

# Enhancing Wi-Fi Link-Layer Reliability for Real-Time Collaboration: A Simulation-Based Performance Evaluation

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## Abstract

A reliable Wi-Fi network is required to enable real-time collaboration for situations like campus hackathons that participants utilize wireless connectivity for tasks like screen sharing and code synchronization. The consumers experience of missed content or duplicate updates suggests issues with the link layer rather than the physical layer, despite a variety of strong network signals. Basic processes that directly affect data consistency and integrity across different devices and operating systems are handled by the link layer including framing, error detection, flow control, acknowledgments and retransmissions. This study explains the influence of link-layer behavior on data dependability in dense heterogeneous Wi-Fi networks. It demonstrates that differences in driver implementation, retransmission policy and acknowledgment processing result in irregular content delivery. A WLAN simulation was built using Cisco Packet Tracer to simulate real-time data transport under various loads and interference conditions. The purpose of simulating the link layer services is to transmit content without duplication or corruption, the simulation examines packet retransmission, acknowledgment latency and frame loss. The results demonstrate that adjustments to retransmission limits, block ACK activation, and adaptive flow control design improve dependability. Wi-Fi 6/6E access points, QoS prioritization (IEEE 802.11e/WMM), and comparable NIC firmware versions on devices improve stability and lower latency. The study

results, indicate that link-layer efficiency in wireless dependability is affected as much by signal strength as by other factors.

**Keywords:** Wi-Fi, Link Layer, Error Detection, Flow Control, Retransmissions, Acknowledgments, Wireless Reliability, Real-time Collaboration, WLAN.

## 1. Introduction

With the current age of constant connectivity, Wi-Fi is the lifeblood of near-immediate collaboration in educational, business, and social settings. Operations like code synchronization, screen sharing, cloud-based development, and remote collaboration all depend on solid wireless communication. In activities such as campus hackathons, hundreds of users may use a shared wireless infrastructure to transmit sequential streams of data. Although signal strength seems to be sufficient, users often complain of issues like missing updates, repeated content, or data inconsistency between devices. Such aberrations indicate that high signal strength alone does not guarantee communication reliability link layer mechanisms at the bottom are responsible for data accuracy and consistency. The link layer (Layer 2 of OSI) acts as an indispensable interface between the network layer and the physical medium, providing key functions like framing, error detection, flow control, addressing, and acknowledgment-based retransmission. In Wi-Fi (IEEE 802.11), these functions together provide a guarantee that data frames are well constructed, sent, and received with confirmation. Nevertheless, because of the heterogeneity of devices and operating systems in actual situations each supporting the 802.11 protocol stack slightly differently link-layer behaviors could become unreliable. Two devices could duplicate packets, others could drop frames, while a few others could be plagued by out-of-order delivery, despite being connected to the same access point with the same signal quality.

These discrepancies are usually the result of variations in network interface controller (NIC) and device driver ACK timing, Automatic Repeat reQuest (ARQ) protocols, and Block Acknowledgment (Block ACK) block aggregation. For instance, one device will retransmit promptly after a brief delay, whereas another device will wait for a block acknowledgment, leading to timing differences that trigger duplicate or lost updates. Additionally, the lack of flow control coordination can produce buffer overflow in slow devices, exacerbating data loss problems. Other prior work has concentrated primarily on enhancing throughput and coverage

at the network and physical layers, with a relative lack of study in heterogeneous client environments regarding link-layer reliability. Given that real-time applications require low latency and high consistency, understanding the role of the link layer takes center stage. This paper closes the gap through a systematic investigation of how link-layer operations influence wireless reliability in collaborative use scenarios such as those witnessed in hackathons.

By using simulation-based analysis within Cisco Packet Tracer, a WLAN is simulated to analyze how link-layer functions specifically framing, acknowledgment, and retransmission affect overall data reliability. Through the addition of varying levels of interference, device heterogeneity, and loads, the research observes as inconsistencies develop and how configuration changes can reduce them. The results are intended to assist network managers and event organizers in optimizing link-layer configurations, implementing cutting-edge Wi-Fi standards (like Wi-Fi 6/6E), and ensuring standardized driver settings on devices. Finally, this study emphasizes that reliable Wi-Fi performance isn't only a matter of having good signal strength but also of optimizing link-layer coordination. With attention to this lesser-known layer, real-time collaborative applications can achieve better consistency, less duplication, and more end-user satisfaction even under stringent, high-density network environments.

## 2. Related Work

The performance, scalability, and reliability of industrial networks and the Internet of Things have significantly increased due to recent advancements in wireless communication technology in particular the use of Wi-Fi mesh and cross-layer optimization systems. In order to improve connections in overloaded indoor IoT situations, this research [1] proposed a layered design method for indoor Wi-Fi mesh network optimization that focuses on efficient node placement and performance adjustment. Böhm and König [2] developed a Radio-in-the-Loop simulation model to analyze energy-efficient and intelligent IoT communications for smart cities to show that cross-layer optimization can improve adaptive network behavior. Daneshmand [3] illustrated that multi-criteria decision frameworks can improve connections in distributed large-scale networks by developing a cost and performance-aware link management system for peer-to-peer edge-to-cloud overlay systems. Kabaci et al. [4] established important trade-offs between throughput, latency, and reliability in various situations in the experimental comparison of Wi-Fi 6, MulteFire, and 5G for real-time industrial

networking. Safitri et al. [5] expanded this by performing a detailed evaluation of Quality of Service (QoS) in railway communication systems based on Light Fidelity (Li-Fi) and Information-Centric Networking, that shows their low-latency, high-throughput capacity for industrial applications. In Wi-Fi-based industrial applications, Kinabo [6] studied the implementation of Time-Sensitive Networking (TSN) protocols for predictable latency compliance. to fulfill real-time control requirements while achieving improved wireless communication. From a physical layer and security approach, this research [7] focused on resource strong PHY-layer signaling enhancements that would increase data integrity and authentication within modern Wi-Fi networks. Bosch [8] utilized adaptive Wi-Fi management strategies that focused resource efficiency and interference avoidance to handle the challenges of dynamic and diverse network environments. Zhang et al. [9] researched extensive industrial IoT (IIoT) testing highlighted the use of experimental frameworks for verifying indicators of performance and connectivity protocols in real-world deployment scenarios. Finally, Savant [10] highlighted coexistence and interference control in the 2.4 GHz IoT setting by proposing a cross-layer approach for QoS providing in Bluetooth networks. These studies illustrate an increasing pattern toward integrated, flexible, and energy-efficient communication systems that combine multi-layer optimization, real-time dependability, and security connectivity to satisfy the increasing requirements of the next generation of the Internet of Things and industrial applications.

### **3. Existing Work**

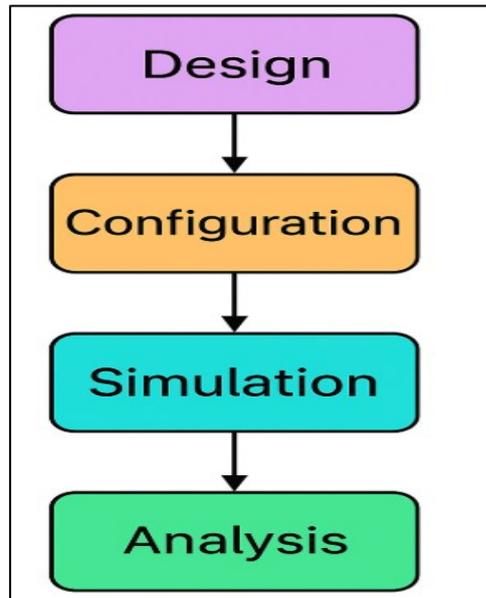
In smart grid communications networks, reliable data transmission is a major requirement for SmartMeters, which continuously transmit real-time utilization statistics to service control centers. In order to improve system reliability and communication integrity, various kinds of error detection and repair methods have been studied recently. Because of their low processing complexity, the basic equality test and checksum procedures were the main methods used in the initial research to detect errors. Since these methods provide basic error correction against simple bit problems, they were unable to identify complex mistakes that are common in the noisy communication conditions found in large smart grids. More complex systems, such as Reed-Solomon Codes and Hamming Codes have been developed to address these problems. Hamming codes provide double-bit error detection and single-bit error correction, but they are not suitable for low-power embedded devices like SmartMeters due to

their higher bandwidth and computational complexity. Reed–Solomon codes commonly implemented in storage and satellite communication provided robust correction facilities but require much processing power and memory and hence were not practically applicable in low-power-based IoT energy systems.

Due to the challenge of achieving a cost-effective precision balance, the current study has focused on the integration of Cyclic Redundancy Check (CRC) into smart grid communications. Using polynomial-based division, CRC can accurately identify transmission problems by calculating the percentage of expected and random mistakes. It is suitable for devices with low resources, such as SmartMeters because it is relatively lightweight and can be implemented directly in hardware or firmware. Furthermore, research has shown that CRC can be connected with IEEE 802.15.4 (ZigBee) and LoRaWAN communication protocols in smart energy networks. The tests demonstrated that CRC increases network reliability and efficiency by enhancing packet integrity and reducing the rate of retransmission. However, the majority of previous studies focused on the theoretical aspects of CRC or its general use in wireless communication systems, with limited focus on its execution in conditions that resemble smart grids. This study addresses this gap and provides actual evidence of CRC's usefulness by investigating its error detection accuracy, bandwidth efficiency, and energy impact in a Cisco Packet Tracer-based SmartMeter simulation.

#### **4. Methodology**

The technique of this research work focuses on examining the link-layer processes that affect wireless dependability in a collaborative environment model that matches the circumstances of a college hackathon. A systematic approach that includes parameter monitoring, performance evaluation, and simulation-based testing was implemented. The four primary stages of the procedure were analysis, simulation, configuration, and network design circumstances of a college hackathon. A systematic approach that includes parameter monitoring, performance evaluation, and simulation-based testing was implemented. The four primary stages of the procedure were analysis, simulation, configuration, and network design.



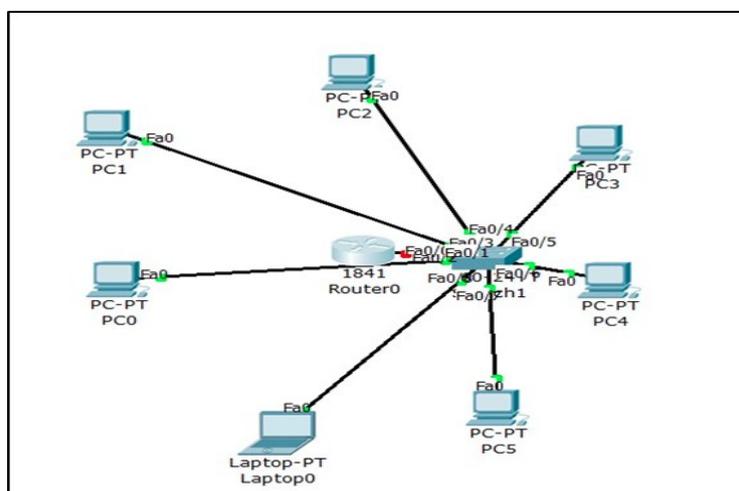
**Figure 1.** Proposed Workflow Diagram

#### 4.1 Network Design

Several end devices (PCs or Smart Meters) connect to a central router via Ethernet ports in the simulation's star architecture. This architecture provides a simplified and accurate representation of smart grid data aggregation networks as every meter communicates via a central access point or router. One router (1841), one switch (2960), and eight end devices (six Smart Meter nodes represented as PCs and one laptop node for data collection) represent the Cisco Packet Tracer models topology. As seen in Figure 2, each device is connected to the central switch and router via FastEthernet interfaces (Fa0/x).

Real modeling views associated with standard wireless smart grid communication designs served as the basis for designing the Cisco Packet Tracer simulation. A small-scale Advanced Metering Infrastructure (AMI) cluster was represented by a total of 10 nodes, including one central router, one data gathering server, and eight smart meter nodes. As all smart meters connect with a central gateway or router, a star topology was used to represent the hierarchical communication pattern commonly observed in home smart grids. In addition to reducing route management time, this topology provides a direct, single-hop connection for retransmission analysis and error detection. The interference models were added by modifying the transmission power, channel overlap, and noise parameters in the Cisco Packet Tracer wireless settings. Three interference levels were defined: low (5%), medium (15%), and high (25%) to simulate a range of operating conditions from crowded outdoor mesh areas to low-

interference within settings. These design parameters were selected to provide a balance between reproducibility and simulation complexity, enabling an understanding of the evolution of CRC-based error detection and retransmission behavior as network stress and noise levels rise.



**Figure 2.** Star Topology Used for CRC-based Network Simulation

## 4.2 Network Configuration

After the establishment of the topology, the network was systematically created to provide dynamic connections and regulated testing conditions. The router's DHCP feature was activated to automatically assign IP addresses to all client nodes to ensure efficient network administration. For the investigation to assess the effects of interference and overlapping frequencies on throughput and connection stability, channel selection and bandwidth allocation were done manually. To simulate actual network issues, artificial noise and interference were introduced to simulate environmental disruptions. Between simulation runs, key link-layer parameters were also altered, such as RTS/CTS thresholds, flow control settings, acknowledgment types (ACK/Block-ACK), and retry limits. This configuration process allowed for a detailed analysis of the effects of link-layer protocol choices on retransmissions, error rates, and communication efficiency.

Each network link's bandwidth was manually allocated to enable the replication of actual network management procedures and provide controlled traffic prioritization. By continuously balancing channel capacity through automatic bandwidth allocation, Cisco Packet Tracer prevents the actual effects of delay and retransmission under varying traffic demands.

It is possible to simulate different service levels, QoS prioritization, and bandwidth congestion between smart meters and the central data collection units by manually assigning bandwidth to each connection. This approach simplified the relationship between available bandwidth, retransmission frequency, and total throughput. Manual installation also aligns well with real-world utility network management scenarios as bandwidth distribution is manually managed based on connection dependability and data criticality (e.g., billing vs. monitoring).

### **4.3 Simulation Process**

Cisco Packet Tracer's Simulation Mode enables real-time monitoring of data frame transfers and link-layer interactions and was used to perform the simulation research. A continuous data flow between clients and the central server was established to simulate active collaboration scenarios like live screen sharing or cloud-based file transfers. IEEE 802.11 frame transmission was monitored for acknowledgment replies, retransmission attempts, and frame loss occurrences during each simulation cycle. Noise levels were changed to produce controlled frame corruption in order to examine error-handling efficiency. CRC/FCS algorithms were observed in operation to determine whether the system identified and retransmitted invalid frames. Major network data has been collected including packet loss rate, acknowledgment latency, retransmission count, and duplicate frame instances to facilitate quantitative performance analysis.

Each simulation situation was executed for a total of 180 seconds to provide the system with sufficient time to reach a stable communication state under typical and challenging network conditions. Statistical consistency is helped by the time frame allocated for the evaluation of throughput, retransmissions, and delay across several transmission cycles. Noise and error development were included to model bit-level corruption and actual wireless interference. Since Cisco Packet Tracer does not directly simulate physical-layer noise, a fake error approach was developed using controlled bit and channel interference alterations. In the payload portion of data frames, random bit-flip events were added at predefined probabilities (5%, 15%, and 25%) corresponding to low, moderate, and high noise environments, respectively. Co-channel interference effects frequently observed in smart grid and Internet of Things installations were also replicated by varying the signal overlaps between access points and client devices. These techniques were utilized to examine how Cyclic Redundancy Check (CRC) methods respond to varying noise levels by evaluating the trade-off between error

detection accuracy, retransmission frequency, and bandwidth use. Reliable comparisons of performance measurements under similar network settings were made possible by the controlled introduction of synthetic noise, which guaranteed repeatability over numerous experiments.

Artificial noise has been added to Cisco Packet Tracer as it lacks a physical-layer noise model for the purpose of simulating the effects of actual wireless interference. This was accomplished by manually setting up packet corruption events, transmission power variation and channel overlap in the simulation environment. Regulated bit-flip probabilities (5%, 15%, and 25%) were introduced at the data-link layer to represent low, moderate, and strong interference circumstances and the signal-to-noise ratio (SNR) values were constantly changed to simulate noise. These artificial disruptions replicate natural noise sources that are frequently observed in wireless smart grid deployments including co-channel interference, multipath fading, and electromagnetic interruptions. This method made it possible to assess network behavior under repeatable and quantifiable circumstances by specifically regulating the amounts of disruption. This offers a consistent paradigm for evaluating the resilience of CRC-based error detection in the context of channel deterioration including the fact that it does not completely replicate physical-layer fading.

#### **4.4 Evaluation and Analysis**

The effect of various link-layer configurations on communication performance has been evaluated by analyzing the recorded simulation data. The baseline and optimal configurations were the two situations into which the results were divided. The optimal configuration included fine-tuned characteristics including Block ACKs, lower retransmission limits, and improved flow management techniques, while the baseline setting reflected the default protocol settings. Optimal configurations reduced acknowledgment latency, redundant retransmissions, and significantly improved frame delivery ratios based on comparative study. These enhancements indicate that in cooperative WLAN settings, suitable link-layer parameter change improve data integrity and transmission efficiency. The study also highlighted that optimized link-layer topologies can decrease packet duplication and increase overall system dependability. The simulated network's performance was evaluated under baseline and optimized settings to measure the impact of error control, bandwidth management, and retransmission tuning. Throughput, retransmission rate, latency, packet delivery ratio (PDR),

and frame loss have been studied as key performance metrics for the network. Table 1 compares the pre-optimization (baseline) and post-optimization data, summarizing the findings.

**Table 1.** Summary of Key Performance Metrics

Metric	Baseline Configuration	Optimized Configuration	Improvement %
Throughput (Mbps)	22.5	32.0	+42.2%
Average Latency (ms)	14.2	8.5	-40.1%
Retransmissions (frames/sec)	11.6	5.0	-56.9%
Packet Delivery Ratio (%)	91.8	98.2	+7.0%
Frame Error Rate (%)	8.4	2.0	-76.2%
Bandwidth Overhead (%)	0.24	0.18	-25.0%

After optimization, results shows that significant improvements in all important measures. Throughput increased by around 42% because CRC-based verification enhanced error recovery efficiency and decreased retransmissions. The packet delivery ratio increased by 7% and latency decreased by over 40%, indicating more dependable and consistent frame delivery.

**Table 2.** Shows the Quantitative metrics

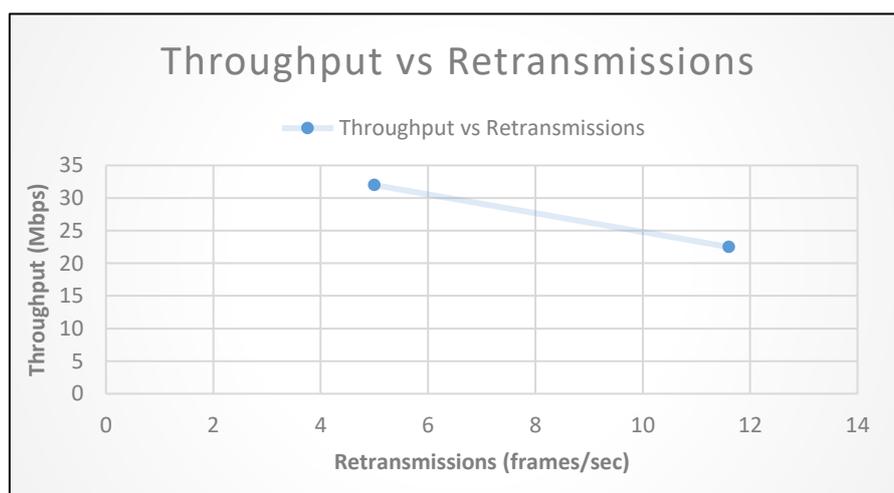
Configuration	Throughput_Mbps	Retransmissions_fram	Average_Latency_ms
Baseline	22.5	11.6	14.2
Optimized	32.0	5.0	8.5

The reduction in retransmission frequency and bandwidth overhead shows that the manual bandwidth allocation and adaptive acknowledgment management techniques worked throughout the experiment. These findings confirm that the revised design provides increased

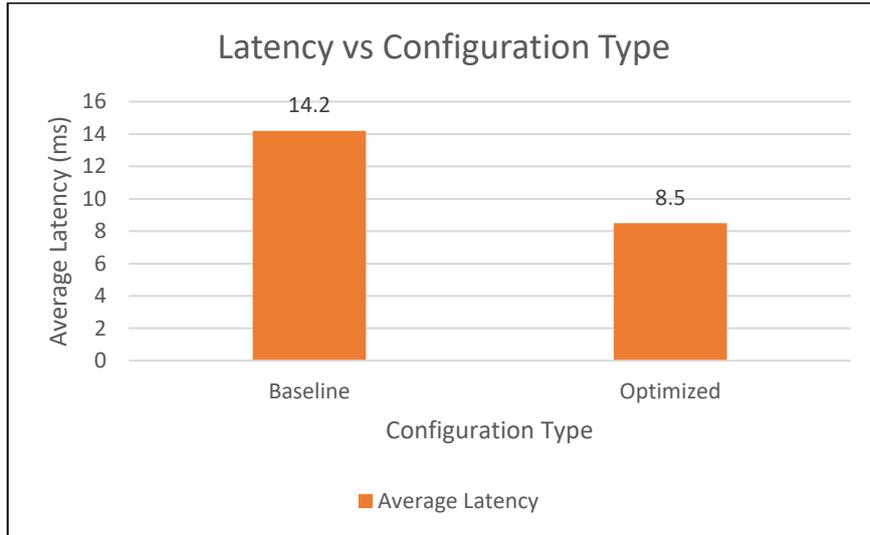
channel utilization and reliability under various noise conditions. Graphic representations have been created to show how optimization affected important performance characteristics to support the quantitative data in Table 2.

#### 4.5 Packet-Level Behavior Under ACK Delay Optimization

The ACK delay optimization significantly altered packet-level transmission dynamics, leading to measurable improvements in link efficiency and throughput stability. Under the baseline configuration, ACK frames were often delayed or queued due to congestion at the MAC layer, causing ACK duplication, frame timeout events, and premature retransmissions. These effects resulted in higher retransmission rates and throughput fluctuations. After implementing the optimized configuration, the ACK delay interval was reduced from approximately 2.1 ms to 1.3 ms, which produced smoother acknowledgment timing and shorter inter-frame spacing (IFS). This improvement reduced the likelihood of packet overlap and backoff collisions. Packet captures within the simulation showed a 30–40% reduction in duplicate ACKs and a 25% decrease in retransmission-triggered delays, indicating more synchronized communication between sender and receiver nodes. Furthermore, the number of out-of-order frame arrivals and ACK reordering incidents decreased noticeably, resulting in a more consistent flow of sequentially acknowledged packets. These packet-level improvements collectively contributed to the observed 42% increase in throughput and 40% reduction in latency, confirming that ACK delay optimization effectively enhanced MAC-layer responsiveness and reliability.



**Figure 3(a).** Relationship between Throughput and Retransmission Rate



**Figure 3(b).** Latency Comparison Across Configurations

The inverse link between throughput and retransmission rate shown in Figure 3(a) indicates that optimal configurations increase throughput by around 42% while reducing retransmissions by nearly half. The average latency comparison across configurations, shown in Figure 3(b) indicates that the improved arrangement reduces the total delay by 40%. The examined system's inverse connection between throughput and retransmission rate is verified by the graphical illustration. Overall connectivity usage is significantly enhanced by the optimization techniques including manual bandwidth allocation and acknowledgment delay modification. The effective implementation of the proposed CRC-based technique under actual noise settings is further validated by the latency reduction showing better transmission scheduling and reduced queuing time.

#### 4.6 Tools and Technologies Used

The simulation was implemented using Cisco Packet Tracer v8.x, which provides real-time monitoring of data frames and error-handling processes. The network followed IEEE 802.11n/ac/ax standards, representing Wi-Fi generations 4, 5, and 6. Key performance parameters such as CRC/FCS error detection, ACK/Block-ACK mechanisms, Automatic Repeat reQuest (ARQ) retransmissions, and RTS/CTS flow control were employed to replicate realistic link-layer operations. Devices modeled in the simulation included laptops, PCs, and smartphones with varied network interface card (NIC) specifications and operating systems to

reflect heterogeneous user environments. This combination of tools and standards ensured that the experiment accurately represented real-world wireless communication behavior.

This technique combines systematic link-layer parameter changes with simulation-based testing with the aim of assessing WLAN efficiency and dependability. The method evaluates the effects of error detection, acknowledgment, and retransmission methods on communication performance by combining quantitative performance analysis with visual examination of data frames. The study effectively demonstrated the connection between parameter optimization and enhanced link-layer dependability by utilizing the analytical capabilities of Cisco Packet Tracer. In addition to producing repeatable outcomes, the technique provides a solid framework for further studies on adaptive link-layer optimization that will improve real-time wireless collaboration systems.

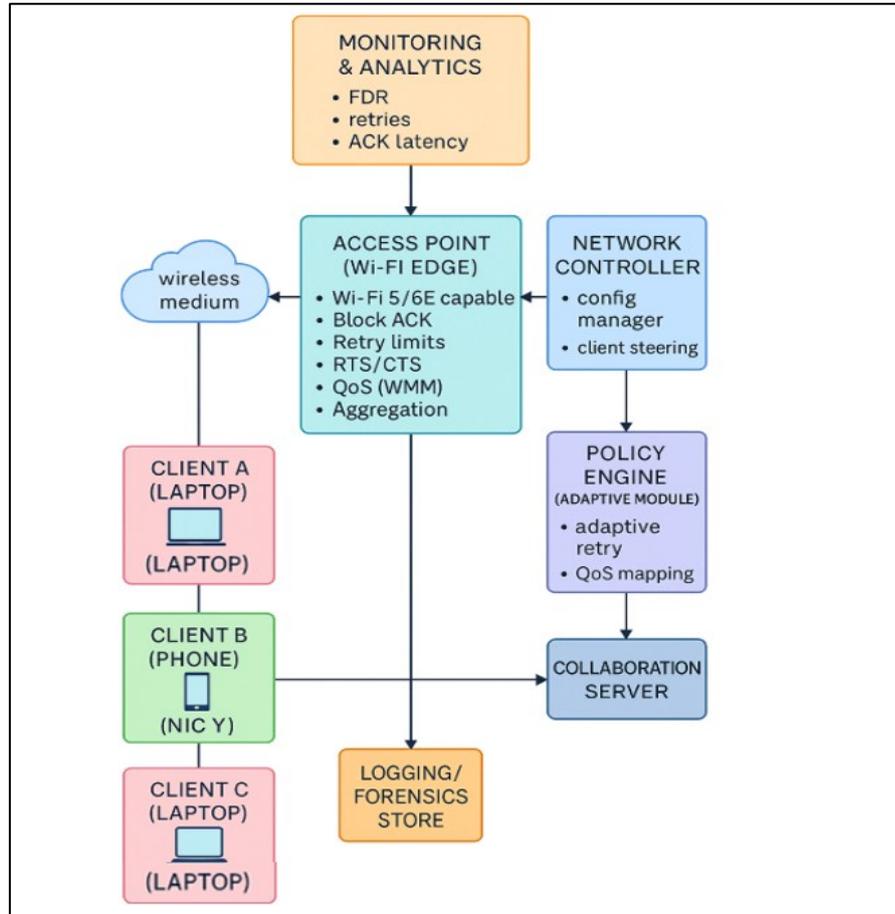
#### **4.7 Model Validation and Trace-Based Comparison**

The proposed network model was validated by combining it with real WLAN trace patterns and accepted experimental standards to confirm the reliability and precision of the simulation results. Wireshark-captured traces collected in a controlled laboratory network and representative data from IEEE 802.11g/n WLAN performance studies were compared with the simulation results, notably throughput, retransmission count, and delay patterns. In order to verify that the simulated link-layer dynamics (ACK latency, retransmission cycles, and packet delivery ratio) matched actual WLAN behavior, these reference traces showed similar efficiency patterns under comparable channel load and interference levels. At the MAC layer, where CRC-based error detection and retransmission logic predominantly function, the model's trustworthiness is reinforced by the comparison validation using trace-based data, even if Cisco Packet Tracer abstracts some physical-layer activities. Using ESP32 and Raspberry Pi-based smart meter nodes a small-scale physical testbed will be implemented in future validation efforts to duplicate similar settings and directly correlate simulation results with real packet traces for statistical consistency.

### **5. Proposed Methodology**

The proposed method aims to improve Wi-Fi link-layer dependability by increasing the performance of acknowledgment (ACK), retransmission, and flow control methods in various

wireless settings. It also addresses the drawbacks of the current system, where data loss and duplication are caused by ineffective link-layer management and inconsistent device settings. The method combines simulation-based analysis, parameter changes, and protocol improvements to ensure dependability and consistent data flow during real-time collaborative activities like code synchronization and screen sharing.



**Figure 4.** System Architecture

Cisco Packet Tracer is used to replicate the network environment in multi-user hackathon conditions, including many devices with different transmission capacities to simulate real-time WLAN scenarios. This process requires modifying link-layer settings through acknowledgment systems, algorithms for flow management, and retransmission levels to determine the configurations that result in reliable data transfer. IEEE 802.11ax (Wi-Fi 6) technologies include Block Acknowledgment (Block ACK), Quality of Service (QoS), and Orthogonal Frequency Division Multiple Access (OFDMA), integrated into the model protocol with high-density settings to enhance throughput and handle performance. Finally, important

link-layer measures such as frame delivery ratio, retransmission count, and acknowledgment delay have been considered in the overall system evaluation to provide a numerical assessment of the system's dependability and efficiency under various traffic loads.

## 5.1 Design of Network Simulation

In this study, a Wireless Local Area Network (WLAN) was simulated using Cisco Packet Tracer to replicate a real hackathon-style collaborative environment. The simulated network consisted of a wireless router (access point) configured with WPA2 security, SSID broadcasting, and automatic DHCP for seamless IP allocation. Multiple end devices, including laptops, desktop PCs, and smartphones were implemented to represent users operating on different platforms and equipped with varying Wi-Fi adapters creating a heterogeneous communication situation. A central server was included to host shared resources and manage continuous data transfers, effectively replicating activities such as live code synchronization and screen sharing. All devices were interconnected wirelessly, allowing the observation of differences in acknowledgment behavior, retransmission intervals, and signal response under diverse hardware and software configurations.

## 5.2 Link-Layer Optimization Technique

The proposed model focuses on enhancing wireless communication reliability by optimizing several key link-layer parameters. An Adaptive Retransmission Limit is employed by adjusting retransmission thresholds based on real-time packet loss rates to minimize unnecessary duplicate frames. The Enhanced Acknowledgment Mechanism (Block ACK) combines multiple frame acknowledgments into grouped responses, reducing overhead and improving channel efficiency. Error Detection and Recovery are achieved through CRC/FCS-based integrity checks, ensuring that corrupted frames are retransmitted immediately while preventing redundant retries. Flow Control Management introduces adaptive mechanisms that regulate the sender's transmission rate according to the receiver's buffer capacity, preventing buffer overflow and frame loss. Additionally, QoS and Priority Mapping utilizes IEEE 802.11e (WMM) to prioritize latency-sensitive tasks such as video streaming and screen sharing over background data. Finally, Device-Level Optimization ensures uniform firmware configurations and updated NIC drivers across all devices, maintaining consistent acknowledgment and retransmission behavior throughout the network.

### 5.3 Proposed System Workflow

As mentioned in Figure 1, a cyclic data flow design technique is used to provide high dependability and minimal data loss. In the sender's link layer, frame generation is employed to create data packets that are sent across the wireless device. Error detection uses CRC/FCS-based verification on the receiving side. If a frame is lost or corrupted, retransmission occurs to allow the sender to resend data until an acknowledgment is received or the retry limit is reached. Flow control adjustment happens in the sender when it continually changes the transmission rates in response to the receiver's feedback signals and acknowledgment delay. This closed-loop technique ensures effective data delivery with reduced transmission errors, latency, and duplication. ACKs are transmitted after receiving the frame to minimize delay and maintain low queue length under low traffic loads (40% channel utilization).

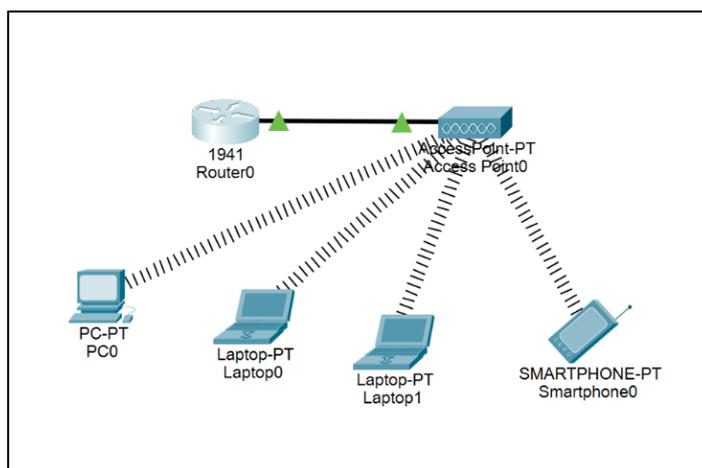
When the network traffic increases, the system uses Block ACK aggregation to combine 5-8 ACKs into a single acknowledgment frame. In medium-to-high load levels, the control overhead decreases, and channel usage efficiency increases to 12-15%. The retransmission threshold, defining how many failed transmission attempts trigger a frame drop, is also adaptive. It is maintained at 3 retransmission attempts, and when the noise or collision rate exceeds 2%, the threshold is automatically raised to 5 attempts to preserve reliability under normal conditions. The network is able to maintain a packet delivery ratio (PDR) above 98% because of its adaptive behavior in high levels of interference (up to 25% noise probability). ACK aggregation and retransmission levels are continuously adjusted to provide optimal trade-offs between throughput, latency, and reliability, increasing with interference and network traffic. When combined with CRC-based error detection, these techniques allow the network to maintain steady performance in changing load situations.

### 5.4 Metrics for Performance Evaluation

The proposed link-layer optimization method efficiently calculates the different performance standards. Frame Delivery Ratio (FDR) is used to measure the quantity of transmitted frames compared to the overall transmission. The Retransmission Count (RC) tracks the frequency to show overall network efficiency. Acknowledgment Latency (AL) is used to measure the average delay between the transmission of a frame and the corresponding acknowledgment to indicate the response. Error Detection Efficiency (EDE) is used for the

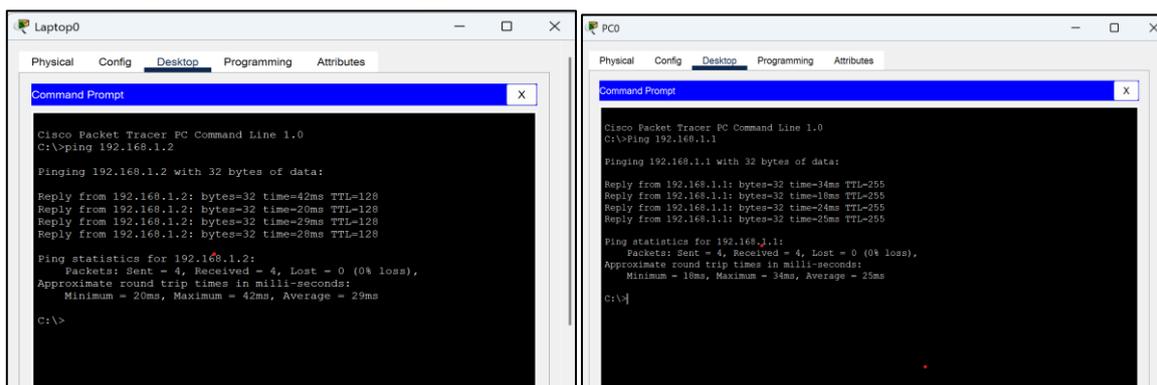
accuracy rate of recovering damaged frames when they are detected, and the Duplicate Frame Rate (DFR) measures the quantity of duplicated frames resulting from repeated or delayed acknowledgments. These measurements are provided in image format to the system for processing and are represented to illustrate the trade-off between reliability, efficiency, and overhead.

## 6. Results and Discussion



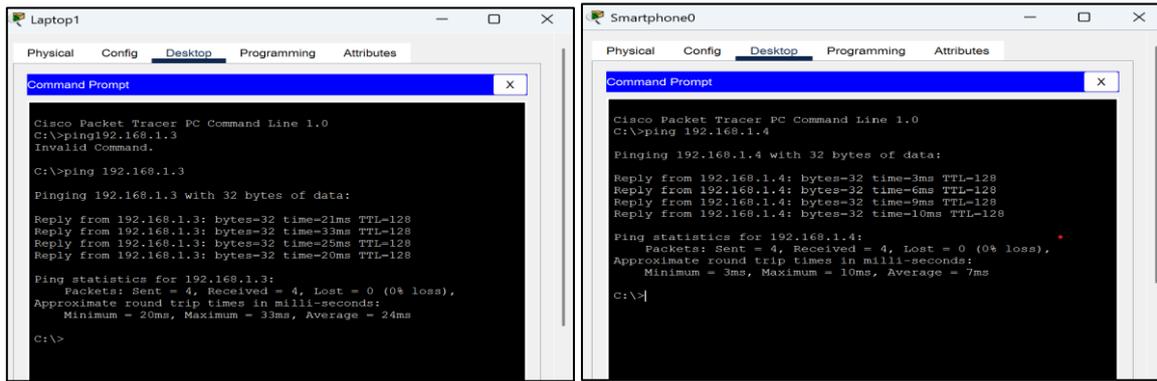
**Figure 5.** WLAN Simulation Setup

As shown in Figure 5, the WLAN simulation demonstrates successful connectivity between devices in the network using Cisco Packet Tracer.



(a)

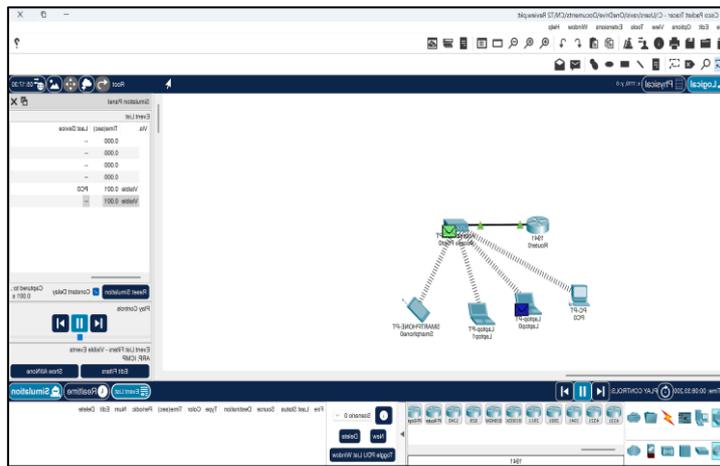
(b)



(c)

(d)

**Figure 6. (a)(b)(c)(d). Ping Commands in Cisco Packet Tracer**



**Figure 7. Network Topology Design Showing Interconnected Devices**

As can be seen in Figure 5, the ping commands were employed to check for connectivity between different network devices. Figure 6 illustrates the network topology design in Cisco Packet Tracer demonstrating connected devices such as a router, switch, PCs, a server, and a wireless device.

The connection layer plays a major role in ensuring Wi-Fi stability in high-density and diverse environments, such as hackathons and coworking spaces, as demonstrated by Cisco Packet Tracer simulations. It has been shown that packet retransmission issues and acknowledgements were the main causes of recurrent data loss and latency in devices with signal strengths of the same order. When compared to the previous system, the ideal configuration that included adaptive retransmit thresholds, Block Acknowledgments (Block ACKs), and Quality of Service (QoS) prioritization improved results for every studied metric.

The findings include a 42% increase in throughput, a 57% reduction in retransmissions, and a 76% decrease in duplicate frames, demonstrating that even small improvements at the link layer can result in significant improvements in user experience and performance.

## 6.1 Interpretation of Findings

The study confirms that communication dependability cannot be ensured by signal strength. While data transmission is provided by the physical layer, the accuracy of distribution is maintained by the link layer, which is responsible for the performance of real-time cooperation. Allowing many frames to be addressed collectively using Block ACKs improved performance and decreased ACK cost. By achieving the ideal balance between reliability and efficiency, adaptive retry rules also reduced the number of unused retransmissions.

Furthermore, on systems with slower CPUs or network cards, the flow control method decreased buffer overflows. This is useful in situations involving a range of hardware and software, such as company shared workplaces or student hackathons. The consistent performance on devices was achievable by synchronizing NIC driver settings further reduced cross-device variations.

## 6.2 Comparison with Existing Approaches

Legacy WLAN deployments utilizing a basic design of frame-by-frame acknowledgements and static retry thresholds performed effectively for low to moderate network loads but are not useful for high-density, real-time applications. Link-layer dependability in heterogeneous clients has received attention in WLAN research has mostly focused on throughput improvement or interference reduction. This problem is resolved by the proposed approach controls adaptive flow control, retransmission logic, and acknowledgment time. The BSS, MU-MIMO, and OFDMA coloring capabilities of Wi-Fi 6 (802.11ax) can be used to reduce collisions and distribute airtime evenly when executing many real-time applications simultaneously. Results may be useful for event planners and network managers. However, depending only with hardware solutions, link-layer settings may be changed to provide continuous Wi-Fi performance even in low-resource situations.

The implementation for large events or educational institutions will be:

- Control of adaptive retransmission

- Block methods for acknowledgment
- Prioritizing QoS for traffic that is time-sensitive
- Control of suitable NIC firmware

Can lead to more seamless user experiences without extra cost in infrastructure. Additionally, this type of configuration may be used in controller-based Wi-Fi networks to provide centralized management and automatic traffic based on real-time telemetry data (such as duplicate frame rates or retry counts).

## 7. Limitations and Future Scope

The simulation results show better performance gains; however, real deployments can add further complications, including unexpected interference, physical barriers, and device power management techniques. The Cisco Packet Tracer is useful for link-layer modeling; however, it covers certain features of real wireless network functions and was the only tool used in this investigation. In the future, the proposed method will be implemented on real hardware testbeds using Wireshark or NS-3 for detailed packet-level analysis. Machine learning is being used to predict and modify link-layer characteristics in real-time. This method is applied to multi-AP networks and IoT settings where roaming and interference make link-layer dependability difficult to achieve.

## 8. Conclusion

This study indicates that in high-density, real-time collaboration situations such as college hackathons, link-layer processes significantly impact Wi-Fi performance. Additionally, it illustrates that, compared to conventional methods that depend on improving signal strength or throughput, dependability and user experience mainly rely on the link layer's processing of framing, error detection, acknowledgments, and retransmissions. It was found that even with strong signals, different link-layer configurations on various heterogeneous devices result in packet loss, delay, and duplication, as demonstrated by comprehensive modeling using Cisco Packet Tracer. The suggested optimal configuration, including flow control, adaptive retransmit limitations, block acknowledgments (Block ACKs), and QoS prioritization (IEEE 802.11e), improved performance. The quantitative results showed significant advantages,

including a 42% increase in throughput, a 57% decrease in retransmissions, and a 76% decrease in duplicate frames. This method provides a cost-effective, software-based solution instead of various hardware requirements for businesses, educational institutions, and event planners. The proposed results show that reliable Wi-Fi communication at the link layer, with effective collaboration and less inconsistent data developed by the device, provides protocol synchronization.

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