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

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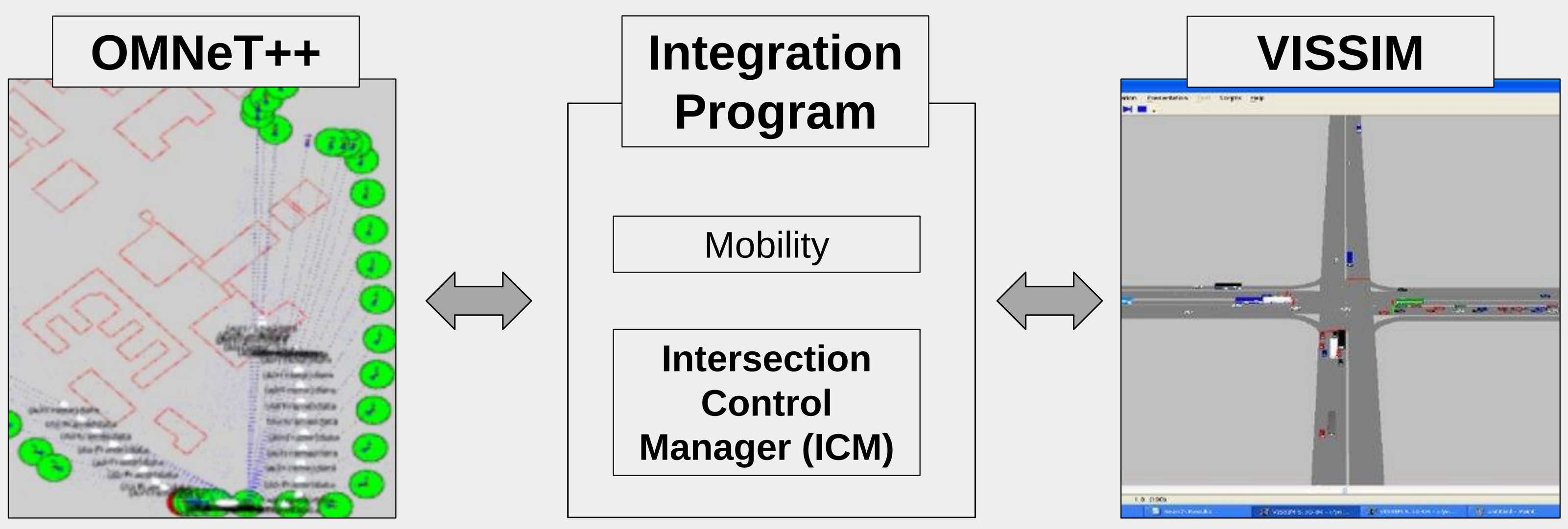
Introduction

- 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 theses 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.

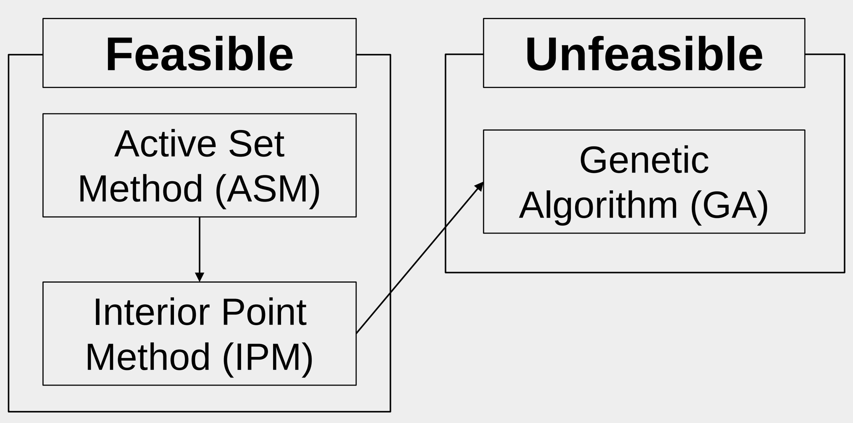
Integrated Simulation Framework

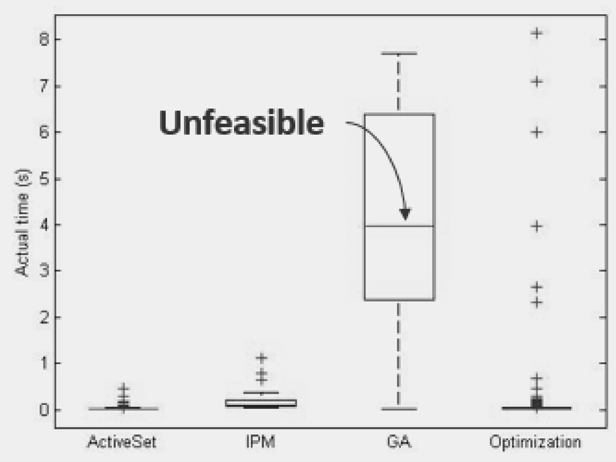
- In order to evaluate the two challenges, we integrated a microscopic traffic simulator, VISSIM 5.40 and a communication network simulator, OMNeT++ 4.6. This integrated framework is based on a well known vehicular network simulator, Veins.
- Features:
  - Trusted vehicular mobility models that consist of car following model, lane changing model, and lateral behavior within a lane
  - 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
  - Reasonable standard messages like a basic safety message (BSM)
  - **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:

$$\min_{u_i} J = \min_{u_i} \frac{1}{2} \sum_{i=1}^{n} \int_{t_i^0}^{t_i^f} {u_i}^2$$

Subject to:

$$\underbrace{\dot{x}_i = v_i, \dot{v}_i = u_i}_{\text{Vehicle Dynamics}} \quad \underbrace{x_i(t_i^0) = 0, v_i(t_i^0) = v_i}_{\text{Initial Conditions}} \quad \underbrace{x_i(t_i^f) = x_{i-1}(t_{i-1}^f) + \delta, v_i(t_i^0) = v_{i-1}}_{\text{Final Conditions}}$$

where i is a vehicle index, n is the number of vehicles in the control zone, t^0 is initial time of this event, t^f is time to enter the merging zone, x is vehicle's position, v is speed, u is acceleration, and δ is minimum safety distance.

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

$$\boldsymbol{x_i^*(t) = \frac{1}{6} a_i t^3 + \frac{1}{2} b_i t^2 + c_i t + d_i}$$

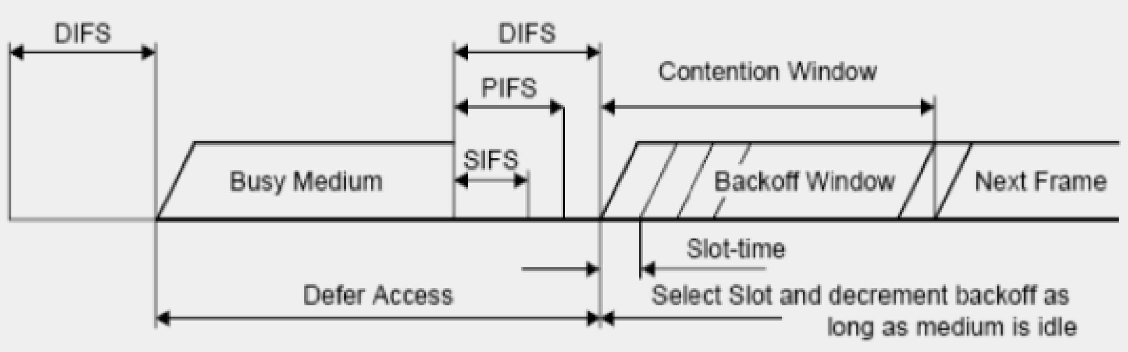
$$\boldsymbol{v_i^*(t) = \frac{1}{2} a_i t^2 + b_i t + c_i}$$

$$\begin{bmatrix} 1/6\,(t_i^0)^3 & 1/2\,(t_i^0)^2 & t_i^0 & 1 \\ 1/2\,(t_i^0)^2 & t_i^0 & 1 & 0 \\ 1/6\,(t_i^f)^3 & 1/2\,(t_i^f)^2 & t_i^f & 1 \\ 1/2\,(t_i^f)^2 & t_i^f & 1 & 0 \end{bmatrix} \begin{bmatrix} a_i \\ b_i \\ c_i \\ d_i \end{bmatrix} = \begin{bmatrix} x_i(t_i^0) \\ v_i(t_i^0) \\ x_i(t_i^f) \\ v_i(t_i^f) \end{bmatrix}$$

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, b_i, c_i and d_i.

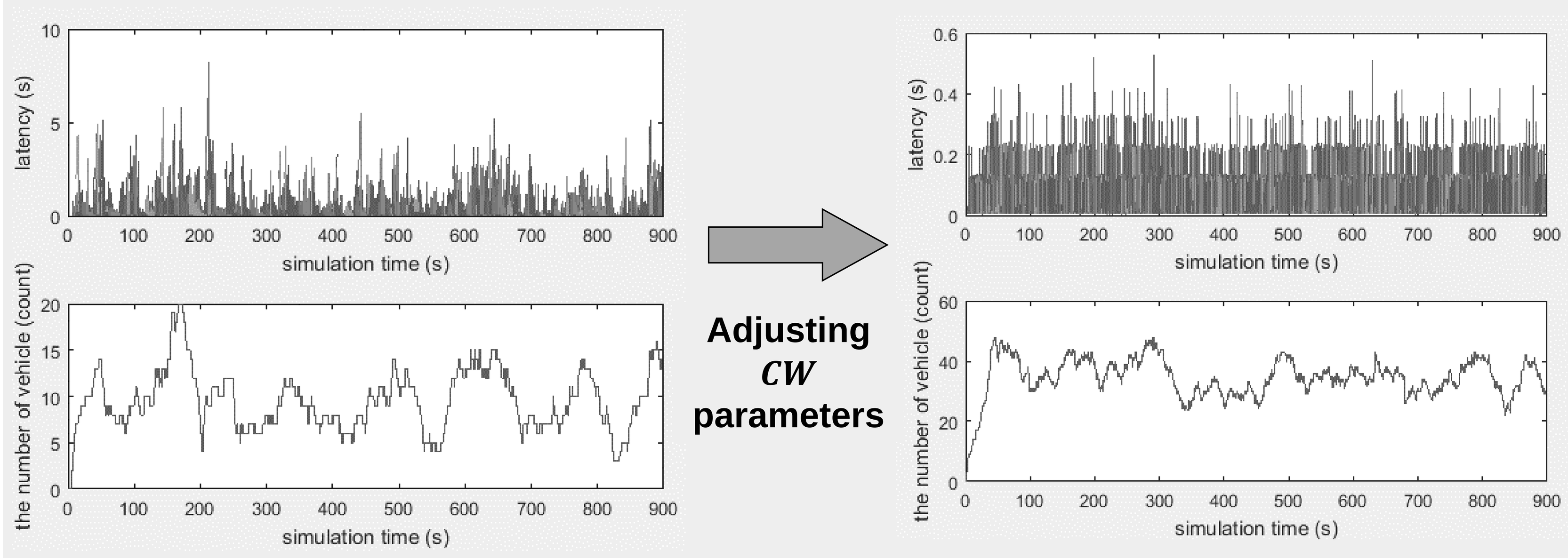
Second Challenge: Communication Latency

- Carrier access is managed by Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA):
  - If the medium is busy during Distributed Inter Frame Space (DIFS), a random back-off value from the interval [0, CW] will be chosen.
  - After successful transmission of a packet or if a packet is dropped, **CW is set back to CW_{min}**



[Default parameters]

Parameter	Value
SIFS	32 μs
SlotTime	13 μs
CW_{min}	15
CW_{max}	1023



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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