CReTS – Co-simulation Framework for Control, Communication and Traffic for Vehicle Platoons

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I. Motivation

Vehicle platooning is defined as a convoy of vehicles traveling together safely at high speed while keeping a short distance between them. It has gained attention for its potential to achieve an increased road capacity and safety, and a higher fuel efficiency. Vehicles communicate wirelessly over: (1) industrial wireless communication standard e.g. IEEE802.11p [8] for sharing information between vehicles such as: acceleration, velocity, position, braking actions, road and intersection status (2) other sensors e.g. radar, lidar, and camera for measuring position of the preceding vehicle. By exchanging information with other members via wireless communication, a platoon member computes its desired acceleration which is then passed on to the engine control system via in-vehicle network to physically realize the acceleration. This leads to a multi-layer control scheme. The upper-layer is influenced by the behavior of IEEE802.11p communication and network congestion due to transmissions by other vehicles in the traffic. The lower-layer engine control loop communicates over the fast and reliable in-vehicle networks (e.g., FlexRay, Ethernet) [9].

The design of a platoon system depends on:

- Network behavior: The number of vehicles equipped with V2V communication devices affect the congestion level of the network. It is not a trivial task to test platoon system under different network congestion levels in real experiments. Realistic network simulator such as ns-3 [1] can handle this challenge. ns-3 is an event based discrete simulator. It provides a realistic network behavior and it implements the architecture for IEEE802.11p.
- Traffic behavior: Traffic simulation tools such as SUMO [7] can generate real driving behavior on highways or urban areas while considering different traffic densities. SUMO is an open source, microscopic road traffic simulator. It provides graphical user interface (GUI) to observe the motion of the vehicles.
- Control design: Analysis and evaluation of different control architectures under (1) different network congestion levels and traffic densities (2) different sampling rates of the inter-vehicle network (1-10Hz – IEEE802.11p) and intra-vehicle network (20Hz or 50Hz over FlexRay or Ethernet). Matlab is used for implementing such control design.

We present CReTS – a co-simulation framework consisting of Matlab (for the multi-layer control algorithms), ns-3 (for the 802.11p network) and SUMO (for the traffic behavior) [12]. The framework can be used to validate different platooning setups. As an illustrative case study, we consider a multi-layer control strategy where the upper-layer uses Model Predictive Control (MPC) [11] at a rate in compliance with IEEE802.11p and the lower-layer uses state-feedback control at a higher sampling rate in line with in-vehicle networking capabilities. The control strategy is evaluated considering various realistic traffic and network congestion scenarios.

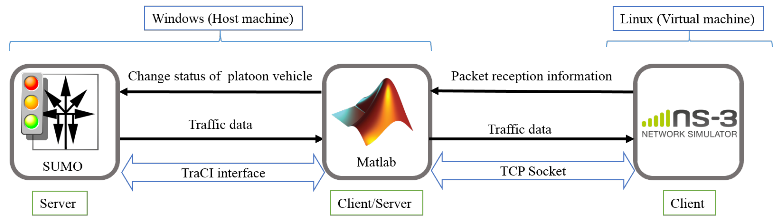

Fig. 1: Proposed co-simulation framework with ns-3, SUMO and Matlab and interaction.

II. CReTS Components

Our co-simulation framework CReTS combines ns-3, SUMO and Matlab. As shown in Fig.1, TCP connection is established between SUMO and Matlab using TraCI (Traffic Control Interface). Whereas socket programming is used for the TCP connection between Matlab and ns-3.

The interaction between tools is based on client-server model; SUMO acts as a server and is responsible of viewing all the vehicles (platoon vehicles and other vehicles) through GUI. SUMO allows Matlab to modify and retrieve states of the simulated vehicles. The control algorithm is computed on Matlab which acts as the interface between SUMO and ns-3. Matlab acts as server for ns-3 and client for SUMO. ns-3 simulates V2V communication between all vehicles based on the state information of each vehicle received from Matlab. ns-3 updates matlab with the packet reception information of the platoon vehicles.

Synchronization is considered between tools. SUMO waits to receive the new information of the platoon vehicles from Matlab; then it simulates and updates all traffic members. Next, the states of all traffic members are sent to ns-3 through Matlab which simulates V2V communication between vehicles; ns-3 finds and updates Matlab with the packet reception information between platoon vehicles. Then Matlab runs the control algorithm based on the received information from ns-3. In reality, synchronization can be achieved with acceptable accuracy via GPS with the state-of-the-art 802.11p devices e.g. MK5 On-Board Unit (OBU) from Cohda Wireless [10].

Scenario1	600 vehicles, Low congestion, channel load <70%	Average PRR %	83.41
		Average delay(ms)	6.69
Scenario2	800 vehicles, medium congestion, channel load =70%	Average PRR %	67.33
		Average delay(ms)	11.44
Scenario3	1000 vehicles, high congestion, channel load >70%	Average PRR %	51.43
		Average delay(ms)	20.15

TABLE I: Average Packet Reception Ratio (PRR) and average delay in different traffic scenarios

III. Related Work

Co-simulation frameworks for platoons have been presented in recent literature. In [2], a co-simulation environment has been implemented using VISSIM (for traffic simulation), ns-3 and Matlab. In this framework, the control architecture is simplified with constant desired gap and mainly focuses on upper-layer control (using a simplified PI controller). Moreover, it was assumed that only platoon members communicate over the 802.11p standard. A co-simulation framework based on OMNET++ (for network simulation), SUMO and SIMULINK (for the control application) is reported in [3]. The focus has been on string stability with different packet reception rates and headway times. Packet loss is artificially accomplished by a module which drops the received beacons by using a loss probability with uniform distribution. The controller uses the previously received and stored acceleration values in case of packet losses. Our proposed framework provides a template for multi-layer control architecture with both realistic traffic scenarios and network congestion behavior.

Plexe [4] is an integrated simulator framework combining OMNET++ and SUMO that extends Veins (vehicular network simulator framework [5]). It focuses on joining maneuvers of platoon vehicles and it adds models to SUMO e.g. cruise control (CC), ACC, CACC. Another framework, VENTOS [6] also combines OMNET++ and SUMO and implements platoon maneuvers e.g. merge, split and lane-change. How to extend the aforementioned frameworks to implement modern controllers (e.g. MPC) is not clear.

IV. Case Study

We consider network congestion of low, medium and high levels over 3km road segment; four lanes in each direction while Lane 1 is dedicated to platoon members. Moreover, we consider multi-layer control design; the upper-layer receives information of the preceding platoon member then it generate the acceleration setpoint ensuring safety and efficiency. The message are received every 100ms (10Hz message rate) assuming channel load < 70% (complying with IEEE802.11p standard). Model Predictive Control (MPC) is chosen for its ability to handle constraints and its predictive behavior relevant to deal with packet losses. The lower-layer is responsible for reaching the acceleration setpoint as soon as possible. State-feedback control is used at higher sampling rate e.g. 50Hz, 20Hz (i.e. 2ms or 5ms), supported by common automotive operating systems.

V. Results and discussions

Average PRR and delay for the wireless link between any two consecutive platoon vehicles are computed and reported in Table I for different scenarios. Table I shows that 83.41% of the packets are received for Scenario1; the average delay = 6.69ms. Scenario2

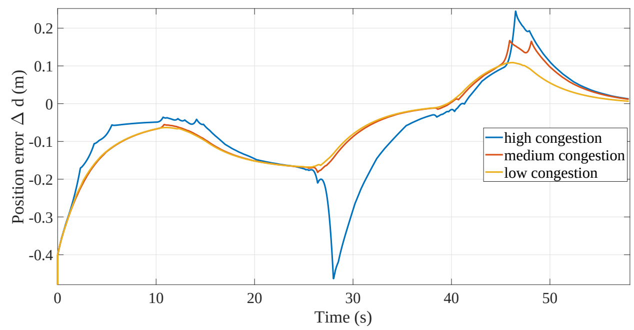

Fig. 2: Position error Δd between the first two platoon vehicles (V_0 & V_1)

shows 67.33% PRR and average delay 11.44ms. Average delay might be ignored for low and medium congestion in the control design. Scenario3 shows 50% of lost packets and 20.15ms average delay. That huge delay should be considered and transmission rate must be lowered (i.e. < 10Hz). Results from Table I are nondeterministic i.e. by running the simulation different times we could obtain different results. That is due to: (i) other traffic members controlled by SUMO to mimic human driving behavior (ii) ns-3 finding of different PRR of platoon members due to new positions and velocities of traffic members.

Controller performance under different scenarios is depicted in Fig. 2. Fig. 2 shows position error is bounded within 0.5m between the first two platoon vehicles i.e. V_0 and V_1. Thus vehicles can be driven very close to each other, minimizing air drag while maintaining safety.

VI. Conclusion

Our co-simulation framework provides a design and testing template for all three relevant components (network behavior, traffic density, control design). This framework can be used for development, testing and validation of both platoon control and communication in different traffic scenarios.

VII. Acknowledgment

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