Semi-Autonomous Intersection Management

Extended Abstract 254

ABSTRACT

Autonomous Intersection Management (AIM) is a reservation-based intersection control protocol that leverages the capacities of autonomous vehicles to dramatically reduce traffic delay at intersections. In the future, however, some vehicles on the road may still be driven by human drivers, but AIM is designed to work solely with autonomous vehicles. Moreover, we anticipate that there will be a long transition period during which most vehicles have some but not all capabilities of fully autonomous vehicles. In fact, this transition period has silently begun—adaptive cruise control systems and lane departure warning systems have become widely available as optional equipment on luxury production vehicles since the late 90s. In this paper, we introduce a new protocol called *Semi-Autonomous Intersection Management* (SemiAIM), which allows vehicles with partially-autonomous features such as adaptive cruise control to make reservations in AIM. We demonstrate the feasibility for vehicles with limited autonomy to make reservations to enter an intersection in AIM-like style. Our simulation results show that traffic delay of semi-autonomous vehicles in SemiAIM can be greatly reduced.

1. INTRODUCTION

Recent robotic car competitions and demonstrations have convincingly shown that autonomous vehicles are feasible with current generation of hardware [1]. Looking ahead to the time when autonomous cars will be common, Dresner and Stone proposed a new intersection control protocol called *Autonomous Intersection Management* (AIM) and showed that by leveraging the control and network capabilities of autonomous vehicles it is possible to design an intersection control protocol that is much more efficient than traffic signals [3]. By removing human factors from control loops, autonomous vehicles, with the help of advanced sensing devices, can be safer and more reliable than human drivers. The AIM protocol exploits the fine control of autonomous vehicles to allow more vehicles simultaneously cross an intersection, thus effectively reducing the delay of vehicles by orders of magnitude compared to traffic signals [4].

AIM works solely with autonomous vehicles. But we anticipate that there will be a long transition period during which most vehicles have some but not all capabilities of fully autonomous vehicles. In fact, this transition period has silently begun. Since the late 90s, adaptive cruise control systems and lane departure warning systems have become widely available as optional equipment on luxury production vehicles. Today's automatic parking systems such as those in the Toyota Prius and various BMW models can perform parallel parking with little or no human intervention. Hence, it is important to develop an intersection control protocol that works with human-controlled vehicles and semi-autonomous vehicles.

Previously, Dresner and Peter proposed FCFS-Signal, a.k.a. FCFS-Light, which allows human-controlled vehicles to share the road with autonomous vehicles at intersections in AIM [2]. However, their approach has some drawbacks. First, the efficiency of FCFS-Signal decreases over time during red signals since more and more human-controlled vehicles stop at the intersection and block the entrances of the intersection. Second, a large number of tiles are reserved for green signals, severely interrupting the traffic flow. Third, FCFS-Signal cannot take advantages of the limited autonomous capabilities of semi-autonomous vehicles. To remedy these issues, we propose a new autonomous intersection system called *SemiAIM* that works with not only with autonomous vehicles but also human-controlled vehicles and semi-autonomous vehicles.

2. CONSTRAINT-BASED RESERVATION SYSTEMS

SemiAIM extends AIM by allowing human-controlled vehicles and semi-autonomous vehicles to make reservations in the same way as autonomous vehicles. The key idea of SemiAIM is to turn AIM into a *constraint-based reservation system*, which allows vehicles to make reservations in terms of constraints over (1) their driving profile such as their arrival time and arrival velocity, and (2) the relationships with other vehicles. In AIM, a reservation request is a 5-tuple $\langle l_1, l_2, t_0, v_0, p \rangle$, where l_1 is the entry lane, l_2 is the exit lane, t_0 is the arrival time, v_0 is the arrival velocity, and p is the physical characteristics of the vehicle. These information allows the Intersection Manager (IM) to compute the exact trajectory of the vehicle in the intersection and reserve tiles for the vehicle on the trajectory. However, this computation *assumes* the vehicle can be controlled precisely in the intersection, which is a difficult task for human drivers due to human errors. Likewise, semi-autonomous vehicles may be "handicapped" and cannot choose the trajectories they want. For example, vehicles with cruise control can only guarantee to maintain certain speed on a strange road, and their reservations are limited to this type of maneuvers. Similarly, vehicles with adaptive cruise control can maintain a certain distance from the vehicle in front, and its reservation requests cannot allow these vehicles to drive freely due to the dependency of the trajectories of other vehicles. Therefore, we need a new reservation system that relaxes the assumption of exact trajectories so as to allow both hu-

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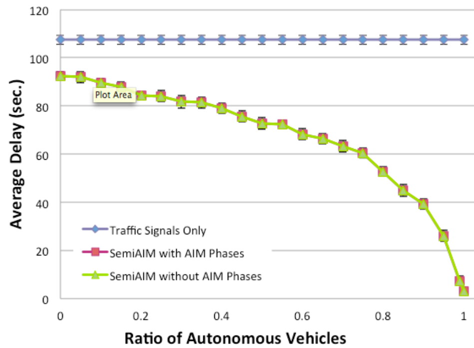

Figure 1: Average delay vs. the ratio of autonomous vehicles to human-controlled vehicles. Traffic level = 720 veh./hour/lane.

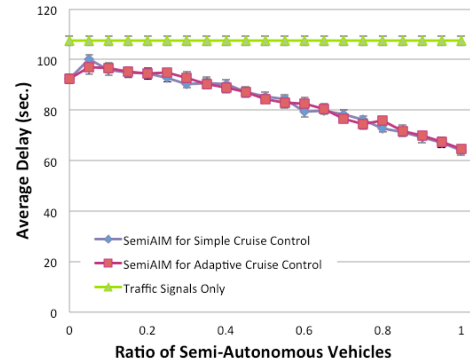

Figure 2: Average delay vs. the ratio of semi-autonomous vehicles to human-controlled vehicles. T. L. = 720 veh./hour/lane.

man drivers and semi-autonomous vehicles to make reservations.

We propose a new constraint language to facilitate communications between vehicles and IMs. A vehicle has to express their reservation requests in this language, and the IM will be able to interpret the requests and determine whether it is possible to reserve a set of tiles for the requests. The language is a logic-based action language similar to the STRIPS-style operators with numerical constraints. As an example, a human driver, with the help of a cellphone or other communication devices, can make a reservation like this: "(eq arrival-velocity 30mph) $\wedge$ ($\geq$ arrival-time 10:15:30am) $\wedge$ ($\leq$ arrival-time 10:15:05am) $\wedge$ (direction straight)". Upon receiving this reservation request, the IM will determine the set of tiles on *all* possible trajectories of the vehicle and check whether any of these tiles have been reserved by other vehicles. If none of these tiles is reseved, the IM sends a confirmation message to the vehicle and the human driver will then turn on the cruise control accordingly. While this maneuver may seem dangerous when there are other vehicles in the intersection, the human driver can propose a request with more relaxed constraints that allows him/her to enter the intersection comfortably and safely, and the IM can guarantee there is no collision. If the human driver fails to enter the intersection according to the proposed reservation or the driver does not have any equipment to make reservations, the human driver must follow the traffic signals at the intersection.

For semi-autonomous vehicles with adaptive cruise control, a reservation request can be like this: "(follow-within GXC345 5m)", where GXC345 is the tag of the vehicle in front of the vehicle. To determine the set of tiles for this vehicle, the IM in SemiAIM has to derive the trajectories from the reservation request of the vehicle GXC345. Hence, the IM in SemiAIM will retain all reservation requests in symbolic forms. If the vehicle GXC345 is also a semi-autonomous vehicle whose request depends on other requests, the IM has to deduce the trajectories by constraint propagation. Cyclic dependences may occur if vehicles send requests simultaneously. The IM should break the cycle to prevent deadlock and let all vehicles enter the intersection eventually.

3. PRELIMINARY RESULTS FROM SIMULATIONS

To demonstrate the feasibility of SemiAIM as well as evaluate the hypothesis that SemiAIM can offer substantial improvements over traffic signals and FCFS-Signal, we modified the AIM4 simulator at `http://www.cs.utexas.edu/~aim` to simulate the behavior of vehicles in the constraint-based reservation system and measured the average delays of vehicles under (1) AIM, (2) SemiAIM, and (3) traffic signals with optimized signal timing.

The experiments were conducted in a 3x3 intersection. In the first experiment, the traffic consisted of human-controlled vehicles and fully autonomous vehicles only. We gradually increased the percentage of autonomous vehicles while keeping the traffic level at 720 vehicles/hour/lane. We compared two variants of SemiAIM with optimized traffic signals in which all vehicles must follow the traffic signals. Figure 1 shows that as the number of autonomous vehicles increases, the average delay decreases. In particular, when most vehicles are autonomous, the average delay is close to zero. In the second experiment, we created a traffic consisting of human-controlled vehicles and two kinds of semi-autonomous vehicles but no autonomous vehicles. We measured the average delay of all vehicles when we gradually increased the percentage of semi-autonomous vehicles. Then we compared SemiAIM with optimized traffic signals. The results in Figure 2 shows that as the number of semi-autonomous vehicles increases, the average delay decreases under SemiAIM. While the decrease is not as dramatic as the decrease when the percentage of autonomous vehicles is near 100% in Figure 1, SemiAIM can reduce about 43% of the average delay when most vehicles are semi-autonomous.

4. CONCLUSIONS AND FUTURE WORK

In this paper, we described the idea behind SemiAIM, a new constraint-based autonomous intersection management system that allows human-controlled vehicles and semi-autonomous vehicles, in addition to fully autonomous vehicles, to make reservations and enter an intersection in AIM. Our experimental results showed that our system can greatly decrease traffic delay when most vehicles are semi-autonomous. In the future, we will investigate how different types of reservation requests affect the efficiency of SemiAIM.

5. REFERENCES

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