Design and Evaluation Tools for Automated Highway Systems

Akash Deshpande, Datta Godbole, Aleks Göllü, Pravin Varaiya
{akash,godbole,gollu,varaiya}@eecs.berkeley.edu
Department of Electrical Engineering and Computer Sciences
University of California at Berkeley
Berkeley, CA 94720

1 Introduction

The Automated Highway Systems (AHS) project at UC-Berkeley is part of a comprehensive program initiated by the U.S. government under the Intermodal Surface Transportation Efficiency Act of 1991 to improve safety and reduce congestion in the surface transportation system. UC-Berkeley's PATH program is a partner in a nine-member consortium along with General Motors, Bechtel, Parsons Brinckerhoff, Martin Marietta, Delco, Hughes, Caltrans, and Carnegie Mellon University. The consortium is funded in part by the U.S. Department of Transportation and it is responsible for designing, evaluating, and demonstrating a prototype AHS.

There is also substantial related activity in Europe under the PROMETHEUS\(^2\) and the DRIVE\(^3\) projects, and in Japan under the RACS\(^4\), AMTICS\(^5\) and VICS\(^6\) projects.

In the rest of this section we present a brief description of the PATH hierarchical control architecture for AHS. In section 2 we present the framework for AHS design and evaluation and give a summary of simulation and analysis tool needs. In section 3 we describe some of these tools being developed by us based on the hybrid systems approach.

1.1 The PATH AHS Architecture

The PATH Program at UC-Berkeley has proposed a hierarchical control architecture that yields up to four-fold increase in transportation capacity while enhancing safety [4, 3]. The architecture proposes a strategy of platooning several vehicles as they travel along the highway. The separation of vehicles within a platoon is small (2m) while separation of platoons from each other is large (60m). The movement of vehicles is realized through simple maneuvers—join, split, lane change, entry, and exit—that are coordinated.

The automation strategy of the PATH AHS architecture is organized in a control hierarchy with the following layers:

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1 This research is supported by California PATH, Institute of Transportation Studies, University of California at Berkeley
2 Program for European Traffic with Highest Efficiency and Unprecedented Safety
3 Dedicated Road Infrastructure for Vehicle Safety in Europe
4 Road/Automobile Communication System
5 Advanced Mobile Traffic Information and Communication System
6 Vehicle Information and Communication System
Physical Layer—
the automated vehicles. The vehicle dynamical models are given in terms of nonlinear ordinary differential equations.

Regulation Layer—
control and observation subsystems responsible for safe execution of simple maneuvers such as join, split, lane change, entry, and exit. Control laws are given as vehicle state or observation feedback policies for controlling the vehicle dynamics.

Coordination Layer—
communication protocols that vehicles and highway segments follow to coordinate their maneuvers for achieving high capacity in a safe manner. The protocols are given in terms of finite state transition systems.

Link Layer—
control strategies that the highway segments follow in order to maximize throughput. Control laws are given as traffic state and observation feedback policies for controlling the highway traffic using activity flow models. And,

Network Layer—
end-to-end routing so that vehicles reach their destinations without causing congestion. Control laws are given in terms of queuing models.

The physical, regulation, and coordination layers reside on each vehicle and the link and network layers reside on the roadside.

To avoid single-point failures and to provide maximum flexibility, the design proposes distributed multi-agent control strategies. Each vehicle and each highway segment is responsible for its own control. However, these agents must coordinate with each other to produce the desired behavior of high throughput and safety.

The PATH architecture demonstrates hybrid system characteristics in three significant ways.

- Interaction between the coordination and regulation layers. The coordination layer acts as a planning and supervisory controller that selects maneuvers to be executed by the vehicle based on safety and throughput considerations. It then directs the regulation layer to activate the appropriate feedback control laws for controlling the vehicle dynamics.
  This illustrates the usual hybrid control configuration treated in literature wherein a discrete event controller supervises a continuous parameter plant.

- Interaction between the link and coordination layers. The link layer acts as an optimizing controller that selects vehicle activity profiles on highway segments based on throughput optimization considerations. It then directs the vehicles’ coordination layer controllers to select maneuvers consistent with the desired activity profiles.
  This illustrates a novel hybrid control configuration wherein a continuous parameter controller directs the behavior of a discrete event plant.

- Switched modes of operation. The system’s operating modes are switched when available system capability changes due to failure events and weather conditions.