Proceedings of the
2007 IEEE Intelligent Vehicles Symposium
Istanbul, Turkey, June 13-15, 2007

Propagation Characteristics of Dynamic Information Collected by In-Vehicle Sensors in a Vehicular Network

K. Ozbay[1] , H. Nassif[2] and S. Goel[3]

Abstract—. **In this paper we see vehicles as mobile sensors and disseminators of information about their surroundings. This emerging concept goes beyond the past efforts of dealing only with traffic congestion that has become a part of daily life for most of us. Many researchers worked on various congestion information systems that are mainly based on the concept of collecting and disseminating traffic information through the use of vehicles roaming throughout the transportation network. Today a number of commercial solutions exist for disseminating traffic information (e.g., Traffic.com, Metrocommute, Etak- Traffic). However, these solutions are plagued by prohibitive deployment and maintenance cost that prevents widespread deployment. As an alternative, solutions based on peer-to-peer architecture have also been proposed. But most these systems are limited with collecting and disseminating the concept of travel time or congestion information. In this paper, we propose a three layered implementation architecture that will use vehicles to collect, process and disseminate information other than travel time including visibility, pavement, and weather conditions. We first describe vehicle-based experiments that we conducted to assess the feasibility of the proposed system. Then, we use a well-calibrated microscopic traffic simulation model of a relatively large network in New Jersey to test the speed and the range of information dissemination.**

I. Introduction

"Highway congestion is not just a problem of recurring "rush hour" delay in major cities. More than half of all congestion is non-recurring, caused by crashes, disabled vehicles, adverse weather, work zones, special events and other temporary disruptions to the highway transportation system." [8]. One possible way of controlling the extent of congestion is by disseminating information about all of these "**environmental and infrastructure conditions as well as traffic conditions**". Today a number of commercial systems exist for collecting and disseminating traffic information (e.g., Traffic.com [9], Etak Traffic [5]). However, these systems are limited in their coverage of the network as well as the information. They tend to cover select highways while leaving out a major fraction of roadways, thereby creating a "digital divide". More importantly, they are mainly focused on "travel time" information. The main factor that prevents these systems from covering the entire road network of the US is the cost involved. Each of these systems requires an infrastructure to be deployed (e.g., helicopters, cameras, flow sensors). This represents a huge amount of money in one-time deployment cost, and a significant annual cost in maintenance. On the other hand, the idea of providing information related to environmental and infrastructure is relatively new and none of these commercial systems has this capability.

As an alternative solution of information dissemination, system based on peer-to-peer architecture have been recently proposed [13]. In this solution, vehicles equipped with GPS and a Wi-Fi link collect traffic information as they travel. (throughout this paper, we use the term Wi-Fi to refer to wireless link based on any flavor of IEEE 802.11 protocol [10] or one that is part of the DSRC standard [2]) They disseminate some of the collected traffic information by communicating directly with other vehicles via Wi-Fi link. Like any other peer-to-peer system (e.g., Napster [6]), the effectiveness of the solution depends on number of vehicles participating in the system. If the number of vehicles volunteering to participate in the system reaches a critical mass, the system has the promise to address many of the problems faced by the existing commercial solutions — firstly, a true peer-to-peer solution would require zero-additional infrastructure [13] cutting down maintenance costs; secondly, it would have wide coverage, covering not only urban heavily traversed highways, but also other part of transportation network frequented by participating vehicles; thirdly, it would be extremely reliable because of its highly distributed nature. A true peer-to-peer solution results in an ad hoc network of highly mobile vehicles. The high mobility and large geographical extent results in characteristics that are significantly different from that of traditional ad hoc networks studied in the literature [14]. Most importantly, the resulting peer-to-peer network will not be connected. Instead, it would consist of clusters of vehicles in communication range. These clusters merge and disintegrate dynamically, as vehicles move in and out of range. The degree to which the network is connected is highly dependent on two factors — the range of the wireless link and the fraction of participating vehicles. Lack of connectivity raises questions about whether the vehicular ad hoc network can effectively disseminate traffic information.

In this study, we have two major goals: 1) to test the feasibility and accuracy of getting data from on-board and external sensors 2) to test the feasibility of disseminating this information over a peer-to-peer network using a microscopic

[1] K. Ozbay is with the Department of Civil and Environmental Engineering at Rutgers University (corresponding author, phone: 732.445.0579 (127); e-mail: kaan@ rci.rutgers.edu).
[2] H. Nassif is with the Department of Civil and Environmental Engineering at Rutgers University (e-mail: nassif@ rci.rutgers.edu)
[3] . S. Goel is with the Department of Computer Science at Rutgers University (e-mail: gsamir@research.rutgers.edu)

traffic simulator namely, Paramics [7], In [19], [20] authors have also proposed using a peer- to-peer network of cars for spreading traffic information, where each car is equipped with a Wi-Fi link . These papers tacitly assume that Wi-Fi link is appropriate for this purpose. In [12], the authors argue that the packet load in such a network would exceed the channel capacity, and suggest different aggregation techniques. In this paper, we would like to examine the validity of these assumptions. Examining the requirements of the domain is the necessary first step in this process. In the next section, we give an overview of our research approach and the proposed system. In section III, we discuss our evaluation tests using sensors that are on the car. In section IV, we outline our approach to test proposed peer-to-peer approach using simulations. In section VI, we enumerate the performance metrics. In section VII, we present the simulation results and finally discuss their implications and conclude in section VIII.

II. Overview of the Proposed System Overview

A three-layer system architecture shown in Figure 1 is proposed.

1. At the first layer raw data is obtained from the individual sensors that already exist in the car. These data are collected by a data acquisition board specifically designed to interface with the car's sensors.
2. At the second layer, estimation algorithms will use the relevant data to determine dangerous situations such as "possibility of not being able to stop given the car, road and environmental characteristics". Several important scenarios can be briefly described as follows:
   - A car approaching to a busy signalized intersection is not aware of the very slippery pavement conditions and the estimation algorithm uses the raw data obtained about the car and the pavement conditions to produce an estimate of the imminent accident danger for other approaching vehicles about.
   - A hazardous material truck traveling at a high speed on an Interstate highway is getting ready to exit but due to heavy fog, its driver does not anticipate the possibility of an accident while trying to negotiate the quite sharp turning angle at the exit ramp (this is one of the major sources of fatality accidents in the US). At the third layer, a decision is made as to whether or not to disseminate these estimates to the vehicles involved and if the answer is positive a decision has to be made in terms of the determination of vehicle that will get the information and the best way to disseminate this information. Third layer can be looked at as the "coordination" layer where final decisions are made based on the input from the second layer.

Although acquiring the data from the in-vehicle sensors can be seen as a relatively simple task, this is an important step in achieving a car-based sensing and information dissemination system that is similar to the one proposed in this paper.

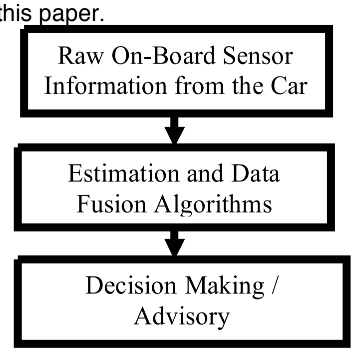


Figure 1. Three Layered Architecture

In a recent report published in 2006 [22], UC Berkeley researchers summarizes this challenge of collecting information from in-vehicle sensors in the context of Vehicle Infrastructure Integration (VII) initiative spearheaded by USDOT as follows: ***"The idea that vehicles, these days equipped with several hundred sensors, the real possibility of Global Positioning System becoming an additional and ubiquitous sensor, and a means to send sensed information off the Controller Area Network (CAN) bus to the infrastructure (and also from the infrastructure to the CAN bus) has manifold, revolutionary applications in Intelligent Transportation Systems. But what about in-the-ground implementation? This effort directly addresses this topic, as it gives Caltrans and its PATH research partner – in addition to the DaimlerChrysler Research and Technology North America (DCRTNA) – a very significant "leg up" on VII".*** The project presented in that same report describes a project between "*Caltrans, California PATH and DCRTNA that demonstrated two potential VII services, one in traffic data probes and another with safety, using real cars and on Caltrans roadways*".

The in-vehicle data acquisition efforts coupled with making sense of that location-specific data described in this paper has a very similar goal of demonstrating the feasibility of the use of already available in-vehicle sensor information to provide important advisory information in a highly mobile ad-hoc vehicular network. Moreover, making sense of this information and generating useful and timely advisory information is a quite challenging task. Section IV of this paper presents a real implementation of this concept to provide the reader with a good idea about the type of engineering application described in this paper. In fact, there are a number of federally and privately funded research and implementation projects that attempt to deploy similar in-vehicle systems. In our envisioned peer-to-peer system, we believe that only a small fraction of the vehicles would participate. Each of these participating vehicles would be equipped with a device that we call TrafficRep. This device is responsible for collecting and disseminating traffic information. The TrafficRep device connects to the in-vehicle navigation system, supplying it with current environmental, infrastructure and traffic conditions. A TrafficRep device is attached to four components: a GPS device, a static digital map database of the road network, a data acquisition device, and a WiFi link. We assume that the static digital map database is organized by road segments, where a road segment is a stretch of a road between two successive exit points (junction, exits, etc). For each road segment, the database stores several attributes: GPS coordinates of its endpoints, and sensor information such as the free-flow travel time, acceleration, and others. TrafficRep uses the location and time information from the GPS unit and the static information about location of end-points of road-segments to calculate the travel time of vehicle for different road segments. Every time the vehicle travels on a road segment and reaches the end of it, TrafficRep records the corresponding environmental (visibility, precipitation, temperature) and infrastructure (ice or wet pavement conditions, existence of bumps or pot holes, etc.) information obtained from on-board and external sensors as well as travel time information as a travel log report (TLR). This includes identifier of the road segment, environmental and infrastructure data, the travel time, and the time-stamp of the report. As TLRs get older, they are discarded by the TrafficRep device to create space for new ones. TrafficRep device disseminates sensed information (TLR) to other vehicles. They act independently of other vehicles based on locally available information in order to decide what and when to disseminate. Each TrafficRep device maintains an estimate of the conditions on all the links. In the absence of any additional information, this estimate is set to defaults values such as the free-flow travel time on the link (obtained from static database of the transportation network). On receiving disseminated traffic reports, the vehicles update their estimates. In this paper, we assume that TrafficRep device cannot query other TrafficRep devices. As a result, the TrafficRep device assumes that the traffic information available locally is the accurate information.

III. Disseminating Information Using Vehicular Ad Hoc Network

Different flavors of 802.11 have a typical range of 100 meters (outdoors) (D-Link DWL-500 has a communication range between 100 to 300 meters [4]). With simple external antenna, the range can be increased to up to 1Km [18], [1]. In DSRC standard, a wireless link is expected to have a maximum "line-of-sight" range of 1Km [2]. Since non line-of-sight communication will be more common in vehicular ad hoc network, it is not clear what this range would translate to in reality. Even a 1Km communication range may be small compared to the geographical extent of a typical transportation network. Given this and the fact that only a small fraction of all vehicles would participate in the system, the vehicular ad hoc network will have characteristics very different from traditional ad hoc network that have been studied in the literature [14]. In particular, a vehicular ad hoc network is unlikely to be connected. Instead it would consist of clusters of communicating vehicles, where vehicles in each cluster are connected. These clusters merge and disintegrate as a result of high mobility of vehicles. For vehicular ad hoc network to operate without support of any additional infrastructure and serve as an effective traffic sensing and dissemination mechanism, it must be able to meet the requirements of the application with respect to 1) The radius in which the traffic information needs to be disseminated 2) The speed of traffic reports generated during unexpected conditions such as traffic congestion or accidents.

We expect this load to be non-negligible as vehicles take independent decision on whether or not to disseminate information. We attempt to answer these two questions in this paper. Drivers would like to know the information about traffic / infrastructure / environmental on their intended route as early as possible (question of speed of dissemination). However, given a specific transportation network, a specific road segment within it that is congested, there is always a dissemination radius (centered on the congested road segment) beyond which disseminating traffic information is not "useful".

IV. In-Vehicle System Description

A. Data Acquisition System

The eDAQ system manufactured by Somat, Inc., is used as the in-vehicle data acquisition system. The system's main board is equipped with an AMD Elan 486 processor that is capable of processing 10 digital input/output and 8 pulses counter. The system has a vehicle bus interface, and an eight-channel analog high-speed low-level data acquisition board. The vehicle bus interface provides the means of collecting data from the vehicle bus. The advantage of acquiring data from the vehicle bus is to minimize the use of external sensors. The unit has a sampling rate of 10 kHz per channel. Furthermore, the eDAQ unit shown in Figure 2 has the ability to collect data from a GPS unit.

Figure 2. eDAQ system

B. On Board Vehicle Sensors

There are many on board vehicle sensors. These sensors vary from one car manufacturer to another. Furthermore, not all sensors are installed on every vehicle. However, the most common sensors that can be used to collect environmental, infrastructure, vehicle specific information are throttle position sensors, air temperature sensors, vehicle speed sensors, wheel speed sensors on ABS systems, airbag crash sensors, and brake pressure sensors. For example, wheel speed sensors combined with some estimation algorithms can be used to detect slippery pavement conditions. Furthermore, these sensors are connected to the On-Board Diagnostic (OBD II) so there are already processed parameters that will help us diagnose the vehicle (emission, engine misfire, etc), driving conditions, and traffic flows.

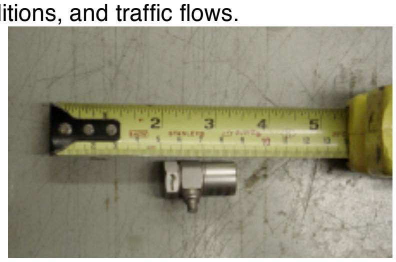


Figure 3. Accelerometer

C. External Sensors

Despite the fact that there are many on board vehicle sensors, external sensors might also be needed to determine road condition, position relative to other vehicles and road intersections. Accelerometers, laser, or sonar can be mounted on the vehicle axles to determine road roughness, bumps, and potholes. Figure 3 shows the accelerometer used.

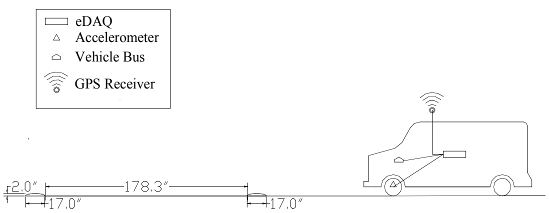


Figure 4. Schematic of the speed- bump detection test

The data collected from the external sensors is processed in conjunction with the on-board vehicle sensors since different driving conditions will have an effect on the signals of the external sensors. For example, vehicle traveling over a speed bump at different speed will cause different response on the accelerometers (Figure 4).

1) Preliminary Tests of External Sensors

The objective of the preliminary tests was to 1) see if the accelerometer could detect bumps or potholes on the road, 2) checking the sensors relationship, and 3) determine the accuracy of the GPS signals. In order to perform these tasks, the preliminary test was performed in a parking lot by driving a Ford Econoline 250 at 10 mph and 20 mph between two speed bumps shown in Figure 4. In order to detect the two bumps, the vehicle was instrumented with one accelerometer on one of the suspensions adjacent to the right wheel. The speed, engine rpm and brake pressure were detected from the signals coming from the vehicle bus. A GPS unit, Garmin III Plus, was used to detect the location of the vehicle. The sampling rates of the accelerometers and other signals were set at 100 Hz and 1 Hz, respectively. A sampling of 1 Hz was used for the vehicle bus and GPS unit since this was the maximum sampling rate available.

D. Results

In figure 5.1a, the signal from the accelerometer identifies the two bumps from flat road surface condition. The distance between the two bumps was calculated by from the time between the two bumps and the vehicle speed of 20 mph

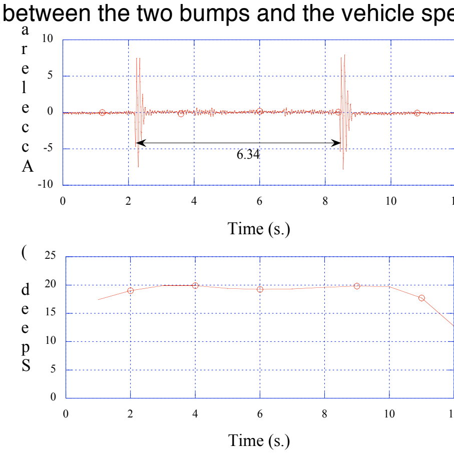


Figure 5.1a. Accelerometer and speed response at 20 mph

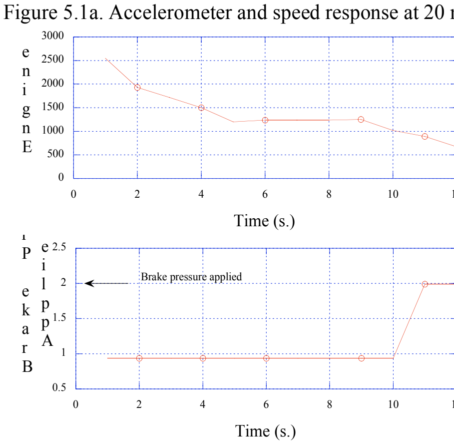
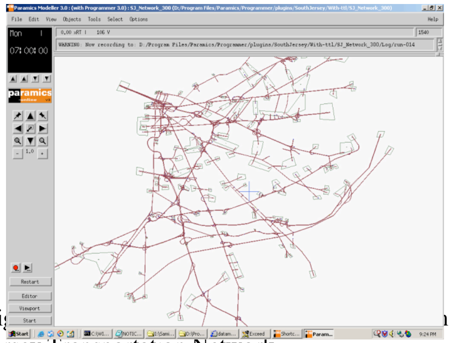


Figure 5.1b. Engine and brake pressure response at 20 mph

Thus for the second objective, the relationship of the sensors are highly related. In Figures 5.1b and 5.2b, the engine rpm follows a similar trend as the vehicle speed. As the engine rpm drops (the gas paddle is not initiated), the speed drops also. The applied brake pressure data also shows a relationship between the vehicle speed and engine rpm.

As for the GPS, the latitudinal and longitudinal coordinates at where the two bumps (peaks) were plotted using mapping software. It was found that the distances between the two bumps were 168 ft. and 201 ft. for 10 mph and 20 mph runs, respectively. That gives error values of 6 percent and 13 percent due to higher error in the GPS unit as result of low sampling rate.



Fi… n of Southern New Jersey Transportation Network

V. SIMULATION BASED TESTING

We have used a microscopic traffic simulation model of the most of the highways in Southern New Jersey shown in Figure 5. The transportation network model consists of approximately 4000 road segments drawn to closely match reality. The parameters controlling the flow in our simulations were based on the data provided by the Delaware Valley Regional Planning Commission (DVRPC [3]) and calibrated in [17] to make sure that the traffic characteristics closely match the ones seen in reality. Paramics [7], a micro-traffic simulator simulates movement and behavior of each individual vehicle and allows programmable control of route chosen by each vehicle. We have augmented Paramics to simulate communication between vehicles. Since the goal of this simulation is not to test dynamic traffic assignment techniques as discussed in [16], [11], [15], we employ a simple route choice mechanism described below.

In order to simplify our analysis we focus on the generic travel time information collection and dissemination problem. However, it is clear that information that is detected and then disseminated can be considered as generic information about travel, environmental, infrastructure, as well as vehicle specific. In this paper, we consider only the vehicles traveling between a specific origin-destination zone pair. In order to evaluate the effectiveness of the dissemination mechanism, we simulate an incident on the default route in our simulations. This incident results in closure of lanes. The incident occurs 40 minutes after the start of simulation, and lasts for 25 minutes. Note that the dissemination radius is a function of the duration of incident and the number of lanes affected by it. Clearly if an incident lasts longer and affects more lanes, the traffic information would have to be disseminated farther. Incident duration of 25 minutes is close to the average incident duration. In simulations, we have set the market penetration (fraction of vehicles participating in the system) to 3%, 5%, and 10%. Market penetration has direct bearing on the wireless bandwidth used. The higher the market penetration, the higher the wireless bandwidth used. We tested the speed of information dissemination as a function of market penetration. In our simulations, in all the cases, the information originates at approximately the same point in the network. Also, in all cases, the Wi-Fi range of 200m was used. In our earlier work [21], [22], we took snapshots at different instants of time. For each snapshot, we divided the network into islands of connectivity. We then measured the size of different islands to determine the instantaneous reach. In this paper, instead of limiting ourselves to instantaneous reach, we can now define the notion of “reach(t)”, which is the reach of the network after time ’t’ units of time. In this work, we are expressing reach(t) in terms of number of cells “infected”. We coin the terms ”infection” to depict the fact that information has reached that cell.

A. Effect of Market Penetration: Simulation Results

We examine the effect of market penetration on the performance of a naïve dissemination scheme. The performance metric used is the total number of cells infected with the information. Note that once a cell is infected, it stays “infected”. As expected the performance improves with increasing market penetration rates. Figures 6, 7, and 8 present a visual of spread of information after 2 minutes and after 5 minutes for different market penetration levels.

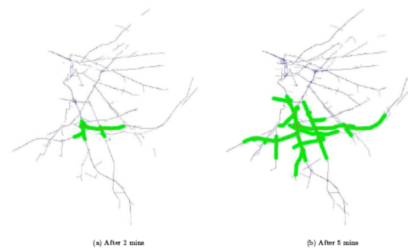


Figure 6. View of spread of information after 2 mins and 5 mins (Market penetration: 3%)

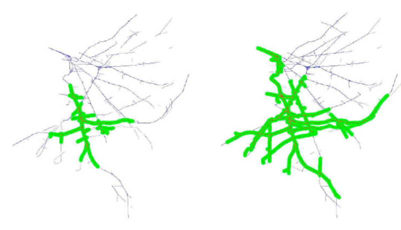


Figure 7. View of spread of information after 2 mins and 5 mins (Market penetration: 5%)

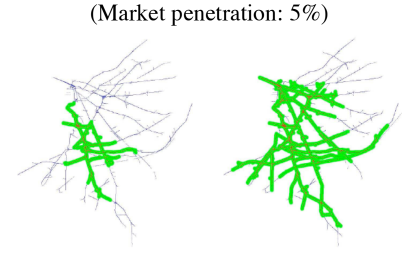


Figure 8. View of spread of information after 2 mins and 5 mins (Market penetration: 10%)

In Figure 9, the dynamic propagation of the information is shown using different color schemes. Red color indicates the "infected" cells, green color indicates "coverage" assuming the given Wi-Fi range, and blue color approximates the underlying road network. Figure 9, which, shows the same information about the "speed of infection" for different market penetration rates depicts the fact that at lower market penetration rates not only the speed of the infection is slow, the extent of information is also limited.

VI. CONCLUSION

In this paper we presented a vehicle-based system that can use already existing and additional in-vehicle sensors to collect traffic, infrastructure, and environmental information and a WiFI ink to communicate this information with other vehicles. We tested the feasibility of using vehicle-based sensors coupled with GPS to detect hazardous roadway conditions such as pot-holes or bumps that can cause accidents. Of course other road hazards such as ice, flooding or debris on the roadway can also be detected using in-vehicle sensors and smart algorithms similar to the ones presented in [23]. Furthermore, we used microscopic traffic simulation to demonstrate the speed and range of he dissemination of this information using a concept of "infection" for various market penetration rates. We clearly showed that lower market penetration doe not only reduce the speed of infection, it also reduces the range of infection for a given time period. Our future goals are to generalize simulation results using closed form expressions of this relationship and also continue vehicle tests for different type of on-board and external sensors.

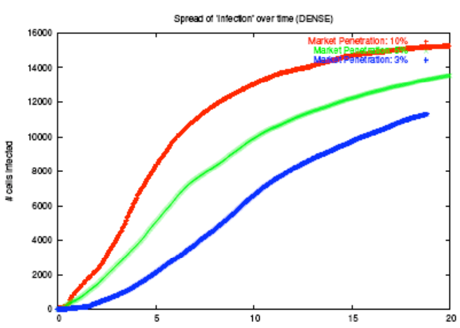


Figure 9. Rate of spread of information over time

REFERENCES

[1] AIR-ANT2506, Omni-directional antenna, Cisco Inc. http://www.cisco.com/univercd/cc/td/doc/pcat/aoo1.htm.

[2] Dedicated Short Range Communication (DSRC). http://grouper.ieee.org/groups/scc32/dsrc/faq/index.html.

[3] Delaware Valley Regional Planning Commission. http://www.dvrpc.org.

[4] DWL-500, Wireless LAN PCI Card, D-Link Inc. http://www.dlink.com.au/products/wireless/dwl500/.

[5] Etak Traffic-Real Time Traffic Information. http://www.etaktraffic.com.

[6] Napster, Roxio Inc. http://www.napster.com/. Quadstone Paramics V4.0 - Microscopic traffic simulation system. Quadstone Limited. http://www.paramics- online.com.

[7] Traffic Congestion and Sprawl. Federal Highway Administration, US Department of Transportation. http://www.fhwa.dot.gov/congestion/congpress.htm.

[8] Traffic Information for US Cities. http://traffic.com.

[9] IEEE Std. 802.11a - Wireless LAN MA Cand PHY layer specifications: High Speed Physical Layer in the 5GHzBand, 1999.

[10] Chen, P., Srinivasan, K., and Mahmassani, H., S. "Effect of information quality on compliance behaviour of commuters under real-time in formation". Transportation Research Record 1676, pages 53–60, 1999.

[11] Dashtinezhad, S., Nadeem, T., Liao, C., and Iftode, L. "Traffic view: As calable traffic monitoring system". In Proceedings of 2004 IEEE International Conference on Mobile Data Management, January 2004.

[12] Goel, S., Imielinski, T., Ozbay, K., and Nath, K. "Grassroots–a scalable and robust information architecture". Technical Report DCS-TR-523, Rutgers University.

[13] Johnson, D., B., and Maltz, D. A. "Dynamic source routing in ad-hoc wireless networks". In Mobile Computing, volume 353. Kluwer Academic Publishers, 1996.

[14] Kachroo, P., and Ozbay, K. "Feedback control theory for dynamic traffic assignment". Springer-Verlag Series on Advances in Industrial Control, Springer-Verlag, 1999.

[15] Mahmassani, H., S. "Dynamic network traffic assignment and simulation methodology for advanced systems management applications". Network and Spatial Economics1, 2001.

[16] Ozbay, K. and Bartin, B. "South Jersey Real-time Motorist Information System, NJDOT Project Report. March 2003.

[17] Singh, J. P., Bambos, N., Srinivasan, B., and Clawin, D. "Wireless LAN performance under varied stress conditions in vehicular traffic scenarios". In IEEE Vehicular Technology Conference, volume2, 2002.

[18] Wischhof, L. , Ebner, A., Rohling, H., Lott, M., and Halfmann, R. "SOTIS- A Self-Organizing Traffic Information System". In Proc. of 57th IEEE Vehicular Technology Conference (VTC 03Spring), Jeju, South Korea, April 2003.

[19] Ziliaskopoulos, A., K. and Zhang, J. "A Zero Public Infrastructure Based Traffic Information System". In Proc. of 82nd Annual Meeting of Transportation Research Board, 2003.

[20] Goel, S., Imielinski, T., Ozbay, K., and Nath, K. "Sensors on Wheels – towards a Zero-Infrastructure Solution for Intelligent Transportation Systems" CD-ROM Pre-Prints of the 83th TRB Annual Conference, 2004, Washington, D.C..

[21] Goel, S., T. Imielinski, and Ozbay, K. "Ascertaining viability of Wi-Fi based Vehicle-to-Vehicle Network for Traffic Information Dissemination, Published in the CD-Rom of the 7th IEEE International Conference on Intelligent Transportation Systems, 2004, Washington, D.C.

[22] Xuanming, D., K., L., Misener, J., Varayia, P., Zhang, W. "Expediting Vehicle Infrastructure Integration (EVII) UCB-ITS-PRR-2006-20, California PATH Research Report, 2006, UC Berkeley.

[23] Petersson, N., and Santesson, M. "Experimental Slip Based Road Condition Estimation" Report Number 5635, Lund Institute of Technology , 2000. .