Comparing the GPS Capabilities of the iPhone 4 and iPhone 3G for Vehicle Tracking using FreeSim_Mobile

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Abstract – **In this paper, we present a comparison between the Apple iPhone 3G™ [2] and the iPhone 4™ [2] using the real-time vehicle tracking application FreeSim_Mobile [24]. The built-in GPS receiver and web capabilities of the iPhone™, coupled with a V2I architecture, are used to send a continuous flow of data to a central server for processing by FreeSim [13-15], which is a real-time traffic simulator. The proportional model algorithm [18] is then used to determine the time to traverse a roadway in order to report in real-time the current flow of traffic. At the University of Alaska Anchorage, we currently have vehicle tracking devices installed in 80 probe vehicles that traverse the Anchorage area. Due to the high cost associated with vehicle tracking devices, it is difficult to penetrate a large vehicular network on a finite amount of money, so we must look towards other available technologies, such as the constantly-expanding cellular network. In this paper we look at the iPhone 4™ capability of reporting accurate and reliable locations and compare it to the recent study of the iPhone 3G™ [24]. Drivers equipped with an iPhone 4™ cellular phone and a vehicle tracking device manually timed how long it took to travel along a 0.99 mile/1.59 kilometer section of roadway. The vehicle tracking device and the iPhone 4™ report speed and location every 10 seconds whereas the iPhone 3G™ reported every 8 seconds [24]. From this data, we calculated the amount of time to traverse the test section of roadway using the proportional model algorithm [18] and compared it to the actual amount of time it took to traverse the test section of roadway as manually timed. We found that the vehicle tracking device had an average error factor of 4.94% from the actual time to traverse the section of roadway (as determined by the stopwatch), whereas the iPhone 4™ was found to have an error factor of 1.10%. The outcome of the case study is used to determine that the iPhone 4™ has higher accuracy than a vehicle tracking device, though it is important to note that the iPhone™ is more limited than a device attached to a vehicle since it can only report its location. If paired with another third party OBD device, however, it can also send the same information as a vehicle tracking device.**

I. INTRODUCTION

Gathering the speed and location of individual vehicles has become essential for many Intelligent Transportation System (ITS) applications that have been proposed. Determining the time to travel from one location to another has been attempted using many discrete forms of technology, including inductor loops, video cameras, and speed sensors, though no discrete technology can provide as much information about a vehicle as a device that is traveling with the vehicle. Probing devices, such as cellular phones, navigation systems, tracking devices, and mobile communication devices, provide a means for communicating with other vehicles or some roadway infrastructure from within a moving vehicle. The architectures employed for this communication are typically vehicle-to-infrastructure (V2I, also known as vehicle-to-roadway, V2R) or vehicle-to-vehicle (V2V). With a V2I architecture, vehicles communicate with some central computing device that is connected through a roadway infrastructure, such as the cellular network.

Many applications of ITS data have been proposed, including fastest path determination, incident identification, origin-destination (OD) matrix determination, emergency vehicle routing, signal timing modification, ramp metering, and congestion relief, among others too numerous to list. The common theme among all of these proposed applications is the lack of data available from vehicles. Obtaining static data from discrete devices has been an acceptable substitute for obtaining data from individual vehicles in real-time, but technology has advanced to the point of being able to gather data from vehicles in a distributed manner.

Vehicles equipped with tracking devices have shown to be the most accurate means of gathering real time traffic data, with a major advantage over stationary detection systems being that probe vehicles can give information about any road along which they travel. The downside to probe vehicles is the cost of the tracking device, the installation, and the monthly charges of whatever network is used for V2I communication, such as the cellular network. To fully equip every vehicle even within a fairly small city would be extremely costly and impractical based on the number of vehicles.

The large growing demand for smart phones with their high penetration rate in the market place has provided a potential solution to this problem. As of November 2010 it is estimated that iPhones™ are responsible for 25% of the smart phone market in the United States [10], and with the recent termination of the iPhone™ exclusive contract with AT&T in the United States, other carriers such as Verizon will be able to add to the increase in smart phone penetration. In Alaska, however, AT&T is the largest cellular provider so we can estimate this percentage to be higher. This allows us to conclude that *at least* 25% of all smart phone users in the United States are already capable of acting as probe vehicles. With that amount of penetration we may be able to offer the public accurate traffic data of an entire road system based on gathering vehicle location from those smart phones as well as being able to tie into the current infrastructure to provide a highly accurate map.

The location of all these cellular phones can potentially be retrieved with the simple process of writing an application for the phone. Currently in Anchorage we are utilizing 80 probe vehicles that have been equipped with tracking devices to report their speed, location, direction, rate of acceleration/ deceleration, and fuel consumption back to our central server every 10-60 seconds. Based on this data, a map is generated that provides drivers with the amount of time to traverse arterial roadways in Anchorage. From the capabilities of the iPhone™ we are able to get a location and a timestamp transmitted to the server. Through the use of the proportional model [18] for mapping the discrete data retrieved from GPS receivers to the time to travel along a roadway section, we compute the average speed along the roadways.

In this paper, we continue the feasibility of using smart phones for real-time traffic analysis. We start with section II describing the related work towards gathering vehicular data in a real-time fashion. Section III shows the accuracy of both iPhone 3GS and 4™ is acceptable for this application and how the proportional model algorithm is used to analyze our data. Section IV compares the iPhone 4™ results with that of a vehicle tracking device and a manual determination of the time to travel along a roadway. Section V provides a conclusion and describes our future work of using smart phones to create a low cost alternative to installing vehicle tracking devices.

II. RELATED WORK

With the current number of loop detectors and video cameras installed along U.S. highways, discrete identification devices have become the most commonly used technology in detecting traffic patterns. Studies have concluded that the more space there is between loop detectors, the more inaccurate the reported congestion level [6]. Even with advanced algorithms, loop detectors can still produce extreme errors. Using single or double loop estimations can produce inaccuracies of 25-30% [5]. However, using an adaptive algorithm to cope with the fluctuation of congestion significantly reduces the error percentage [8]. Nevertheless, even with these advances in loop detector algorithms, comparing the collected information against probe vehicle data during times of congestion either from traffic, incidents, or construction, loop detectors produce data with a much greater percentage of error [4]. Further, closed circuit television (CCTV) cameras along with loop detectors have estimated speed with an error percentage of 10% [7].

With loop detectors being prone to errors and with the advancement of global positioning systems (GPS), it is now quite reasonable to consider tracking vehicles in continuous intervals and collect their locations. This allows for a map to be constructed that represents real-time traffic. Using probe vehicles, map-matching has been combined with an algorithm for computing speed from point-to-point locations to allow accurate mapping of the traffic [3]. Probe data by itself during peak traffic times can cause prediction errors to increase due to more probes in close proximity to each other [1]. It becomes important to determine the proximity of probe vehicles in addition to the number of probe vehicles when working with prediction algorithms. In Shanghai, researchers have combined probe vehicle and loop detector data to produce a very precise map with an accuracy of 97.5% [12].

While vehicle GPS sensors are not as common as cell phones, there have been major developments in using the GPS functionality of smart phones to determine real-time traffic conditions. Florida International University found through their investigations that using cell phones as vehicle probes is feasible under normal traffic flow conditions for travel time estimation. However, their research also found that the cell phone probing is not as accurate in congested traffic conditions, and the accuracy decreases rapidly as the congestion increases [9]. Waze, a real-time traffic application for smart phones is currently testing the GPS capabilities of cellular phones to report live traffic to users based on speed calculation algorithms and additional user input, such as accidents and road construction [11]. Waze's data is entirely user-based and updated with minimal server-assisted calculations. Another similar application, buddyway [21], tracks a user's driving through his mobile phone to provide the speed of the user on his phone and computer. Studies from some projects, including MIT's CarTel [16] and UC Berkeley's Mobile Millennium [17], have begun publishing results and providing access to the data gathered through cellular phones. In [23] they recognize the potential of the use of mobile phones for real-time location data, as well as the added cost of energy and transmitted data associated with the continuous calculation and transmission of location data from a user's phone to a server. To overcome these obstacles they developed two new application-level algorithms that reduce the number of user locations calculated and transmitted while continuing to report an accurate real-time travel path.

Since smart phones are not connected to a vehicle like most vehicle tracking devices, smart phones can only send the location data for the vehicle whereas vehicle tracking devices connected via the OBD port can also provide a whole realm of additional data. There has been some work on linking iPhones™ to a vehicle's OBD port to relay information about the vehicle directly to a user's phone [25-27]. Rev [25] is an application for the iPhone™ that works with the OBD port and can show the user diagnostic codes via their phone. Audi [27] will soon be launching an OBD application for their vehicles that will also relay their vehicles' information to phones. Although our application is not gathering vehicle information, we are planning to incorporate that type of application in our future work.

FIGURE 1 - CONFIDENCE RADII OF THE IPHONE 4™ POSITIONING

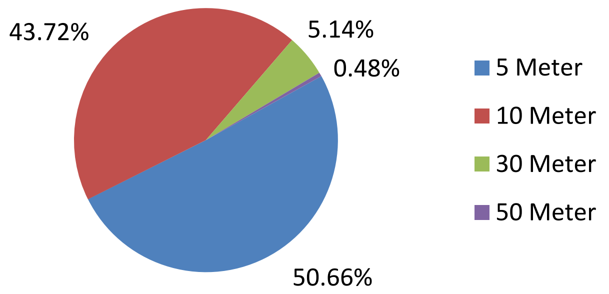
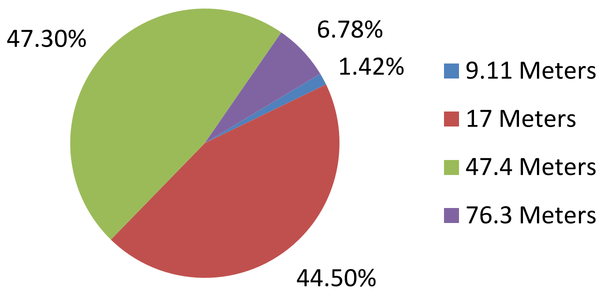


FIGURE 2 - CONFIDENCE RADII OF THE IPHONE 3G™ POSITIONING



UC Berkeley's Mobile Millennium [17] project, in collaboration with Nokia, has led the way in cell phone tracking development. With navigation systems, TomTom [22] utilizes data from their own devices, third parties such as national and local governments, and commercial traffic information providers to offer their users real-time traffic.

Our application conceals all personal information of users' phones and creates a complex user ID that changes every time the application is executed. Similar to the Mobile Millennium project, we used a single type of phone, though we included highways and arterial roads in our study. Like TomTom we look towards incorporating other phones, as well as devices and third party data, into our software. Because of the relatively small road system in Anchorage, we are able to show the true potential of how accurate a traffic map can be based on a small number of vehicle probes, and when paired with the proportional algorithm, the calculated speed of a road section falls within a margin of error of 2% of the actual time to traverse.

III. FOUNDATION

The iPhone™ location identification uses a three step tier for determining location, starting with using GPS satellites to triangulate the position to a high level of accuracy. The second identification means is WiFi positioning, which is rarely used while driving. The last identification determination is through cell tower positioning, which is the least accurate of the three approaches. For real-time traffic analysis the application is set to use a high degree of accuracy. The accuracy of the phone is reported as a radius cloud which can be perceived as the device's confidence in the reported location. For the iPhone 4™ its accuracy can range from its least accurate report of within 50 meters to its most accurate of 5 meters. It can be seen in Figure 1 that 94.38% of the time the iPhone™ reported within 10 meters and 50.66% of the time being within 5 meters. The data for Figure 1 is comprised of over 12,000 sample data points used in this case study. The iPhone 3G™ ranges from 9.11 meters to 76.3 meters as seen in Figure 2 [24], and the distribution of the accuracy ranges from within 50 meters 93.22% of the time to within 18 meters 45.92% of the time. As can be seen, the iPhone 4™ accuracy is superior to the iPhone 3G™, where 46% of the time the iPhone 3G™ is within 18 meters while the iPhone 4™ is within 5 meters 51% of the time.

FreeSim_Mobile uses the location and its associated timestamp along with its level of accuracy as input. This data is sent via the cellular network to a central server through a V2I architecture. The data then gets stored in a database where the proportional model algorithm determines the amount of time to traverse a roadway based on a set of locations and timestamps.

The proportional model [18] for determining the time to traverse a roadway uses the data from a unique vehicle as well as the location data from the phone. Since the vehicles (via tracking devices and the iPhone 4™) are transmitting their speed, location, and direction every 10 seconds, the probability of the data being transmitted at the start and the end of a section of roadway is highly unlikely. If that were the case, the amount of time to traverse the edge could easily be calculated based on the times at which the data was transmitted. Since the data will be transmitted at locations other than at the start and end of an edge, the proportional model uses an algorithm to determine the amount of time to traverse an edge based on the corresponding point locations inside that section of roadway as well as the points that the vehicle reported before and after traveling along that edge.

The weight on the edge will be calculated after a vehicle has finished traversing the roadway section identified by the edge. To simplify how the algorithm works, here is a simple walk-through of how the proportional model determines the edge weight with four data points. Assume the first point is the last location reported before the vehicle entered the edge, the second point is the first location reported after the vehicle entered the edge, the third point is the last location reported before the vehicle left the edge, and the last point is the first location reported after the vehicle left the edge. For this case, assume the following:

1. TTT(M, N) is the time to traverse the edge between node M to node N
2. The distance between any two locations X and Y can be found by D(X, Y)
3. The time at which a vehicle transmits the data at location X is t_x

FIGURE 3a – TEST ROADWAY USED

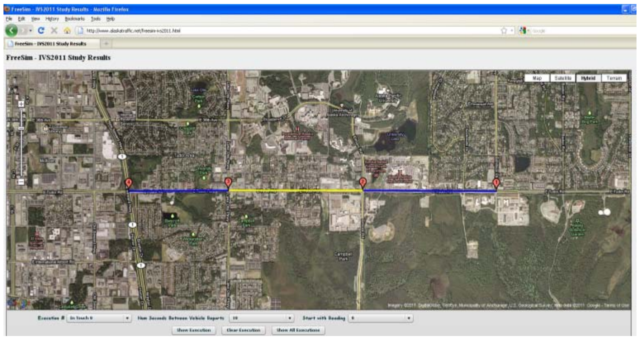


FIGURE 3b – SAMPLE RUN WITH VEHICLE TRACKING DEVICE DATA

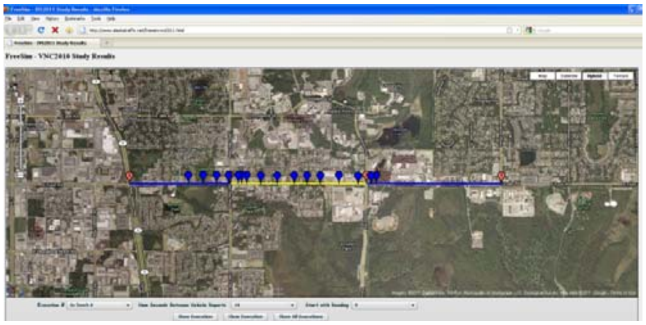
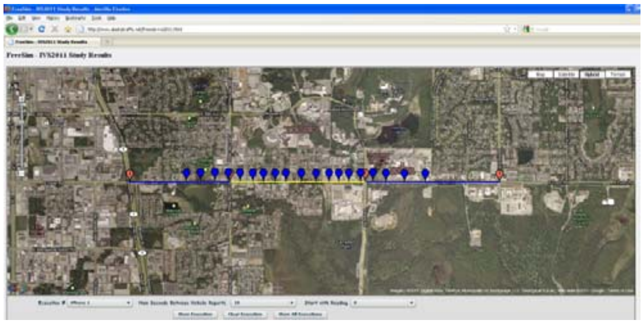


FIGURE 3c – SAMPLE RUN WITH IPHONE 4™ DATA



Assume that location A is the last location transmitted from the vehicle before entering the edge between nodes 2 and 3 of Figure 3a, location B is the first location transmitted from the vehicle while on the edge between nodes 2 and 3, location C is the last location transmitted from the vehicle while on the edge between nodes 2 and 3, and location D is the first location transmitted from the vehicle after exiting the edge between nodes 2 and 3. If there are more than two locations transmitted from the vehicle while on the edge, only the first and last locations will be used in the calculation. The proportional model uses the following formula to calculate the time to travel along the roadway between nodes 2 and 3:

$$\mathrm{TTT}(2, 3) = \mathrm{TTT}(2, B) + \mathrm{TTT}(B, C) + \mathrm{TTT}(C, 3)$$

$$= (t_B - t_A)\,\frac{D(2,B)}{D(A,B)} + (t_C - t_B) + (t_D - t_C)\,\frac{D(C,3)}{D(C,D)}$$

The preceding equation breaks the edge into three different segments based on the four locations and times they were transmitted and then determines the weight of the edge in question by multiplying the time to traverse each segment by the proportion of the edge that was traversed in each segment. The middle term ($t_C - t_B$) is completely on the edge in question, so the proportion of the edge that is traversed by that term is 1.

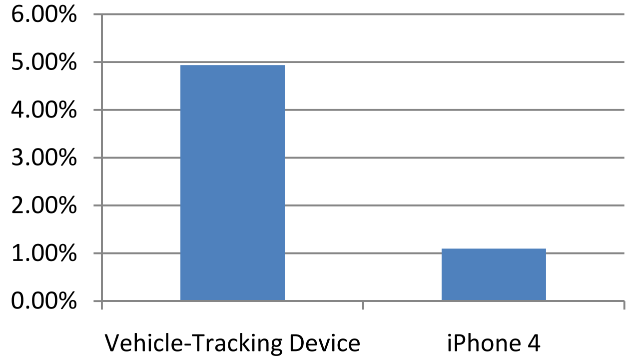
The proportional model algorithm [18] is concluded to have an error factor of 1.8% from the actual amount of time to traverse a road section based on manual timing. This value was calculated from the tracking devices installed in vehicles that report the location every 10 seconds compared to manually timing the duration of traveling along that roadway. Our application on the iPhone 4™ is sending its location data every 10 seconds but the time in which it reports can be varied. Accompanied with accurate position data, the iPhone 4™ is able to provide better data readings for small segments of road where other devices that respond in larger amounts of time may miss or give inaccuracies.

IV. APPLICATION

A 0.99 mile/1.59 kilometer section of roadway in Anchorage, Alaska was chosen for its viability to the city and because of its periods of heavy and light congestion throughout the day, with heavier congestion during the morning and afternoon commutes ranging from 7:00a.m.-9:00a.m. and 4:30p.m.-6:30p.m. Figure 3a shows the selected section of roadway tested with intersections represented as nodes connected by a color-coordinated line to outline the different sections of roadway. The sections outlined in blue are the entering (the section starting with node 1 and ending with 2) and exiting (the section starting with node 3 and ending with 4) sections, with the middle section in yellow (the section between node 2 and 3) being the section we timed. Test vehicles equipped with a stopwatch, a vehicle tracking device, and an iPhone 4™ drove the roadway at different times of day. The test vehicle entered the starting section of the road (between nodes 1 and 2), drove though the entire test section (between nodes 2 and 3), and exited through the last section (between nodes 3 and 4). The time to travel along the middle edge was determined by manually timing using a stopwatch and calculated algorithmically using the proportional model based on the vehicle tracking device and iPhone 4™ data.

Ten drivers drove the section of roadway where Figure 3b shows one execution of the vehicle tracking device's location data and Figure 3c shows one execution of the iPhone 4™ location data. All ten executions can be seen online at http://www.alaskatraffic.net/freesim-ivs2011.html. Through the use of FreeSim [13-15] utilizing the proportional model algorithm, we were able to compute the average percentage difference between the ten test runs by comparing the actual time to traverse (TTT) the test section to the calculated time to traverse based on the vehicle tracking device and the iPhone 4™. The percentage difference from the calculated vehicle tracking device was 4.94% from the actual TTT whereas the iPhone 4™ was

FIGURE 4 – PERCENTAGE DIFFERENCE IN ACTUAL TIME TO TRAVERSE AND CALCULATED TIME TO TRAVERSE FOR VEHICLE TRACKING DEVICE AND IPHONE™ 4



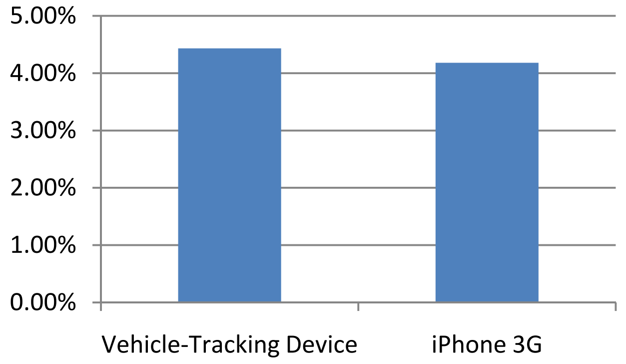
1.10% from the actual TTT, as is shown in Figure 4. From these results we can state with confidence that the iPhone 4™ has a higher accuracy than a tracking device installed in a vehicle. One important difference to note, however, is that the iPhone™ is only able to obtain location unless paired with a third party OBD reader as opposed to tracking devices that are installed through a vehicle's OBD port, which may be able to obtain additional data about the vehicle.

Although the vehicle tracking devices and the iPhone 4™ reported every 10 seconds, the iPhone 3G™ reported every eight seconds [24]. The difference in reporting period could have influenced the result of the iPhone 3G™ having a slightly higher accuracy over the vehicle tracking device, as shown in Figure 5. Furthermore, as we compare the current test of the iPhone 4™ to the previous test of the iPhone 3G™ with 10 different drivers at different levels of congestion, we can conclude that they both are acceptable forms for tracking probe vehicles. As we have seen now with the iPhone 4™, which was reporting at the same rate as the vehicle tracking device as well as having a higher tolerance of accuracy than its predecessor, we have clearly shown that the time difference is not a factor and that the iPhone 4™ has the ability to more accurately report the location and speed of a vehicle. The authors have previously shown that the vehicle tracking device was accurate to within 1.8% of the actual time to traverse using a similar measurement [18].

V. CONCLUSION AND FUTURE WORK

FreeSim_Mobile [24] works in accordance with FreeSim [13-15] to achieve a detailed real-time traffic map for the Anchorage area. FreeSim_Mobile [24] is intended to be used in conjunction with other means of vehicle tracking devices in order to build the most accurate map of traffic patterns to be used by commuters for making decisions on decreasing the amount of time to drive to a destination, in addition to departments of transportation for improving congestion on roadways by accurately having real-time congestion data.

FIGURE 5 – PERCENTAGE DIFFERENCE IN ACTUAL TIME TO TRAVERSE AND CALCULATED TIME TO TRAVERSE FOR VEHICLE TRACKING DEVICE AND IPHONE™ 3G



The degree of accuracy realized by the iPhone 4™ has provided a basis for creating similar applications for other smart phones, such as the Blackberry [19] and Android-based [20] phones. An Android-based application is being developed for reporting its position to also work with the proportional model algorithm in reporting real-time traffic conditions. As this study was conducted on an iPhone 4™, we have shown that the accuracy exceeds that of the iPhone 3G™.

We hope to reach as many drivers with smart phones as possible, not only to impact and raise our penetration rate of reporting vehicle locations but also to ensure the cellular network can handle the increase in data experienced by users accessing the positioning hardware of their phones and reporting it frequently. This application can then be expanded to include V2V communication based on embedded cellular devices in vehicles as well as including the ability to quickly connect to WiFi hotspots to build a more reliable V2I environment within major cities where tall buildings obstruct the GPS line-of-site.

In this paper we presented a comparison between a previous study of an iPhone 3G™ against the iPhone 4™ and how the two smart phones are to be considered a relatively acceptable form of a device to use in a probe vehicle as both devices provide a similar level of accuracy as a vehicle tracking device. We explained how the iPhone™ declares its accuracy as a ring of confidence and that 94.38% of the time it is accurate to within 10 meters with the iPhone 4™. We then described how the proportional model algorithm was used to take a device's location and timestamp relative to other positions and timestamps to calculate the amount of time to travel along a roadway. To prove that the iPhone™ can be a reliable source, we presented a case study in which 10 test vehicles drove a potentially congested section of roadway at different times throughout the day. It was concluded through the real-time traffic simulator FreeSim that the average percentage of accuracy of the vehicle tracking device compared to the actual time to travel along the roadway was 95.06%, whereas the accuracy of the iPhone 4™ using the same comparison was 98.90%, and, as previously shown, the iPhone 3G™ was 95.82% [24]. We have provided evidence that the iPhone 4™ is more accurate than a vehicle tracking device, although it lacks the additional data that could be potentially retrieved from a vehicle tracking device installed through a vehicle's OBD port unless a third party OBD reader for the iPhone™ is used. The associated cost is substantially lower than that of a vehicle tracking device (assuming the user already has the hardware), and based on the current penetration rate of smart phones in the market, there is a much more likely chance to solicit widespread adoption of the iPhone™ application for determining real-time traffic conditions.

VI. REFERENCES

[1] Miller, Jeffrey. "Vehicle-to-Vehicle-to-Infrastructure (V2V2I) Intelligent Transportation System Architecture." *IEEE 4th Intelligent Vehicles Symposium*, June 2008.

[2] Apple website. http://www.apple.com.

[3] Miller, Jeffrey, Ellis Horowitz. "FreeSim – A V2V and V2R Freeway Traffic Simulator." *IEEE 3rd Workshop on Vehicle-to-Vehicle Communication* in conjunction with *IEEE 3rd Intelligent Vehicles Symposium*, June 2007.

[4] Miller, Jeffrey. "Fastest Path Determination at Lane Granularity using a Vehicle-to-Vehicle-to-Infrastructure (V2V2I) Intelligent Transportation System Architecture." *IEEE 4th Workshop on Vehicle-to-Vehicle Commmunication* in conjunction with *IEEE 4th Intelligent Vehicles Symposium*, June 2008.

[5] Blum, Jeremy, Azim Eskandarian. "A Reliable Link-Layer Protocol for Robust and Scalable Intervehicle Communications." IEEE Transactions on Intelligent Transportation Systems. Volume 8, Number 1, March 2007.

[6] Tarng, Jenn-Hwan, Bing-Wen Chuang. "Investigation of Vehicle-to-Infrastructure Communications based on IPv6-based Automotive Telematics." *IEEE 7th Conference on Intelligent Transportation Systems Telecommunications*, June 2007.

[7] Sklavos, Nicolas, Maire McLoone, Xinmiao Zhang. "MONET Special Issue on Next Generation Hardware Architectures for Secure Mobile Computing." Mobile Networks & Applications, Volume 12, Number 4, August 2007.

[8] Zhanfeng, Jia, Chao Chen, Ben Coifman, Pravin Varaiya. "The PeMS algorithms for accurate, real-time estimates of g-factors and speeds from single-loop detectors." *IEEE 4th Intelligent Transportation Systems Conference*, February 12, 2001.

[9] Chen, Yanyan, Michael Bell, Klaus Bogenberger. "Reliable Pretrip Multipath Planning and Dynamic Adaptation for a Centralized Road Navigation System." IEEE Transactions on Intelligent Transportation Systems, Volume 8, Number 1, March 2007.

[10]comScore website. http://blog.comscore.com/2011/01/verizon_iphone_mobile_market.html.

[11] Vlahogianni, Eleni, Matthew Karlaftis, John Golias, Nikolaos Kourbelis. "Pattern-Based Short-Term Urban Traffic Predictor." *IEEE 9th International Intelligent Transportation Systems Conference*, September 17-20, 2006.

[12] Quek, Chai, Michel Pasquier, Bernard Boon Seng Lim. "POP-TRAFFIC: A Novel Fuzzy Neural Approach to Road Traffic Analysis and Prediction." IEEE Transactions on Intelligent Transportation Systems, Volume 7, Number 2, June 2006.

[13] FreeSim website. http://www.freewaysimulator.com.

[14] Miller, Jeffrey, Ellis Horowitz. "FreeSim – A V2V and V2R Freeway Traffic Simulator." *IEEE 3rd Workshop on Vehicle-to-Vehicle Communication* in conjunction with *IEEE 3rd Intelligent Vehicles Symposium*, June 2007.

[15] Miller, Jeffrey, Ellis Horowitz. "FreeSim – A Free Real-Time Freeway Traffic Simulator." *IEEE 10th Intelligent Transportation Systems Conference*, October 2007.

[16] MIT's CarTel Project. http://cartel.csail.mit.edu.

[17] UC Berkeley's Mobile Millennium Project website. http://traffic.berkeley.edu.

[18] Miller, Jeffrey, Sun-il Kim, Muhammad Ali, Timothy Menard. "Determining Time to Traverse Road Sections based on Mapping Discrete GPS Vehicle Data to Continuous Flows" *IEEE 6th Intelligent Vehicles Symposium*, June 2010.

[19] Blackberry website. http://www.blackberry.com.

[20] Android website. http://www.android.com.

[21] buddyway website. http://www.buddyway.com.

[22] TomTom website. http://www.tomtom.com/hdtraffic.

[23] Barbeau, Sean, Miguel A. Labrador, Alfredo Perez, Philip Winters, Nevine Georggi, David Aguilar, Rafael Perez. "Dynamic Management of Real-Time Location Data on GPS-Enabled Mobile Phones," *ACM 2nd International Conference on Mobile Ubiquitous Computing, Systems, Services, and Technologies*, 2008.

[24] Menard, Timothy, Jeffrey Miller. "FreeSim_Mobile: A Novel Approach to Real-Time Traffic Gathering using the Apple iPhone™." *IEEE 2nd Vehicular Networking Conference*, December 2010.

[25] DevToaster website. http://devtoaster.com/products/rev/index.html.

[26] iPhone 3G Hacked website. http://iphone3ghacked.com/2011/01/05/griffin-iphone-obd-ii-port-with-the-cartrip-bluetooth-adapter/.

[27] Social Car News website. http://www.socialcarnews.com/blog/1051146_audi-joins-the-crowd-launches-iphone-carmonitor-app.