A Hierarchical Control Framework for CAV Platoon: Fusing DRL and Robust Control to Enhance Eco-Driving and Cut Emissions

Zekai Lv
Northwestern Polytechnical University, Xi'an, Shaanxi, China

Jianzhong Chen *
Northwestern Polytechnical University, Xi'an, Shaanxi, China

Abstract

With the global focus on transportation decarbonization, connected and automated vehicle (CAV) platooning has emerged as a promising solution to balance traffic efficiency and ecological sustainability. This study addresses the critical challenge of ensuring platoon reliability and minimizing environmental impact under real-world constraints. We propose a novel hierarchical control framework that synergistically combines distributed control theory with deep reinforcement learning (DRL), with contributions in three key areas: First, we designed a distributed robust consensus controller that explicitly accounts for practical impairments, including actuator failures, saturation, and communication delays. This foundation ensures resilient and stable platoon operation in non-ideal conditions, providing a reliable baseline for ecological optimization. Second, we developed a deep reinforcement learning framework to autonomously learn and fine-tune the key parameters of the consensus controller. The core innovation lies in the design of a multi-objective reward function that explicitly trades off tracking precision against energy consumption. This allows the control policy to be directly optimized for minimal environmental impact without compromising safety. Finally, to fully unleash the synergistic advantages of intelligent decision-making and robust execution, this study innovatively proposes a two-layer hierarchical control framework, where the DRL agent serves as the upper-layer decision optimizer and the robust controller acts as the lower-layer execution guarantor, with seamless integration between the two layers to form an adaptive and computationally efficient control strategy. Simulation results demonstrate that the proposed method achieves a superior balance between platoon performance and ecological benefits compared to conventional approaches, offering a viable pathway toward greener and more intelligent transportation systems.

Keywords

Connected and automated vehicle, Hierarchical control framework, Deep reinforcement learning, Eco-driving, Robust control.