Master Thesis

Online Reinforcement Learning-Based Data Rate Prediction for Reliable Teleoperation

Future autonomous applications promise significant gains in efficiency and safety. But even in its most developed form, rare cases exist where human operators need to take over. In this case, teleoperation is an important fallback. A human operator in a remote location can take over the control of the vehicle based on video streams from the vehicle transmitted via mobile networks. However, this application has demanding data rate and latency requirements [1], which need to be fulfilled all the time for safe operation. In the event of insufficient communication resources, the teleoperation must be stopped and the vehicle needs to be brought to a safe state.

Especially due to the highly fluctuating channel conditions at high velocities and the competition with other users, predicting the available link capacity is challenging. Nevertheless, predicting the available data rate is crucial to proactively adjust the video bitrate accordingly. Furthermore, accurate predictions of multiple mobile network links can be used to select the link with the highest available data rate, thereby increasing the overall reliability. This is showcased in [2], where we demonstrated the application of RISE, a system to proactively adapt bitrates in 5G networks in combination with multi-link communication. In [2], the data rate was determined using analytical methods, why partly rely on configuring parameters, thereby potentially restricting its usability.

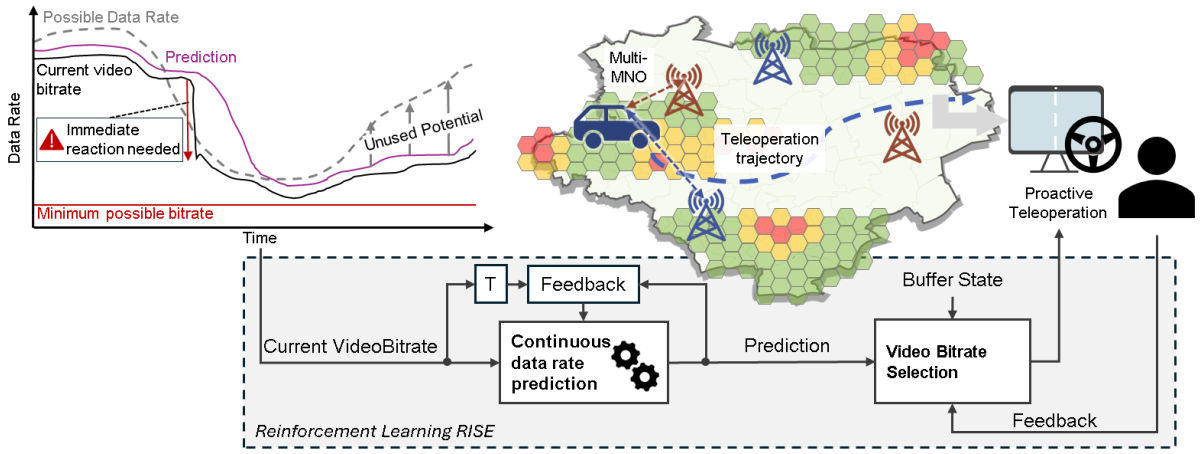

Figure 1: Proactive video bitrate adaption for reliable tele-operated driving based on continuous data rate predictions

These restrictions are commonly overcome by utilizing machine-learning-based predictions. For data rate predictions, some state-of-the-art methods rely on passive indicators to predict the data rate [3]. Other related work propose time series prediction with precisely measured ground truth values. During teleoperating, both passive indicators and the history of the achieved video bitrate can be utilized, giving the possibility to increase the accuracy of the data rate predictions. To adapt deviating predictions, Reinforcement Learning can be utilized. However, during live teleoperation, the prediction can only be partly validated. Only if the prediction is too high, can immediate feedback be acquired, as shown in Figure 1. If the predicted data rate is lower than the maximum possible data rate, the video feed can still be transmitted successfully, but the quality could be improved, if a higher bitrate had been used. Assessing if and how much headroom is left is non-trivial, making the reinforcement learning process asymmetric and more complex.

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In this work, a live data rate prediction mechanism for real-time video bitrate adaptation shall be developed, including data acquisition in real-world vehicles. The developed method shall be validated in field trials, potentially using the predictions for the link selection.

Requirements

- Interest in future mobile networks and automotive applications
- Excellent English skills are highly desirable; Willingness to write the thesis in English is a plus
- Advanced Python programming skills, basic LaTeX/TikZ skills
- Confident use of Linux systems and understanding of core Linux networking principles
- A Driving license is a plus for acquiring the needed measurement data

References

[1] Bundesministerium der Justiz und für Verbraucherschutz, "Bundesgesetzblatt Teil I - Verordnung über Ausnahmen von straßenverkehrsrechtlichen Vorschriften für ferngelenkte Kraftfahrzeuge", Bundesgesetzblatt, Germany, July 2025

[2] H. Schippers, T. Gebauer, K. Heimann, C. Wietfeld, "RISE: Multi-Link Proactive Low-Latency Video Streaming for Teleoperation in Fading Channels," in IEEE 101st Vehicular Technology Conference (VTC-Spring), Oslo, Norway, June 2025.

[3] B. Sliwa, C. Wietfeld, "A reinforcement learning approach for efficient opportunistic vehicle-to-cloud data transfer", In 2020 IEEE Wireless Communications and Networking Conference (WCNC), Seoul, South Korea, May 2020.