Vehicular Networks in Urban Transportation Systems

Hao Wu
Mahesh Palekar
Richard Fujimoto
College of Computing
Georgia Institute of Technology
Atlanta, Georgia 30332-0280
{wh,fujimoto}@cc.gatech.edu

Jaesup Lee, Joonho Ko
Randall Guensler
Michael Hunter
School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332-0355
randall.guensler@ce.gatech.edu

ABSTRACT
Recent results concerning the development and exploitation of wireless vehicle-to-vehicle and vehicle-to-infrastructure communications in future generation intelligent transportation systems are discussed, as well as simulation techniques and tools used to effectively model such systems. Specifically, new algorithms to disseminate information in vehicle-to-vehicle networks have been developed, and their performance evaluated using simulation modeling of traffic along the I-75 corridor in the Atlanta metropolitan area. Work to validate the simulations models is summarized. Field experiments with wireless communication along I-75 are described, as well as extensions of these results to investigate communication architectures for vehicular networks. Results concerning multi-resolution simulation of urban transportation networks involving the use of aggregated data from regional planning models in microscopic traffic simulations are summarized.

Categories and Subject Descriptors
C.2.4 [**Distributed Systems**]: Network architecture and design
I.6 [**Simulation and Modeling**]: model development, validation

General Terms
algorithms, measurement, performance, design, experimentation

Keywords
Intelligent transportation systems, vehicle networks, v2v.

1. INTRODUCTION
Congestion, safety, and pollution remain as serious challenges in urban transportation systems. While existing Intelligent Transportation System deployments are focused on infrastructure-centric approaches, an emerging trend is the inclusion of in-vehicle computer systems with vehicle-to-vehicle and vehicle-to-infrastructure (e.g., roadside base stations) communications capabilities. These systems offer the potential to greatly lower system operating costs and lessen dependence on government-maintained infrastructures. In-vehicle systems allow coverage to extend beyond areas where roadside sensors have been placed. Driver assistance and safety applications exploiting upstream traffic information to help users avoid congestion [1] and the use of information concerning nearby vehicles to provide early warning of hazards are sample applications discussed in the lieterature [2, 3].

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2. DATA DISSEMINATION
In instrumented vehicle networks, vehicle-to-vehicle (v2v) communication is an important means of data dissemination. Based on our studies, opportunistic forwarding appears to be a viable approach for data dissemination using vehicle-to-vehicle communications for applications that can tolerate some data loss and delay [4]. Opportunistic forwarding is a store-carry-forward scheme leveraging vehicle mobility to disseminate information. We developed a methodology for designing opportunistic forwarding protocols. Based on this methodology, two algorithms, MDDV and optimistic forwarding, were derived. MDDV employs a group of vehicles to actively forward the message in order to improve reliability. Optimistic forwarding designates a message owner to forward the message. Algorithm performance was evaluated and compared using simulations based on vehicle traffic in the Atlanta area. Results from this research are described in [5].

3. SIMULATION MODELS
Simulation models were developed to explore the exploitation of vehicle-to-vehicle communication in surface transportation systems. Initial investigations revealed several observations. First, vehicle-to-vehicle communication is a feasible way to propagate information along freeways in metro areas, although propagation performance depends critically on factors such as the density of instrumented vehicles along the end-to-end path. Second, the simulation methodology can be used to estimate the minimum required fleet penetration ratio for effective communication, given the traffic density and application requirements. Third, with a sufficient fleet penetration ratio and traffic flow rate, information can quickly propagate through the system, although the message propagation delay is highly variable when instrumented vehicle density is low. A particular delay may be well below or above the average depending on traffic conditions. Rapid message propagation during low traffic density periods, e.g., nighttime, presents challenges. To reduce path vulnerability roadside relays could supplement the communication infrastructure in critical areas or a subset of vehicles could be equipped with cellular messaging systems, through which critical information could be reliably relayed without relying on vehicle-to-vehicle communication. Details of these results are described in [6].

4. SIMULATION DATA

The compatibility between traditional regional travel demand modeling (i.e., traditional four-step, UTPS-type modeling) and microscopic traffic simulation was examined. Utilizing the large-scale microscopic traffic simulation model developed for this project, methods for deriving the data necessary to develop a microscopic simulation model from UTPS model data were developed and supplemental microscopic model data needs were identified. In addition, compatibility between macroscopic and microscopic models was analyzed and efficient automation procedures for data conversion and integration were developed. Many of the differences in model results are a function of the fundamental differences between microscopic and macroscopic models. These differences and their implications were considered in an effort to improve quality of analysis and accuracy of model output interpretation when large-scale microscopic and macroscopic models are used in combination. Significant data issues and modeling improvements required to support large scale traffic simulation analysis were raised. The three most important data issues include: 1) precise lane configuration data beyond that typically found in UTPS model and roadway characteristics data files are necessary; 2) intersection turn movement ratios are critical to simulation accuracy, and that these data should not be taken directly from UTPS models unless the values are validated; and 3) travel time and traffic volumes are affected by signal timing, indicating the need for actual timing plans. On the modeling side, intrazonal trips within the study area significantly affect simulations, so improved mechanisms and data are needed to account for this travel. Also, simulation results are very sensitive to driver behavior, which is reflected in the models through the algorithms for lane change logic, car following, gap acceptance, etc. These results highlight the need for extensive validation efforts to insure that models are correctly calibrated for driver behavior [7].

5. FIELD EXPERIMENTS

We conducted a series of field experiments to investigate the feasibility and performance of communications between moving vehicles and roadside access points. We are developing a proof-of-concept in-vehicle computing platform that consists of a laptop computer running Red Hat Linux 9, an ORINOCO 802.11b gold card with a 2.5 dB omni-directional external antenna placed on the roof of the vehicle, and a Garmin 72 GPS receiver.

Using this platform we first measured the wireless communication performance between a fixed roadside station and a moving vehicle. The experiments were conducted on I-75 in Atlanta, GA between Howell Mill Road (Exit 252) and West Paces Ferry Road (Exit 255). Experiments were conducted for different deployment configurations. The results show that effective communications is feasible between moving vehicles and roadside stations. Most of our measurements show more than 500 m of effective communication range. Performance depends largely on the geometry of the road, obstructions, vehicle locations and the placement of the roadside station.

We also measured communication performance between two vehicles traveling in opposite directions. Most test cases showed more than 200 m of effective communication range (the longest range was observed to be approximately 1000 m). The average time for effective communication is about 21 seconds. This demonstrates that effective communication is feasible between moving vehicles. Papers summarizing these field experiments are forthcoming.

6. ARCHITECTURE EVALUATION

The future wireless infrastructure for vehicles will be designed to offer reliable broadband channels, transportation related services, and Internet access. The form and function of the transportation services offered will depend on the amount of data that can be carried through the network, and the speed and reliability of data flow. We have identified several design options for vehicular networks both with and without infrastructure-based networks and evaluated these designs. Our evaluation methodology combines field experiments, analytic analysis and simulation. We assess coverage, data traffic load, and actual capacity of individual network infrastructure building blocks (WWAN, WLAN last-hop and multi-hop WLAN), and showed their relevance and interaction when integrated together. Based on these evaluations, we have developed insights into the design of future broadband vehicular networks capable of adapting to varying vehicle traffic conditions over time and space.

7. ACKNOWLEDGMENTS

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