Assessing the Effectiveness of Managed Lane Strategies for the Near-term Deployment of Cooperative Adaptive Cruise Control

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Abstract

Connected and Automated Vehicle (CAV) technology is going to revolutionize the way a vehicle is operated. Among its wide-range applications, Cooperative Adaptive Cruise Control (CACC) is identified as one of the thrust areas by governments, industries, and academia all around the world in improving mobility, environment, and more importantly safety. Thus far, traffic simulation is still a cost-effective way to test the near-term deployment of CACC vehicles in large-scale transportation networks under various traffic conditions.

In this study, the traffic impacts for CACC under mixed traffic conditions are investigated under four managed lane strategies and with various market penetration rates (MPRs). An integrated Vissim-based simulation testbed is developed. The highlights of the testbed include: 1) Enhanced Intelligent Driver Model (E-IDM) for vehicle longitudinal control; 2) the adoption of the Vissim User Defined Attributes (UDAs) that enables information exchanging between the DriverModel.DLL(VEDM) and the Component Object Model (COM) Interface; 3) multi-objective-optimization (MOOP)-based cooperative driving where CACC vehicles within a platoon actively cooperate to achieve overall platoon goals, 4) parallel computation in COM for solving the MOOP-based platoon maneuvering with Genetic Algorithm; 5) Nakagami-based radio propagation model, implemented via VEDM, for evaluating CACC platooning under imperfect wireless communication at individual vehicle level; 6) VT-Micro emission model for instantaneous fuel consumption and CO_2 emission implemented in Vissim EmissionModel.DLL (VEMD); 7) CACC system fall-back algorithm that is designed according to the Society of Automotive Engineers International (SAE) Level 3 automation.

A segment of Interstate Highway 66 (I-66) located in Fairfax County, Virginia, outside of the Washington D.C. Beltway (I-495) was used for the evaluation. The network has been calibrated with two independent data sources (i.e., INRIX travel time and remote traffic microwave sensor volume) to ensure realistic representation of real-world conditions. The 8-km (5-mile) segment has 4-lane in each direction and two interchanges that are 2.3 kilometers (1.43 miles) apart. Four managed lane strategies were studied. The simulation period for each replication/run is 3900 seconds with the resolution of two and 300-second warm-up time. Five replications for each scenario with different random seeds were conducted to factor in the variability of the simulation.

We have taken measures to ensure the scalability of the simulation framework. The VEDM deals with vehicle-level maneuvers, whereas the COM typically provides a global access to most of the objects in Vissim but with a significant computational cost when the data being exchanged between Vissim and an external program. The new UDA feature enables us to implement most of the CACC behavior models in VEDM while making the CACC parameters accessible by COM.

Also, one of the limitations of VEDM, when enabled, is that only single core can be used by Vissim. By accessing the vehicle information computed in VEDM, the MOOP with higher computational complexity can be moved to COM for multi-core computing, which can drastically reduce the computation time and increases the scalability of the simulation testbed. The vehicle information for each platoon, which is collected in VEDM then accessed by COM via the shared memory, was distributed to a logical CPU core for computation in every five simulation time steps. To put it into perspective, the server used is with 32 logical CPU cores, which means 32 CACC platoons optimizations can be solved simultaneously. The parallelization of the optimization plays a crucial role in the scalability of implementing MOOP-based CACC platoon maneuvering.

In addition, as shown in previous research, simulation of the imperfect wireless communication environment has been a primary obstacle when it comes to the scalability of a simulation testbed, whether by using a network simulator or by coupling a network simulator with a traffic simulator. By the adoption of the analytical model that is derived from empirical packet-level network simulator (e.g., ns-2), we are able to increase the simulated traffic volume to thousands of vehicles per hour in a much more computationally tractable way. Moreover, since the packet reception probability is calculated during the simulation,its impact is accounted for the CACC operation, thereby playing a role in affecting the trajectories of CACC vehicles.

Custom platooning-related performance measures (i.e., the percentage of platooned CACC vehicles, total number of platoons within a network, and average platoon depth that describes the position of a CACC vehicle within its platoon) are made available via UDA. Additionally, the analytical DSRC module provides transmission density and packet reception probability for each individual platooned CACC vehicle. The CACC vehicle is assumed with SAE Level 3 automation which requires a fallback-ready driver. In the event of reception failure during simulation, a CACC vehicle executes the safety protocol by increasing the following headway and the platoon is subsequently dissolved until communication is re-established or resumption of vehicle control by a human driver.

According to the traditional traffic flow performance measures (i.e., throughput, vehicle hour traveled, user group equity, and safety) and the platooning performance measures, policy recommendations are derived for stakeholders. The two primary decision-making factors are: 1) the existence of a managed lane on a roadway and 2) the MPR of CACC. The priority usage of an existing managed lane could be implemented even when the MPR is less than 20%. For the roadways that do not have existing managed lane infrastructure, it may be hard to justify the infrastructure investment of a managed lane for CACC vehicles which is a small portion of the overall traffic demand. As such, the mixed traffic strategy without a managed lane is somehow more viable until MPR rises to a certain level. When the MPR reaches 30% or above, an existing managed lane can be converted to a dedicated CACC lane. Additionally, physical barriers could be added for access control for a managed lane. As the simulation data shows, it can greatly facilitate platoon formation and therefore enhance the performance of CACC.

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