CAN MOBILE MILLENNIUM HANDLE CONGESTION PRICING?

Sarah M. Stern, Department of Mechanical Engineering, University of California, Berkeley, CA, 94720-1710, smstern@berkeley.edu

ABSTRACT

The Internet's adaptability to the mobile world is impacting the transportation cyberphysical system at a very fast pace. In the last five years, cellular phone technology has leapfrogged several attempts to monitor traffic with dedicated infrastructure systems. Today, Global Positioning System (GPS) enabled smartphones are increasingly becoming a prevalent data source for traffic monitoring systems which allow users to collectively supply and receive real time traffic information. Mobile Millennium was a pilot project representative of this new type of technology and allows the general public to partake in bettering traffic conditions on their daily commute. One of the problems tackled by this research is to know: Can the Mobile Millennium system deter congestion enough to prevent the need for congestion pricing or will it need to be adaptive in case congestion pricing becomes a larger priority for policy makers? A research trip to Finland allowed this problem to be analyzed and the following proposal was written.

Keywords: congestion pricing, GPS, privacy, traffic

INTRODUCTION

Our team, composed of UC Berkeley researchers alongside Nokia Research Center Palo Alto and Navteq, with support from United States Department of Transportation (US DOT) and California Department of Transportation (Caltrans), has designed a monitoring system for traffic using cellular mobile phones, known as *Mobile Millennium*. The Mobile Millennium project, officially launched on November 10, 2008, is a pilot traffic monitoring system that collects traffic data from GPS-equipped mobile phones using participatory sensing to estimate real-time traffic conditions. Commuters are able to make more intelligent route and trip decisions because the traffic conditions are broadcast back to the users' mobile phones. The deployment area is currently centralized on commuters in Northern California, including Sacramento and the San Francisco Bay Area, because these areas have heavy recurring congestion on many of the roadways. The pilot program is a follow up of the *Mobile Century* experiment (Work 2008), where 165 UC Berkeley graduate students drove a ten-mile loop of Interstate 880 in California for a day; ultimately demonstrating the reality and accomplishment of a real-time traffic estimation service using GPS enabled devices only.

Mobile Millennium significantly increases the scale and scope of the work done by Mobile Century since it demonstrates the first real-time, permanent traffic monitoring system capable of using GPS data from thousands of mobile devices. The GPS data is further enriched with existing fixed traffic sensors such as inductive loop detectors embedded in the pavement, which in turn construct velocity fields and travel time estimates. While the previous experiment focused on traffic estimation on a single segment of highway, Mobile Millennium intends to develop traffic estimations on all major highways in and around the target area, as well as on major arterial roads with sufficient user penetration. Mobile Millennium attains the traffic data by providing a free downloadable software client (Figure 1), which users install on their cellular device that has GPS and Java capabilities.

With congestion on the rise, Mobile Millennium may have what it takes to tackle the issue without the need for extra infrastructure while maintaining user privacy. If Mobile Millennium cannot reduce congestion by a percentage outlined by a government, then maybe it can be adaptive to include congestion charging so that it meets the requirement. Congestion charging is already being used in the State of California and is under high evaluation in New York City (McGoldrick 2008). California has already implemented voluntary highway toll charging on SR-91 in Orange County and I-15 in San Diego. They have dedicated High Occupancy/Toll (HOT) lanes in both directions that create free flowing traffic and relatively dedicated commute times (Flamm 2005). However, the other lanes that are not HOT, still suffer from congestion. And there are discussions indicating that Caltrans is considering charging all highway lanes that suffer from major congestion (Hymon 2008). If that was the case, then major infrastructure costs need to be avoided and the system needs to be expandable so it can gradually be inclusive of all highways or whatever plans Caltrans has.

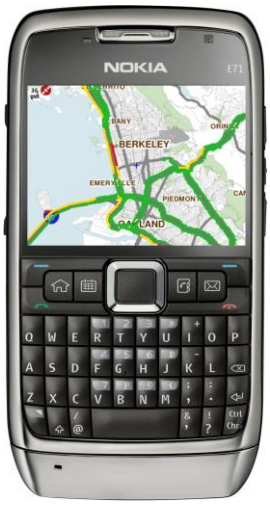

Figure 1 – The Mobile Millennium software client running on a Nokia E71. Colors convey traffic congestion on highways and major arterial roads. (http://traffic.berkeley.edu)

MOBILE MILLENNIUM AND CONGESTION

One of the goals of this project was to first consider whether Mobile Millennium with its current goals could meet the requirements of the Departments of Transportation (DOTs) to

reduce congestion. In London, the local government was able to reduce congestion by 14-16% using automatic number plate recognition (ANPR) and user declaration for congestion charging (Opiola 2008). Stockholm uses ANPR and dedicated short-range communications (DSRC) for its congestion charging and experienced a 20-25% decrease in congestion in the city (Opiola 2008). For example, Caltrans may require a 10-15% decrease in traffic congestion along certain highways and in select cities. According to the field tests conducted summer 2008 by our team, Mobile Millennium can attain 5-7% penetration based on current GPS-enabled cell phone policies of the time. With increased adoption of GPS-enabled cell phones, the penetration is guaranteed to increase as well and exceed the 10-15% outlined by Caltrans.

Proposed Field Test

In order to more fully determine whether Mobile Millennium can meet the requirement, traffic flow data of a certain time and area with all the vehicles running the Mobile Millennium software client needs to be compared to historic traffic flow data for that same time and area. A new field test that allows the drivers to make the route decisions and avoid congested areas using the Mobile Millennium software client will need to be conducted, unlike the summer 2008 Berkeley field tests that had the drivers on a predetermined route. A key to a successful field test is to prevent the voluntary drivers from knowing the ultimate goal of the test is to try to reduce congestion; and that they should just drive and use the client as normal. Each driver would be assigned the goal of going from a point “A” to a point “B” in the shortest amount of time within adherence of the law. To prevent the drivers from creating false congestion, they will be released into traffic in intervals. The drivers in the later intervals should see the congestion via the client and hopefully choose an alternate route to avoid the congestion and reach the destination first. The scale would have to be large in order to create realistic highway congestion. It can be somewhat scalable if arterial roads are used because the speed limit is relatively lower and there are fewer lanes, which would allow congestion to be created more easily than on a highway. If the software client is ready to, it will offer the alternative routes and the drivers can take those. From the data collected by the field test, the effectiveness of Mobile Millennium for reducing congestion can be determined. A field test is necessary since Mobile Millennium does not track users or record user driving habits. Hopefully, the field test will show a 10-15% reduction in congestion for a certain area, which will reciprocate to all other areas.

MOBILE MILLENNIUM AND CONGESTION CHARGING

Whether Mobile Millennium is able to reduce congestion enough or not is still probably not enough to avoid congestion charging since DOTs are interested in a way to create revenue for other transportation programs, i.e. San Francisco Bay Area Rapid Transit (BART) and the proposed California High-Speed Rail System. Of course, reducing traffic congestion and vehicle emissions are pros. To do this successfully, Mobile Millennium must maintain user privacy, but still be able to identify that each user is charged the correct amount. Based on the Virtual Trip Line (VTL) technology, personal identification and location are kept separate,

so the key is to figure out how to keep those crucial pieces of data separate while accurately charging the correct user (Hoh 2008).

Either the Mobile Millennium system can be adapted to include calculating congestion charging; or it can be integrated with another system that will utilize the GPS capabilities of the cell phone, while Mobile Millennium is still transmitting real-time traffic data. A research trip to Finland, where several case studies of different proposed congestion pricing systems were analyzed, helped to increase the reality of Mobile Millennium as a viable option for congestion pricing.

Oregon pilot and the Swiss LSVA

A case study of an Oregon pilot and the Swiss LSVA (nation-wide distance-related fee) discussed by Hamilton (2008) is an example of Mobile Millennium pairing with another concept. The Mobile Millennium client would know when a new toll band was entered because of VTLs set up to mark spatial tolls. The VTLs are used to verify what road type the driver drove on since different road types can "cost" different amounts. For example, a highway may cost 1.5 times more than an arterial or secondary highway road. It can determine if you have entered a residential area and not charge the driver or even track them after a certain point. The software client can add features, such as a GPS odometer, to keep the wheel spin odometer readings in check or vice versa. In order for the odometer readings to communicate, a device such as Microsoft Sync in the car could assist in this. The reporting and billing can be the same as discussed by Hamilton (2008). When the car fills up at the petrol station, those readings can be communicated to the pump and the fuel tax is deducted. By using VTL technology, privacy of the user is maintained and the system will prevent certain areas from being charged, such as residential or private roads.

Digital Short Range Communications (DSRC) and Cellular Network/Global Navigation Satellite System (CN/GNSS)

Kersten's (2008) proposal addresses the main concern of road user pricing all road types. However, Mobile Millennium would deal with congestion pricing, but Kersten's addition of DSRC to a system like Mobile Millennium should be addressed. In order to establish a hybrid system, infrastructure would have to be built, and in a large country like the United States, that would not be cost effective. Also, the DSRC would have to be maintained, which continues to add to the cost. The Mobile Millennium system is already reinforced with other data sources for determining congestion time periods and areas that adding DSRC will not be advantageous. This hybrid concept requires the use of DSRC, which means more infrastructure and maintenance costs, and we are trying to avoid that.

Map matching Geographic Information System (GIS)

Aigong (2008) uses map matching geographic information system (GIS) data that is similarly based on Navteq data that the Mobile Millennium map system is based on. But, what if

instead of basing the charge on a link-by-link basis, the charge is based on a new type of link that is depicted by the road distance between two VTLs. This would be similar to when a user is charged after crossing a VTL into a congestion charge zone. Only this time, the "link" charges are additive and the user will be charged the summation of all the "links" he/she drove on.

Unique Cell Point Identification (UCPI)

A similar technology to VTLs is addressed in Mileros' (2008) article called Unique Cell Point Identification (UCPI) and also uses GPS and Global System for Mobile communications (GSM). It has shares many of the same benefits that a congestion pricing Mobile Millennium system offers. It is also able to determine a charge based on distance or by time spent in an area. However, its accuracy and intent of privacy is questionable because Mileros never addressed them.

VPriv

VPriv (Popa 2009) is a concept that focuses on protecting user privacy when it comes to the specific application of location based services and vehicles. A perfect application for this system is to use it in congestion charging. In the article, it mentions how the VTL technology in Hoh's (2008) paper can actually be used for congestion charging purposes. Even though the VTL system assumes the user and server are good and will not deviate from their protocols, it can possibly be set up as a road charging method.

Mobile Millennium system architecture

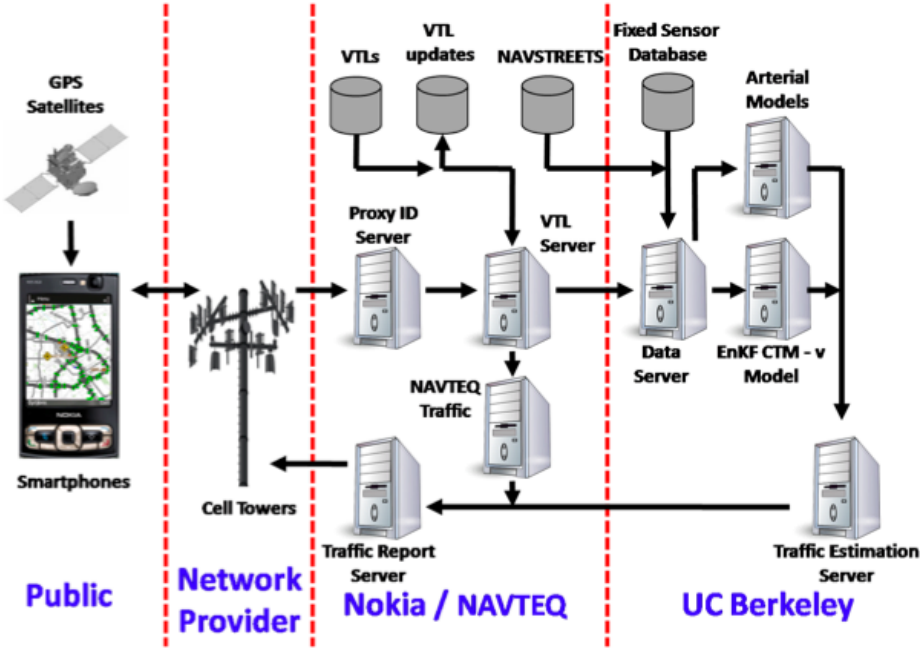

Figure 2 – Current Mobile Millennium system architecture.

From the case studies, there are many different routes the Mobile Millennium project can take in order to include a congestion pricing system. Figure 3 is an example in which the actual system architecture is analyzed to accompany the congestion pricing. Different VTL and VTL update databases would be established with fewer VTL entries compared to those used for the traffic analysis because the pricing VTLs would be minimally placed just enough to determine if the driver traversed a congested road section. The information as to what road sections were traversed and when would be sent to the pricing model for the charge to be calculated. Once the price is calculated, it is sent to the specific user's account.

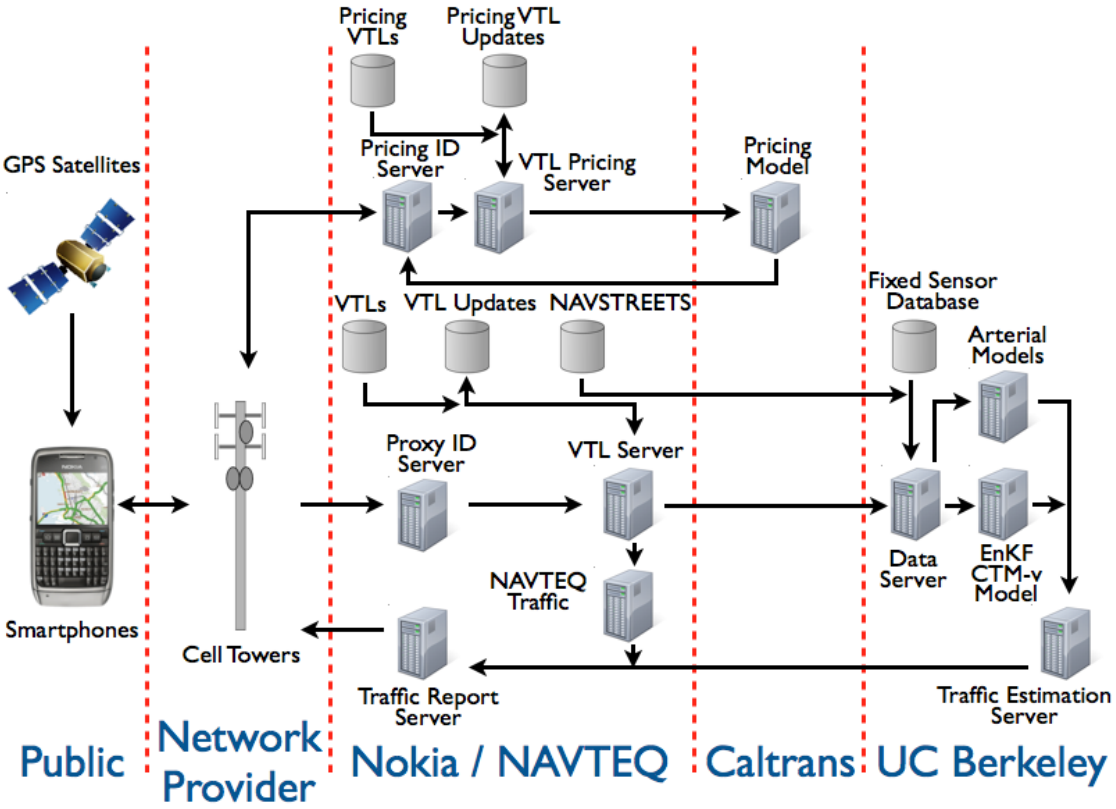

Figure 3 – Example of Mobile Millennium system architecture with congestion pricing

COSTS AND PROBLEMS

There are over 23 million licensed drivers in the State of California as reported by the US DOT (2008). The worst-case scenario in which every licensed driver is on California roads running the Mobile Millennium client that transmits two successive GPS readings every 3 seconds will create a lot of data traffic for the cellular network towers. Actually, it is too much data for the current state of cellular networks in California or any other region in the world. Either Caltrans or other DOTs will have to make it mandatory for the cellular network providers to update their towers, or the DOTs can help subsidize the update process.

A problem that Mobile Millennium and other Global Navigation Satellite Systems (GNSS/GPS) technologies need to face is that they have difficulties with data retrieval in urban canyon settings and when the weather is not good. To overcome this type of pitfall,

Grush (2008) discuses a new GPS signal processing methodology that manages signal errors, residual positioning errors, and spatial pricing conflicts. This article also addresses congestion charging and interoperability between different technologies and systems, which is a major concern in the European Union. It also tackles the issue of user privacy much like Mobile Millennium does by keeping certain data separate and utilizing encryption techniques.

CONCLUSION

Caltrans and other DOTs will eventually want to incorporate congestion charging on a much larger scale than what is currently being implemented. Their intentions will not be solely based on reducing traffic congestion or vehicle emissions, but will also be based on interest in gaining revenues for departmental projects and other government departments. If that is the case, then Mobile Millennium then needs to consider whether it will try to stand-alone and change some of its VTL protocols to include a charging service. Or will it decide to partner with another concept to make the shift to congestion charging more viable. When Mobile Millennium offers alternative routes, it will make it easier for commuters to choose a route to take. The Mobile Millennium system is the best choice for congestion pricing because of the little infrastructure costs, maintained user privacy, and applicability to most regions.

ACKNOWLEDGEMENTS

The author wishes to thank Alexandre Bayen, Ryan Herring, and Steve Andrews at the California Center of Innovative Transportation; and Pekka Leviäkangas, Raine Hautala, and Heidi Auvinen at VTT Technical Research Centre of Finland for their comments and direction, which shaped this paper in a number of ways. This research was supported by Caltrans, the Finnish Funding Agency for Technology and Innovation (Tekes), and Nokia.

REFERENCES

Aigong, X. (2008). Investigation on Road Pricing with GPS and GIS. *Proceedings of the 15th World Congress on ITS and ITS America's 2008 Annual Meeting*. New York, USA.

Flamm, B. and G. Rosston (2005). Traffic Congestion, Congestion Pricing, and the Price of Using California's Freeways. Policy Brief: Stanford Institute for Economic Policy. Palo Alto, USA.

Grush, B. (2008). GNSS 'Superoperability' Changes the Incumbent Tolling Landscape. *Proceedings of the 15th World Congress on ITS and ITS America's 2008 Annual Meeting*. New York, USA.

Hamilton, C. J. (2008). A Proposed Architecture for Protecting Driver Privacy When Implementing Distance Based Road User Charging in Europe. *Proceedings of the 15th World Congress on ITS and ITS America's 2008 Annual Meeting*. New York, USA.

Hoh B., M. Gruteser, R. Herring, J. Ban, D. Work, J.-C. Herrera, A. Bayen, M. Annavaram and Q. Jacobson (2008). Virtual Trip Lines for Distributed Privacy-Preserving Traffic Monitoring. Mobisys.

Hymon, S. (2008). Congestion pricing is a tough sell. In: *Los Angeles Times* (14 April), viewed 3 August 2009, <http://articles.latimes.com/2008/apr/14/local/me-roadsage14>.

Kersten, J. (2008). The Thin Client Approach – A CN/GNSS Based Road Charging Solution Ready for the Future! *Proceedings of the 7th European Congress and Exhibition on ITS*. Geneva, Switzerland.

McGoldrick, J. (2008). Paying the price for congestion. In: *San Francisco Chronicle* (5 March), viewed 3 August 2009, <http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2008/03/05/EDENVAJ7S.DTL>.

Mileros, M. D., D. Gundlegård, J. Karlsson and A. Fürdös (2008). Autonomous Cellular Road User Charging Based on Unique Cell Point Identification. *Proceedings of the 15th World Congress on ITS and ITS America's 2008 Annual Meeting*. New York, USA.

Opiola, J. and M. Dorfman (2008). Four Generations of Congestion Charging. *Proceedings of the 15th World Congress on ITS and ITS America's 2008 Annual Meeting*. New York, USA.

Popa, R. A., H. Balakrishnan and A.J. Blumberg (2009). VPriv: Protecting Privacy in Location-Based Vehicular Services. *Proceedings of the18th Usenix Security Symposium*. Montreal, Canada.

Work, D., O.-P. Tossavainen, S. Blandin, A. Bayen, T. Iwuchukwu and K. Tracton (2008). An ensemble Kalman filtering approach to highway traffic estimation using GPS enabled mobile devices. *Proceedings of the 47th IEEE Conference on Decision and Control*, pp. 2141-2147. Cancun, Mexico.

U.S. Department of Transportation (2008). Federal Highway Administration. Highway Statistics 2007. Washington, DC.