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Travel Time Estimtion Using Cellular Phones

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Abstract
Typical travel conditions on roads and highways are becoming very strenuous, unsafe, and unpleasant and this problem is compounded by road constructions, incidents, and accidents. Travel time has become synonymous with wasted time and resources. Furthermore, the ever increasing travel time on the roads is a source of stress and emotional and health problems.

Acknowledging the importance of reducing travel time the USA government has established the nationwide 511 system to inform travelers about road conditions and travel time estimate between two locations. Cities, counties and states have also tried to reduce travel time by installing a variety of vehicle location and identification sensors on main roadways. The computations of this data are transmitted to drivers for travel time information. Unfortunately, these traditional methods are very expensive. Only principal roads have this kind of equipment because economically is close to impossible to install and maintain sensors for entire cities.

In the past several years, research on travel time estimation using cellular phones has made possible its implementation as an inexpensive solution to complement the existing traffic information in some cities around the world. In this article, the authors will present the technical details of how these methodologies are being used in general for travel time estimations and the general architecture of the cell phone companies to process the call and the positioning information.

Keywords
Road traffic control, road transportation, road vehicle identification, road vehicle location monitoring

1. Introduction

At first glance it appears that calculating travel time on roads travel should be easy using cellular phone signals. After all, cell phone carriers are periodically probing the cell phones, obtaining the user identification as well as the cell phone location. This probing is done because the area serviced by the network is divided into many sectors, each of them serviced by a base station. In order to communicate with the cell phone, the network must know in which area the cell phone is. Moreover, as a cell phone moves from one sector to another, the call must be handed over to the appropriate base station, as shown in **Figure 1**. Therefore, the network must always identify and track the cell phones to perform the hands over, when necessary. Then, with so many cell phones in traveling vehicles, traffic conditions for all roads would be expected. To understand the reasons why it is not that simple it is necessary to comprehend the cell phone network architecture and the cellular phone methodology to calculate roads travel time.

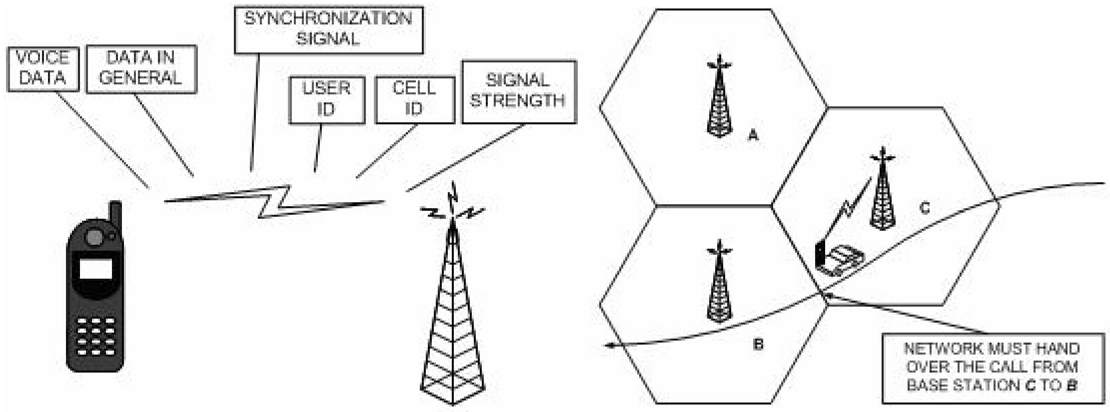

Figure 1: Cell Phone Handover

1.1 Cellular Phone architecture

The network consists of many base stations that service nearby cell phones. The base stations are controlled by the Base Station Controller, which in turned is controlled by the Switching Center. The Switching Center routes the call between cell phones or between a cell phone and a fixed telephone. The Switching Center also store the identification of files and location of the cell phones for billing purposes, as shown in **Figure 2**. A couple of methods to calculate locations are explained in the next section.

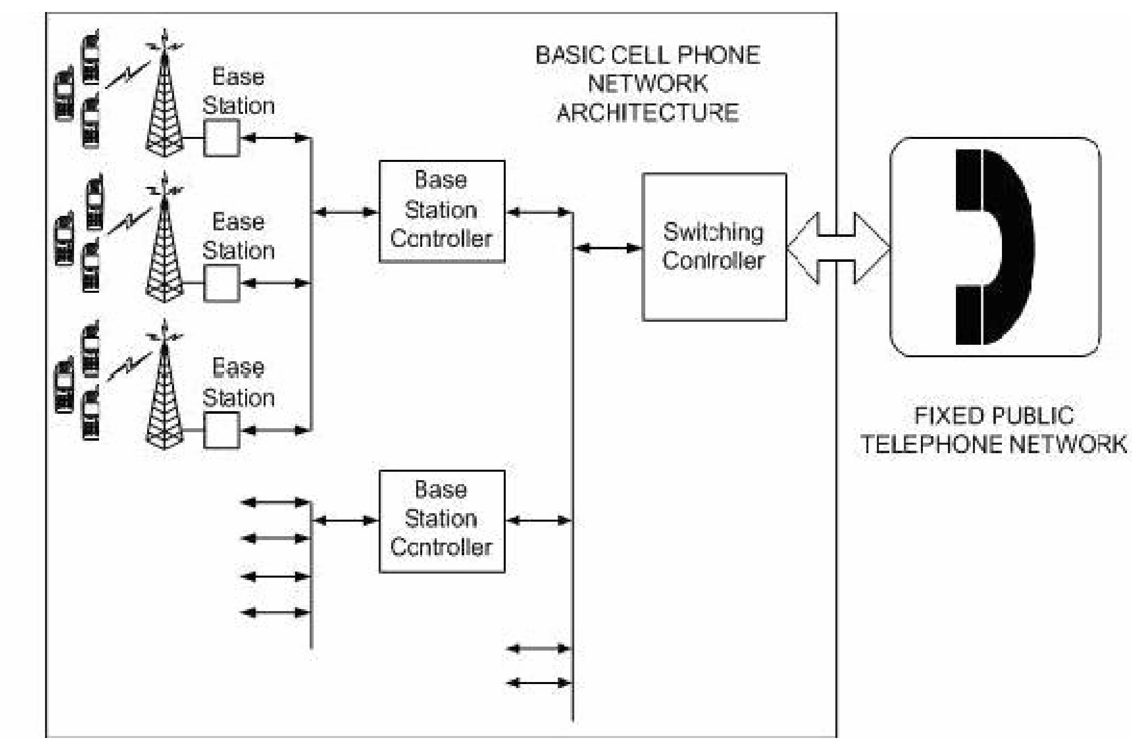

Figure 2: Basic Cellular Network Architecture

1.2 Cell Phone Location Calculation Methods

1.1.1 Time of Arrival (TOA)

After the cell phone transmits its signal strength level, the network reads this level and also measure the received strength level at nearby base stations. Then the attenuation of the signal is calculating by subtracting the received level at each base station to the transmitted level. Since the attenuation depends on the distance, the distance of a cell phone to each base station can be calculated. Finally, the cell phone position is calculated using the triangulation method with computed distances at three nearby stations, as shown in **Figure 3.** Unfortunately, the attenuation is also dependent of the reflections, diffractions and multipaths occurrences. The typical accuracy of this method is method about 50-200 m (Openwave Developer Network, 2002).

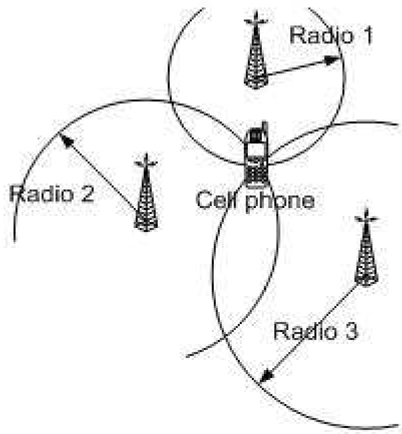

Figure 3: TOA Location Method

1.1.2 Angle of Arrival (AOA)

In this method special arrays the antennas are installed at the base stations to calculate the direction the signal is coming from. Then, two stations are enough to calculate the location of the cell phone, as shown in **Figure 4**. This method has an accuracy of about 50-300m (Openwave Developer Network, 2002).

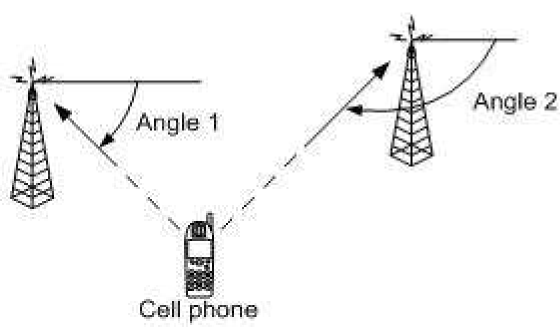

Figure 4: AOA Location Method

1.1.3 Assisted-GPS

This method uses the GPS satellite system to calculate the position of the cell phone, assisted by the network, which has a GPS receiver with a known position and clear line of sight to the satellites (Motorola, Inc., 2001). The assistance takes the complex location calculation off the phone. The methodology is shown in **Figure 5.** Its accuracy is 5-30m (Openwave Developer Network, 2002).

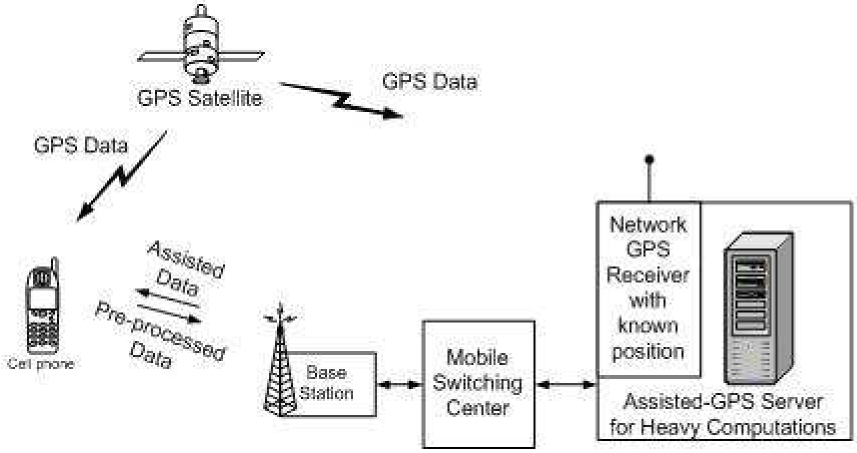

Figure 5: Assisted-GPS Location Methodology

2. Methodology

A typical traffic provider network architecture is shown in **Figure 6.**

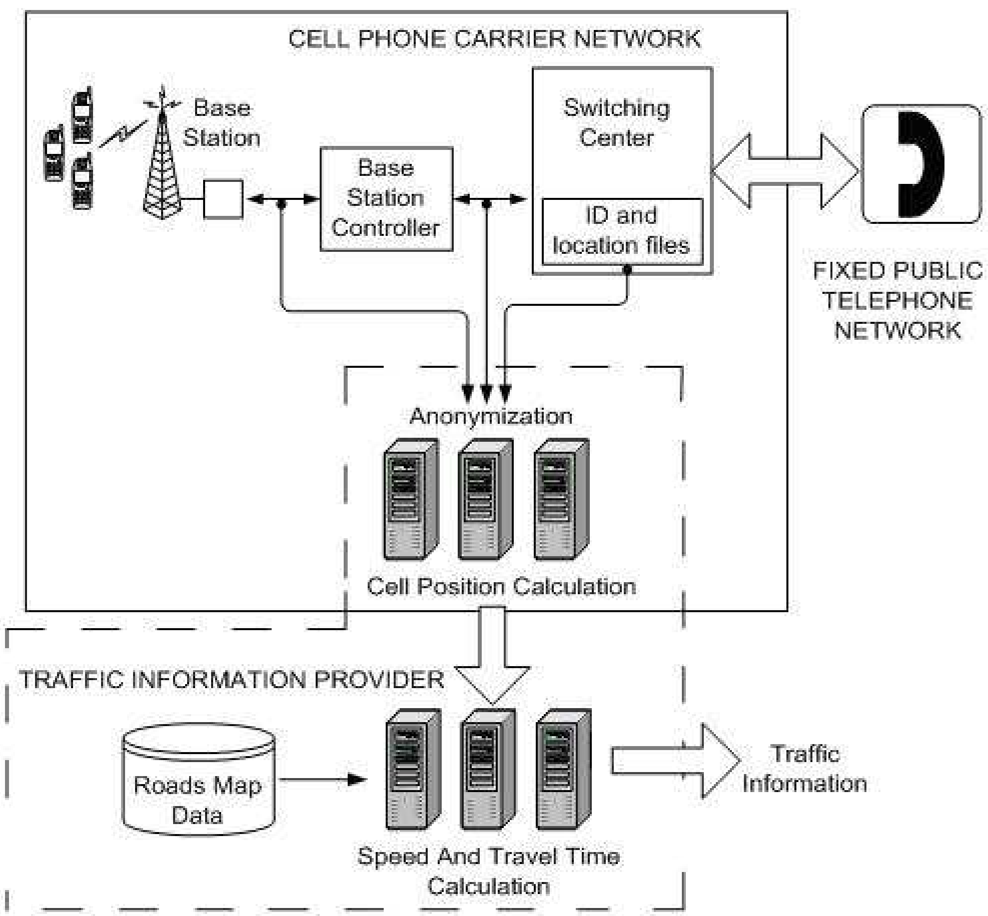

Figure 6: Typical Traffic Information Provider Network

The cell phone providers' network is tapped for data or files (Smith et al, 2005), containing identification of the users and the position of their phones. Anonymization is the first step of the process to protect the privacy of the users (Smith et al, 2005). Then a log of the vehicle positions is obtained, as shown in **Figure 7**. These calculations are done in the carrier premises with equipment that belong to the traffic service provider.

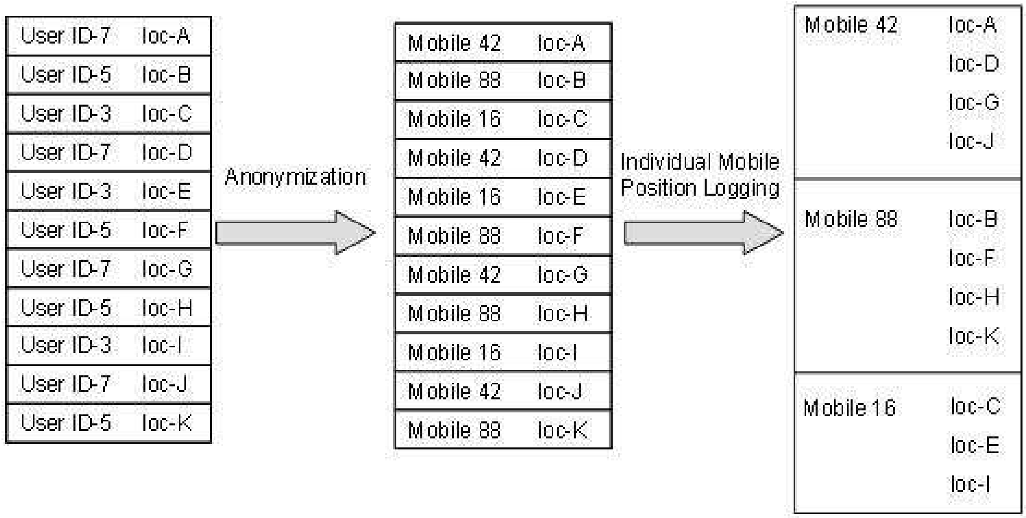

Figure 7: Cell Phone Position Tracking

Then the data is send to the traffic service provider for more processing.

The positions are then correlated to a map to assigns the position to a segment of a road. The difficulty of assigning a location to a road depends of the source that provides the location (Cayford R, 2003). A location given by an assisted-GPS method may have an accuracy of 15 m., 50m for a 911 call, and 200m for a TOA-AOA radiolocation method. Therefore, depending method used to obtain the mobile position, there may many possible road segments where the mobile really is. For example in **Figure 8** the black triangle indicates the position given by the cell phone network, which is not necessarily the actual cell phone position. If the position was obtained by Assisted-GPS the cell phone is in 2nd St. or 11th Av. If it was obtained by the network and it is a 911 call it is in 10th Av, 11th Av, or 2nd St. But if the position is not a 911 call and the network used the TOA-AOA method to obtained it, the cell phone could be in any road but 13th Av.

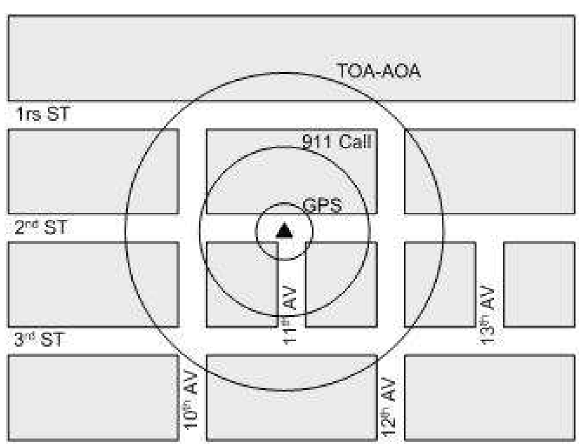

Figure 8: Cell Phone Position Range

Furthermore, even if their position were accurately established and associated to a road, there may be many possible routes between two consecutive position readings for a mobile, as shown in **Figure 9**. In order not to use much bandwidth, the network cannot transmit location reading continuously, so if a cell phone is moving at 45 mph it would travel 600 m between two readings 30 seconds apart.

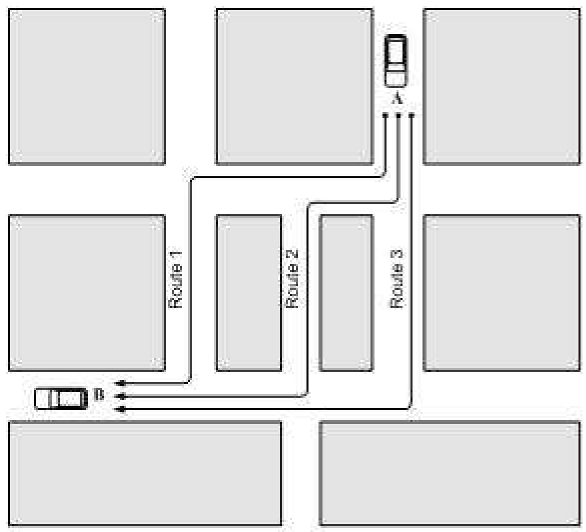

Figure 9: Possible Routes Between Two Location Readings

In order to estimate the traffic conditions on the roads, road traffic providers using the cell phone method use complex algorithms, statistical methods (Feldman et al, 2003), driver behavior models (Cayford R and T. Johnson, 2003) and data from many cell phones.

3. Finding and Conclusions

Travel time calculation using cellular phones has correlation with travel time obtained by other traditional method, such as loop sensors. A typical graphic, for a road segment of 200 meters as a unit is shown in **Figure 10.**

The figure shows that both data are similar in light traffic conditions, less than one second (15%) difference. At heavy traffic conditions, the difference is up to seven seconds (60%). The travel time of a segment with many units segments is calculating by adding up the travel time of their units segments. Because a unit segment with heavy traffic will probably incur in larger differences than unit segments with light traffic, the travel time difference between the data from cellular phones and sensor loops will depend on the ratio of number of unit cells under light traffic and the ones with heavy traffic.

Some traffic information providers evaluate their system by measuring only the absolute difference average of their data versus another traditional system such as sensor loops, and they may claim an absolute average of 3-5 mph difference for segment. After computing the speed for the segment, the above graphic shows an absolute average difference of 6 mph in speed. However, it provides individual results up to 15 mph difference.

Traffic information obtained from anonymous cellular phones has been making inroads in the traffic information market by offering a system implementation of months instead of years and 1/10 the cost of traditional methods. Some cities around the world have already implemented this method. However, the validation of this method in the USA may be established after analyzing the real-time data in projects already in progress in some American cities.

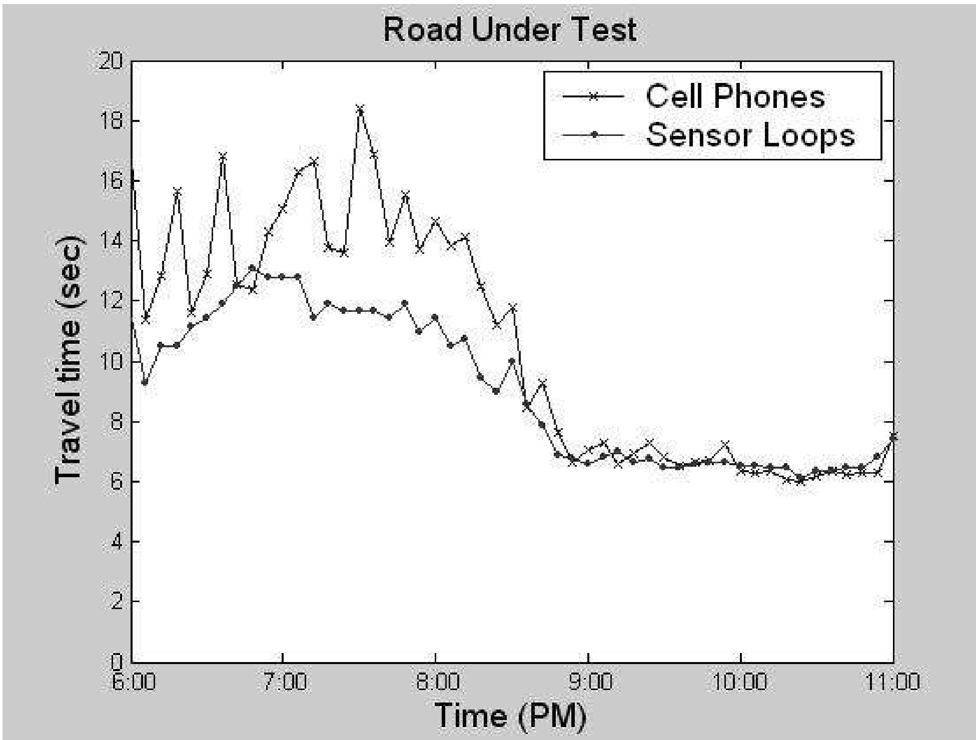

Figure 10: Comparison of Travel Time Calculation Using Cellular Phones and Loop Sensors

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