CELLULAR TELECOMMUNICATION AND TRANSPORTATION CONVERGENCE:

a Case Study of a Research Conducted in California and in France on Cellular Positioning Techniques and Transportation Issues

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Special session: Chris Drane and Jean-Luc Ygnace
Location-Based Wireless Technologies

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ABSTRACT

The paper describes the methodology and preliminary results obtained from a study started at the University of California Berkeley PATH Program by a team of researchers from INRETS, Bron (France), the University of Technology Sydney and U.C. Berkeley, USA. The study continues in France within the European SERTI program. The program goal is to promote trans European new technologies deployment for traffic management and traveler information purposes. Our project intends to test network based cellular positioning methods to 1-assess emergency calls management on national roads and motorways and 2- give travel times estimates on road segments from the current fleet of vehicle equipped with cell phones. The initial results from the simulation work conducted at PATH show that we can expect a good estimate of travel time from cell phones used as probe vehicles. A more detailed analysis of traffic volume data and call volume data observed from the cellular network in France confirm that there are strong relationships between the cellular network load and the adjacent road network. The results suggest the need of new research directions to investigate and test the robustness of these relationships.

OBJECTIVES

There are almost 80 millions cellular phones subscribers in the U.S. and 21 millions in France alone and we can estimate that the percentage of cars travelling on major roads and motorway corridors with a phone switched in the "on" position is high enough to give a good sample of the travelling population. The travel time estimates of these probes on the road network is a good approximation of the travel time of the same network for the entire vehicle population. On the other hand, we have already evaluated that 50% of emergency calls on the motorway network are coming from cell phones and it is crucial to locate these phones to optimize the rescue effort and the clearing of the incidents.

The objective of the study is to locate the phones within 150 meters in order to get a good estimate of the speed of the probes. A second step is to evaluate the percentage of probes necessary to obtain an estimate of travel times within 5% of accuracy. The methodology will be applied to different road network segments i.e. national road, motorways and urban freeways. A third step is to test a positioning technology and infer travel times during a filed test experiment conducted in France.

The work presented here aims to foster new opportunities to use existing cellular network and positioning technologies in conjunction with traditional road infrastructure dedicated to traffic management; another aim is to use the telecommunication network based technologies in lieu of road infrastructure technologies when the deployment cost is too high.

BACKGROUND AND FIRST RESULTS

As part of the information age the transportation sector is motivated to obtain reliable information in order to observe and control traffic flow. Providing traffic information and travel time estimates between any two points is becoming a major challenge for the public institutions and private companies of providing such information may vary from country to country and involve a wide range of possibilities; changeable Messages Signs installed at strategic highway intersections,
dedicated in-car devices or even simple radio or internet messages.
Travel time estimates are becoming an important part of nations’ Intelligent Transportation Systems regardless of the distribution channel. Basic traffic data are usually collected by a data collection system along the road. Such systems mostly use inductive loop detectors. The detectors help to define the traffic density, the traffic flow and speed. These are the basic parameters needed by the operational traffic engineers.

Cell Positioning Overview

Cellular telephone systems are radio-based mobile communications systems. In this case cellular means that the systems use many base stations to transmit or receive the signals from the mobile telephones. These base stations are distributed over the service area, nominally in a hexagonal pattern. The area in the closest vicinity of a base station is known as a cell.

The mobile’s power level is adjusted so that the signal from a mobile is unlikely to be received by base stations that are not in the immediate vicinity of the mobile. This means that frequencies can be reused in different parts of the service area, allowing many more telephones to operate for the same frequency allocation.
For some time it has been realized that it is possible to carry out positioning using a cellular telephone system [1]. In the United States a number of factors, especially the FCC E911 mandate for positioning of emergency calls, has meant that cellular positioning has become an active area of research and development [2]. There are a number of advantages to a cellular telephone positioning system:

- It makes use of the installed infrastructure of the cellular telephone system, so greatly reducing establishment costs.
- Cellular systems already have a spectrum allocation.
- In areas of the worst propagation, cellular systems tend to have the greatest number of cells.
- There is already a very large installed user base.
The cellular system provides a two-way communications link.

There are several ways that position can be derived in a cellular positioning system:

The Signal Profiling involves measuring the characteristics of the received signal and comparing it with a database of previous measurements.
The Angle-of-Arrival technique uses a large antenna in order to estimate the angle-of-arrival of the received signal.
The Timing Measurement technique, in its simplest form, requires a receiver to make an accurate determination of the time-of-arrival of received signals.

Travel Times Issues

The concept of using a probe vehicle for estimating travel time has been investigated for some time, [3], [4]. These studies have all shown the concept is technically feasible. The results show that in general, roughly 5% need to be instrumented in order to achieve reasonable estimates of the travel time. These studies have assumed that the probes are able to estimate their location with a very high order of accuracy.

This assumption has to be evaluated in the case of cellular telephone positioning systems. Such systems are likely to have an
error of the order of 100 meters RMS. This error can cause the following problems:

- Assignment of a vehicle to the wrong road.
- Mistakes in the direction of travel.

In addition, in order to make a position measurement the mobile has to be turned on. Users might turn a phone on for a brief period then turn it off again, so that cellular probes will operate in an intermittent, more random fashion that dedicated probe technologies.

In addition to the issue of accurately tracking mobile telephones, there is an additional technical issue of the system capacity needed in order to actually make the measurements. Given the probe application is likely to be a secondary application to the management of emergency calls, it is important the cellular probe application does not use too much of the capacity of the cellular positioning system. If the usage by the cellular probe application is too high, this could jeopardize the primary application, or necessitate the installation of many additional positioning receivers.

Accordingly, a preliminary analysis that we have conducted [5], [6] has focused on these differences, rather than completely duplicating earlier work. We have taken two complimentary approaches. The first was to construct a series of analytical models that addressed different issues. The second was to develop a simple discrete event simulation.

A. Analytical Model

The model was developed in terms of coverage, i.e. fraction of links for which the links have been measured in the time frame of interest. The result was a surprisingly simple approximation:

\[ E = 1 - \exp(-\alpha \rho L) \]

Where \( \alpha \) = fraction of vehicles sampled
\( \rho \) = density of traffic per unit length
\( L \) = average link length
\( E \) = coverage.

This formula says that to improve the coverage you need to increase the fraction of vehicles sampled or increase the average link length. The latter arises because the larger the link length the more likely you are that a randomly chosen vehicle will be on that link. The heavier the traffic density, the greater the coverage because the total number of sampled vehicles becomes larger. The exponential nature of the formula indicates why only a relatively small fraction of vehicles is needed to characterize a network, once \( \alpha \rho L \) is greater than one, the coverage rapidly approaches 100%. Note that although the coverage increases with increasing \( L \), the travel time accuracy does not necessarily increase at the same rate. This is because for large \( L \), the travel times are measured over too long a link length, and so do not provide local travel time information.

Highlights of this analysis are as follows. For just 5% of the vehicles sampled, the coverage was very high, i.e. in a 15 minute time window and a link length of 1.5 km (which is relevant to most of the situations we can consider), most links in the network would be sampled. The model also indicated that for a spacing of 250 meters between roads, the probability of assigning a vehicle to the wrong road was very small, less than .001. It was found that the raw standard deviation of the travel time was about 10 seconds (about 10% of the travel time for the link) and was only degraded slightly by wrong road assignment and non-sampled links. The effect of directional errors was not included in the model, but it is considered likely that it will be small.
Assuming that 400 positioning receivers were used to make the position measurements, it was found the average utilization of each positioning receiver would be less than 1%. This low value is due the large number of base stations, the small amount of time needed to make a measurement (100 ms), and the relatively long time interval between measurements (ten seconds or more).

B - Simulation Model

The simple simulation model does not capture the complexity of vehicle movement along a freeway. Accordingly, we prepared a complementary analysis to the analytical models presented above. Building a discrete event simulation of travel along part of a freeway did this. The aim of this simulation was to compare average link travel time for a simulated traffic flow situation with different size samples of vehicle probes (5% to 50%, at 5% intervals) drawn from the total population. The position accuracy of the probes is given at random in a 150 meters range, which is what we can expect from cellular positioning methods. We studied different road network configuration to test the robustness of the estimates in travel times.

We simulated vehicles entering the network at constant speed, with a Gaussian speed distribution. We used distributions with different means corresponding to the different network and lane situations, and we were able to input different volume and speed parameters for two lanes of freeway, plus an adjacent road. The network was divided in links of 1.5 km. The model counts the number of cars per link and their speed on a 3 minutes cycle with a refreshment period of 15 minutes. The results are average (harmonic mean) link travel time estimates over an hour (simulated time).

The results show that even for a complex network the estimation of the probes link travel times remains in a 8% accuracy interval from the observed traffic situation. 5% accuracy can be easily obtained for a more simple network. In both cases the accuracy is obtained as soon as the percentage of probes reaches 5% of the total vehicle population per link (figure 1).

<table>
<thead>
<tr>
<th>average speed</th>
<th>Density</th>
</tr>
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<tbody>
<tr>
<td>lane 1 100 km/h</td>
<td>1600 v/h</td>
</tr>
<tr>
<td>lane 2 80 km/h</td>
<td>2400 v/h</td>
</tr>
</tbody>
</table>

Figure 1: travel time estimates free flowing conditions on both lanes (simple network condition)

Call Volume and Traffic Volume

The European part of the project aims at testing a technology to locate cell phones and calculate speed and relevant travel time on freeways. A survey conducted in August and September 2000 on a freeway South of Lyon France showed that 72% of cars have a cell phone in position “on” while traveling on the freeway. Even if the positioning techniques developed with the French cellular carrier SFR do not involve the measurement of in coming and out going
cellular calls along the freeway we decided to analyze the cell load in light of the traffic measured along the freeway in order to establish potential relationships between the phone call volume and the traffic data on the road network. It is known that the cellular carriers started to implement their cellular network along the major road network axes, assuming that the natural usage of the mobile phone was while traveling. These assumptions have to be confirmed by carefully assessing the links between the road network and the adjacent cellular network.

In a first step, we recorded cellular call volume ("outcalls", calls sent by the subscribers and "incalls", calls received by the subscribers) for nine Base Station Transceivers (BTS) along a seven kilometer stretch of the urban freeway continuing the A7 motorway around Lyon between St Fons and the tunnel of Fourvière in Lyon. The data are recorded from August 1st to September 30th, 24 h a day and aggregated on a 12 minute interval. In parallel, traffic volume, speed, occupation and incidents are recorded for the same period by the Direction Départementale du Rhône, managing this freeway. The road traffic data are recorded from the 10 loops along the freeway.

The same procedure is used to record BTS call volume along a 90 kilometer stretch of the motorway A7, South of Lyon between Chanas and Montelimar. There are 21 BTS covering the network and the same traffic data are recorded from the 20 loops operated by the motorway operator ASF. The recording period and the interval for aggregation is the same than in a first case. The two major objectives are 1) to evaluate the relations between the telecommunication and the road network mainly in terms of network load and demand and 2) evaluate the possibility of using the cellular network as a tool to detect incidents by scanning any significant differences in the call volumes explained by a road incident.

This preliminary analysis is to be completed before June and July 2001. At that time we start to collect the travel times obtained from the cell positioning technologies; the estimates will be compared with the ground truth data from the two road operators involved in the study.

As expected, a preliminary data analysis along the A7 stretch shows similarities among the telecommunication and road network loads, fig.2.

![Traffic Flow and Cellular Call Volume Along the Freeway](image)

The average number of calls along the freeway per 12 minute interval over 60 days is in the same range as the average number of vehicles, e.g. between 600 and 800 per unit of time. The difference is at the highest between 4:00 pm and 20:00 pm when the number of calls is still increasing whilst the number of vehicles decreases.

The observed similarities do not change much when considering the month period of the study (August or September). August can be considered as an exceptional month for the traffic volume. During that month the
traffic volume is almost twice higher than the out-call volume but the correlation between the two set of data is similar (The Pearson coefficient is in a same range of value, ~ 0.7, Sig. 0.000).

**CONCLUSION**

The preliminary indications are that despite the low accuracy of cellular positioning, a probe based travel time measurement system would be able to give reasonable estimates of travel time with the proportion of probes likely to be available in the near future. Furthermore the system load needed to make the measurements is only a small proportion of the total capacity, so that it is quite possible that cellular operators might be interested in implementing the probe vehicle travel time estimation system as a secondary application.

The analysis of existing relation between cellular network and adjacent road network shows a correlation between vehicular traffic volume and cell phone call volume. This further justifies the need of an extended scientific investigation. The potential of cellular positioning techniques pave the way to the new deployment of cellular telecommunication related technologies and applied to road traffic management. The socio-economic viability of such technologies are being considered within the on-going research program in Europe and in the U.S.

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