

Article

Wi-Fi 7 Streaming Stability: A Multi-Band, Multi-Bitrate Performance Assessment

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Abstract

Wi-Fi 7 (IEEE 802.11be) introduces key physical and medium access control (MAC) layer advancements, including wider channel bandwidths up to 320 MHz, 4096-QAM modulation, preamble puncturing, and tri-band operation across 2.4 GHz, 5 GHz, and 6 GHz to support high-bandwidth and low-latency wireless applications. Despite these advances, the application-level streaming behavior of Wi-Fi 7 networks under realistic multi-factor conditions remains insufficiently characterized in the literature. This paper presents an empirical and simulation-based evaluation of Wi-Fi 7 streaming stability, assessing, with one variable changed at a time, the separate effects of received signal strength (RSS), codec bitrate, frequency band, network layer protocol, media type, and network contention on playback delay for MP3 audio and MP4 video streams. A physical testbed comprising a Wi-Fi 7 access point and client devices is used to conduct controlled experiments across varying signal and network conditions, complemented by OMNeT++ simulation to assess MAC layer scalability under higher client densities. Each band was evaluated independently with Multi-Link Operation (MLO) disabled, so the results characterize single-link operation on Wi-Fi 7 hardware rather than coordinated 802.11be MLO; the codec bitrates tested (192–320 kbps) are low relative to the link capacity, so link saturation was not exercised in the testbed. Results show that RSS degradation non-linearly increases playback delay in the pooled results. Pooled across the conditions tested, not as a strong-signal subset, the bands rank as follows by mean playback delay: 2.4 GHz (7.05 s), 5 GHz (5.21 s), and 6 GHz (4.26 s). Higher codec bitrates were associated with lower playback delay, most plausibly because VLC's pre-buffering threshold is filled sooner at higher bitrates on an unsaturated link. Network layer protocol (IPv4 vs. IPv6) showed no material difference in mean playback delay. Network contention, modeled through increasing concurrent client counts, increased playback delay from one to three testbed clients, and simulated network-layer delay increased from 40 to 80 clients. These findings provide a descriptive, multi-parameter, single-link performance baseline for Wi-Fi 7 audio and video streaming, providing practical guidance for network deployment and serving as a reference for future benchmarking of next-generation Wi-Fi 8 (IEEE 802.11bn) networks.



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Keywords: IEEE 802.11be; Wi-Fi 7; playback delay; received signal strength; streaming performance; frequency band; network contention; codec bitrate

1. Introduction and Background

High-quality multimedia content has become a fundamental component of modern digital communication, with video and audio streaming now central to both entertainment and professional collaboration. As demand for low-latency and uninterrupted playback continues to increase, wireless networks play a critical role in ensuring a smooth and consistent user experience. In such applications, performance is not solely determined by throughput, but also by factors such as playback delay, buffering behavior, and connection stability. To meet these growing demands, wireless local area network (WLAN) technologies have evolved significantly, with IEEE 802.11be (Wi-Fi 7) representing the latest advancement. Wi-Fi 7 introduces enhanced capabilities including higher data rates, reduced latency, and improved reliability through wider bandwidth channels and tri-band operation. In particular, the ability to operate across multiple frequency bands offers new opportunities for improving performance, but also introduces variability due to differing propagation characteristics, interference conditions, and coverage ranges.

1.1. PHY and MAC Layer Considerations

Streaming performance in Wi-Fi 7 networks is governed by the interplay between physical (PHY) and medium access control (MAC) layer behavior, which collectively determine the throughput, latency, and reliability experienced at the application level [1,2]. At the PHY layer, IEEE 802.11be introduces channel bandwidths up to 320 MHz, 4096-QAM modulation, preamble puncturing for interference resilience, and tri-band operation across 2.4 GHz, 5 GHz, and 6 GHz, enabling theoretical peak rates up to 46 Gbps [1, 3]. Despite these gains, link performance remains sensitive to received signal strength (RSS) and propagation loss, particularly in the 6 GHz band where higher attenuation and building entry loss can rapidly degrade link stability. At the MAC layer, channel access is governed by carrier sense multiple access with collision avoidance (CSMA/CA), where devices incur backoff delays, retransmissions, and queueing effects that intensify with network density and directly impact streaming continuity [2,3]. Wi-Fi 7 partially mitigates these limitations through Multi-Link Operation (MLO), Multi-Resource Unit (Multi-RU) orthogonal frequency-division multiple access (OFDMA), and restricted Target Wake Time (r-TWT), all targeting reduced worst-case latency for time-sensitive traffic [2,4]. MLO has demonstrated end-to-end latency reductions from approximately 145 ms to 18 ms compared to single-link Wi-Fi 6 under equivalent load conditions [5]. In the downlink streaming scenarios evaluated in this study, the access point (AP) is the transmitter.

Together, these PHY and MAC characteristics shape streaming performance beyond raw throughput capacity. Figure 1 conceptually illustrates the relationship between PHY/MAC layer mechanisms and the application-level playback delay considered in this study.

To ensure reproducibility and accurate interpretation of the results, the key PHY and MAC layer parameters of the IEEE 802.11be standard are summarized in Table 1. Table 1 lists standard capabilities rather than the configured testbed settings.

Table 1. Key Wi-Fi 7 (IEEE 802.11be) PHY/MAC parameters.

Parameter	Value
Standard	IEEE 802.11be (Wi-Fi 7)
Frequency bands	2.4 GHz, 5 GHz, 6 GHz
Channel bandwidth	Up to 320 MHz (standard maximum)
Modulation scheme	Up to 4096-QAM
Max. throughput	~46 Gbps (theoretical)
MAC access mechanism	CSMA/CA (EDCA)
Multi-Link Operation (MLO)	Supported by standard; not enabled in the experiments
Preamble puncturing	Supported (mandatory)
Guard interval	0.8/1.6/3.2 μ s

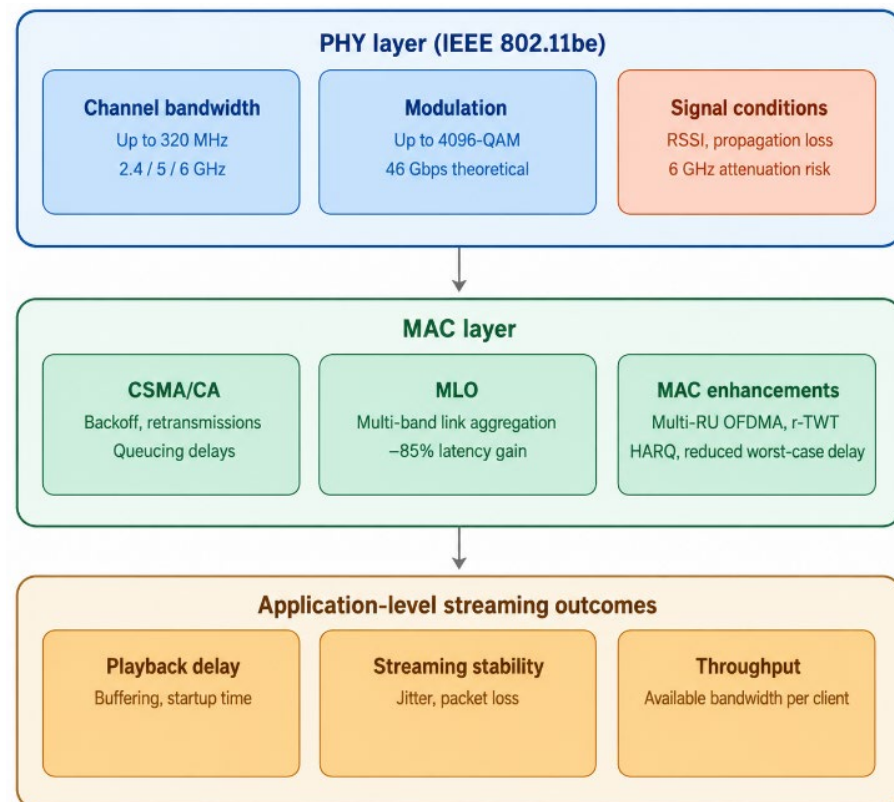


Figure 1. Relationship between PHY/MAC layer behavior and playback delay in Wi-Fi 7 streaming environments.

1.2. Research Challenges and Questions

Despite recent advancements in Wi-Fi technologies, the streaming performance experienced by end users in real-world scenarios remains highly dependent on several key factors, including received signal strength (RSS), media bitrate, network layer protocol behavior, and the level of channel contention. While prior studies have examined aspects of Wi-Fi 7 performance and reliability, the separate effects of RSS, media bitrate, tri-band operation, network protocol, and channel contention on playback delay and streaming stability, under a design that changes one variable at a time, have not been fully characterized. To address the separate-factor gap, this paper investigates the impact of key wireless and network parameters on streaming performance in Wi-Fi 7 environments. The primary research question guiding this study is as follows:

RQ: What impact do signal strength, codec bitrate, frequency band, network layer protocol, media type, and channel contention have on playback delay in a Wi-Fi 7 streaming environment?

To answer this question, a combined testbed and simulation-based approach is adopted. Controlled field experiments evaluate the effect of RSS, bitrate, IPv4/IPv6, and real-time traffic conditions on playback delay. The effect of increasing channel contention is analyzed by introducing multiple active nodes under fixed conditions. Simulation-based analysis is then used to extend the evaluation and estimate MAC layer scalability under higher client densities impractical to test physically.

1.3. Study Contributions

The main contributions of this work are as follows.

- We examine the separate effects of RSS, codec bitrate, and frequency band on audio and video streaming playback delay over a Wi-Fi 7 (802.11be) client-server testbed, changing one variable at a time.
- We explore the effect of 802.11be tri-band operation across 2.4 GHz, 5 GHz, and 6 GHz on streaming performance through comparative per-band measurement (each band evaluated independently, with MLO disabled).
- We develop and configure OMNeT++ simulation models to assess MAC layer scalability under client densities of 40, 60, and 80 nodes, extending the analysis beyond physical testbed constraints. Note that the simulation captures MAC layer contention behavior and is not intended to replicate absolute application layer delay values from the testbed.
- We analyze playback delay stability under varying wireless channel conditions, network layer protocols, media types, and contention levels, changing one variable at a time.

Collectively, these contributions address a gap that existing literature has not fully resolved: a cross-layer, application-level evaluation of Wi-Fi 7 streaming stability that systematically varies RSS, bitrate, frequency band, protocol, media type, and contention within a unified testbed and simulation framework. This work varies individual parameters one at a time and provides direct measurement of user-perceived playback delay as the primary outcome.

Beyond its immediate contributions, this study is motivated by the longer-term trajectory of WLAN evolution. IEEE 802.11bn (Wi-Fi 8), currently in active standardization with Draft 1.0 completed in 2025 and publication expected in 2028 [6], is expected to build upon the MAC and PHY foundations established by 802.11be. Establishing a rigorous, multi-parameter performance characterization of Wi-Fi 7 streaming behavior now provides the wireless research community with a quantitative baseline against which Wi-Fi 8 improvements, including coordinated multi-AP operation, enhanced MLO, and AI-driven resource allocation, can be measured and validated. This study therefore serves a dual purpose: (i) addressing an immediate gap in the Wi-Fi 7 literature; and (ii) laying the groundwork for comparative next-generation Wi-Fi evaluation.

The remainder of this paper is organized as follows. Section 2 presents the related work. Section 3 describes the experimental and simulation methodology. Section 4 presents the empirical results and analysis. Section 5 discusses the implications of the findings. Section 6 concludes the paper.

2. Related Work

Wi-Fi 7, formally IEEE 802.11be, has been introduced to support extremely high throughput, lower latency, and improved reliability for dense and delay-sensitive wireless applications [7]. A central feature of Wi-Fi 7 is Multi-Link Operation (MLO), which allows stations and access points to use multiple frequency bands, including 2.4 GHz, 5 GHz, and 6 GHz, in a coordinated manner. Prior work [8,9] has shown that MLO can provide link diversity and help reduce the impact of degraded channel conditions, congestion, and link failures. However, MLO also introduces new challenges because each band has different propagation, interference, and contention characteristics [2,10,11]. For example, higher frequency bands may offer greater throughput but can be more sensitive to distance and obstruction, while lower frequency bands generally provide more stable coverage at the cost of reduced data rates. It is noted that the present study evaluates each frequency band independently rather than using coordinated MLO operation, establishing a per-band performance baseline. MLO evaluation under coordinated multi-band conditions is identified as a direction for future work.

Recent studies have also examined reliability mechanisms for Wi-Fi 7, particularly through the integration of IEEE 802.1CB Frame Replication and Elimination for Reliability (FRER) with MLO. Ergenç, Reisinger, and Dressler [12] present an implementation of FRER over MLO in OMNeT++ and evaluate its behavior under link failures, congestion, and mobility. Their results indicate that redundancy can improve packet delivery ratio and help maintain bounded latency, although this comes with additional channel overhead and reduced efficiency. Their work demonstrates the potential of Wi-Fi 7 multi-link communication, but its focus is on redundancy mechanisms and network-level reliability rather than application-level streaming performance.

The propagation characteristics of the 6 GHz band—now central to Wi-Fi 7 performance—have been studied through dedicated measurement campaigns. Dogan-Tusha et al. [13] conducted an extensive indoor measurement campaign of a dense Wi-Fi 6E network, reporting median outdoor received signal strength indicator (RSSI) between -75 dBm and -85 dBm and building entry loss between 12 dB and 16 dB through low-emission windows. Dogan-Tusha et al. [14] further characterized 6 GHz indoor and outdoor propagation through fixed and walking measurements, demonstrating outdoor RSSI ranging from -64 dBm to -95 dBm and confirming that higher frequency bands experience meaningful coverage constraints. These findings motivate the signal strength sensitivity analysis conducted in the present study.

The behavior of the MAC layer under multi-user and contention-heavy conditions has been well studied in prior Wi-Fi generations, providing a useful baseline for interpreting Wi-Fi 7 results. Liu and Choi [3] conducted a first-of-its-kind measurement study of Wi-Fi 6 (IEEE 802.11ax), demonstrating that OFDMA achieves up to $5\times$ latency reduction compared to CSMA/CA in downlink multi-client scenarios. Their results show that under CSMA/CA, downlink contention causes latency to increase sharply to 170.5 ms at high traffic load, while OFDMA limits this to 35.6 ms. Bellalta and Kosek-Szott [15] studied AP-initiated multi-user transmissions in 802.11ax and confirmed that downlink AP scheduling overhead grows with the number of concurrent streams. Sarkar and Gul [16] examined the combined effect of RSSI, bitrate, and network topology on video playback delay in IEEE 802.11ax networks using a combined testbed and OMNeT++ simulation methodology closely related to the present study, establishing that RSS and topology jointly determine application-level delay in Wi-Fi environments. The present study adopts a closely related methodology. Its increment over [16] is Wi-Fi 7 hardware with MLO disabled, separate tests on 2.4, 5, and 6 GHz, IPv4 and IPv6, and both MP3 and MP4.

Other work [17] on redundancy and time-sensitive networking over Wi-Fi has similarly shown that packet duplication, multi-radio operation, and traffic steering can improve reliability and latency predictability. These studies are useful for understanding how Wi-Fi networks can support time-sensitive applications, especially under congestion or unstable link conditions. However, many of these works are either conceptual, simulation-based, or focused on reliability protocols rather than actual media playback behavior. As a result, they do not fully explain how users experience streaming performance when RSS, codec bitrate, wireless band, media type, or network layer protocol changes. This study changed one variable at a time.

Streaming performance is not determined by throughput alone. For media applications, playback delay, jitter, packet delivery consistency, and connection stability strongly influence user-perceived quality [7,11]. A wireless connection may provide high peak throughput but still produce poor streaming quality if signal degradation, retransmissions, and contention increase buffering time. The effect of network layer protocol on streaming delay has been studied in prior Wi-Fi environments. Our earlier study of IEEE 802.11ax networks [16] found no statistically significant performance differences attributable solely to IP version for video streaming, and Gamess and Shah [18] reported only slight differences

between IPv4 and IPv6 in TCP and UDP throughput and round-trip time over 2.4 GHz and 5 GHz Wi-Fi—findings consistent with the IPv4/IPv6 results presented in this study. Abdullah et al. [19] examined the impact of wireless network packet loss on real-time video streaming using H.265 and H.266 codecs, demonstrating that even modest packet loss rates produce significant buffering and playback degradation, reinforcing the relationship between link reliability and application-level delay. Studies on virtual reality (VR) and high-definition video streaming further confirm that increasing client density introduces substantial AP scheduling delays, with Maura, Wilhelmi, and Bellalta [20] demonstrating that Wi-Fi channels saturate rapidly under concurrent high-bitrate streams even in newer standards. Therefore, studying playback delay across multiple bands and signal strength levels is necessary to understand the practical performance of Wi-Fi 7 streaming.

The role of OMNeT++ as a simulation tool for Wi-Fi MAC layer analysis has been established in prior work. Ergenç et al. [12] used OMNeT++ with INET to evaluate MLO reliability under congestion and failure scenarios. The INET framework has been used widely for modeling 802.11 MAC contention behavior, AP scheduling, and scalability under increasing node counts [21]. Regarding VR and immersive media streaming, Maura et al. [20,22] evaluated Wi-Fi performance for VR streaming using realistic High Efficiency Video Coding (HEVC) video traffic, showing that Wi-Fi channels support up to four concurrent VR users before saturation, and that intra-refresh coding reduces latency variability—providing useful context for the scalability limitations observed in the present study’s simulation results. Morshedi and Noll [23] further demonstrated that RSSI is the primary predictor of streaming quality of service (QoS) in Wi-Fi networks, using machine learning models trained on 802.11 signal parameters to estimate user-perceived quality—reinforcing the central role of signal strength in determining streaming stability observed in this study.

Existing literature provides strong foundations on Wi-Fi 7 architecture, MLO, reliability mechanisms, and low-latency communication. However, the literature remains fragmented. Some studies focus on Wi-Fi 7 features and MLO design, while others focus on redundancy, traffic steering, and general QoS behavior. Comparatively, fewer studies jointly examine the effect of RSS, bitrate, multi-band operation, network protocol, and network load on playback delay in a Wi-Fi 7 environment. This research gap motivates the present study. This paper investigates streaming stability from an application performance perspective, changing one variable at a time. Specifically, it examines how RSS, codec bitrate, frequency band, IPv4/IPv6 protocol, media type, and node contention each relate to playback delay and connection stability in a Wi-Fi 7 testbed and simulation environment.

Table 2 summarizes the related work discussed above, highlighting the study focus, key contributions, methods, and limitations of each prior work in relation to the present study.

Table 2. Summary of related work.

Ref.	Study Focus	Key Contributions	Methods	Limitations
[7]	MLO performance for AR applications in Wi-Fi 7	Evaluates MLO with different traffic-to-link allocation policies for AR workloads; compares MLO vs. single-link operation	Simulation-based evaluation of 802.11be MLO under AR traffic	Focused on AR traffic only; no general media streaming or QoE analysis
[8]	TCP latency over MLO in Wi-Fi 7	Shows MLO improves TCP latency only when additional link is idle; performance degrades under partial link load	ns-3 simulation of MLO STR mode with TCP traffic	Limited to transport layer behavior; no media streaming or QoE analysis; findings are loading condition dependent

Table 2. Cont.

Ref.	Study Focus	Key Contributions	Methods	Limitations
[9]	Traffic allocation and MLO/SLO coexistence	Proposes latency-optimal traffic-to-link allocation strategies for MLDs coexisting with legacy SLDs; derives analytical model for end-to-end delay and jitter	Analytical modeling validated with ns-3 simulation	Does not evaluate real user-perceived streaming performance or QoE
[10]	IEEE 802.11be standard specification	Defines EHT features including MLO, multi-band operation, and PHY/MAC enhancements	Formal IEEE standard document	No experimental validation or application-level insights
[11]	Wi-Fi configuration and media streaming	Shows how wireless settings affect volumetric video streaming performance	Experimental multimedia evaluation	Focus limited to volumetric video; lacks multi-factor cross-layer analysis
[12]	FRER with MLO for network reliability	Demonstrates improved reliability via packet replication and elimination combined with MLO	OMNeT++ simulation under failures and congestion	Introduces overhead; focuses on network-level reliability, not QoE or streaming
[13]	6 GHz band indoor propagation and interference measurement	Reports median outdoor RSSI between -75 and -85 dBm and building entry loss of 12–16 dB for dense Wi-Fi 6E indoor deployments	Extensive indoor/outdoor measurement campaign at University of Michigan	Focused on interference potential and incumbent protection; does not evaluate streaming performance
[14]	6 GHz indoor and outdoor propagation characterization	Characterizes RSSI and building entry loss at 6 GHz; confirms higher frequency bands experience significant coverage constraints	Fixed location and walking measurements for Wi-Fi 6E deployments	Focuses on propagation measurement; no application-level streaming evaluation
[15]	AP-initiated downlink scheduling in 802.11ax	Demonstrates that AP-controlled airtime distribution across concurrent downlink streams reduces contention overhead and improves multi-user performance	Analytical modeling of 802.11ax MU transmission scheduling	Focuses on throughput optimization; does not evaluate application-level streaming delay
[16]	Signal strength, bitrate, and topology effects on Wi-Fi 6 video streaming	Evaluates combined effect of RSSI, bitrate, and network topology on video playback delay using testbed and OMNeT++ simulation in 802.11ax	Combined testbed and OMNeT++ simulation for 802.11ax	Limited to Wi-Fi 6; does not cover tri-band operation, IPv4/IPv6, or media type comparisons
[18]	IPv4 and IPv6 network performance over Wi-Fi and Ethernet	Reports slightly better performance for IPv4, but only small IPv4/IPv6 differences in TCP/UDP throughput and round-trip time in most experiments	Experimental benchmarks on five Raspberry Pi models over 2.4 GHz and 5 GHz Wi-Fi and Ethernet	Bulk-transfer benchmarks only; does not evaluate media streaming, the 6 GHz band, RSS, or contention effects
[19]	Packet loss impact on real-time video streaming using H.265 and H.266	Shows that even modest wireless packet loss causes significant buffering and playback degradation; proposes adaptive codec selection	Simulation using FFmpeg with H.265 and H.266 codecs	Simulation-based; limited to codec-level analysis without physical testbed validation

Table 2. *Cont.*

Ref.	Study Focus	Key Contributions	Methods	Limitations
[22]	Multi-user VR streaming over Wi-Fi 6	Shows VR streaming to three users works under DCF and DL OFDMA up to 100 Mbps each; UL OFDMA disrupts tracking and increases latency	Experimental evaluation with one AP and three HMDs using Wi-Fi 6	Limited to VR workloads; does not evaluate audio, general video, or Wi-Fi 7
[21]	OMNeT++ discrete event simulation framework	Establishes OMNeT++ as a flexible, widely adopted simulation tool for network protocol modeling, including Wi-Fi MAC layer behavior	Simulation framework and tool description	Framework reference; does not evaluate specific Wi-Fi 7 features
[23]	RSSI-based QoS estimation for Wi-Fi video streaming using machine learning	Demonstrates that RSSI is the primary predictor of streaming QoS in Wi-Fi networks; proposes ML model for QoS estimation from signal parameters	Experimental study using 802.11 RSSI measurements and ML classification	Limited to QoS estimation; does not evaluate Wi-Fi 7 or multi-factor streaming scenarios
This work	Wi-Fi 7 streaming performance	Evaluates playback delay under varying RSS, bitrate, band, protocol, media type, and contention; establishes multi-parameter baseline for Wi-Fi 8 benchmarking	Combined testbed and OMNeT++ simulation (MP3/MP4 streaming over 802.11be)	Addresses gap in cross-layer, application-level evaluation; MLO evaluation identified as future work; limited to a single AP and client adapter model, MLO disabled (per-band single-link operation), low (192–320 kbps) bitrates

3. Methodology

3.1. Experimental Testbed Setup

A controlled physical network testbed was set up to evaluate audio and video streaming performance in a Wi-Fi 7 (IEEE 802.11be) environment under varying network conditions (Figure 2). The testbed consisted of a single access point (AP) configured using an ASUS RT-BE92U tri-band Wi-Fi 7 router (ASUSTeK Computer Inc., Taipei, Taiwan), operating across 2.4 GHz, 5 GHz, and 6 GHz frequency bands. A wired media server was connected to the AP via Ethernet, while client devices accessed the network wirelessly. The server node was implemented on a Windows 11 desktop system equipped with an ASUS PCE-BE92BT Wi-Fi 7 network adapter. The client nodes consisted of three laptops, each running Windows 11 and equipped with TP-Link TBE400UH tri-band Wi-Fi 7 USB adapters (TP-Link Technologies Co., Ltd., Shenzhen, China), enabling consistent support for 802.11be features across all participating devices. All measurements therefore used a single AP model and a single client adapter model, which limits the generalizability of the results to other hardware. Multimedia content was streamed from the server to client devices over a local network using VLC media player, allowing controlled delivery of audio and video streams while maintaining consistent encoding and playback conditions across all scenarios.

To evaluate the impact of signal conditions, RSS was varied by positioning the client devices at predefined locations within an indoor environment. Measurements were conducted at four representative RSS levels (−48 dBm, −56 dBm, −63 dBm, and −70 dBm), corresponding to typical strong to weak indoor wireless conditions. The server and access point remained fixed throughout all experiments to ensure consistency, while only the client

position was varied to achieve the desired signal levels. RSS was measured at the client device using the network adapter's reported signal strength, averaged over the duration of each test run. The four RSS levels serve as representative indoor signal conditions rather than distance-calibrated measurements. Because RSS was varied by physically repositioning the clients, each RSS level is also associated with a different location and therefore potentially different multipath, shadowing, and local interference conditions; the effects attributed to RSS in this study cannot be fully separated from these location-specific factors.

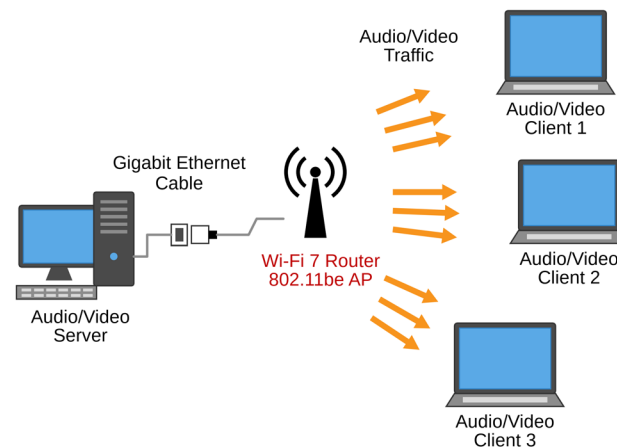


Figure 2. Wi-Fi 7 (802.11be) testbed with multiple clients.

3.2. System Parameter Settings

To systematically evaluate streaming performance, key parameters including RSS, codec bitrate, frequency band, and number of client nodes were varied across controlled experimental conditions. The RSS was evaluated at four representative levels (-48 dBm, -56 dBm, -63 dBm, and -70 dBm), corresponding to typical indoor wireless environments ranging from strong to weak signal conditions. Codec bitrate varied across three levels (192 kbps, 256 kbps, and 320 kbps) to represent low, medium, and standard quality streaming configurations. These bitrate levels are typical of compressed audio streaming and are well below the multi-Mbps bitrates typical of high-definition (1080p) or 4K video. At these bitrates, a multi-gigabit Wi-Fi 7 link remains far from saturation, so link saturation and the associated queueing were not exercised in the testbed; the results are therefore relevant to low-bitrate streaming start-up behavior and should not be read as representative of high-definition video workloads. Both audio and video media types were evaluated using MP3 and MP4 formats, respectively, to compare MP3 and MP4. The same three bitrate settings, 192, 256, and 320 kbps, are described as one factor for both MP3 and MP4. Network layer protocol effects were examined by comparing IPv4 and IPv6 configurations under identical conditions. Performance was evaluated across all three Wi-Fi 7 frequency bands (2.4 GHz, 5 GHz, and 6 GHz), enabling analysis of the trade-offs between coverage, stability, and throughput associated with each band.

All experiments used downlink traffic only, with the AP serving media streams to client devices. The MAC layer access configuration followed the default EDCA settings of the ASUS RT-BE92U router. Modulation and coding scheme (MCS) selection was handled automatically by the driver's rate adaptation mechanism. Each frequency band was evaluated independently; coordinated Multi-Link Operation (MLO) was not enabled in these experiments, as the goal is to establish a per-band performance baseline. Consequently, each experiment exercised single-link operation on Wi-Fi 7 hardware, functionally closer to single-link (Wi-Fi 6/6E-style) operation than to coordinated 802.11be MLO. The results do not benchmark MLO and should not be interpreted as representative of full Wi-Fi 7 MLO performance.

To assess the impact of network contention, experiments were conducted with varying numbers of clients. Initial measurements were performed using a single client, followed by a multi-client scenario with three simultaneous streaming devices (Figure 2). Further scalability analysis was conducted through simulation for larger client counts, as discussed in Section 3.5.

3.3. Performance Metrics

The primary performance metric used in this study is playback delay, defined as the time elapsed between initiating media playback at the client device and the start of continuous media streaming. This metric directly reflects user-perceived responsiveness and is well-suited for evaluating streaming stability in real-world applications. Playback delay includes network transmission delay and application-layer pre-buffering behavior of the VLC media player and is therefore an application-level metric rather than a purely network-level one. Playback delay was measured in seconds for all experimental conditions. Playback delay was measured from the initiation of playback to the onset of continuous playback, as defined above.

To support application-level observations, packet-level measurements were also collected using Wireshark. Network traffic corresponding to the streamed media was captured at the client device, allowing analysis of packet arrival times and transmission behavior during playback. The captured packet data were exported and processed using a custom Python 3.12.4 script to extract timing information and ensure consistency across repeated measurements. Each experimental scenario was conducted a minimum of three times to improve measurement reliability. Results were examined for anomalies and outliers, and where necessary, additional runs were conducted. All differences are therefore descriptive differences between means. The final reported values represent averages across valid runs, ensuring that reported playback delays reflect consistent trends rather than isolated observations.

3.4. Multi-Node Contention Scenario

To evaluate the impact of network contention on streaming performance, a multi-client scenario was implemented using three simultaneous streaming nodes. All client devices accessed the same AP and received media streams concurrently from the media server, introducing controlled channel load. During these experiments, RSS and codec bitrate were held constant to isolate the effect of contention. All devices were maintained at fixed positions corresponding to a predefined signal strength, and a uniform bitrate was applied across all streams. Under these conditions, the influence of media type, network layer protocol, and frequency band was evaluated in the presence of competing traffic.

In this downlink scenario, the AP is the sole device competing for channel access. Three streams occupy only a small fraction of link capacity, so AP-side airtime partitioning and airtime saturation are not treated as testbed findings.

3.5. Simulation Model

To extend the analysis beyond the physical testbed, a simulation-based evaluation was conducted using the OMNeT++ discrete-event simulation framework (v6.0) with the INET v4.5 library. The primary objective of the simulation is to assess MAC layer scalability under increased client load and to estimate the impact of large numbers of concurrent streaming devices on end-to-end delays. The simulation environment was configured to reflect the key parameters of the experimental testbed, including signal strength conditions, bitrate settings, and traffic characteristics.

Network load was varied by increasing the number of active client nodes, with scenarios evaluated at 40, 60, and 80 simultaneous streaming devices connected to a single

AP. These configurations represent moderate to high density deployment scenarios that are not feasible to reproduce physically.

It is important to note that the simulation measures network-layer end-to-end packet delivery delay, which does not include application-layer pre-buffering or VLC decoding overhead. The absolute delay values from the simulation are therefore not directly comparable to the application-level playback delay values measured in the testbed. The two evaluations are complementary: the testbed captures real application-level user experience, while the simulation captures MAC layer network behavior at scales impractical to test physically. Table 3 summarizes the simulation parameters used.

Table 3. Simulation parameters.

Parameter	Value
Simulation framework	OMNeT++ v6.0/INET v4.5
Number of client nodes	40, 60, 80
Codec bitrate	256 kbps
RSS level	−56 dBm
Packet size	1000 bytes
Traffic type	UDP streaming (downlink only)
Simulation duration	15 s
Channel model	Log-normal shadowing

While OMNeT++ does not fully implement all Wi-Fi 7 PHY layer features, the model captures key MAC layer behaviors including contention and traffic dynamics, enabling a qualitative scalability analysis under varying network load. Specifically, the simulation does not model coordinated MLO or 6 GHz PHY layer characteristics, which should be considered when interpreting the scalability results. More specifically, the INET model used is a legacy IEEE 802.11 CSMA/CA MAC/PHY model: it does not implement the 802.11be MAC/PHY (including 320 MHz channels, 4096-QAM, and Multi-RU OFDMA), coordinated MLO, or 6 GHz-specific propagation, and it therefore offers limited insight into true 802.11be multi-user performance. The simulation was run with a single parameter set (Table 3: 256 kbps, −56 dBm, 1000-byte packets).

3.6. Experimental Procedure

To ensure consistency and reliability, all experiments were conducted under controlled and repeatable conditions. The server and AP remained fixed throughout testing, while client devices were positioned at predefined locations corresponding to specific RSS levels. Field experiments were performed during periods of low external network activity to minimize interference from unrelated devices.

Parameters were varied systematically with only one variable modified at a time while others were held constant, enabling clear isolation of individual factor effects. Prior to each experiment, the streaming application was reset to ensure a consistent initial state. Each test was conducted for a fixed duration, allowing sufficient time for stable data collection. A minimum of three repetitions were performed for each configuration; outliers were excluded, and results were averaged across valid runs. Baseline measurements were periodically repeated across sessions to ensure that environmental variations did not significantly influence observed performance trends.

4. Results and Analysis

4.1. Impact of Signal Strength on Playback Delay

The impact of received signal strength (RSS) on streaming performance was evaluated across four representative signal levels: −48 dBm, −56 dBm, −63 dBm, and −70 dBm.

Figure 3 illustrates the relationship between RSS and average playback delay across all experimental conditions.

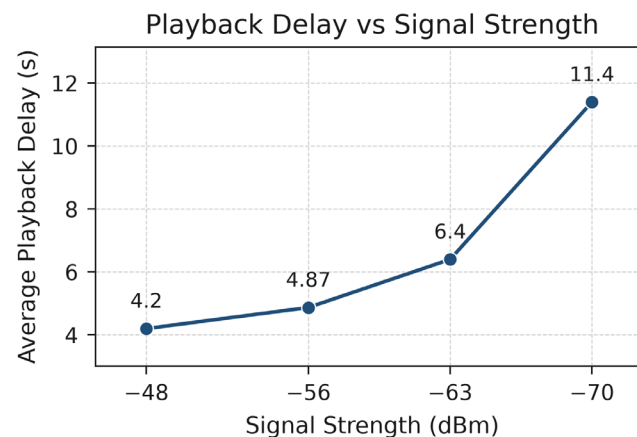


Figure 3. Impact of RSS on playback delay, showing a non-linear increase in delay as signal strength degrades.

Results show a clear and non-linear increase in playback delay as signal strength degrades. At -48 dBm, playback delay remains relatively low and stable, with an average delay of approximately 4.2 s. As RSS decreases to -56 dBm, a modest increase in delay is observed. Further degradation to -63 dBm and -70 dBm results in substantially larger increases, with playback delay reaching approximately 6.4 s and 11.4 s, respectively.

Playback delay can be expressed as inversely proportional to the effective throughput, which depends on signal strength:

$$D_{\text{playback}} \propto \frac{1}{T_{\text{effective}}(\text{RSS})} \quad (1)$$

where D_{playback} represents playback delay and $T_{\text{effective}}(\text{RSS})$ denotes effective throughput as a function of signal strength. Equations (1)–(4) in this paper are qualitative relationships intended only to illustrate the direction of the effects discussed.

Runs that ended in connection loss were not included in the averages. The pooled results show higher playback delay at weaker RSS. They are not a strong-signal per-band result, and they do not show that the impact of RSS is particular to the 5 GHz or 6 GHz band.

4.2. Impact of Band on Playback Delay

The impact of Wi-Fi frequency band on streaming performance was evaluated across the three Wi-Fi 7 operating bands: 2.4 GHz, 5 GHz, and 6 GHz. Figure 4 presents the average playback delay observed for each band under the conditions tested.

The results show a clear performance differentiation between the three frequency bands. The 6 GHz band achieves the lowest average playback delay (approximately 4.26 s), followed by the 5 GHz band (5.21 s), while the 2.4 GHz band exhibits the highest delay (7.05 s). These are pooled means across the conditions tested in each band, not a strong-signal subset, so they do not show that 6 GHz has the lowest playback delay under strong signal. It should be noted that the 6 GHz average is computed over fewer valid measurements ($n = 31$) compared to 2.4 GHz ($n = 46$) and 5 GHz ($n = 37$), as a larger proportion of 6 GHz measurements resulted in connection loss at weaker signal levels, which is itself indicative of reduced link reliability. These per-band counts are numbers of valid measurements pooled across the conditions tested in each band. Because each configuration was run a minimum of three times, additional runs were added where anomalies were found, and runs ending in connection loss were excluded, the counts do not correspond to a fixed multiple of three. Excluding failed connections also

biases the comparison: the 6 GHz mean is conditional on the link being maintained and omits the weaker-signal cases in which 6 GHz connections were lost, so Figure 4 may overstate the 6 GHz advantage relative to a comparison over all attempted runs.

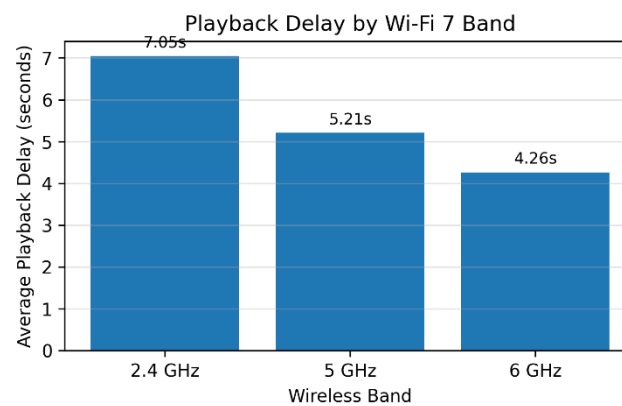


Figure 4. Average playback delays across 2.4 GHz, 5 GHz, and 6 GHz.

This performance advantage of higher frequency bands is accompanied by reduced link reliability. RSS was varied by repositioning the client device rather than measuring specific geometric distances; the observed connection loss behavior is therefore attributed to signal degradation rather than geometric range. However, because repositioning also changes the multipath and local interference environment at each location, signal-strength effects cannot be fully separated from these location-specific factors.

4.3. Impact of Codec Bitrate on Playback Delay

The impact of codec bitrate on playback delay was evaluated across three levels: 192 kbps, 256 kbps, and 320 kbps. Figure 5 illustrates the relationship between bitrate and average playback delay. Streams at 192 kbps exhibited the highest average playback delay (approximately 6.8 s), followed by 256 kbps (5.1 s), while 320 kbps yielded the lowest delay (approximately 5.0 s). While 320 kbps consistently yields the lowest delay, the difference between 256 kbps and 320 kbps is marginal, suggesting diminishing returns at higher bitrates under the tested conditions.

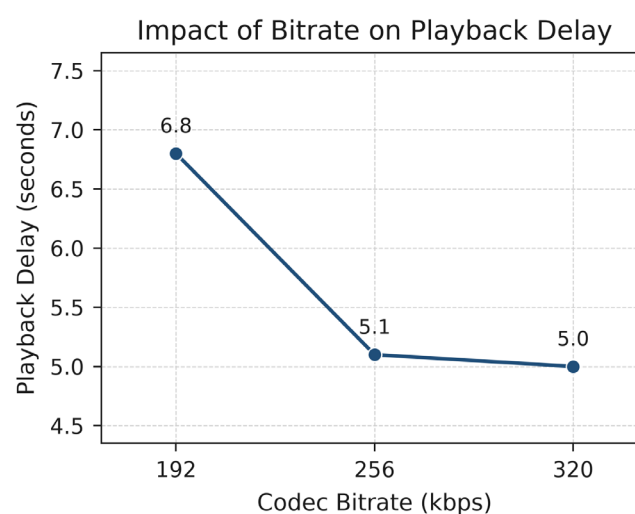


Figure 5. Average playback delay at codec bitrates of 192, 256, and 320 kbps.

At first glance, this result appears counterintuitive, as higher bitrate streams typically require greater bandwidth and would be expected to increase buffering time. Because the tested bitrates are low relative to the link capacity, the link was not saturated, and the rate at

which stream data reach the client is governed largely by the stream bitrate rather than by link capacity. VLC begins playback once its pre-buffering threshold has been satisfied; because this threshold requires a sufficient number of bytes to be accumulated, a higher-bitrate stream satisfies it in less wall-clock time. The observed reduction in playback delay with increasing bitrate is therefore most plausibly an artifact of this application-layer buffering behavior on an unsaturated link, rather than evidence of improved MAC-layer efficiency.

In idealized form (an illustrative relationship), playback delay can be approximated as:

$$D_{\text{playback}} = \frac{B_{\text{buffer}}}{T_{\text{effective}}} \quad (2)$$

where B_{buffer} represents the amount of data required before playback begins and $T_{\text{effective}}$ denotes the effective throughput of the connection. On an unsaturated link, the rate at which stream data arrive at the client is bounded by the stream bitrate, so for a fixed buffer requirement, Equation (2) predicts shorter delay at higher bitrate, consistent in direction with Figure 5.

It is acknowledged that this descending trend may not continue indefinitely at higher bitrates, where network capacity constraints would eventually cause delays to increase. Evaluation at higher bitrates representative of standard-definition and high-definition video workloads is identified as a direction for future work. These findings highlight that playback delay is not solely determined by the volume of data transmitted, but also by application-layer buffering dynamics. Bitrate selection therefore plays an important role in streaming performance optimization within the low-bitrate range tested.

4.4. Impact of Network Layer Protocol

The impact of network layer protocol on streaming performance was evaluated by comparing IPv4 and IPv6 configurations under identical experimental conditions. Figure 6 illustrates the average playback delay observed for both protocols. The results indicate that the difference in playback delay between IPv4 and IPv6 is minimal across all tested scenarios, with no consistent advantage observed for either protocol. This comparison is descriptive.

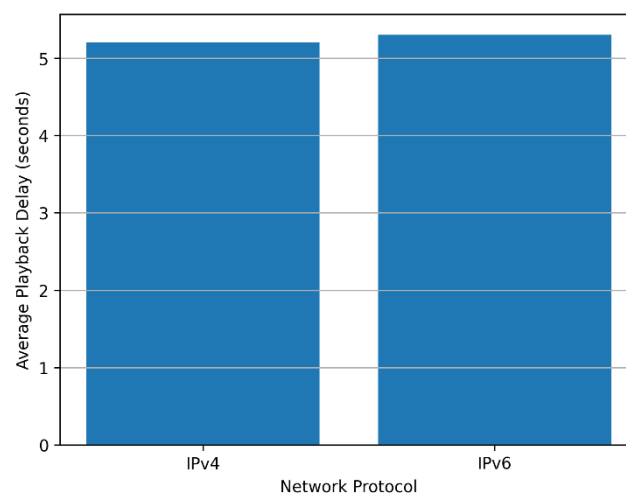


Figure 6. Comparison of playback delay between IPv4 and IPv6, showing negligible difference in performance across network layer protocols.

This behavior can be attributed to the fact that playback delay in wireless streaming is primarily influenced by lower-layer factors such as signal strength, channel conditions, and medium access contention, rather than network layer protocol overhead. While IPv6

introduces a larger header size compared to IPv4, this difference has negligible impact in high-throughput Wi-Fi 7 environments where link capacity significantly exceeds the additional protocol overhead. These findings suggest that for local Wi-Fi 7 streaming scenarios, the choice between IPv4 and IPv6 did not materially affect playback delay or streaming stability. Consequently, performance optimization efforts should focus on PHY and MAC layer parameters, which have a more pronounced impact on user-perceived quality.

4.5. Impact of Network Contention

The impact of network contention on streaming performance was evaluated by comparing single-client and multi-client scenarios within the Wi-Fi 7 testbed. In the multi-node configuration, three client devices simultaneously received media streams from the same AP, introducing controlled channel load. Figure 7 illustrates the resulting increase in playback delay under concurrent streaming conditions.

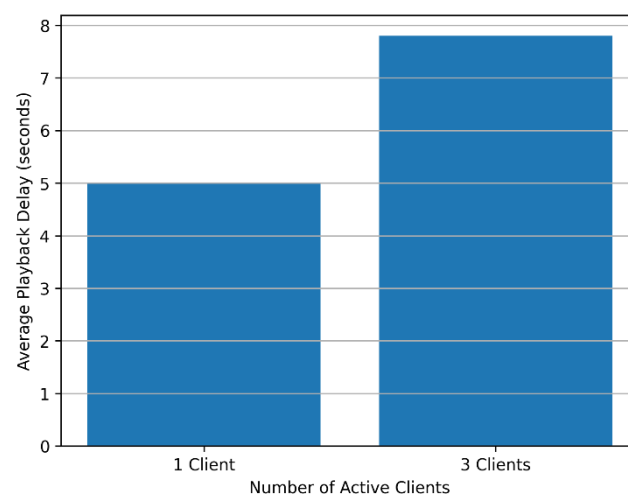


Figure 7. Impact of network contention on playback delay, showing increased delay with multiple concurrent streaming clients.

The results show a clear increase in playback delays as the number of active clients increases. Compared to the single-client scenario, the three-client configuration exhibits substantially higher average delay. The increase is not attributed to shared AP airtime or to AP airtime saturation. Three streams at the tested bitrates occupy only a small fraction of the nominal link capacity, so the testbed increase is unlikely to reflect channel saturation. With only one- and three-client configurations, the testbed also cannot establish the functional form (linear or non-linear) of delay growth with client count.

The relationship between the number of active clients and playback delay can be expressed qualitatively as:

$$D_{\text{playback}} \propto f(N_{\text{clients}}, C_{\text{contention}}) \quad (3)$$

where N_{clients} represents the number of active devices and $C_{\text{contention}}$ reflects contention-related delays, including AP scheduling overhead. As N_{clients} increases, these effects are expected to grow; Equation (3) indicates only this dependence and does not specify a functional form.

In addition to increased delays, multi-client scenarios also introduce variability in performance across devices. The multi-client results do not show that performance is constrained by AP airtime sharing.

4.6. Simulation-Based Scalability Analysis

To evaluate the scalability of Wi-Fi 7 networks under high client density, simulation-based analysis was conducted using the OMNeT++ framework. The number of active streaming clients was increased to 40, 60, and 80 nodes, extending beyond the limits of the physical testbed. However, the largest simulated delays (approximately 13 s at 80 clients; Figure 8) approach the 15 s simulated duration (Table 3), so it is uncertain whether a true steady state was reached at the highest densities.

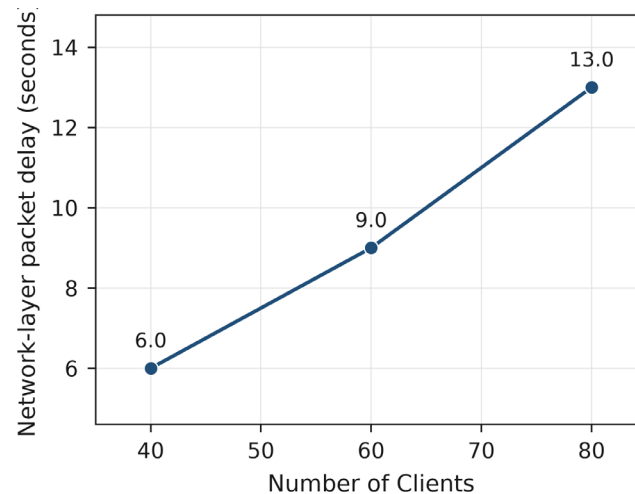


Figure 8. Simulated (OMNeT++/INET) network-layer end-to-end packet delay versus number of clients (40, 60, and 80), showing increasing delay with client count.

It is important to note that the simulation measures network layer end-to-end packet delivery delay, which does not include application layer pre-buffering or VLC decoding overhead. The absolute delay values in Figure 8 are therefore not directly comparable to the application-level playback delay values in Figure 7. The simulation is intended to capture MAC layer contention behavior and scalability trends, not to replicate testbed delay magnitudes.

Figure 8 shows a clear increase in simulated network-layer end-to-end packet delay as the number of active nodes grows. The 40-client delay is not described as acceptable, and the rise is not attributed to saturation or to a queueing mechanism. As the following paragraph states, the simulated delays of approximately 6 s to 13 s are only a relative indication of overload, not realistic absolute delays. The direction of this trend (delay increasing with client count) agrees with the testbed contention experiment in Section 4.5; however, the testbed compared only one and three clients and measured application-level playback delay, so it cannot validate the simulated delay magnitudes or the shape of the curve, and the simulation does not validate the absolute testbed delay values.

The simulated delays of approximately 6 s to 13 s on a single wireless hop are far larger than would be expected for a real-time UDP stream, which in practice would experience packet drops at finite AP queues well before delays of this magnitude accumulated. These values are indicative of excessive queueing in the simulation (bufferbloat, e.g., from a large AP queue limit) and should be interpreted only as a relative indication of overload, not as realistic absolute delays. This is a limitation of the simulation model.

The relationship between client density and delay can be expressed as a qualitative proportionality:

$$D_{\text{playback}} \propto \frac{N_{\text{clients}}}{C_{\text{network}}} \quad (4)$$

where $N_{clients}$ represents the number of active streaming devices and $C_{network}$ denotes the effective network capacity. As $N_{clients}$ approaches or exceeds $C_{network}$, delay increases rapidly. Equation (4) captures only the direction of this dependence: the rapid growth near capacity reflects queueing behavior that a simple proportionality does not represent. These results highlight the scalability limitations of contention-based wireless networks as modeled here with a legacy CSMA/CA MAC. They do not show that client density must be managed to prevent AP airtime saturation. The simulated delays are only a relative indication of overload.

4.7. Impact of Media Type on Playback Delay

The impact of media type on streaming performance was evaluated by comparing MP3 audio and MP4 video playback delay across the three Wi-Fi 7 bands. Figure 9 shows the average playback delay for each media type per band. The results demonstrate a clear and consistent difference in playback delay between the two media types across all bands. MP4 streams exhibited substantially higher average playback delays compared to MP3 streams in the per-band values reported below. The difference is not explained by greater video bandwidth demand.

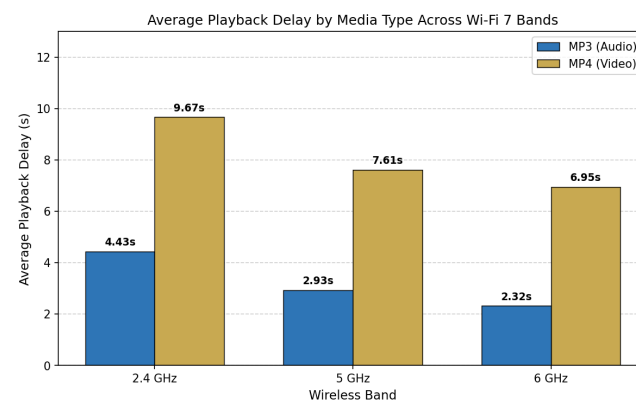


Figure 9. Average playback delay for MP3 and MP4 across Wi-Fi 7 frequency bands.

Across frequency bands, the performance gap between MP3 and MP4 persists but narrows at higher frequencies. At 2.4 GHz, MP3 and MP4 averaged 4.43 s and 9.67 s, respectively. At 5 GHz, these values dropped to 2.93 s and 7.61 s, while at 6 GHz, the lowest delays were observed at 2.32 s for MP3 and 6.95 s for MP4. This trend indicates that higher frequency bands benefit both media types, but the absolute reduction in delay from 2.4 GHz to 6 GHz is larger for MP4, although the relative (percentage) reduction is larger for MP3.

These findings highlight that media type is an important determinant of playback delay and must be considered alongside signal strength, band selection, and bitrate when evaluating streaming performance in Wi-Fi 7 environments. The per-band means show higher playback delay for MP4 than for MP3.

5. Discussion and Implications

The results are the separate effects of each factor. Parameters were varied one at a time.

5.1. Separate Factor Effects

Parameters were varied one at a time. Playback delay rose as RSS fell, from about 4.2 s at -48 dBm to about 11.4 s at -70 dBm. Pooled across the conditions in each band, mean delay was 7.05 s at 2.4 GHz, 5.21 s at 5 GHz, and 4.26 s at 6 GHz. Delay fell from 6.8 s at 192 kbps to 5.0 s at 320 kbps. The bitrate comparison and the client-count comparison were run separately.

5.2. Pooled Band Means

Pooled mean playback delay was 7.05 s at 2.4 GHz, 5.21 s at 5 GHz, and 4.26 s at 6 GHz (Figure 4). Each band was used on its own. Prior work reports that multi-link operation can add link diversity and, in some conditions, lower latency than a single link [5,8,9], depending on the load on the extra links [8].

5.3. Counterintuitive Role of Bitrate in Playback Delay

One of the most notable findings of this study is the observed reduction in playback delay with increasing bitrate. On the unsaturated link tested, this behavior is most plausibly explained by VLC's application-layer pre-buffering: a threshold that requires a sufficient number of bytes to be accumulated is satisfied sooner by a higher-bitrate stream. The bitrate finding is understood primarily as an application-buffering effect rather than a MAC-efficiency effect. It is acknowledged that this trend is expected to reverse at bitrates approaching network capacity limits, and evaluation at higher bitrates representing standard and high-definition video workloads is identified as a direction for future work. This insight has practical implications for bitrate configuration in Wi-Fi 7 environments, suggesting that conservative bitrate selection may not always yield optimal playback responsiveness under stable, high-capacity wireless conditions within the low-bitrate range tested.

5.4. Impact of Contention and Network Scalability

The results from both testbed and simulation experiments demonstrate that network contention plays an important role in determining streaming performance under multi-user conditions. In the testbed, three streams occupy only a small fraction of link capacity, so the client-count increase is not attributed to AP airtime saturation. The simulated delays are only a relative indication of overload, not evidence of saturation. It is noted that the absolute delay values from the simulation are not directly comparable to testbed playback delay measurements, as the simulation captures network-layer packet delivery delay while the testbed measures application-level playback delay, including VLC pre-buffering. Both evaluations show delay increasing with client density in the same direction (although the two-level testbed comparison cannot establish non-linearity, and the simulation does not validate the absolute testbed delay values). This manuscript does not conclude that client density must be managed to prevent AP airtime saturation.

5.5. Implications for Wi-Fi 7 Deployment

The findings of this study have several practical implications for the deployment and optimization of Wi-Fi 7 networks. First, pooled playback delay increased as RSS decreased (Figure 3). Second, bitrate configuration should account for network efficiency and application layer buffering behavior rather than relying solely on bandwidth estimation. Third, with one and three clients, the streams were a small fraction of link capacity, and the simulation then showed delay rising as the client count went from 40 to 80. Finally, dynamic use of more than one band at once would need coordination across bands. This study used the bands separately.

5.6. Contribution Beyond Existing Work

Unlike prior studies that primarily focus on isolated network parameters or lower layer performance metrics, this work provides a holistic analysis of streaming stability in Wi-Fi 7 by integrating network testbed measurements with simulation-based scalability evaluation. By focusing on playback delay as a user-centric metric and examining separate, one-variable-at-a-time effects of multiple network parameters, the study offers new insights

into the practical performance characteristics of Wi-Fi 7 networks. These findings establish a descriptive, multi-parameter, single-link baseline for Wi-Fi 7 audio and video streaming performance—one that future studies on Wi-Fi 8 (IEEE 802.11bn) can use as a reference point when benchmarking next-generation improvements in latency, coordinated multi-AP operation, and AI-driven resource management [6].

Relative to our earlier study of IEEE 802.11ax networks [16], which examined the combined effect of RSSI, bitrate, and network topology on video playback delay using a closely related testbed and OMNeT++ methodology, the present study differs in the following respects, consistent with the comparison in Table 2: (i) it uses Wi-Fi 7 (IEEE 802.11be) hardware, although with MLO disabled so that each band operates as a single link; (ii) it evaluates the three bands individually, including the 6 GHz band; and (iii) it adds IPv4/IPv6 and MP3/MP4 media-type comparisons. Codec bitrate was also a factor in [16], so the bitrate analysis is not claimed as new; here it is extended to multi-bitrate audio and video streaming on Wi-Fi 7 hardware across the three bands. The methodological approach is largely shared with [16].

5.7. Limitations

(i) Hardware generalizability. All experiments used a single AP model (ASUS RT-BE92U) and a single client adapter model (TP-Link TBE400UH). Results may differ with other chipsets, drivers, and rate-adaptation implementations, and generalization beyond this hardware is not established.

(ii) MLO disabled. Each band was evaluated independently with MLO disabled. The results characterize single-link operation on Wi-Fi 7 hardware and do not benchmark coordinated 802.11be MLO; any statement in this paper about how MLO would change these results is an untested expectation based on prior work.

(iii) Channel width not reported. The channel width configured in each band was not reported; Table 1 gives only the standard maximum (up to 320 MHz). Band differences therefore cannot be attributed to channel width specifically.

(iv) Low bitrates. The codec bitrates tested (192, 256, and 320 kbps) are typical of audio and far below high-definition video bitrates, so the multi-gigabit link was not saturated and saturation-driven queueing was not observed in the testbed. Whether identical settings were applied to the MP4 stream as a whole is not specified.

(v) Variability and statistical testing. Each configuration was run a minimum of three times, and only means are reported. Per-run values, standard deviations, and confidence intervals are not reported; no significance tests were performed (including for IPv4 versus IPv6), and a quantitative outlier-exclusion criterion was not documented. All reported differences are descriptive.

(vi) Sample sizes and connection loss. The per-band counts ($n = 46, 37$, and 31 for 2.4, 5, and 6 GHz) are valid measurements after exclusion of runs that ended in connection loss. The number of attempted runs and the connection-loss rates are not reported. Because failed 6 GHz runs at weaker signal levels are excluded, the 6 GHz mean may be biased downward, and pooled averages at weak RSS are weighted toward the 2.4 GHz band.

(vii) RSS manipulation by repositioning. RSS levels were obtained by moving the clients, so RSS is confounded with location-specific multipath, shadowing, and local interference, and geometric distances were not recorded.

(viii) Playback-delay measurement. The procedure for timestamping playback start and the onset of continuous playback, and any synchronization with the Wireshark captures, are not specified. The network transmission and VLC pre-buffering components were not measured separately, and the Wireshark captures were not used to decompose delay into MAC overhead and buffering; mechanistic explanations in Section 4 are therefore interpretive.

(ix) Experimental design. Parameters were varied one at a time, so interaction effects were not estimated formally. The testbed contention experiment compared only one and three clients, and the RSS level and bitrate used in that experiment are not stated.

(x) Equations. Equations (1)–(4) are qualitative proportionalities or idealized relationships; no coefficients were fitted, and no R^2 is claimed.

(xi) Unreported settings. The manuscript does not report which extremely high throughput (EHT) features were active on each link, the VLC pre-buffering setting, the AP queue, per-client values, or per-media sample sizes.

(xii) Simulation. The OMNeT++/INET model is a legacy CSMA/CA model that does not implement the 802.11be MAC/PHY, coordinated MLO, or 6 GHz-specific propagation. It was run with a single parameter set (256 kbps, -56 dBm) without sensitivity analysis. It reports network-layer packet delay rather than playback delay, and its delays of approximately 6–13 s indicate excessive queueing in the model. The simulation therefore indicates only a qualitative scalability trend and does not validate the absolute delay values measured in the testbed. The simulation replicate count and confidence level are unreported.

6. Conclusions

Overall, the findings describe signal conditions, bitrate, band, and network load, each varied on its own. A combined testbed and simulation-based methodology was used to analyze system performance under a wide range of operating conditions. All testbed experiments operated each band individually with Multi-Link Operation (MLO) disabled; the results therefore characterize single-link operation on Wi-Fi 7 hardware and do not represent coordinated 802.11be MLO performance. Results demonstrate that playback delay is highly sensitive to RSS, with higher delay at weaker signal levels in the pooled results (Figure 3). Pooled across the conditions tested, not as a strong-signal subset, mean playback delay was 7.05 s at 2.4 GHz, 5.21 s at 5 GHz, and 4.26 s at 6 GHz (Figure 4). A key finding is the counterintuitive relationship between bitrate and playback delay, where higher bitrate streams resulted in lower delay, most plausibly explained by VLC's pre-buffering threshold being filled sooner at higher bitrates on an unsaturated link rather than by MAC-layer efficiency; the tested bitrates (192–320 kbps) were low and did not load the link. Network layer protocol (IPv4 vs. IPv6) showed no material difference in mean playback delay. Analysis of multi-client scenarios revealed that increasing client count increased playback delay from one to three clients, in a downlink scenario in which the AP rather than the clients contends for the channel. Simulation results show the same direction of delay growth at client densities of 40, 60, and 80 nodes, though it is noted that simulation delay values reflect network layer packet delivery delay and are not directly comparable in magnitude to the application-level playback delay measured in the testbed. The simulation uses a legacy CSMA/CA model with a single parameter set and produces delays indicative of excessive queueing, so it supports only a qualitative scalability trend.

Overall, the findings are one-variable-at-a-time descriptions of signal conditions, bitrate, band, and network load. The testbed does not show that client density must be managed to prevent AP airtime saturation. These conclusions are descriptive. These results provide practical insights into the configuration and deployment of Wi-Fi 7 access points in indoor streaming scenarios. They are not guidance for managing client density in order to prevent AP airtime saturation.

Future work will focus on explicitly evaluating Wi-Fi 7 Multi-Link Operation (MLO) under controlled multi-band conditions, expanding the bitrate range to include standard and high-definition video workloads, and incorporating advanced MAC layer scheduling mechanisms. Future measurements should also report per-run variability and connection-

loss rates, document per-band channel widths, and include additional AP and adapter models. Critically, the results of this study are intended to serve as a foundational performance baseline for Wi-Fi 8 (IEEE 802.11bn) research [6]. As next-generation standards introduce coordinated multi-AP operation, deterministic latency scheduling, and AI-assisted resource management, the playback delay baselines established here across RSS, bitrate, band, media type, and contention dimensions will enable direct benchmarking of Wi-Fi 8 improvements. Extending the evaluation to outdoor, mobility, and larger-scale deployment scenarios will further strengthen this baseline for future comparative studies.

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