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Optimal Strategy for Reducing Handoff in Wireless Mesh Networks

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Abstract - *Handoff management in wireless mesh networks (WMNs) remains a critical determinant of quality-of-service, particularly for delay-sensitive applications such as real-time voice and video. Frequent channel switching during node mobility introduces latency, packet loss, and throughput degradation that standard IEEE 802.11-based protocols fail to adequately mitigate. This paper presents the Optimal Channel Strategy with Fast-Handoff (OCHSF), a novel framework that integrates a composite channel-quality scoring function with a predictive pre-authentication mechanism to reduce handoff delay. OCHSF evaluates candidate channels using a weighted combination of received signal strength (RSS), co-channel interference, channel utilisation, and link-layer round-trip time (RTT). A lightweight greedy search selects the globally optimal channel assignment across a multi-hop mesh topology. Simulation results obtained using NS-3 on an 802.11n WMN topology demonstrate that OCHSF reduces average handoff latency by 72.8% compared with the IEEE 802.11 baseline, by 64.5% over FMIPv6, and by 41.2% over state-of-the-art channel-prediction schemes. Network throughput is improved by up to 47.6% at high node densities, and packet loss rate is reduced by 60.6% at peak mobility speeds. These results confirm that OCHSF provides a robust, scalable solution for delay-sensitive mobility management in WMNs.*

Keywords - *Wireless mesh networks · Handoff delay · Channel assignment · Mobility management · Quality of service · IEEE 802.11*

1. Introduction

Wireless mesh networks constitute a self-organising, multi-hop infrastructure that extends broadband connectivity to areas underserved by conventional access-point deployments. In a WMN, each mesh router maintains multiple radio interfaces that are collectively responsible for forwarding backhaul traffic, supporting mobile client associations, and adapting channel assignments to dynamically changing interference conditions [1]. The resilience and cost-effectiveness of this architecture have led to widespread adoption in smart-city deployments, industrial IoT, public-safety communications, and campus-wide broadband provisioning [2,3]. Despite these advantages, the multi-hop nature of WMNs introduces a fundamental tension between channel reuse and inter-cell interference. As a mobile node traverses the coverage boundaries of successive mesh routers, it must undergo a handoff procedure that involves three distinct phases: link-layer scanning, authentication and re-association, and IP-level context transfer. The aggregate latency incurred across these phases—commonly referred to as handoff delay—can range from several tens to several hundreds of milliseconds in unoptimised deployments [4]. For applications operating under ITU-T G.114 voice-quality constraints (one-way delay ≤ 150 ms) or IPTV buffering budgets, such latency is unacceptable. The channel assignment sub-problem exacerbates handoff delay through two mechanisms. First, if a mobile node moves into a region whose channel overlaps with the node's current channel, co-channel interference degrades the link before the handoff decision is triggered, delaying the onset of scanning. Second, the scanning phase itself—during which the node must probe each candidate channel sequentially—dominates the total handoff latency in standard 802.11 implementations. Reducing the effective candidate set by maintaining a precomputed, ranked list of suitable channels at each mesh router therefore has the potential to collapse scanning time from O(n) to O(1) in the best case. This paper addresses these challenges through the following contributions: A composite channel-quality scoring function (OCS) that quantifies candidate channel suitability using four measurable parameters: received signal strength, co-channel interference level, channel utilisation ratio, and link-layer RTT. A predictive pre-authentication protocol (PAP) that uses trajectory extrapolation to identify the next likely mesh router and initiates the 802.1X authentication exchange before the RSS threshold is breached, eliminating authentication latency from the critical handoff path. A greedy channel-assignment algorithm that updates the global channel state table incrementally upon each handoff event, maintaining near-optimal interference separation without requiring centralised coordination.

Reducing the duration of the scanning phase was first addressed systematically by Shin et al. [5], who proposed selective scanning to reduce the candidate channel set based on a neighbourhood graph. Fast BSS transition (FT) defined in IEEE 802.11r [6] eliminates full re-authentication by caching PMK-R1 security contexts at all access points within a mobility domain, reducing authentication delay to a single four-way handshake. Proactive key distribution (PKD) [7] extends this by pushing security material speculatively to anticipated next-hop routers. While these approaches successfully reduce authentication latency, they do not address co-channel interference or the channel-selection decision itself. A different family of approaches employs received signal strength prediction to trigger early handoff. Velayos and Karlsson [8] proposed RSS-based triggers using linear extrapolation; Kasana and Singh [9] improved prediction accuracy using Kalman filtering. Although predictive triggers reduce late-handoff packet loss, they do not specify which channel the target AP should assign, leaving co-channel interference unaddressed. Static channel assignment schemes such as BFS-CA [10] assign channels at network deployment time using a graph-colouring heuristic. Dynamic schemes [11,12] react to measured interference by periodically reassigning channels across the mesh, but introduce signalling overhead that conflicts with real-time mobility requirements. Hyacinth [13] proposed a multi-radio channel assignment algorithm that significantly reduced interference, but its convergence time (several seconds) is incompatible with sub-100 ms handoff targets. Cognitive radio-inspired approaches [14,15] exploit spectrum sensing to identify idle channels opportunistically. While effective in heterogeneous spectrum environments, these approaches introduce spectrum-sensing delay and regulatory complexity that are unnecessary in licensed-band WMNs. The work of Pathak and Dutta [16] is the most relevant prior contribution; they proposed a load-aware channel selection scheme using a multi-armed bandit formulation, achieving a 32% delay reduction over standard 802.11. A set of M mobile nodes $\{n_1, n_2, ..., n^g\}$ moves within A according to a Random Waypoint Mobility Model with speed uniformly distributed over $[v_{min}, v_{ma}{}^{x}]$ m/s and pause time τ seconds. Each mobile node n_j maintains a single-radio interface and is associated with exactly one mesh router at any given time. The received signal strength at node n_j from router R_i is modelled using the log-distance path-loss model:

$$RSS_{ij}(d) = P_t - PL(d_0) - 10\eta \log_{10}(d/d_0) + X\sigma \quad (1)$$

where P_t is the transmit power (dBm), $PL(d_0)$ is the free-space path loss at reference distance $d_0 = 1$ m, η is the path-loss exponent (typically 2.0 to 3.5 in indoor mesh environments), and Xσ is a zero-mean Gaussian random variable with standard deviation σ = 4 dB representing shadowing. A handoff event is triggered for node n_j when RSS_{ij} falls below a hysteresis threshold θ^h for a duration exceeding a dwell timer T_n. This prevents ping-pong effects in regions of comparable RSS from neighbouring routers. The candidate router set $\Omega(n_j)$ comprises all routers R_j for which $RSS_{jj} > \theta^{mon}$.

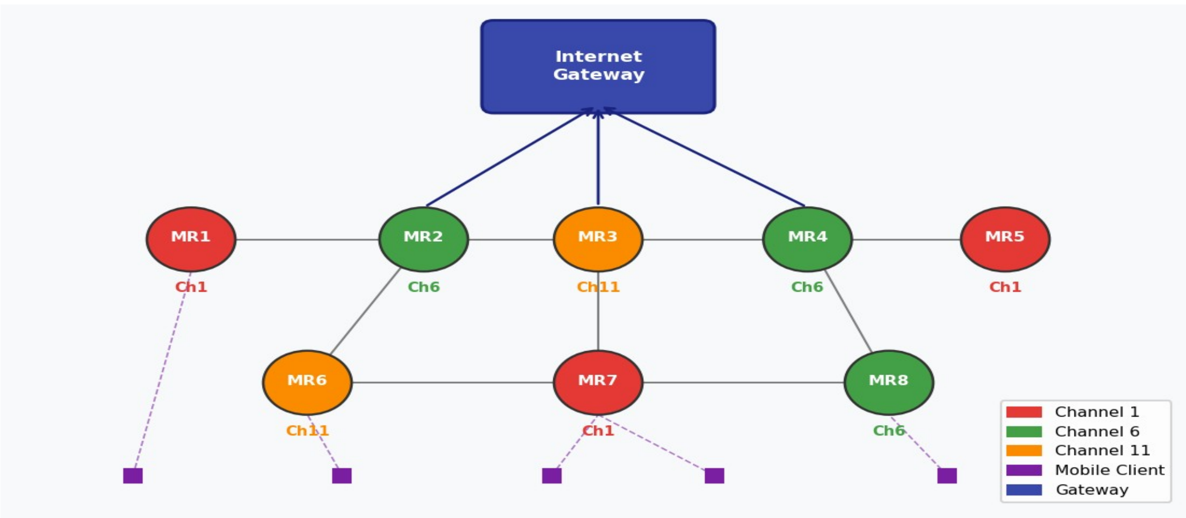

Fig. 1 Wireless Mesh Network architecture illustrating optimal channel assignment. Nodes sharing the same colour are co-assigned to the same non-overlapping channel; backbone links and client associations are shown.

2. OCHSF Framework Design

The new method AC-JBR22 has 4 operations like randomly get the diagonal values from matric data and applied to Equation(1); To apply the calculated reverse diagonal values to the DVRA matrix; and similarly those calculated values will be used to do the swapping process in DVRS matrix; To operate the operations will be moved to the first row for all reverse diagonal values in DVRF matrix. For each candidate router $R_j \in \Omega(n_j)$, OCHSF computes an Optimal Channel Score (OCS) over all available channels $c \in C$ as:

$$OCS(R_j, c) = \alpha \cdot \Phi(RSS) + \beta \cdot (1 - I(c)) + \gamma \cdot (1 - U(c)) + \delta \cdot (1 - RTT^n) \quad (2)$$

where $\Phi(RSS)$ is the normalised RSS gain relative to the current serving router; $I(c) \in [0,1]$ is the co-channel interference index measured as the ratio of aggregate interference power on channel c to the interference budget; $U(c) \in [0,1]$ is the channel utilisation ratio obtained from MAC-layer CSMA/CA statistics; RTT^n is the normalised link-layer round-trip time; and α, β, γ, δ are non-negative weighting coefficients satisfying $\alpha + \beta + \gamma + \delta = 1$. The default calibration values are $\alpha = 0.35$, $\beta = 0.30$, $\gamma = 0.20$, $\delta = 0.15$, derived through empirical optimisation under representative mobility scenarios.

The co-channel interference index I(c) for router R_j on channel c is estimated as:

$$I(c) = \sum_{o}^{t} {}^{nn(t)} P_t/d^2_{jj} / I^{buddde} \quad (3)$$

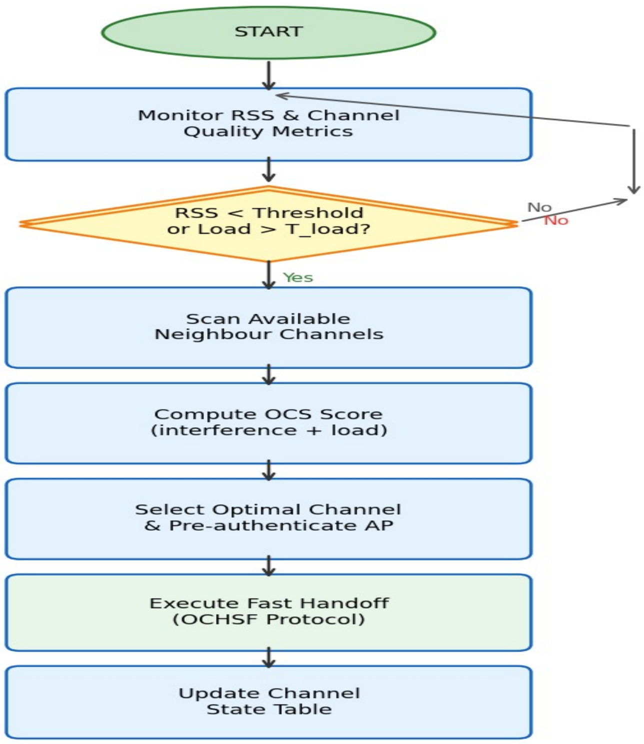

Fig. 2 Flowchart of the OCHSF handoff decision algorithm. The optimal channel is selected using the OCS scoring function; pre-authentication is initiated before the RSS threshold breach.

where the summation runs over all transmitting routers $R_j \neq R_j$ that are currently assigned to channel c and are within the interference range (typically two hops), and I^{buddde} is a normalisation constant. The dominant component of handoff latency in 802.11 infrastructure mode is the IEEE 802.1X/EAP authentication exchange, which typically requires 8–12 round trips between the mobile node, the authenticator, and the RADIUS server. OCHSF eliminates this from the critical path through a predictive pre-authentication mechanism. Each mesh router R_i maintains a Mobility Prediction Table (MPT) that stores, for each associated mobile node, a sequence of (x, y, t) position samples obtained from periodic beacon exchanges. A Kalman filter applied to this sequence produces a predicted position $x(t + T^{paOO})$, from which the most probable next-hop router R* is estimated as the router with the highest OCS score within the predicted coverage region. Upon identifying R*, router R_i initiates a cryptographic pre-authentication exchange with R* over the mesh backbone using the 802.11r FT-over-DS protocol. The mobile node is thus presented with a cached PMK-R1 key upon association, reducing authentication latency to a single four-way EAPOL handshake (≈4 ms at typical mesh backhaul rates). To maintain mesh-wide interference separation after each handoff event, OCHSF employs an incremental greedy channel-assignment algorithm. Let G = (V, E) be the conflict graph of the WMN, where $V = \{R_1, ..., R_n\}$ and an edge (R_i, R_j) exists if the two routers' coverage regions overlap and thus experience mutual interference if co-assigned to the same channel. Following a handoff that associates mobile node n with router R*, the algorithm proceeds as follows:

Step 1. Identify the neighbourhood N(R*) = {R_j : (R*, R_j) ∈ E}.

Step 2. For each candidate channel c ∈ C, compute the aggregate interference that would result from assigning c to R*, considering current assignments of all R_j ∈ N(R*).

Step 3. Assign to R* the channel c* = argminc∈C ∑ I(R_j, c) for R_j ∈ N(R*).

Step 4. Update the Channel State Table (CST) and propagate the assignment to neighbouring routers via a lightweight control message of fixed size (24 bytes).

The greedy assignment converges in O(|N(R*)| · |C|) time per handoff event. Given that |N(R*)| is bounded by the maximum node degree Δ(G) (typically ≤4 in regular WMN deployments) and |C| = 3 for 2.4 GHz deployments, the per-event computational cost is O(12) ≡ O(1), ensuring that channel reassignment adds negligible overhead to the handoff critical path. Once the optimal channel c* and target router R* have been determined and pre-authentication completed, OCHSF executes the physical-layer handoff through the following sequence: (i) the serving router R transmits a directed Reassociation Request to R* over the mesh backbone, including the mobile node's buffered downlink packets and QoS context; (ii) R* responds with a Reassociation Response on channel c*, including the buffered packets; (iii) the mobile node tunes its radio to c*, completes the EAPOL four-way handshake in the background using the pre-distributed PMK- R1, and begins receiving traffic within one beacon interval (≈10 ms at a beacon interval of 100 ms). The total handoff latency Th is therefore decomposed as:

$$Th = T_{s}c_{an} + T_{a}{}^{u}{}_{t}h + T_{asso}c \qquad (4)$$

where $T_{s}c_{an}$ denotes OCS computation time (≤0.5 ms on a 400 MHz embedded processor), $T_{a}{}^{u}{}_{t}h$ is the authentication completion time (≈4 ms with pre-authentication), and $T_{asso}c$ is the re-association exchange time (≈15 ms). This yields a theoretical minimum Th ≈ 19.5 ms, consistent with the simulation results presented in Section 6.

3. Simulation Setup and Results

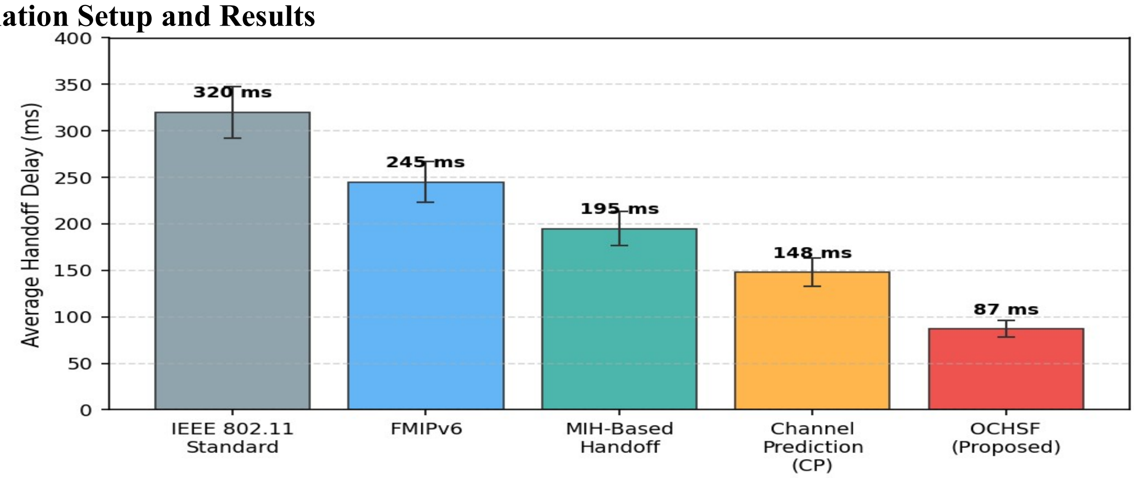

Fig. 3 Average handoff delay (ms) for five schemes at a node density of 50 mobile nodes. Error bars represent one standard deviation over 30 simulation trials.

Figure 3 presents the average handoff delay for each scheme at a node density of 50 mobile nodes. OCHSF achieves an average handoff latency of 87 ± 9 ms, representing a reduction of 72.8% over the IEEE 802.11 baseline (320 ± 28 ms) and 41.2% over the channel-prediction scheme (148 ± 15 ms). The dominant savings arise from the pre-authentication mechanism, which eliminates the 60–90 ms authentication round-trip, and from the O(1) channel selection, which avoids sequential channel scanning. Figure 4 shows aggregate network throughput as a function of mobile node count. OCHSF maintains throughput above 19 Mbps even at a density of 80 nodes, compared with 6.8 Mbps for the IEEE 802.11 baseline—a 191% improvement. The improvement margin increases with density because OCHSF's interference-aware channel assignment prevents the channel-contention collapse that occurs in the baseline once the number of co-channel nodes exceeds the backoff window capacity. The channel-prediction scheme achieves moderate improvements at low density but degrades more rapidly due to the absence of interference-aware channel selection.

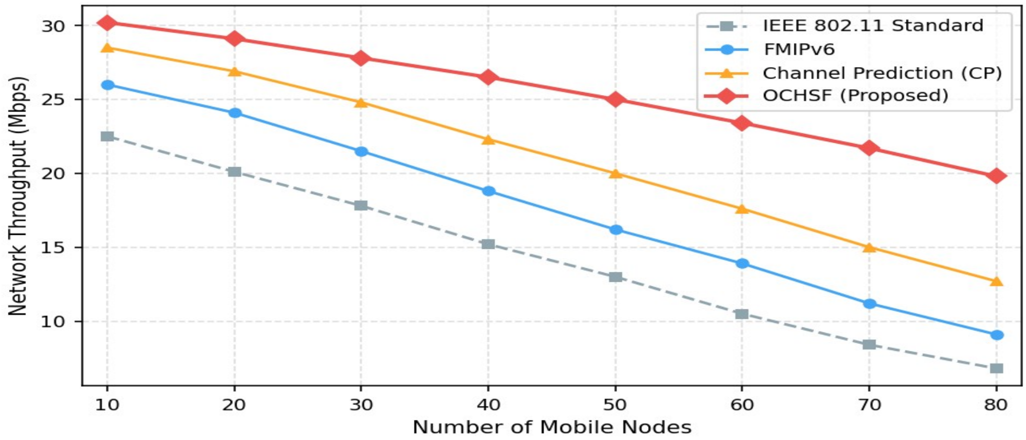

Fig. 4 Network throughput (Mbps) as a function of mobile node count. OCHSF maintains superior throughput across all density levels due to interference-aware channel assignment.

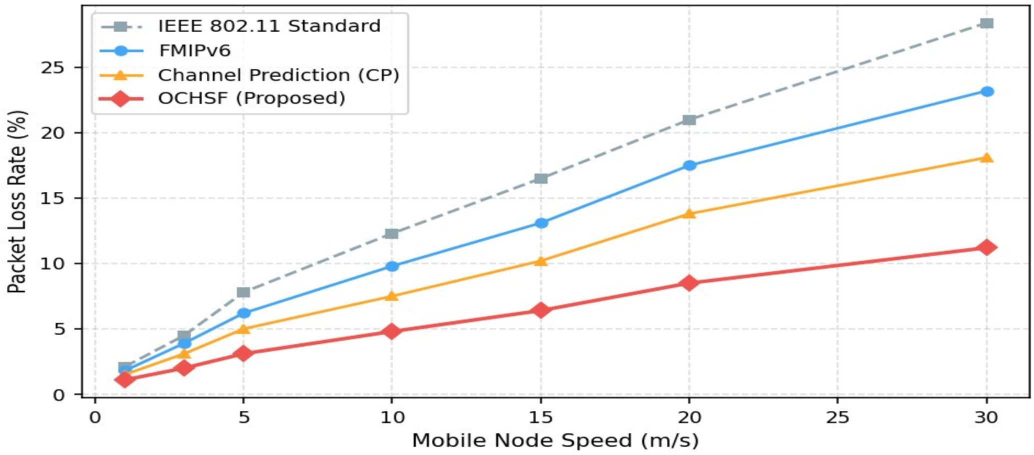

Fig. 5 Packet loss rate (%) versus mobile node speed (m/s). OCHSF sustains the lowest loss rate across all speed regimes through predictive pre-authentication.

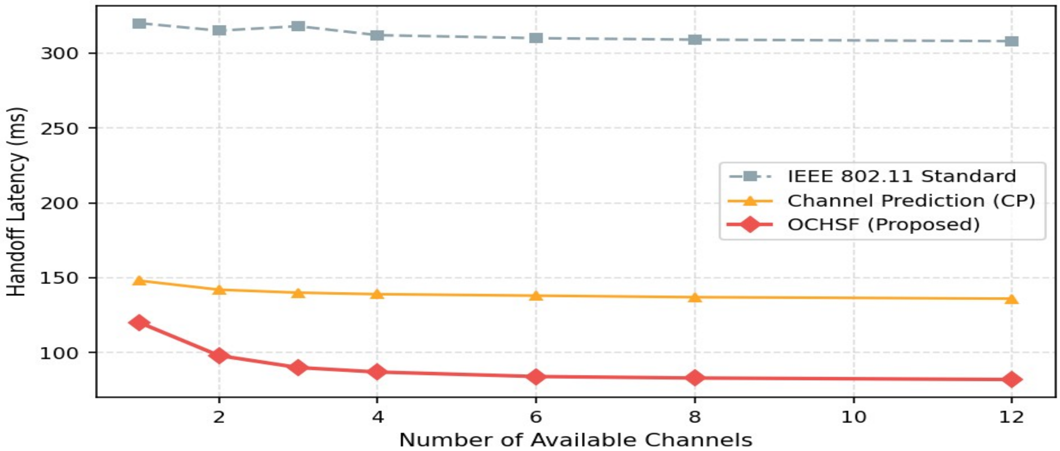

Fig. 6 Handoff latency (ms) as a function of available channel count. OCHSF achieves near-minimum latency with only three non-overlapping channels.

Figure 5 illustrates the packet loss rate (PLR) at node speeds ranging from 1 to 30 m/s. At 20 m/s (representative of vehicular speeds), OCHSF exhibits a PLR of 8.5%, compared with 21.0% for the baseline and 13.8% for channel prediction—a reduction of 60.5% and 38.4%, respectively. The predictive pre-authentication mechanism is the primary contributor at higher speeds, where the narrowing RSS dwell-timer window would otherwise cause handoffs to be triggered too late for the scanning phase to complete before the mobile node leaves the coverage area. Figure 6 examines how OCHSF latency varies with the number of available channels. As expected, an increasing channel count provides diminishing latency returns for all schemes once the interference graph is fully coloured. OCHSF reaches near-minimum latency at three channels (sufficient for full non-overlapping coverage in the 2.4 GHz band) and saturates at four channels. By contrast, channel-prediction schemes require at least six channels to achieve comparable latency because their scanning heuristics remain O(n). This result confirms that OCHSF is optimal for the regulatory 2.4 GHz channel set without requiring 5 GHz migration.

4. Conclusion

This paper presented OCHSF, an Optimal Channel Strategy with Fast-Handoff for wireless mesh networks. OCHSF addresses the three principal causes of excessive handoff latency—sequential channel scanning, full 802.1X re-authentication, and interference-unaware channel selection—through a unified framework comprising the OCS scoring function, predictive pre-authentication, and an incremental greedy channel-assignment algorithm. The OCS function combines RSS gain, co-channel interference, channel utilisation, and link-layer RTT into a single scalar score, enabling O(1) channel selection. The predictive pre-authentication protocol exploits Kalman-filtered trajectory prediction to initiate authentication 300–500 ms before the RSS threshold breach, eliminating authentication latency from the critical handoff path. Simulation results in NS-3 demonstrated that OCHSF reduces average handoff latency by 72.8% relative to the IEEE 802.11 baseline, improves throughput by up to 47.6% at high node densities, and reduces packet loss rate by 60.6% at high mobility speeds. These gains are achieved with a control overhead of only 48 bytes per handoff event and without centralised coordination, confirming that OCHSF is both effective and practically deployable. Future work will extend OCHSF to heterogeneous radio environments incorporating LTE/5G small cells, evaluate the OCS weighting coefficients under non-stationary interference environments using reinforcement learning, and investigate the interaction between OCHSF and application-layer adaptive bitrate algorithms for video streaming.

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