

FreeSim_Mobile: A Novel Approach to Real-Time Traffic Gathering using the Apple iPhone™

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Abstract – In this paper, we present a preliminary application for the iPhone™ [2] that uses the built-in GPS receiver along with the web capabilities utilizing a V2I architecture to send a continuous flow of data to a central server where FreeSim [13-15], a real-time traffic simulator, applies the proportional model algorithm [18] 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. The high cost associated with vehicle tracking devices makes it difficult to penetrate a large vehicular network on limited funds, so we must look towards other available technologies, such as the constantly-expanding cellular network. In this paper we look at the iPhone™ 3G capability of reporting accurate and reliable locations by describing our sample application and comparing its reported GPS accuracy to the existing vehicle probes we have. We will then present a study of its performance of calculating an accurate traffic flow where a chosen section of roadway was driven. Drivers equipped with an iPhone™ 3G cellular phone and a vehicle tracking device manually timed how long it took to travel along the test road section. The vehicle tracking devices report speed and location every 10 seconds whereas the iPhone™ is capable of reporting the location every second, though we were receiving it every eight seconds. From this data, we calculated the amount of time to traverse the test roadway section using the proportional model algorithm and compared it to the actual amount of time it took to traverse the test roadway section. We found that the vehicle tracking device had an average error factor of 4.43% from the actual time to traverse the roadway section (as determined by the stopwatch), whereas the iPhone™ was found to have an error factor of 4.18%. The outcome of the case study is used to determine that the iPhone™ is relatively as accurate as a vehicle tracking device, though it is important to note that the iPhone™ is more limited than a device attached to a vehicle in the data it can obtain to only reporting its location.

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 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 since many vehicles continually travel through a city.

The large growing demand for smart phones with their large penetration in the market place has provided a potential solution to this problem. As of February 2010 it is estimated that iPhones™ are responsible for 25% of the smart phone market in the United States [10]. In Alaska, AT&T is the largest main stream 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.

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 and direction along roadways.

In this paper, we propose 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 that the accuracy of the iPhone™ is acceptable for this application and how the proportional model algorithm can be used to analyze our data. Section IV compares the iPhone™ results with that of a vehicle tracking device and a manual determination of the time to travel along a roadway in order to compare the accuracy of the iPhone™. 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 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.

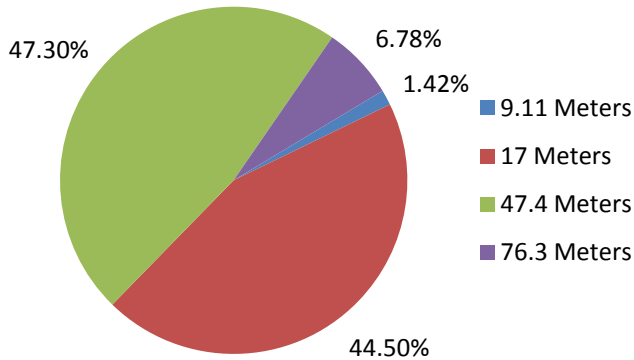
UC Berkeley's Mobile Millennium [17] project, in collaboration with Nokia, has led the way in cell phone tracking development. With navigation systems, TomTom [22] utilizes data from their own devices, third parties such as national and local governments, and commercial traffic information providers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

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 include 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

FIGURE 1 - CONFIDENCE RADII OF THE IPHONE™ POSITIONING



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. This radius cloud can range from 9.11 meters to 76.3 meters. It can be seen in Figure 1 that the distribution of the accuracy ranges from within 50 meters 93.22% of the time to within 18 meters 45.92% of the time. The data of Figure 1 is comprised of the sample data points associated with this case study as well as some preliminary drives along one of the major highways in Anchorage to sample the ability of the device to stay accurate while moving at speeds of 65 miles per hour/104.6 kilometers an hour. In total, nearly 26,000 data points were used.

The location associated with a timestamp and level of accuracy 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 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 are transmitting their speed, location, and direction every 10 seconds and the iPhone™ is reporting every 8 seconds, the probability of the data being transmitted at the start and the end of an edge 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 location inside the edge 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 an 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

Assume that location A is the last location transmitted from the vehicle before entering the edge between nodes 2 and 3 of Figure 2a, 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 weight of the edge between nodes 2 and 3:

$$TTT(2, 3) = TTT(2, B) + TTT(B, C) + TTT(C, 3)$$

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

The preceding equation breaks the edge into three different segments based on the four locations and times that 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. Our application on the iPhone™ is sending its location data every eight seconds on average. Accompanied with accurate position data, the iPhone™ 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. Further, it can be assumed that since the data is transmitted more frequently from the iPhone™ that the granularity of the data will be more accurate as well.

FIGURE 2a – TEST ROADWAY USED

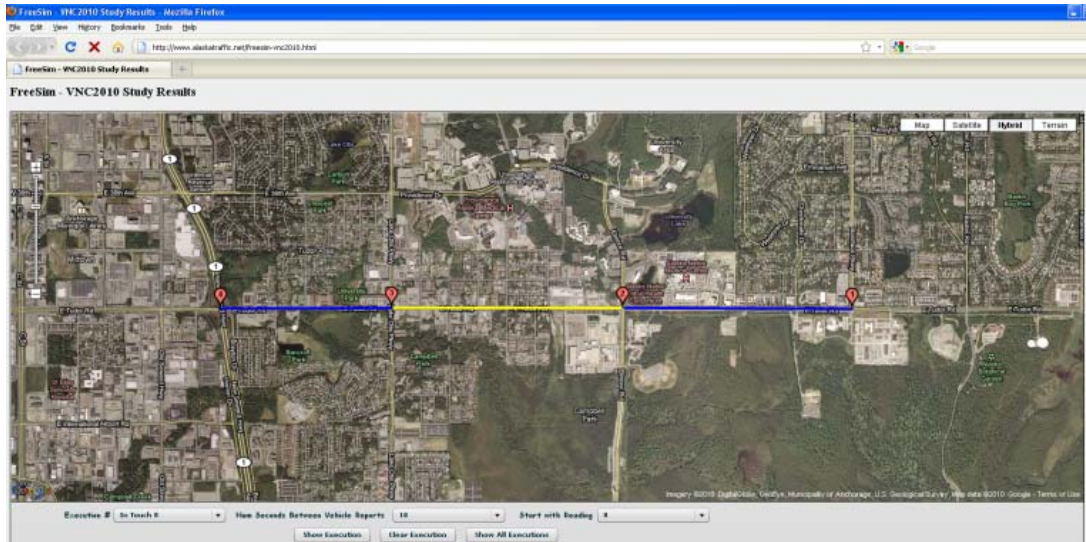


FIGURE 2b – SAMPLE RUN WITH VEHICLE TRACKING DEVICE DATA

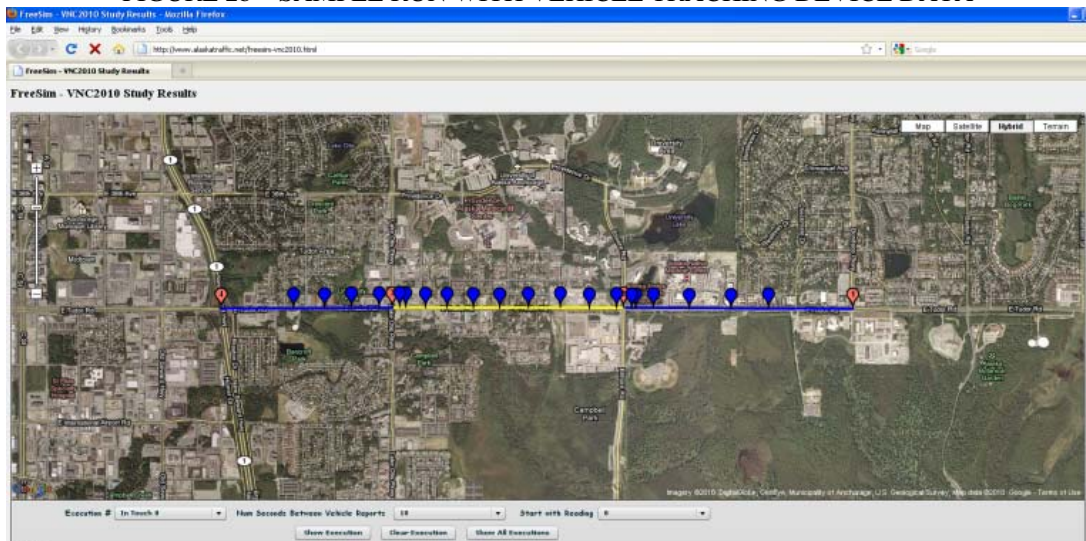


FIGURE 2c – SAMPLE RUN WITH IPHONE™ DATA

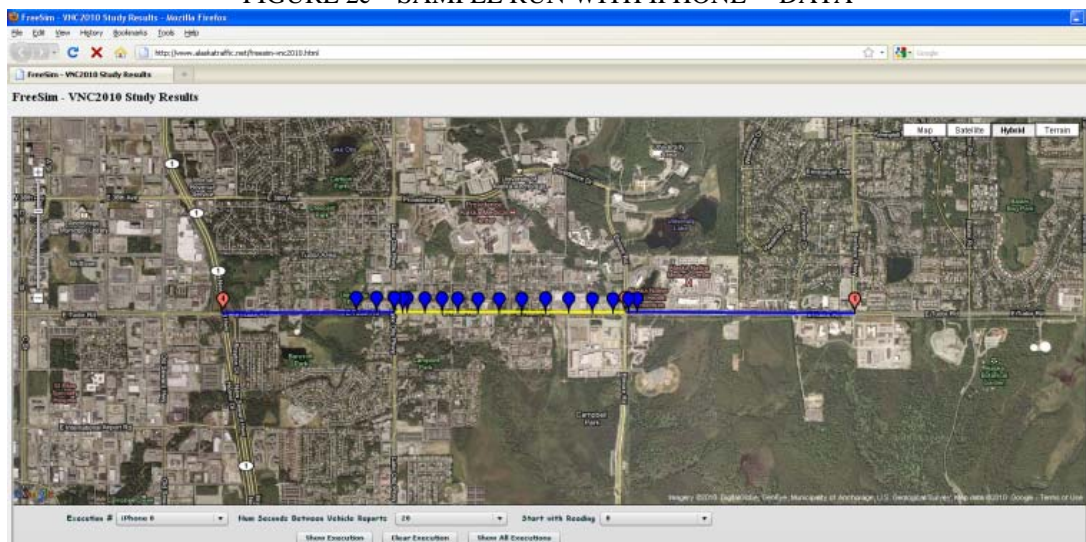
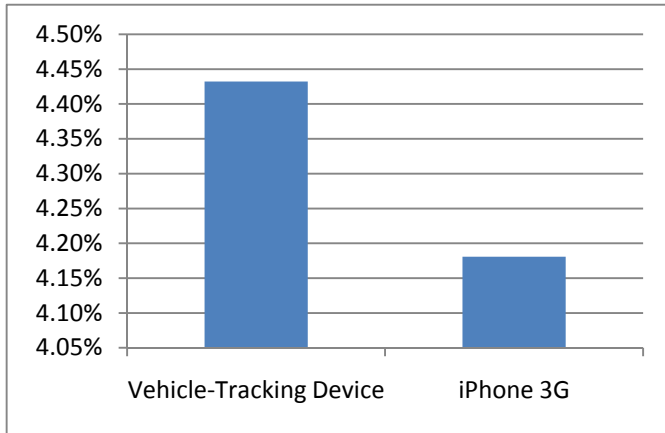


FIGURE 2d –IPHONE™ RAW DATA FROM ONE EXECUTION

iPhoneGPSDataID	vehicleID	latitude	longitude	speed	direction	Accuracy	timestamp
25165	54466774	61.18089676	-149.8005981	52.934998	270	47.4	2010-09-12 16:38:04
25166	54466774	61.18093872	-149.8038177	41.542465	272	47.4	2010-09-12 16:38:12
25167	54466774	61.18095779	-149.806015	30.725313	270	47.4	2010-09-12 16:38:20
25168	54466774	61.18096542	-149.8074646	13.118673	270	17	2010-09-12 16:38:28
25169	54466774	61.18104172	-149.8085632	18.18202	270	47.4	2010-09-12 16:38:36
25170	54466774	61.18104935	-149.8108978	35.443432	272	17	2010-09-12 16:38:44
25171	54466774	61.1810379	-149.8135529	40.161552	268	47.4	2010-09-12 16:38:52
25172	54466774	61.18103027	-149.8162689	40.161552	270	17	2010-09-12 16:39:00
25173	54466774	61.1809845	-149.8190308	41.197235	268	17	2010-09-12 16:39:08
25174	54466774	61.18097305	-149.8219147	42.923378	268	47.4	2010-09-12 16:39:16
25175	54466774	61.18098831	-149.8247528	42.693226	270	17	2010-09-12 16:39:24
25176	54466774	61.1809845	-149.8275146	41.542465	270	17	2010-09-12 16:39:32
25177	54466774	61.18099213	-149.8302155	40.046474	270	17	2010-09-12 16:39:40
25178	54466774	61.18099213	-149.8327637	37.629879	268	47.4	2010-09-12 16:39:48

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



IV. APPLICATION

A study was conducted on a 0.99 mile/1.59 kilometer section of roadway in Anchorage, Alaska that is usually congested through 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 2a shows the road that was 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™ drove the roadway at different times of day. The test vehicle entered the starting section of 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™ data.

Ten drivers drove the section of roadway where Figure 2b shows one execution of the vehicle tracking device’s location data and Figure 2c shows one execution of the iPhone’s™ location data. Figure 2d shows the corresponding raw data. All ten executions can be seen online at <http://www.alaskatraffic.net/freesim-vnc2010.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™. The percentage difference from the calculated vehicle tracking device was 4.43% from the actual TTT whereas the iPhone™ was 4.18% from the actual TTT, as is shown in Figure 3. From these results we can state more confidently that the iPhone™ is relatively as accurate as a tracking device installed in a vehicle. One important difference to note, however, is that the iPhone™ is only able to obtain location as opposed to tracking devices that are installed through a vehicle’s OBD port may be able to obtain additional data about the vehicle.

Although the vehicle tracking devices reported every 10 seconds, the iPhone™ reported every eight seconds. The difference in reporting period could have influenced the result of the iPhone™ having a slightly higher accuracy. As for the deviation from the actual time to traverse, this could easily have been due to human error based on manually timing the traversal. 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 works in accordance with FreeSim [13-15] to achieve a detailed map of real-time traffic data for the Anchorage area. FreeSim_Mobile 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. This data has many potential uses too numerous to enumerate in addition to those listed, with one area in which we are interested concerned with attempting to determine the probability of an accident occurring based on current conditions.

The degree of accuracy realized by the iPhone™ 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™ 3G the data obtained will be compared with that of the iPhone™ 4 [2], in which the anticipated results should show that the iPhone™ 4 is at least as accurate, if not more accurate, based on improved hardware components.

We hope to reach as many drivers with smart phones as we can 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.

In this paper we presented a preliminary study into the use of an iPhone™ 3G smart phone to be a relatively acceptable form of a device to use in a probe vehicle. We explained how the iPhone™ declares its accuracy as a ring of confidence and that 45.92% of the time is accurate to no more than 18 meters. 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 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 95.57%, whereas the accuracy of the iPhone™ using the same comparison was 95.82%. We analyzed the possibilities for error and hypothesized that the cause could have been due to the human factor of time-taking or the two second difference between the vehicle tracking devices reporting every 10 seconds compared to the iPhone™ reporting every 8 seconds. We have provided evidence that the iPhone™ is relatively as accurate as 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. The associated cost is substantially lower than that of a vehicle tracking device, and based on the current penetration 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.

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