Effectiveness of Bluetooth and Wi-Fi re-identification

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Executive Summary

This memo conveys the results of early experience with Wi-Fi re-identification technology compared to Bluetooth-based systems for purposes of travel time and origin-destination assessment, and provides recommendations for dual use moving forward. Bluetooth re-identification technology has been tested and accepted in the highway industry since 2008 when Bluetooth traffic monitoring technology (BTM) was introduced. Within North America, BTM captures are approximately 3 to 5% of through traffic, generating a travel time sample proportional to through traffic volume. This percentage, called the matched pair rate, is the number of vehicles identified at both an upstream and downstream sensor station compared to the total number of vehicle that traversed the segment. The proliferation of Wi-Fi in smart phones has provided additional opportunities for sampling travel time using re-identification techniques. Early deployment of Wi-Fi based systems along with BTM indicates that the Wi-Fi matched-pair rate is 1 to 4 times that of BTM depending on the environment. The speed of the prevailing traffic is the factor that most greatly influences the matched pair rate. Some industry reports claims of 10 times or more detections by Wi-Fi over BTM. This claim refers to the number of Wi-Fi detections at a single station, and NOT the matched pair rate. Due to the proliferation of Wi-Fi enabled devices (laptops, cellphones, computers, networking equipment, etc) the large number of detections at a single station is not unexpected. However, a large portion of these detections are not in the traffic stream, but rather are static background noise. Detections must be paired between an upstream or downstream sensor to yield useful traffic data. The matched-pair rate provides a direct comparison of useful data captured. The communication protocol used in Wi-Fi for device identification differs significantly from that used in BTM, resulting in different characteristics between the two data sets. As a general rule, a travel time estimate from a Wi-Fi matched pair is typically less accurate (on average) than one derived from BTM due to inherent differences in the frequency with which the devices emit identification signals. Also, the matched pair detection rate from Wi-Fi is variable depending largely on the speed of the prevailing traffic, whereas the detection rate from BTM is stable and consistently proportional to through traffic volume.

As a result of the knowledge gained from early deployments, Traffax recommends the dual deployment of both BTM and Wi-Fi re-identification technology. The abundance of Wi-Fi signals boosts the matched-pair rate allowing for use of re-identification technology at even lower traffic volumes. The consistency of Bluetooth detection allows for more predictable detection and better estimates of through volume. When combining BTM with Wi-Fi travel times, BTM travel time samples should be weighted slightly higher.

Details of Data Collection

Data from six sensors with both Bluetooth and Wi-Fi detection were deployed simultaneously over several days. The number of unique detections recorded by each device is shown in Table 1. The Wi-Fi detections are more numerous than that of Bluetooth, and the ratio varied at each detector. This ratio of Wi-Fi to Bluetooth detections at the sensors varied from a low of 6.1 to a high of 19.8. This is not the matched-rate rate, but rather the raw detections at each sensor.

Table 1 – Station detection at five sensor stations

Detector	BTM	WiFi	Total	WIFI Multiplier
A	4376	28265	32641	6.5
B	2307	42226	44533	18.3
C	1345	8218	9563	6.1
D	1035	20542	21577	19.8
E	2006	13254	15260	6.6

In contrast, the number of matched pairs resulting from the data in Table 1 is shown in Table 2 for all combinations of sensor pairing. The ratio of matched pairs per segment for Wi-Fi over BTM ranged from 0.8 to 3.9, with an average of 1.6. On average, Wi-Fi provides approximately 60% more matched-pairs than BTM. Whereas BTM matched pairs are known to be proportional to traffic, the matched pair rate for Wi-Fi varies significantly.

Table 2 – Matched Pair Results

BTM Matched Pairs	END STATION				
BEGIN STATION	A	B	C	D	E
A		540	588	387	762
B	571		151	122	238
C	557	138		355	111
D	346	105	350		75
E	766	229	133	106	

WiFi Matched Pairs	END STATION				
BEGIN STATION	A	B	C	D	E
A		2128	444	481	1273
B	2076		221	347	409
C	541	205		339	125
D	441	221	333		70
E	1369	440	113	112	

WiFi/BTM	END STATION				
BEGIN STATION	A	B	C	D	E
A		3.9	0.8	1.2	1.7
B	3.6		1.5	2.8	1.7
C	1.0	1.5		1.0	1.1
D	1.3	2.1	1.0		0.9
E	1.8	1.9	0.8	1.1	

Other research [Fontaine] identified that Wi-Fi detection probability is mainly impacted by traffic speed. In a controlled bench study, the mean time between Wi-Fi signal bursts which provide the opportunity to detect the Wi-Fi device ranged from 19.3 to 67.3 seconds. For a vehicle with a Wi-Fi device to be detected, it must occupy the sensor detection zone during one of these bursts. Although detection zones can vary by the gain of the antenna, a nominal 100m (~300 feet) detection radius provides 200 linear meters (~600 feet) along a straight roadway for a vehicle to be in the detection zone of the sensor. At highway speeds of 60 mph (88 feet per second), the vehicle will be in the detection zone for slightly less than 7 seconds. For the vehicle to create a matched pair, it must burst information within the detection zone at both the upstream and downstream sensors. If the speed of the traffic were 30 mph, the vehicle would be in the detection zone for 13.7 seconds, increasingly its likelihood for detection at both the upstream and downstream sensor. Thus, as the speed of the traffic increases, the matched-pair rate of Wi-Fi decreases.

Also, as a result of the interaction of the Wi-Fi burst frequency and the sensor detection range, the probably of multiple detections is low, such that the time uncertainty in a Wi-Fi detection is roughly equivalent to half the travel time through the detection zone. For speeds between 30 to 60 mph, this uncertainty is 3.4 to 6.8 seconds based on a 600 feet detection zone. At speeds slower than 30 mph, the probability of multiple detections of single device becomes significant such that the time uncertainty remains on par with that of the 30 to 60 mph range. Bluetooth detection time uncertainty is not linked to a burst rate, but rather the sampling periodicity of the sensors, geometry, and other factors, which tests have shown to be on the order of 1 to 2 seconds.

Recommendations

Although not an exhaustive study, these results indicate a significant benefit of combined Bluetooth and Wi-Fi re-identification sensors, and this is in agreement with other studies. Wi-Fi has a high natural occurrence of devices, both inside and outside of vehicles. This will result is in significantly more detections at each individual sensor, which in turn increases required bandwidth to the sensor. The matched-pair rate with Wi-Fi was found to be on average 60% greater than BTM in tests. However, the matched-pair rate is highly dependent on nominal speed of the traffic. At highway speed it will be less, on slower speed facilities it was as high as 4 times that of BTM. Use of Wi-Fi at signalized intersections, where vehicles will travel slower as well as queue in the detection zone, will have the highest impact to increase matched-rate sampling size. The accuracy of Bluetooth and Wi-Fi travel time samples are roughly the same order of magnitude, though BTM data should be weighted more in fusion algorithms due to less uncertainty in time of detection at the sensor. Wi-Fi is not recommended for origin-destination studies due to largely varying matched pair rates. Consistent match-pair rates that are proportional to traffic volume and do not vary with speed are needed for accurate OD results.