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Autonomous Intersection Management for Semi-Autonomous Vehicles

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ABSTRACT –

Recent advances in autonomous vehicle technology will open the door to highly efficient transportation systems in the future, as demonstrated by Autonomous Intersection Management, an intersection control protocol designed for fully autonomous vehicles. We, however, anticipate there will be a long transition period during which most vehicles have some but not all capabilities of fully autonomous vehicles. This paper introduces a new protocol called *Semi-Autonomous Intersection Management*, which allows vehicles with partially-autonomous features such as adaptive cruise control to enter an intersection from different directions simultaneously. Our experiments show that this protocol can greatly decrease traffic delay when most vehicles are semi-autonomous. Our incremental deployment study reveals that traffic delay keeps decreasing as more and more vehicles employ features of autonomy.

INTRODUCTION

Recent robotic car competitions and demonstrations have convincingly shown that autonomous vehicles are feasible with the 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 [2]. 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 to cross an intersection, thus effectively reducing the delay of vehicles by orders of magnitude compared to traffic signals [3].

AIM is designed for the time when all vehicles are fully autonomous. We, however, 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 already begun. Since the late 1990s, adaptive cruise control systems and lane departure warning systems have become widely available as optional equipment on luxury production vehicles. The National Highway Traffic Safety Administration acknowledges that fully autonomous vehicles represent just the top level in five levels of vehicle automation [4]. Indeed, they define a level below this top level with vehicles that have limited self-driving automation. The main motivation of this paper is to propose a new intersection control system called *Semi-Autonomous Intersection Management (SemiAIM)* that can accommodate both fully autonomous vehicles and *semi-autonomous* vehicles with limited self-driving automation. There is a high likelihood that human-driven vehicles, semi-autonomous vehicles, and fully autonomous vehicles will *coexist* on the road in the future. SemiAIM takes advantages of this trend and allows autonomous intersections to handle a traffic mixture with different types of vehicles.

The main contributions of this paper are 1) the introduction of the concept of SemiAIM; 2) a specification of constraint-based reservation requests for semi-autonomous vehicles; and 3) detailed empirical results demonstrating the effectiveness of this protocol, especially in moderate traffic levels with a mix of human-driven, semi-autonomous, and fully autonomous vehicles. The remainder of the paper is organized as follows. Section II outlines the architecture of AIM which forms the basis of SemiAIM. Section III and Section IV categorize semi-autonomous vehicles and discuss the interaction between human drivers and semi-autonomous vehicles in SemiAIM. Section V describes the constraint-based reservation system in SemiAIM. Section VI presents the results of the simulation experiments we used to evaluate SemiAIM. The related work and the conclusion are given in Section VII and VIII, respectively.

1. THE RESERVATION IDEA

With these seven desiderata in mind, we have introduced a novel approach to efficient intersection management that is a radical departure from existing traffic signal optimization schemes. The solution is based on a reservation paradigm, in which vehicles "call ahead" to reserve space-time in the intersection [2]. In the approach, we assume that computer programs called driver agents control the vehicles, while an arbiter agent called an intersection manager is placed at each intersection. The driver agents attempt to reserve a block of space-time in the intersection. The intersection manager decides whether to grant or reject requested reservations according to an intersection control policy. In brief, the paradigm proceeds as follows.

- An approaching vehicle announces its impending arrival to the intersection manager. The vehicle indicates its size, predicted arrival time, velocity, acceleration, and arrival and departure lanes.
- The intersection manager simulates the vehicle's path through the intersection, checking for conflicts with the paths of any previously processed vehicles.
- If there are no conflicts, the intersection manager issues a reservation. It becomes the vehicle's responsibility to arrive at, and travel through, the intersection as specified (within a range of error tolerance).
- In the case of a conflict, the intersection manager suggests an alternate later reservation.
- The car may only enter the intersection once it has successfully obtained a reservation.
- Upon leaving the intersection, the car informs the intersection manager that its passage through the intersection was successful.

2. INTERSECTION CONTROL POLICY

Our prototype intersection control policy divides the intersection into a grid of reservation tiles. When a vehicle approaches the intersection, the intersection manager uses the data in the reservation request regarding the time and velocity of arrival, vehicle size, etc. to simulate the intended journey across the intersection. At each simulated time step, the policy determines which reservation tiles will be occupied by the vehicle.

If at any time during the trajectory simulation the requesting vehicle occupies a reservation tile that is already reserved by another vehicle, or could be occupied by a human-driven vehicle, the policy rejects the driver's reservation request, and the intersection manager communicates this to the driver agent. Otherwise, the policy accepts the

3. SIMULATION RESULTS.

Empirical results in simulation demonstrate that our proposed reservation system can dramatically improve the intersection efficiency when compared to traditional intersection control mechanisms. To quantify efficiency, we introduce delay, defined as the amount of travel time incurred by the vehicle as the result of passing through the intersection.

In experiments, our fully-implemented custom micro-simulator simulates 3 lanes in each of the 4 cardinal directions. The speed limit in all lanes is 55 miles per hour. Different management systems (reservation system, stop sign, traffic signal) are run for at least 100,000 steps, which corresponds to approximately half an hour of simulated time.

4. INTERACTION MODEL

Safety is a main concern when involving human drivers in the control loop of semi-autonomous vehicles. For the semi-autonomous vehicles defined above to be able to go through an intersection safely, we need to define a simple and clean interface for negotiating with the IM and passing control between the human driver and the driver agent. In this section, we describe how our proposed protocol can be realized safely by having an interaction model between human drivers and driver agents that simplifies the task of the human drivers.We require the inclusion in the vehicle of a single button that signals the driver agent to ask for a reservation. After pressing the button, the driver agent will

reservation and reserves the appropriate tiles. The intersection manager then sends a confirmation to the driver. If the reservation is denied, it is the vehicle's responsibility to maintain a speed such that it can stop before the intersection. Meanwhile, it can request a different reservation.

automatically send a request message to the IM on behalf of the human driver. It is also important that there is a clear "Okay" indicator (such as a green light) installed in the car which indicates when the request has been confirmed. After seeing the okay signal, the driver would have to actively pass control to the driver agent, again by pressing a single button. This way the driver will not be surprised by any sudden autonomous actions of the vehicle.

5. IMPLEMENTATION

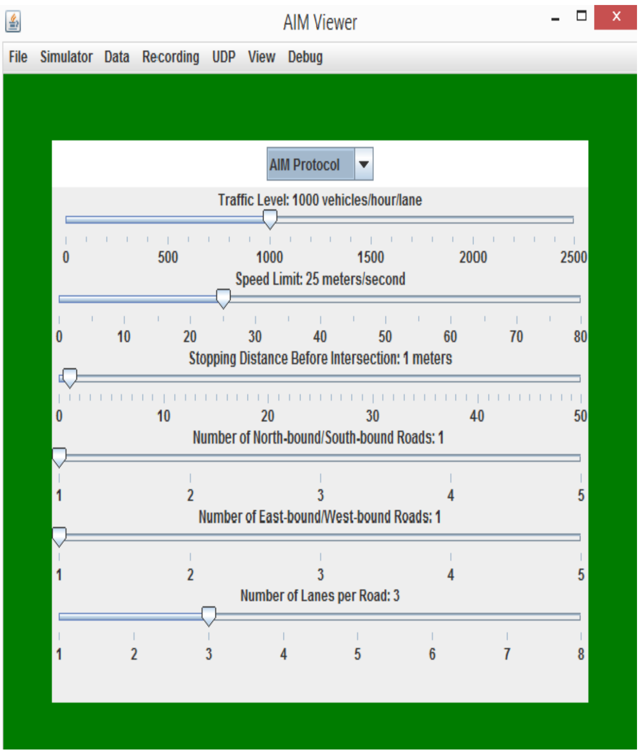

Figure 1Traffic Parameters

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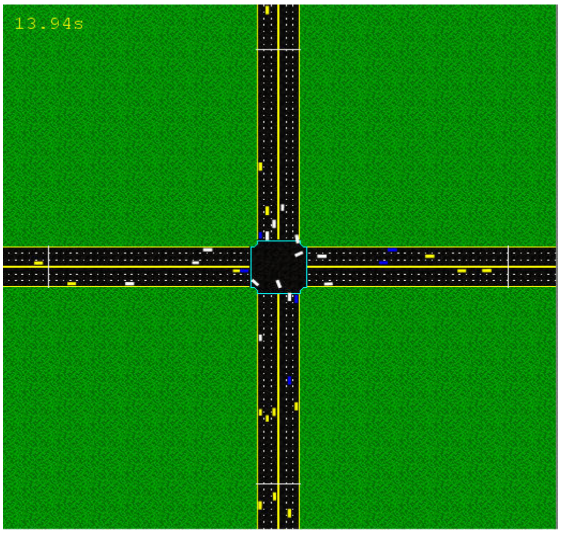

Figure 2 Simulation For Single Intersection

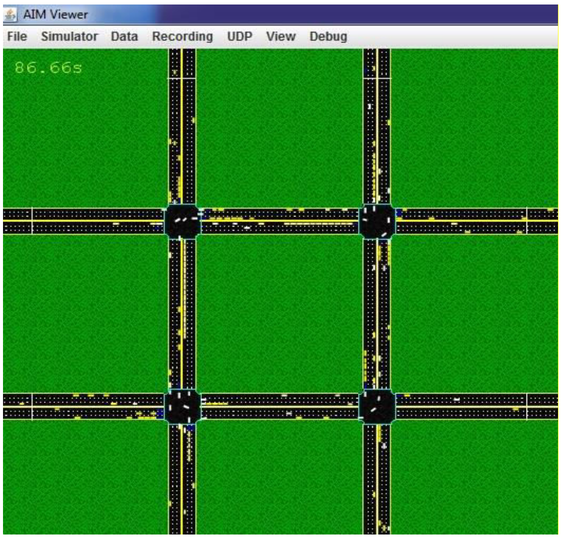

Figure 3 Simulation For Multiple Intersection

6. CONCLUSION

This paper introduces Semi AIM, a new constraint-based autonomous intersection management system that enables human-driven vehicles and semi-autonomous vehicles, in addition to fully autonomous vehicles, to make reservations and enter an intersection in an AIM-like style. To the best of our knowledge, Semi AIM is the first intersection control protocol to leverage limited autonomy of robotic cars to enable smooth interactions between human-driven, fully autonomous, and semi-autonomous vehicles at intersections. Our experimental results showed that our system can greatly decrease traffic delay when most vehicles are semi-autonomous, even when few (if any) are fully autonomous. Our incremental deployment study shows that traffic delay keeps decreasing as more vehicles employ features of autonomy. In the future, we intend to devise better constraint-based reservation requests using more accurate profiling of the vehicles' physical behavior.

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