Caltrans Testing of V2I Communication Latency over DSRC and 4G/LTE

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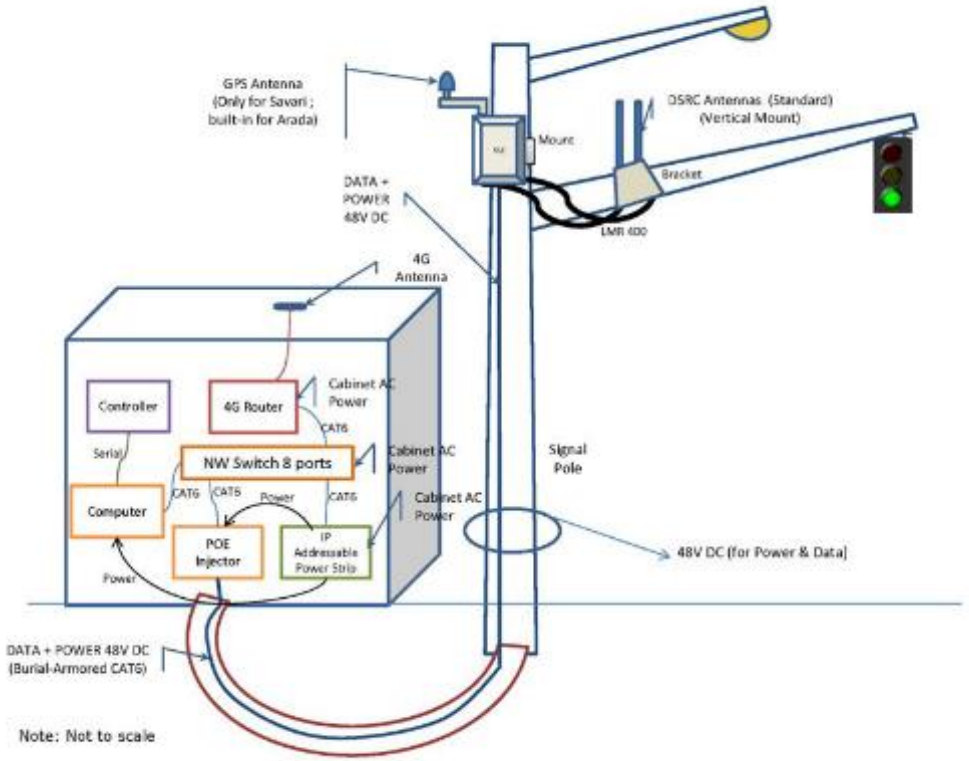
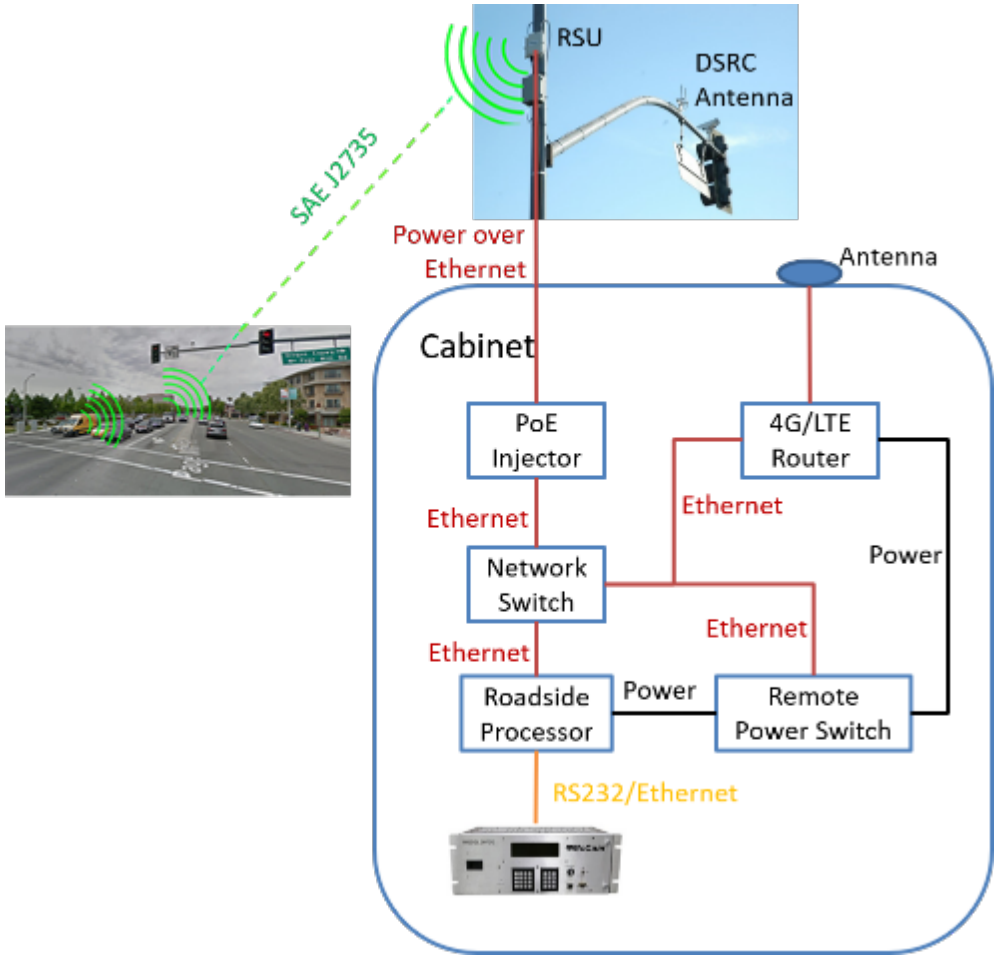
Communication Latency: DSRC vs. 4G/LTE

- Conducted under Caltrans Funded Project – Red Light Violation Warning (RLVW) over Cellular
- Objectives
  - Quantify point-to-point communication latency over DSRC and 4G/LTE
  - Compare the performance of 4G/LTE-based RLVW with DSRC-based RLVW

California CV Test Bed

Example Layout Schematic (Roadside)

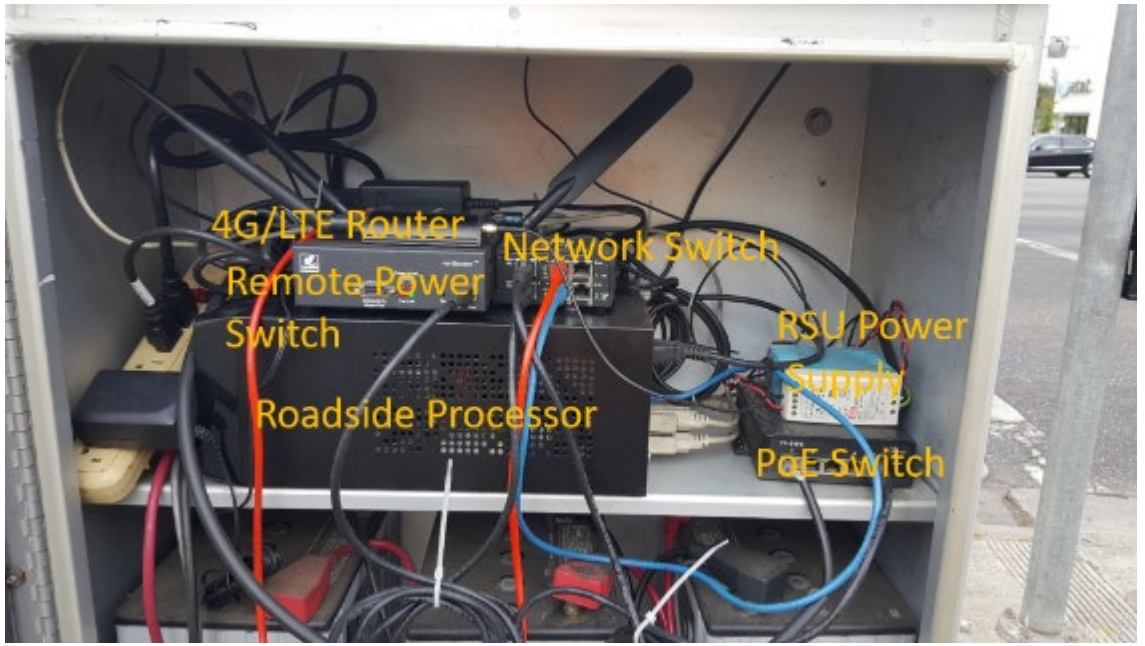




Actual Installation (Roadside)

RSU and Antenna

Cabinet Devices



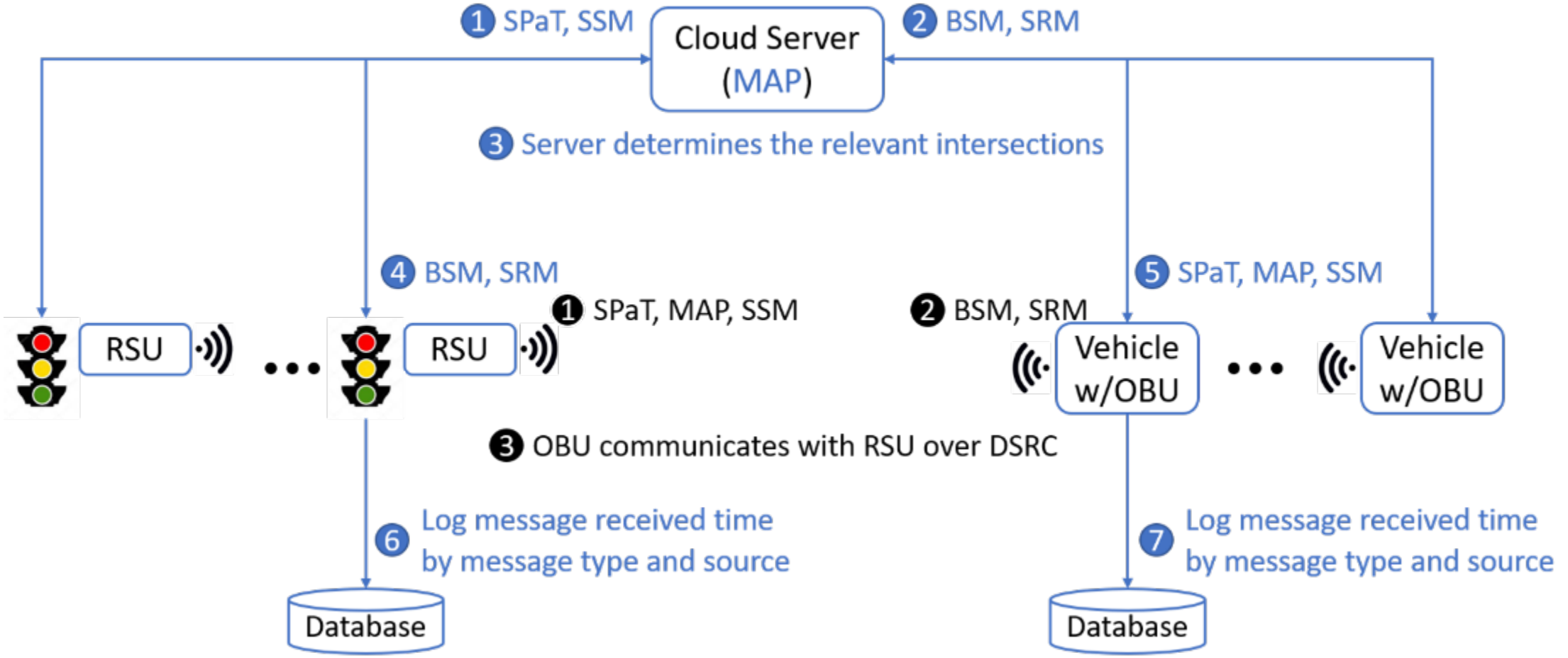
DSRC Messaging Conventions

- SAE J2945-201712 recommendations

Message	Abbreviation	From	Frequency	To	Channel	PSID (Hex)	DSRC Message ID
MAP/GID	MAP	RSU	1 Hz	OBU	172	0p80-02 (0x82)	18
Signal Phase and Timing	SPaT		10 Hz		172		19
Signal Status Message	SSM		1 Hz		184		30
Basic Safety Message	BSM	OBU	10 Hz	RSU	172	0p20 (0x20)	20
Signal Request Message	SRM		Asynchronous		184	0p80-02 (0x82)	29

In-Vehicle CV Equipment

Conceptual Message Flow



- Cloud Server is located at PATH Headquarters
- Same SAE J2735 message payloads are transmitted over DSRC and 4G/LTE

V2I Communication Link, Protocol, and Frequency

Message	Source	Frequency	Network	Transmitted via	Destination	Protocol
BSM	OBU	10 Hz	DSRC	RSU	MRP	WSMP
			4G/LTE	Cloud Server		UDP
SRM	OBU	1 Hz	DSRC	RSU	MRP	WSMP
			4G/LTE	Cloud Server		UDP
MAP	MRP	1 Hz	DSRC	RSU	OBU	WSMP
	Cloud Server	As-needed basis	4G/LTE	-		UDP
SPaT	Controller/MRP	10 Hz	DSRC	RSU	OBU	WSMP
			4G/LTE	Cloud Server		UDP
SSM	Controller/MRP	1 Hz	DSRC	RSU	OBU	WSMP
			4G/LTE	Cloud Server		UDP

- WSMP – Wave Short Message Protocol
- UDP – User Datagram Protocol
- Same SAE J2735 message payloads are transmitted over DSRC and 4G/LTE

V2I Communications over DSRC

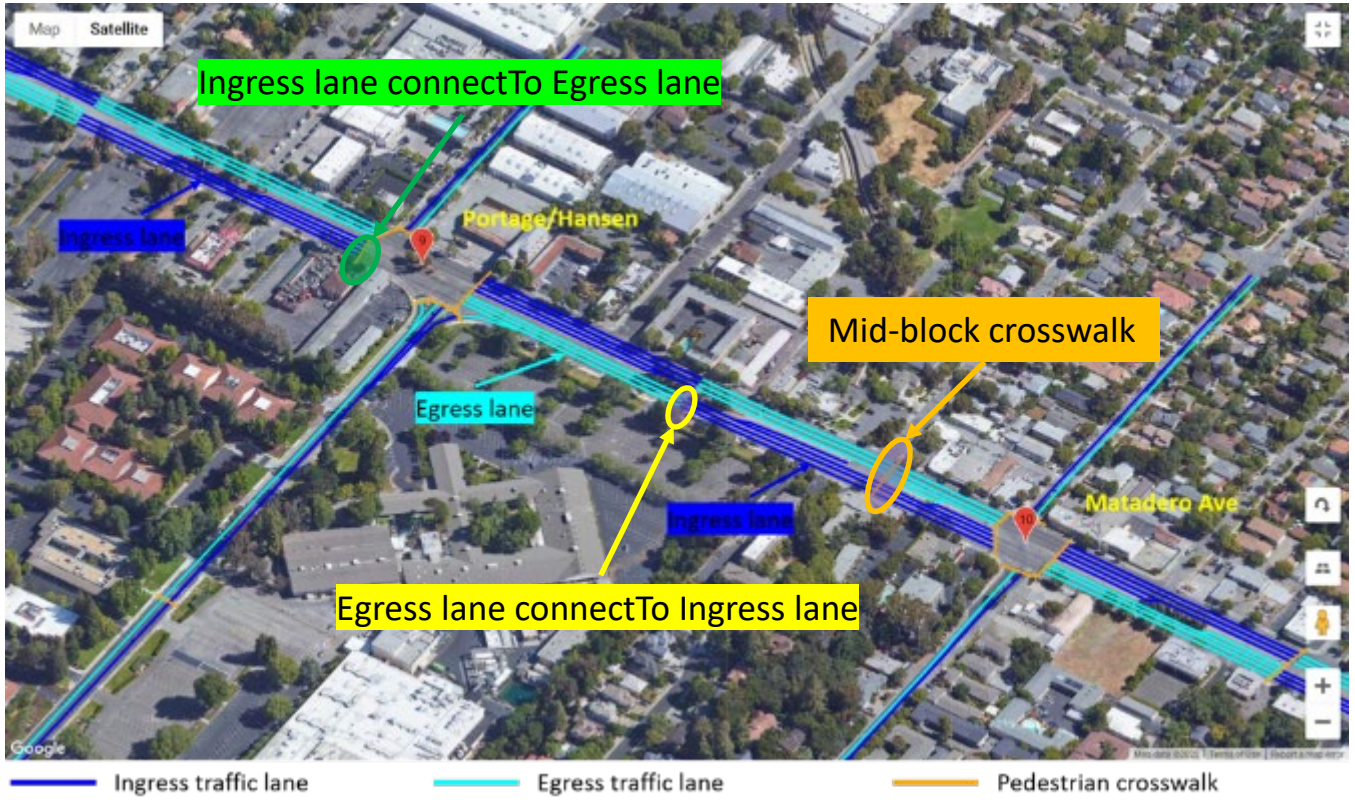
- Each connected intersection broadcasts MAP, SPaT, and SSM messages
- Each connected vehicle broadcasts BSM
- A connected vehicle receives MAP messages from nearby connected intersections, determines the intersection that the vehicle is approaching, generates and broadcasts SRM (to the approaching intersection) if it’s eligible for signal priority
- V2I messages are broadcasted within and outside the DSRC communication range

V2I Communications over 4G/LTE

- Each connected intersection sends SPaT and SSM messages to the cloud server
- The server maintains the MAP of connected intersections
- Each connected vehicle sends BSM to the cloud server
- If it's eligible for signal priority, a connected vehicle sends SRM to the cloud server (after it has received the MAP of the intersection that the vehicle is approaching)
- How the server would know
  - To send the MAP of which intersection to the vehicle and at what frequency?
  - To forward SPaT and SSM from which intersection to the vehicle?
  - To forward BSM to which intersection?

Cloud Server Identifying the Relevant Intersection w.r.t. a Connected Vehicle

- The MAP message contains the information about its connecting intersections

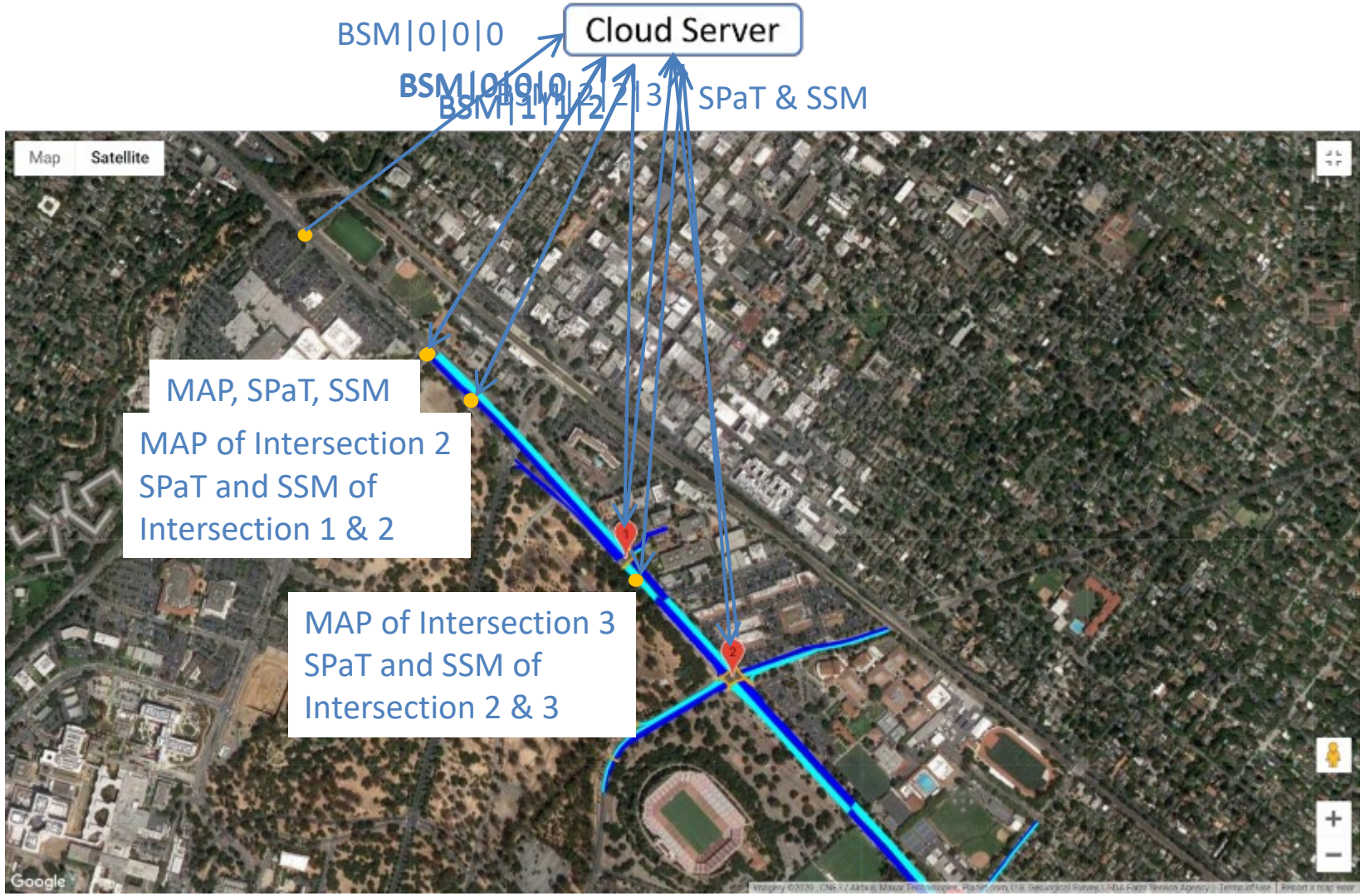


Cloud Server Identifying the Relevant Intersection w.r.t. a Connected Vehicle (Cont'd)

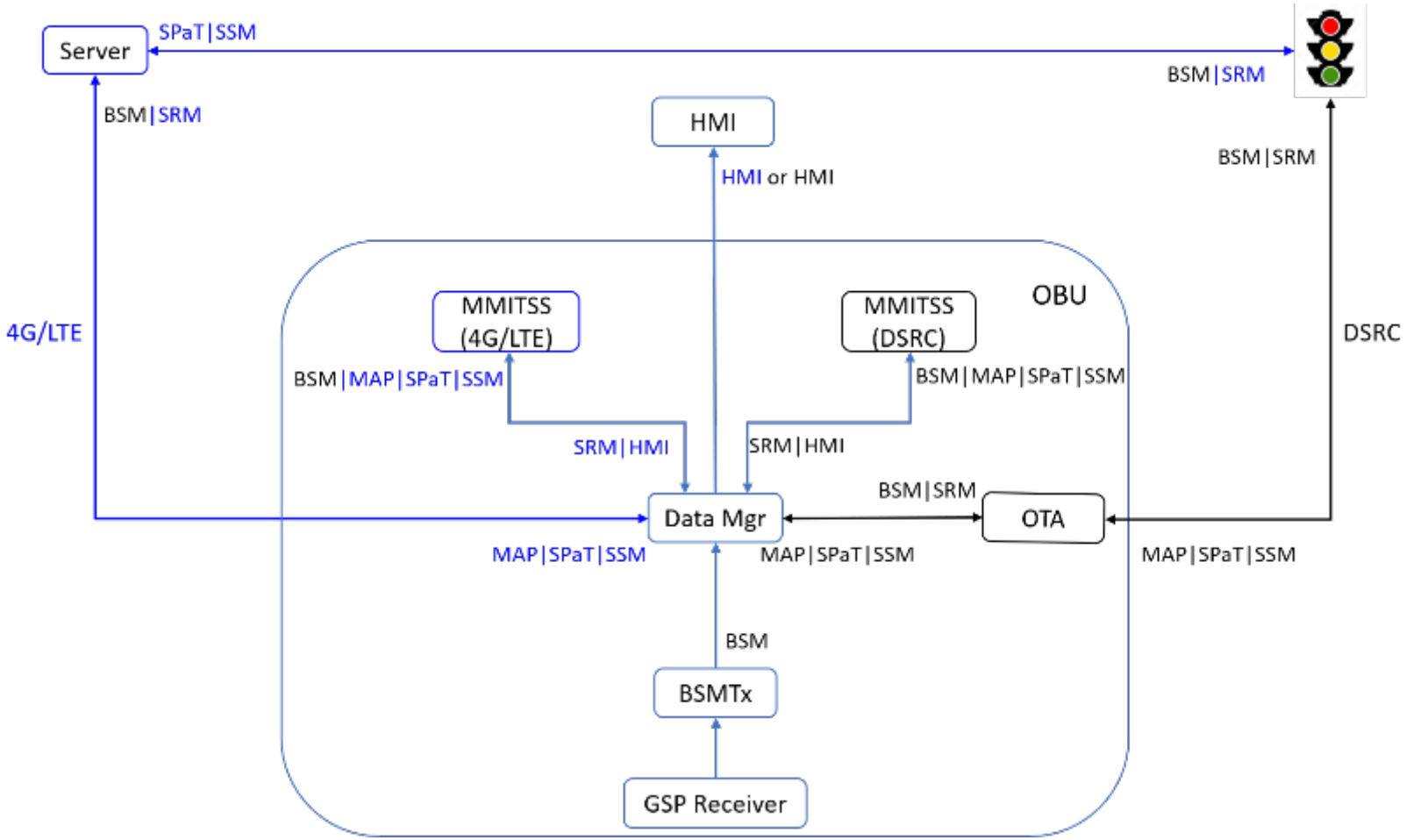
- When the MAP of the approaching intersection is available, a connected vehicle is able to determine the IDs of connecting intersections and can request MAP of connecting intersections from the server
- When the MAP of the approaching intersection is not available, the server sends the MAP of nearby intersections to the vehicle based on the proximity between vehicle location and intersection MAP reference point
- Information about the current (approaching) intersection ID and IDs of connecting intersections is appended to the BSM (part I) that is sent to the server

BSM	Current Intersection ID	# of Received MAPs	IDs of Received MAPs	# Connecting Intersections	IDs of Connecting Intersections

Cloud Server Identifying the Relevant Intersection w.r.t. a Connected Vehicle (Cont'd)

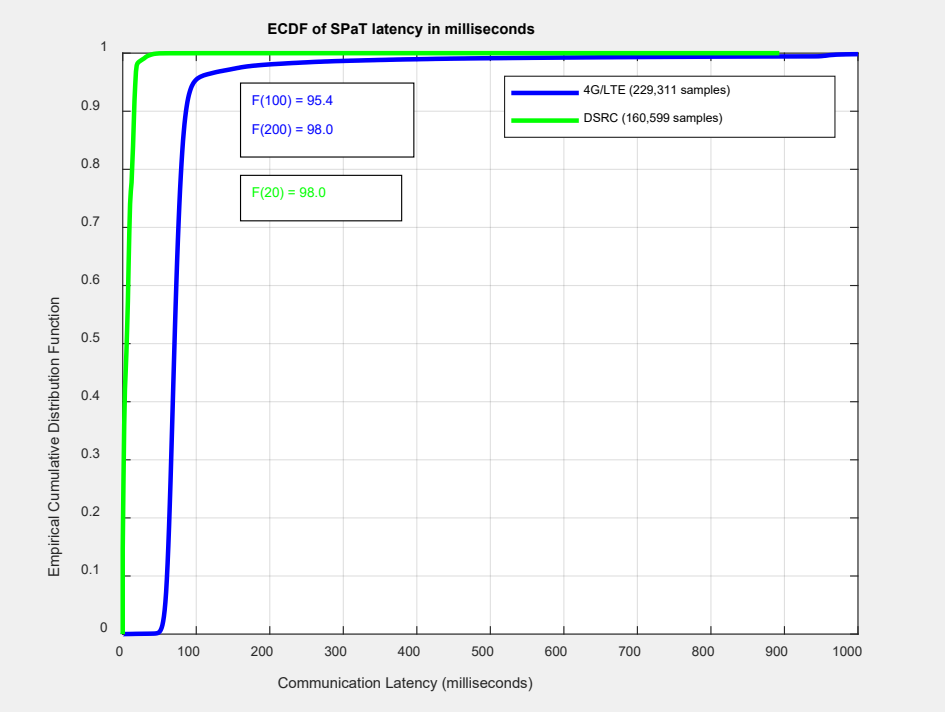


Simultaneous V2I Data Collection over DSRC and 4G/LTE

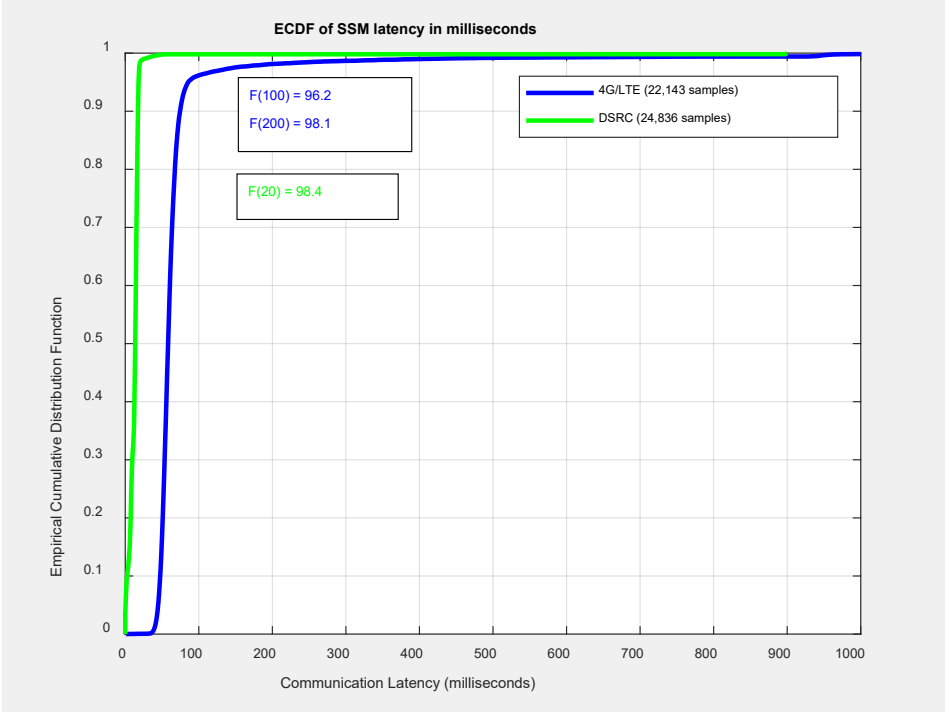


Comparison of Communication Latency over DSRC and 4G/LTE

SPaT (10 Hz, Channel 172)



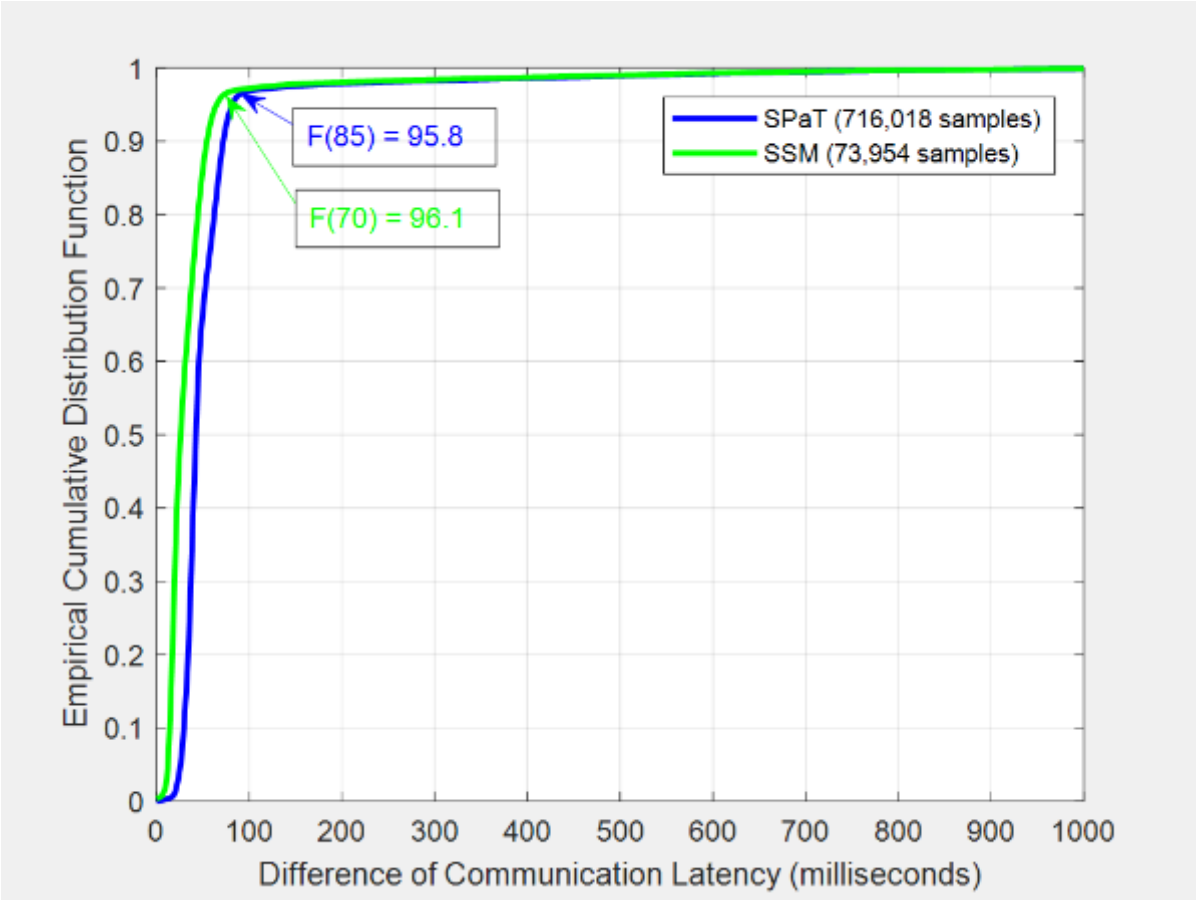
SSM (1 Hz, Channel 184)



ECDF – Empirical Cumulative Distribution Function

Communication latency = Message received time by the OBU – Message generated time at the intersection

Communication Latency Difference



ECDF – Empirical Cumulative Distribution Function

Communication latency difference = Message received time over 4G/LTE – (Same) Message received time over DSRC

Summary of Communication Latency

% of Time	Communication Latency (Milliseconds)	
	DSRC	4G/LTE
95%	< 18 ms	< 100 ms
98%	< 20 ms	< 200 ms
99.99%	< 100 ms	< 2000 ms

- 5.9 GHz band spectrum is critical for safety applications that require reliable and short communication latency
- Existing 4G/LTE could support mobility applications

Comments & Questions?