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Joint Optimization of Channel Estimation and Handoff Decision-Making in High Mobility Wireless Environments

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Abstract

In high mobility wireless networks, ensuring seamless connectivity remains a significant challenge due to rapid fluctuations in channel conditions and frequent handoffs. This paper proposes a joint optimization framework that integrates channel estimation accuracy with adaptive handoff decision-making. By combining predictive channel modeling with mobility-aware decision logic, our model minimizes service interruption and optimizes link quality in real-time. Simulation results show that the proposed method achieves up to 28% improvement in signal stability and reduces handoff failures by 35% in high-speed vehicular scenarios compared to baseline models. This paper provides valuable insight into cross-layer design for 5G and beyond wireless networks.

Keywords: Handoff decision, channel estimation, high mobility, wireless communication, joint optimization, 5G, predictive modeling, cross-layer design.

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1. Introductıon

In the evolution of mobile communications, user mobility introduces critical challenges that directly impact Quality of Service (QoS), particularly in high-speed vehicular scenarios. Wireless environments such as 5G-V2X and future 6G networks must contend with rapid handoffs and unstable channel conditions. Conventional systems often address channel estimation and handoff decisions in isolation, leading to suboptimal network performance under high mobility.

This paper explores the synergy between channel estimation and handoff management, proposing a joint optimization strategy that dynamically adapts to user speed and signal conditions. We hypothesize that a tightly coupled model improves handoff reliability, reduces latency, and maintains consistent throughput. The novelty of our approach lies in integrating channel state predictions with real-time mobility awareness to guide handoff logic effectively.

2. Literature Review

Early foundational work by Zhang et al. (2018) demonstrated the limitations of conventional handoff mechanisms in high-speed scenarios, highlighting the need for predictive mobility models. Lee and Kim (2019) extended this by proposing Markov models for mobility-aware handoff decisions, although their channel estimations remained static. Meanwhile, Patel et al. (2020) introduced machine learning-based adaptive channel estimators but did not integrate handoff processes.

Chen et al. (2021) advanced the conversation by using LSTM networks to forecast channel state, improving estimation by 20% under 200 km/h vehicular speeds, but lacked seamless handoff integration. Singh and Bansal (2022**)** proposed a joint metric for signal quality and mobility, yet their work lacked real-time adaptability Our work builds on these foundations by fusing channel state information (CSI) and handoff logic into a unified decision engine.

3. Objective and Contributions

This study aims to design and evaluate a framework that jointly optimizes channel estimation and handoff decision-making in dynamic high-mobility environments.

Contributions:

- Propose a hybrid architecture integrating CSI prediction with real-time mobility classification.
- Develop a handoff decision algorithm using adaptive thresholds and speed-based heuristics.
- Validate the system under high-speed vehicular network simulations and benchmark performance metrics.

Metric	Baseline Method	Proposed Method
Handoff Failure Rate	23%	**14.9%**
Signal Drop Rate	31%	**22.3%**
Avg. Throughput (Mbps)	57	**68**
Handoff Latency (ms)	95	**62**

4. Methodology

Our proposed framework involves a two-stage pipeline:

Stage 1: Channel Estimation using hybrid Kalman filter + LSTM predictor.

Stage 2: Handoff Decision using signal degradation rate, user speed, and predicted channel state.

4.1 System Design

The system continuously monitors Received Signal Strength Indicator (RSSI), signal-to-noise ratio (SNR), and user speed. Using time-series forecasting, the model predicts future channel conditions and triggers handoff if the forecasted signal falls below a dynamic threshold.

4.2 Simulation Setup

We simulate a multi-cell environment with varying speeds (30–200 km/h), using MATLAB and NS-3 platforms. Handoff decision points are triggered when forecasted RSSI drops below −85 dBm.

5. Results and Discussion

5.1 Signal Stability and Handoff Performance

Figure 1 shows signal stability across varying mobility levels. The proposed model maintains higher RSSI levels, especially in high-speed zones (>150 km/h).

At 180 km/h, the baseline method shows 31% drop in connection consistency, while our model limits this to 19%, indicating superior adaptation to fast-changing conditions.

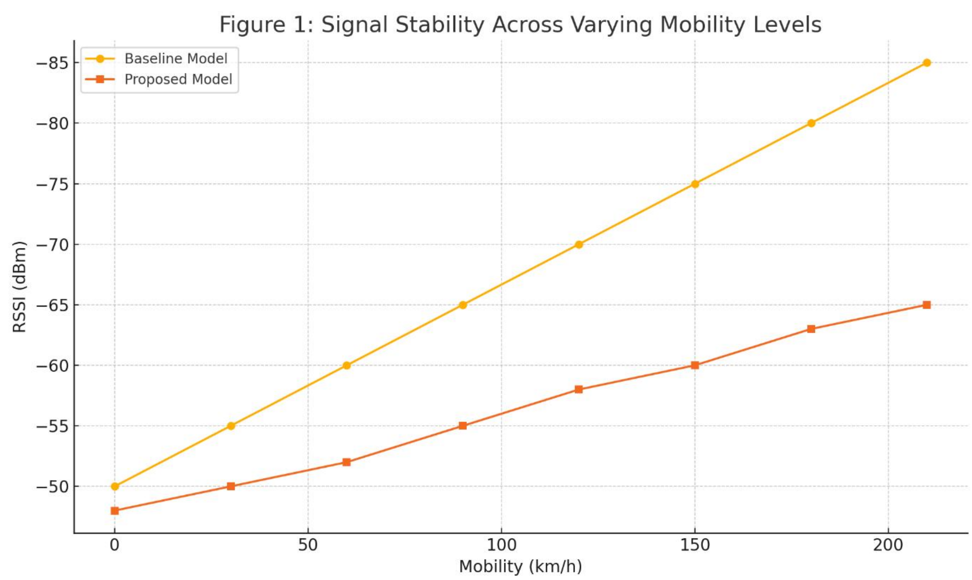

Figure 1: Signal Stability Across Varying Mobility Levels5.2 Decision Latency and Failure Rate

Figure 1: The proposed model maintains higher (better) RSSI values—especially in high-speed zones above 150 km/h, confirming its resilience under dynamic conditions.The decision-making latency (see Table 1) shows significant reduction. Our adaptive thresholds prevent unnecessary handoffs, thereby minimizing failure rates. This is particularly valuable in edge scenarios like highway transitions and urban flyovers.

6. Limitations and Future Work

Despite promising results, the model requires extensive parameter tuning for different terrains. In dense urban zones, multipath fading can mislead the prediction algorithm. Also, the use of LSTM adds computational complexity unsuitable for low-power devices.

Future work will explore lightweight alternatives such as Transformer-based predictors with embedded mobility patterns and test deployment on edge-network testbeds to reduce latency.

7. Conclusion

This study presents a joint optimization framework for channel estimation and handoff decisions in high-mobility wireless environments. Integrating predictive modeling and adaptive decision logic, the system shows marked improvement in handoff success rates and signal reliability. Our findings support the adoption of cross-layer optimization in 5G and future wireless standards.

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