CPS: SYNERGY: CONNECTED TESTBEDS FOR CONNECTED VEHICLES

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Motivation

Connected testbeds, i.e., remotely accessible testbeds integrated over a network in closed loop, can provide an affordable, repeatable, scalable, and high-fidelity solution for early cyber-physical evaluation of connected automated vehicle (CAV) technologies. This vision critically relies on the development of high-fidelity cyber-integration interfaces.

Major Goals

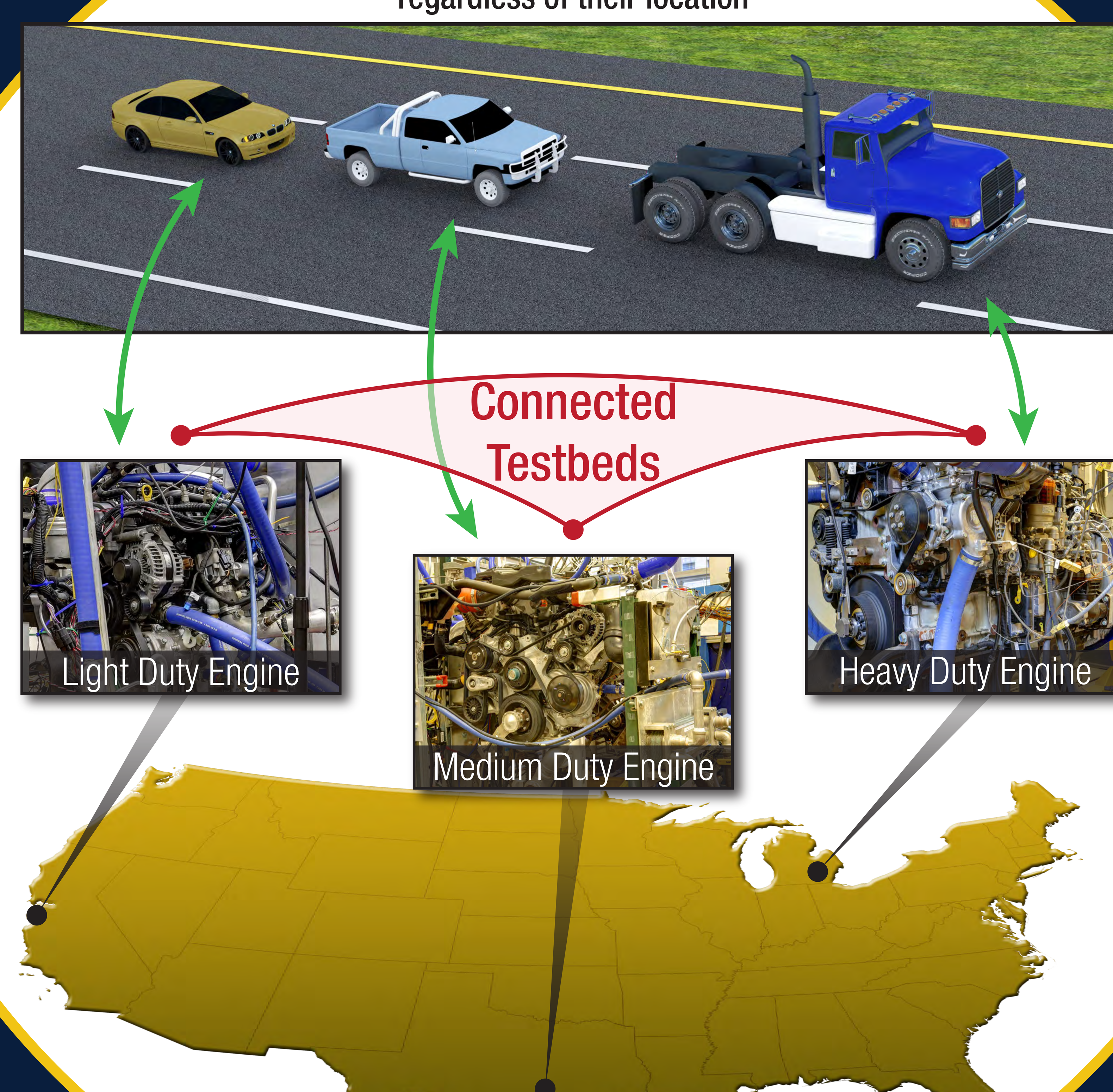
(1) Develop a fundamental framework for connecting remotely-accessible testbeds together over a network with high fidelity despite the presence of network delays.

(2) Develop an algorithm that exploits connectivity and autonomous driving technologies for a powertrain-conscious management of CAV platoons of mixed vehicle types.

(3) Validate the connected testbeds framework and the powertrain management algorithms by creating a cyber-physical experimental setup connecting geographically dispersed engine testbeds and using it to provide a realistic and cost-effective assessment of fuel economy and emissions in CAVs.

Vision

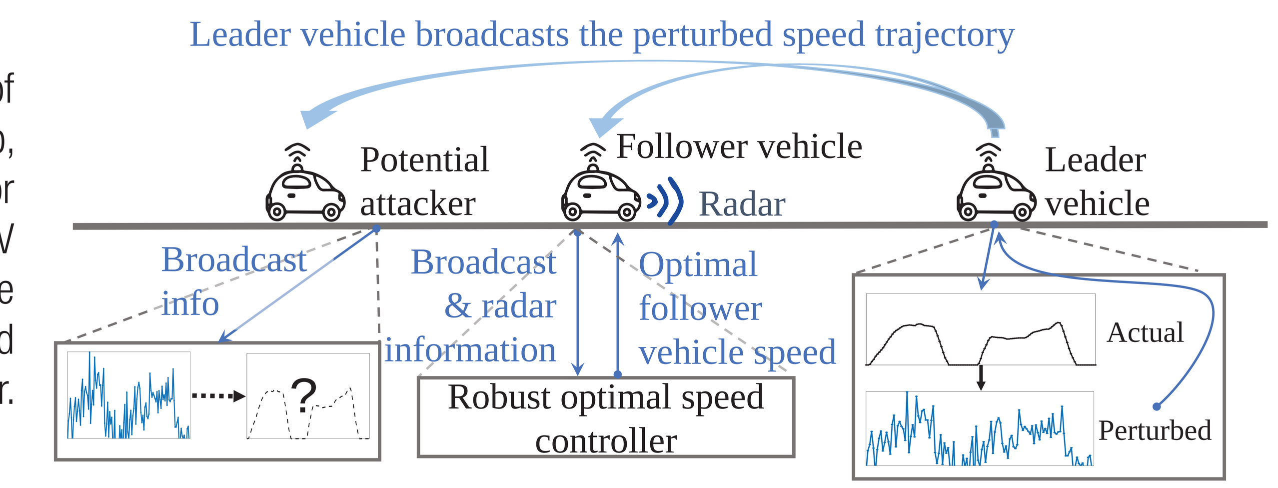
Simulated vehicles in closed-loop with physical powertrains regardless of their location

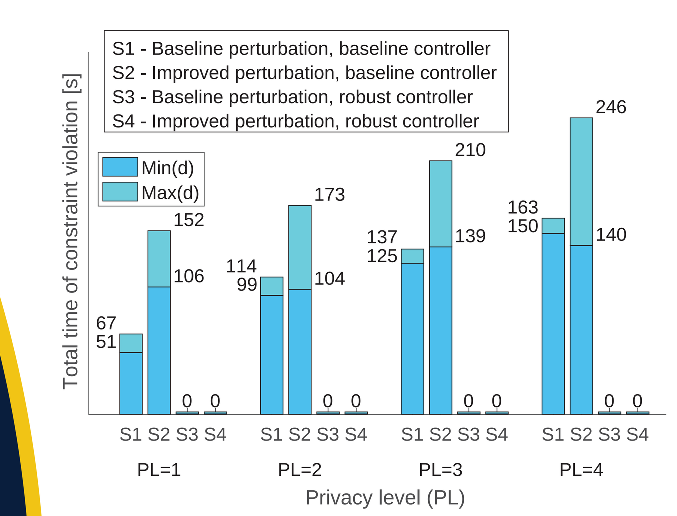


An Optimal Speed Management Strategy with Differential Privacy

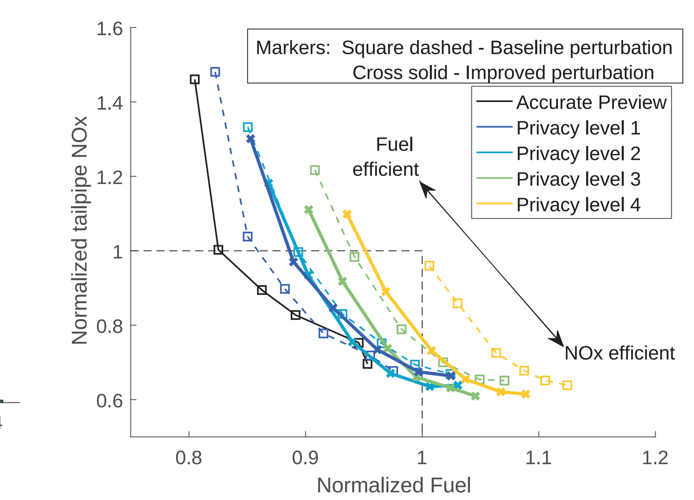
A robust optimal vehicle speed controller is designed to reduce fuel consumption without violating emissions performance when uncertainty exists in speed preview. The controller relies on preview provided using a privacy-guaranteeing V2V communication. Inter-vehicular distance constraint is guaranteed to be satisfied despite error in velocity preview. Reductions are achieved in both fuel and NOx emissions.

Right: Illustration of car-following traffic setup, and framework for differentially private V2V communication and the robust optimal speed controller.





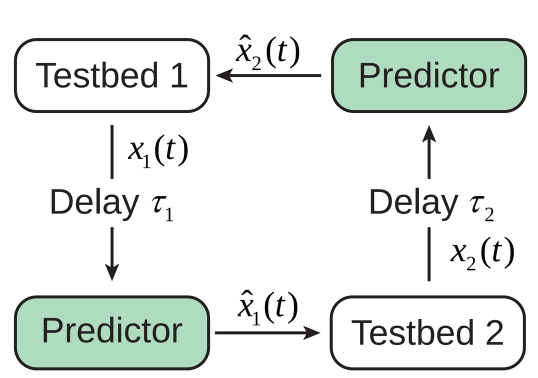
Effectiveness of the robust controller on guaranteeing constraint satisfaction is demonstrated using various levels of privacy and different perturbation methods for privacy.



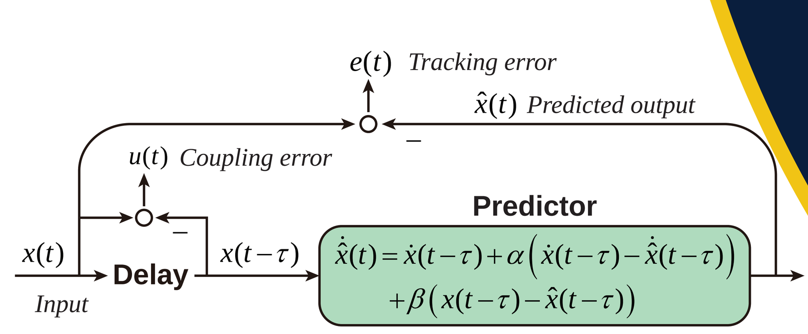
With the improved perturbation method for privacy, better fuel economy and tailpipe NOx emissions performances are achieved while maintaining the same level of privacy guarantee.

A Predictor Framework

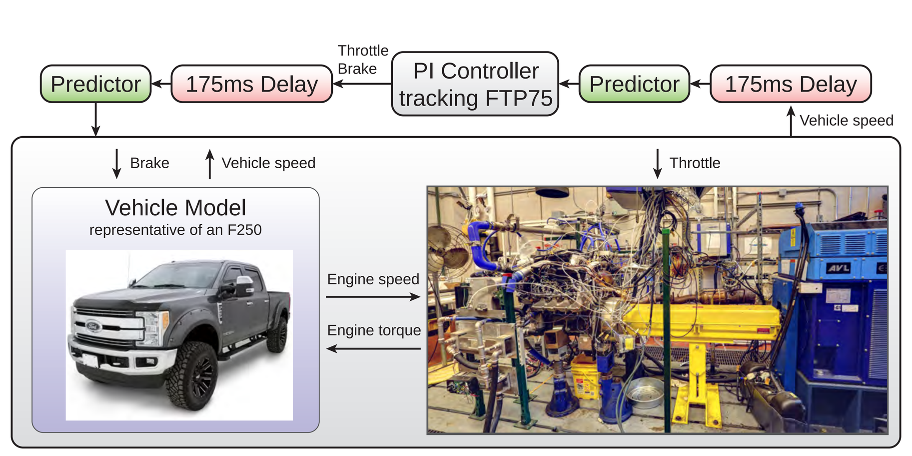
A predictor framework is under development to compensate for the network delays to increase the fidelity in closed-loop integration of remotely accessible testbeds over the network.

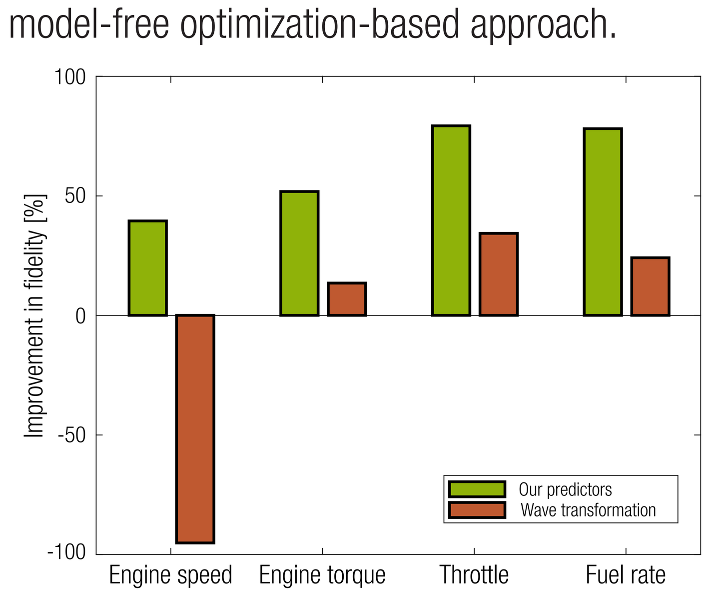


The predictor framework illustrated on an integration of two testbeds over a network represented as delay.



The predictor dynamics are described by a neutral delay differential equation with two design parameters α and β that are self-tuned through a model-free optimization-based approach.

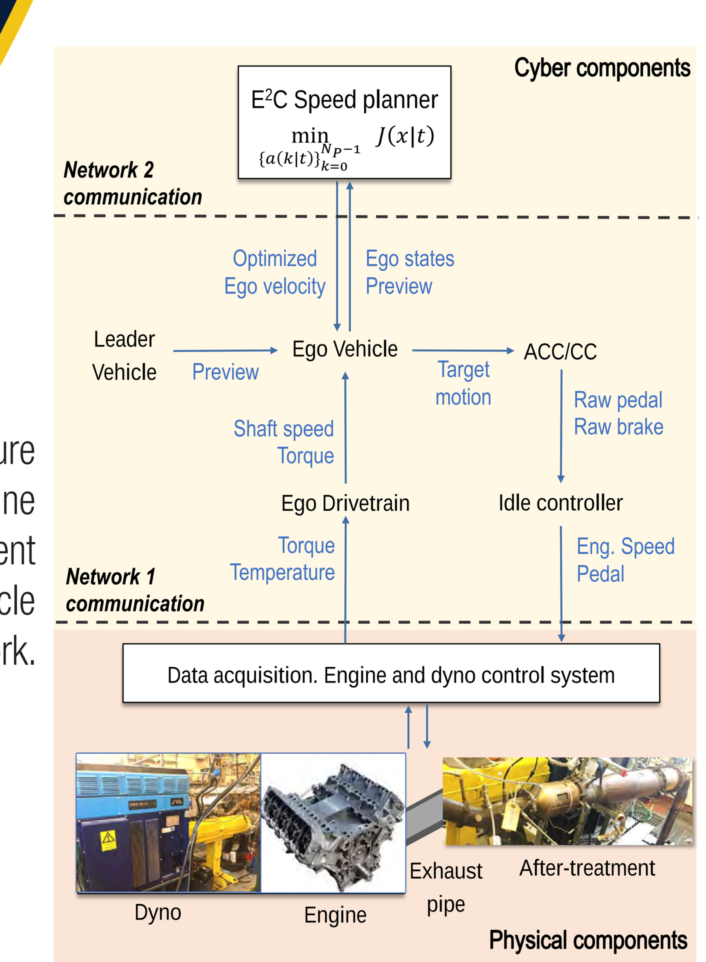


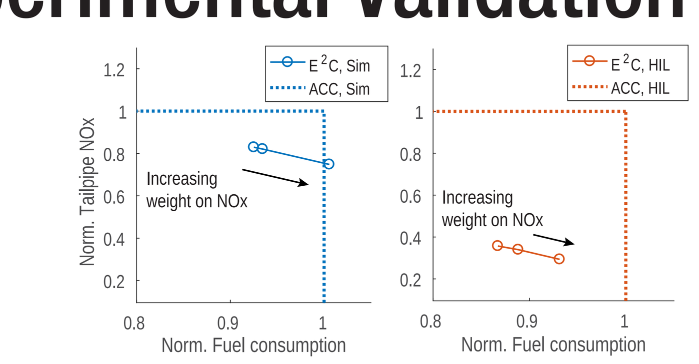


Predictors yield up to 80% improvement in coupling fidelity, but the benchmark method worsens it by up to 95% (left) in a connected testbed model (far left).

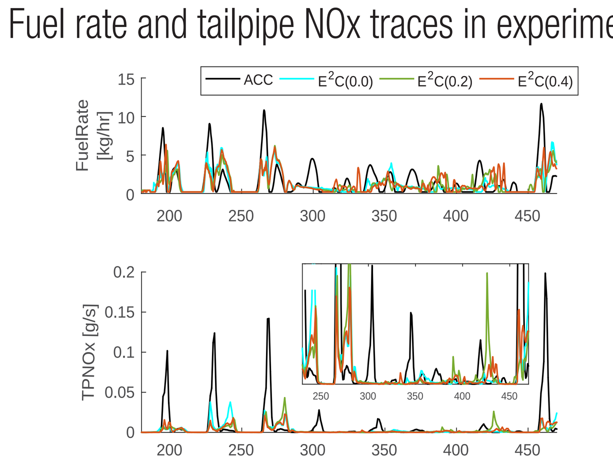
Experimental Validation

Experimental architecture includes a physical engine and a physical after-treatment system integrated with a simulated vehicle over the network.





Above: Comparison of benchmark adaptive cruise controller (ACC) vs. our speed planner in simulation (left) and experiment (right). **Below:** Fuel rate and tailpipe NOx traces in experiment.



Key Takeaway: Hardware-in-the-loop tests using the connected testbed reveal up to 2.3x higher benefits in reducing emissions and fuel consumption simulataneously compared to the simulation results.