_r(d) = P_t + G_t + G_r - L_{FS}(d) \tag{3}$$

where $P_t$ is the transmit power (dBm) and $G_t$ and $G_r$ denote the transmitter and receiver antenna gains (dBi), respectively. The free-space path loss ($L_{FS}(d)$) is defined as

$$L_{FS}(d) = 20\log_{10}(d) + 20\log_{10}(f) + 32.44 \tag{4}$$

with $d$ in kilometres and the carrier frequency ($f$) in MHz.

#### 3.2.2. Two-Ray Ground Reflection Model

The two-ray model accounts for both direct and ground-reflected signal components. Under the far-field approximation, the received power can be expressed as

$$P_r(d) = P_t + G_t + G_r - 20\log_{10}\left(\frac{d^2}{h_t h_r}\right) \tag{5}$$

where $h_t$ and $h_r$ represent the heights of the transmitting and receiving antennas, respectively.

This formulation captures the constructive and destructive interference effects that arise due to multipath propagation in indoor environments.

#### 3.2.3. Log-Distance Shadowing Model

Indoor propagation is significantly influenced by structural obstructions and material absorption. The log-distance shadowing model extends deterministic path loss by introducing a stochastic component:

$$P_r(d) = P_r(d_0) - 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \tag{6}$$

where:

- $d_0$ is a reference distance;
- $n$ denotes the path loss exponent;
- $X_\sigma$ is a zero-mean Gaussian random variable with a standard deviation of $\sigma$.

The parameters $n$ and $\sigma$ were empirically determined from measured RSS data using regression fitting.

### *3.3. Model Evaluation Metric*

To assess the agreement between measured and predicted RSS values, the mean absolute error (MAE) was calculated as

$$\text{MAE} = \frac{1}{M}\sum_{j=1}^{M}\left|P_r^{\text{measured}}(d_j) - P_r^{\text{model}}(d_j)\right| \tag{7}$$

where $M$ denotes the number of measurement locations.

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This metric quantifies the average deviation between empirical data and model predictions across the tested scenarios.

### 3.4. Experimental Scope Alignment

Each experimental configuration was designed to isolate a single dominant propagation impairment. By maintaining a consistent hardware configuration and environmental conditions across tests, observed variations in throughput and RSS can be attributed primarily to geometric separation, obstruction count, or vertical penetration effects rather than hardware variability. The resulting dataset provides a controlled basis for evaluating the suitability of classical propagation models for contemporary indoor Wi-Fi 7 deployments.

## 4. Results and Analysis

This section examines the empirical behaviour of 802.11be links under a range of indoor propagation conditions. Rather than reporting numerical outcomes in isolation, the analysis focuses on identifying dominant performance trends and explaining their physical causes across frequency bands. The floor layout and measurement locations for distance-dependent throughput are illustrated in Figure 1.

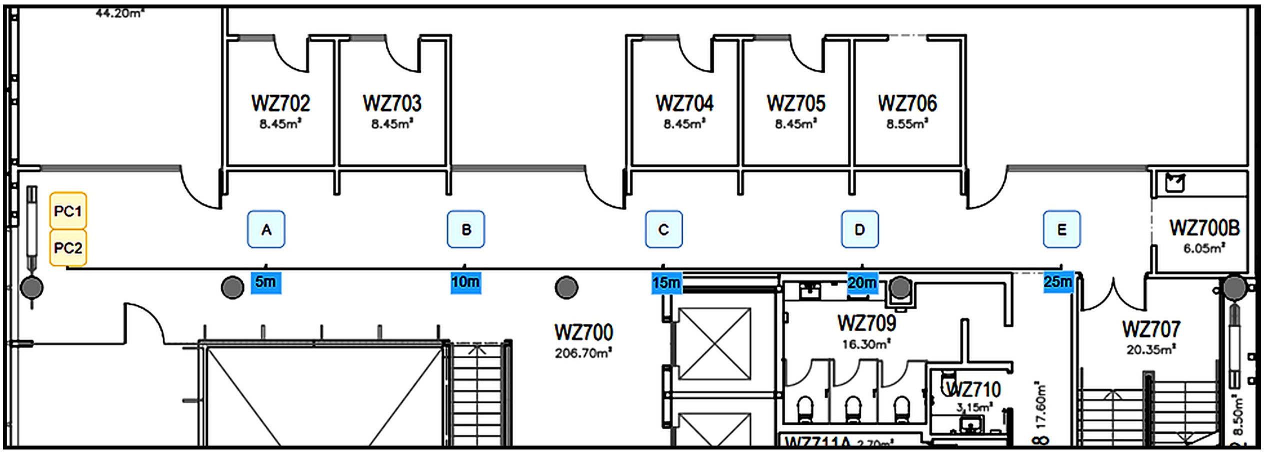



**Figure 1.** Internal floor structure and measurement locations for distance study (University Level 7 WZ Building).

### 4.1. Observed Sensitivity to Device Orientation

Short-range measurements were first used to evaluate whether the relative facing directions of the transmitter and receiver introduce measurable performance variation. Across all bands, throughput remained largely consistent irrespective of whether devices were aligned or oppositely oriented. Minor fluctuations were observed, but these remained within a narrow range when compared to losses introduced by distance or obstructions.

This behaviour suggests that contemporary Wi-Fi 7 client hardware, which employs integrated antennas with near-isotropic radiation characteristics, reduces the practical importance of orientation effects in indoor scenarios. As a result, orientation was not found to be a limiting factor for link performance within the tested environment.

The resulting throughput variation across the three operating bands is presented in Figure 2.

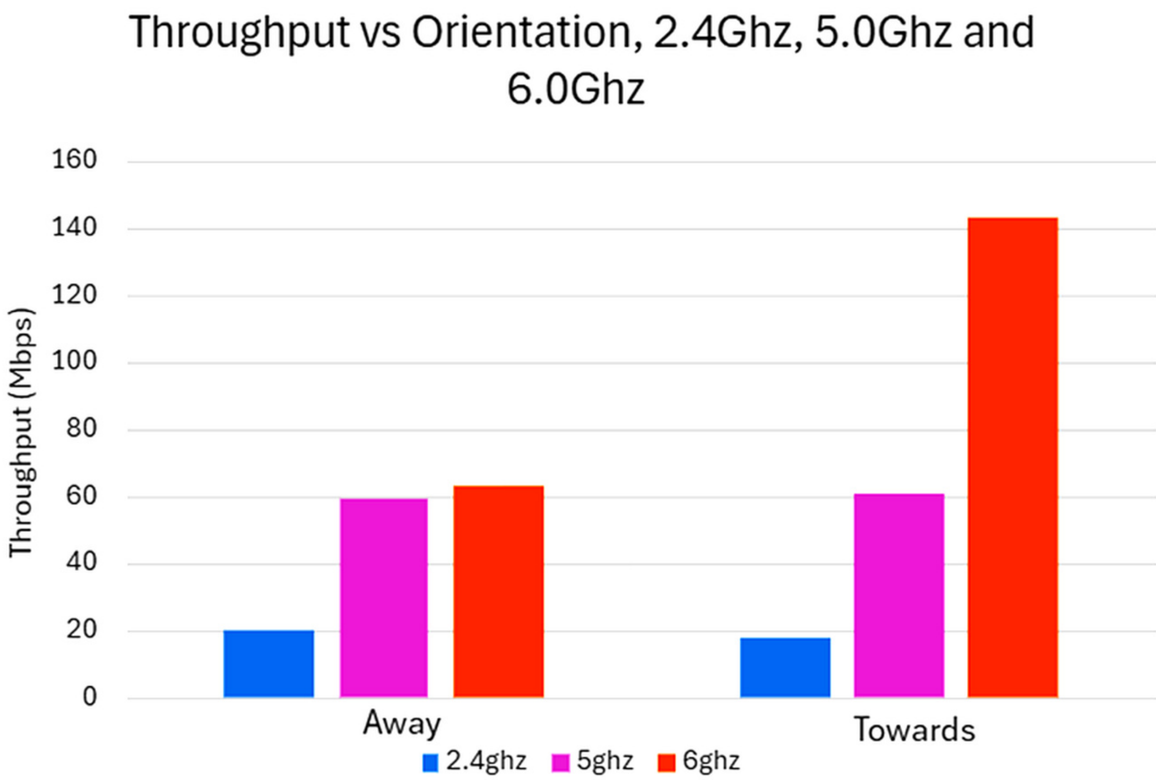



**Figure 2.** Impact on antenna orientation on system performance.

### *4.2. Microwave Interference Characterisation*

A short-range appliance co-location test was conducted to examine whether Wi-Fi 7 throughput changed when a domestic microwave oven was operating near the link path. The purpose of this test was not to measure microwave leakage, since no spectrum analyser or leakage meter was used. Microwave ovens are designed to contain radio-frequency energy within the chamber; therefore, the results should be interpreted only as Wi-Fi performance measurements under the condition of an appliance operating nearby.

The experiment compared throughput when the appliance was inactive and active with the same transmitter–receiver separation. Any observed change in throughput may reflect a combination of local 2.4 GHz channel activity, short-term indoor channel variation, device-rate adaptation, and electromagnetic noise associated with the appliance environment. For this reason, the results are reported as empirical co-location observations rather than direct evidence of microwave radiation leakage.

The measured data showed that the largest throughput change occurred in the 2.4 GHz band, while the 5 GHz and 6 GHz bands were less affected. This pattern is consistent with the fact that 2.4 GHz Wi-Fi operates in a more congested industrial, scientific, and medical band and is generally more exposed to non-Wi-Fi activity than the higher-frequency bands. However, because leakage was not directly measured, the result is used only to indicate that nearby appliance operation may coincide with short-term Wi-Fi throughput variation in indoor environments. It should be noted that the microwave interference experiment was conducted relative to the baseline configuration at the same separation distance (strong signal strength). The effect of the microwave operating (turning-on) condition on 802.11be throughput is shown in Table 4.

**Table 4.** Impact of microwave interference on Wi-Fi 7 performance.

| Band (GHz) | Throughput (Microwave Off) | Throughput (Microwave On) | Throughput Drop (%) |
|---|---|---|---|
| 2.4 | 3.12 | 1.48 | 52.6 |
| 5 | 8.44 | 6.37 | 24.5 |
| 6 | 12.03 | 10.92 | 9.2 |

Each experiment was repeated three times, and the reported values correspond to the mean throughput and RSS. Variability is quantified using standard deviation, and confidence intervals are included in all graphical representations. This approach reduces measurement uncertainty and improves the reliability of comparative analysis. The results indicate that while lower-frequency bands provide reduced peak capacity, they retain greater tolerance to broadband interference sources commonly found in indoor environments. In contrast, higher-frequency links trade robustness for capacity, making them more vulnerable to transient noise, even at short separation distances.

### *4.3. Impact of Wall-Induced Attenuation*

Introducing structural barriers between communicating nodes resulted in substantial throughput degradation that intensified with each additional wall. The decline was not proportional to distance alone, indicating that material absorption and multipath disruption play a significant role in limiting indoor Wi-Fi 7 performance. The throughput performance across different wall obstructions for all operating bands is illustrated in Figure 3. Links operating at 6 GHz achieved the highest throughput in minimally obstructed scenarios but exhibited rapid deterioration as obstructions accumulated. Conversely, 2.4 GHz links maintained connectivity through multiple walls, though at significantly reduced data rates. These outcomes highlight the asymmetric trade-off between penetration capability and throughput efficiency across bands.

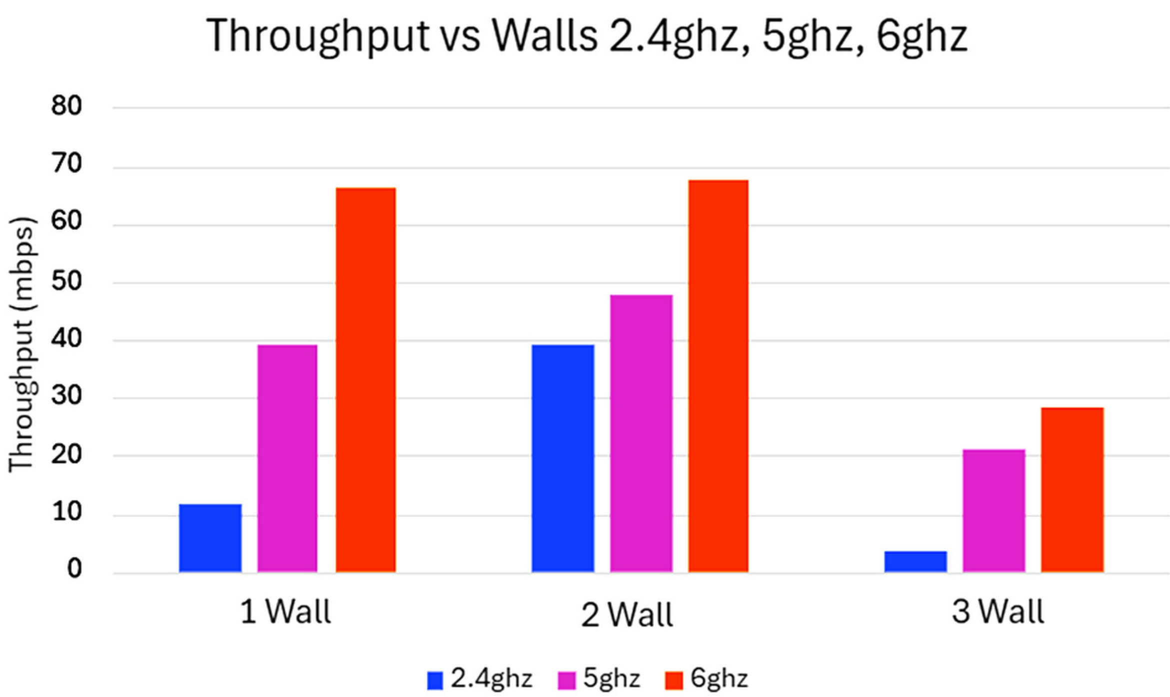



**Figure 3.** Impact of the no. of walls on link throughput (2.4, 5, and 6 GHz).

To improve the clarity of the experimental configuration, a schematic representation of the indoor measurement environment is presented in Figure 4. Unlike photographic illustrations, this diagram explicitly defines the spatial layout, measurement path, and key propagation elements affecting Wi-Fi 7 performance. The access point (AP) is positioned at a fixed reference location, while the client device is moved incrementally along a corridor to evaluate distance-dependent behaviour under controlled line-of-sight (LOS) conditions. Measurements were conducted at predefined distances of 5 m, 10 m, 15 m, 20 m, and 25 m. Structural elements such as walls and partitions are also indicated to reflect realistic indoor propagation effects. This representation aligns directly with the collected experimental data and ensures the reproducibility of the measurement setup.

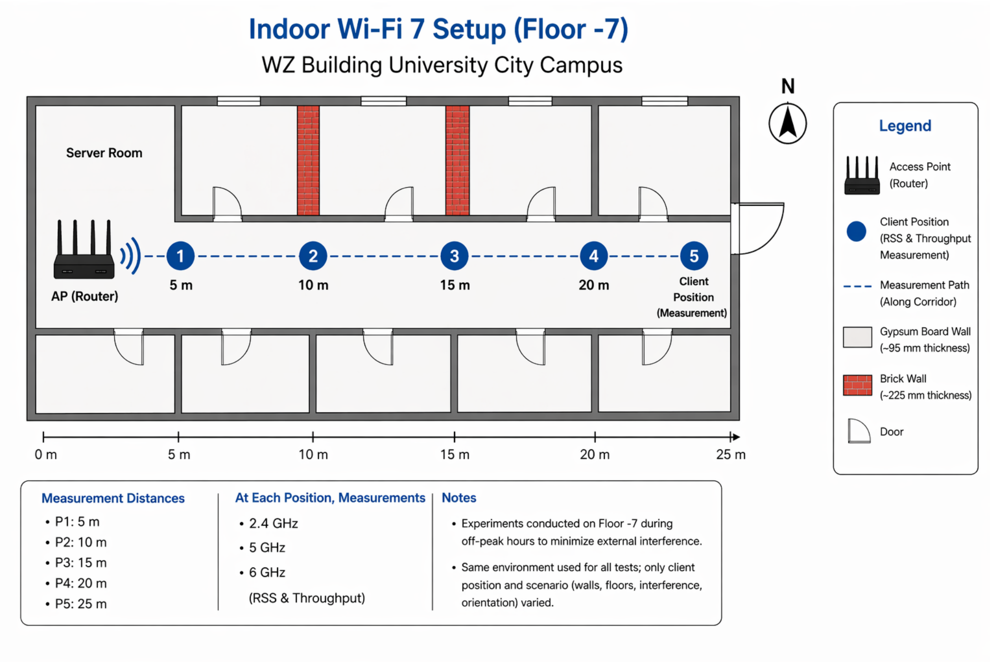



**Figure 4.** Top-view schematic of the indoor Wi-Fi 7 experimental setup.

## *4.4. Distance-Driven Throughput Study*

As transmitter–receiver separation increased under clear visibility conditions, throughput declined across all frequency bands, though the rate of degradation varied. Higher-frequency links demonstrated superior performance at short and moderate distances but experienced a steeper decline beyond a critical range. Lower-frequency bands showed comparatively stable performance over extended distances, albeit with lower maximum throughput. This divergence illustrates the inherent capacity–coverage tension present in multi-band Wi-Fi 7 deployments and underscores the importance of distance-aware band utilisation strategies. Table 5 reports the endpoint comparison for the distance experiment, while the accompanying discussion notes the local RSS and throughput fluctuations observed at intermediate corridor positions.

**Table 5.** Distance-driven throughput under line-of-sight conditions.

| Band (GHz) | Throughput at 5 m (Mbps) | Throughput at 25 m (Mbps) | Endpoint Drop (%) |
|---|---|---|---|
| 2.4 | 7.79 | 7.56 | 2.95 |
| 5 | 38.27 | 37.15 | 2.93 |
| 6 | 70.42 | 41.82 | 40.61 |

The endpoint comparison in Table 5 shows that the 6 GHz link experienced the largest reduction between 5 m and 25 m, with throughput decreasing from 70.42 Mbps to 41.82 Mbps. In contrast, the 2.4 GHz and 5 GHz links showed only small endpoint reductions over the same range. This result should not be interpreted as a perfectly linear distance-loss trend. The full measurement sequence contained local fluctuations at intermediate positions, including a weaker RSS at 20 m than at 25 m in some bands. Such behaviour is expected in indoor corridors, where reflected components from walls, glass, furniture, and structural surfaces may combine constructively or destructively at specific receiver locations. Therefore, the revised interpretation is that 6 GHz shows the clearest endpoint sensitivity to distance, while individual measurement points are also shaped by local multipath conditions.

### *4.5. Impact of Line-of-Sight Disruption*

Line-of-sight (LOS) deviation refers to lateral displacement of the receiver from the direct propagation path. In this study,

- 2 m deviation represents partial obstruction within corridor boundaries;
- 5 m deviation represents complete obstruction involving structural walls.

A schematic top-view representation of the experimental geometry is provided to ensure reproducibility. The removal of a direct line of sight produced the most severe performance impact observed during experimentation. Even small lateral offsets that obstructed the direct propagation path led to drastic throughput reduction or complete link failure, particularly at higher frequencies. These findings demonstrate that reflected and diffracted components alone are insufficient to sustain reliable high-throughput Wi-Fi 7 links in corridor-based indoor environments. Line-of-sight availability therefore emerges as a primary determinant of link viability, especially for 5 GHz and 6 GHz operation.

Table 6 separates the 25 m line-of-sight baseline from the laterally displaced non-line-of-sight cases so that the reported throughput drop is calculated only relative to the unobstructed 25 m condition.

**Table 6.** Impact of line-of-sight disruption at 25 m.

| Scenario | Band (GHz) | RSS (dBm) | Throughput (Mbps) | Throughput Drop (%) |
|---|---|---|---|---|
| 25 m LOS baseline | 2.4 | −55.33 | 7.56 | 0 |
| | 5 | −46.00 | 37.15 | 0 |
| | 6 | −44.00 | 41.82 | 0 |
| 25 m + 2 m lateral offset | 2.4 | −73.00 | 0.43 | 94.31 |
| | 5 | −77.33 | 4.76 | 87.19 |
| | 6 | Link lost | 0 | 100 |
| 25 m + 5 m lateral offset | 2.4 | Link lost | 0 | 100 |
| | 5 | Link lost | 0 | 100 |
| | 6 | Link lost | 0 | 100 |

The LOS disruption results show that link degradation caused by obstruction is much more severe than distance increase alone. At the 25 m LOS baseline, all three bands remained connected. After a 2 m lateral displacement from the direct propagation path, the 2.4 GHz throughput dropped from 7.56 Mbps to 0.43 Mbps, while 5 GHz decreased from 37.15 Mbps to 4.76 Mbps. The 6 GHz link could not be maintained under the same offset. When the receiver was displaced by 5 m from the LOS path, all three bands failed to sustain a usable connection. These results indicate that corridor-based Wi-Fi 7 performance depends strongly on direct path availability. Reflected and diffracted components may support limited connectivity at lower frequencies, but they are insufficient to preserve reliable 6 GHz operation once the direct path is blocked.

*4.6. Vertical Separation and Floor-Penetration Effect*

Measurements conducted across multiple floors revealed that vertical separation introduces attenuation that exceeds expectations based on horizontal distance metrics. Reliable communication was generally confined to a single-floor offset, with higher-frequency links failing to establish stable connections beyond this range. Although the 2.4 GHz band demonstrated superior penetration capability, achievable throughput remained limited, suggesting that vertical coverage in multi-storey buildings cannot rely solely on frequency selection and instead requires additional infrastructure support. Table 7 reports the measured RSS and throughput values for the wall-penetration experiment, showing how additional indoor obstructions affect each Wi-Fi 7 operating band.

It should be noted that the RSS values in Table 7 decrease with additional wall obstruction in all three frequency bands. The apparent irregularity is therefore not an RSS increase, but a non-linear throughput response, particularly in the 6 GHz band between the one-wall and two-wall scenarios.

**Table 7.** Measured RSS and throughput under wall-penetration scenarios.

| Band (GHz) | Walls | Distance (m) | Throughput (Mbps) | Degradation (%) | RSS (dBm) |
|---|---|---|---|---|---|
| 2.4 | 1 | 1.5 | 11.46 | 8.67 | −27.67 |
| 2.4 | 2 | 5.0 | 20.17 | 72.64 | −45.33 |
| 2.4 | 3 | 10.0 | 3.32 | 73.52 | −55.00 |
| 5 | 1 | 1.5 | 39.09 | 37.74 | −33.00 |
| 5 | 2 | 5.0 | 47.83 | 30.67 | −52.33 |
| 5 | 3 | 10.0 | 20.98 | 69.59 | −64.67 |
| 6 | 1 | 1.5 | 66.27 | 17.68 | −26.67 |
| 6 | 2 | 5.0 | 67.71 | 17.68 | −29.33 |
| 6 | 3 | 10.0 | 28.36 | 65.53 | −47.00 |

*4.7. Significance of High-Frequency Operation (6 GHz)*

The 6 GHz spectrum represents the most critical advancement in Wi-Fi 7, offering significantly wider channels and reduced legacy interference. However, its propagation characteristics differ substantially from those of lower bands. Due to higher free-space path loss and increased sensitivity to obstruction, signal attenuation in 6 GHz environments grows rapidly with distance and structural barriers. Experimental observations confirm that while 6 GHz achieves the highest throughput under line-of-sight conditions, its performance degrades sharply under multi-wall and floor-penetration scenarios. This highlights a fundamental trade-off between capacity and coverage, which must be considered in practical deployments.

*4.8. Interpretation of RSS Variability Across Wall Scenarios*

Because the observed throughput rose from 11.46 Mbps to 20.17 Mbps and the RSS fell from −27.67 dBm to −45.33 dBm, the 2.4 GHz result for the two-wall situation needs to be interpreted separately. This suggests that a higher average received signal was not the reason for the throughput change. Rather, short-term channel quality during the file-transfer interval is probably the cause. The extended wavelength at 2.4 GHz offers increased penetration through lightweight partition materials and improved diffraction around indoor edges. Additionally, compared to the one-wall position, the receiver location in the two-wall example might have resulted in a more advantageous multipath combination. Even in situations when the average RSS is lower, the achievable throughput can be increased by using fewer retransmissions or more consistent modulation and coding choices. Therefore, rather than a general improvement brought about by the addition of walls, this result should be understood as a local throughput variation. Both RSS and throughput drastically dropped once the impediment reached three walls and the distance reached ten meters. The entire wall experiment demonstrates that indoor throughput can vary non-linearly, since it depends on multipath interference, retransmissions, rate adaptation, and RSS, but it also confirms the expected conclusion that stronger blockage affects Wi-Fi 7 link performance. The wall-penetration results show a general reduction in RSS as the number of wall obstructions increases. As reported in Table 7, the 2.4 GHz band decreased from −27.67 dBm under the one-wall condition to −45.33 dBm with two walls and −55.00 dBm with three walls. A similar trend is observed for the 5 GHz band, where RSS decreased from −33.00 dBm to −52.33 dBm, then to −64.67 dBm. These results are consistent with progressive attenuation caused by increasing obstruction and distance.

The 6 GHz band also shows RSS degradation, changing from −26.67 dBm with one wall to −29.33 dBm with two walls, then falling sharply to −47.00 dBm under the three-wall condition. Therefore, the measured data do not indicate an RSS increase between one and two walls. Rather, they show that the RSS reduction at 6 GHz is relatively small between the first two wall scenarios before a much stronger degradation occurs with three walls. Interestingly, the throughput at 6 GHz remains almost unchanged between the one-wall and two-wall cases, increasing slightly from 66.27 Mbps to 67.71 Mbps, despite the small RSS reduction. This suggests that throughput was not governed by RSS alone in this short-range wall scenario. Factors such as multipath structure, rate adaptation, local reflections, and instantaneous channel quality may have temporarily supported stable data transmission, even though the received signal level weakened slightly.

Overall, the corrected interpretation is that RSS decreases with additional wall obstruction, while throughput may vary non-linearly because Wi-Fi performance depends on both signal strength and channel conditions. This distinction is clarified to avoid confusing RSS attenuation with throughput variation. This behaviour can be attributed to constructive multipath interference, where reflected signal components combine in phase at specific receiver locations. Indoor environments are characterised by rich scattering due to walls, furniture, and structural materials. Under certain geometric configurations, additional reflections may temporarily enhance received signal strength rather than attenuate it. However, as obstruction increases further, absorption and diffraction losses dominate, resulting in the expected signal degradation. This observation highlights the limitation of deterministic propagation assumptions and reinforces the need for statistical or hybrid modelling approaches. The wall penetration experiment revealed non-linear variations in received signal strength (RSS) that cannot be explained solely by monotonic attenuation models. While an overall decrease in RSS is expected with increasing obstruction, the measured results indicate irregular fluctuations across different wall configurations. Table 7 summarises the measured RSS and throughput across one-, two-, and three-wall scenarios. For the 2.4 GHz band, RSS decreased from −27.67 dBm (1 wall) to −45.33 dBm (2 walls) and further to −55 dBm (3 walls), which is consistent with progressive attenuation. A similar monotonic degradation trend is observed for the 5 GHz band, where RSS declined from −33 dBm to −52.33 dBm, then to −64.67 dBm. However, the 6 GHz band exhibits a deviation from this trend. The RSS changed from −26.67 dBm (1 wall) to −29.33 dBm (2 walls), indicating only a marginal reduction, before dropping significantly to −47 dBm under three walls. This behaviour suggests that attenuation does not increase uniformly with additional obstructions at higher frequencies.

The observed irregularity, particularly in the 6 GHz band, can be attributed to multipath propagation effects within the indoor environment. Under specific spatial configurations, reflected signal components from walls, floors, and surrounding structures may combine constructively at the receiver, temporarily offsetting expected attenuation. This explains the relatively small RSS variation between one- and two-wall scenarios.

However, as the number of obstructions increases further, absorption losses and scattering effects dominate, leading to the sharp degradation observed in the three-wall scenario. This transition highlights the limitation of deterministic propagation assumptions in indoor environments. Additionally, the results demonstrate that RSS alone does not fully capture performance behaviour. For example, despite comparable RSS values between one-wall and two-wall scenarios at 6 GHz, throughput remains sensitive to channel quality, interference, and multipath-induced fading. Overall, the findings confirm that indoor signal propagation is highly environment-dependent and influenced by complex interactions between reflection, diffraction, and absorption. Consequently, simplified linear attenuation models are insufficient to fully characterise RSS behaviour in multi-obstruction scenarios, particularly at higher frequencies, such as 6 GHz.

## 5. Indoor Propagation Modelling Framework

Classical propagation models were evaluated against measured RSS data; however, their applicability varies significantly in indoor environments.

### *5.1. Limitations of Two-Ray Model and Adopted Models*

The two-ray ground reflection model assumes a dominant reflection path and far-field conditions, which are rarely satisfied in indoor environments. Therefore, its use is limited to comparative baseline analysis rather than accurate prediction. To improve modelling fidelity, the following indoor-appropriate models are considered:

- The Close-In (CI) modeluses a reference distance of 1 m and captures realistic attenuation trends.
- The log-distance shadowing model accounts for environmental variability through path-loss exponent adjustment.
- The Multi-Wall/Floor (MWF) model incorporates attenuation due to structural elements.

These models provide a more physically consistent representation of indoor propagation compared to simplified deterministic approaches.

### *5.2. Best Fit Between Measured Data and Propagation Models*

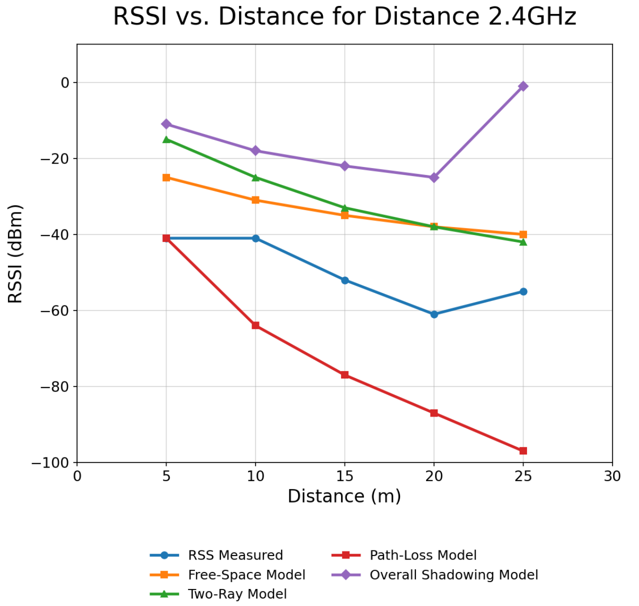
Comparison between measured RSS values and analytical propagation models revealed consistent divergence from idealised predictions. Table 8 presents the Mean Absolute Error (MAE) between measured RSS values and analytical model predictions for the distance study (5–25 m), calculated directly from the experimental dataset reported in the study.

The free-space model systematically overestimated received power, particularly in obstructed and multi-floor scenarios. The two-ray model improved accuracy at short ranges but failed to capture the variability introduced by complex indoor structures. The correlation between the measured RSS and analytical model predictions at 2.4 GHz, 5 GHz, and 6 GHz under distance-based line-of-sight conditions is shown in Figure 5, which shows the measured RSS trends against distance and highlights that indoor corridor measurements may include local fading variations in addition to the expected path-loss behaviour. In all three bands, the empirical curve is not consistently covered by any one propagation model across the whole measurement period. While increasing spacing provides variability that represents indoor structural interaction rather than idealized path geometry, deterministic theories approximate early-range behaviour. Therefore, rather than interpreting frequency-dependent attenuation characteristics based on a single modelling assumption, the combined figure emphasizes the need to consider both range and environmental complexity.

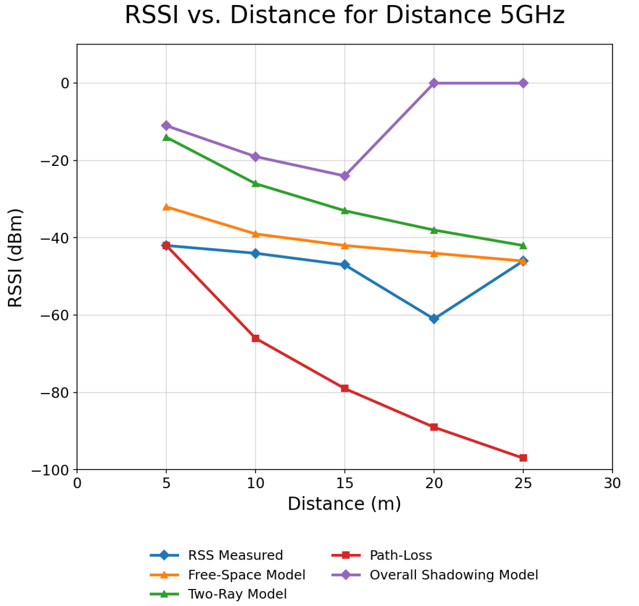
**Table 8.** MAE comparison (distance experiment).

| Band (GHz) | FS (dBm) | TR (dBm) | PL (dBm) | OS (dBm) | MM-RSS (dBm) |
|---|---|---|---|---|---|
| 2.4 | 16.10 | 10.34 | 42.33 | 25.12 | −50.86 |
| 5 | 7.32 | 11.94 | 39.61 | 23.84 | −47.13 |
| 6 | 2.53 | 18.47 | 38.77 | 22.91 | −39.53 |

Note: FS = free space; TR = two-ray ground reflection; PL = path loss (shadowing, B = 5); OS = overall shadowing model (5–25 m); MM-RSS = mean measured received signal strength.

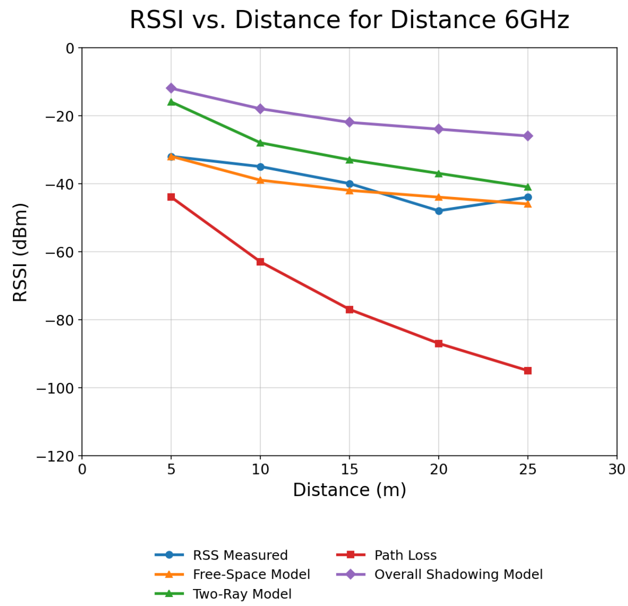



(**a**) 2.4 GHz




(**b**) 5 GHz

**Figure 5.** *Cont.*




(**c**) 6 GHz

**Figure 5.** RSSI versus distance across (**a**) 2.4 GHz, (**b**) 5 GHz, and (**c**) 6 GHz, comparing measured RSS with analytical propagation models.

Although the measured RSS generally decreased with increasing transmitter–receiver separation, the 2.4 GHz and 5 GHz profiles showed a local increase after the 20 m point. This effect does not contradict the expected distance-dependent path-loss trend. It is more likely caused by position-specific multipath behaviour within the corridor, where reflected components from walls, floor surfaces, doors, glass panels, and nearby structural elements may combine constructively at the receiver. In such an indoor corridor, a more distant point can occasionally produce a stronger RSS than a nearer point if the local reflection geometry is more favourable. Therefore, the 25 m measurements should be interpreted as a local fading variation rather than a general increase in received power with distance. Model alignment varied with frequency and scenario; in the distance analysis, free-space and two-ray formulations produced lower prediction error in multiple bands, while shadowing models captured general attenuation behaviour without consistently delivering the smallest deviation from the measured RSS. These results suggest that deterministic models alone are insufficient for predicting Wi-Fi 7 behaviour in realistic deployments.

## 6. System Validation and Implications

This study is guided by a set of research questions that directly inform the design of the experimental campaign and the subsequent analysis. Rather than treating measurements as isolated observations, each experiment was selected to address a specific uncertainty associated with indoor Wi-Fi 7 operation.

The first research question examines what factors constrain achievable throughput when 802.11be operates across heterogeneous frequency bands. To address this, measurements were performed across the 2.4 GHz, 5 GHz, and 6 GHz bands under controlled indoor conditions, allowing throughput and RSS to be compared in identical spatial configurations. This approach enables band-dependent performance trends to be observed without confounding environmental variables. The second research question focuses on identifying which indoor impairments most severely degrade link performance. Experiments were therefore structured to systematically introduce propagation challenges, including wall penetration, floor separation, line-of-sight obstruction, and interference from a domestic microwave source. By isolating these effects, the study distinguishes between loss mechanisms driven by geometry, material absorption, and external interference. The third research question addresses the suitability of analytical propagation models for representing Wi-Fi 7 signal behaviour in real indoor environments, as in Figure 6. Measured RSS values obtained from all experimental scenarios were compared against predictions from established free-space, two-ray ground reflection, and shadowing-based models. This comparison enables evaluation of model accuracy and highlights the limitations of deterministic assumptions when applied to contemporary WLAN deployments.

Together, these research questions define the experimental scope of the study and ensure that all measurements contribute directly to the resolution of practical and theoretical uncertainties surrounding indoor Wi-Fi 7 performance.

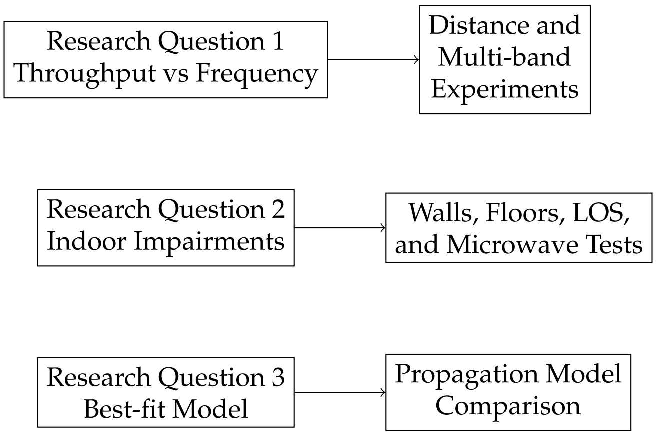



**Figure 6.** Mapping between research questions and practical scenarios.

### *6.1. Results Accuracy and Validation*

To ensure that the reported trends reflect propagation effects rather than transient artefacts, each scenario was executed under controlled indoor conditions with repeated trials and averaged measurements for both throughput and RSS. The resulting cross-band patterns are internally consistent across the measurement campaign: orientation changes produce only marginal variation, whereas obstruction-driven mechanisms (walls, floors, and LOS loss) generate step-like performance degradation. This separation of "weak" versus "dominant" effects supports the validity of the experimental design because the strongest impairments align with the physical expectations of higher-frequency indoor propagation.

Model-based validation further corroborates the measurements. When measured RSS is compared with analytical predictions, deterministic free-space formulations systematically overestimate received power, particularly once structural attenuation is introduced. The two-ray ground model offers partial improvement in simple geometries but fails to capture the variability induced by indoor shadowing and multi-path richness. In contrast, the log-distance shadowing model better matches the measured RSS behaviour and yields fitted path-loss exponents in the range of $n \in [3, 6]$, consistent with increasing obstruction density in the tested environment. Overall, the repeatability of measurements and the relative model agreement provide a coherent validation pathway from raw data to propagation-aware interpretation.

### *6.2. Practical Implications*

The measurements provide deployment-relevant guidance for IEEE 802.11be in offices and multi-storey buildings. First, band selection should be treated as a capacity–coverage decision: 6 GHz is well suited for short-range, high-rate links where clear visibility can be maintained, but it should not be relied upon for vertical reach or multi-room penetration.

Conversely, 2.4 GHz offers more robust connectivity through structural barriers at the expense of achievable throughput, while 5 GHz often provides a pragmatic middle ground for typical office layouts. Second, access-point placement and cell planning should prioritise preserving line of sight (or near-line of sight) for high-capacity service regions and should anticipate rapid performance collapse when corridors, corners, or reinforced floors obstruct the direct path. In multi-storey deployments, the observed floor penetration limits imply that consistent service typically requires additional infrastructure (e.g., per-floor AP placement) rather than assuming that a single high-power node can provide vertical coverage. Finally, for planning and prediction, practitioners should prefer shadowing-aware models (or calibrated site-specific models) over idealised deterministic assumptions, as the latter can materially misestimate indoor link budgets and coverage boundaries for Wi-Fi 7.

### 6.3. Effect of Dynamic Indoor Occupancy

The measurements in this study were taken under low-activity indoor conditions so that the effect of fixed propagation factors could be separated from short-term environmental movement. This design helped isolate the influence of distance, walls, floors, line-of-sight obstruction, and device orientation on the measured Wi-Fi 7 link. In normal office use, however, the channel is rarely static. People walking through corridors, open doors, movable furniture, monitors, cabinets, and other office equipment can introduce additional shadowing, scattering, and reflection.

In more occupied settings, the measured throughput and received signal strength (RSS) would therefore be expected to vary more strongly over time. Human-body blockage is likely to affect the 5 GHz and 6 GHz bands more noticeably than the 2.4 GHz band because higher-frequency signals are generally more sensitive to obstruction and local fading. A busy corridor or open-plan office may also produce short bursts of packet retransmission and rate adaptation, even when the average RSS remains acceptable. For this reason, the present results should be read as a controlled baseline. Future work will extend the measurement campaign to dynamic occupancy scenarios, including moving people, active office equipment, and typical working-hour traffic conditions.

### 6.4. Scope, Generalisation, and Building Diversity

The measurements reported in this study were obtained from a single multi-storey university building. Therefore, the numerical throughput and received signal strength (RSS) values should be interpreted as site-specific rather than universally representative of all indoor buildings. Indoor Wi-Fi 7 propagation is strongly affected by construction materials, wall thickness, floor and ceiling composition, corridor geometry, furniture density, glazing, metallic structures, and local interference. A building with lightweight partition walls may produce less attenuation than the environment tested here, whereas reinforced concrete floors, metal-coated glass, lift shafts, dense furniture, and service ducts may cause stronger shadowing, reflection, and multipath fading.

Accordingly, the broader value of the present results lies in the observed propagation trends rather than in the exact numerical values. The experiments showed that 6 GHz links can provide high short-range throughput but are more vulnerable to obstruction and vertical separation, while 2.4 GHz links offer stronger penetration at lower data rates. The 5 GHz band generally provides intermediate behaviour. These trends are expected to remain relevant in many indoor deployments, although the magnitude of loss will vary with building design and material composition.

In more diverse settings, additional variation should be expected. Open-plan offices may support a stronger line of sight and reflected paths, producing smoother coverage. Dense office layouts with multiple partitions may reduce throughput more rapidly, especially at 5 GHz and 6 GHz. Buildings with reinforced concrete or metallic structures may experience severe floor and wall attenuation, while residential houses with timber framing and plasterboard may show less aggressive signal loss. For this reason, Wi-Fi 7 planning should use site-specific measurements or calibrated propagation models rather than relying only on generic free-space assumptions.

Future work will extend the measurement campaign to multiple building types, including residential, laboratory, office, and industrial environments, and will include material-aware analysis of walls, floors, and ceilings. Such measurements would allow for the development of more generalised deployment guidelines for IEEE 802.11be across heterogeneous indoor environments.

## 7. Conclusions

This paper presented a systematic empirical evaluation of 802.11be (Wi-Fi 7) performance in a complex, indoor, multi-storey environment. Controlled experiments were conducted to isolate the effects of distance, wall penetration, line-of-sight obstruction, floor separation, antenna orientation, and microwave interference across the 2.4 GHz, 5 GHz, and 6 GHz bands. Results confirmed a clear capacity–coverage trade-off: the 6 GHz band achieved the highest peak throughput under unobstructed conditions but exhibited rapid degradation under obstruction and vertical penetration, while 2.4 GHz demonstrated superior robustness at the cost of lower data rates. Line-of-sight disruption emerged as the most critical performance-limiting factor, particularly at higher frequencies. It should be noted that advanced IEEE 802.11be features such as Multi-Link Operation (MLO) and 320 MHz channels were not enabled in the present study. The experimental design deliberately focused on single-link behaviour to isolate propagation effects. Future work will extend the analysis to include these advanced capabilities and examine their interaction with indoor radio propagation. We analysed four selected theoretical propagation models to find the best-fit model that most closely matched with the measured RSS performance. Propagation model comparison revealed that deterministic free-space and two-ray ground formulations overestimate indoor performance, whereas the log-distance shadowing model more accurately reflects measured RSS behaviour, with environment-dependent path-loss exponents between three and six. Overall, the study bridges theoretical Wi-Fi 7 capability and real-world indoor constraints, providing practical guidance for band selection, access-point placement, and coverage planning in enterprise and residential deployments. Further investigation could examine how indoor propagation characteristics can be incorporated into adaptive link-selection strategies for Wi-Fi 7, particularly in environments where frequency-dependent attenuation varies significantly across floors and structural barriers. Since the measurements were collected in a single building, the reported numerical values should be treated as site-specific; however, the observed capacity–coverage trade-off across the 2.4 GHz, 5 GHz, and 6 GHz bands provides useful guidance for Wi-Fi 7 deployment planning in comparable indoor environments.

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**Conflicts of Interest:** The authors declare no conflicts of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| WLAN | Wireless Local Area Network |
| RSS | Received Signal Strength |
| RSSI | Received Signal Strength Indicator |
| LOS | Line of Sight |
| NLOS | Non-Line of Sight |
| PHY | Physical Layer |
| MAC | Medium Access Control |
| MLO | Multi-Link Operation |
| QoS | Quality of Service |
| RTT | Round-Trip Time |
| MAE | Mean Absolute Error |
| AP | Access Point |
| TCP | Transmission Control Protocol |
| SMB | Server Message Block |
| EHT | Extremely High Throughput |

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