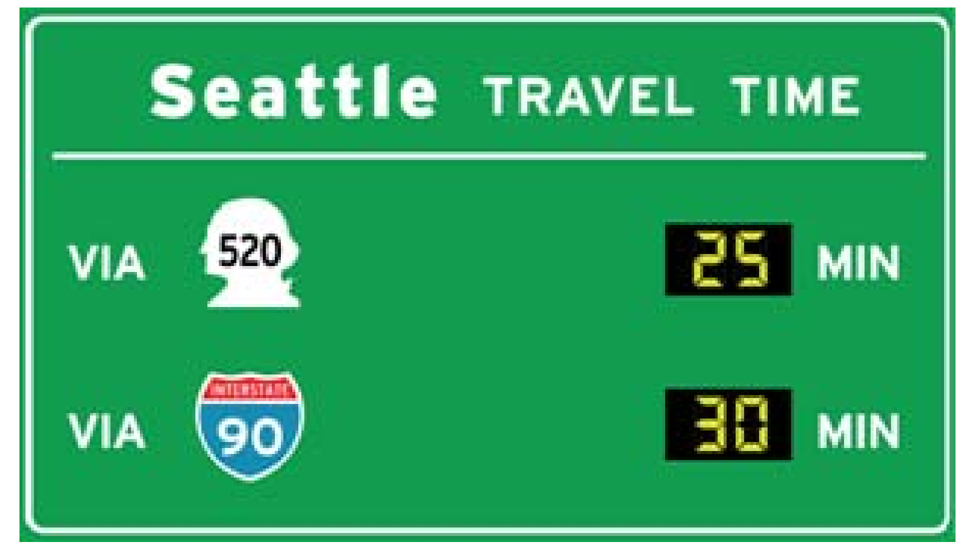
Research Note

Travel Time Data Obtained from Bluetooth Technology

From the WSDOT Research Office
December 2011



WSDOT Travel Information

Introduction

Roadway users easily understand travel time, and consider it one of the most important transportation metrics. Users often get travel time directly through dynamic message signs (DMS), 511 phone services, and online systems that allow individuals to make route choices. A new methodology for obtaining travel time measurements, Media Access Control (MAC) address matching, is generating great interest. The growing popularity of mobile devices, combined with the wireless communications used to connect these devices to each other and the Internet, allowed researchers to develop a MAC address-based tracking method. This method relies on recording the MAC addresses of bypassing devices at one location and noting the time difference between matching MAC addresses at a different location. This approach experienced increasing popularity because of its significantly lower overall costs, ease of deployment, and fewer privacy concerns compared to traditional methods. The lower costs relate primarily to the lower cost of the Bluetooth reader, and that the MAC address collection device spans multiple lanes. This provides a significant advantage compared to Automatic License Plate Recognition (ALPR) systems that require lane-based detection to determine travel times. Additionally, Bluetooth-based travel time data collection systems are easy to install and do not require high bandwidth for communications. Compared to Global Positioning Systems (GPS), the MAC address-based systems do not require willing volunteers with vehicles equipped to provide constantly recorded GPS coordinates. Instead, all surrounding devices get free broadcast of the MAC address. Users not wishing to disclose their location can simply turn off the broadcast function on their MAC devices.

Although the MAC address-based collection techniques have significant advantages, there are some drawbacks to their use. Relatively small sample size is an issue for some purposes; most studies using MAC addressing match between 5 and 10 percent of the total vehicle volume. An additional and perhaps more serious issue is the ambiguity of accuracy due to the inherent properties of the MAC address broadcast protocols. The uncertainty

Washington State Department of Transportation

collection system, especially if the chosen corridor has a short travel time. The travel time data collected with Bluetooth sensors along the 0.98-mile-long corridor tested in this study for sensor configurations, produced average errors of between 2.4 and 11.4 seconds (4 to 13 percent). The absolute errors were generally determined by sensor configurations and surrounding conditions and may not change with the length of a corridor. This suggests that the relative errors will decrease if corridor travel times increase, meaning that longer corridors will tend to allow a better performance by the Bluetooth-based data collection systems.

Implementation

The findings of this study will be helpful to transportation professionals attempting to understand the errors associated with the Bluetooth-based travel time data collection technology and to configure the sensors to mitigate errors. The research has and will continue to benefit WSDOT and others in the following ways:

1. Bluetooth / MAC address matching is a viable, cost effective way to capture travel time data in both urban and rural environments. Understanding the issues associated with manufacturing and deploying a device in both these settings was a critical component of this research.
2. The research provided technical insight that was valuable in evaluating and successfully procuring a commercially available Bluetooth product that is or will be deployed along three corridors.
    a. The deployment along SR 522 around Lake Washington will be used to measure traffic diversion as a result of SR 520 tolling.
    b. The deployment along SR 395 in the Tri-Cities is being used for travel times on a signalized corridor.
    c. The pending deployment over the I-90 Snoqualmie Pass will be used to monitor third party data for use in future planning and decision making.
3. The research has been shared with multiple agencies through technical forums such as the Western States Rural Transportation Consortium, ITS Washington, the National Rural ITS Conference, and the Transportation Research Board (TRB).

Contact Information

Report Title and Number
Error Modeling and Analysis for Travel Time Data Obtained from Bluetooth MAC Address Matching
WA-RD 782.1

www.wsdot.wa.gov/research/reports/fullreports/782.1.pdf

Researchers
Yinhai Wang, Ph.D.
Professor
Department of Civil & Environmental Engineering
University of Washington
Seattle, WA 98195-2700
206-616-2696
yinhai@u.washington.edu

Yegor Malinovskiy
Graduate Research Assistant
Department of Civil & Environmental Engineering
University of Washington
Seattle, WA 98195-2700
206-734-1352
yegorm@u.washington.edu

Un Kun Lee, Ph.D.
Visiting Professor
Busan Kyungsang College
Busan, Korea
ulee@u.washington.edu

Yao Jan Wu, Ph.D.
Assistant Professor
Parks College of Engineering, Aviation and Technology
Saint Louis University
314-977-8249
yao@slu.edu

Technical Monitor
Ted Bailey
Traffic Signals, Illumination & ITS Engineer
Traffic Design and Operations
Washington State Department of Transportation
360-705-7286
baileyt@wsdot.wa.gov

Research Manager
Doug Brodin
Office of Research and Library Services
Washington State Department of Transportation
360-705-7942
brodind@wsdot.wa.gov

Funding

$100,000	WSDOT Federal
25,000	WSDOT State
81,000	TransNow Federal

12-01-1088

about the accuracy of the Bluetooth protocol for travel time measurement comes from its characteristic random frequency hopping. The constantly changing frequency mandated by the Bluetooth protocol could delay the device connection time by up to 10.24 seconds. The variety of ranges a receiving Bluetooth sensor device may have exacerbates the “connection time” complication. Devices mounted in tandem could provide better results by increasing the detection range and decreasing detection time. The transportation research community has not investigated the accuracy issues that arise in using MAC address-based travel time measurements.

Obtaining travel time measurements with Bluetooth devices involves matching an observed MAC address between at least two locations. The difference in time between the two observations is the travel time. Because the Bluetooth readers are capable of detecting MAC addresses within a specific range, the travel times obtained can be thought of as zone to zone rather than point to point as a Bluetooth reader’s detection range is much larger than the ALPR window of video-based detection. This is illustrated in Figure 1, where the dashed lines represent Bluetooth detection zones and the squares represent ALPR detection “points.” A vehicle’s MAC address may be detected multiple times by the Bluetooth sensor, so it is imperative that the convention is consistent, either matching first detection to first detection or last detection to last detection, to mitigate detection errors.

Our process

This study investigated the Bluetooth travel time errors inherent to the collection technique. To analyze Bluetooth travel time error, researchers used ALPR-collected travel times as benchmarks. Relative to the large detection zone of a Bluetooth device, an ALPR has a very small detection window. This window results in a small travel time error, particularly at higher speeds. Therefore, ALPR-collected travel times were chosen to serve as ground-truth data in this study. After travel times were calculated, the absolute travel time error for each period was calculated. The researchers used the absolute travel time error to compare a variety of Bluetooth sensor configurations to determine which was most accurate in comparison to the ALPR sensors mounted at the same location. The short length of the corridor studied greatly exacerbated any detection errors relative to the total travel time, and this procedure ensured that the errors were significant and their determination relevant.

This study developed a complete MAC address detection system, called MACAD, shown in Figure 2. It is capable of reading MAC addresses and matching them for travel time data collection. The MACAD system is a highly mobile, affordable, and energy efficient solution to MAC address data collection needs. It can be easily deployed anywhere because it does not require a power source or wired communication infrastructure at the installation site. It has a GPS module to locate itself, a Global System for Mobile Communications (GSM) model to communicate with the data server for MAC address data processing and matching, and a solar power module for charging its batteries. The design does not require expensive parts, and therefore, the unit cost is much lower than the ALPR devices.

Figure 1: Segment composition

Figure 2: STAR Lab MACAD device

A) Mounted device

B) Device interior

A customized computer program is used to process both ALPR and Bluetooth MAC address data. A screen shot of the software is shown in Figure 3. The software system is capable of processing the data manually, using two or more ALPR text files for matching (obtained from the MicroSD cards mounted in the MACAD devices), or doing it automatically, using data sent to the server via GSM communications.

Figure 3: STAR Lab MAC address processing software screenshot

Researchers conducted four experiments to verify the effectiveness and reliability of the MACAD system for travel time data collection. Three of the test corridors were equipped with ALPR sensors. The researchers compared the travel time data obtained from the two sensor systems. Researchers tested variations of antenna type (directional and omni-directional), antenna strength (7 dBi, 9 dBi and 12 dBi) and sensor configuration (tandem sensors vs. single sensor set-ups) to determine the optimal configuration and obtain the lowest error.

Results

Upon conducting numerous tests with a variety of sensor configurations and then verifying the data obtained with ALPR data, we found that Bluetooth sensors were an adequate surrogate for ALPR sensors at our test locations, with detection errors ranging from 4.0 percent to 9.4 percent for the MACAD system test on SR 520. While the sample size obtained (typically 4 percent to 10 percent) was significantly smaller than what can be achieved with ALPR systems, it was still representative of the actual conditions.

We found that although it may be tempting to reduce the detection area in order to reduce the spatial error, doing so dropped the matching rate dramatically. In the experiments conducted, configurations that used just one detector per site (thus significantly reducing the detection zone size) had less than half the matching rate of configurations that used two detectors per site, regardless of antenna choice. Of all the configurations attempted, combinations of omni-directional antennae with the largest detection zones provided the best results, with a low absolute error and high matching rates. Combination configurations had an average matching rate of 7.92 percent and a detection rate of 15.35 percent. In comparison, single-sensor (at each location) configurations had a matching rate of 3.43 percent and a detection rate of 9.37 percent. The matching rates were shown to be statistically significant in reducing error.

Across all configurations, the reported Bluetooth travel time was 8.0 percent higher than the actual travel times reported by the ALPR sensors. All error rates encountered were well within FHWA’s recommended levels. Lower overall errors could be obtained by using a more discerning filtering algorithm and/or better sensor configurations. Among the eleven sensor configurations tested in this study, the least error prone configurations reported travel times that were, on average, 4 to 7 percent above the ALPR average travel time.

What the researchers recommend

Based on experimental results and lessons learned in this study, the researchers make the following recommendations for future studies of Bluetooth-base travel time collection:

First, Bluetooth-based MAC address matching can be an effective, low cost means for travel time data collection. Bluetooth-based travel times are sufficiently accurate for most transportation applications. However, because slower vehicles have a better chance to be detected by Bluetooth readers, the Bluetooth-based protocol may contribute to slightly overestimated travel times.

Second, extraneous delay sources such as traffic signals and nearby bus stops may worsen the overestimation and efforts are needed to mount and configure the MACAD systems in ways that will avoid such undesirable factors.

Third, a method for correcting the travel time bias caused by the Bluetooth protocol is highly desirable and should be developed in future studies.

Fourth, combinations of sensors working in tandem help reduce error in most cases. Tandem set-ups greatly increase the accuracy of the detection and matching rates, which is important for time-critical applications such as real-time travel information.

Finally, sensor configuration can significantly affect the performance of the Bluetooth-based travel-time