IV 2010 PhD Forum: Analytical Modeling of Delay-Tolerant Data Dissemination in Vehicular Networks

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Index Terms—Vehicular ad hoc networks, delay tolerant networks, routing protocol, performance modeling.

Abstract—Vehicular networking is an emerging technology to support applications involving communications between vehicles, between vehicles and fixed access points, and between vehicles and the Internet cloud. The goal is to enable vehicles to exchange information for improved safety through situational awareness, enhanced convenience, and achieve increased levels of efficiency in time and energy consumption. Safety messaging, real-time traffic updates, remote diagnostics, Internet access and in-car entertainment are examples of applications targeted by this technology. This dissertation considers communication and networking among vehicles that are constrained to navigable roadways. We propose a novel routing technique that incorporates attributed (labeled) messaging; geographic routing; and delay tolerant networking techniques in a solution that operates in a network characterized by rapid mobility and time-varying partitioning (fragmentation). An analytical model is developed to demonstrate the performance of opportunistic data exchange in a delay tolerant network setting. Contributions of the work include revelation of phase transition behavior due to vehicle density and transmission range. We are able to identify regimes of density where gains are achieved by exploiting the opportunistic contacts between vehicles traveling in opposing directions. Also significant is the observation that increased mobility of nodes from 0 m/s to 10 m/s yields an order of magnitude increase in the performance of messaging from 0 m/s to 200 m/s. The proposed architecture is compared with existing mobile ad hoc networking schemes and performance gains achieved are detailed. It is demonstrated that in a hybrid environment with intermittently placed access points, large separations are possible when supported by multihop networking. Under delay tolerant networking assumption, minimum delay and maximum propagation rates are achieved for low vehicular traffic densities of 20 vehicles/km, for given parameters. A path based messaging scheme would achieve similar performance at 40 vehicles/km.

INTRODUCTION

Vehicular networking is an emerging technology to support applications involving communications between vehicles and between vehicles and fixed access points, and between vehicles and the Internet cloud. The goal is to enable applications that enhance awareness of the vehicle for improved safety, convenience and increased levels of efficiency in time and energy consumption. Safety messaging, real-time traffic and route updates, traffic monitoring, remote diagnostics, Internet access and in-car entertainment are examples of applications targeted by this technology.

We consider the problem of enabling networking among vehicles traveling on the roadway. Vehicle traffic density on the roadway varies between the extremes of sparse and dense traffic, depending upon the roadway (urban or rural) and time (day or night). From a network connectivity standpoint, the network is partitioned when the density is sparse and likely connected in dense situations. In the event of partitions, MANET routing schemes based on path formation strategies, such as AODV and DSR, will likely perform poorly due to absence of end-to-end connectivity.

We focus on developing a mechanism to enable data propagation in a network formed over moving vehicles characterized by vehicles as nodes in a network that is likely partitioned. As vehicles move at a relatively fast rate, the topology of the network changes and vehicles come in intermittent contact with other vehicles on the roadway. We propose a novel routing technique that incorporates elements of mobile ad hoc networks such as attributed (labeled) messaging, geographic routing to build a solution that operates in a network characterized by rapid mobility. Further we apply delay tolerant networking techniques to enable message exchange in the event of time-varying partitioning and exploit transient connectivity over bidirectional traffic. To demonstrate the applicability of this solution, we develop an analytical model to determine the performance of messaging in the network. The model is parametrized for network variables that permits us to study the behavior for various scenarios and settings.

PERFORMANCE RESULTS

We compare the analytical model with simulations for a set of parameters; radio range \( R = 125 \text{m} \), vehicle speed \( v = 20 \text{m/s} \), radio propagation speed \( v_{\text{radio}} = 1000 \text{m/s} \). To evaluate the performance, we define average message propagation speed \( (v_{avg}) \), similar to vehicle speed, to determine the average rate at which messages are disseminated over a physical distance. The traffic density is varied from 1 vehicle/km to 100 vehicles/km to cover the sparse, intermediate and high traffic scenarios. Figure 1(a) shows the simulation results of average message propagation speed lies well within the upper and lower bounds defined by analytical model, at various traffic densities. The message dissemination lies predominantly in two regimes, one – where the network is fully connected, messages are propagated multihop at maximum speed, as defined by the radio, \( (v_{radio} \)
m/s); second — where nodes in the network are partitioned, messages are disseminated as the vehicles move (v m/s). Of interest is the intermediate density where vehicle mobility offers opportunistic data dissemination. Here, the network is partitioned, however, the delay tolerance assumption is able to exploit the transient connectivity. Thus, the messaging performance on average is better than vehicle speed, but not always the maximum achievable speed.

The graph in Figure 1(b) depicts the three regimes of performance for density on the eastbound and westbound roadway. In Regime I, the density of vehicles is low and there is no connectivity over eastbound and westbound roadway. Thus, there are no gains achieved from the delay tolerant assumption. In Regime III, on the other hand, there are significant gains achieved in message propagation rates. A small increase in westbound or eastbound vehicle traffic density yields gains in message propagation speed. In Regime II, the gains achieved are limited.

**SUMMARY**

The contributions of this work include a novel routing technique and an analytical model that captures qualitatively the behavior of messaging in a delay tolerant vehicular networking environment. The performance of messaging is compared with simulation results. The performance results depict that messaging is a function of vehicular traffic density. The model is parametrized and can be adapted for various scenarios of vehicle density and physical radio technologies. Significant is the observation of phase transition phenomenon in the performance of the network with respect to vehicle density. This is consistent with previous work in mobile ad hoc network (MANET) research. Important in this work is the demonstration of density relationships at which this transition occurs. The phenomenon is observable from simulation, however, the density value and its occurrence cannot be validated. Interestingly, we demonstrate, under assumptions, increased mobility provides gains in messaging, an observation that is counter-intuitive to most MANET protocols. In scenarios where the network is partitioned, our technique is able to exploit the time-varying connectivity to achieve gains in messaging performance. MANET protocols that rely on path formation strategies would perform poorly in similar scenarios. Access point placement in the network can be minimized (optimized) by extending multihop connectivity over vehicles and for known network parameters.

**REFERENCES**


**BIOGRAPHICAL SKETCH**

Ashish Agarwal recently completed Ph.D. degree at the Electrical and Computer Engineering Department at Boston University (May 2010), where he received his M.S. degree in Computer Systems Engineering (Jan. 2007). Prior to that, he earned a B.E. degree from Delhi Institute of Technology, University of Delhi, New Delhi, India in 2003, (now Netaji Subhas Institute of Technology (NSIT)).

His research interests include wireless, mobile and ad hoc networks (MANETs) including sensor networks and vehicular networks (VANETs). He is also interested in message dissemination schemes for intermittently connected and delay tolerant networks (DTN). His current work focuses on application of DTN techniques in vehicular networks.