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An Analysis of the Detection Probability of MAC Address from a Moving Bluetooth Device

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Abstract

Traffic monitoring using Bluetooth MAC addresses has been intensively studied for a decade. Nevertheless, estimation of Origin-Destination volume is still challenging, because of the unstable nature of the detection. With the aim to reveal the factors affecting the detection probability of MAC addresses from moving Bluetooth device, this study conducted a series of driving tests to collect detection samples under various scenarios. The data was then utilised to develop a Logistic Regression Model to estimate detection probability considering the installation positions of the scanner and the driving speed of the experiment car. The results agreed on the contribution of distance and angle between the scanner and the car, as well as the car speed, as reported in preceding studies. This study further identified the contribution of driving direction, and height and timeout duration of the scanner. The proposed model successfully estimated the detection probability with reasonable accuracy.

Keywords: Bluetooth; MAC Address Scanner; Detection Probability; Logistic Regression Model

1. Introduction

Effective traffic management requires understanding traffic performance and travel demand. To gain such knowledge, road authorities have been collecting traffic data from various sources, ranging from conventional vehicle detectors to recent Bluetooth Media Access Control (MAC) address scanners. The scanners capture anonymous, electric identifiers, the MAC addresses, from Bluetooth-enabled devices that pass within the scanning zone. Because the MAC address is unique to each device, the records from time-synchronised scanners give the direct observation of the movements of active Bluetooth devices over the road network. Assuming the devices are transported by vehicles, the data is then utilised to retrieve valuable traffic data, including travel time and vehicle paths, which has been challenging to gain from traditional vehicle detectors. Since the Bluetooth communication has become widespread in many on-board devices, such as headsets, car navigation systems and smartphones, increasing number of literatures have reported on the use of Bluetooth data as a complementary traffic data source.

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One of the promising applications of the Bluetooth data is traffic volume estimation between origin and destination (OD) pairs. Tracking MAC addresses among multiple scanners within a road network provides the sample (Bluetooth) OD volume, which is then expanded to full traffic volume by applying appropriate expansion factors. The use of Bluetooth MAC addresses for OD volume estimation has attempted researchers (Barceló et al., 2010; Blog et al., 2010). They demonstrated that the Bluetooth data is able to effectively capture OD pattern, how traffic moves across the network. However, the volume estimation proved difficult using the Bluetooth data.

One of the impeding factors for the reliable OD volume estimation using Bluetooth data is the unstable nature of the detection by the scanner. The OD volume estimation from sample data requires expanding the sample volume by applying the inverse of penetration rate X – the ratio of sample counts n to the full traffic N ($X = n/N$). Note that the sample counts n are the number of the samples with the active Bluetooth devices, but in reality, the scanner may fail communication, and it only provides the captured sample counts $n_{\%} = p \cdot n$, where p is the detection probability. The measured penetration rate is, therefore, not the true penetration rate, but the capturing rate ($X_{\%} = n_{\%}/N$). If the etection probability is high ($p \approx 1$), the capturing rate can be approximated to the penetration rate. However, n case of the Bluetooth scanner, missed detections may occur even when the Bluetooth device is nearby the scanner. An indoor experiment revealed that the detection probability of a Bluetooth scanner could be 0.7, and it fluctuated depending on the position of the scanner (Kitazawa et al., 2014). In fact, a field observation by two Bluetooth scanners along a basic motorway section found the cases when a device was detected by the upstream scanner but was missed by the downstream one (and vice versa), evidencing the fact that a device discoverable by a scanner may not be found by others (Wang et al., 2011). Another field observation further supported that the detection probability was affected by installation position of the scanner and the distance from the Bluetooth device (Odaka et al., 2015).

Aiming to identify the factors influential to the detection probability in a controlled environment, Nishiuchi et al. (2015) conducted a series of detection tests using a Bluetooth scanner developed by Kitazawa et al. (Kitazawa et al., 2014). They tried two main factors: angle and distance between the scanner and the stationary Bluetooth device, and concluded that the Bluetooth devices was more likely captured when the scanner and the device make some angle. The findings, however, needs further validation tests using moving Bluetooth devices.

This research aims to reveal the factors that affect detection probability of on-board Bluetooth device by conducting a series of driving tests. The rest of this paper is structured as follows. Section 2 is devoted to a literature review to identify the factors examined in this study before detailing the driving test in Section 3. The detection probability is modelled in the Section 4, and Section 5 presents the factors significantly affecting the detection probability along with the model validation. Finally, the paper is concluded with the discussion on the findings and future research needs.

2. Literature Review

The unstable nature of Bluetooth detection has been concerned by researchers (Barceló et al., 2010; Blogg et al., 2010), but field evidence in the context of traffic monitoring has been limited. One of the first observations was reported by Odaka et al. (2015). They installed the scanners (Kitazawa et al., 2014) at seven intersections along a circular arterial in Matsuyama City, Japan, to collect the Bluetooth MAC address. The capturing rate varies in different locations, ranging from 2.7% to 6.0%. The rate is particularly low, around 2% on average, at eight-lane sections (four lanes per direction), whereas the rate is higher in four-lane sections (two lanes per direction). The results suggested that the distance between the scanners and the vehicles (or the number of lanes) and the installation position of the scanners (e.g., height and angle) might have influenced the capturing rate.

The findings by Odaka et al. (2015) was later supported in an experimental environment. Nishiuchi et al. (2015) performed a thorough experiment to unveil the relationships between the installation position of the Bluetooth scanner (Kitazawa et al., 2014) and the detection probability of MAC addresses from stationary devices. The study identified key characteristics of the scanner: the directivity of the detection and the scanning coverage. The detection probability was the highest when the angle between the scanner and the Bluetooth device was 45%. The coverage varied depending on the device locations, but the scanner could capture 50% of signals when the device was within 60m radius from the scanner.

Detection probability is also affected by the transportation mode of Bluetooth devices. Abedi et al. (2015) monitored the Bluetooth MAC addresses from moving devices carried by pedestrians and bicycles. Commercial scanners were installed on a pedestrian bridge in Brisbane, Australia. The scanner coverage is defined by the antenna's gain; the observe can change the coverage by replacing the antenna. The study examined the difference in capturing rate in relation to the scanner coverage and the speed of the device, carried by either walkers, runners or cyclists. They recommended that wider coverage was preferred to capture the fast-moving devices (carried by cyclists), whereas enough samples were collected from walkers even when the coverage was small. The results suggest that the speed of the transportation may affect the detection rate.