Can We Solve Transportation Problem with Vehicle Networks?

by David H.C. Du, University of Minnesota

The transportation problem becomes more serious as population growing in many US cities. The increase of time spending on the road from home to work has a huge impact on the overall productivity of US. The extra energy consumed by driving a car for longer commute creates carbon dioxide problem and damage our living environment. Although the total number of vehicle accidents has declined in the last few years, US still have a higher death rate per 100,000 populations than 60 other countries from vehicle accidents.

Public transit systems like buses and subways can be a solution to this problem. However, unlike European and Asian countries most of the US households are living in scattered suburban areas. It is hard to convince people to leave their vehicles instead of using public transit system for their daily commute. In quest for a solution, Personal Rapid Transit (PRT) has developed and experienced. A PRT is like automated (driverless) taxis operating on a system of guide-ways. The advantages of such a system include operating on demand (not like public transit), energy saving (most of them are electrically powered and small vehicle size like an automobile), and high level of service (driverless and fast speed). However, its disadvantages are high cost (both infrastructure and special vehicles have to be constructed) and restricted service areas. Due to the disadvantages of the PRT, very few new PRTs are under development in the last three years.

Over the last few years, other technology advancements including sensor, control and navigation techniques have made major impact on a number of related applications. For example, Google recently (Oct. 2010) announced that "It's been building robotic cars that have been driving themselves around California — down curvy Lombard Street in San Francisco, across the Golden Gate Bridge, along the Pacific Coast Highway, around Lake Tahoe". The self-driving automated cars use video cameras, radar sensors and a laser range finder to "see" other traffic, as well as detailed maps to navigate the road ahead. Another example is DARPA's urban grand challenge that tests self-driving cars in an urban environment. Some of the advanced features in luxurious cars like adaptive cruise control and self parallel parking have also benefited from these new technology advancements. The downside of these new technologies is the high cost and it is unlikely they will be available in most of the cars any time soon.

To improve the transportation environment in the aspects of *safety enhancement*, *intelligent traffic management*, and *data communication*, Inter-Vehicle Communications (IVC) systems are proposed.
Wireless access in vehicular environments (WAVE) is the latest IVC technology that provides the physical platform for ITS to achieve its claimed goals of enhancing safety, management, and data services. WAVE systems are based on the Dedicated Short Range Communications (DSRC) standard, which were ratified in April, 2009.

Recently WAVE has attracted increasing attention from both academia and industry worldwide. Even though researchers in the US have made effort in this area, we are lagging behind Europe to deploy wireless vehicle networks. Example European projects include CarTALK, COMCAR, FleetNet, and CAR2CAR. An ACM workshop on vehicle networks (VANET) was launched in 2004, and two IEEE workshops, V2VCOM and AutoNet, were initiated in 2005 and 2006, respectively. These activities provided platforms for the state-of-the-art research to be reported. Topics that have been studied include security, data access, safety applications, traffic routing, simulation and modeling, and power control.

In 1999, FCC allocated 75MHz licensed DSRC spectrum in the 5.9GHz band to support low-latency vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. The DSRC spectrum is divided into seven 10MHz channels, with the control channel (Channel 178) generally restricted to safety applications only. The DSRC standard (i.e., IEEE 802.11p) is essentially based on the IEEE 802.11a PHY and the IEEE 802.11/e MAC adjusted for low-overhead operations.

Considering all the technological improvements recently, we envision a possible solution to US transportation problem as follows. Each vehicle will be equipped with GPS and DSRC communication capability. In most likely to be congested areas or even city-wide, RSUs are deployed to form a multi-tier control system as shown in Figure 1. For simplicity of the control, we assume these roads are either uni-directional like Manhattan Streets in New York City as shown in Figure 2 or bi-directional with only right turn allowed. Each vehicle entering these areas will report its trajectory (i.e., a selective path to a destination) based on GPS to a Control Center via a RSU. RSUs can monitor the vehicles passing by and assist the data delivery between Control Center and vehicle or vehicle to vehicle. The Control Center will be responsible for smoothing the traffic based on the current traffic load by adjusting the trajectories of some vehicles. The nearby vehicles are self-driving and coordinated with each other via DSRC for shorter response time. The goal is to achieve safety and maintain certain speed for each vehicle. Therefore, stop lights at intersections are no longer required. The advantages of the proposed infrastructure are its low cost when compared with other alternatives and its effectiveness by fully taking the benefits of current technology advancements.

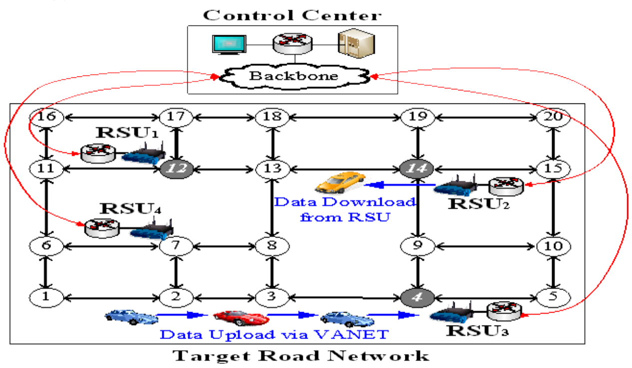

Figure 1. Proposed Road Network

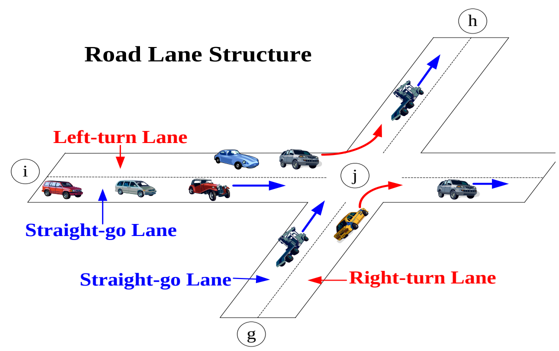

Figure 2. Road Lane Structure

We assume a RSU may be deployed at each intersection of the roads. For a long segment of the roads, several RSUs may be deployed. Each RSU has a good wired connection to the Control Center. In order to reduce the cost of the proposed road infrastructure, it is important to reduce the number of RSUs to be deployed. However, too few RSUs may increase the latency of the data to be delivered in such a road network. Each vehicle is only equipped with a GPS and DSRC communication capability. Each vehicle has a road map of the region that including the locations of RSUs. With the GPS, the trajectory of a vehicle can be identified and announced to the Control Center. However, the trajectory information of a vehicle is not shared with other vehicles due to the privacy concern. Another important component in a vehicle is its (On-Board Diagnostic) OBD-II device. OBD-II is a standard computer interface that is available on all the vehicles since 1996. The interface will enable the access to all sensor data gathered by the vehicle. Through the DSRC communication device, vehicles can share these data with nearby vehicles for cooperative driving and other safety related applications.

It is essential to evaluate the feasibility of such an infrastructure. The research issues to be addressed include 1) How can each vehicle report its trajectory and current location to Control Center via multi-hop vehicle communication to nearby RSUs? 2) How can Control Center communicate with each vehicle in a timely effective manner? 3) How can vehicles coordinate with each other to avoid collisions and run at a reasonable speed to reach their destinations? 4) How does the multi-tier control work? Is it feasible? and 5) How to thoroughly valid the proposed system with simulations and real measurements?

In order to communicate with the Control Center, each vehicle may have to go through multiple vehicles via DSRC devices to link up to a nearby RSU. For the Control Center to communicate to a vehicle, the Control Center has to estimate the current location of the vehicle and forward the message to a nearby RSU. Once the RSU receives the message, it has to forward the message via one or multiple paths and through multiple vehicles to reach to the targeted vehicle. The type of communication between vehicles and Control Center seems to be the same as the existing V2V (Vehicle-to-Vehicle) and V2I (Vehicle-to-Infrastructure) wireless communication. However, we believe that the trajectory of each vehicle known to the Control Center (but not to other vehicles due to privacy concern) and the continuously updated information reported by vehicles and RSUs play an extremely important role for accomplishing the goals of the proposed infrastructure. The Control Center based on the report of the trajectory from each vehicle and monitoring information from RSUs will have a good understanding of the traffic in the region and can re-direct the trajectories of several vehicles to smooth out the traffic. The capability and response time of the Control Center will go beyond the traffic statistics that are available via a commercial navigation service provided by Garmin Traffic. The Control Center can coordinate with V2V communications in a troubled spot to speed up the delivering of safety related urgent messages. However, the coordination between nearby vehicles is necessary via DSRC to ensure driving safety.

There are many questions to be answered if the proposed infrastructure is feasible. How to efficiently design such an infrastructure and can it provide reasonable communication performance to moving vehicles at fast speeds to solving transportation problem? To reduce the overall cost for the proposed infrastructure, an important issue is to reduce the number of RSUs to be deployed while still guarantee the required performance. Since a vehicle runs very fast, there is a very short period that allows a vehicle to be communicated with a nearby RSU. Intuitively, if not enough time to make a connection, we can give priority to data with shorter deadline and smaller size of data to increase its effectiveness. A simple scheduling for data delivering based an additional factor, the number of pending requests for the data, and other information is required. It is important to understand the effect of the following possibilities: a) adding more RSUs, b) using additional channels in DSRC MAC layer protocol, and c) enhancing the coordination between RSUs. For example, a query can be send by a passing vehicle without waiting for the response from the same RSU. Since the trajectory of the vehicle is known to the Control Center. The response can be sent to the next RSU along the vehicle's trajectory such that the contacting time for each vehicle to a RSU can be reduced. The V2V communication capability needs to be evaluated based on the requirements of many applications.

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