Priority-based Traffic Management Protocols for Autonomous Vehicles on Road Networks

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Motivation

This paper describes a generic simulation platform for testing traffic management protocols on road networks with autonomous vehicles. Firstly, we introduce a graph representation for road networks. In a road graph, the vertices represent intersections of roads while the arcs that link vertices represent the roads between respective intersections. Lanes on each road are indicated by labels. We then describe traffic management protocols in terms of the priority over roads or vehicles. Based on the open source project "Autonomous Intersection Management (AIM)" conducted by the Learning Agents Research Group of the AI Laboratory in the Department of Computer Sciences at the University of Texas at Austin3, we developed a generic simulation platform that can simulate traffics on any road network that has a graph representation of roads and a configuration of priorities among roads and vehicles4. With the new system, we can set the roads between any intersections with various speed limits. The vehicles can autonomously choose their routes and speeds to travel. The intersections are independently managed under different traffic control protocols based on preset priorities of roads and vehicles. Furthermore, the simulator provides a variety of data collection APIs, which allow automated data collection for different traffic scenarios.

Objectives

1. Formal model to complex road network
2. Formal representation of internal connection of an single intersection
3. Formal representation of traffic management protocols
4. Implementation of simulator

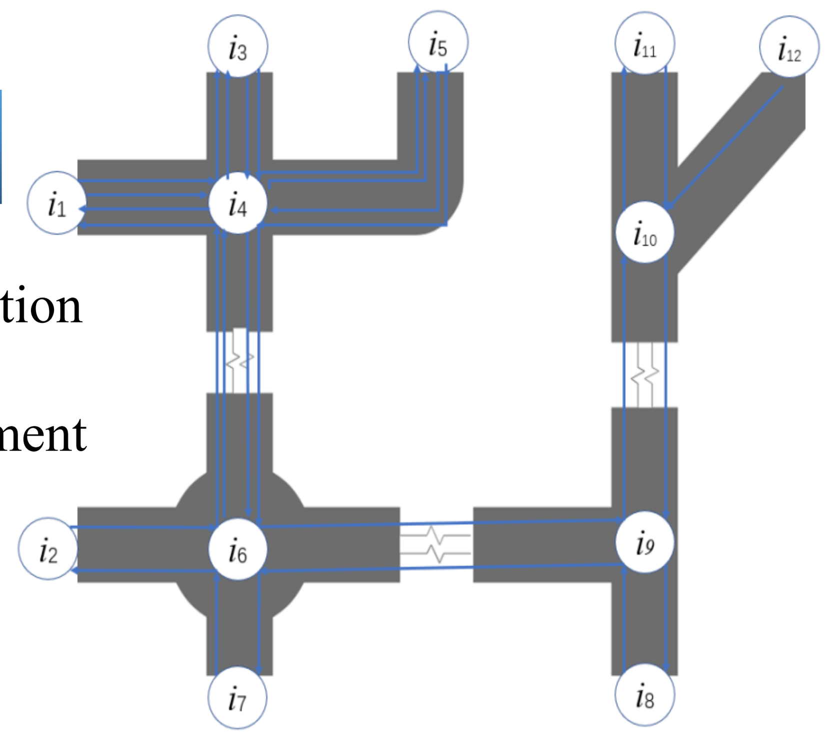


Fig. 1. Example of road network

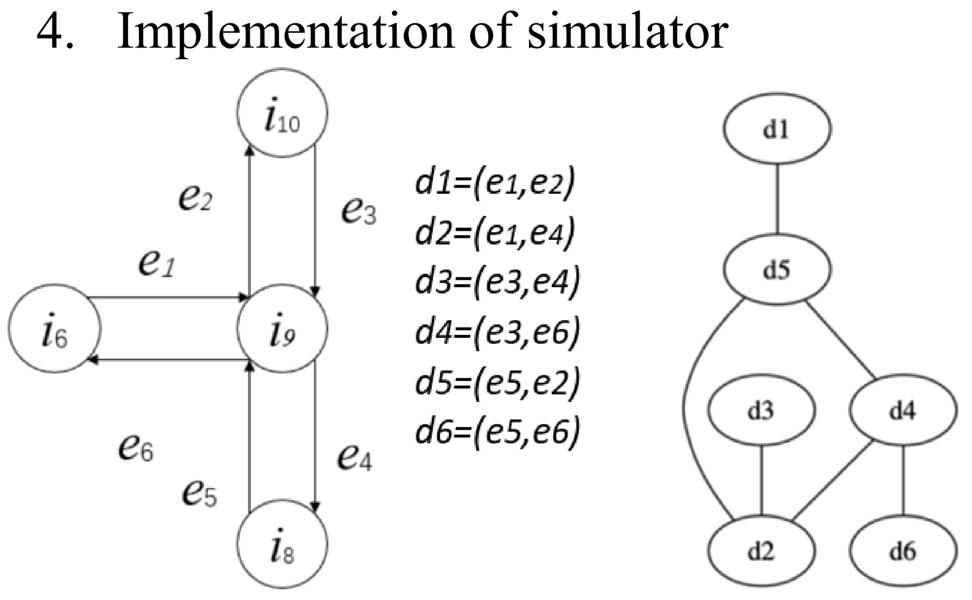


Fig. 2. Example of intersection relations

Intersection relations

Intersection relations (see figure 2):

Connection relation (D_i): a binary relations between edges at an intersection. It specify the legal connection between an incoming lane and an outgoing lane.

Conflict relation (C_i): a undirected graph that represents potential collision between connections at an intersection.

Road Network Modelling

Road Graph G=(N, L, E):

Nodes (N): a set of intersections

Edges (E): a set of road lanes linked between intersections

Labels (L) are used to identify the road lanes

Motivation

Vehicles often collide with other vehicles because they're routes intersect and thus obstruct the paths of others. The general rule that determines who has the right of precedence is called right of way. It defines who has the right to use the conflicting portion of the route and who must wait for the other to do so. For example, in a country where driving on the left, vehicles will give way to traffic on the right whenever they approach an intersection, which means that the road on the right has higher priority than the road on which the vehicle is traveling. Despite major variances in traffic management methods and systems, all traffic management methods can be classified into two types of traffic management protocols: road-based priority traffic management protocol and vehicle-based priority traffic management protocol. More specific, the road-based priority management can be divided into static-priority and dynamic-priority.

Static priority traffic management protocol

The static priority management protocol (see figure 3) is based on predefined priorities of the links at each intersection. Given a road network G = (I, L, E). For each intersection i ∈ I, and its connection relation D_i and conflict relation C_i, a static-priority management protocol $p_i = (D_i, \Phi_i)$ is a sub-graph of conflict relation Ci, where $\Phi_i \subseteq E_i$. It must satisfy the following conditions:

– Anti-symmetric: For any links d, d' ∈ D_i such that (d, d') ∈ Ei. If (d, d') ∈ Φ_i then (d, d') ∉ Φ_i;

– Transitive: For any links d, d', d'' ∈ Di such that (d, d'), (d', d''), (d', d'') ∈ E_i. If (d, d'), (d', d'') ∈ Φ_i, then (d, d'') ∈ Φ_i;

– Complete relative to E_i: For any links d, d' ∈ D_i, if (d, d') ∈ E_i, then (d; d') ∈ Φ_i or (d', d) ∈ Φ_i

Dynamic priority traffic management protocol

Given a road network G = (I, L, E), connection relation D_i and conflict relation C_i, for each intersection i ∈ I. A dynamic-priority management protocol $\eta_i : T \rightarrow 2^{P_i}$ is a function that maps each time period to a priority graph.

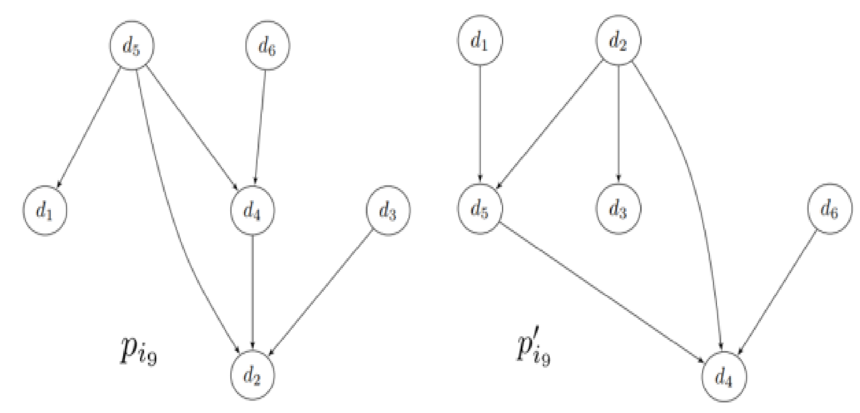


Fig. 3. Example of priority graph

Algorithm 1 Vehicle-based priority management protocol

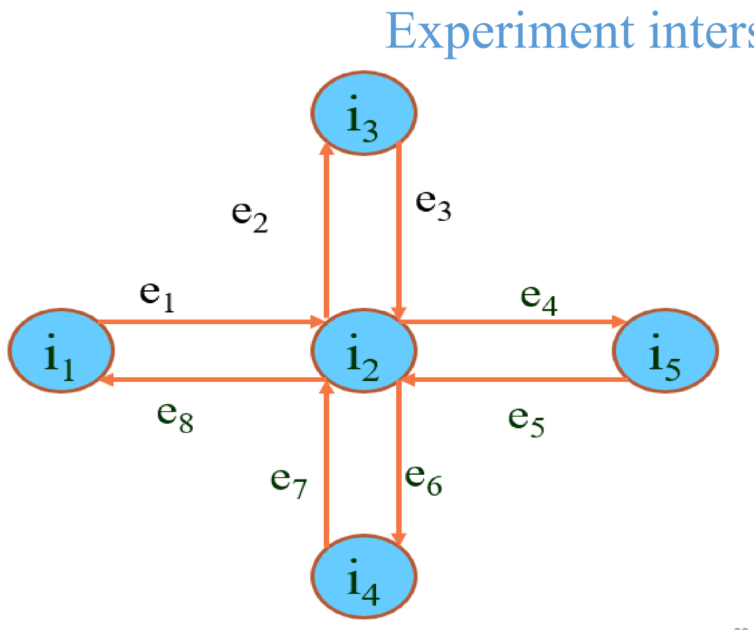
Input: V_i is a set of vehicles that cross an intersection i.

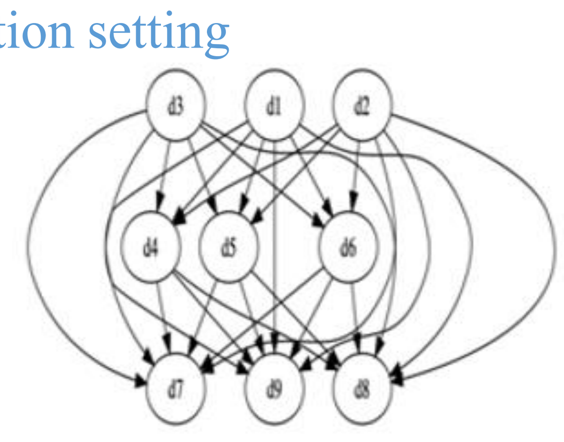
Output: $CS[|V_i|]$ is cross sequence of vehicles.

```
1: round = 0;
2: Participants(round): A set of first vehicles on every incoming edges of intersection i;
3: while round < |V_i| do
4:    Proposal(round) = {t(v) | ∀v ∈ Participants(round)};
5:    Winner = arg min_{v∈Proposal(round)} arrivetime(v);
6:    CS[round] = Winner;
7:    round = round + 1;
8:    Participants(round) = Participants(round) ∪ {new_vehicle} \ winner, where
      new_vehicle is the vehicle behind of the winner vehicle.
9: end while
```

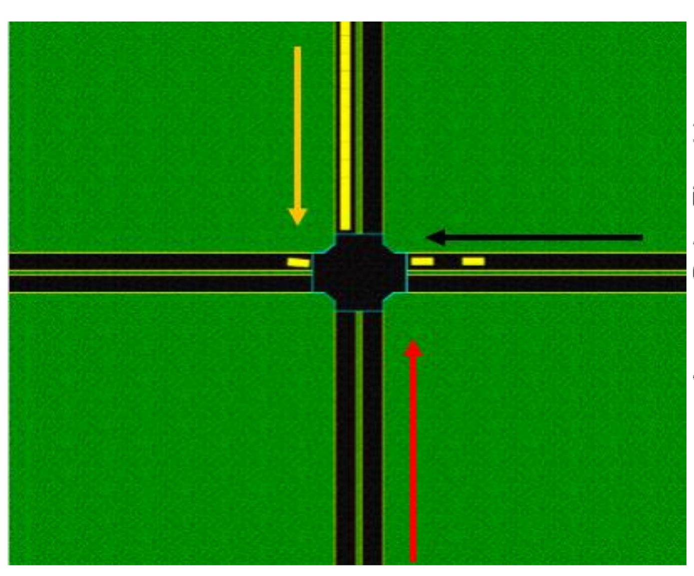
Experiment setting and results

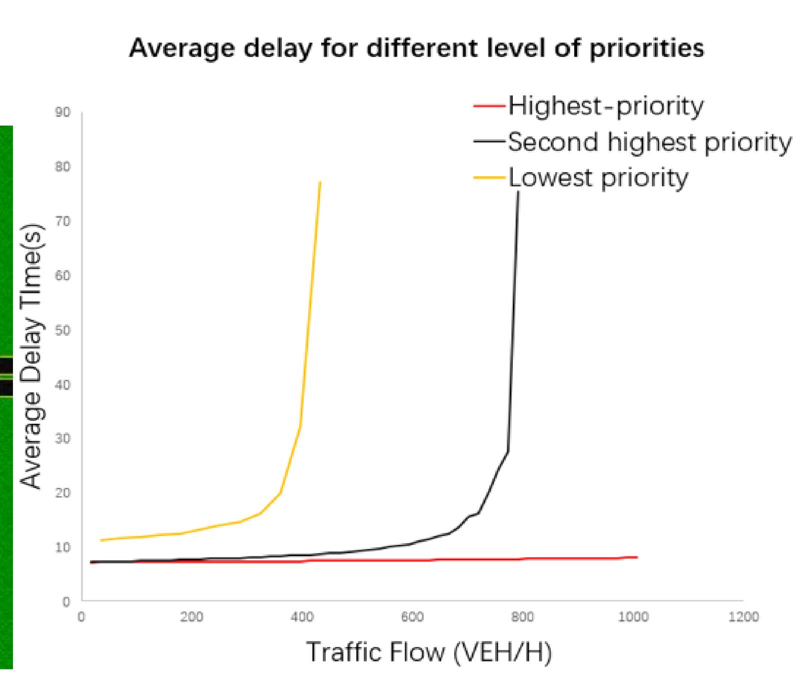
Experiment intersection setting





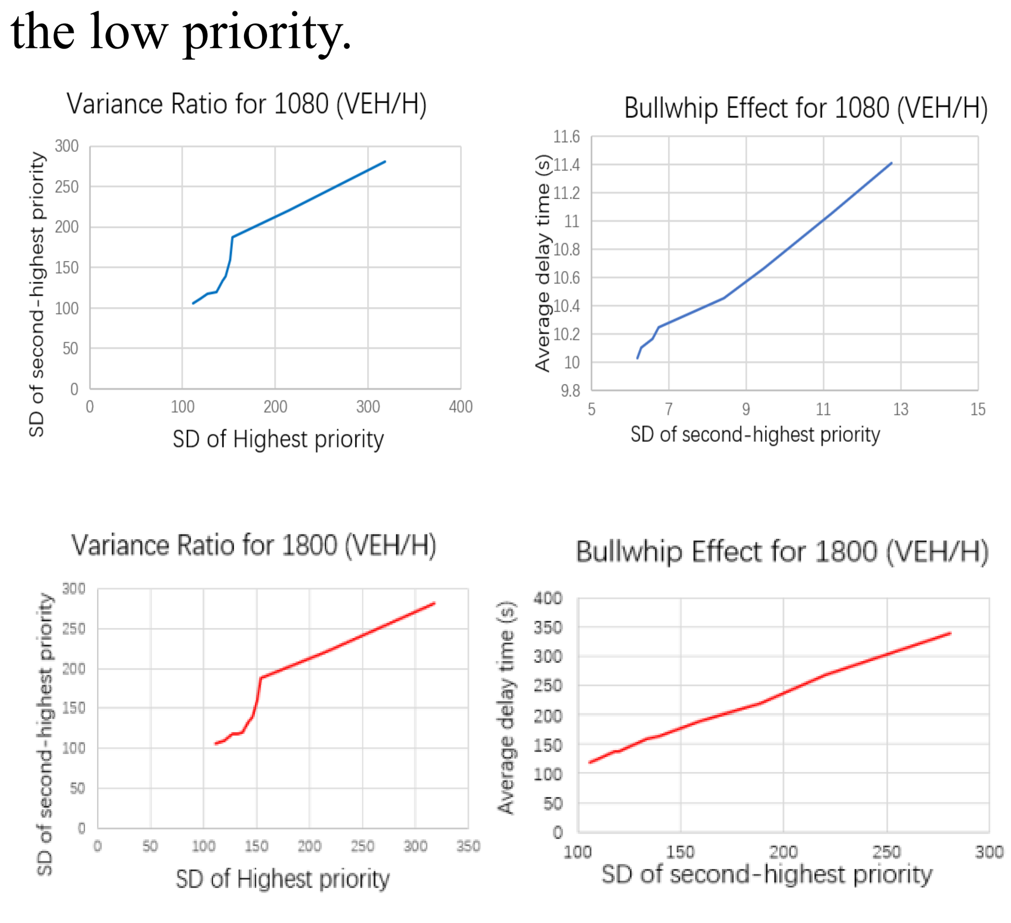
Priority Graph





Bullwhip effect

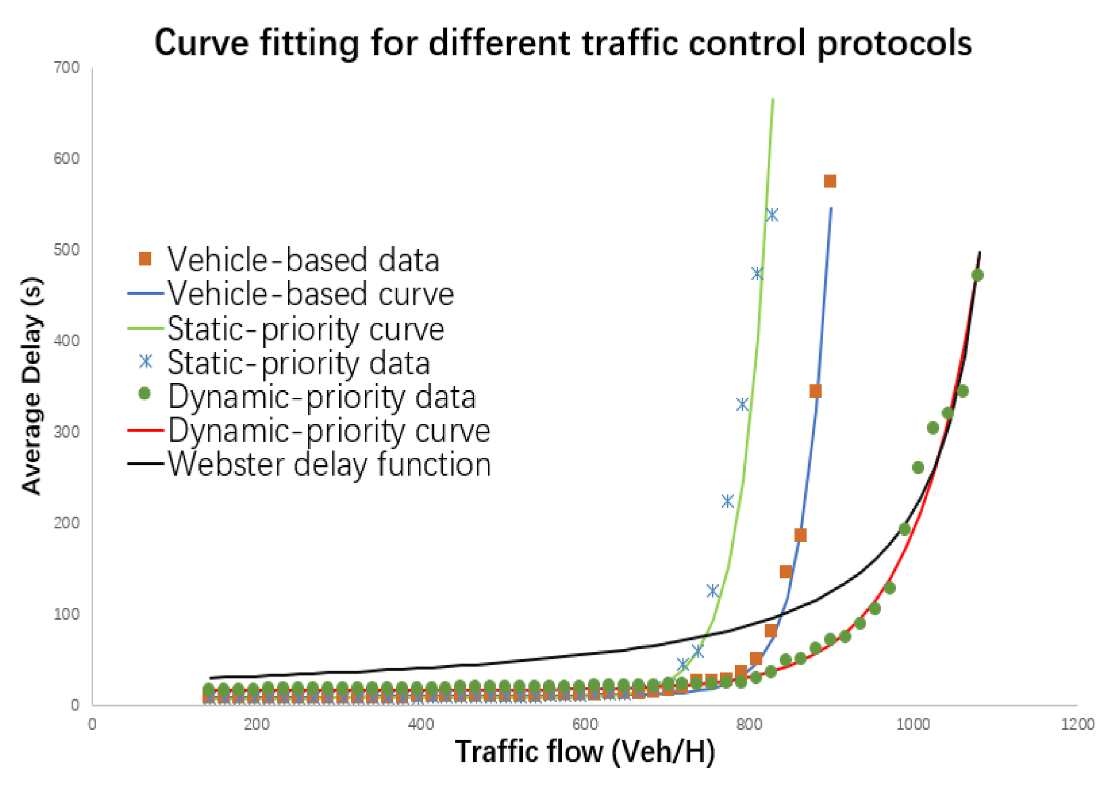
In the static-priority management protocol, the bullwhip effect is interpreted as whether the change of the standard deviation of the low priority will be affected when the standard deviation of the high priority changes, thereby affecting the delay time of the low priority.



Latency function

Given traffic flow f, the latency of traffic D, the latency function for each link is defined as

$$D = ae^{bf} + cf + d$$



Curve fitting results

$$D_s = (4.233 \times 10^{-8})e^{0.02834f} + 0.00189f + 7.0244$$

$$D_v = (1.002 \times 10^{-9})e^{0.03f} + 0.00581f + 7.24$$

$$D_t = (6.34 \times 10^{-4})e^{0.01253f} + 0.000338f + 16.17$$

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