Perceptive Stochastic Coordination in Mass Platoons of Automated Vehicles

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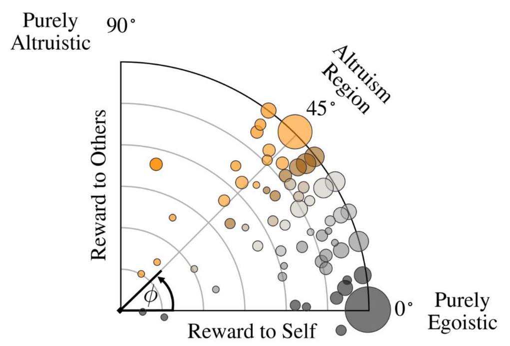
Cooperative Driving

- Autonomous and human-driven vehicles must learn to co-exist by sharing the same road infrastructure.
- To attain socially-desirable behaviors, autonomous vehicles must be instructed to consider the utility of other vehicles around them in their decision-making process. This is a challenging problem due to the ambiguity of a human driver's willingness to cooperate with an autonomous vehicle.
- We take an end-to-end approach and let the autonomous agents implicitly learn the decision-making process of human drivers only from experience.

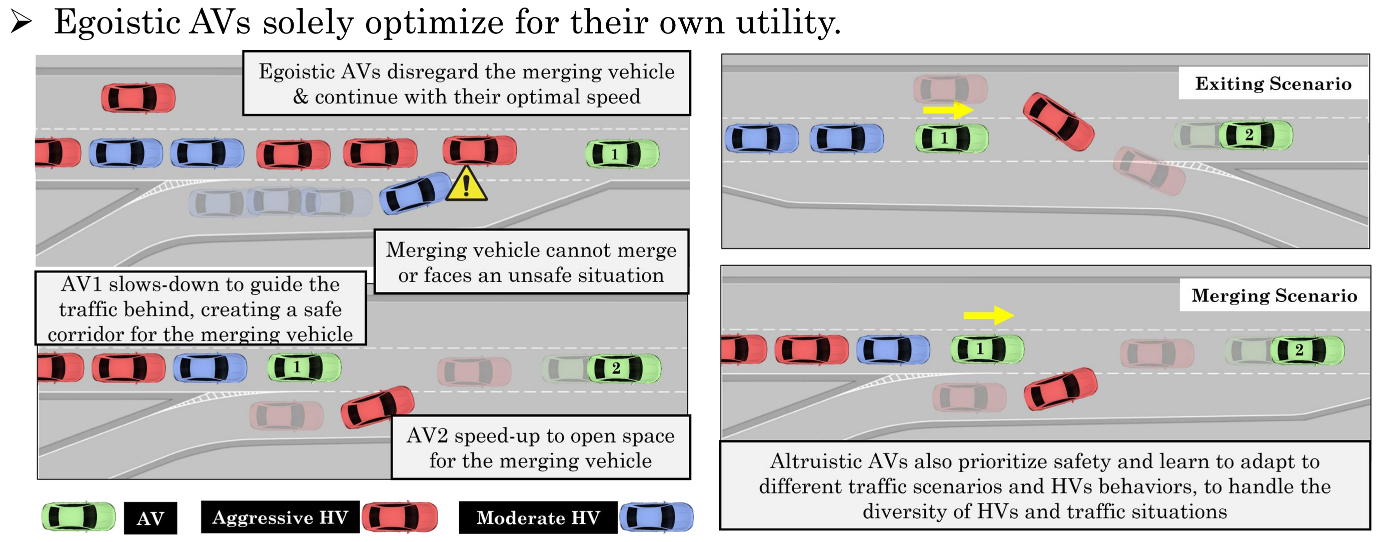
Social Preferences

- The Social Value Orientation (SVO) ring demonstrates different behaviors based on a human/robot's preference to account for others.



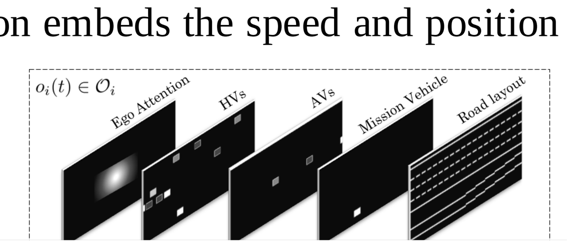
Agent Type	Cares about itself	Cares about its allies	Cares about humans
Egoistic	✓		
Cooperative	✓	✓	
Cooperative Sympathetic	✓	✓	✓

➢ Egoistic AVs solely optimize for their own utility.

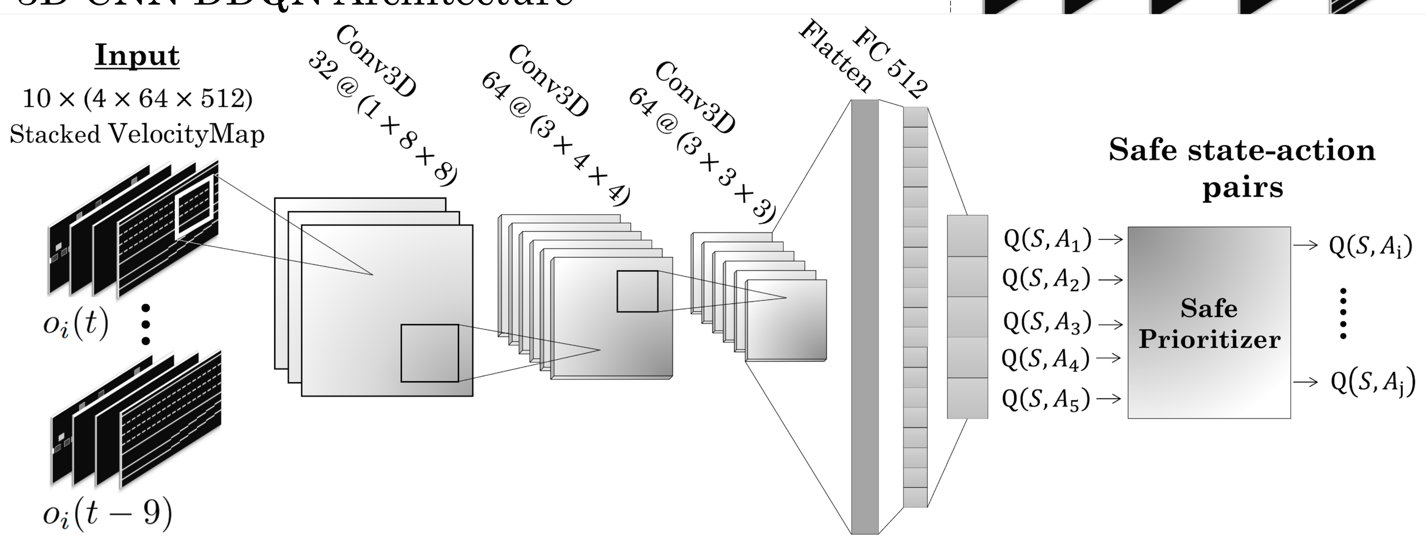


Altruistic Cooperative Driving

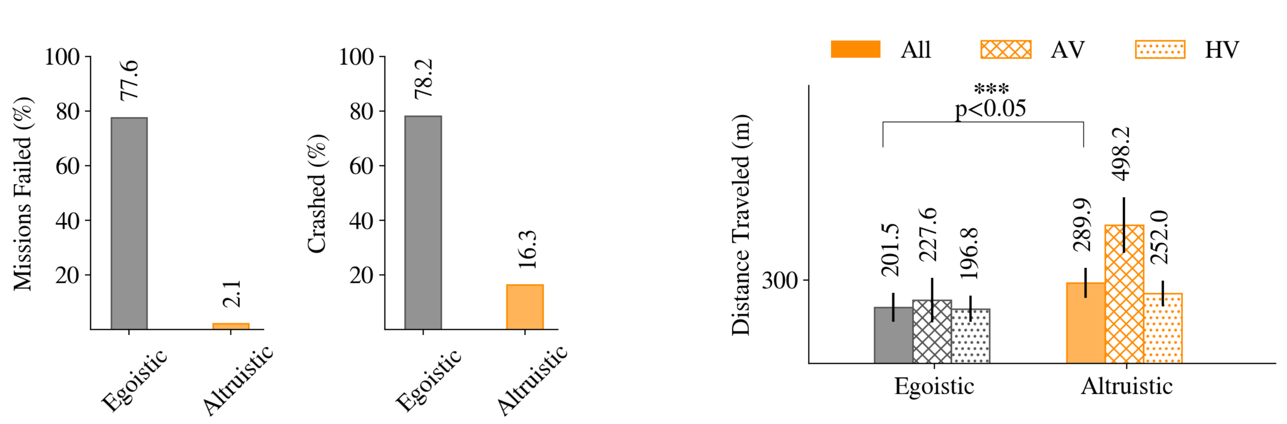
- Stacked multi-channel VelocityMap state representation embeds the speed and position of vehicles, as well as the road layout.



3D CNN DDQN Architecture



- Sympathetic cooperative AVs improve traffic-level metrics.



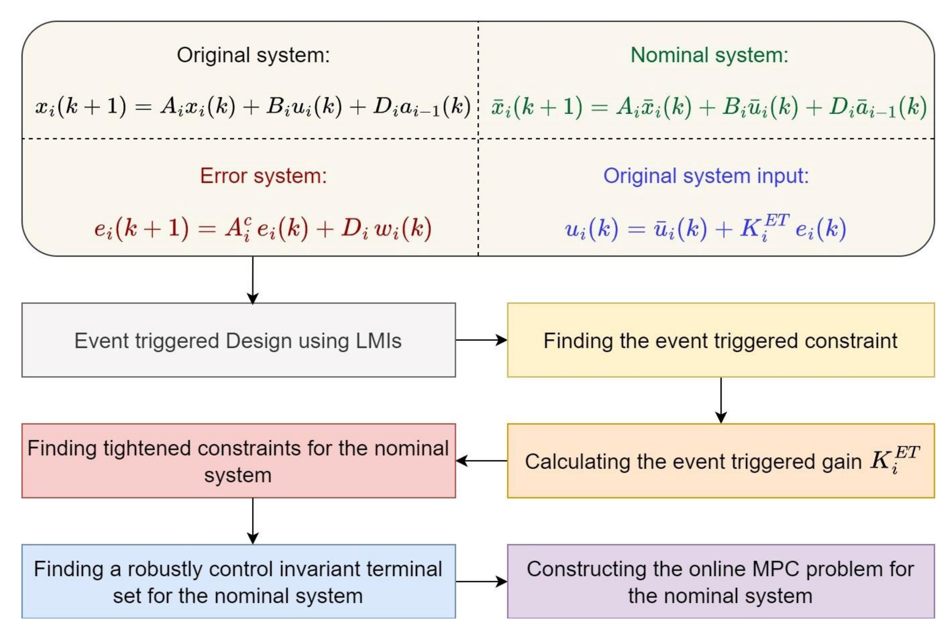
- Using our proposed decentralized multi-agent learning scheme, we are able to induce altruism into the decision-making process of AVs and adjust their SVO. Our altruistic agents not only learn to drive on the highway environment from scratch but also are able to coordinate with each other and affect the behavior of humans around them to realize socially-desirable outcomes to eventually improve traffic safety and efficiency.

Event Triggered MPC Design for CACC

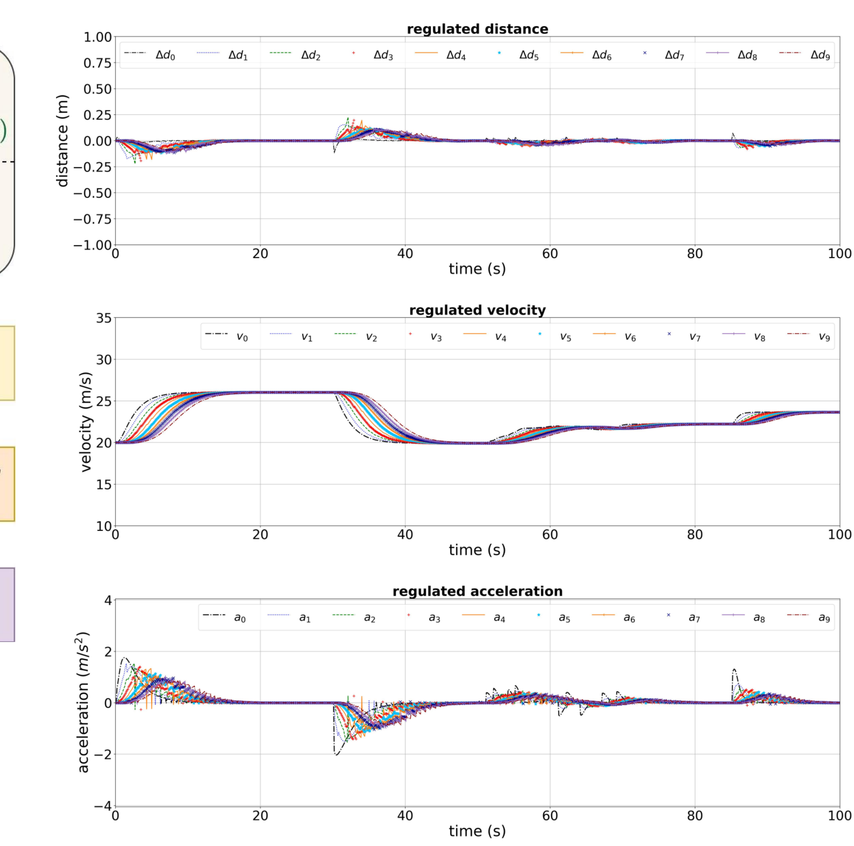
- Wireless communication among CAVs has limitations such as limited bandwidth; hence, unnecessary use of available communication resources affects the CACC system performance.
- A resource-aware communication approach is suggested to strike a balance between the CACC performance and communication usage.
- The proposed event-triggered, tube-based predictive control approach avoids unnecessary information exchange while assuring the platoon stability and achieving the desired behavior of CAVs.
- Results indicate ~70% reduction in communication instances among vehicles in CACC systems, compared to time-triggered approaches, while performance remains intact.

Problem: Design an event-triggered model predictive controller to reduce the communication instances compared to the time triggered case while benefiting from the predictive information that CAV_i receives from its predecessor (a_{i-1}). To realize this, a tube-based MPC approach is proposed with guaranteed feasibility and stability as

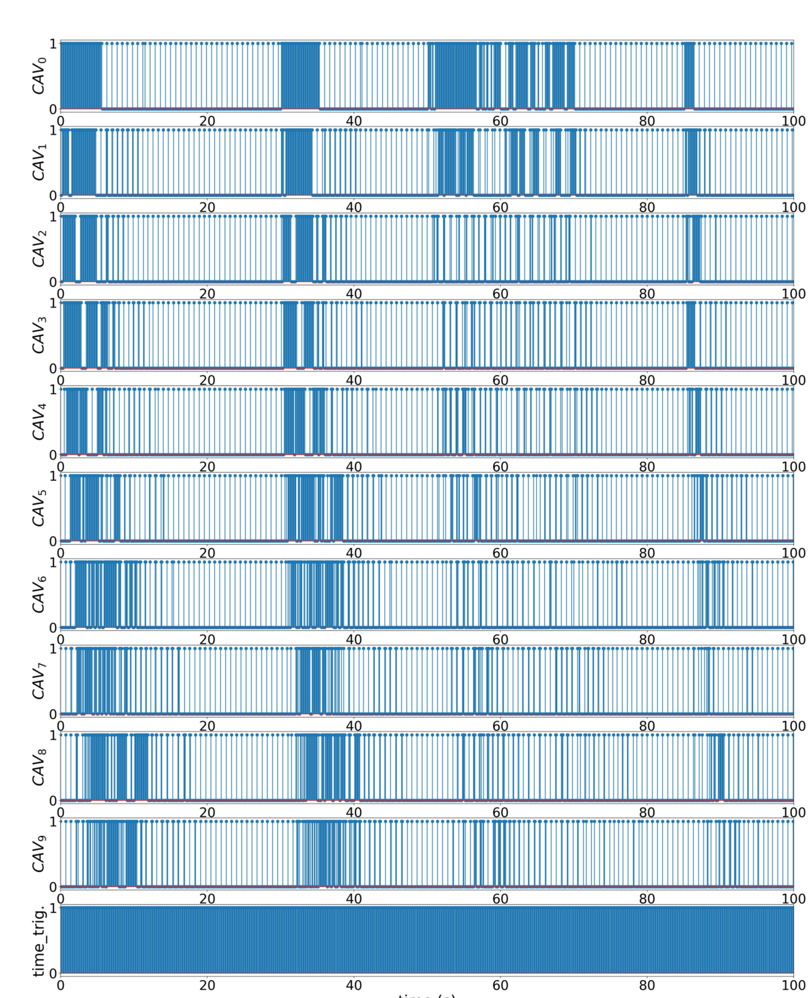
$$u_i(k) = \bar{u}_i(k) + K_i^{ET}\,(x_i(k) - \bar{x}_i(k))$$



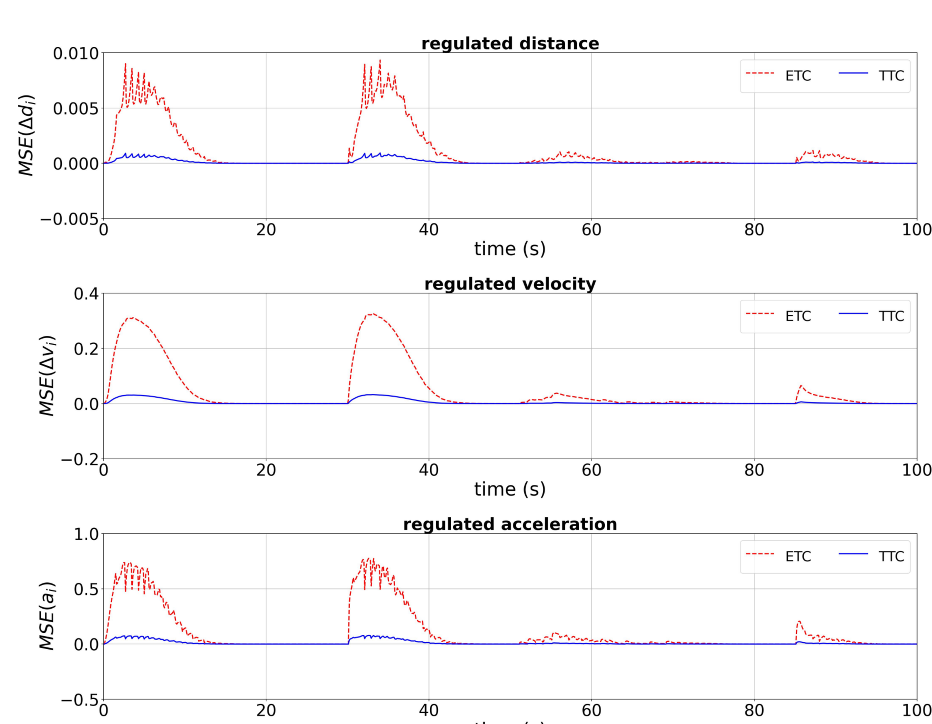
Control gain K_{ET} and event-triggered constraint (event detector) come from solving an LMI. Tightened constraints for the nominal system can be found by knowing gain. Next is to find a robustly control invariant terminal set. Finally, the online MPC problem can be constructed to calculate $u_i(k)$.



Performance of the proposed event-triggered MPC. While the event-triggered mechanism results in noisy acceleration profiles, it substantially reduces the communication usage compared to the time-triggered case.

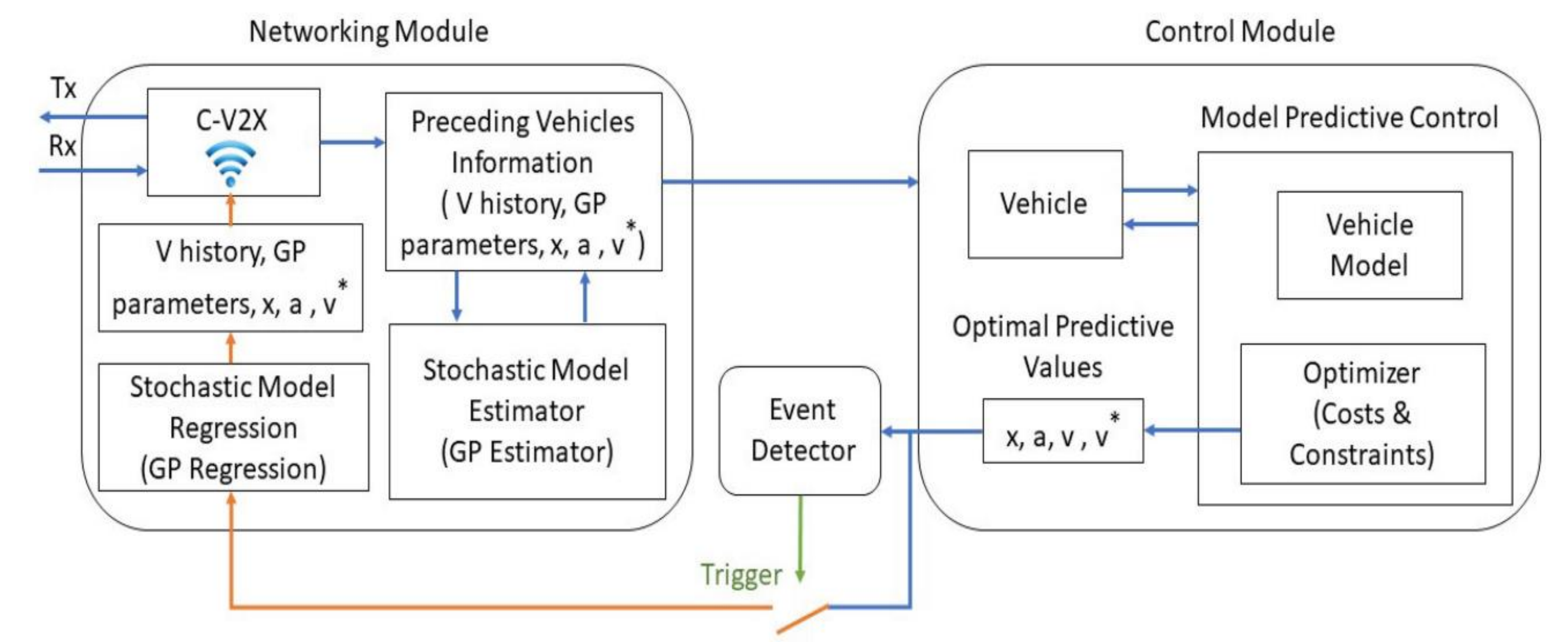


Triggering status of CAVs for event-triggered MPC (subplots 1-10) and time triggered MPC (subplot 11); event-triggered noticeably reduces the communication instances for all CAVs.

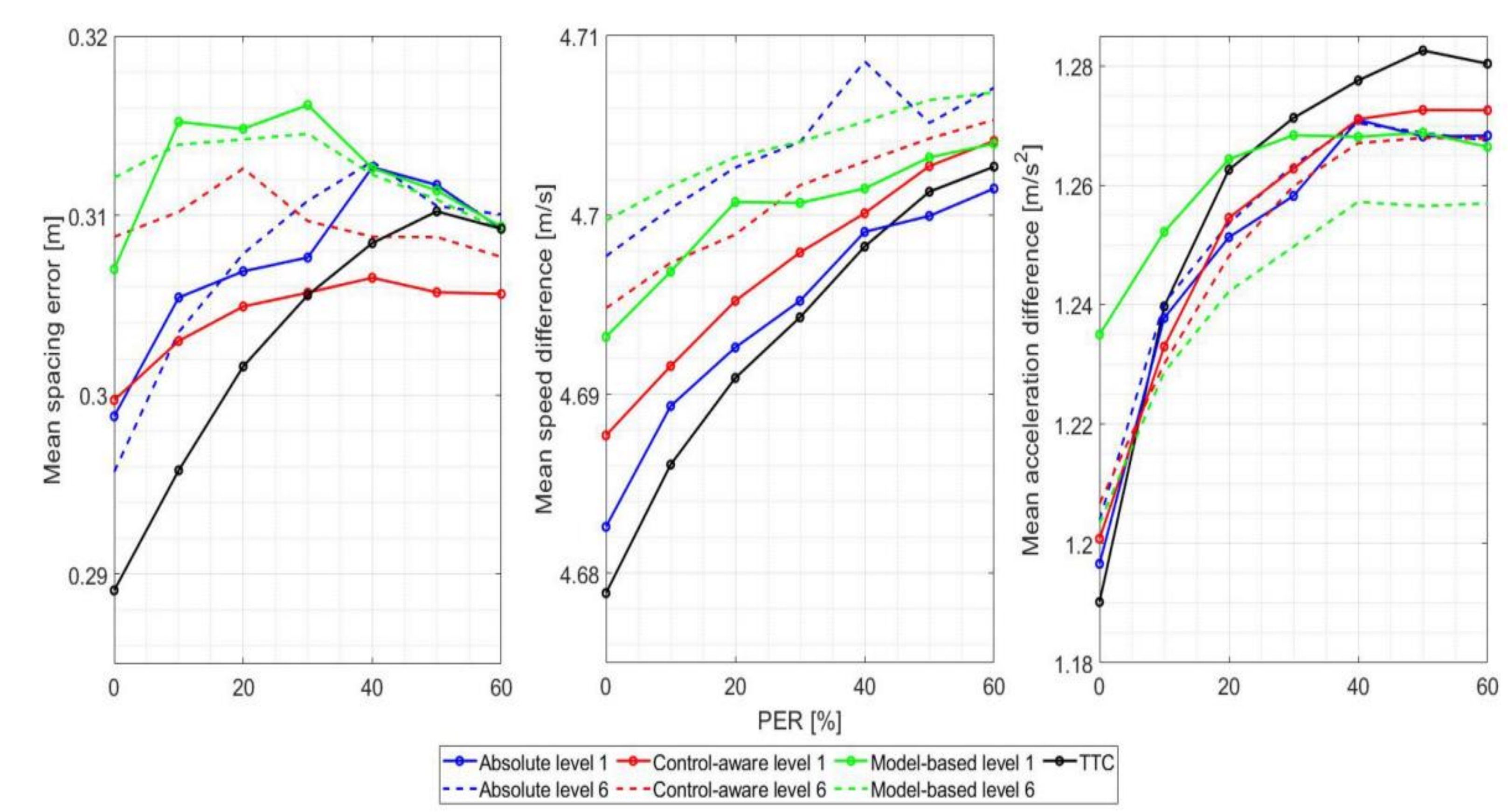


Comparing the mean squared error for two control approaches: event-triggered MPC and time-triggered MPC. As expected, the event-triggered MPC has higher MSE values due to sacrificing performance to achieve less frequent use of communication and computation resources.

Control-Aware Communication for Cooperative Driving



Networking and control modules in each member of the platoon. Ego vehicles receive information from preceding vehicles upon successful communication or predict state of those vehicles using the stochastic models when communication fails. Hybrid stochastic MPC uses the information from the networking module for control purposes. Finally, the control module passes the current states and velocity predicted values to the networking module for broadcasting. Communication timing is selected such that control objectives are optimized.



ACC performance (errors) for different communication policies under different loss rates (PER). TTC (fixed comm rate of 10 Hz), absolute triggering ETC (average rate of 4.75 Hz), control-aware triggering ETC (average rate of 5.28 Hz), and model-based triggering ETC (average rate of 1.80 Hz). Level 1 and 6 correspond to tracking error thresholds of 0.1m and 1.1m.

Conclusion: results demonstrate that with the combined model based and control aware communication, an ETC can be implemented with good performance, reducing network load by 82% compared to a TTC, with only a small reduction in control performance (less than 1% speed deviation).

References

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