CPS: Small: Behaviorally Compatible, Energy Efficient, and Network-Aware Vehicle Platooning Using Connected Vehicle Technology

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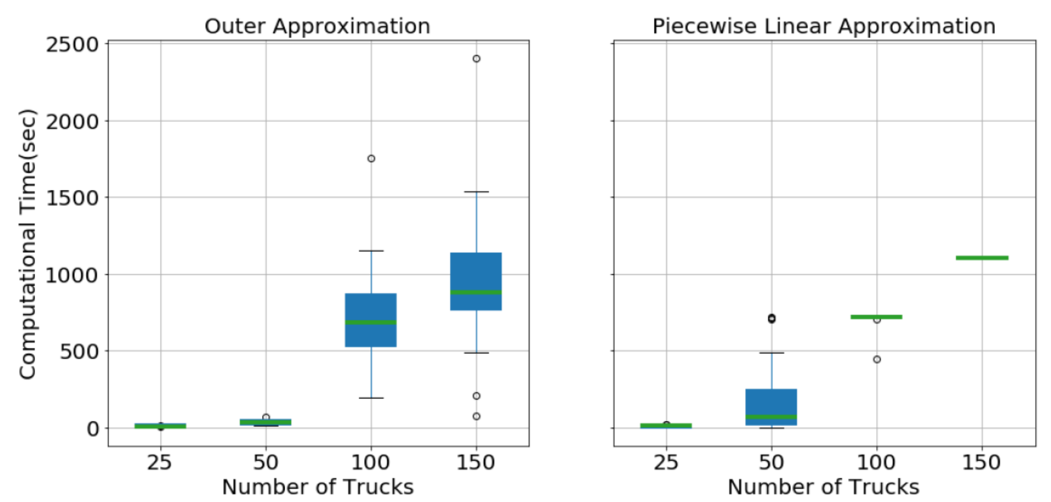
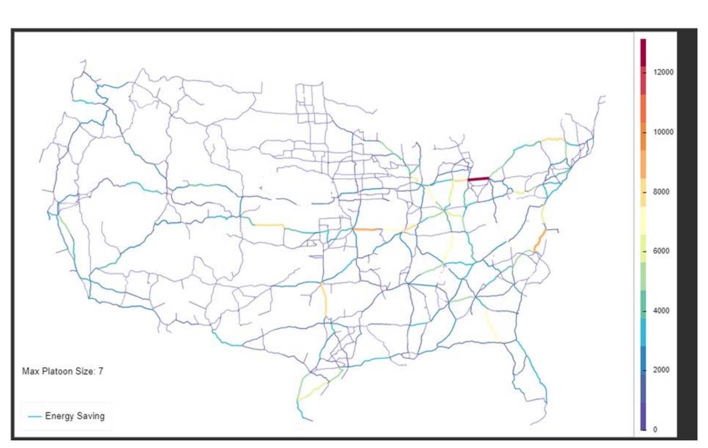
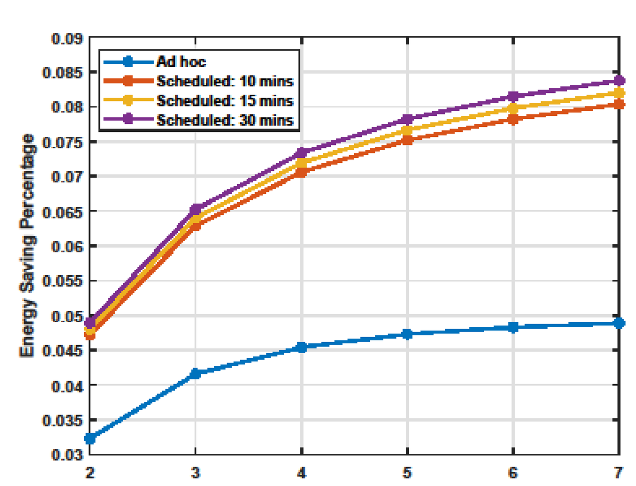
Scheduled Platooning

- A platoon is a set of virtually linked trucks that owing to connected and automated vehicle (CAV) technology can drive with small inter-vehicle headways.
- Due to comparatively low penetration rate of trucks in traffic streams, platooning should be scheduled ahead of time. Scheduled platooning determines routes, schedules, and speeds of trucks to ensure they "meet" at platoonable locations and can form platoons.
- Based on a constructed time-expanded network, the problem is formulated as a multicommodity flow problem with concave cost function non-convex. Scalable solution methodologies are proposed:



- Applied to large-scale networks, our methods can find high-quality solutions in a shorter period of time compared to the state-of-the-art.
- Empirical analyses show that the scheduled platooning for truck movements in the U.S. can yield 6.7% fuel savings (as compared to 2.7% by ad-hoc platooning)





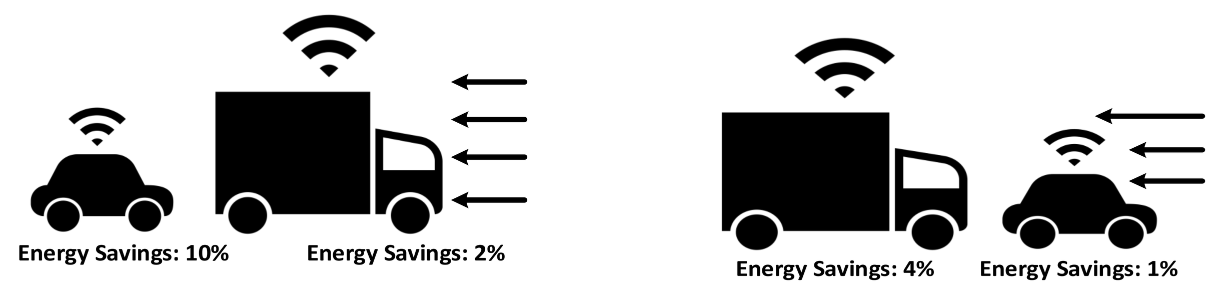
Intellectual Merit

- ✓ Developing a number of scalable and high-quality scheduled platooning algorithms that specify truck routes, schedules, and speeds
- ✓ Accounting for the behavioral components of platooning by integrating stable platoon structures into trajectory planning
- ✓ Enhancing traditional optimal-control-theory-based trajectory planning models by complementing them with Markov decision processes, to allow for incorporating strategically-condensed network-level data into the decision making process

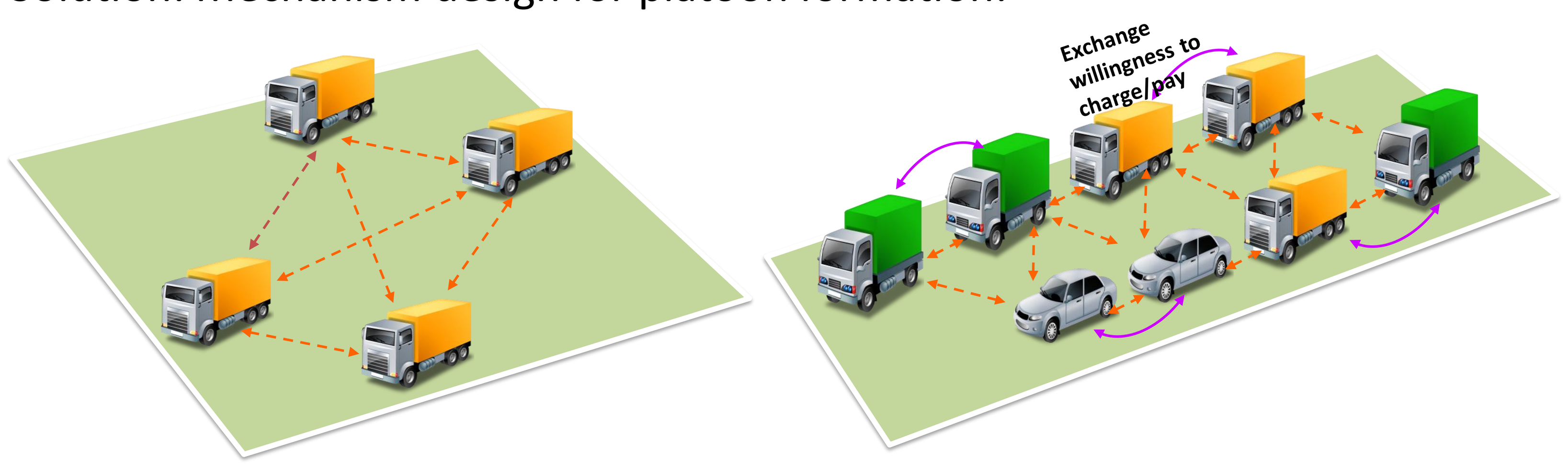
Stable Platoon Formation

Not all platoons are created equally. A vehicle's utility from participating in a platoon could vary depending on:

1. The composition of the platoon it joins
2. Its position in the platoon (typically vehicles in the middle of the platoon enjoy higher energy-efficiency benefits)



Solution: Mechanism design for platoon formation:



In the single-brand trucks scenario, an auction mechanism is utilized where multiple agents bid for the lead position of a platoon.

In the multi-brand trucks scenario, two mechanisms are used to determine the platoon formation and benefit reallocation: Bargaining with a random neighbor; Bargaining with multiple neighbors

Centralized and decentralized platoon formation is considered, where in the decentralized case neighbors negotiate using V2V communication technology:

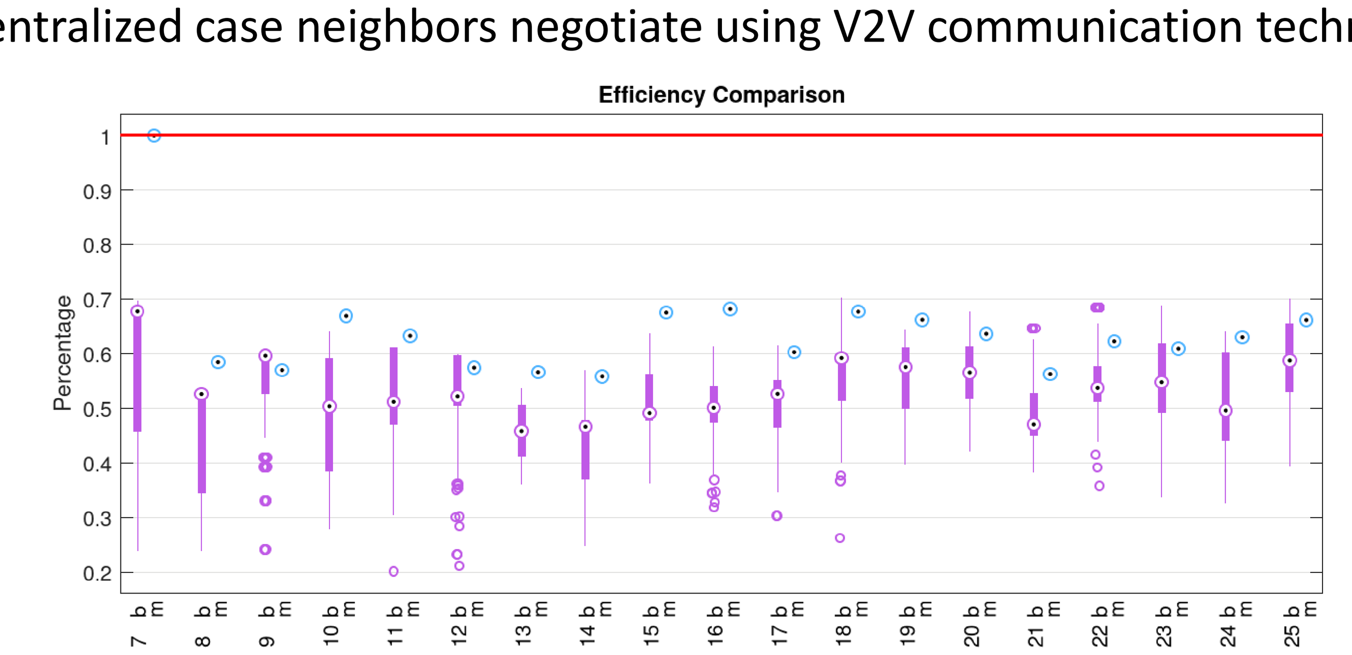


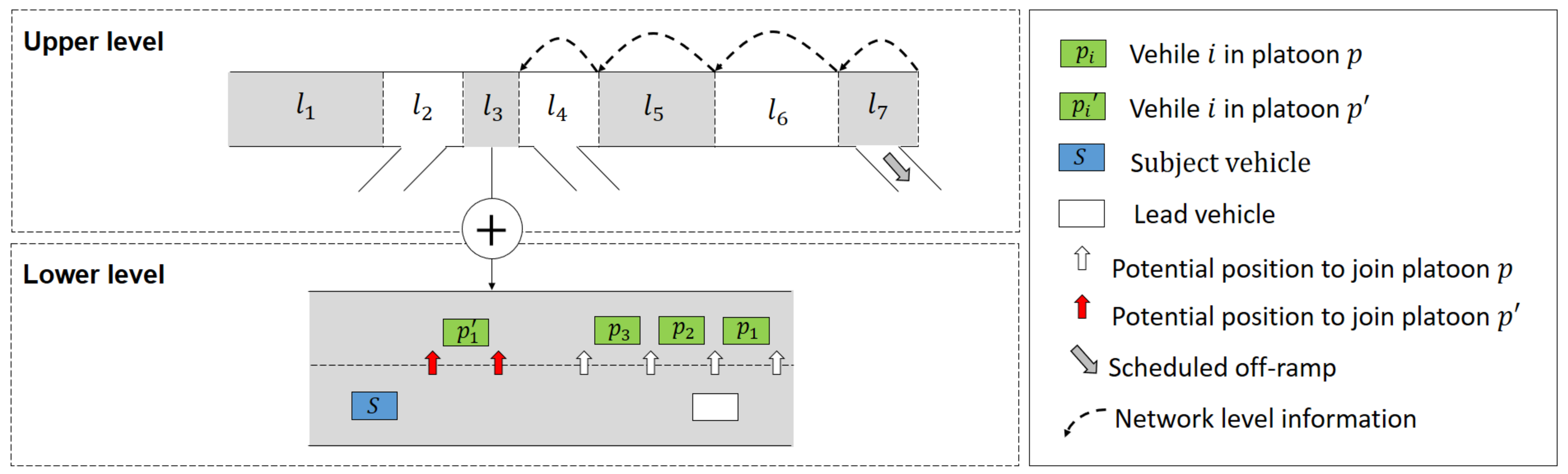
Figure 8: Centralized vs. Bargaining and Matching

- Assuming that each agent has at most 4 neighbors, local matching yields on average 64% of the efficiency of the centralized approach.
- Improvements from increasing neighborhood are marginal

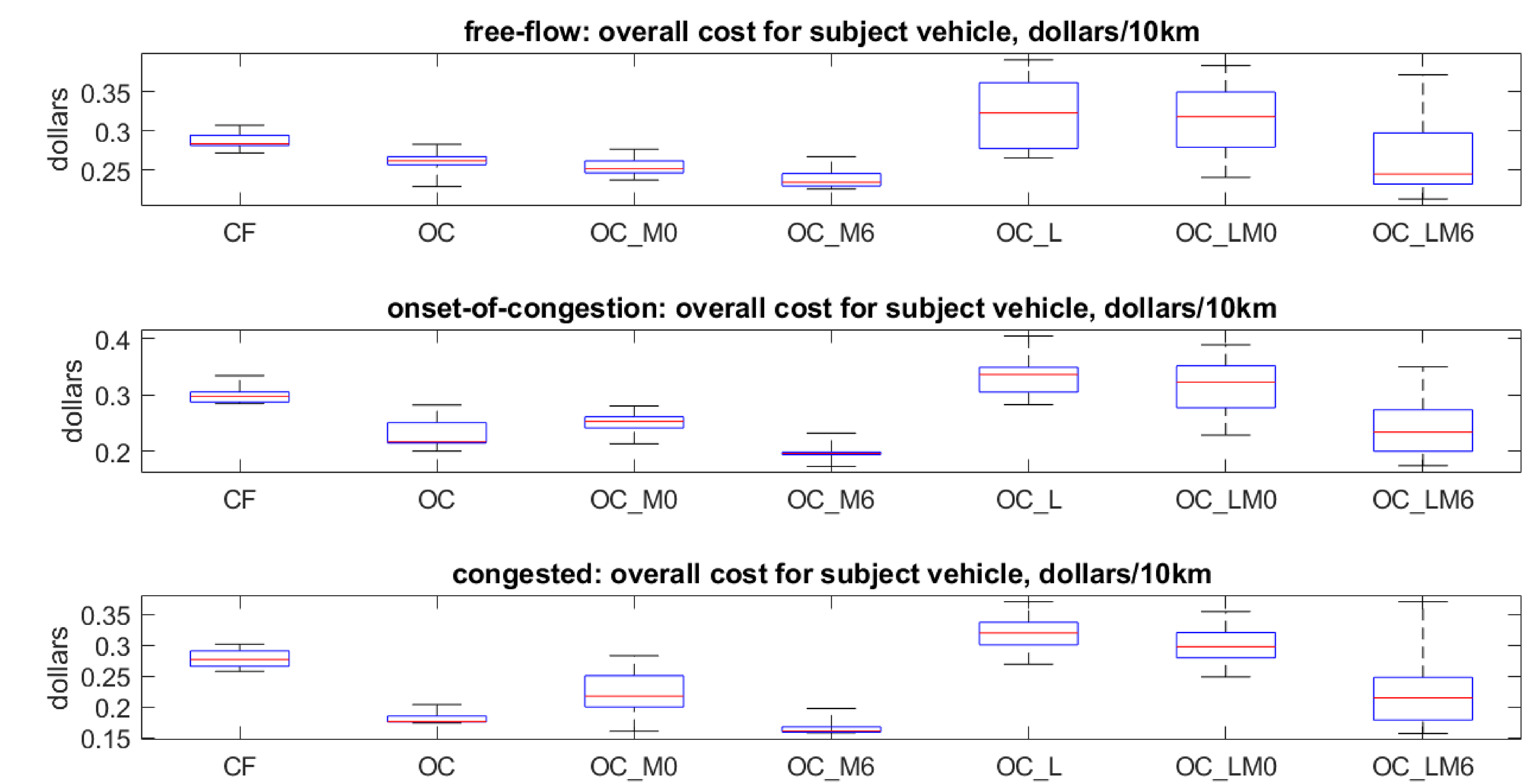
Real-Time Trajectory Planning

An optimal-control model that incorporates platoon merging and lane changing, while balancing global vs. local stability:

1. Trajectory planning to physically guide vehicles to form stable platoons
2. Incorporate future network-level information into trajectory optimization



Platooning is shown to have fuel-efficiency benefits for the subject vehicle as well as surrounding vehicles.



CF: IDM car following model
OC: Optimal control model with no platooning and lane changing
OC_Mm: OC, without lane changing, and requiring a platoon to continue for at least m km
OC_L: OC, with lane changing and without platooning
OC_LMm: OC, with lane changing, and requiring a platoon to continue for at least m km

Broader Impacts

- ✓ Creating energy efficiency through reducing aerodynamic drag on trucks participating in platoons
- ✓ Reducing truck emissions through speed harmonization, which can be realized as a side-benefit of platooning
- ✓ Increasing road capacity through reducing inter-vehicle gaps
- ✓ It is demonstrated that platooning offers fuel-efficiency benefits to the surrounding vehicles that are not part of the platoon
- ✓ Reducing cost of freight transportation

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