Simulation-Based Operations Planning For Regional Transportation Systems

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1. Introduction

Traffic congestion resulted in an estimated cost of $69.5 in extra delays and wasted fuel in 75 urban areas in the U.S. in 2001 [1]. Over 6 million crashes occur each year in the U.S., resulting in over 40,000 fatalities and an estimated $150 billion in economic loss [2, 3]. Intelligent Transportation Systems (ITS) are being deployed to attack these problems [3]. However, existing ITS deployments are "infrastructure heavy," relying largely on roadside sensors, cameras, networks, etc. leading to high maintenance costs. It is often difficult for government agencies to obtain adequate funding to keep these systems fully operational, causing some systems to fall into disrepair, severely degrading their effectiveness.

An emerging trend is the inclusion of in-vehicle computer systems with off-vehicle communications capabilities [4-9]. These systems offer the potential to greatly lessening dependence on government-maintained IT infrastructures by exploiting equipment that will be continually upgraded and maintained as new vehicles are purchased and existing vehicles enhanced. In-vehicle systems allow coverage to extend beyond areas where roadside equipment has been placed. Subject to privacy considerations, in-vehicle sensors offer the potential for much more detailed, accurate information (e.g., vehicle emissions) than would otherwise be possible, enabling new ways to improve and optimize the transportation system. In-vehicle computing systems facilitate the customization of information services to the needs and characteristics of individual travelers. Driver assistance and safety applications exploiting upstream traffic information to help users avoid congestion [8] and the use of information concerning nearby vehicles to provide early warning of hazards are two examples that are being explored [5, 6].

There are several possible configurations of inter-vehicle communications: a pure wireless ad-hoc network, a wired backbone with wireless last-hop, or a hybrid architecture combining the two. We are considering approaches using V2V networks (with or without base stations). We assume all participating vehicles are equipped with on-board computing and wireless communications, a GPS device enabling the vehicle to track its spatial-temporal trajectory, a pre-stored digital map, and other sensors reporting crashes, engine statistics, etc. Vehicles communicate directly with each other on a peer-to-peer basis, and data may be partially evaluated while moving from vehicle to vehicle.

2. Data Propagation Models

To better understand the fundamental system properties of V2V networks, we have developed analytical models to study spatial propagation of information in highly mobile vehicle-to-vehicle ad-hoc networks. We have studied how a message propagates in one direction along the road. We are primarily interested in the scenario where the message propagates in the direction in which the traffic is traveling along the road though we also showed that a message can propagate in the opposite direction of the vehicle traffic. The *message head* at time t refers to the informed vehicle with the largest position coordinate, which represents the outreach of the message propagation. Vehicles taking the role of the message head may change over time. Thus we are primarily concerned with the movement of the message head.

We have explored various vehicle traffic scenarios: one-way traffic, two-way traffic and general road networks. These models can help better understand data dissemination in this environment. In this work we have shown that message propagation depends on the vehicle traffic characteristics, especially vehicle density, average vehicle speed and speed variance among vehicles. These models lead to some interesting discoveries, e.g. a message can propagate in the opposite direction as the traffic flow, and can propagate much faster than the movement of vehicles. Simulations were used to validate these models and highlight the need to include more sophisticated traffic models.

3. Distributed Simulation Tools

Test bed environments are needed to evaluate new techniques and system designs and architectures. Toward this end, a distributed simulation prototype has been developed to explore issues such as the above, and has been populated with traffic data in the Atlanta metropolitan area obtained from government partners. Using a federated simulation approach, we are creating a simulation-based test bed for rapid evaluation of innovative transportation infrastructures. Specifically, we have developed a software backplane to integrate autonomous simulations of transportation and wireless communication networks in a distributed computing environment. The backplane provides communications and synchronization services necessary to link autonomous simulators. In addition to the backplane software, the test bed includes transportation simulations based on CORSIM, a highly regarded micro-simulation model that has been under development by the Federal Highway Administration for more than two decades. It also includes Qualnet, a commercial high fidelity wireless network simulator. Second-by-second sensor data concerning the vehicles' location, speed, heading, and onboard diagnostics system data (engine coolant temperature, RPM, etc.) are being collected and processed.

4. Modeling Traffic in the Atlanta Area

A model of traffic in Atlanta is being developed utilizing current travel demand data, existing geometrics, and in-field signal timing control plans. The study area is ringed by I-285 to the East, West, and North and I-20 to the south. The North-West quadrant of this study area, the I-75 corridor, has been completed and is currently being integrated with the vehicle-to-vehicle communication simulation. The completed 1-75 corridor models approximately 45 signalized intersections, 100 miles of arterial, and 16 miles of freeway (approximately 190 nodes and 350 links). The entire modeled area in Atlanta (which is approximately 50% complete) will contain over 800 signalized intersections, 900 miles of arterial, and 200 miles of freeway (approximately 800 nodes and 4500 links).

5. References

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