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

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

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Introduction

Vehicle platooning:

A convoy of vehicles travelling together safely at high speed while keeping a short distance between them.

Vehicles communicate wirelessly over:

- Wireless communication standard e.g. IEEE802.11p for sharing information between vehicles such as: acceleration, velocity, position, braking actions, road and intersection status)
- Other sensors e.g. radar and lidar, camera (measuring position of the preceding vehicle).

Figure 1. vehicle platooning
Image source: Scania Newsroom

Challenges

The design of a platoon system depends on:

1. **Network behavior:**
   - Number of vehicles equipped with V2V communication devices
   - Simulating V2V communication using realistic simulator
   - Designing the control system according to different packet reception ratios and delays occur depending on the network congestion level.
2. **Traffic behavior:**
   - Generating real driving behavior on highways or urban areas.
   - Considering different traffic densities
3. **Control design:** Analysis and evaluation of different control architectures under:
   - different network congestion levels and traffic densities
   - different sampling rates of the inter-vehicle (1-10 Hz, 802.11p) and intra-vehicle network (20 Hz or 50 Hz over FlexRay or Ethernet)

Co-simulation Framework Components

1. **Network simulator ns-3**[1]
   - Event based discrete simulator
   - Realistic network simulator
   - Implements the architecture for IEEE802.11p
2. **Traffic simulator SUMO**[2]
   - open source, microscopic road traffic simulator
   - generate real driving behavior
   - Provide graphical user interface (GUI) to observe the motion of the vehicles
3. **Matlab for control design**

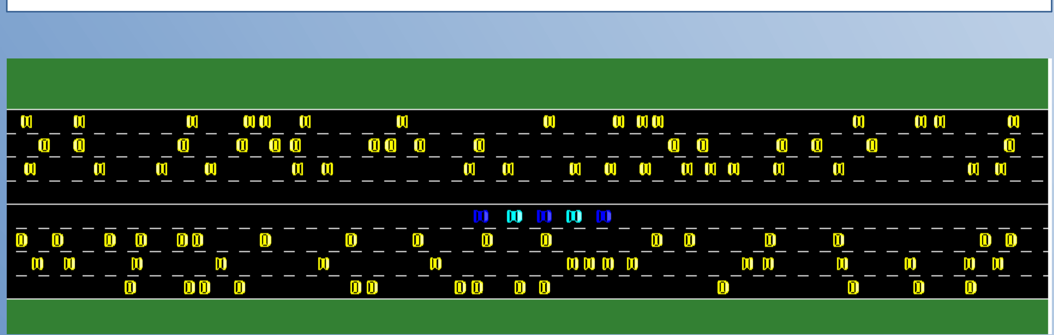


Figure 2. SUMO GUI

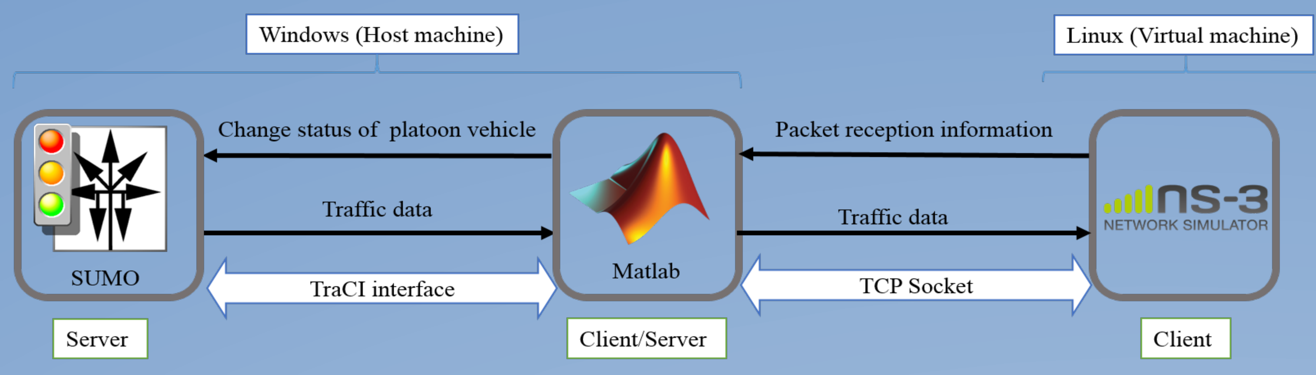


Figure 3. Interaction between tools

How it works?

1. **Connecting the tools:**
   TCP connection is established between tools:
   - Between Matlab and SUMO using TraCI (Traffic Control Interface).
   - Between Matlab and ns-3 using socket programming
2. **Interaction 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
3. **Synchronization is considered between tools:**
   - SUMO waits to receive the new information of the platoon vehicles from Matlab
   - Then SUMO simulates and update the whole traffic members.
   - Then, the states of the whole traffic members are sent to ns-3 through Matlab which simulates V2V communication between vehicles.
   - ns-3 simulates packet broadcast of every vehicle using a uniform velocity mobility model. That is, ns-3 simulates constant speed motion of every vehicle.
   - ns-3 finds the packet reception information between platoon vehicles.
   - Hence, Matlab waits to receive packet reception details from ns-3 and then it runs the control algorithm based on this information.
- 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[3]

		Average PRR %	Average Delay (ms)
Scenario 1	600 vehicles, Low congestion, channel load <70%	83.41	6.69
Scenario 2	800 vehicles, Medium congestion, channel load = 70%	67.33	11.44
Scenario 3	1000 vehicles, High congestion, channel load > 70%	51.43	20.15

Table 1. Average Packet Reception Ratio (PRR) and average delay in different traffic scenarios

Acknowledgment

This research was partially funded by the European Union's Horizon 2020 Framework Programme for Research and Innovation under grant agreement no 674875 (oCPS Marie Curie Network).

Case study

- Low, medium and high congestion levels are considered
- 3 km road segment (4 lanes in each direction), lane 1 is dedicated to platoon members

Multi-layer control design

- Upper-layer:
  - receives information of the preceding platoon member
  - Generate the acceleration setpoint ensuring safety and efficiency
  - the message could be received every 100ms (10 Hz message rate) assuming channel load < 70% (complying with IEEE 802.11p standard)
  - Message rate could be lower (i.e. < 10 Hz) if the channel load > 70 % (controlled via Decentralized Congestion Control (DCC) algorithm)
  - Model Predictive Control (MPC) is chosen for its ability to handle constraints and its predictive behavior relevant to deal with packet losses
- Lower-layer:
  - Reach the acceleration setpoint as soon as possible
  - State-feedback control is used at higher sampling rate e.g. 50 Hz, 20 Hz (i.e. 2ms or 5ms), supported by common automotive operating systems.

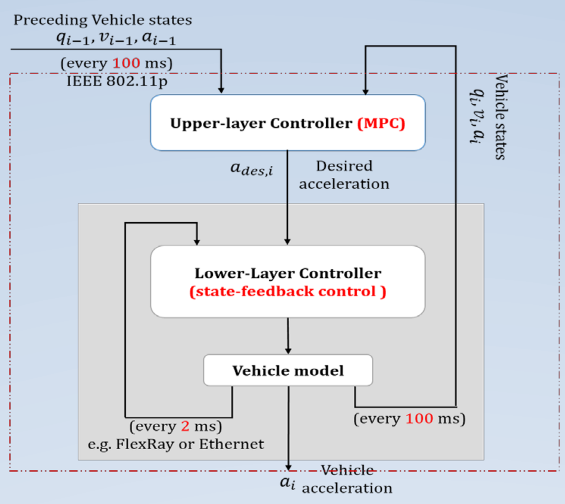


Figure 4. Multi-layer multi-rate control structure of vehicle *i*

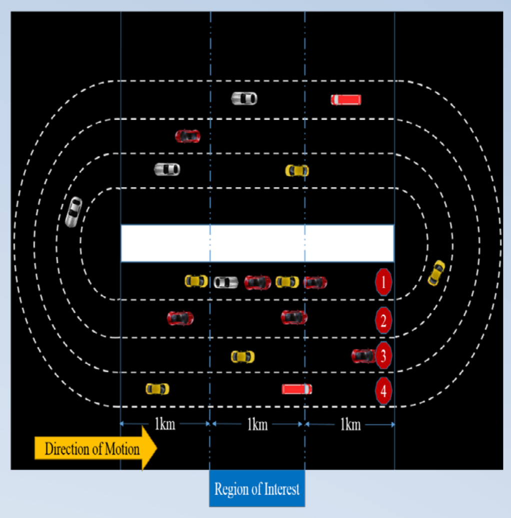
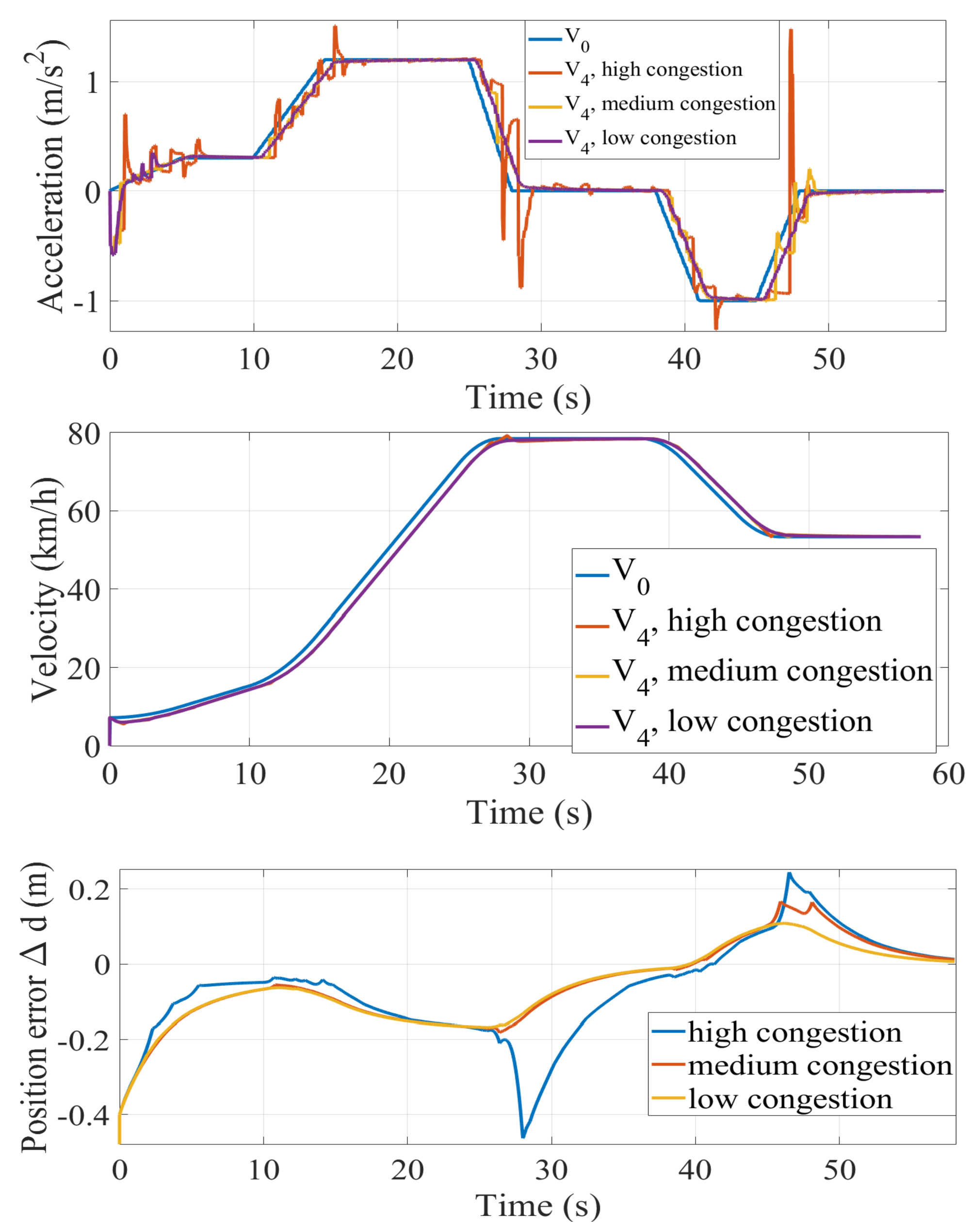


Figure 5. traffic scenario considered on SUMO

Results



Conclusion

- Our 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.

References

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2. Krajzewicz, Daniel, et al. "Recent development and applications of SUMO-Simulation of Urban MObility." International Journal On Advances in Systems and Measurements 5.3&4, 2012.
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