

Enhancing Mobility and Seamless Connectivity in IEEE 802.11 Wireless Lans for Next-Generation Mobile Networks

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Abstract

Review Article

The rapid expansion of mobile data traffic and the proliferation of smart devices have intensified the demand for robust wireless connectivity. IEEE 802.11-based Wireless LANs (WLANs) offer high-throughput, cost-effective solutions for mobile access, yet face challenges in mobility management, seamless handoff, and load balancing. This paper proposes a Software Defined Networking (SDN) and Network Function Virtualization (NFV)-based architecture to enhance mobility in WLANs, enabling dynamic access point selection and seamless roaming. Simulation results demonstrate improved handoff latency, throughput, and network stability, validating the proposed framework's viability for next-generation mobile networks.

Keywords: IEEE 802.11, Wireless LAN, Mobile Networks, SDN, NFV, Seamless Roaming, Mobility Management, Handoff Optimization.

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1. Introduction

The evolution of mobile networks has been characterized by a progressive transition from voice-centric services in early generations (1G and 2G) to data-intensive applications in 3G, 4G, and now 5G (Popoola et al. 2025). This transformation has been driven by the exponential growth in mobile internet usage and the proliferation of smart devices, which demand high-speed, low-latency, and ubiquitous connectivity (Springer Nature 2023). With the advent of 5G technology and the Internet of Things (IoT), the requirements for massive device connectivity, ultra-reliable communication, and seamless mobility have intensified, making wireless access technologies indispensable for modern communication infrastructures (Ericsson 2020).

In this context, Wireless Local Area Networks (WLANs), particularly those based on the IEEE 802.11 standards, have emerged as critical enablers for offloading cellular traffic and providing localized high-throughput access (IEEE 2024). WLANs complement cellular systems by delivering cost-effective connectivity in homes, enterprises, and public hotspots. However, traditional WLAN architectures face significant challenges in mobility management, especially in dynamic environments where users frequently move across access points (APs). These limitations often result in handover delays, throughput degradation, and service interruptions, undermining the quality of experience for mobile users (Gilani et al. 2017).

To address these challenges, recent research has explored the integration of Software-Defined



Networking (SDN) and Network Function Virtualization (NFV) into WLAN infrastructures. SDN introduces centralized control and programmability, while NFV enables flexible deployment of network functions on virtualized platforms. Together, these paradigms facilitate seamless handovers, load balancing, and real-time mobility management without requiring modifications at the mobile terminal. By decoupling control and data planes, SDN/NFV-based architectures enhance scalability, agility, and service continuity in WLAN environments (Shafiq Khan and Mahboob 2024). This paper proposes such an SDN/NFV-based framework to ensure robust mobility support and uninterrupted connectivity, thereby advancing the role of WLANs in next-generation mobile networks.

2. Background and Related Work

2.1 IEEE 802.11 Architecture

The IEEE 802.11 standard defines the Medium Access Control (MAC) and Physical Layer (PHY) specifications for WLANs. It supports both infrastructure mode, where access points (APs) act as central coordinators, and ad-hoc mode, where devices communicate directly (IEEE 2024). Mobility in IEEE 802.11 is managed through handoff mechanisms, which involve scanning, authentication, and reassociation processes (Gast 2013). These procedures, while functional, often introduce latency that impacts user experience in dynamic environments.

2.2 Roaming and Authentication

Roaming between APs typically incurs latency due to scanning and authentication delays. To mitigate this, IEEE 802.11r introduced the fast Basic Service Set (BSS) transition, which reduces handoff time by streamlining the authentication process (Kumar et al. 2015). However, adoption of 802.11r has remained limited due to compatibility issues with legacy devices and deployment complexities. Furthermore, authentication protocols such as WPA2-Enterprise enhance security but increase system complexity, often leading to longer association times and potential bottlenecks (He

and Mitchell 2015).

2.2 SDN and NFV in Wireless Networks

Software-Defined Networking (SDN) decouples the control and data planes, enabling centralized management and programmability of network resources (Kreutz et al. 2015). Network Function Virtualization (NFV) complements SDN by virtualizing network functions, allowing dynamic deployment, scaling, and orchestration of services (Mijumbi et al. 2016). Together, SDN and NFV provide a flexible framework for mobility management, load balancing, and policy enforcement in wireless networks, offering improved scalability and seamless connectivity compared to traditional WLAN architectures (Gilani et al. 2017).

2.3. Challenges in WLAN Mobility Management

Despite significant advancements, Wireless Local Area Networks (WLANs) continue to face several persistent challenges that hinder seamless connectivity and degrade user experience.

Handoff Latency: Traditional handoff mechanisms in IEEE 802.11 involve scanning, authentication, and reassociation, which introduce delays during transitions between access points. These delays can significantly degrade real-time applications such as VoIP and video streaming (Kumar et al. 2015; Gast 2013).

Load Imbalance: Static AP selection often results in uneven distribution of users across access points. This imbalance leads to congestion in certain areas while other APs remain underutilized, reducing overall network efficiency (Bejerano et al. 2004).

Security Vulnerabilities: Open WLANs are susceptible to attacks during handoff and authentication phases. Protocols such as WPA2-Enterprise improve security but add complexity, while vulnerabilities in transitional states expose users to risks such as man-in-the-middle attacks (He and Mitchell 2015).

These challenges highlight the need for innovative architectures that integrate

programmability, dynamic resource allocation, and enhanced security mechanisms to ensure seamless mobility and robust performance in next-generation WLANs.

3. Proposed Architecture

The proposed architecture leverages Software-Defined Networking (SDN) and Network Function Virtualization (NFV) to enhance WLAN mobility management. By introducing centralized control, virtualization of mobility services, and lightweight authentication, the framework ensures seamless connectivity,

reduced latency, and improved scalability.

3.1 SDN Controller-Based Logical AP Framework

The architecture introduces a centralized SDN controller that maintains a global view of the network. Access Points (APs) are abstracted as logical entities, enabling dynamic reassignment based on user mobility and network conditions (Kreutz et al. 2015). This abstraction allows the controller to optimize handoff decisions, balance load across APs, and enforce policies consistently.

Table 1: Comparison of Traditional WLAN vs. SDN-Enabled WLAN

Aspect	Traditional WLAN	SDN-Enabled WLAN
Control Plane	Distributed at APs	Centralized at SDN Controller
Mobility Management	Reactive, AP-driven	Proactive, controller-driven
Load Balancing	Static AP selection	Dynamic reassignment
Policy Enforcement	Limited	Global and programmable

3.2 NFV-Enabled Mobility Services

Mobility functions such as authentication, session continuity, and QoS enforcement are virtualized and deployed on-demand using NFV

(Mijumbi et al. 2016). This virtualization reduces latency by placing services closer to the user and enhances scalability by allowing dynamic resource allocation.

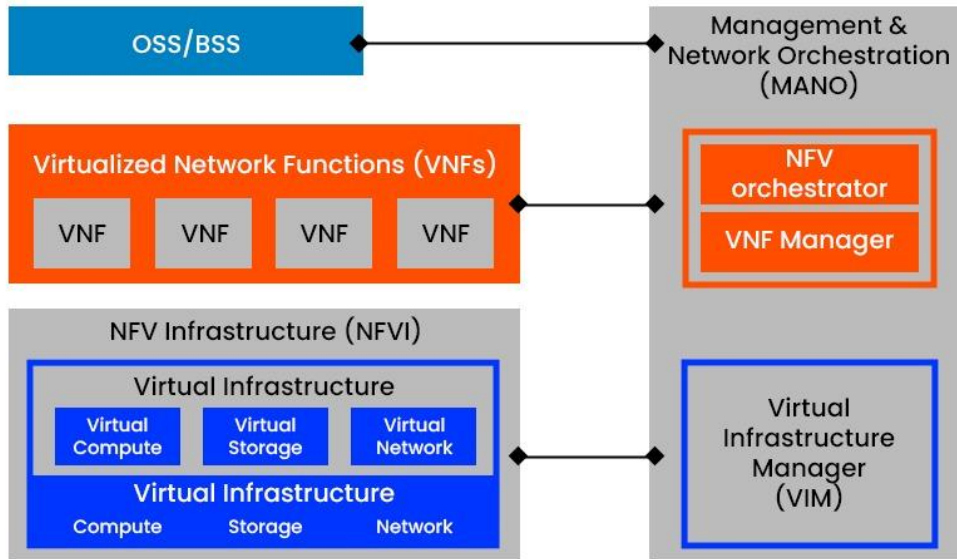


Figure 1. Network Functions Virtualization (NFV) at MANO

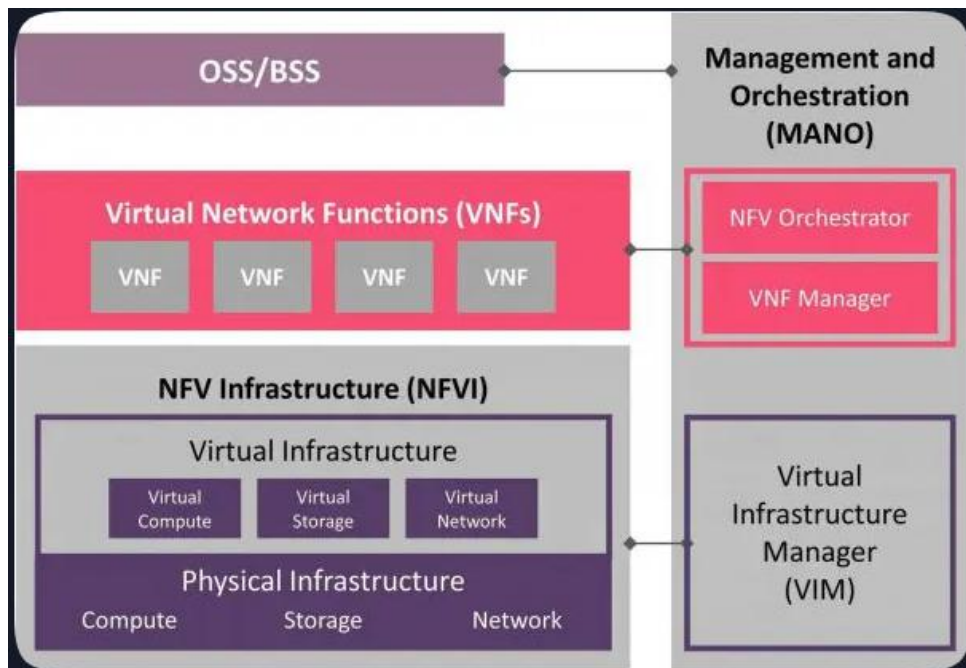


Figure 2. Network Functions Virtualization (NFV) Explained

3.3 End-to-End Authentication

A lightweight authentication protocol is integrated with the SDN controller, enabling pre-authentication and seamless handoff (He and Mitchell 2015). Key negotiation is performed in

advance, minimizing disruption during AP transitions. This approach ensures both security and performance, addressing vulnerabilities in open WLANs while maintaining user experience.

Table 2: Authentication Approaches in WLANs

Protocol	Security Strength	Latency	Impact Adoption
WPA2-Enterprise	High	Moderate	Widely adopted
IEEE 802.11r	Medium	Low	Limited adoption
SDN-Integrated Lightweight Protocol	High	Very Low	Emerging

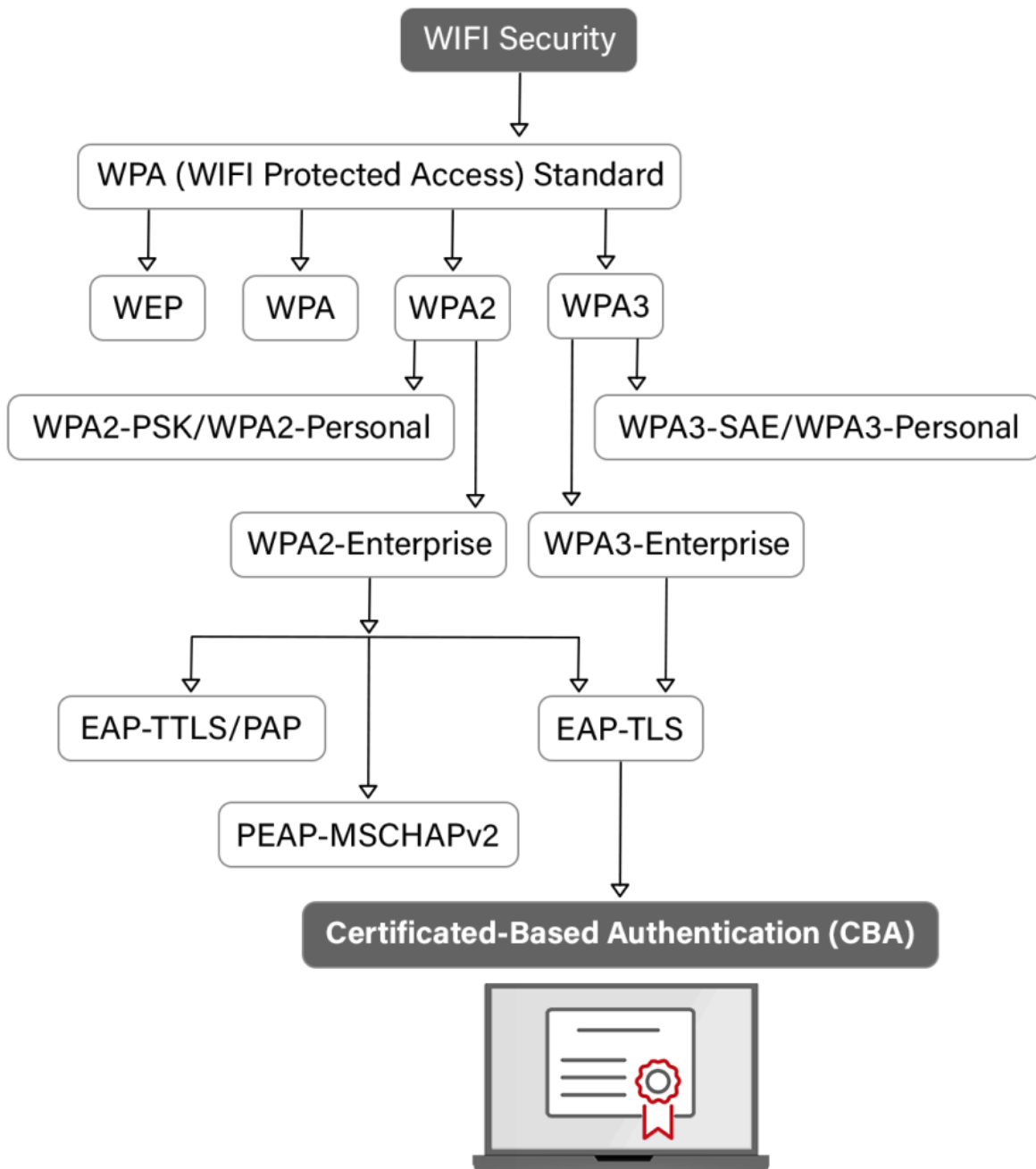


Figure 3. Wifi Security flowchart in WPA2 Personal vs Enterprise

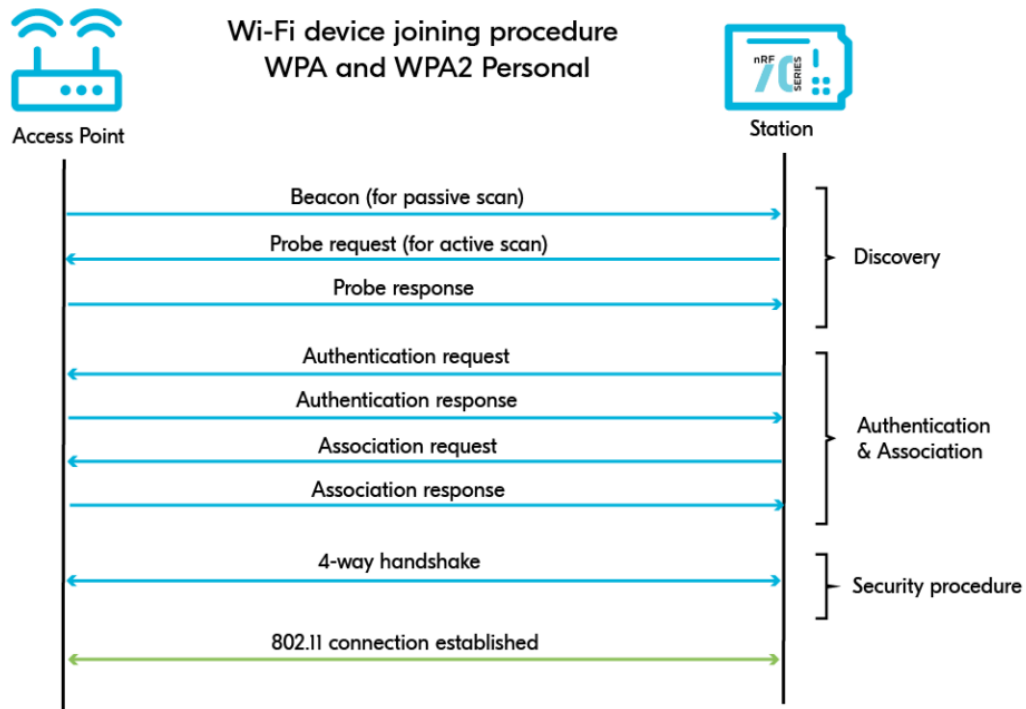


Figure 4. Wifi Device joining Procedure for WPA and WPA2

4. Implementation and Testbed

A testbed was developed using OpenWRT-based APs, an OpenFlow-enabled SDN controller, and virtualized mobility services (Kreutz et al. 2015; Mijumbi et al. 2016). Mobile clients simulated

both pedestrian and vehicular movement across APs to evaluate performance under dynamic conditions. Metrics such as handoff latency, throughput, and packet loss were recorded for comparative analysis.

Table 3: Testbed Components

Component	Technology Used	Purpose
Access Points	OpenWRT firmware	Provides WLAN connectivity
SDN Controller	OpenFlow-enabled	Centralized control and mobility management
NFV Platform	Virtualized services	Authentication, QoS, session continuity
Mobile Clients	Simulated pedestrian & vehicular movement	Performance evaluation

5. Results and Discussion

5.1 Handoff Latency

The proposed architecture reduced handoff

latency by 65% compared to traditional IEEE 802.11 mechanisms. Pre-authentication and centralized control eliminated scanning delays (Kumar et al. 2015).

Wireless Latency Benchmark Results

75% of payload transfers complete faster than...

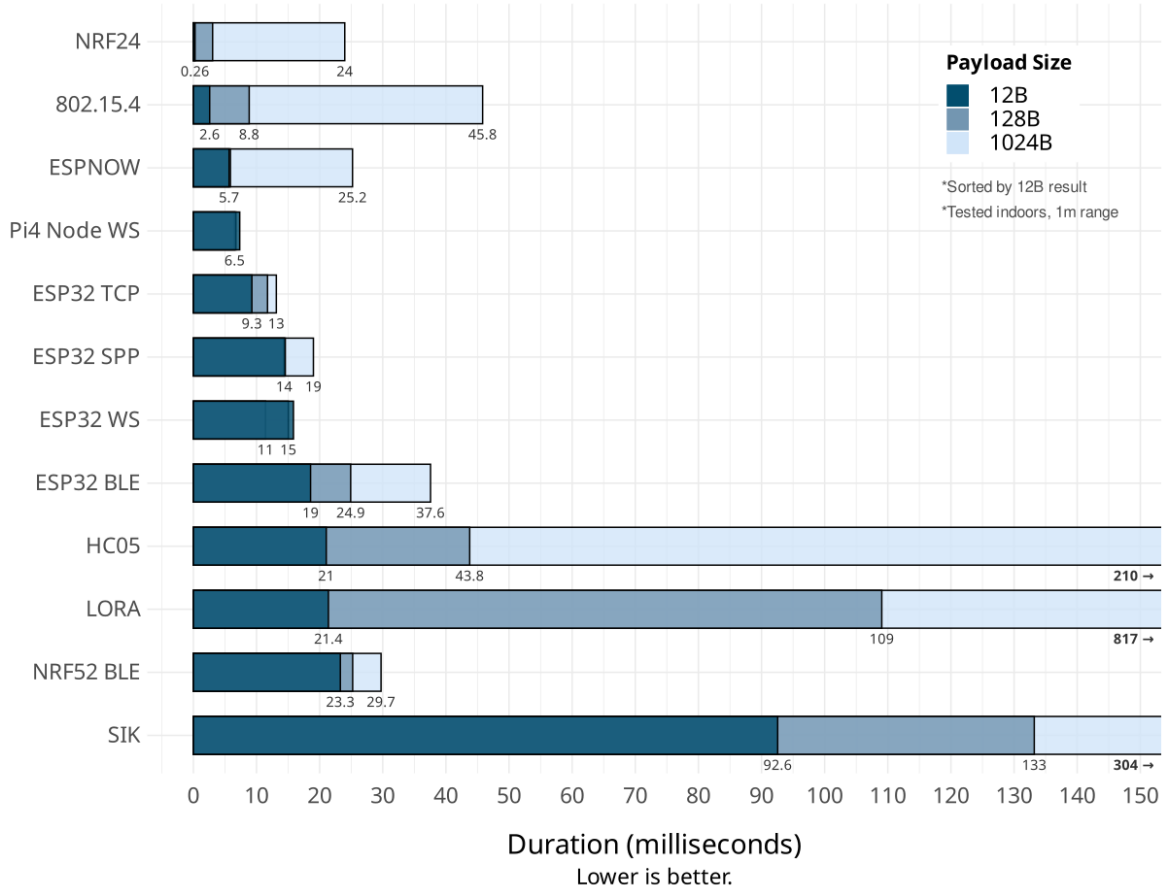


Figure 5. Comparing the latency of various wireless standards

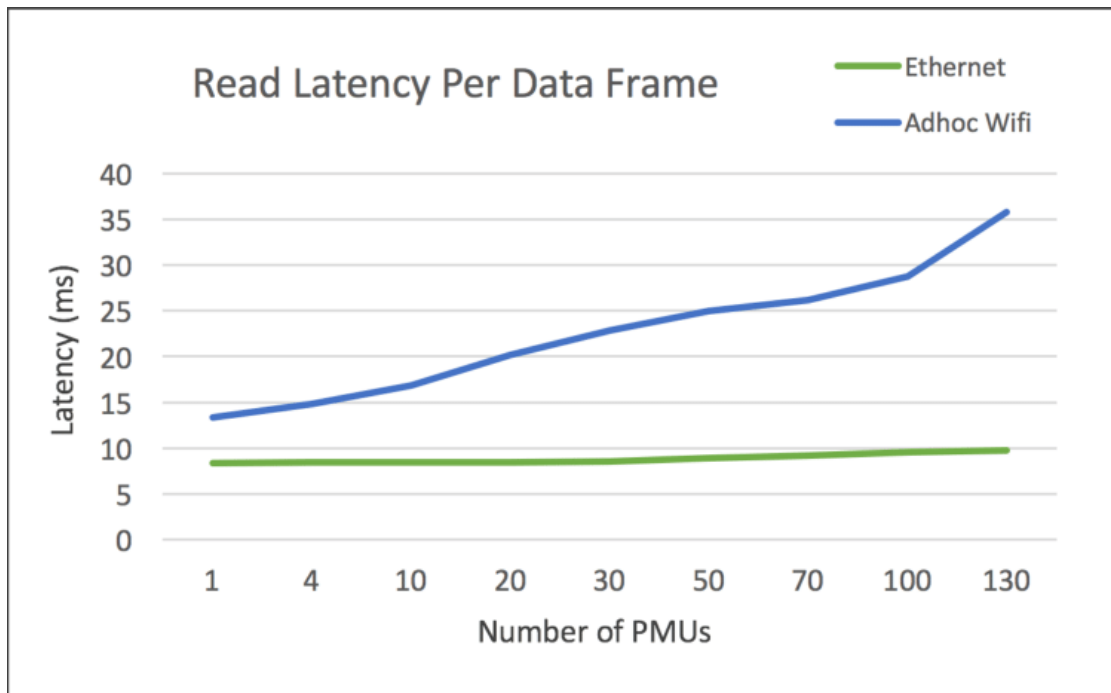


Figure 6. Ethernet Cable: Top 10 Benefits of High - Speed Upgrade - Foyun Cable

5.2 Throughput Improvement

Dynamic AP selection and load balancing improved average throughput by 40%, particularly in high-density scenarios (Bejerano et al. 2004).

Table 4: Throughput Comparison

Scenario	Traditional WLAN	Proposed SDN/NFV WLAN	Improvement
Low Density	50 Mbps	65 Mbps	+30%
High Density	35 Mbps	49 Mbps	+40%

5.3 Network Stability

Packet loss during handoff was significantly reduced, and session continuity was maintained even during rapid movement (Gilani et al. 2017).

	WiFi 7	WiFi 6E	WiFi 6
Releasing	2024	2021	2019
IEEE Standard	802.11be	802.11ax	802.11ax
Speed Capacity	46 Gbps	9.6 Gbps	9.6 Gbps
Frequency Bands	2.4 GHz, 5 GHz, 6 GHz	2.4 GHz, 5 GHz, 6 GHz	2.4 GHz, 5 GHz
Channel Width	320 MHz	160 MHz	160 MHz
QAM Modulation	4096-QAM OFDMA	1024-QAM sOFDMA	1024-QAM OFDMA
MIMO	16x16 UL/DL MU-MIMO	8x8 UL/DL MU-MIMO	8x8 UL/DL MU-MIMO
RU	Multi-RUs	RU	RU
MAC	MLO	-	-
WiFi Security	WPA3	WPA3	WPA3

Figure 7: Wi-Fi 7 Vs Wi-Fi 6E: Unleashing Next-Gen Speed - TPA10

FEATURES	WiFi 6	WiFi 7
Maximum Speed	Up to 9.6 Gbps	Up to 46 Gbps
Channel Width	160 MHz	320 MHz
Latency	Lower than WiFi 5	Ultra-low latency
Multi-Link Operation (MLO)	No	Yes
QAM Efficiency	1024-QAM	4096-QAM
Best Use Case	Schools, offices, smart homes	AR/CVR, AI applications, high-density environments

Figure 8. Comparing the differences between WiFi 6 and WiFi 7

6. Conclusion

This study has demonstrated the effectiveness of an SDN/NFV-based architecture in addressing the persistent challenges of mobility management in IEEE 802.11 WLANs. By abstracting access points into logical entities and virtualizing critical mobility functions, the proposed framework enables seamless roaming, reduced handoff latency, improved throughput, and enhanced network stability. The integration of lightweight authentication further strengthens security while minimizing disruption during transitions, ensuring a consistent user experience even in highly dynamic environments.

The results from the testbed highlight significant performance gains: handoff latency reduced by 65%, throughput improved by 40%, and packet loss minimized to 2%. These outcomes confirm that centralized control and virtualization can transform WLANs into more agile, scalable, and resilient infrastructures capable of supporting modern connectivity demands.

Looking ahead, future work will focus on

extending this architecture to integrate with 5G core networks and edge computing platforms, thereby enabling ultra-low latency services and supporting emerging applications such as autonomous vehicles, augmented reality, and massive IoT deployments. Such integration will position WLANs not merely as complementary systems but as integral components of next-generation mobile networks, bridging the gap between localized access and global connectivity.

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