A MILP-based Vehicle-Intersection Coordination under the Autonomous Vehicle Environment

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Biography

S. AliReza Fayazi received his B.Sc. from K. N. Toosi University of Technology, Tehran, Iran and his M.Sc. from University of Tehran, Tehran, Iran both in Electrical Engineering. He is currently a Ph.D. candidate in mechanical engineering at Clemson University, Clemson, SC, USA. His current research interests include intelligent transportation systems implementation, and connected vehicle technologies.

Overview:

This research work proposes optimal scheduling of autonomous vehicle arrivals at intersections, eliminating the need for physical traffic signals. The proposed intersection control algorithm is assumed to have bi-directional communication links to approaching vehicles. After receiving subscription requests and status of approaching vehicles, the intersection control node calculates an arrival schedule that ensures safety while significantly reducing number of stops and intersection delays. The vehicle-intersection coordination problem is formulated as a Mixed-Integer Linear Program (MILP). A customized traffic micro-simulation and a cyber-physical test environment are developed which demonstrate the effectiveness of the proposed intersection control scheme in comparison to baseline scenarios.

Motivation

While traffic signals ensure safety of conflicting movements at intersections, they also cause much delay, wasted fuel, and tailpipe emissions. However, vehicle to signal connectivity can improve this situation. The situation can get even better with 100% penetration of autonomous vehicles since not only a physical traffic light is not needed anymore but also no minimum green time needs to be considered. However, the optimal scheduling of the autonomous vehicle arrivals at such intersections remains an open problem. This work attempts to address the gap in scheduling problem formulation and to show its benefits in microsimulation as well as experiments.

State of the Art

Smart traffic signal controllers (intersection controllers) will do more than just signaling right of ways and act intelligently as hubs that sense, route, and harmonize the flow of arterial traffic. More recent research has focused on two-way communication under the connected vehicle environment which allows the geographical data (positions, headings, and speeds) of the connected vehicles to be also wirelessly transmitted in real-time to smart intersection controllers [1].

Towards the most related work, Raravi et al. [2] determined the merge sequence in which vehicles cross the intersection region by formulating an optimization problem with constraints to ensure safety. The key difference between our work and [2] is that the formulations proposed in [2] are nonlinear and does not guarantee a global optimum. In addition to this, Lee et al. [3] also employed optimal control for a cooperative vehicle intersection control; however, their solution would not always be collision-free, and would not always provide a feasible solution because of the complexity of the optimization formulations (the objective function and constraints are nonlinear and non-convex) [4-5]. A recent work by Zhu et al. [5] uses a Mixed-Integer Linear Program (MILP) formulation, but the vehicles' capability to meet the scheduled time of arrival is not specifically addressed, nor shown in microsimulations. Our research work considers the interaction between vehicles in microsimulation as well as experimental environment and ensures that the vehicles can meet the scheduled arrival time by a robust tracking algorithm. Our proposed approach also encourages platooning although this is not explicitly incorporated into our formulations. By encouraging platoon formations, the intersection throughput is expected to significantly increase as shown by recent simulation results in [6-7].

Intellectual Merit

A novel intersection control scheme is proposed at the cyber layer to encourage platoon formation and facilitate uninterrupted intersection passage. Our three key contributions are in: i) an intersection control algorithm that anticipate vehicle arrivals and guides them into fast moving platoons, ii) reducing the vehicle-intersection coordination problem to a mixed-integer linear program, and iii) developing a customized microsimulation test environment in which simulated vehicles are guided by our MILP-based controller.

In communication, and experimental point of view, our novel scalable mechanism allows a large number of vehicles to subscribe to the intersection controller via cellular networks technology. This research also provides a vehicle-in-the-loop test bed with a real vehicle interacting with the intersection control cyber-layer and with the microsimulations in a virtual road network environment. In order to estimate the fuel consumption reduction of the implemented system, a new method is proposed for estimating fuel consumption using the basic engine diagnostic information.

Broader Impact

This research is expected to transform driving experience in smart cities under an autonomous driving environment (100% penetration rate of equipped vehicles). We hypothesize that the proposed optimization will result in reduced fuel consumption and intersection delay, even though these factors are not explicitly incorporated into the objective function.

Research Approach

We seek an intersection controller that coordinates and harmonizes the flow of the approaching connected/autonomous vehicles. As shown in Figure 1, the intersection controller resides on a computational server and receives

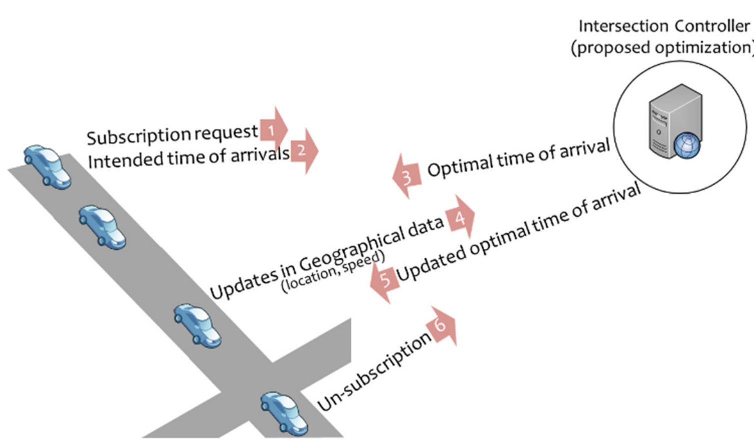

Figure 1: Path of data exchanged between the intersection controller and an approaching vehicle.

information of all subscribing vehicles and then optimally and regularly schedules the intersection arrival-times for each vehicle. The scheduled arrival-times are sent to all subscribing vehicles so that they can adjust their speed accordingly. The challenge is to find appropriate arrival-times that ensure safety, passenger comfort, and potentially traffic flow.

The formulations proposed in this research make it possible to solve this scheduling problem by MILP. The arrival-times are computed by periodically solving a MILP with the objective of minimizing intersection delay, while ensuring intersection safety and considering each vehicle's desired velocity.

Findings to Date

Microsimulation results demonstrated that our linear formulations not only minimized the intersection delay and number of stops significantly compared to pre-timed intersection benchmarks, but also ensured no crash occurred and did not compromise the average travel time.

Conclusions and Future Work

Our ongoing work is focused on implementing the Vehicle-In-the-Loop (VIL) simulation, allowing us to analyze the fuel consumption reduction potential of our intersection-vehicle coordination scheme (please see Figure 2). As no autonomous test vehicle is available at this stage of the work, the test-driver is guided via a virtual driver assistant.

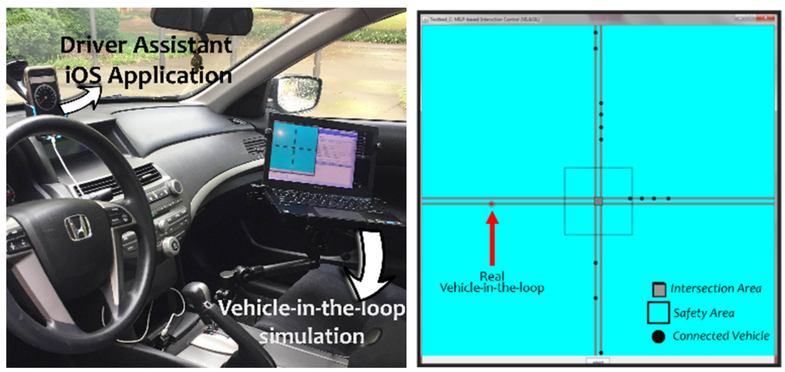

Figure 2: The real vehicle interact with hundreds of simulated vehicles in a microsimulation environment.

References

[1] N. J. Goodall, B. L. Smith, and B. Park, "Traffic signal control with connected vehicles," Transportation Research Record: Journal of the Transportation Research Board, 2381(1):65–72, 2013.

[2] G. Raravi, V. Shingde, K. Ramamritham, and J. Bharadia, "Merge algorithms for intelligent vehicles," In Next Generation Design and Verification Methodologies for Distributed Embedded Control Systems, pages 51–65. Springer, 2007.

[3] J. Lee and B. Park, "Development and evaluation of a cooperative vehicle intersection control algorithm under the connected vehicles environment," Intelligent Transportation Systems, IEEE Transactions on, 13(1):81–90, 2012.

[4] S I. Guler, M. Menendez, and L. Meier, "Using connected vehicle technology to improve the efficiency of intersections," Transportation Research Part C: Emerging Technologies, 46:121–131, 2014.

[5] F. Zhu and S. V Ukkusuri, "A linear programming formulation for autonomous intersection control within a dynamic traffic assignment and connected vehicle environment," Transportation Research Part C: Emerging Technologies, 55:363–378, 2015.

[6] R. Tachet, P. Santi, S. Sobolevsky, L. I. Reyes-Castro, E. Frazzoli, D. Helbing, and C. Ratti, "Revisiting street intersections using slot-based systems," PloS one, 11(3):e0149607, 2016.

[7] J. Lioris, R. Pedarsani, F. Y. Tascikaraoglu, and P. Varaiya, "Doubling throughput in urban roads by platooning," Accepted in the IFAC Symposium on Control in Transportation Systems, 2015.