# Connecting Vehicles to “The Grid”*

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**Abstract**–Providing Internet connectivity is a near-term goal for vehicle development. But much more profound advancements in transportation systems are expected as vehicles become an integral part of networked information and control systems. Future systems will need to address the balance between personal transport and societal challenges including growing population density, carbon emissions, global industrialization. By interconnecting vehicles with networking technology we will enable distributed local control applications such as accident prevention, route optimization, and traffic management; while permitting global optimizations that balance societal constraints such as throughput, regional energy use and air quality. In this position paper we explore some of the near term advancements and their possible long term impacts.

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# Introduction

Technologies such as the Internet, personal computing and wireless communications have seen an explosive rate of innovation and growth over the past 10 years. The Internet is increasingly ubiquitous aided by the recent developments in wireless communication technologies. While the developments in semiconductor technologies are increasing personal computation capabilities. Meanwhile much research in vehicular technology focuses on energy efficiency and safety.

Human population density is consistently on the rise. Transportation systems designs need to consider the increased requirement for personal mobility as the physical diversity increases. In the current generation, several techniques such as public transportation, high occupancy dedicated lanes, and use-based taxation have been explored to encourage/discourage the use of roadways. Congestion is an acute socioeconomic problem as it causes considerable energy losses, pollution and psychological aggravation. Safety is another area for concern. The loss to human life caused by accidents is undesirable as are their subsequent economic impacts.

## Automated Travel Vision

A vision for future transportation systems includes automated vehicle scheduling in which vehicles transit the network of roadways and highways autonomously. The vehicles are able to drive themselves through computer control and negotiate roadways assisted by navigation devices. Such a system has benefits of efficiency, throughput and safety, especially in urban and dense populations. Roadways can be scheduled as a resource, permitting for high speed densely packed trains of vehicles yielding higher utilization and throughput. Using a computer network analogy, vehicles (packets) are routed based on source destination addresses on the roadway (network). Access to a roadway will be restricted to provide control over quality of service, bandwidth, guarantee of service and latency. Vehicles will be able to re-route themselves when they sense congestion on the roadway. The cost function for travel can be based on minimization of personal or system-wide metrics as established by policy. For Example, the goal can be to minimize system-wide energy usage or minimization of latency per vehicle (packet).

The automated travel vision for future road travel is becoming technically feasible given recent developments in network technology and system design [1]. In the remainder of this article we discuss the key building blocks for the automated travel vision. We discuss some interesting application scenarios for present generation systems. Finally, we conclude with a summary and benefits of autonomous travel systems.

## Building Blocks for Automated Travel

Today vehicles leverage autonomous control in the form of a human operator. Traffic laws and driving conventions provide the common rule-sets guiding the system behavior. They process the road conditions based on visual input, limited to periphery of vision, and make control decisions. Knowledge of other vehicles in the system is limited to visual (turning lamps, headlights) and sound (horns) signals. Traffic is ordered or chaotic based on the negotiation principles of vehicle controllers (drivers). When a controller fails to successfully negotiate, accidents occur.

In the future, vehicles can be autonomous either as a mirror of a human operator, or under more centralized model, utilize data originating from a region beyond what is now observable by a human. The vehicles will be potentially driven by technologies such as self-piloted steering and automatic braking. Automated control will rely on visual sensors for pathway information and positioning systems for routing information. More importantly, vehicles will be able to communicate wirelessly with neighboring vehicles and negotiate the use of the shared resource, roadway. Vehicles share location and future actions for coordination. We envision a safe automated system using distributed sensing and control enabled by inter-vehicle networking.

The problem of efficient routing of vehicles is one of global optimization. Vehicle speeds (throughput) are dependent upon the density in the system. Higher density usually implies slower speeds and vice-versa. Availability of system-wide traffic information will enable a system whereby vehicles can make routing decisions to distribute load on the roadway.

The system is likely to be tightly coupled with little or no margin for error. The control systems for autonomous vehicles are critical components and their robustness is important. The system is sensitive to malicious intent as any attack can potentially lead to losses, inefficiency or failure. Thus, anomaly detection and intrinsic security of vehicle control infrastructure is critical for the system.

## Recent Developments

There is a rush to develop vehicular communications and networking applications. The IEEE WAVE (Wireless Access for Vehicular Environments) is an effort to develop standards and protocols for inter-vehicle communication [2]. The consortium combines the efforts of government organizations, universities and industrial groups towards the development of dedicated short-range communications band at 5.9 GHz. The primary motivation is safety messaging.

With respect to vehicular safety, there are efforts to establish and enforce safety norms. One technique relies on enhancing safety by equipping vehicles with sensors that warn drivers of possible impacts with other vehicles. Examples include proximity sensors that aid the braking process by maintaining safe speed and distance. 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. Inter-vehicle communication adds to these efforts by enabling exchange of information via networking to assist in proactive accident avoidance.

The DARPA Urban Challenge is a research and development program with the goal of developing technology that will enable autonomous ground vehicles maneuvering in a mock city environment, executing simulated military supply missions [1]. The vehicles are expected to perform actions such as merging into moving traffic, navigating traffic circles, negotiating busy intersections, and avoiding obstacles. The challenge showcases developments in robotics and vehicle control systems that will eventually be incorporated in production vehicles.

# Current Application Scenarios

## Information Warning Functions

Safety is a primary motivator for developing inter-vehicle communication. Sharing information among neighboring vehicles potentially increases the awareness of a driver beyond the line of sight. Road conditions such as icing or solar glare can be sensed and reported to other vehicles by enabling inter-vehicle communication. This can be extended to incorporate police, fire, and rescue facilities for an efficient response, control and coordination of rescue procedures. Other instances of safety critical information are:

- Lane merging/lane changing on highways
- Blind spots of vehicles
- Adaptive cruise control and cooperative driving
- Catastrophes such as hurricanes, floods, fires

### Smart Traveler Services

Efforts to provide traffic information include the use of web-cameras, magnetic loop and pressure sensors to determine traffic density. Traffic control centers monitor and control traffic with the help of these sensors. These systems are latent, i.e., they do not relay active information to the traveler on the road. There is an opportunity to develop a distributed automated system that shortens the collection, aggregation and dissemination of localized traffic data. Congestion scenarios can be mitigated by disseminating information to vehicles that are headed towards the point of incidence. Instances include accidents, tolls, construction zones, detours, etc. to name a few.

An interesting observation with vehicular networking is that data are often times coupled with vehicle routes. Discovery of parking spaces in urban settings is an example where a vehicle may query parked vehicles or meters along a road to find an empty spot. A clever application is the ability to find cabs for fares by initiating a query on a mobile device.

Enabling Internet access in vehicles has potentially several benefits. Information about ATMs, rest areas and fuel stations, etc. can be dynamically updated from the Internet. Special promotions and advertisements can be targeted specifically at travelers. Internet access is also a useful distraction for fellow passengers especially children, providing activities such as movies, social networking, music, chatting, etc.

## Current Challenges

Vehicular ad hoc networks (VANETs) are a unique case of mobile ad hoc networks (MANETs). While several architectures have been proposed for implementing a vehicular network scenario, we believe the most likely deployment is a hybrid installation, multi-hop connectivity of vehicles supported by roadside infrastructure (access points). Infrastructure support is essential for connectivity to the Internet backbone and low node density scenarios where the network is partitioned.

The problem of traffic information can be described as extracting data from a large distributed spatial-temporal database and disseminating aggregated estimates to a subset. Traffic data are observed for a section of the highway, at a particular time and become obsolete after sometime. Vehicles interested in traffic data bear a spatial correlation in that they are likely approaching that section of the highway. 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.

With respect to improving vehicular safety, there is a significant challenge of providing predictable and reliable message delivery in wireless communication channels. A viable accident avoidance system demands tight latencies and deterministic bounds on propagation delays. Finally, the issue of security and anonymity of vehicular transit data is an important design constraint. To achieve the benefits, participants will be required to share location, velocity, and other private data. This issue is perhaps addressed in policy decisions, and protection of privacy is achieved with the use of technological solutions.

# Conclusion

Automated vehicles are the next generation of vehicular technology as a means to support the ever increasing population density and the growth of developing industrial nations. In this position paper, we have outlined the initiatives to enhance safety and increase connectivity of vehicles of the future. An ongoing effort is to develop standards and protocols for inter-vehicle communication that will enhance safety and introduce new applications. Apart from safety, the applications are expected to add 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 will guide the vehicle on available paths to create an efficient system that is optimized for throughput, latency and other parameters. Vehicular networking, in the future, will serve as an enabler to automated transportation services and create a safer and sustainable transportation system.

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