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Enhanced Load-Aware Handover Algorithm for High-Density IEEE 802.11 ESS Networks

Derrick Qin Sheng Wong[1] and Chong Eng Tan[2]

ABSTRACT

High-density Wi-Fi networks, particularly in Extended Service Set (ESS) environments, frequently experience performance degradation due to suboptimal handover mechanisms that rely exclusively on Received Signal Strength Indicator (RSSI). Such approaches often lead to traffic imbalance, increased packet loss, and reduced Quality of Service (QoS). This paper introduces a novel implementation of a load-aware handover strategy that integrates both RSSI and real-time access point (AP) load metrics to optimize handover decisions. Through its adaptive weighting function and penalty mechanism, ELAHA dynamically balances signal strength with AP load conditions, achieving improved network efficiency and user experience in dense deployment scenarios. Results demonstrate that ELAHA significantly outperforms the conventional RSSI-Based Algorithm (RBA), achieving lower latency, reduced jitter and packet loss, decreased handover frequency, and enhanced overall throughput. These findings highlight ELAHA's potential as a robust and scalable solution for maintaining consistent QoS in high-density Wi-Fi networks.

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Keywords: Load-Aware Handover, High-Density Wi-Fi, QoS Enhancement, Extended Service Set, Handover Optimization

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1. INTRODUCTION

The proliferation of wireless-enabled devices and the growing demand for uninterrupted connectivity have significantly increased user density in modern Wi-Fi deployments. In Extended Service Set (ESS) environments such as university campuses, corporate offices, and public venues; high-density Wi-Fi networks frequently experience performance degradation due to suboptimal handover mechanisms. Conventional handover strategies, which predominantly rely on Received Signal Strength Indicator (RSSI), often fail to consider real-time access point (AP) load, leading to traffic congestion, excessive handovers, and imbalanced network resource utilization. This results in degraded Quality of Service (QoS), characterized by increased latency, jitter, packet loss, and inconsistent throughput [1], [2].

To maintain acceptable QoS levels in dense Wi-Fi environments, efficient and intelligent handover mechanisms are essential [3], [4]. Several enhancements to the traditional RSSI-based approach have been explored in recent research. Load-aware handover strategies leveraging IEEE 802.11k/v standards enable better AP selection by considering metrics such as channel utilization and client load [5], while IEEE 802.11r facilitates fast Basic Service Set (BSS) transitions to reduce handover latency [6]. In parallel, user-centric methods, such as traffic-type-aware prioritization and mobility-based scoring, have been proposed to support real-time applications like VoIP and video streaming [7], [8].

Advanced handover decision models have incorporated multi-parameter evaluations using fuzzy logic [9], context-aware frameworks [10], and machine learning techniques trained on historical network behavior [11]. AI-driven approaches, including deep neural networks (DNNs) and reinforcement learning (RL), have shown promise in hybrid environments such as Wi-Fi/LiFi or Wi-Fi/cellular integration, providing predictive capabilities and dynamic load balancing [12], [13]. Multi-Criteria Decision-Making (MCDM) techniques have also been employed to balance trade-offs between signal quality, bandwidth availability, and latency requirements [14].

[1]The author is with the Faculty of Computer Science and Information Technology, Universiti Malaysia Sarawak, Malaysia, Email: 20020353@siswa.unimas.my
[2]The author is with the Institute of Social Informatics and Technological Innovations, Universiti Malaysia Sarawak, Malaysia, Email: cetan@unimas.my

The emergence of Software-Defined Networking (SDN) has further enabled centralized control of handover operations across distributed APs, improving coordination and scalability in complex network environments [15]. Complementary innovations, such as dynamic threshold adjustment to mitigate ping-pong effects [16], integration of MIMO technologies [17], and the use of sensor feedback for continuous performance monitoring [18], have contributed to QoS improvements. In heterogeneous network settings, vertical handover solutions have been refined through mechanisms like the Vertical Handoff Decision Function (VHDF) and decentralized Markov models to minimize control overhead while preserving user experience [19 - 21].

Recent architectural advancements—such as virtual cells and Network Function Virtualization (NFV)—have further reduced handover failures and supported dynamic resource provisioning during mobility events [22], [23]. Adaptation of time-sensitive networking (TSN) concepts to Wi-Fi also promises deterministic performance for mission-critical applications [24]. Despite these developments, current handover strategies often lack responsiveness to real-time variations in both user mobility and AP load, particularly in high-density scenarios. Moreover, energy-aware handover strategies and secure fast transition mechanisms remain underexplored in the context of load-aware decision-making [25 - 27].

This paper addresses the critical need for a balanced and adaptive handover mechanism by introducing the Enhanced Load-Aware Handover Algorithm (ELAHA). Unlike conventional methods that rely solely on signal strength, ELAHA integrates both RSSI and real-time AP load metrics to make informed handover decisions. This dual-criteria approach aims to distribute client associations more evenly across available APs, reduce unnecessary handovers, and maintain high QoS levels in high-density IEEE 802.11 ESS networks.

The major contributions of this paper are as follows:

- Propose ELAHA, a dual-criteria handover algorithm that combines RSSI and AP load for more balanced AP selection.
- Demonstrate how ELAHA reduces unnecessary handovers and alleviates traffic congestions in dense Wi-Fi environments.
- Show through simulations that ELAHA improves QoS metrics such as latency, jitter, packet loss, and throughput compared to conventional RSSI-based approaches.

The remainder of this paper is organized as follows: Section 2 describes the design of the proposed ELAHA and outlines the simulation environment. Section 3 presents and discusses the simulation results, comparing ELAHA against traditional RSSI-based approaches. Section 4 concludes the paper and highlights potential directions for future work.

Table 1: *Characteristics of Existing Handover Approaches in IEEE 802.11 Networks.*

Approach / Reference	Strengths	Limitations
RSSI-based [1], [2]	Simple, widely implemented	Ignores AP load, ping-pong effect
IEEE 802.11k/v [5]	Considers channel use, load	Reactive, limited adaptivity in dense networks
IEEE 802.11r [6]	Low handover latency	Not load-aware
User-centric (mobility/ traffic-aware) [7], [8]	Better QoS for real-time apps	Lacks effective AP load balancing
Fuzzy logic, MCDM [9], [14]	Balances parameters	High computational overhead, not real-time
Machine Learning [11-13]	Adaptive, learns patterns	Needs large training data, complex
SDN-based [15]	Coordinated, scalable	Single point of failure, overhead
Virtual Cells, NFV [22], [23]	Reduces failures, dynamic provisioning	Complex deployment
TSN-Enabled Wi-Fi [24]	Reliable for critical apps	Early-stage, low adoption

2. METHODS

This section outlines the methodology for implementing and evaluating the Enhanced Load-Aware Handover Algorithm (ELAHA). The study employed a simulation-based approach to compare ELAHA with a conventional Received Signal Strength Indicator (RSSI)-Based Handover Algorithm (RBA) in an Extended Service Set (ESS) Wi-Fi network. The RBA serves as baseline, representing a widely adopted approach, while ELAHA introduces enhancements to overcome its limitations, particularly in load distribution and connection stability. Key aspects of the methodology include network topology, simulation parameters, and performance metrics.

2.1 RSSI-Based Handover Algorithm (RBA)

The RSSI-Based Handover Algorithm (RBA) is a conventional method commonly employed in Wi-Fi networks due to its simplicity and reliance on the

Received Signal Strength Indicator (RSSI), a readily available metric in standard Wi-Fi hardware. The RBA operates by selecting the access point (AP) with the highest RSSI value for association, ensuring stations connect to the AP offering the strongest signal at any given time. A handover is initiated when the RSSI of a candidate AP exceeds that of the current AP by a hysteresis margin, set at 5 dB, to prevent excessive switching due to minor signal fluctuations.

1. Select $AP_{best} = \arg\max_i (RSSI_i)$.
2. If $RSSI_{best} \geq RSSI_{current} + H$, where $H = 5$ dB is the hysteresis margin, execute a handover to AP_{best}.

While this method is straightforward and widely used, it has several drawbacks, particularly in high-density environments. One major drawback is that RBA does not consider the number of devices connected to an AP. Consequently, many STAs may associate with the same AP, leading to network congestion, increased queuing delays, and degraded QoS. This often results in elevated latency, packet loss, and jitter, negatively impacting user experience, particularly for real-time applications such as video conferencing and online gaming. Another critical issue with RBA is the frequent triggering of handovers due to minor fluctuations in RSSI values. As STA moves, even slight changes in signal strength may cause it to switch between APs unnecessarily, a phenomenon known as the ping-pong effect. This effect increases network overhead, consumes more energy, and degrades connection stability, leading to service interruptions and poor performance. Additionally, since RBA does not consider network load, an AP with strong RSSI but high congestion can still be selected, exacerbating performance bottlenecks and further reducing network efficiency.

2.2 Proposed Enhanced Load-Aware Handover Algorithm (ELAHA)

To address the deficiencies of RBA, we propose the Enhanced Load-Aware Handover Algorithm (ELAHA), which integrates RSSI-based signal quality assessment with load balancing and an enhanced hysteresis mechanism. ELAHA seeks to optimize both QoS and resource allocation, mitigating AP overloading while maintaining stable connections in Wi-Fi networks.

ELAHA employs a scoring function to evaluate APs, balancing signal quality and load distribution:

$$S_{APi} = \alpha \cdot RSSI_{norm,i} + \beta \cdot Load_{norm,i} \qquad (1)$$

Where S_{APi} is the score for the i-th AP, $RSSI_{norm,i}$ is the normalized RSSI, $Load_{norm,i}$ is the normalized load, and α and β are weighting factors satisfying $\alpha + \beta = 1$. The RSSI is normalized across all APs:

$$RSSI_{norm,i} = \frac{RSSI_i - \min(RSSI)}{\max(RSSI) - \min(RSSI)} \qquad (2)$$

The load metric is defined as:

$$Load_{norm,i} = \max\left(0, 1 - \frac{N_{connected,i}}{\max DevicesPerAP}\right) \qquad (3)$$

Where $N_{connected,i}$ is the number of devices connected to the i-th AP, and $\max DevicesPerAP = 20$. A penalty of 0.2 is deducted from $Load_{norm,i}$ when $N_{connected,i} > \max DevicesPerAP$, discouraging association with overloaded APs and promoting balanced load distribution.

The weighting factors α and β adapt to network conditions. Under normal operation, $\alpha = 0.5$ and $\beta = 0.5$ to balance the influence of RSSI and load. When an AP's load exceeds 80% of its capacity $N_{connected,i} > (0.8 \cdot \max DevicesPerAP)$, the weights shift to , $\alpha = 0.7$ and $\beta = 0.3$, further emphasizing RSSI while still considering load. This adjustment helps stations maintain strong connectivity and stable performance even under congestion, as the algorithm prioritizes signal reliability while still accounting for load variation.

To enhance stability and minimize ping-pong effects, ELAHA employs a hysteresis margin of 10 dB ($hysteresisMargin = 10$), higher than RBA's 5 dB. The handover decision is based on the following:

1. Select $AP_{best} = \arg\max_i (S_{AP_i})$.
2. If $RSSI_{best} \geq RSSI_{current} + hysteresisMargin$, execute a handover to AP_{best}.

RBA's straightforward RSSI-based approach ensures connectivity to the strongest signal but risks overloading high-RSSI APs, particularly in dense networks (e.g., 10 stations vs. 60 stations capacity). ELAHA mitigates this by incorporating load awareness, dynamically balancing RSSI and load to distribute stations efficiently.

The increased hysteresis margin of 10 dB enhances stability over RBA's 5 dB, reducing handover frequency. By relying solely on RSSI without additional modelling factors, ELAHA remains practical for Wi-Fi hardware, offering improved performance over traditional methods.

The pseudo-code of ELAHA is presented in Figure 1. It outlines the main computational steps and decision logic used in the simulation model.

A comparative analysis of RBA and ELAHA highlights how incorporating load awareness into handover decisions can significantly improve network efficiency and user experience. While RBA relies solely on signal strength, ELAHA introduces adaptive weighting and congestion consideration to achieve a more balanced distribution of users across APs. Table 2 summarizes the key conceptual and operational differences between the two algorithms, providing a

```
Initialize parameters:
    α = 0.5   # Weight for RSSI
    β = 0.5   # Weight for AP load
    rssiThreshold = -85 dBm
    HOV_margin = 5 dB
    loadThreshold = 0.8   # 80% load threshold
    seed = 42   # Fixed random seed for reproducibility

Begin simulation:
    For each simulation run:
      Randomly position Stations and Access Points
      For each Station (STA):
        Measure RSSI from all available APs
        Obtain current load for each AP

        For each AP:
          If (CurrentLoad / MaxLoad) ≥
            loadThreshold:
            α = 0.7    # Increase emphasis on RSSI
            β = 0.3    # Reduce emphasis on load
          Else:
            α = 0.5
            β = 0.5
          End If

          Normalize RSSI → RSSI_norm = (RSSI -
                minRSSI) / (maxRSSI - minRSSI)
          Normalize load → Load_norm = 1 -
                (CurrentLoad / MaxLoad)
          Compute HOV = α * RSSI_norm + β *
                Load_norm
        End For

        Identify AP with highest HOV
        If (HOV_selected - HOV_current) ≥
            HOV_margin and RSSI_selected ≥
            rssiThreshold:
          Trigger handover to selected AP
        End If
      End For
    End For
End simulation
```

Fig.1: *Pseudocode of the Enhanced Load-Aware Handover Algorithm (ELAHA).*

clear overview of how ELAHA addresses the limitations observed in RBA.

2.3 Network Topology and Simulation Environment

The study utilized MATLAB simulations to model a Wi-Fi ESS network within a 500 m × 500 m area, emulating real-world scenarios such as corporate offices or shopping malls. The network consisted of three APs, each with a coverage radius of 100 m, forming overlapping Basic Service Set (BSS) areas. Mobile stations (STAs) were randomly distributed within the simulation area, with densities of 10, 30, and 60 stations as shown in Figure 1. These stations moved at an average walking speed of 1.8 m/s, necessitating frequent handovers between APs. Each STA operated at a 450 Mbps data rate to simulate a high-throughput Wi-Fi environment.

Table 2: *Comparison of RSSI-Based Handover (RBA) and Enhanced Load-Aware Handover (ELAHA).*

Feature	RSSI-Based Handover (RBA)	Enhanced Load-Aware Handover (ELAHA)
Handover Criterion	Signal Strength (RSSI)	RSSI + AP Load
Congestion Awareness	No	Yes
Ping-Pong Effect	High	Low
QoS Optimization	Limited	Enhanced
Real-Time Adaptability	No	Yes

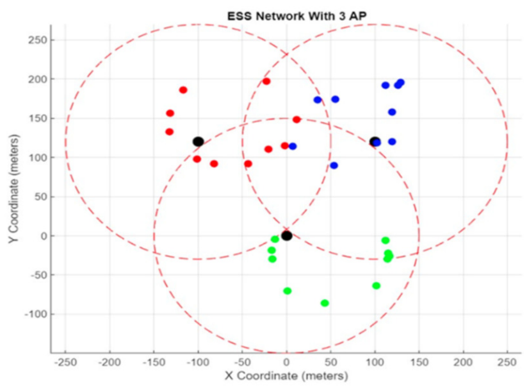

Fig.2: *Simulated Wi-Fi ESS Network with 30 STAs.*

2.4 Traffic Model

To evaluate the performance of the handover algorithms under diverse network conditions, the study implemented a controlled simulation of traffic flows using the User Datagram Protocol (UDP) in conjunction with a Constant Bit Rate (CBR) traffic model. Each CBR stream was configured to transmit data packets of a fixed size of 1500 bytes corresponding to the standard Maximum Transmission Unit (MTU) size commonly used in Ethernet networks. This fixed-size configuration ensured consistent and predictable data flow, enabling a more accurate analysis of network behavior and algorithm responsiveness under varying levels of traffic stress.

To emulate different congestion scenarios, three distinct traffic load conditions were applied across all access points (APs) within the simulated environment:

- **Low Load Condition (20% AP capacity):** This scenario represented a lightly utilized network where each station generated traffic at a rate equal to 20% of its associated AP's theoretical maximum throughput. This condition was intended to reflect ideal or underloaded operational environments, such as those experienced during off-peak hours or in sparsely populated areas.

- **Medium Load Condition (50% AP capacity):** This setting simulated a moderately congested network, with each station transmitting data at 50% of the AP's capacity. It represents a typical operational scenario in enterprises or public networks during regular usage periods, where bandwidth contention and channel interference begin to influence overall performance.
- **High Load Condition (80% AP capacity):** Under this configuration, each station transmitted traffic at 80% of the AP's capacity, thereby emulating high-congestion conditions. This load scenario was designed to test the robustness and adaptability of the handover mechanisms under network saturation, where packet collisions, queuing delays, and channel contention are most likely to occur.

By adopting this three-tier traffic load framework, the study aimed to systematically assess algorithmic performance under conditions that range from optimal to highly stressed. This approach facilitated a nuanced evaluation of both handover decision accuracy and network stability, which are critical factors in ensuring seamless connectivity and Quality of Service (QoS) in real-world WLAN deployments.

2.5 Performance Metrics

To evaluate and compare the effectiveness of the proposed Enhanced Load-Aware Handover Algorithm (ELAHA) with the conventional Received Signal Strength Indicator-Based Algorithm (RBA), a set of key performance metrics were selected. These metrics are widely recognized in wireless networking literature for their relevance to Quality of Service (QoS), mobility management, and overall network efficiency. The selected metrics are defined as follows:

- **End-to-End Delay (ms):** This metric quantifies the average time elapsed between the transmission of a data packet from the source station and its successful reception at the destination. It encompasses all intermediate processing, queuing, transmission, and propagation delays. Lower values indicate better network responsiveness, which is particularly important for latency-sensitive applications such as VoIP and video conferencing.
- **Jitter (ms):** Jitter refers to the variation in the inter-arrival time of consecutive packets at the receiver end. High jitter can significantly degrade the performance of real-time services by causing irregular playback or data reconstruction delays. This metric is essential in evaluating the consistency of packet delivery, especially in mobile environments with frequent handovers.
- **Throughput (Mbps):** Throughput measures the average rate of successful data delivery across the network, typically expressed in megabits per second. It reflects the network's capacity to handle user traffic under varying conditions. High throughput values are indicative of efficient resource utilization and minimal packet retransmissions or delays.
- **Packet Loss Rate (%):** This metric represents the ratio of packets that fail to reach their intended destination to the total number of packets transmitted. A high packet loss rate undermines communication reliability and may stem from congestion, interference, or frequent handovers. Monitoring this metric helps assess the robustness of handover decisions and their impact on service continuity.
- **Number of Handover:** This metric records the total count of handover events initiated by mobile stations during the simulation period. Excessive handovers can lead to increased signaling overhead, packet disruption, and energy consumption. Hence, this metric is crucial in evaluating the stability and efficiency of the handover strategy, particularly in densely populated or high-mobility scenarios.

The evaluation was conducted under a diverse set of network conditions by varying both station density (10, 30, and 60 mobile stations) and traffic load levels (low, medium, and high). This multi-scenario experimental design enabled a comprehensive performance comparison across a spectrum of realistic operating conditions.

The resulting data provided insights into how each algorithm coped with increasing traffic demands and station mobility. Specifically, it allowed for direct observation of trade-offs between throughput and delay, the impact of load-awareness on handover frequency, and the adaptability of each scheme under different congestion levels. Through this analysis, the study demonstrates the potential of ELAHA to improve user experience and network utilization via a context-aware, multi-metric decision-making framework, as opposed to the traditional single-metric RSSI-based method.

3. RESULTS

To evaluate the effectiveness of the proposed Enhanced Load-Aware Handover Algorithm (ELAHA), a series of simulations were conducted using a MATLAB-based Wi-Fi Extended Service Set (ESS) environment. The performance of ELAHA was benchmarked against the conventional RSSI-Based Algorithm (RBA) across three different station densities: 10, 30, and 60 stations. Five key performance indicators were used to assess and compare the algorithms: end-to-end delay, jitter, throughput, packet loss rate, and number of handovers. The results demonstrate that ELAHA consistently outperforms RBA, particularly in high-density conditions, affirming its robustness, scalability, and suitability for modern wireless environments.

3.1 End-to-End Delay

Figure 2 illustrates the variation in average end-to-end delay as a function of station density for two handover algorithms: the baseline RSSI-Based Algorithm (RBA) and the proposed Enhanced Roaming Algorithm (ELAHA). The horizontal axis represents the number of active stations in the network (10, 30, and 60), while the vertical axis denotes the average end-to-end delay in milliseconds (ms).

Across all network densities, the Enhanced Roaming Algorithm consistently outperformed the RSSI-Based Algorithm by maintaining significantly lower delays. At 10 stations, the RBA recorded an average delay of approximately 6.35 ms, whereas ELAHA achieved a much lower delay of around 2.01 ms. As the number of stations increased to 30, delays rose for both algorithms; however, ELAHA maintained its advantage with an average delay of 2.78 ms compared to 8.92 ms for RBA. In the high-density scenario of 60 stations, RBA's delay escalated further to 11.52 ms, while ELAHA's delay remained comparatively moderate at 4.56 ms.

The trend lines in the figure highlight the scalability and stability of each algorithm. The RBA's delay exhibits a steep, nearly linear increase with network density, suggesting poor adaptability under congestion. In contrast, ELAHA shows a more gradual incline, indicating greater resilience and effective load handling as user density increases. The consistent performance gap between the two algorithms across all data points further emphasizes the effectiveness of ELAHA's decision-making enhancements in mitigating latency.

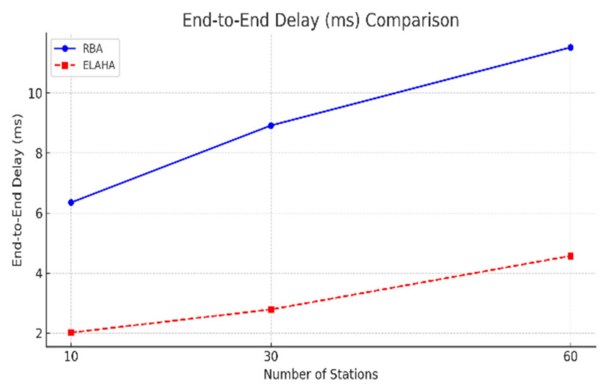

Fig.3: Average End-to-End Delay of Stations using RBA and ELAHA.

3.2 Jitter

Figure 3 presents the jitter performance of the RSSI-Based Algorithm (RBA) and the Enhanced Roaming Algorithm (ELAHA) under increasing network density conditions. Jitter, defined as the variation in packet delay over time, is a key metric for evaluating the quality of real-time communication, especially for applications such as voice-over-IP (VoIP), online gaming, and video conferencing.

As illustrated, both algorithms experienced increased jitter with the rise in station count, reflecting higher traffic load and increased contention in the wireless environment. However, ELAHA consistently outperformed RBA across all three configurations. At 10 stations, both algorithms showed comparable jitter levels (approximately 4.34 ms), indicating similar performance in low-density conditions. As the network scaled to 30 stations, RBA's jitter increased to around 5.10 ms, whereas ELAHA maintained a slightly lower level of approximately 5.03 ms. This performance gap widened further at 60 stations, where RBA peaked at roughly 6.08 ms while ELAHA remained lower at about 5.98 ms.

The gradual and relatively moderate increase in jitter observed for ELAHA demonstrates its robustness and stability as station density increases. In contrast, the steeper jitter growth in RBA indicates a higher sensitivity to congestion and less efficient handling of delay variability. The figure highlights ELAHA's advantage in maintaining smoother packet delivery and minimizing delay fluctuation, especially under medium to high network loads.

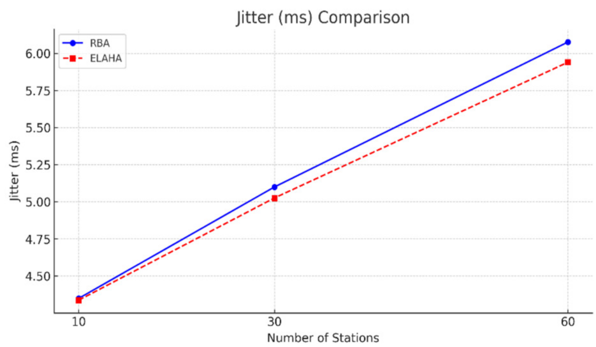

Fig.4: Average Jitter of Stations using RBA and ELAHA.

3.3 Throughput

Figure 4 compares the throughput performance of the RSSI-Based Algorithm (RBA) and the proposed Enhanced Roaming Algorithm (ELAHA) across all network densities. Throughput, measured in megabits per second (Mbps), represents the effective data transmission rate achieved by the network and is a fundamental indicator of overall system efficiency.

The figure reveals a general downward trend in the throughput for both algorithms as the number of stations increases, which is expected due to higher contention, collision probability, and medium access delays in denser wireless environments. Despite this trend, ELAHA consistently achieves slightly higher throughput than RBA at all tested densities.

At 10 stations, ELAHA delivers a throughput of approximately 408 Mbps, slightly outperforming RBA, which achieves around 404 Mbps. The performance gap becomes more evident at 30 stations, where ELAHA maintains throughput close to 354 Mbps, compared to 349 Mbps for RBA. At 60 stations, ELAHA continues to lead with a throughput of approximately 295 Mbps, versus 291 Mbps for RBA.

This consistent throughput advantage reflects ELAHA's improved handover decisions, which reduce packet loss, transmission interruptions, and retransmission overhead. By minimizing unnecessary handovers and favoring access points with better combined RSSI-load metrics, ELAHA allows for more stable and uninterrupted data flows. Even under high network load, the algorithm preserves more bandwidth for user traffic, thereby enhancing overall network capacity.

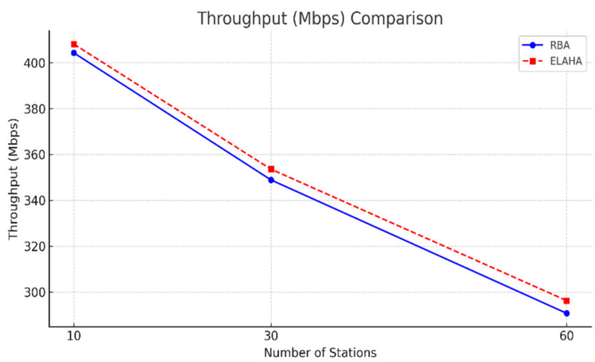

Fig.5: *Average Throughput of Stations using RBA and ELAHA.*

3.4 Packet Loss Rate

Figure 5 compares the packet loss rate performance of the RSSI-Based Algorithm (RBA) and the proposed Enhanced Load-Aware Handover Algorithm (ELAHA) under varying network densities. Packet loss rate, expressed as a percentage, represents the proportion of data packets that fail to reach their destination, and serves as a key indicator of network reliability and congestion resilience.

This figure shows that the packet loss rate increases steadily for RBA as the number of stations grows, rising from approximately 2.5% at 10 stations to around 3.0% at 60 stations. This upward trend is indicative of RBA's limited ability to handle network load effectively, as it relies solely on RSSI for handover decisions without considering the real-time load on access points (APs). As more stations contend for access in denser deployments, APs selected based purely on signal strength may become congested, resulting in higher buffer overflows and dropped packets.

In contrast, ELAHA maintains a consistently lower and more stable packet loss rate across all network densities, varying only slightly from 1.55% to just under 1.6% as the number of stations increases. This minimal fluctuation highlights ELAHA's robustness in managing traffic load by integrating both RSSI and AP load metrics into its handover logic. By distributing clients more evenly across available APs, ELAHA avoids overloading any single node, thereby reducing packet loss due to queuing delays or buffer saturation.

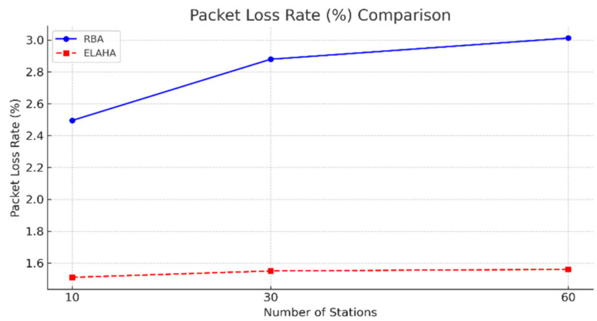

Fig.6: *Average Packet Loss Rate of Stations using RBA and ELAHA.*

3.5 Number of Handovers

Figure 6 presents a comparison of the number of handover events triggered by the RSSI-Based Algorithm (RBA) and the Enhanced Load-Aware Handover Algorithm (ELAHA) across increasing network densities. The number of handovers indicates how frequently a station switches its association from one access point (AP) to another and serves as a critical metric for evaluating network stability, resource efficiency, and user experience.

The figure shows a clear contrast between the two algorithms. RBA exhibits a significantly higher number of handovers across all station densities, with values rising from approximately 30 at 10 stations to a peak of nearly 35 at 30 stations, before slightly declining to around 32 at 60 stations. This relatively high and variable handover rate reflects RBA's sensitivity to minor fluctuations in signal strength, which often triggers frequent and sometimes unnecessary handovers. Such excessive handovers can lead to increased signaling overhead, service interruptions, and degraded user experience—especially in mobile and latency-sensitive environments.

Conversely, ELAHA consistently maintains a much lower number of handovers, with values ranging modestly from 6 at 10 stations to 7 at 30 stations and remaining stable at 60 stations. This stability indicates the algorithm's capability to avoid unnecessary handovers by incorporating both RSSI and AP load conditions into its decision-making process. By ensuring that handovers are only initiated when there is a clear benefit in terms of both connectivity quality and AP resource availability, ELAHA enhances session continuity and minimizes disruptions.

The stark difference in handover frequency underscores ELAHA's efficiency in preserving network stability. By significantly reducing the number of handovers, ELAHA not only lowers the operational burden on the network but also improves the end-user experience by reducing delays and packet loss associated with handover processes. These results further support the algorithm's effectiveness in dynamic and high-density wireless environments.

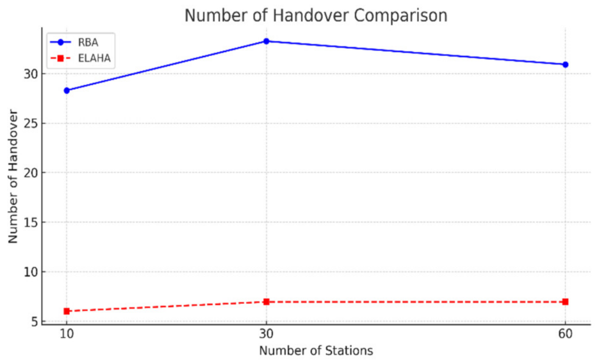

Fig.7: *Average Number of Handover of Stations using RBA and ELAHA.*

4. DISCUSSION

The simulation results clearly illustrate the performance benefits of the proposed ELAHA over the traditional RSSI-based approach. ELAHA's integration of real-time AP load metrics with signal strength measurements enables more informed and balanced handover decisions. This results in substantial reductions in end-to-end delay (up to 2.5 times lower), handover frequency (up to 90% reduction), and packet loss rate (steady at 1.6% compared to RBA's 3.0% at peak density), all of which contribute to maintaining a high Quality of Service (QoS) in dense network environments.

While improvements in jitter and throughput are more modest (4–5% and 1–3%, respectively), the consistency of these gains across all densities reinforces the overall stability and reliability of ELAHA. The algorithm's ability to sustain performance under growing traffic loads and station counts demonstrates its scalability and potential applicability to real-world Wi-Fi networks, including enterprise WLANs, university campuses, and public hotspots.

The reduction in handover frequency is particularly significant, as it minimizes network disruptions and overhead associated with frequent AP transitions. This not only conserves resources but also enhances user experience, especially in applications requiring session persistence. Conversely, RBA's reliance on signal strength alone leads to aggressive and often unnecessary handovers, contributing to network instability and degraded user performance.

Despite these advantages, further investigation is warranted into the computational complexity and resource requirements of ELAHA, particularly in resource-constrained environments such as IoT networks. Future work should also examine the algorithm's performance in heterogeneous networks, its adaptability to user mobility models, and integration with emerging standards like IEEE 802.11ax and 802.11be. Moreover, the inclusion of interference metrics, client energy profiles, and real-world deployment scenarios would provide deeper insights into ELAHA's practical viability and optimization potential.

5. CONCLUSIONS

This study presented the Enhanced Load-Aware Handover Algorithm (ELAHA), a novel implementation of a load-aware handover mechanism designed to address the limitations of conventional RSSI-based strategies in high-density IEEE 802.11 Extended Service Set (ESS) networks. By incorporating both Received Signal Strength Indicator (RSSI) and real-time access point (AP) load metrics into the adaptive weighting function and penalty mechanism, ELAHA enables more optimized and balanced user distribution across available APs.

Simulation results demonstrate that ELAHA significantly outperforms the traditional RSSI-Based Algorithm (RBA) across multiple key performance metrics. Notably, it achieves substantial reductions in end-to-end delay, jitter, packet loss rate, and handover frequency, while maintaining higher throughput levels under increasing network loads. These improvements highlight ELAHA's scalability, stability, and effectiveness in maintaining Quality of Service (QoS) in dense wireless environments.

Importantly, ELAHA is fully compatible with existing IEEE 802.11 network infrastructure and does not require specialized hardware, making it a practical and cost-effective solution for deployment in real-world scenarios such as enterprise campuses, educational institutions, and public venues with dynamic user densities.

Future work will focus on validating ELAHA in real-world testbed environments to evaluate its robustness under dynamic network conditions. Additionally, integrating supplementary metrics such as channel quality, traffic type, and user mobility, as well as exploring machine learning-based optimization of weighting factors, may further enhance the algorithm's adaptability and overall effectiveness in next-generation wireless networks.

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AUTHOR CONTRIBUTIONS

Conceptualization, Derrick Qin Sheng Wong and Chong Eng Tan; methodology, Derrick Qin Sheng Wong and Chong Eng Tan; software, Derrick Qin Sheng Wong; validation, Derrick Qin Sheng Wong and Chong Eng Tan; formal analysis, Derrick Qin Sheng Wong; investigation, Derrick Qin Sheng Wong and Chong Eng Tan; data curation, Derrick Qin Sheng Wong; writing—original draft preparation, Derrick Qin Sheng Wong and Chong Eng Tan; writing—review and editing, Derrick Qin Sheng Wong and Chong Eng Tan; visualization, Derrick Qin Sheng Wong; supervision, Chong Eng Tan; funding acquisition, Chong Eng Tan. All authors have read and agreed to the published version of the manuscript.

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Derrick Qin Sheng Wong was born in Sarawak, Malaysia, in 1996. He received the B. Computer Science degree in Network Computing from University Technology Sarawak (UTS), Malaysia, in 2019. He currently pursuing the master's degree at University Malaysia Sarawak. His research interest includes Wi-Fi technology enhancement, Handover Mechanism improvement. He can be contacted at email: 20020353@siswa.unimas.my.

Chong Eng Tan is a professor at University Malaysia Sarawak (UNIMAS). He has been a faculty member at the Faculty of Computer Science and Information Technology (FCSIT) at University Malaysia Sarawak (UNIMAS) since 1999. He earned his Ph.D. from the University of Cambridge in 2004, specialising in wireless network and broadband access technology. With more than 25 years of expertise in wireless and network research, he has committed his endeavours to devising, innovating, and implementing solutions for rural Information and Communication Technology (ICT) development. In 2010, he successfully implemented the inaugural long-range wireless system in Bario and assumed the role of chief ICT architect for the TPOA Telecentre across four remote Orang Asli sites in West Malaysia. His notable research accomplishments encompass the Virtual Telecentre concept, power self-sufficient ICT design, and modular solar power system. As a distinguished senior member of the Institute of Electrical and Electronics Engineers (IEEE), he actively engages with leading professional organisations, staying abreast of the latest developments in his field. He presently serves as the director of the Institute of Social Informatics and Technological Innovations (ISITI) at UNIMAS, concurrently leading the 5G & Connectivity Keylab under the auspices of the Sarawak Digital Economy Corporation (SDEC). He can be contacted at email: cetan@unimas.my.