

# Comparing the GPS Capabilities of the Samsung Galaxy S, Motorola Droid X, and the Apple iPhone for Vehicle Tracking Using FreeSim\_Mobile

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**Abstract** – In this paper, we present a comparison of the Samsung Galaxy S™ [20], the Motorola Droid X™ [3], and the iPhone 4™ [2] using the real-time vehicle tracking application FreeSim\_Mobile [1,19]. Using the built-in GPS receiver and the web capabilities of these smart phones, coupled with a V2I architecture, we are able to send a continuous flow of speed and location data to a central server for processing by FreeSim [13-15], a real-time traffic simulator. The proportional model algorithm [17] is then used on this data to determine the time to traverse a section of 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. In addition there is a small test fleet of probe vehicles using the iPhone 4 [1,2,19]. In this paper we analyze the capability of two different Android-based [18] phones, the Samsung Galaxy S and the Motorola Droid X, on reporting accurate and reliable locations and compare them to a vehicle tracking device as well as the iPhone 4, which has been shown to be as accurate as a vehicle tracking device [1,19]. Drivers equipped with a Samsung Galaxy S, Motorola Droid X, iPhone 4, and vehicle tracking device manually timed how long it took to travel along a 0.98 mile/1.58 kilometer section of roadway. From this location and speed data reported by each device, the amount of time to traverse the test section of roadway was determined using the proportional model algorithm [17] and compared to the actual amount of time it took to traverse the test section of roadway as manually timed. The results of the vehicle tracking device had an average error factor of 0.79% from the actual time to traverse the section of roadway, whereas the Samsung Galaxy S was 4.59%, the Motorola Droid X was 0.84%, and the iPhone 4 was found to have an error factor of 0.60%. We conclude that the iPhone 4 and Motorola Droid X have higher accuracy than 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. However, no discrete technology can provide with 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. A major advantage over stationary detection systems is 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. 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.

As the recent growth of smart phones has become more prevalent within the marketplace, so has their penetration within our nation's vehicle infrastructure. This has provided a potential solution to the expense problem. As of January 2011, Android-based phones comprised 31.2% of the U.S. smart phone market place while the iPhone (iOS, iPhone Operating System) comprised 24.7% of the smart phone market in the United States [10]. This allows us to conclude that *at least* 55.9% 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 a road system based on gathering vehicle locations 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 smart phones can 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. Alongside the vehicle tracking devices we have a small number of iPhone™ users running an application that reports their location every 10 seconds. Based on this data, a map is generated that provides drivers with the amount of time to traverse arterial roadways in Anchorage. Through the use of the proportional model algorithm [17], for mapping the GPS data at specific times to the time to travel along a roadway section, we compute the amount of time to travel along the roadway.

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 the Samsung Galaxy S and Motorola Droid X are acceptable for this application and how the proportional model algorithm is used to analyze our data. Section IV compares the results of the three smart phones 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].

While vehicle GPS transceivers 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 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 typically connected to a vehicle like many tracking devices would be, 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 [12,24-26]. Audi [25] 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 this ability into our application in our future work.

With navigation systems, TomTom [22] utilizes data from their own devices, as well as from third parties such as national and local governments, to offer their users real-time traffic conditions. In previous work by Menard and Miller, we have shown that the iPhone 3G and iPhone 4 can be used for vehicle tracking and produce results of being just as accurate as a vehicle tracking device [1,19].

## III. FOUNDATION

The three different smart phones we compared use very similar steps in retrieving their locations. The general process consists of three steps 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's position is reported like any other GPS receiver, giving a confidence radius of its position. For the Galaxy S, 97% of all the data points received from the trial runs were within 5 meters of accuracy, as can be seen in Figure 1a. As for the Motorola Droid X, 80.15% of the data points reported were within 5 meters, and 95.94% were within 10 meters, as can be seen in Figure 1b. The iPhone 4 reported 58.63% of its data points to be within 5 meters and 97.77% to be within 10 meters of accuracy, shown in Figure 1c. The Galaxy S reported 652 data points, the Motorola Droid X reported 665, and the iPhone 4 reported 626.

FIGURE 1a - CONFIDENCE RADII OF THE SAMSUNG GALAXY S GPS DATA

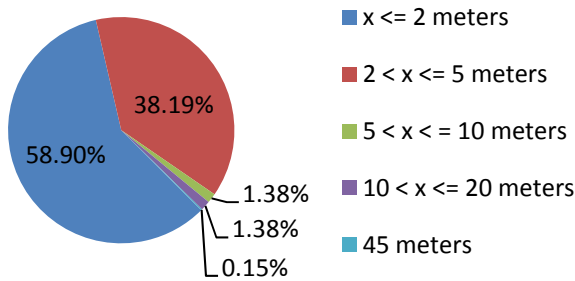


FIGURE 1b - CONFIDENCE RADII OF THE MOTOROLA DROID X GPS DATA

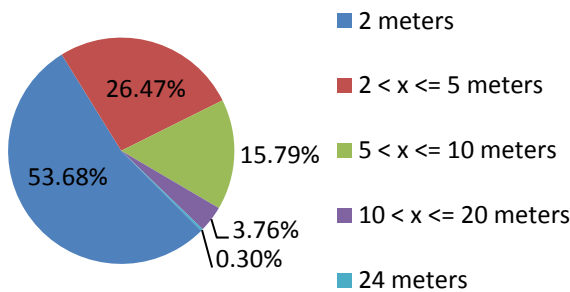
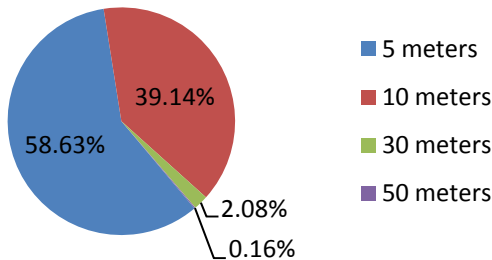


FIGURE 1c - CONFIDENCE RADII OF THE MOTOROLA DROID X GPS DATA



FreeSim\_Mobile uses the phone's location and its associated timestamp as input to determine the current speed of the vehicle. 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 [17] determines the amount of time to traverse a roadway based on the set of locations and timestamps.

The proportional model algorithm [17] 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 smart phones) 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 roadway 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 a roadway, the proportional model uses an algorithm to determine the amount of time to traverse a roadway 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.

#### IV. APPLICATION

A 0.98 mile/1.58 kilometer section of roadway just outside of Chicago, Illinois was chosen based on its periods of heavy and light congestion throughout the day. Since it runs through the center of Northern Illinois University's main campus, using this section of roadway gave us a wide range of traffic variation. The traffic is both vehicular and pedestrian and can rise and fall with the beginning and end of class periods, as well as the usual 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 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 sections (the area starting with node 1 and ending with node 2), and the exiting sections (the area starting with node 3 and ending with node 4). The middle section in yellow (the section between node 2 and node 3) is the section we timed. Test vehicles equipped with a stopwatch, a vehicle tracking device, a Galaxy S, a Motorola Droid X, and an iPhone 4 drove the roadway at different times of day. The test vehicle entered the starting section of the road, drove through the entire test section, and exited through the last section. The time to travel along the middle edge was determined by manually timing and calculated algorithmically using the proportional model based on the vehicle tracking device and the data from the three smart phones. The proportional model was executed four times, with the data from each device used independently of the other devices.

Ten drivers traveled along the section of roadway, where Figure 2b shows one execution of the Galaxy S location data, Figure 2c shows one execution of the Motorola Droid X, and Figure 2d shows one execution of the iPhone 4 location data. Each of the ten executions per device can be seen online at <http://www.alaskatraffic.net/freesim-vc2011.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 (as determined by the stop watch) to the calculated time to traverse based on the vehicle tracking device and the three smart phones. The percentage difference from the actual TTT to the calculated TTT based on the vehicle tracking device was 0.79%, whereas the iPhone 4 was 0.60%, the Galaxy S was 4.59%, and the Motorola Droid X was 0.84%, as shown in Figure 3. From these results we can state with confidence that the Motorola Droid X and iPhone 4 have a higher accuracy than a tracking device installed in a vehicle. One important difference to note, however, is that the smart phones are only able to obtain location unless paired with a third party OBD reader, as

FIGURE 2a – TEST ROADWAY USED

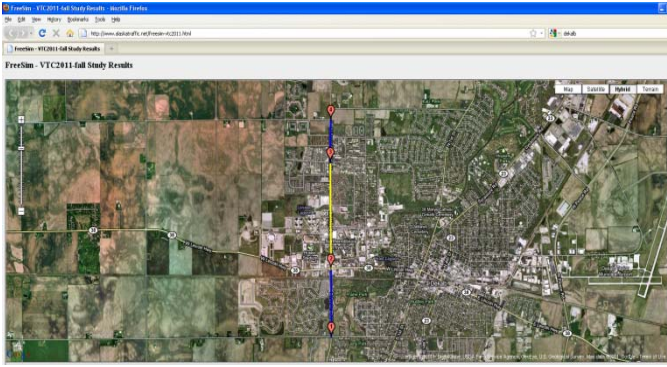


FIGURE 2b – SAMPLE DATA OF SAMSUNG GALAXY S

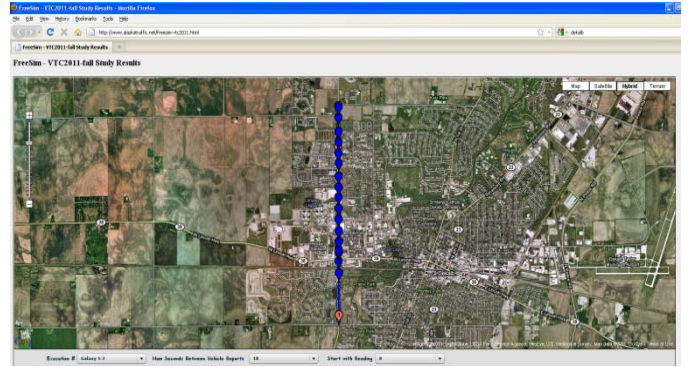


FIGURE 2c – SAMPLE DATA OF MOTOROLA DROID X

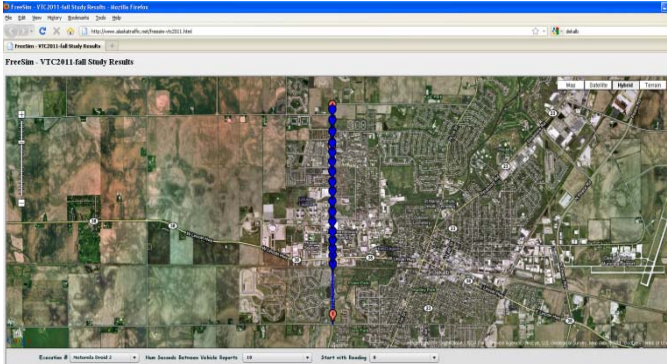


FIGURE 2d – SAMPLE DATA OF APPLE IPHONE 4

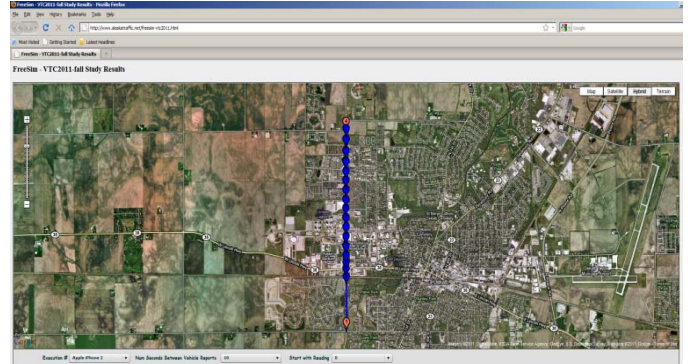
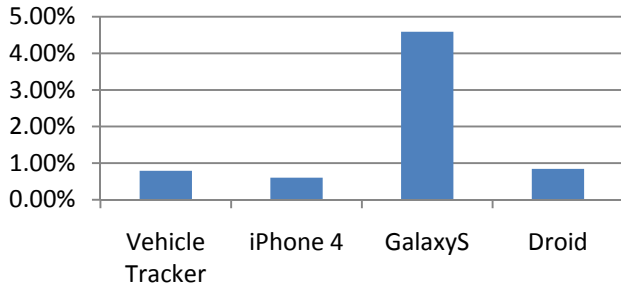


FIGURE 3 – PERCENTAGE DIFFERENCE IN ACTUAL AND CALCULATED TIMES TO TRAVERSE



opposed to tracking devices that are installed through a vehicle’s OBD port, which may be able to obtain additional data about the vehicle.

The trial runs have shown that all three smart phones and the vehicle tracking device are more accurate than loop detectors, which report within a 10% margin of error. When Comparing the Galaxy S to the other two smart phones, the Galaxy S reported poorly on two trial runs, which may have been caused by external forces. The Motorola Droid X and Galaxy S have very similar hardware, and if the set of data is recalculated with the two poor trial runs dropped, the Galaxy S had a margin of error of 1.92%, the Motorola Droid X had a margin of error of 0.77%, the iPhone 4™ had a margin of error of 0.53%, and the vehicle tracking device had a margin of error of 0.52% from the actual TTT. Menard and Miller have previously shown that the vehicle tracking device was accurate to within 1.8% of the actual time to traverse using a

similar measurement [17], and the iPhone 4 has been shown to be accurate to within 1.10% from the actual time to traverse using a similar measurement [1].

## V. CONCLUSION AND FUTURE WORK

FreeSim\_Mobile [1,19] works in accordance with FreeSim [13-15] to achieve a detailed real-time traffic map. FreeSim\_Mobile is intended to be used with other means of traffic gathering in order to build an accurate map of traffic patterns. This information can be used by commuters for making decisions for 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, among other uses too numerous to list.

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 could obstruct the GPS line-of-site.

In this paper, we presented a comparison between three different smart phones running the vehicle tracking application FreeSim\_Mobile [1,19] and concluded that they are an acceptable alternative to tracking devices installed in probe

vehicles. We showed that about 95% of the time all the phones were accurate to within 10 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 these phones should be considered 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. We concluded through the real-time traffic simulator FreeSim [13-15] that the average percentage of accuracy of the vehicle tracking device compared to the actual time to travel along the roadway was 99.21%, whereas the accuracy of the iPhone 4 was 99.40%, the Motorola Droid X was 99.16%, and the Galaxy S was 95.41% using the same comparison. When the Galaxy S was resolved of its outliers, the accuracy became 98.08%. Further testing will be needed though to narrow down the exact cause of its error. We have provided evidence that the iPhone 4 and Motorola Droid X are more accurate than a vehicle tracking device and that all three tested smart phones produce a lower margin of error than loop detectors, although they lack 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 is used. The associated cost is substantially lower than that of a vehicle tracking device, assuming the user already has the hardware and a cellular data plan. Based on the current penetration rate of smart phones in the market, there is a much higher chance to solicit widespread adoption for determining real-time traffic conditions.

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