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ADAPTIVE INTER-VEHICULAR COLLABORATION FOR LEVEL 5 AUTONOMOUS DRIVING

by

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Abstract

The evolution of sensor technologies, mobile networks, and artificial intelligence has significantly expanded the horizons of various sectors, notably in autonomous driving. According to the World Health Organization, over 1.3 million people succumb to traffic accidents annually, predominantly due to human negligence. Complex urban environments, characterized by mixed traffic flow involving Human Driven Vehicles and Connected and Autonomous Vehicles, intricate traffic patterns, frequent lane changes, and slow speeds, face escalating challenges related to traffic accidents and congestion. These challenges lead to wasted time, increased fuel consumption, and heightened pollution emission levels. Hence, the development of a safe and robust version of collaborative autonomous driving, known as convoy driving, is anticipated to greatly enhance road safety, traffic efficiency, and overall mobility by transitioning driving control from humans to autonomous systems. While collaborative autonomous driving solutions have existed for some time, the focus has predominantly been on classical problem domains of lower automation levels and vehicular networks on highways. Although substantial research has been dedicated to convoy driving for heavy-duty trucks, demonstrating its benefits on highways, challenges arise when extending collaborative driving functions to smaller lightweight vehicles in urban settings. Having highlighted such challenges, this work justifies the need for an evolved version of collaborative autonomous driving. The primary focus of this thesis is to investigate and overcome existing limitations and challenges associated with urban convoy driving by proposing novel theoretical frameworks. It introduces integrated solution components tailored to enable urban convoys, envisioning a future where convoy driving becomes a win-win solution - beneficial for the environment, the collective transportation system, and individual vehicle owners, contributing to the goals of achieving Level 5 autonomous driving. This means that it is investigated how convoy driving adds to road safety and efficiency, which is translated into a number of local objective functions. It is believed that this work is among the pioneers that study the aspects of collaborative autonomous driving, addressing not only collaboration for short time quanta but its benefits at societal and individual vehicle levels. This claim is supported by extensive literature surveys conducted to highlight gaps and differentiate the standing of this work, which is published in reputable venues. This thesis covers the following three main dimensions: I) Defining, modeling, and simulating the environment that captures the dynamics of a complex urban setting. The environment is modeled using a probabilistic graphical model (PGM), and an extension of the Car Learning to Act (CARLA) simulator, termed CARLA+, is developed by integrating the PGM framework. This proposed approach provides a unified framework to automate the behavior of dynamic environments using PGMs. II) Modeling Convoy Driving - Convoy driving is modeled by leveraging coalitional game theory in urban settings. Novel utility functions capturing relevant parameters and various benefits for convoy driving are designed and developed. The proposed theoretical framework can decide which traveling mode - coalition-driven or traveling alone - is beneficial for a vehicle in a given setting. This also forms the basis of the next contribution. III) Modeling Societal and Individual Vehicle Level Benefits of Convoy Driving. A theoretical incentivizing framework is proposed to investigate how the adoption of convoy driving can be incentivized to promote convoy driving in a mixed-traffic environment. The fundamental diagram model, VT-Micro model, and coalitional game theory framework are employed to model benefits at both the societal and individual vehicle levels. Experimental results demonstrate the pronounced advantages of convoy travel over solo travel. It is concluded that convoy travel is advantageous for a convoy size of two-six vehicles with an inter-vehicle spacing of less than four meters, considering the stability of the traffic flow and the urban environment limitations. Traveling in a convoy allows vehicles to save fuel, reduce travel time, and enhance safety and comfort. Notably, the research findings underscore that realizing the substantial benefits of coalition-driven driving necessitates finding the right equilibrium between vehicle speed, inter-vehicle distance, and coalition size.

Keywords: collaborative autonomous driving, convoy driving, coalitional game theory, incentivization, traffic optimization.