Addressing Challenges of Connected-and-Automated Vehicle based Intersection Control

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Introduction

- Connected and automated vehicles have a great potential to improve transportation system efficiency, and many applications have been demonstrated through simulations and even real field implementations (e.g., cooperative adaptive cruise control).
- However, there is no field demonstration on intersection control algorithms that do not require traffic lights. This is in part due to two challenges:
  1) Computation time to generate connected-and-automated vehicle trajectories
  2) Latencies in the communication
- To deal with these two challenges, we developed an integrated framework that includes a well-known traffic simulator (i.e., VISSIM) and network simulator (i.e., OMNet++).
- To solve the two challenges, we applied an optimal control algorithm (OCA) instead of a cooperative vehicle intersection control (CVIC) and investigated an option of adjusting contention window (CW) parameters available in the MAC layer. Consequently, we found that OCA would work well in the integrated framework.

Integrated Simulation Framework

- In order to evaluate the two challenges, we integrated a microscopic traffic simulator, VISSIM 5.40 and a communication network simulator, OMNet++ 4.6. This integrated framework is based on a well-known vehicular network simulator, Veins.
- Features:
  1) Trusted vehicular mobility models that consist of car following model, lane changing model, and lateral behavior within a lane
  2) Fully-detailed models of IEEE 802.11p and IEEE 1609.4 DSRC/WAVE network layers, including multi-channel operation, QoS channel access, noise and interference effects
  3) Reasonable standard messages like a basic safety message (BSM)
  4) Explicit consideration of latencies in the communication and computation time in the intersection control algorithm while simulating connected-and-automated vehicles for the proposed intersection control.

First Challenge: Computation Time

- A cooperative vehicle intersection control (CVIC), one of well-known intersection control algorithms, was formulated as a nonlinear optimization problem and was solved using traditional optimization approaches (i.e., interior point method, active set method) and a heuristic approach (i.e., genetic algorithm).

- An optimal control algorithm (OCA) based on Hamiltonian analysis that can calculate each vehicle trajectory by solving an inverse of Hessian Matrix, based on current location and speed, assigned travel time to the stop bar and the exit speed. The problem can be formulated as follows:

$$\min_{u_i} = \min_{u_i} \frac{1}{2} \sum_{i=1}^{n} u_i^2$$
$$\text{Subject to:}$$
$$x_i(t_f) = 0, v_i(t_f) = v_i(0)$$
$$x_i(t_f) = x_i(t_0) + \delta_i, v_i(t_f) = v_i(0)$$

where \(i\) is a vehicle index, \(n\) is the number of vehicles in the control zone, \(t_f\) is initial time of this event, \(t_0\) is time to enter the merging zone, \(x_i\) is vehicle's position, \(v_i\) is speed, \(u_i\) is acceleration, and \(\delta_i\) is minimum safety distance.

Using Hamiltonian function and the vehicle dynamics equations, the optimal speed and position for each vehicle such as:

$$x_i(t) = \frac{1}{2} a_i t^2 + \frac{1}{2} b_i t^2 + c_i t + d_i$$
$$v_i(t) = \frac{1}{2} a_i t^2 + b_i t + c_i$$

The solution to the system can be calculated as \(p_i = (T_i)^{-1} q_i\), where \(p_i\) is a vector containing the four unknown constants \(a_i, c_i, b_i, \) and \(d_i\).

Conclusions

- We evaluated an intersection control algorithm called OCA in an isolated intersection using the developed integrated framework. The topology of the road network is a crossing intersection with two-lanes. Vehicles and ICM periodically send BSM and command message, respectively (period: 0.1s). Consequently, there was no collision at the intersection despite of the environment with various volumes (e.g., 720, 1440, 2160, and 2880). Our future works are as follows: 1) Multiple intersections, 2) Various intersections, and 3) Sophisticated adjusting techniques for CW parameters.

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