WIDE-AREA WIRELESS TRAFFIC CONDITIONS MONITORING: REALITY OR WISHFUL THINKING?

Pedram Izadpanah, Bruce Hellinga

Proceedings of the ITE Canadian District Annual Conference
held May 6-10, 2007 in Toronto, Canada.

Abstract:

In large urban areas dedicated fixed traffic sensors are deployed on major freeways (e.g. COMPASS and RESCU systems in Ontario) enabling traffic operators to collect high quality road condition information in real time. However, almost no real time information is available for all other roadways and full instrumentation of all major highways and arterials is cost prohibitive. Consequently, travellers are unable to make informed decisions about the best travel mode, departure time, and route, and traffic managers are unable to predict or monitor the effect of management strategies for roadways outside of the instrumented freeway corridors. The lack of information causes frustration on the part of travellers and transportation system managers and often results in sub-optimal decisions.

New developments within the wireless communication field (dedicated probe systems, cell phone based systems or Vehicle Infrastructure Integration) provide the opportunity to obtain traffic condition information over a wide spatial area in near real time without the deployment of dedicated traffic sensors. A limited number of commercial systems have emerged in the market and several evaluation studies in North America are currently underway or have been recently completed. Most research and commercial activity in the area of network wide traffic monitoring has focused on the estimation of speed or travel time; however, this technology may support a wide range of other traffic management activities.

This paper (a) describes the techniques that can be utilized to obtain wireless network wide traffic monitoring; (b) explores the opportunities that wide area traffic monitoring provides; (c) identifies existing commercial systems; and (d) summaries the published results of North American evaluations of these systems.

1 INTRODUCTION

One of the most significant challenges to more effectively using the existing transportation infrastructure is the lack of accurate, up to date traffic condition data for the entire road network. In large urban centres, dedicated traffic sensors are deployed on major freeways (i.e. COMPASS and RESCU) enabling traffic operators to collect high quality road condition information in near real-time. However, almost no real-time information is available for all other roadways. Consequently, travellers are unable to make informed decisions about the best travel mode, departure time, and route. And traffic managers are unable to predict or monitor the effect of management strategies for roadways outside of the freeway corridors having dedicated traffic monitoring equipment. The lack of information causes frustration on the part of travellers and transportation system managers and often results in sub-optimal decisions.

The wide spread deployment of dedicated traffic sensors is cost prohibitive and consequently, dedicated sensors are typically deployed on only heavily travelled freeways within large urban centres. For example, Highway 401 is the only freeway that traverses the province - running 820 km from Winsor in the West to Cornwall in the East - and is a vital transportation corridor for the movement of goods and people. Despite its importance, only approximately 59 km (7%) of it is instrumented. However, new developments within the wireless communication field provide the opportunity to obtain traffic condition information over a wide spatial area in near-real time without the deployment of dedicated traffic sensors. These developments can be categorized into three main approaches, namely (1) dedicated probe systems; (2) cell phone based systems; and (3) ad-hoc wireless mobile networks (referred to in the transportation sector as Vehicle-Infrastructure Integration or VII).

Specially instrumented vehicles can be used as dedicated probes to obtain traffic conditions data. Probe vehicles are typically equipped with a GPS receiver, an electronic map database, and a wireless communication link, and optionally additional sensors such as pavement temperature sensors, etc. The probe is typically configured to send sensor and position data to a central data processing facility on a pre-defined time periodic basis or in response to specific events (such as passing a geographical position or when speed is less than a predefined threshold).

Cell phone based systems have become possible as a result of the development of the ability to determine the location of a mobile phone. The locationing techniques were originally developed in response to the CRTC (Canadian Radio and Telecommunications Commission) and FCC (Federal Communications Commission) requirements that wireless carriers be able to provide an estimate of the location of a mobile phone in the event of an emergency call to 911. Currently, the accuracy of the estimated locations in cell phone based systems is sufficient to support the estimation of speeds and travel times on roadway segments. A limited number of commercial systems have emerged in the market and several evaluation studies in North America are currently underway or have been recently completed. Most research and commercial activity in the area of network wide traffic monitoring has focused on the estimation of speed or travel time; however, this technology may support a wide range of other traffic management activities.

The concept of Vehicle Infrastructure Integration (VII) was first introduced in the mid 1990s in terms of applications for intersection collision avoidance systems. Within a VII system, every car manufactured would be equipped with Dedicated Short Range Communication (DSRC) and a GPS unit so that data can be exchanged between individual vehicles and with a nationwide instrumented roadway system. Currently, most of the vehicles being manufactured in North America have a large array of sensors required for maintenance and operation of the vehicles. These vehicles have the ability to measure outside temperature near the surface of the pavement, they can determine whether it is raining or not, they can also know when traction control or antilock braking system (ABS) is activated. If this information is coupled with location data (as determined from GPS), there is the potential for a broad range of stakeholders in the transportation industry to obtain benefits from such a deployment. For example, in addition to obtaining traffic information necessary for maximizing capacity of the network, maintenance crews could operate more efficiently by receiving real time information regarding the pavement surface conditions.

This paper is organised as follows: Section 2 describes in more detail each of the three categories of traffic monitoring systems. Section 3 explores the opportunities that wireless monitoring of traffic may provide. Section 4 identifies and describes the commercial systems that are currently available in the market and also reports the published evaluations of these systems. Section 5 summarises the issues that need to be resolved before any wide spread deployment of any wireless monitoring system. The last section makes several concluding remarks.

2 TECHNIQUES FOR THE WIRELESS MONITORING OF TRAFFIC CONDITIONS

This section describes three methods of wireless monitoring of traffic flow, namely dedicated probes, cell phone based systems, and Vehicle Infrastructure Integration (VII).

2.1 DEDICATED PROBES

Instrumented vehicles can be used as dedicated probes to obtain traffic conditions data. Vehicles are typically equipped with a GPS receiver, an electronic map database and a wireless communication link. The vehicles periodically send position data to a central data processing facility.

Dedicated probe vehicles have been used extensively for the purposes of obtaining traffic information, however, the majority of these applications have been for either short term data collection (e.g. travel time or speed and delay studies) or make use of special purpose vehicles (e.g. commercial vehicles such as trucks or taxis; public transit buses; or winter maintenance vehicle fleets).

The most evident disadvantage of use of commercial fleets as probe vehicles is the bias that would be introduced because the probe vehicles are not a random sample of the population of vehicles. A second disadvantage is the limited number of vehicle probes from which data may be obtained. Naturally this second limitation becomes less problematic when there are very many dedicated probe vehicles.

In Section 4, several commercial systems that make use of data from dedicated probes to estimate traffic conditions are introduced.

2.2 CELL PHONE BASED SYSTEMS

Cell phones are now used as a regular medium of communication around the world. A cell phone system consists of a set of base stations, located on a cell grid typically depicted as a series of adjacent hexagons (Figure 1). One base station is associated with each cell. The base station consists of a tower and a small building containing the radio equipment to communicate with cell phones located within the cell and land-line equipment to communicate with a Mobile Telephone Switching Office (MTSO). The MTSO handles all of the phone connections to the normal land-based phone system for several base stations in a region. Consequently, the MTSO knows the cell in which each cell phone currently connected to the network is located.

The cell ID information available at the MTSO represents one source of data for inferring traffic conditions. However, extracting meaningful information requires that:

1. It is possible to determine if the mobile phone is in a vehicle, and

2. The road segments a mobile phone has traversed can be identified from a time series of cell IDs and electronic road map database.

As the cell phone is moving toward the edge of a cell, the base station associated with the cell can measure that the strength of the signal from the cell phone is diminishing. At the same time the neighbouring cell notes that the cell phone's signal is strengthening. Consequently, the two base stations communicate with each other through the MTSO and at some point, the cell phone gets a message that tells the cell phone to begin communicating with another base station. This process is termed "hand-off" and is depicted in Figure 2 (Layton et al., 2006).

Knowledge of the time of hand-off and the geographical region of hand-off provides a second source of data for extracting road conditions data. This source provides more information than just the cell IDs obtained from the MTSO providing the potential for more accurate determination of the mobile phone's position.

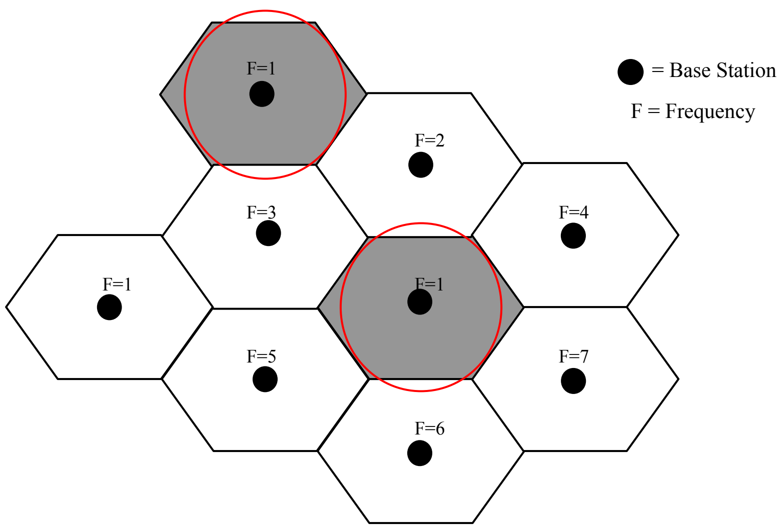


Figure 1: A typical cell grid and associated base stations.

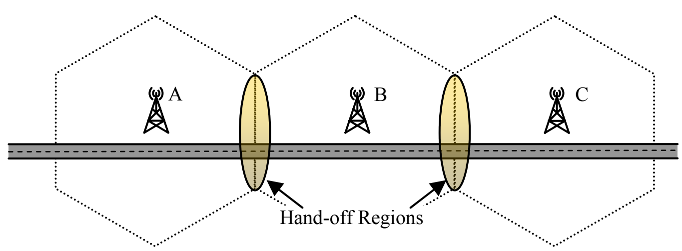


Figure 2: Hand-off mechanism of a moving cell phone.

Although, using locations and time associated with locations, traffic conditions along the route of the probe vehicles could be determined, it requires a few steps to be taken to convert the raw data into travel time and speed. (Hellinga *et. al.*, 2003) and (Hellinga *et. al.*, 2005) provide detailed information about these steps.

2.2.1 Cell Phone Location Identification Techniques

The cellular phone system was not designed originally to provide handset locations and therefore, carriers have had to develop new modules and deploy additional hardware to determine the locations with sufficient accuracy to satisfy the 911 requirements established by the CRTC and FCC.

Location identification techniques can generally be divided into one of 3 categories (Laitinen et al., 2001):

- Network-based
- Handset-based (GPS)
- Assisted- GPS

Each of these location identification techniques are described in the following sections.

2.2.1.1 Network-based Techniques

In network-based implementations, one or several base stations are involved in locating a mobile phone. Moreover, all required measurements are conducted at the base stations and the measurement results are sent to a location centre where the position is calculated. In this type of implementation, there is no requirement to make any changes to the current handsets. However, the mobile phone must be in active mode (i.e. in "talk" mode or sending a signal through the control channel) to enable location measurement. A number of network-based location identification techniques have been developed. Following are descriptions of the most common techniques.

Cell Identification Technique

Knowledge of the cell in which a handset is located is an intrinsic characteristic of a cellular phone system, and therefore there is no need for network hardware enhancements. In this technique, the location of the mobile phone is approximated by the location of the base station. Relatively minor software changes enable these cell IDs to be obtained continuously over time rather than only when a 911 call is initiated. Obviously, the accuracy of this technique is dependent on the size of the cell; the accuracy in rural areas, where the sizes of cells are substantially bigger than urban areas, is much lower.

Time of Arrival Technique

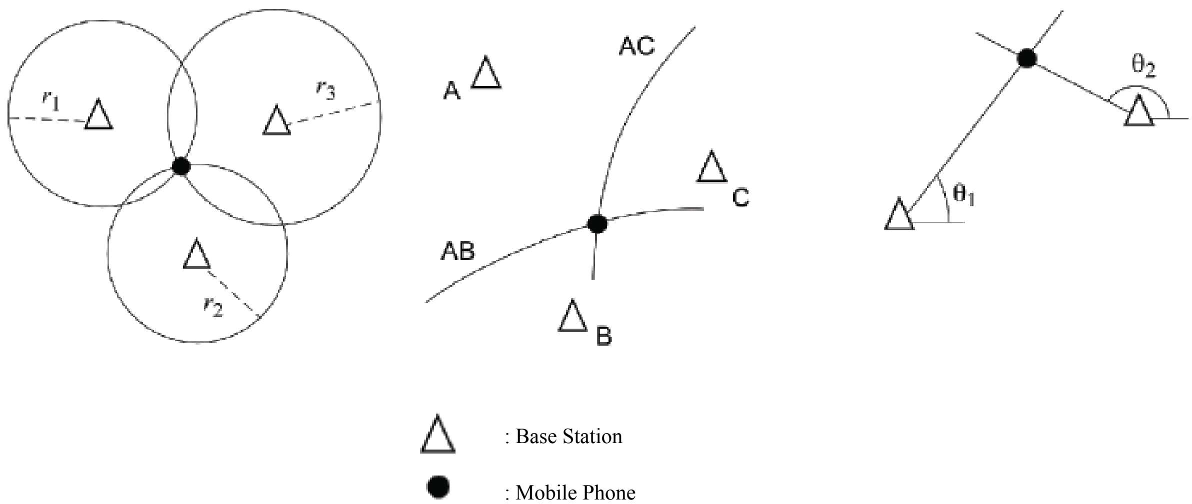
Since radio waves between base stations and mobile stations travel at a constant speed equal to the speed of light, the distance between a mobile phone and a base station is directly proportional to the time of arrival of the wave (Zhao, 2000). Consequently, if at least three base stations identify the time of arrival of a signal from a specific handset, then the location of the handset can be estimated as the intersection of the three circles centered on these base stations (Figure 3-a).

Time Difference of Arrival Technique

Another technique, termed "time difference of arrival" is based on the characteristic that the locus of time difference of arrival of a signal between two base stations and a mobile phone forms a hyperbola. Thus, the mobile phone's location lies at intersection of two hyperbolas associated with two pairs of base stations (Figure 3-b).

Angle of Arrival Technique

The location of a cell phone can also be determined by measuring the angle of arrival of the radio wave. In this case, the intersection of two directional lines of bearing defines a unique position (Figure 3-c) (Takada, 2006). This technique requires at least two base stations and also requires directional antennas or antenna arrays to be installed at the base stations to measure the angle of arrival. Since the angle of arrival technique requires line-of-sight propagation conditions to accurately estimate the location of a mobile phone, this technique is not appropriate in dense urban areas (Zhao, 2000).



a) Time of Arrival   b) Time Difference of Arrival   c) Angle of Arrival

Figure 3: Network-based methods of estimating handset locations.

Timing Advance

Timing Advance (TA) is a Time Division Multiple Access (TDMA) term used in Global System for Mobile communications (GSM) networks. GSM uses the TDMA technology for sharing one frequency between several users in order to avoid interference. The TA value is normally between 0 and 63 and each step represents an advance of one symbol period (approximately 3.69 microseconds). Since the radio waves travel at the speed of light (300,000,000 m/s), each TA step represents 550 m from the base station (Eberspacher et al., 2001). In urban areas, the maximum TA step is usually 2 (i.e. cell diameter ≤ 2 Km) while in rural areas it could be as large as 20 (i.e. cell diameter ≤ 20 Km). Consequently, TA can be used to identify the location of a cell phone with maximum error of approximately 550 m.

2.2.1.2 Handset-based Techniques

In handset-based implementations all the measurements and calculations are performed in the handset and the results (i.e. location) are transmitted to the base station. In this category of implementation, handsets must be able to measure their own locations, typically through the use of GPS.

GPS uses satellites orbiting the earth to determine position, speed, and time anywhere around the globe. The system is developed and maintained by the US Department of Defence. Civilian access is available through an agreement with the US Department of Transportation (Zhao, 2000). The GPS receiver determines the position of itself based on time of arrival technique.

The use of GPS in mobile phone as a locationing technique suffers from three main disadvantages (Zhao, 2000): First, the time required to obtain a GPS position is relatively long, ranging from 60 seconds to a few minutes due to the time required to acquire the satellite navigation message. Second, GPS signals are too weak to detect indoors and in urban canyons especially with small cellular sized antennas. Third, due to long signal acquisition time, GPS power dissipation is very high.

2.2.1.3 Assisted GPS Techniques

Assisted GPS (AGPS) is a technique devised to overcome the limitations associated with GPS based locationing. In an AGPS system, a network of fixed GPS receivers (often located at the base stations) is deployed. These receivers are located to have a clear view of the sky and can operate continuously. The reference network is also connected with the cell phone network and continuously monitors the real time satellite constellation status and provides precise data. At the request of the mobile phone, data derived from the GPS reference network are transmitted to the cell phone's GPS receiver to "bootstrap" the position acquisition process (Zhao, 2000). Through this technique, acquisition time and consequently power consumption is reduced due to the fact that the search space is limited by data from the reference network. Furthermore, sensitivity of the receiver is increased when the signals are weak (Zhao, 2000). Obliviously, legacy cell phones can not be used in this system.

2.3 VEHICLE INFRASTRUCTURE INTEGRATION

The VII initiative was one of the nine new programs of the US DOT that was formally announced in 2004 and when the "VII Coalition" formed. This organisation is composed of the US Department of Transportation, representatives from automotive manufacturers, state and local transportation agencies (e.g. CALTRANS, Florida DoT, Metropolitan Transportation Commission - San Francisco Bay Area, etc.), and transportation association such as ITE and ITS America. The general structure of the organization is provided in Figure 4.

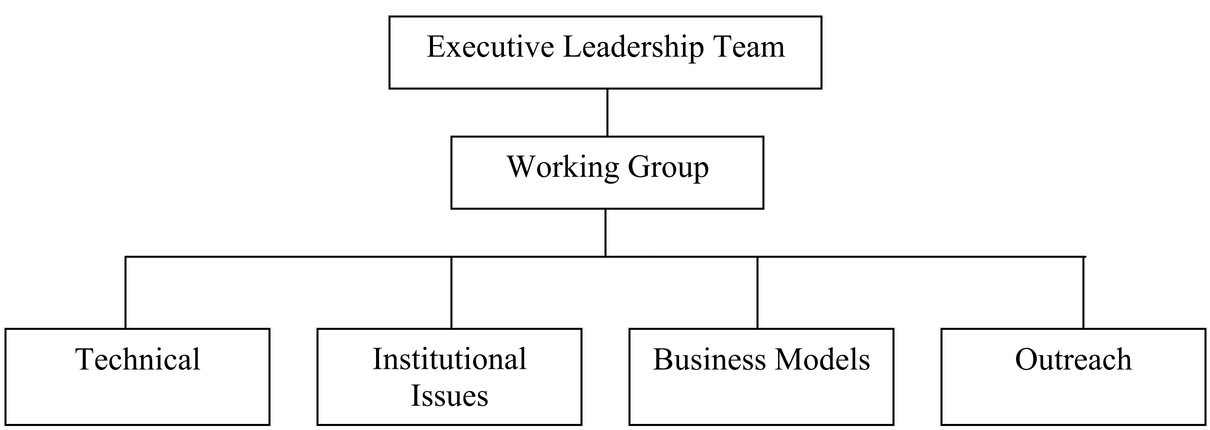


Figure 4: General organization of VII Coalition.

The effort of the VII Coalition working groups has resulted in the national VII architecture which is briefly explained below.

The general concept of the VII is demonstrated in Figure 5. In the VII system, vehicles are equipped with some On-Board Equipment (OBE). The OBE collects data from different sensors installed in the vehicle and has the capability to store the data (limited only by its storage capacity). Moreover, the OBE includes a Dedicated Short Range Communication (DSRC) and a GPS to communicate with Roadside Equipment (RSE). The RSE may be installed at any locations in the network (e.g. freeway interchanges, intersections, etc.) to communicate with vehicles in range. An RSE may be composed of a GPS unit, a DSRC receiver, an application processor, and an interface to the VII communications network. Where applicable, the RSE is equipped with an input/output controller to communicate with local traffic control devices (e.g. traffic signals). In the VII system it is assumed that RSE would be deployed all over the network at the national level.

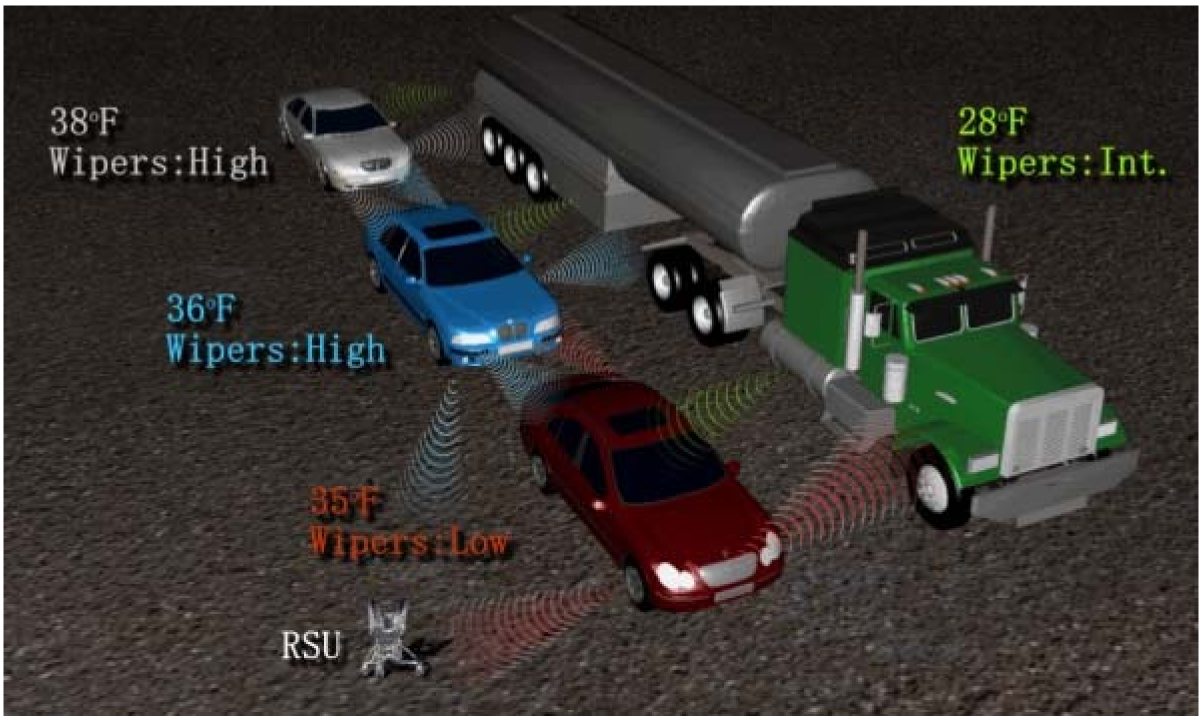


Figure 5: Concept of Vehicle Infrastructure Integration (Source: US DOT, 2006).

In the VII architecture, all vehicles in the network will disseminate two types of data, namely periodic data and event data. Periodic data are the information that is changing over time such as vehicle's speed and position. This kind of data will be disseminated frequently. Event data are the information that is relevant only under specific circumstances which typical occur infrequently. An example of event data is the deployment of a vehicle's airbag.

The architecture proposes that the use of memory bins, termed "snapshots", to store vehicle data. When it is time to record periodic or event data, the data along with the GPS data and timestamp will be stored in the next available snapshot. When the vehicle comes within the range of an individual Road Side Unit (RSU) or another vehicle, all of the stored snapshots are transmitted to the RSU and the RSU immediately sends them to the corresponding VII Message Switch. The

VII Message Switch then publishes the data to the appropriate subscribers, depending on their subscription privileges. The VII Message Switches are not responsible for storing the data and the data are overwritten once they are published to the authorized network users. The network subscribers are accountable for data storage. It is expected that the VII Message Switches be connected to each other and VII operation center(s) will control all of them.

3 POTENTIAL OPERATIONAL CAPABILITIES

The type of data that dedicated probe vehicles systems and cell phone based systems provide are similar in that positions of the probe vehicles would be available over time. In the VII system though, types of data that would be disseminated are very dependent upon the structure of the system. However, it is believed that the VII system should be able to disseminate much more information in addition to position and time.

Table 1 provides a list of potential activities that can be supported by cell phone based systems and dedicated probe systems. As can be seen in this table, these activities have been associated with five broad categories of transportation activities, namely traffic management, traveller information, transportation planning, winter maintenance, network performance monitoring, and public transit. Some specific activities can contribute to more than one of the six categories. These activities are either currently being performed by Ministries of Transportation or of interest of them.

Table 1: List of transportation activities that potentially could be supported by wireless network conditions monitoring data

	Automatic incident detection	Freeway congestion balancing	Integrated freeway/arterial management	Origin/destination demands	Identification of routes	Pre-trip planning	Current travel times	Road conditions	Historical network travel times	Border crossing travel times
Traffic Management	X	X	X							
Traveller Information						X	X			X
Transportation Planning				X	X				X	
Winter Maintenance							X	X		
Network Performance Monitoring									X	
Public Transit									X	

3.1 TRAFFIC MANAGEMENT

3.1.1 Automatic Incident Detection

The detection of incidents has been viewed as a critical component of a traffic management system. Automatic detection of incidents on freeways has been the subject of extensive research for over 40 years. The majority of this research has focussed on the development of automatic incident detection algorithms (AID) that rely on induction loop detector data for input and surveillance cameras for confirmation of occurrence of the incident. Currently, there is no incident detection algorithm developed for arterials or rural areas. The wireless monitoring of the network provides the opportunity of early detection of incident in the network without relying on fixed sensors or cameras.

The VII based wireless network monitoring systems are expected to be able to provide event specific information, such as notification that an airbag has been deployed. These detailed data may support the direct identification of an incident. However, the other two systems require development of specific algorithms to infer the occurrence of an incident.

3.1.2 Congestion Balancing

Highways similar to Highway 401 through Toronto that consist of collector and express lanes may experience different levels of congestion in the collector and express facilities. To minimize the total delay of users, the congestion should be balanced between these two facilities. A wireless network conditions monitoring system has the potential to improve the existing average speed estimates used within the current traffic management system (e.g. COMPASS in Ontario) due to the ability to directly measure travel times. This capability is particularly important during periods of construction and road maintenance when loop detector data often are not available. However, the most significant challenge is the necessity to distinguish between vehicles in the express lanes and vehicles in the collector lanes. Wireless monitoring systems that rely on data with relatively low location accuracy will not be able to distinguish between vehicles in the express versus the collector lanes and therefore will not be able to reliably estimate travel times separately for the two facilities.

3.1.3 Integrated Freeway/Arterial Management

The integration of freeway and arterial control and management is an area of traffic management that has not yet seen significant progress. One reason for this limited progress is the lack of real-time road condition information for the arterial road network. Wireless road conditions monitoring systems present the opportunity to obtain road conditions data in near real-time. These data are not restricted to freeways or selected major arterials, but to almost the entire road network. Consequently, there is the potential to use these data to support more integrated freeway/arterial control than is currently possible.

3.2 TRAVELLER INFORMATION

From the perspective of road users, travel time typically is the single most important measure of road network performance. Unfortunately, most traffic sensors are not able to measure travel time and therefore typically, there are little or no empirical travel time data available.

Travellers make origin, destination, route, mode, and departure time choices, in part on the basis of their personal prediction of what the travel time for their trip will be. Choices of origin and destination are typically long term choices, such as location of home and work. The other choices are shorter term choices and made on a trip basis. For a trip between any given origin and destination, the departure time is a function of not only the average trip time but also the distribution (variability) of travel times. Travellers who frequently make a specific trip gain an understanding of the mean and distribution of trip travel times based on personal experience. However, this experiential data is:

- restricted to the route(s) taken (i.e. drivers don’t know what their travel time would have been if they had taken a different route),

- subjective and qualitative (i.e. drivers generally do not objectively measure their travel times. Rather they form qualitative or approximate impressions such as the trip was "much longer" today than expected),
- not easily disseminated to other travellers.

Wireless network conditions monitoring systems provide the capability to compile a real-time and historical data set of measured travel times and to use these data to support various pre-trip and en-route traveller decisions (i.e. traveller information) and infrastructure planning (i.e. transportation planning) activities.

3.2.1 Pre-trip Route Planning

In the context of traveller information, the most common pre-trip planning choices are those associated with travel mode (e.g. transit, auto, walk, etc.), route, and time of departure. Time of departure is dictated almost exclusively by the expected mean and variance of trip travel time while route and mode may be influenced by other factors (e.g. car ownership, out of pocket cost, perceived convenience, etc.).

Pre-trip planning tools have already been implemented with respect to specific modes, such as transit (for example Mississauga Transit's "Click n' Ride" web-based trip planner: http://www.mississauga.ca/portal/residents/publictransit). These tools enable travellers to identify appropriate routes and determine the expected trip travel time.

There exists the opportunity to create a true multi-modal (e.g. public transit, active modes such as walk and bike, and auto) trip planning tool that has the ability to estimate journey times. Such a tool would also be very valuable as a component of a 511 traveller information service. It is anticipated that the first phase of developing such a tool would be the development of the tool for auto trips as tools for transit already exist.

3.2.2 Roadway Travel Times

Perhaps one of the most significant opportunities presented by wireless wide-area network conditions monitoring systems is the ability to obtain travel time information for the majority of the road network in near real-time. This information is not currently available and cannot be obtained in a cost effective manner using existing fixed point dedicated traffic sensors.

3.2.3 Border Crossing Travel Times

Wireless monitoring of road network traffic conditions provides the opportunity to specifically target the travel times on roadway approaches to and through the international border crossings. This information would be of high value to commercial carriers (although some large carriers may already obtain similar information on the basis of internal company fleet tracking systems) as well as private motorists.

3.3 TRANSPORTATION PLANNING

A wireless network monitoring system provides near-real time road condition data which are of prime importance for traffic management and traveller information. However, these data can also be archived to build a rich historical database that can be mined in support of various off-line activities, including transportation planning. Five specific activities that relate to transportation planning have been identified:

- Identification of origin/destination demands
- Identification of routes
- Historical network travel times
- Mobility monitoring
- Public transit planning

3.4 WINTER MAINTENANCE

Wireless wide-area conditions monitoring provides at least three opportunities in the area of winter road maintenance. The first is the direct measuring and reporting of road surface conditions. The second is the inference of road surface conditions on the basis of traffic speeds. The third is the use of current travel time data to manage the dispatch of winter maintenance vehicles.

The direct measuring of road surface conditions is only viable for VII-based systems in which the vehicle is able to report data from the traction control system, anti-lock braking system, use of wipers, etc. The data can be used to directly infer road surface conditions.

The inference of road surface conditions on the basis of traffic speeds is also conceptually possible. In general, there is a relationship between traffic speeds and road surface conditions. If the road surface is slippery from falling or drifting snow or from ice, the traffic stream will be travelling more slowly than if the road surface is just wet. Consequently, it may be possible to identify specific roadway sections requiring additional winter maintenance treatments without the need to have patrol vehicles traverse the section.

The use of current travel time data may be of value in optimizing the dispatch of winter maintenance vehicles.

3.5 NETWORK PERFORMANCE MONITORING

The road transportation network represents a very significant financial investment. Continued growth in travel and changes in travel patterns can result in operating conditions on portions of the network degrading to unacceptable levels.

Transportation agencies typically monitor network performance using periodic data collection efforts (e.g. MTO’s travel time surveys conducted every two years) or using data from stationary sensors such as permanent vehicle count stations.

The cost of dedicated data collection surveys necessarily limits the frequency at which the surveys can be conducted, the portions of the network included with the surveys, and the number of observations taken for each road segment. As a consequence, these survey methods are constrained in terms of the extent to which they are able to reliably reflect network operating conditions and support infrastructure expansion decisions.

Wireless wide-area road conditions monitoring systems provide the opportunity to collect and compile network performance data (e.g. travel times) over the majority of the road network on a continuous basis. Such as database would cover a larger portion of the road network, cover a larger portion of the year (and thereby capturing effects of seasonality, weather, etc.), and contain more observations, than is economically feasible using dedicated survey methods.

It is expected that the availability of such a data source would permit the accurate and reliable tracking of road network performance without the need to conduct dedicated travel surveys.

3.6 PUBLIC TRANSIT

One of the inputs to the public transit bus route planning process is an estimate of the roadway travel times. Traditionally, these data have been estimated on the basis of experience or on the basis of dedicated travel time studies. If a travel time database were constructed on the basis of data from a wireless road conditions monitoring system, the transit planners would have available to them a comprehensive set of travel times (by time of day, time of year, etc.) and would be able to use these data to devise appropriate bus routes. This would result in reduced costs as dedicated travel time surveys would not be required, and may also result in cost savings as a result of optimized routes and schedules that more accurately reflect travel times.

4 COMMERCIAL WIRELESS TRAFFIC MONITORING SYSTEMS

Several wireless area-wide road conditions monitoring systems based on cell phones and dedicated probe systems have been developed into commercial products and are now available world wide. Unfortunately, due to commercial confidentiality reasons, there is little or no detailed information publicly available regarding the specific models and algorithms used within these systems. Nevertheless, the following sections describe identify the existing systems and describes their system approach.

4.1 DEDICATED PROBE SYSTEMS

iTIS Holdings, a company based in London in the UK has developed a system to estimate road traffic conditions on the basis of dedicated probes which they call Floating Vehicle Data system. In the *iTIS* Holdings' system, several commercial vehicle fleets are equipped with GPS. The fleet disseminates location and time data to a cellular operator and then after analysis of data, the traffic information is sent to the subscribers through the cell phone network. Consequently, they are using the concept of "dedicated probes". Since these probes are chosen from a particular category of vehicles, the traffic information could be biased and may not be representative of the whole population.

Another method that can potentially use "dedicated probes" is General Motors OnStar technology. The OnStar system, introduced by GM in 2004, is a vehicle assistant and vehicle diagnostic service provided to subscribers. All OnStar subscribers' vehicles are equipped with GPS and also a cellular wireless communication connection. The system is primarily marketed as an emergency driver assistance system and a vehicle maintenance tool. For example, every 30 days, the OnStar system checks engine, airbags, antilock brakes, and the OnStar system sends an email to the subscriber with odometer readings and remaining oil life of the vehicle (GM, 2006). Moreover, the drivers can communicate with OnStar advisory center if they have any problem with their vehicles. In case of emergency, drivers can directly connect with OnStar operators and request emergency assistance. OnStar operators can dispatch the emergency crews to the scene by locating the vehicle through GPS.

Currently, OnStar service has more than two million subscribers in North America and if the OnStar system sent an inquiry to the subscribers regarding their position, they would be able to collect traffic information through these dedicated probes. Unlike most of the dedicated probe fleets (e.g. taxis, trucks, transit buses, etc) the OnStar probe fleet would likely introduce much smaller bias.

4.2 CELL PHONE BASED SYSTEMS

Table 2 summarises information about commercial products developed by five vendors. All of these products use data obtained from anonymously tracked cellular probe vehicles. These products estimate travel time and speed for road segments. Some are able to produce incident alerts based on changes in speed and also provide a comparison of current speed with historic speeds. The traffic information then is published on a digital map similar to Figure 6.

Table 2: Summary of commercial products for cell phone based systems.

Company	Product	Deployments
CellInt	TrafficSence	• Goergia (2006) • Tel-Aviv • Kansas City, Kansas (2004)
Delcan.NET/iTIS Holdings	CFVD	• Antwerp, Belgium (2004) • Baltimore, Maryland (2004) • Missouri (2005) • Tel-Aviv, Israel
Applied Generics	RoDIN24	• Noord Brabant, Holland (2003)
AirSage	x-10	• Virginia, Hampton Roads (2003)
Globis Data	-	• Ottawa, Ontario (2004)

As can be seen in Figure 6, links of the network are coloured based on their average speed in the current time interval. However, due to the confidentiality of these commercial products, little is known about the algorithms that are used by different vendors. The other concern is about the accuracy and evaluation of the products. At the time this study was conducted (mid- 2006) the only published evaluation was associated with a deployment in Hampton Roads, Virginia which was conducted by research at the University of Virginia (Smith, 2006). The final evaluation report states that "…it can be concluded that the Hampton Roads Airsage system, as of December 2005, cannot provide data of sufficient quality to support operations within VDOT." The report also states that:

- "Airsage cannot produce reliable segment travel time or average speed estimates on arterials or on congested freeways. Under congested conditions, 84% of the Airsage speed estimates have an error greater than 15 miles/hour."
- "Airsage cannot produce data on the reversible HOV facility on I-64."
- "Airsage cannot produce a confidence measure for traffic data records."

It is important to note, that the evaluation report also states that "…the results should not be considered to be definitive in describing the capabilities or potential of wireless location technology-based traffic monitoring in general. Rather, they reflect the capabilities of the Airsage system in Hampton Roads as of December 2005 – a system described by the company as 'interim'."

Other system evaluations are underway. For example, the University of Maryland has been contracted to perform an evaluation of the data produced by the Delcan.NET system. However, as of mid-2006, the projects in Maryland and Missouri were on hold because the wireless carrier which had partnered with Delcan.NET to deliver the location data withdrew from the projects.

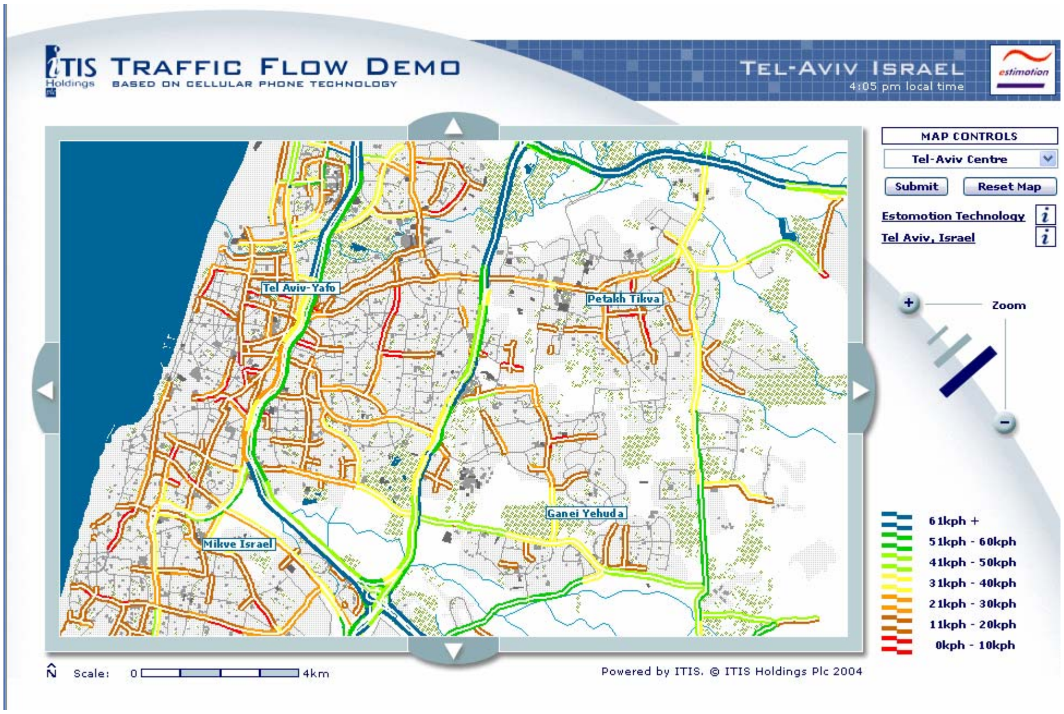


Figure 6: iTIS Holdings CVFD technology interface for Tel Aviv, Israel.

(Source: *iTIS* Holdings, 2006)

5 KNOWLEDGE GAPS

While wireless techniques appear to be quite appealing to obtain traffic information, a number of issues still need to be addressed.

5.1 TECHNICAL ISSUES

Cell phone based systems provide the opportunity to acquire data of a type and quantity not possible with conventional sensors. The availability of these data provides the opportunity to enhance existing transportation and traffic management capabilities and to support new capabilities.

However, the existing monitoring systems being tested have focussed on providing average link speeds and/or travel times primarily for use in traveller information systems. They have not explored the much wider range of possible decision support tools. Consequently, there remains a rather large knowledge gap related to what decision support tools could be developed to make use of these data and how well these tools would perform.

The other technical concern regarding cell phone based systems is quality of data. There are four main attributes associated with data quality, namely: accuracy, reliability, spatial coverage, and timeliness of the data. Much more work remains to be done to objectively quantify the quality of data from cell-phone based systems.

To overcome the technical issues, many research works have been conducted in the literature which can be categorized into field studies (Cayford *et. al.*, 2006) and simulation model studies (Takada *et. al.*, 2006 and Fountain *et. al.*, 2005).

In VII systems, the VII Coalition proposed the VII architecture in response to technical needs of the system. However, deployment of VII systems requires the development of many codes and standards. The process of standardization has already begun. For instance, DSRC standard is under study by the Institute of Electrical and Electronic Engineering (IEEE), the American Society for Testing and Materials (ASTM), and the Society of Automotive Engineers (SAE). Nevertheless, completion and acceptance of these standards is required before any meaningful VII implementation can begin.

5.2 INSTITUTIONAL ISSUES

A number of institutional issues ought to be studied prior to any deployment of wireless monitoring system including:

- Customer requirements: The system should be able to provide services to wide range of customers for wide variety of applications. Consequently, the customers and applications should be prioritized for the time when there is competition for system resources.
- Security: All users must obtain authorization to access the system. Moreover, the wireless system must ensure security of data transmission through encryption techniques and all messages must be digitally signed to be trusted by the precipitants.
- Privacy: It should be ensured that the data being made available to the public can not be reversed-engineered to identify an individual driver or vehicle.
- Data ownership: The wireless system will support public and private data. Who will own what data?
- Certification and registration: It should be ensured that the devices communicating on the system are authorized.

5.3 BUSINESS MODEL

The wireless systems are a unique participation of several private and public entities in transportation industry. Consequently, they require a unique business model to be defined in order to finance the deployment and operation of the systems. The model should be able to allocate the costs of the system to the participants in line with their expected benefits of all stakeholders (Shladover, 2005).

6 CONCLUSIONS

In this paper three methods were introduced to obtain wireless monitoring of traffic conditions namely: dedicated probe systems, cell phone based systems, and VII. Furthermore, a number of potential opportunities that the wireless monitoring of traffic provides were identified under the six categories of traffic management, traveller information, transportation planning, winter maintenance, network performance monitoring, and public transit. Commercial systems that are currently available in the market were identified and briefly described.

Based on the technology scan that was performed in this paper, it was observed that though dedicated probe based systems are being utilised in several locations in the world, these systems face challenges in terms of fleet size (dictating spatial and temporal coverage) and bias in data. A number of test deployments of cell phone based systems have been reported in the literature demonstrating the technical feasibility of this approach. However, the technical capabilities of these commercial packages have yet to be confirmed by way of comprehensive objective evaluation.

VII is currently in its early stages and based on the VII Coalition's milestone schedule, the VII deployment feasibility determination will not be performed prior to the beginning of 2009 and therefore VII can not realistically be expected to be operational, even on a limited scale, within the next 5 years.

7 REFERENCES

Cayford, R. and Y. Yim (2005) *A Field Operation Test Using Anonymous Cell Phone Tracking for Generating Traffic Information.* Proceedings of 2006 TRB, 85th Annual Meeting, Washington.

CellInt (2007), Accessed from http://www.cellint.com/traffic_data/how_to_test_data.html in January 2007.

Eberspacher, J., Vogel. H.J. and C. Bettstetter (2001) *CSM Switching, services, and Protocols*, second edition, John Wiley and Sons (UK), Chapter 5.3 on Synchronization.

Fountain, M.D. (2005) *Improving the Effectiveness of Wireless Location Technology-Based Traffic Monitoring: An Exploration of System Design Issues*. PhD Thesis, School of Engineering and Applied Science, University of Virginia.

General Motors Company (2006). Accessed from http://www.onstar.com.

Hellinga, B., Fu, L., and H. Takada (2003) *Traveller Information via Mobile Phone Location Referencing – Challenges and Opportunities*. Proceedings of the Annual Conference of the Transportation Association of Canada held September 21-24, 2003 in St. John's, Newfoundland, Canada.

Hellinga, B., Fu, L., and H. Takada (2005) *Traffic network condition monitoring via mobile phone location referencing – an emerging opportunity*. Proceedings of the 6th Transportation Specialty Conference of the Canadian Society of Civil Engineers held in Toronto Canada June 2-4, 2005.

iTIS Holdings Company Website (2006). Accessed from Http://www.itisholdings.com.

Laitinen, H., Ahonen, S., Kyriazakos, S., Lahteenmaki, J., Menolascino, R., and S. Parkkila (2001) *Cellular Network Optimization Based on Mobile Location*, 2001 Cello Consortium, IST-2000-25382-CELLO.

Layton, J., Brian, M. and J. Tyson (2006) *How Cell Phone Work.* Accessed from http://www.howstuffworks.com.

Shladover, S.E., 2005, *Preparing the Way for Vehicle-Infrastructure Integration*. California PATH Research Report UCB-ITS-PRR-2005-31.

Smith, B. (2006) *Wireless Location Technology-Based Traffic Monitoring Demonstration and Evaluation Project - Final Evaluation Report.* Smart Travel Laboratory Center for Transportation Studies University of Virginia.

Takada, H. (2006) *Road Traffic Condition Acquisition via Mobile Phone Location Referencing*. Ph.D. thesis, Department of Civil Engineering, University of Waterloo, Waterloo, Ontario, Canada.

Takada, H., Hellinga, B., and L. Fu (2006) *Link Travel Time Estimation Based on Mobile Phone Location Tracking*. Accepted for presentation at the 13th ITS World Congress on Intelligent Transportation Systems held October 8 – 12, 2006 in London, UK.

US Department of Transportation (2006) *Vehicle Infrastructure Integration Concepts*. Accessed from http://www.its.dot.gov/vii/.

Zhao, Y. (2000) *Mobile Phone Location Determination and Its Impact on Intelligent Transportation Systems*. IEEE Transactions on Intelligent Transportation Systems, Vol.1, No.1, pages 55-64.

About Authors:

Pedram Izadpanah
PhD Student
Department of Civil and Environmental Engineering
University of Waterloo
Waterloo ON
Canada N2L 3G1
Email: pizadpan@uwaterloo.ca

Bruce Hellinga, PhD PEng.
Associate Professor
Department of Civil and Environmental Engineering
University of Waterloo
Waterloo ON
Canada N2L 3G1
Email: bhellinga@uwaterloo.ca
www: www.civil.uwaterloo.ca/bhellinga/