Towards High Confidence Cyberphysical Systems for Intelligent Transportation Systems

Aniruddha Gokhale, Sumant Tambe, Larry Dowdy and Gautam Biswas
Dept of EECS, Vanderbilt University, Nashville, TN 37235
Contact: a.gokhale@vanderbilt.edu

Abstract: *The transportation sector worldwide is significantly stressed due to the inability of the infrastructure to meet the demands of ever increasing traffic volumes. Traffic congestion problems continue to worsen, leading to substantial adverse economic and environmental impact. Increased volume and hazardous weather/road conditions lead to an increasing number of multi-vehicle accidents and fatalities. The Intelligent Transportation System (ITS) efforts across the world are aimed at addressing a range of problems including decreasing congestion, reducing fuel consumption, and improving safety of our roadways. Cyberphysical systems (CPS) will play a major role in the design and implementation of ITS systems. For example, CPS such as automatic collision avoidance systems may prevent accidents, while automated vehicle re-routing services may alleviate traffic congestion. This position paper outlines research opportunities for cyberphysical systems in ITS, and discusses the challenges in realizing them.*

1 Introduction

Commuters in major cities worldwide are experiencing an increase in traffic congestion and delays. This is a result of growing urban sprawl, increasing population, and improving vehicular affordability to the masses. Thus, there are more drivers and more vehicles but not a corresponding increase in road and highway capacities. According to a recent report [1], in 2006 there were an estimated 199 million licensed drivers in the USA alone.

Traffic congestion has adverse consequences on safety, the economy, and the environment. The loss of productivity due to delays stemming from suboptimal traffic patterns and increased fuel consumption leads to adverse economic consequences. For example, a recent report [2] from the American Association of State Highway and Transportation Officials (AASHTO) estimated losses incurred within the USA amounted to $78 billion in the year 2006. Several studies [3][4][5] demonstrate an increase in greenhouse emissions due to idling vehicles during traffic jams.

Safety issues can also stem from hazardous weather and road conditions. For example, slick roads and icy bridges during winter are known to cause numerous accidents and loss of life. Other weather phenomena, such as fog and high wind, often result in multi-vehicle collisions. For example, as recently as January 9, 2008, brush fire and fog resulted in a 70 car chain-reaction accident on I-4 in Florida leaving three people dead.

To address the increasing demands placed on our transportation resources, and the resulting challenges, research organizations, governments, and industry worldwide are focusing on Intelligent Transportation Systems (ITS) [6]. The ITS problem and its solution space naturally falls within the cyberphysical system framework since it involves a close coupling between physical systems (vehicles) and a distributed information gathering and dissemination infrastructure (wired and wireless networks, sensors, processors, and the accompanying software infrastructure) that provides a variety of information to guide and control the operation of these systems.

2 The Problem Space and Technical Challenges

In more detail, Figure 1 illustrates the spectrum of cyberphysical system (CPS) research opportunities within the framework of ITS. These opportunities are categorized according to the *degree of physical control* involved in the application. At one extreme are the "Per-vehicle CPS", which are safety critical and deeply embedded control solutions for individual vehicles (*e.g.*, collision avoidance or skid control). These systems require hard real-time and reliability guarantees. At the other extreme are the "Infrastructure CPS", which are resource intensive systems (*e.g.*, decision support systems and visualization centers) that require global information of the system, such as the rate at which vehicles are entering a specific highway segment. Some of these functions may be mission critical, others may be designed to provide acceptable levels of performance. In the center are the "Vehicle-Infrastructure CPS," which although are not hard real-time systems (*e.g.*, automated re-routing for congestion control) yet require significantly higher levels of performance assurances than the global scale systems.

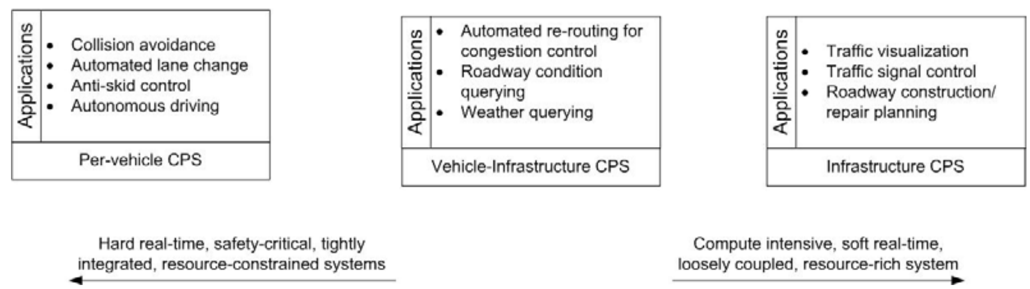

Figure 1: Spectrum of ITS CPS Research Opportunities

We are interested in investigating solutions that provide support for the *humans-in-the-loop* and in some cases may remove the humans from the loop to ensure hard real time constraints are not violated (*e.g.*, skid control). A number of computational and communication infrastructure challenges that we have outlined below must be addressed simultaneously to realize effective cyberphysical systems for ITS.

Mobility-aware real-time and scalable dissemination middleware – Since vehicles are in motion, mobility is a critical issue that must be considered in real-time traffic monitoring and disseminating information to the vehicles over vehicular ad hoc networks (VANETs). Real-time information dissemination is critical for applications such as automated collision avoidance or even re-route planning since information on alternate route selection must reach the drivers in a timely manner so that drivers have sufficient time to make an informed decision. A real-time publish/subscribe middleware may be a promising approach to solving this problem.

Heterogeneous communication middleware – Vehicles must communicate with each other and with stationary road-side units over wireless communication links. The road-side units are connected via backend servers and databases over a wireline network. Road-side units must also sense and receive information from road and bridge sensors. Service differentiation and resource management are necessary within this mixed mode communication environments depending on the application criticality. Connectivity, routing, and resource management are particularly challenging in wireless ad hoc networks.

Capacity planning – Transportation planners are required to determine how many road-side units, (*e.g.*, cameras and wireless transmitters/receivers) will be required. Their location deployment directly impacts their scalability with respect to the information flow among the mobile vehicles and the fixed road-side units.

Real-time local and global planning – Real-time traffic conditions must be monitored and disseminated to local and global planning algorithms that aim to maintain the overall health of the system. For example, a traffic re-routing algorithm must ensure proper load balancing to prevent new congestion hotspots due to re-routed traffic (*i.e.*, traffic convoy effects). Automated re-routing decision algorithms will need to be developed that can alleviate congestion as much as possible. Providing a scalable solution may require partitioning the network of roads into regions, and providing both intra- and inter-region planning.

A critical requirement for research in cyberphysical systems for ITS is the availability of simulation models, analysis tools, and testbeds for validation. Our survey indicates that the state of art in simulating realistic wireless communication with mobile traffic scenarios is weak.

3 Author Bio

Prof. Aniruddha Gokhale is an Assistant Professor of Computer Science and Engineering in the Department of Electrical Engineering and Computer Scince at Vanderbilt University. His research expertise includes Model-driven Engineering and QoS-enablers for Middleware solutions for distributed real-time and embedded systems.

Sumant Tambe is a Doctoral Student in the Department of Electrical Engineering and Computer Science at Vanderbilt University. His research includes middleware and model-driven engineering solutions for distributed real-time systems with focus on ITS applications.

Prof. Larry Dowdy is a Professor of Computer Science in the Department of Electrical Engineering and Computer Science and Vanderbilt University. His research expertise includes performance evaluation, capacity planning, queuing theory, analytic/Petri-net modeling, and validation case studies of large enterprise grid computing systems.

Prof. Gautam Biswas is a Professor of Computer Science and Engineering in the Department of Electrical Engineering and Computer Scince at Vanderbilt University. His research expertise includes modeling, simulation, analysis, and fault-adaptive control of complex, embedded systems. He also performs research in intelligent systems.

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