Chapter 5: Conclusion and Future Work

5.1 Summary of the Study

This project addressed the persistent challenge of optimizing video streaming performance over inherently variable mobile networks, with a specific focus on mitigating the negative impacts of network latency often overlooked by traditional Adaptive Bitrate (ABR) algorithms. High latency, manifesting as startup delays and playback stalls (buffering), significantly degrades the Quality of Experience (QoE) for end-users. The primary objective was to design, implement, and evaluate a latency-aware ABR algorithm capable of improving viewing stability compared to conventional buffer-based approaches.

To achieve this, a mixed-methods approach, outlined in Chapter 3, was partially implemented. A simulation framework was developed to evaluate ABR performance. This framework utilized real-world mobile network *bandwidth* traces from the HSDPA dataset to capture realistic bandwidth variability across diverse scenarios (bus, metro, train, car, ferry). Crucially, as the chosen dataset lacked network Round-Trip Time (RTT) data, fluctuating *synthetic network delay* traces were generated and used alongside the real bandwidth data. This allowed for testing the core principle of incorporating delay awareness into the ABR decision process. Two algorithms were compared: a baseline Buffer-Based (BB) ABR and the proposed Latency-Aware (LA) ABR, which uses simple prediction models for throughput and delay and explicitly factors estimated RTT into its bitrate selection logic. Performance was assessed using key metrics including startup delay, buffering ratio, average bitrate, quality switch frequency, and a simplified QoE score.

5.2 Summary of Key Findings

The simulation results, presented and discussed in Chapter 4, yielded several key findings regarding the comparative performance of the Latency-Aware and Buffer-Based ABR algorithms under the tested conditions (real HSDPA bandwidth + synthetic fluctuating delay):

1. **Reduced Buffering:** The Latency-Aware (LA) algorithm demonstrated a substantial reduction in playback stalls, achieving an average buffering ratio approximately 60% lower than the Buffer-Based (BB) algorithm across the tested traces (13.8% vs 33.3%). This indicates a significantly more stable and continuous viewing experience.
2. **Improved Quality Stability:** The LA algorithm exhibited vastly superior stability in bitrate selection, resulting in far fewer quality switches compared to the BB algorithm (average of 16 vs 114 switches per run). This contributes to a less visually jarring experience for the user.
3. **Lower Average Bitrate:** The improved stability of the LA algorithm came at the cost of a lower average delivered bitrate (826 kbps vs 2509 kbps for BB). The LA algorithm's

tendency to be more conservative, accounting for potential download delays caused by RTT, prevented it from consistently selecting the highest possible qualities available during periods of high bandwidth.

4. **Enhanced Estimated QoE:** Despite the lower average bitrate, the LA algorithm achieved a significantly better score on the simplified QoE metric (-14.3 vs -50.7). This suggests that, within this model, the penalties associated with frequent stalls and quality switches outweighed the benefit of the higher average bitrate achieved by the BB algorithm.
5. **Confirmation of Latency Impact:** The marked difference in stability between the LA (delay-aware) and BB (delay-agnostic) algorithms, even with synthetic delay, strongly supports the hypothesis that failing to account for network RTT significantly contributes to the instability of traditional ABR approaches in variable networks.

5.3 Contributions of the Study

This research makes the following contributions to the field of mobile video streaming optimization:

1. **Demonstration of Latency-Aware Benefits:** It provides simulation-based evidence demonstrating the feasibility and significant stability advantages (reduced buffering, fewer quality switches) of an ABR algorithm that explicitly incorporates network delay estimations into its decision-making process.
2. **Quantification under Semi-Realistic Conditions:** By utilizing real-world bandwidth traces combined with controlled synthetic delay, the study offers a quantitative comparison of latency-aware versus buffer-based strategies under conditions that reflect genuine mobile bandwidth variability, going beyond purely synthetic network models.
3. **Highlighting the Stability-Quality Trade-off:** The results clearly quantify the inherent trade-off between maximizing average bitrate and ensuring playback stability, providing data points that inform the design of ABR algorithms aiming for optimal QoE.
4. **Adaptable Simulation Framework:** The developed simulation code provides a flexible framework that can be extended to test more sophisticated ABR algorithms, incorporate different network traces (including potentially complete traces with real delay), and model additional network phenomena.

5.4 Limitations of the Study

It is essential to acknowledge the limitations of this study, which temper the generalizability of the findings:

1. **Synthetic Network Delay (Primary Limitation):** The inability to use real, synchronized RTT delay data alongside the real bandwidth data is the most significant limitation. The synthetic delay model, while incorporating fluctuations, cannot capture the true complex patterns, distributions, or potential correlations between real-world bandwidth and delay.

The quantitative results are therefore dependent on the realism of this synthetic component.

2. **Dataset Characteristics:** The HSDPA bandwidth traces used are relatively old (2010-2011) and represent 3G network technology. Modern 4G/LTE and 5G networks exhibit different characteristics, and the algorithms' performance might differ significantly on contemporary networks.
3. **Excluded Network Factors:** The simulation did not model the impact of packet loss or network jitter, both of which can significantly affect download times and QoE in real mobile networks.
4. **Simplified ABR Algorithms:** The implemented LA algorithm uses basic prediction (Simple Moving Average). More advanced predictive models (e.g., ML-based) might yield different performance. Similarly, the BB algorithm is a simplified representation.
5. **Simplified QoE Model:** The composite QoE score is illustrative. Accurate QoE assessment requires subjective user testing to capture the complex human perception of video quality, stalls, and switches.
6. **Simulation Fidelity:** No simulation can perfectly capture all aspects of real-world systems, including intricate TCP dynamics, client device processing limitations, or exact handover behaviors.

5.5 Recommendations for Future Work

Based on the findings and limitations of this study, the following directions for future research are recommended:

1. **Utilize Comprehensive Network Traces:** The highest priority is to acquire and utilize datasets containing synchronized, real-world measurements of **bandwidth, RTT delay, packet loss, and jitter** for contemporary mobile networks (4G/5G). Re-evaluating the LA algorithm using such comprehensive data is crucial for robust validation.
2. **Enhance Prediction Models:** Integrate and evaluate more sophisticated bandwidth and delay prediction techniques within the LA ABR framework, potentially employing machine learning models (LSTMs, etc.) as suggested in the methodology (Sec 3.3.2), to improve accuracy and adaptation performance.
3. **Incorporate Packet Loss and Jitter:** Extend the simulation model to include realistic models for packet loss and jitter and modify the ABR algorithms (particularly download time estimation) to account for their impact.
4. **Conduct Subjective QoE Studies:** Perform user studies comparing the LA and BB algorithms under various network conditions (potentially emulated based on real traces) to obtain subjective Mean Opinion Scores (MOS) and validate the findings regarding user-perceived quality and the stability/quality trade-off.
5. **Investigate Algorithm Parameter Tuning:** Explore methods for dynamically tuning the parameters of the LA algorithm (e.g., prediction window size, safety factor, conservatism threshold) based on network conditions or user preferences.
6. **Expand to VR/360 and Heterogeneity:** Adapt the latency-aware framework to address the unique requirements of VR/360 streaming (ultra-low latency needs, viewport

prediction, tile-based streaming – Sec 1.2, 2.4.4, 3.3.2) and consider device heterogeneity (Sec 2.4.3).

7. **Prototype Implementation and Testing:** Implement the LA algorithm in a real video player prototype (e.g., using DASH.js or a custom player) and test its performance on actual mobile devices over live networks.

5.6 Concluding Remarks

This project successfully demonstrated, through simulation using real bandwidth traces, that incorporating awareness of network RTT delay into ABR decision-making can significantly enhance the stability of mobile video streaming compared to traditional buffer-based methods. While the proposed Latency-Aware algorithm resulted in a lower average bitrate, its substantial reduction in playback stalls and quality switches led to a superior estimated Quality of Experience. The findings underscore the critical role of network delay in mobile streaming performance and highlight the limitations of ABR strategies that primarily focus on bandwidth occupancy. Although constrained by the use of synthetic delay data, this study provides strong motivation for developing and validating more sophisticated latency-aware adaptation techniques using comprehensive real-world network data. Addressing network latency proactively, rather than reactively through buffer management alone, holds significant promise for delivering the seamless, high-quality viewing experiences demanded by users in the challenging mobile environment.