# FEASIBILITY STUDY AND ASSESSMENT OF COMMUNICATIONS APPROACHES FOR REAL-TIME TRAFFIC SIGNAL APPLICATIONS

# Introduction

Connected vehicle (CV) technology is expected to significantly improve transportation systems due to the mobility, safety, and environmental benefits gained from connectivity between different vehicles and with infrastructure. Enabled by wireless communications, connectivity to real-time traffic signal data is a key component of CV applications. Latency in wireless communications is defined as the amount of time taken for a transmitted packet to reach a receiver (analogous to delay). This study analyzed the latency differences between two communications approaches—dedicated short-range communications (DSRC) and cellular (3rd Generation Partnership Project 4G/long-term evolution [LTE])—to assess the feasibility of using these methods for various connected and automated vehicle (CAV) applications.

## Objective

The goal of this project was to collect and analyze communications attributes (i.e., latency and coverage) of signal phase and timing (SPaT) data using DSRC and the cellular network and assess the feasibility of these communications approaches in supporting different types of applications (safety, mobility, environmental, etc.) that use SPaT data from infrastructure systems.

The primary outcomes of this project include:

- Characterization (including latency and coverage) of real-time traffic signal data transmitted through DSRC and through the cellular network
- Assessment of the feasibility of those data feeds to support various CAV applications
- Dissemination of process and results to other agencies considering real-time traffic signal data distribution.

### Approach

Operated by the Virginia Department of Transportation (VDOT) and Virginia Tech Transportation Institute (VTTI), the Virginia Connected Corridor (VCC) served as the testbed for this study. The VCC is a cluster of more than 60 intersections in northern Virginia that are equipped with roadside units (RSUs). These RSUs provide SPaT data to end users via DSRC and cellular technology to support the early deployment of CV applications.

While the ultimate source of the subject data is the traffic signal controller (TSC), the data sent from the controller are received, repackaged, and retransmitted by several systems before making it to the end user, providing several opportunities for data collection throughout the system. Figure 1 shows the test setup based on different data points where, if applicable, data measurements could be performed.

The study collected data at three points:

- C: SPaT messages broadcasted from the RSU antenna interface via DSRC.
- H: SPaT messages received on the onboard unit (OBU) via DSRC.
- G: SPaT messages received on the laptop via the VCC Cloud (cellular networks)

Two data delivery paths were explored:

- ▶ Cellular **C** RSU  $\rightarrow$  VCC Cloud  $\rightarrow$  **G** Laptop
- ▶ DSRC C RSU  $\rightarrow$  H OBU.



Source: FHWA. SPAN = switched port analyzer.

The DSRC network broadcasts SPaT locally in the 5.9 GHz spectrum band. SPaT messages are generated at the RSU after receiving National Transportation Communications for Intelligent Transportation Systems Protocol (NTCIP) 1202 messages (AASHTO 2018) from the TSC. The flow of messages begins at the TSC and includes local network switches, the RSU, and an OBU in the vehicle. In comparison, the cellular LTE network includes, in general, base stations, the evolved packet core (EPC) network, and end-user devices, along with a series of network switches and routers that route the packets to their destination. The flow of messages starts at the TSC, from which the messages are routed to the VCC Cloud using a high-speed connection and subsequently to the laptop through different cellular network components.

### Data Types

Various intelligent transportation system (ITS) components generate data in different formats. These data are subsequently processed and converted into a standardized format based on the communications methods implemented. The Society of Automotive Engineers (SAE) J2735 standard defines the SPaT message, which contains much of the information of interest for this project, and the basic safety message (BSM):

The SPaT message conveys the status of the signalized intersection by indicating the current state of signals (i.e., the current movement state of each active phase in the system) and the time remaining for the next change in state. Also included are current signal preemption and priority status values (when present or active). SPaT messages are required for various vehicular applications, such as traffic optimization for signalized corridors (TOSCo), transit signal priority (TSP), and red-light violation warning (RLVW).

Figure 1. Data collection in the northern Virginia connected vehicle system

While not directly related to latency measurements, the **BSM** provides a convenient means to collect the current location of the vehicle with a common timestamp. The latitude and longitude are available from the OBU's GPS receiver and populated in the appropriate fields of the BSM. The location enables an assessment of the coverage of the communication technologies under consideration.

### Locations

SPaT data were collected at three separate intersections within the VCC (shown in Figures 2 through 4), selected based on their differing characteristics.

**Virginia Route 7 (VA-7) and Springhill Road.** This four-way intersection is very close to Tysons Corner Center, providing an area of dense infrastructure development. The intersection has protected left turns and an elevated Metrorail running along the median. The traffic signal patterns are 180 seconds (s) cycle length, six-vehicle phases.

**Virginia State Route 650 and Yorktowne Center.** This T-type intersection is located near a small shopping center, a major arterial, and a nearby interstate. The intersection has protected left turns and a three-lane, bidirectional arterial. The traffic signal patterns are 120 s cycle length, four-vehicle phases.

**U.S. Route 50 (US 50) Corridor.** This location runs through a tree-lined suburban area over rolling hills. The corridor contains multiple T-type and four-way intersections, which feature protected left turns and two-lane, arterial intersections. The traffic signal patterns are 150 to 200 s cycle length, three- or four-vehicle phases.

All selected data collection sites are equipped with RSUs that constantly broadcast SPaT messages over DSRC, and the intersections are able to push SPaT messages over the backhaul network to VCC Cloud services. In addition, time synchronization within milliseconds (ms) is achievable between different observation points at the intersections.

#### Figure 2. Map of test routes at Virginia Route 7 and Springhill Road.



Figure 3. Map of test route at Gallows Road and Yorktown.



Figure 4. Map of test route for U.S. Route 50 Corridor.



### **Data Collection Effort**

Data collection occurred over the course of one day at each site and was broken up into separate morning and afternoon sessions, wherever possible, to cover different levels of traffic demand. Data was collected over 60-to 90-minute runs, and collected data were checked for any collection-based inconsistencies between runs. In addition to the CV data (from the stationary vehicle, moving vehicle, and RSU), additional companion field data (GPS positions, estimated traffic patterns, weather information, etc.) were collected when possible. Figures 2 through 4 present the routes driven during each data collection activity.

### Results

The collected data were pre-processed to identify values that deviated further away from the median. These outliers were eliminated by first finding the interquartile range (IQR) based on first quartiles (Q1) and third quartiles (Q3). The outliers were removed using the following method:

### IQR=Q3-Q1

Outliers lower cutoff =  $Q1-1.5 \times IQR$ , data values below this point are removed.

Outliers upper cutoff =  $Q3-1.5 \times IQR$ , data values above this point are removed.

The algorithm gives more weight to values closer to the median and potentially removes data points further from the median value. The actual value of the cutoff range depends on the spread of the collected data and the interquartile range.

### **Latency Analysis Results**

The collected data were first analyzed in terms of latency and distance coverage. In particular, the analysis considered the difference in time when the same SPaT message was received at the OBU through DSRC and on the laptop through cellular. For the latency to be valid, the two events must be time-synchronized with a reliable time source. In this case, the time sync was maintained using GPS. This study presents latency observed over different wireless networks at different locations when the tests were run at various times of day. A set of tests was run in the morning (9:30 to 11:30 am), and another set was run in the afternoon (1:30 to 3:30 pm). The latency observed over the test runs is presented in terms of percentile analysis, which shows the variability of data over confidence percentages. The confidence levels are divided from 60 to 100 percent and show how the latency varies over that span. Sixty percent was selected as the starting range because values above the median (50 percent) carry more information about the confidence of the analysis. In addition, the variation in latency below 60 percent was found to be much smaller than the variation in latency above 60 percent.

Given that the same trend was observed for all three sites, only the result for the US 50 site is presented here. The latency over DSRC does not vary significantly compared to cellular (variation is less than 1 ms between the morning and afternoon tests for DSRC but more than 1 ms for cellular). The latency over DSRC varies from 1.14 ms to 1.25 ms between 60 to 90 percent, and from 1.25 ms to 1.50 ms between 90 to 100 percent. However, at the same location, the latency over cellular network varies from 42.50 ms to 51.00 ms between 60 to 90 percent, and from 51.00 ms to 69.00 ms between 90 to 100 percent. Latency difference also shows a similar trend, where at 90 percent the latency difference is measured to be 51.00 ms. Figures 5 through 7 show the latency and latency difference data trends observed at the US 50 corridor.

#### **Spatial Coverage Analysis Results**

Latency data logged at various locations and GPS locations logged during the test may be used to plot a spatial observation over longitudinal distance. This aids in the understanding of latency as the vehicle moves along the test route. The longitudinal distance of multiple intersections from the reference intersection serving as the origin of the x-axis is plotted to build an elevation profile. For the US 50 corridor, the origin is placed at the Williams Drive intersection (see Figure 8).

Figure 8. Site location at US 50 corridor with multiple intersections and elevation profile.



Source: FHWA

The latency over longitudinal distance is plotted for analysis. In Figures 9 through 12, the x-axis range shows the length of the test drive. The plots also show the locations of individual intersections with respect to the Williams Drive intersection. Note that the shorter range of DSRC at the Cedar Lane intersection is due to the topographical location of the RSU in a dip (see Figure 8). Figures 9 through 12 show the latency observed from the RSU to the OBU over DSRC and from the RSU to the laptop over cellular, plotted along the x-axis, which is the longitudinal distance from the Williams Drive intersection over the length of the test. As expected, cellular data exhibits a much wider range, irrespective of the intersection (the latency is about 40 ms). However, DSRC is highly affected by range, and it cuts off at different distances from the respective intersections based on intersection geometry and location topography. The solid lines on the plots represent a linear estimation line based on the observations of the latency. The shaded portion over

#### Figure 5. DSRC latency along US 50 corridor.



Source: FHWA.

#### Figure 6. Cellular latency along US 50 corridor.



Source: FHWA.

#### Figure 7. Latency difference between DSRC and cellular along US 50 corridor.



Source: FHWA

the solid line represents error during the linear estimation. If there are more data points available for estimation, the shaded region becomes smaller because more data points render higher confidence in estimation. Since there is a large difference in the number of data points collected through DSRC and cellular, at the rate of 10 messages per second for DSRC against only signal status change updates for cellular, the shaded regions look thicker for cellular compared to DSRC.

Figure 9. Latency versus distance at various intersections.





Source: FHWA.

c. Cedar Lane intersection.



#### b. Javier Drive intersection.



Source: FHWA

#### d. Barkley Drive intersection.



#### **Results Summary**

Table 1 summarizes the distributions of latency for DSRC and cellular.

Table 1. Summary of average latencies and ranges using DSRC and cellular for all three sites.

	Latency (milliseconds)			Range (meters)	
Туре	Minimum	Median	Maximum	Minimum	Maximum
DSRC	0.80	1.10	1.50	430.53	1,365.50
Cellular	7.70	36.46	68.00	1,171.00	3,751.00

Source: FHWA.

An initial comparison shows that DSRC has a shorter range but very low latency (less than 2 ms), whereas cellular has a longer range but higher latency (greater than 40 ms).

## **Feasibility Analysis**

The study analyzed the impact of latency and coverage on the feasibility of supporting various safety and nonsafety CAV applications, including Glidepath, TOSCo, TSP, and RLVW. Table 2 summarizes the results.

Table 2. Feasibility o	f applications	using DSRC a	nd cellula
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Application	DSRC	Cellular	Hybrid (DSRC and Cellular)
Glidepath	Yes	Yes	Yes
TOSCo	Yes	Yes	Yes
TSP	Yes	No*	Yes
RLVW	Yes	No	Yes

Source: FHWA.

\*Cellular may be acceptable for TSP at speeds  $\leq$ 50 miles per hour.

The findings suggest that for applications such as Glidepath and TOSCo, receiving SPaT data over cellular might enhance the performance of the system, as the delay induced by cellular may be negated by the message being received over a wider distance. However, applications such as TSP (if speed limit is greater than 80 kilometers per hour) and RLVW, which require low latency, may not be supported by the cellular network.

### Conclusion

Both DSRC and cellular LTE demonstrate strengths and weaknesses in supporting applications in terms of timing and communications range requirements. The results of this study will be disseminated to other agencies that are considering real-time traffic signal data distribution and aim to help developers and deployers improve the safety and performance of the nation's roadways. Opportunities for further work include the study of other performance metrics, such as accuracy and reliability, and of alternate communications methods.

### References

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