Prospects for Networked Vehicles of the Future*

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Abstract–Applications of vehicular networking are set to explode much in the way that Internet technology emerged in the early 1990s. The convergence of in-car navigation systems, high-bandwidth wireless communications, protocols for highly-mobile ad hoc networks, and the inherent ability to instrument vehicles with sensing and control devices leads to many potential personal and community-based services for vehicles. We discuss potential applications enabled in this scenario based on the ability of vehicles to localize information sourced and consumed from and by vehicles in the network.

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1 Introduction

We envision a future transportation system in which vehicles transit the network of roadways and highways under complete computer control. Such a scheme has many benefits of efficiency, throughput, and safety as the world becomes more urban and densely populated. Using a computer network analogy, vehicles (packets) can be routed based on source and destination addresses on the network (roadway). Roadways can be scheduled as a resource, permitting for example, densely packed trains of vehicles (analogous to slots in computer networking) yielding higher utilization and throughput. Vehicles will be expected to meet minimum performance requirements and will be restricted by access control to high-speed roadways. Access mechanisms will provide control over the analogs of quality of service, bandwidth, guaranteed service, and latency. Depending on the control paradigm, vehicles will be able to re-route when they experience congestion along pathways. (But of course, packets can be dropped and vehicles cannot.) The cost function for travel can be based on minimization of personal or system-wide metrics as established by policy (e.g., based on system energy consumption or time of day latency).

To realize this vision, vehicles and the corresponding roadside infrastructure will need to be quite sophisticated to meet performance, and particularly, safety requirements. However, the degree of instrumentation of vehicles and the extent of existing networking technology today suggests we are not far off, at least from a technical perspective. In this position paper, we explore our vision with a focus on existing vehicular communications and near term applications which we expect to be precursors to future transportation networks.

1.1 Automated Travel Vision

It is technically palatable for future road travel to be an automated experience wherein the task of driving will be achieved by a computer. Travel can be safer, faster, and potentially very pleasant as automation enforces standard behavior. The precursor to creating an automated highway system lies in achieving a large scale distributed autonomous control system. Today, vehicles comprise elements of an autonomous control system in which humans are the control units. Traffic laws and driving conventions (or lack thereof) provide common rule sets guiding system behavior. To achieve higher performance under computer control requires more effective communication among driving elements and the state of the whole system.

One key aspect of automated transportation is safety. Many accidents occur due to human error or lack of awareness in the vehicle. For safe and efficient travel, awareness of the immediate surroundings and coordination amongst vehicles is essential. This is achieved by the use of distributed sensing and control implemented by inter-vehicle networking. Enabling vehicles to communicate, making them aware of their surrounding vehicles and bringing traffic information services to vehicles are the building blocks to creating an automated highway system. Thus, wireless mobile communication is one of the cornerstones to creating an automated highway system. Some of the sensing and communication components that comprise a *'smart'* vehicle of the future are illustrated in Figure 1.

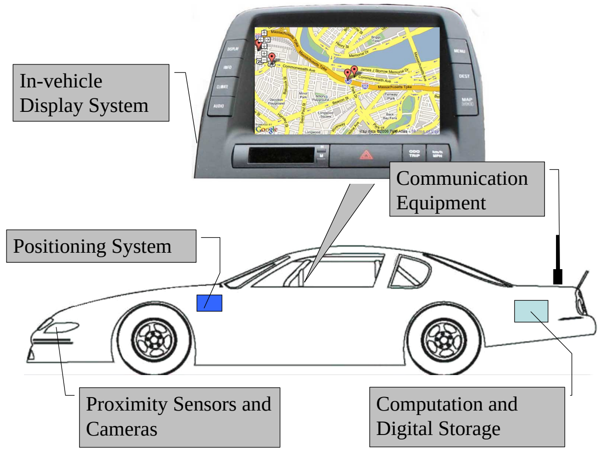

Figure 1: Conceptual elements of a 'smart' vehicle.

1.2 Recent Developments

We are on the cusp of a rush to vehicular communications and networking applications. Just as we are writing this article (February, 2007) the *Boston Sunday Globe* reported on several companies developing access mechanisms to support Internet access from vehicles [1]. Clearly there is an opportunity to bring information services to vehicles, but there are a variety of other applications of networked vehicles preceding our vision that are relevant to the present day driver.

With respect to vehicular safety, advances in vehicular technology include efforts to establish and enforce safety norms [2]. One technique relies on enhancing safety by equipping vehicles with sensors that warn drivers of possible impacts with other vehicles. Examples of such technologies under development include proximity sensors which aid the braking process by maintaining a safe speed and distance from the vehicle in front. Vehicles are also increasingly being equipped with visual aids in the form of cameras and in-car display systems to aid vision in difficult corners and behind a vehicle. Safety developments also include the exchange of information via networking to assist in proactive accident avoidance. Notable are the efforts of a consortium comprised of government organizations, universities, and industrial groups towards the development of standards for these accident avoidance systems [3]. The IEEE WAVE (Wireless Access for Vehicular Environments) is one such effort to develop standards and protocols for inter-vehicle communication [4]. The WAVE protocol uses the dedicated short-range communications band at 5.9 GHz for communication with other vehicles and road-side infrastructure.

2 Current Application Scenarios

2.1 Information Warning Functions

Safety is one of the primary motivators for establishing inter-vehicle communications. For example, by sharing information among neighboring vehicles, conditions or events beyond the sight of a driver can be exposed. Events "over the horizon" can often cause congestion that propagates to great distances. These scenarios can be mitigated by disseminating information to vehicles that are inbound to, for example, an accident event. Moreover, road conditions, such as icing or solar glare can be sensed and reported to other vehicles as a result of enabling inter-vehicle communication. Instances where the exchange of safety critical information is significant are highlighted below:

- Lane merging/lane changing at highway intersections
- Blind spots of vehicles
- Hidden driveway collision warning
- Adaptive cruise control and cooperative driving
- Roadway condition awareness

When an accident occurs, the system and network will initiate an alert to approaching vehicles. Nearby vehicles are expected to participate in the dissemination of the alert, including the propagation of the alert to police, fire, and rescue facilities. The enabling of this communication should significantly hasten the response time for these services. In the event of a catastrophe such as hurricanes, floods or fires, the same network could be used to coordinate and control evacuation procedures.

2.2 Traffic Information Services

Efforts to provide traffic related information include the use of web-cameras which help visually determine traffic density on roads. Magnetic loop and pressure sensors are also used to determine the traffic rates and densities on roads. Traffic control centers monitor and control traffic with the help of these sensors. However, these systems are latent and do not relay active information to the traveler on the road. There is clearly an opportunity to develop a more distributed automated system that shortens the collection, aggregation, and dissemination of localized traffic data. With the help of inter-vehicle communication, up-to-date and accurate information can be relayed to compute travel estimates. Coupled with GPS systems, a traveler can get information such as traffic congestion on routes, occurrence of accidents, tolls, and road construction. Armed with this information, alternate routes can be planned thereby saving travel time, frustration, and fuel use. Some highways use large display technology to warn travelers of heavy traffic. However, this information is not fully exploited unless coupled to in-car navigation systems that provide alternative routes.

Detour paths can be guided by wireless beacons where map-based information is not available to the road user.

A vast distributed network of vehicles equipped with sensors provides real-time data for transportation research applications. Data collection from roadside observations can be automated, revealing traffic flow characteristics and road usage data. Lane charging or fee-based usage of special high speed lanes on highways is a concept proposed to ease congestion and generate revenue to support highways. Toll collection and access management are applications aimed at easing congestion on sections of the highways and ensuring smooth travel. All are enabled by vehicular networking. Depicted below in Figure 2 is the interaction of networked vehicles with road-side infrastructure such as access points.

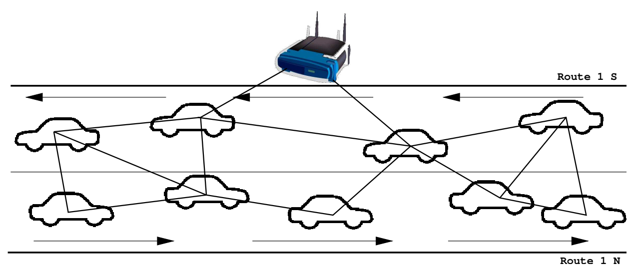

Figure 2: Illustration of inter-vehicle communication with road-side infrastructure.

2.3 Smart Traveler Services

Vehicles in the network are highly mobile elements that traverse predictable paths and can be exploited as *'messengers'* carrying 'packets.'

There are many possible services that we envision here. For example, consider how one 'hails a cab' today. We meet one at a taxi stand or optimistically wait on the street. Drivers are similarly challenged to opportunistically meet a fare. A clever application would find fares for the cab driver and find cabs for the fare. For example, via a mobile phone one could initiate a localized query to explore the network space involving taxis (and vice versa). This application could be extended to public transport such as buses and subways where people can know the time interval until the next arrival. The mass transit authorities might use this information devise efficient means of reallocating resources such as buses on busy routes.

A similar concept exists for identifying the availability of parking spaces [5]. In this case, meters are networked and vehicles serve as messengers to relay information about available spaces to approaching cars. The net is savings in time, fuel, and emissions. Vehicles are being made smarter in that they are able to predict and warn users of mechanical faults and service-check requirements. In the event that a vehicle breaks down on the road, the networked-vehicle can self-diagnose the problem, call for assistance from the nearest mechanic with the right spare parts to fix the fault.

Finally, providing Internet access to networked vehicle has many general purpose uses. In-car navigations systems already provide information about fuel stations, ATMs, rest areas, etc. However, this information is typically static and not updated regularly. With Internet connectivity one can gain access to current information that is as current as can be delivered by information sources. One can envision promotions for services or food that are delivered specifically to vehicular travelers. Internet access is also a very useful distraction for fellow passengers especially children. The ability to access Internet while on the move is very desirable for young netizens and the Web offers several activities such as movies, social networking, music, chatting, etc.

3 System Constraints and Solutions

The vehicular network is a unique case of a mobile ad hoc network in that it is comprised of mobile nodes traveling at high rates on predictable paths or roads. At the same time, they are less constrained in terms of available energy, computation or storage. Vehicles on the road become sources of traffic information. The problem of traffic information can be described as extracting data from a large distributed database and disseminating it to an interested subset. An observation is the spatial-temporal correlation of traffic data. Traffic speeds are observed for a section of the highway at a particular time and this data becomes obsolete after sometime. Similarly, nodes which are interested in data about a section of the traffic bear a spatial correlation in that they are approaching the section of the roadway. Thus, the dissemination of traffic information is region-based and constrained by a dual function of time and space.

While several architectures have been proposed for implementing a vehicular network scenario, we believe the most likely deployment is a hybrid installation with multi-hop connectivity of vehicles supported by road-side infrastructure in the form of access points or digital relay boxes. Infrastructure support is essential for connectivity to the Internet backbone and for scenarios of low density of nodes in the network where the network is partitioned. A great opportunity is to integrate vehicles into the municipal Wi-Fi scheme. Projects in several cities are directed towards deploying rooftop access points to provide Internet connectivity to all residents in range. Vehicular networks can exploit these installations for network connectivity.

The vehicular area network is characterized by vast fabric of roadways and the seemingly fast pace at which data are generated by moving vehicles and become obsolete. The applications described above should thus be autonomous in nature. The requirement is of a decentralized solution that automates the task of data collection at source, traversal to the destination and dissemination amongst interested nodes. While some data will be push-based, the system should be able to support pull-based data traffic like queries.

With respect to improving vehicular safety, there is a significant challenge of providing predictable and reliable message delivery in wireless communication channels. Safety information is critical and requires tight latencies and deterministic bounds on propagation delays. A viable accident avoidance system demands rapid and guaranteed availability of localized information to be effective.

Finally, the issue of security and anonymity of vehicular transit data is an important design constraint. To achieve the benefits of safety and improved throughput, participants will be required to participate in sharing of location, velocity, and other data. This issue is perhaps addressed in policy decisions, and protection of privacy is achieved with the use of technological solutions.

4 Conclusion

Automated driving is a vision that may soon be realized. In this position paper, we have outlined some of the initiatives to enhance safety and increase connectivity of vehicles of the future. An ongoing effort is to equip vehicles with sensors to detect roadway conditions and with communication equipment to enable inter-vehicle networking. Many new applications are possible. These applications, including improving driver safety, are expected to bring benefits to the economy by saving fuel costs, reducing emissions and creating revenue in the form of services. Local coordination will control the vehicle while global knowledge of the network will guide the vehicle on available paths and prevent congestion in an efficient manner. Positioning systems have already transformed the travel experience. In the future, we expect vehicular networking will serve as a key enabler to automated transportation services.

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