PhD Forum: Routing Protocol and Performance Modeling in Delay Tolerant Vehicular Networks *

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Introduction

Development of networking protocols is essential for an emerging class of applications described as vehicular ad hoc networks (VANETs). The scope and requirements of applications vary significantly, and existing techniques do not apply. The nature of data exchange varies in time and space and thus, the protocols need to accommodate and adapt to the requirements. Furthermore, the dynamics of the vehicular networking architecture and topology present interesting challenges to develop a fresh perspective on routing algorithms and protocols. The vehicular networking environment is characterized by time-varying partitioning in a network formed over moving vehicles. There is absence of instantaneous connectivity in the network, yet there is an opportunity to exploit the transient connectivity. In this context, we explore the application of delay tolerant networking in vehicular networks and describe a novel routing technique and protocol. We have developed an analytical model that captures the performance of messaging in this unique setting. We discuss the gains achieved by our proposed techniques and the significance of the analytical model in determining the parameters for the routing protocol.

Vehicle manufacturers are developing driverless cars for the future [1]. The DARPA Urban Challenge is an autonomous vehicle research and development program with the goal of developing technology that will enable driverless vehicles. Related work in vehicular control has established that communication will play key role in enabling autonomous vehicles [2]. The design of DSRC (Dedicated Short Range Communication) is key to enabling wireless inter-vehicle communication. On-going efforts are targeted towards applications such as accident avoidance messaging,

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congestion sensing, traffic metering, and general purpose Internet access. The IEEE WAVE (Wireless Access for Vehicular Environments) [3] is a group dedicated to development of the 802.11p draft to enable vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. The CarTel project has developed a method for low latency connection establishment for 802.11 access points [4].

VANET Environment

Vehicular ad hoc networks (VANETs) present challenges that are unique with respect to MANET research. Vehicles that form nodes in the network are not nearly as constrained as MANETs in available energy, computational power and storage. VANETs are characterized by high mobility and rapidly changing topology. Adopting existing routing protocols from MANET research is difficult. There are several models discussed in related work for interconnecting vehicles on the roadway. An infrastructure based model utilises existing or new infrastructure such as cell towers or access points (WiFi) to enable messaging. Another solution is an ad hoc model that exploits multihop networking. In our work, we assume a hybrid model where vehicles communicate multihop supported by intermittently placed access points. There are several challenges to enabling networking in such a scenario that are discussed at length in reference [5]. A significant challenge is the absence of end-to-end connectivity in vehicular networks owing to the unique characteristics of vehicle mobility and time-varying vehicular density. Vehicles tend to travel in blocks that are partitioned from other blocks in terms of radio connectivity [6]. Thus, routing protocols that rely on end-to-end path formation are inefficient solutions.

Data exchange in VANETs is illustrated in Figure 1. Applications such as *safety messaging* are near-space applications where vehicles in close proximity, typically of the order of several hundred meters, exchange status information to increase safety awareness. The aim is to enhance safety by alerting of emergency conditions. The messaging has strict latency constraints, of the order of few milliseconds, with very high reliability. In contrast, applications such as *traffic and congestion monitoring* require collecting information from vehicles that span several kilometers. The latency requirements for data delivery are relatively relaxed, i.e. they are 'delay-tolerant', however, the physical scope of data exchange is much larger. Finally, general purpose *Internet access* requires connectivity to the backbone network via infrastructure such as road-side access points.

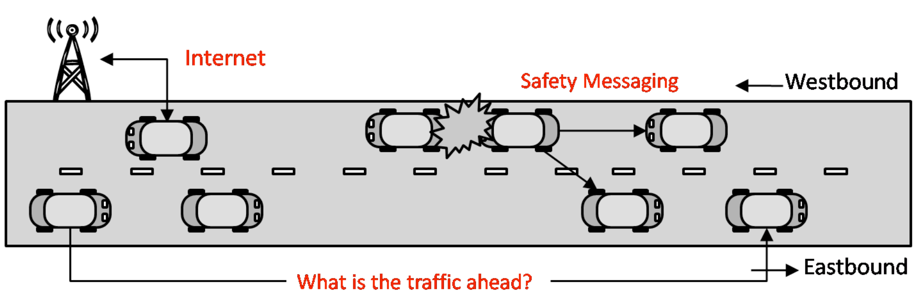

Figure 1: Three classifications of data exchange in vehicular networks.

Proposed Solution

Here we briefly describe our solution in the form of a new routing algorithm and corresponding protocol. The performance is supported by an analytical model that is developed for the vehicular networking environment.

Routing Protocol

We proposed a novel information propagation scheme for VANETs, based on the assumption of attributed (labelled) data and map information such as those obtained from GPS [5]. We consider the problem of dissemination of safety messaging beyond the point of incidence, i.e., dissemination of message in one direction on the roadway, in a multi-hop network formed over vehicles moving on a bi-directional roadway. Data in a vehicular network, such as safety messaging and traffic information, bear a high spatial co-relation. While there are existing schemes that rely on location information to route data, we propose a time-to-live (TTL) parameter that is a function of time and space, henceforth, called *Space-Time-TTL* or *STTL*. The parameter enables data propagation in the network exploiting topology changes in the context of time and/or space. Thus, the messages are attributed or labeled with location information and *STTL*, such that each node in the network is able to make an independent routing decision based on its own attributes and those observed in the message. This creates a connection-less messaging paradigm where the messages are forwarded without the need for path formation.

To solve the problem of time-varying partitioning that exists in the VANET environment, we exploit the intermittent connectivity offered by traffic moving in opposing direction. We use the concept of *custody transfer mechanism* in our protocol for directional data dissemination, described in [5, 7]. Thus, the protocol is able to exploit transient connectivity, irrespective of direction of mobility, to enable a greedy data forwarding approach. In Figure 1, a *westbound* node is able to forward data in the *eastbound* direction, as the attributes defined in the message, in conjunction with *STTL* describe the direction and scope (limit) of data transfer.

Analytical Model

We have developed an analytical model to demonstrate the performance of messaging in a partitioned vehicular network with intermittent connectivity [8, 9]. The model is relevant for the extremes of traffic densities observed in vehicular environments. Traffic densities vary as sparse (< 10 vehicles/km), intermediate ($30 - 45$ vehicles/km) and dense (> 65 vehicles/km) conditions. As a result, the network maybe highly partitioned or fully connected. Correspondingly, the performance of messaging will vary as the available connectivity. The model is parametrized for vehicular traffic density, physical radio characteristics and vehicle speed. We analyze the dissemination of messages over the physical distance and derive the upper and lower bounds on expected performance [9]. This model demonstrates that the custody transfer mechanism described in the protocol is able to exploit the intermittent connectivity offered by traffic moving in opposite directions. Further, it demonstrates the relationship between the performance of messaging and the vehicular traffic density.

Performance Results

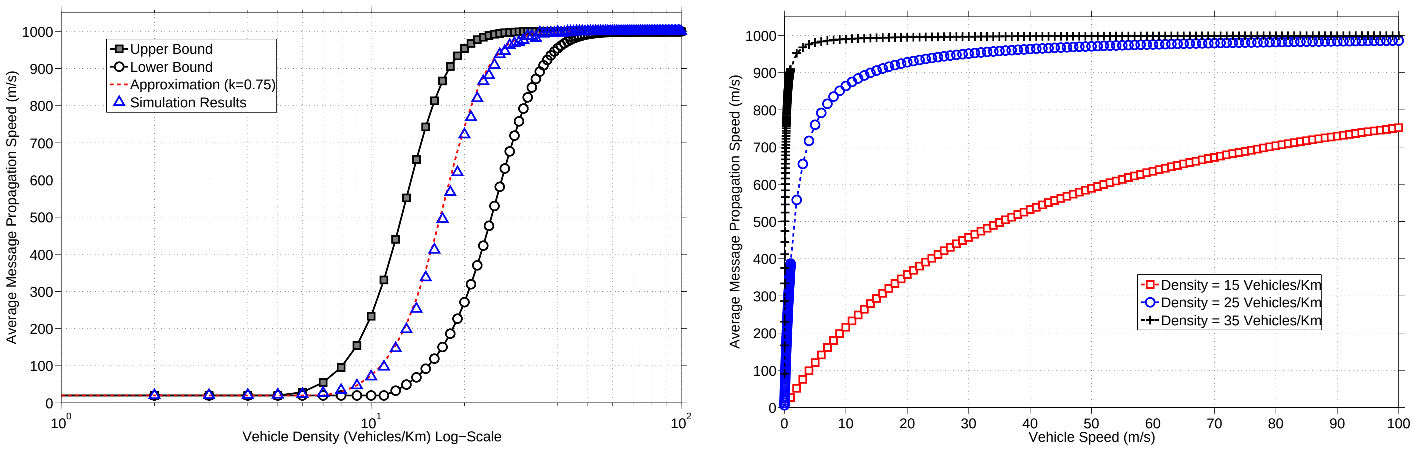

Figure 2: Performance results – (a) Average message propagation speed as vehicular traffic density in the network increases. (b) Average message propagation speed as vehicular speed increases.

We compare the analytical model with simulations for a set of parameters; radio range $R = 125$m, vehicle speed $v = 20$m/s, radio propagation speed $v_{radio} = 1000$m/s. To evaluate the performance of the protocol, 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 2(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 multi-hop 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 2(b) depicts the performance of messaging as vehicle speed increases at fixed vehicle traffic density. We compare the messaging performance using our analytical model for various densities of vehicle traffic. The results shows that the messaging performance increases by order of magnitude from 0 m/s to 200 m/s as vehicular mobility increases from 0 m/s to 10 m/s. This is counter-intuitive to the observation in conventional MANET protocols that increased mobility decreases the messaging performance owing to short-lived paths. However, in this connection-less messaging paradigm, it is observed that messaging performance is aided by increased mobility. The partitions that occur in the network are bridged at a faster rate leading to increased messaging performance. The gains achieved increase in magnitude as the density.

Summary

We have described the scenario of messaging in the vehicular networking environment. We highlight the challenges and the need for an adaptive routing protocol for the unique scenario. The proposed routing protocol exploits concepts of delay tolerance and custody transfer mechanism to enable messaging. The performance of routing is modeled analytically and compared with simulation results. The performance results depict that messaging is as a function of vehicular traffic density. These observations impact the selection of *STTL*, a time-to-live parameter based on time and space. We demonstrate that the protocol is able to adapt to varying traffic conditions and is able to route data in the event of time-varying partitioning in the network. Interestingly, we demonstrate, under assumptions, increased mobility provides gains in messaging, an observation that is counter-intuitive to most MANET protocols. Finally, we show that delay tolerant networking assumption provides significant gains over existing routing techniques. In scenarios where the network is partitioned, the protocol is able to exploit the time-varying connectivity to achieve gains in messaging performance. MANET protocols that relay on path formation strategies would perform poorly in similar scenarios. Future work will extend the existing models and protocols to develop an optimization scheme for the placement of access points in the network.

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Biographical Sketch

Ashish Agarwal is currently working towards his Ph.D. degree, (expected completion *May 2010*), at the Electrical and Computer Engineering Department at Boston University, Boston, MA. He received his M.S. degree in Computer Systems Engineering from Boston University, Boston, MA in 2007 and B.E. degree from Delhi Institute of Technology, University of Delhi, New Delhi, India in 2003, (now Netaji Subhas Institute of Technology).

His research interests include semantic routing with application towards 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).