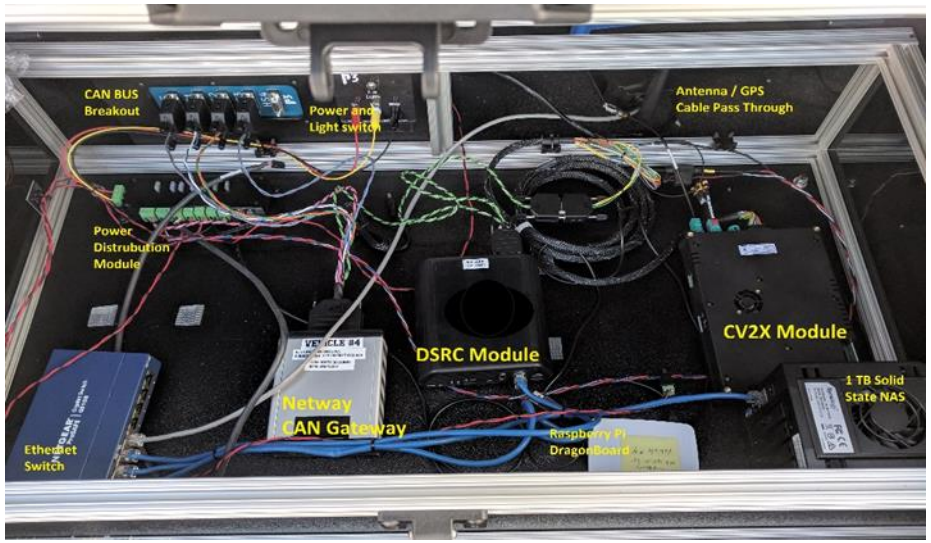
V2X Technology Benchmark Testing

September 2018

Technology Performance Characterization Approach

- Provision for interchangeable DSRC and C-V2X systems.
- Technology agnostic capability assessment procedures documented and harmonized in 5GAA for global consistency.
- Tests conducted with scrupulous control of factors influencing radio wave propagation to ensure fair comparison:
  - Antenna characteristics and placement
  - Vehicle geometry and cabling
  - Location and environmental conditions
  - Power, interference and other settings



Performance Characterization

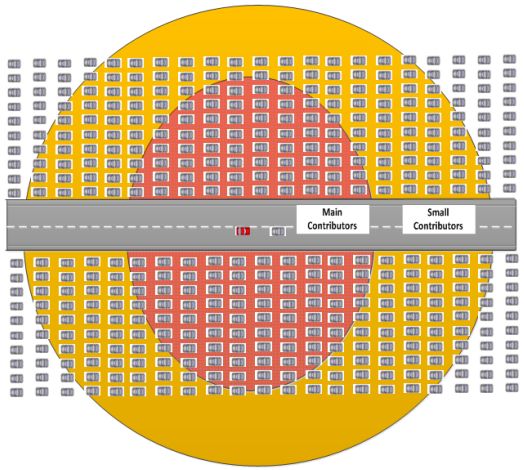
Ford and Qualcomm conducted testing to compare radio performance of CV2X and DSRC in Ann Arbor and San Diego. Key tests performed:

Congestion	**Lab** Cabled Congestion Control
Reliability	**Lab** Cabled Tx and Rx Tests
	Field Line-of-Sight (LOS) Range Tests
	Field Non-Line-of-Sight (NLOS) Range Tests
Interference	**Lab** Cabled Test with Simulated Co-channel Interference
	Lab Cabled Near-Far Test
	Field Co-existence with Wi-Fi 80 MHz Bandwidth in UNII-3
	Field Co-existing of C-V2X with Adjacent DSRC Carrier

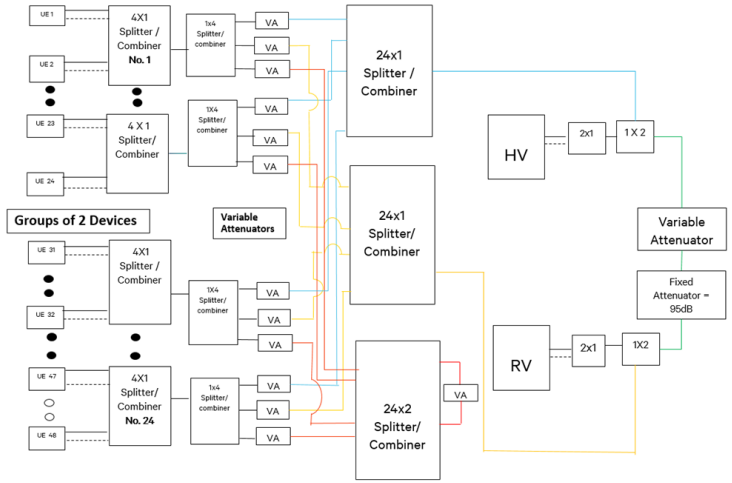
Congestion Lab Test

Purpose:

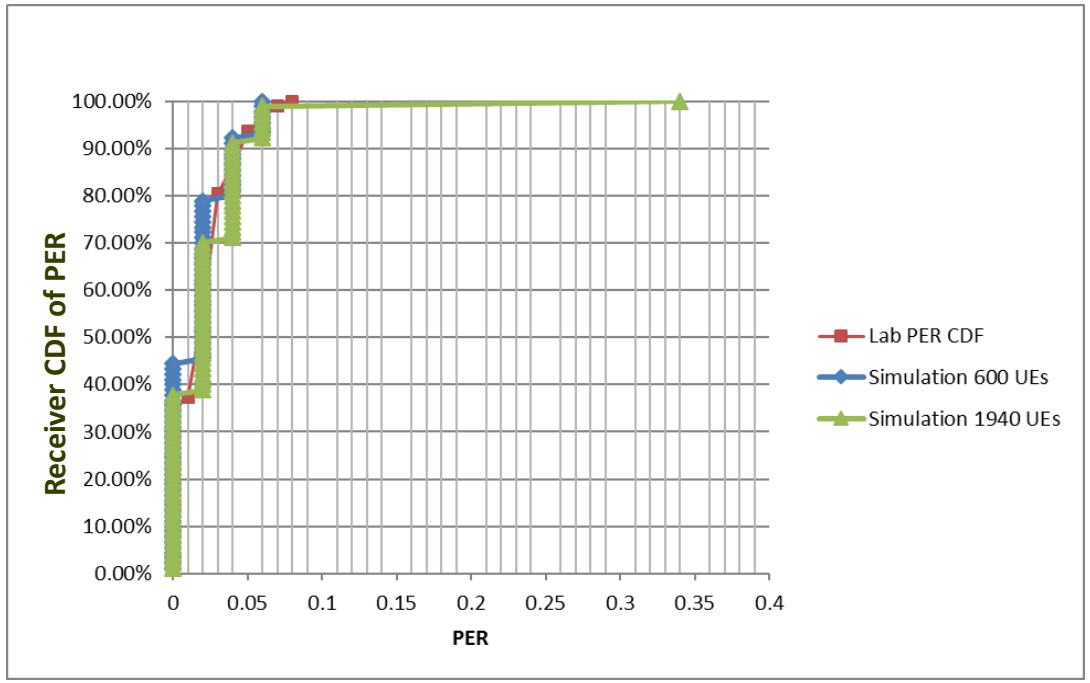
Assess CV2X ability to manage congestion per SAE 2945/1.



"Equivalent" highway scenario



Cabled RF Lab setup



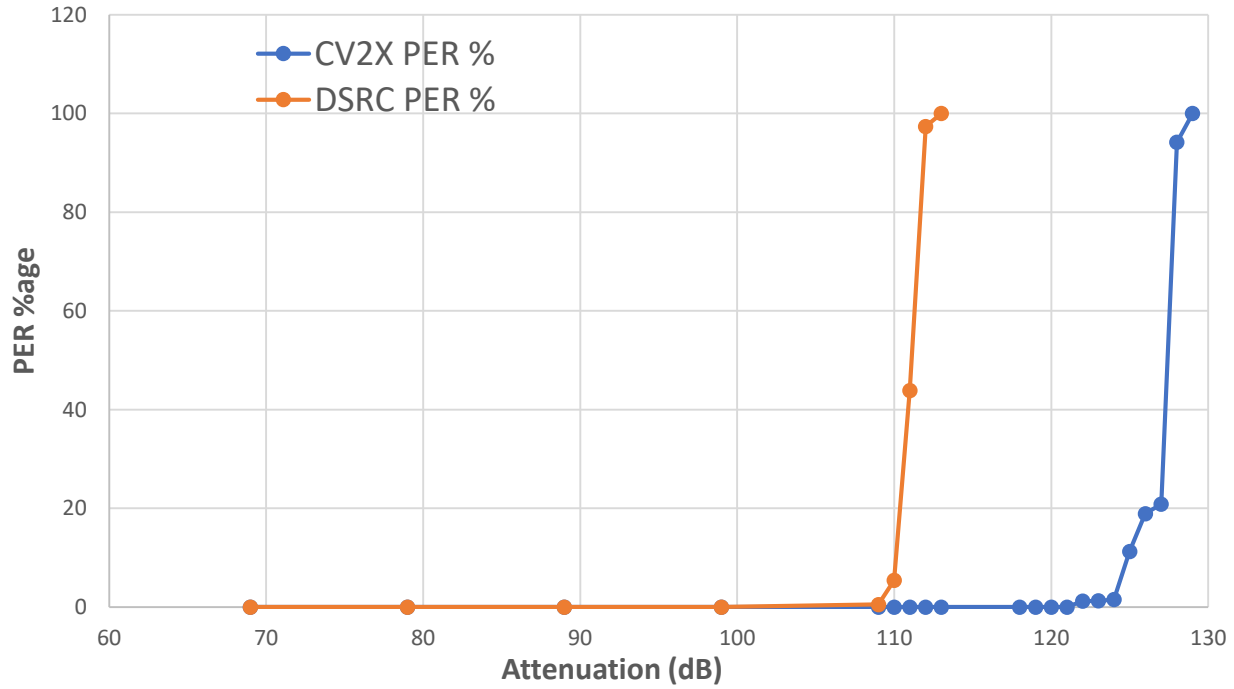
Packet error rate remains below 10% while CBR is ~30% with congestion management.

SAE-like congestion control works well for CV2X.

Cabled Radio Lab Test

Purpose:

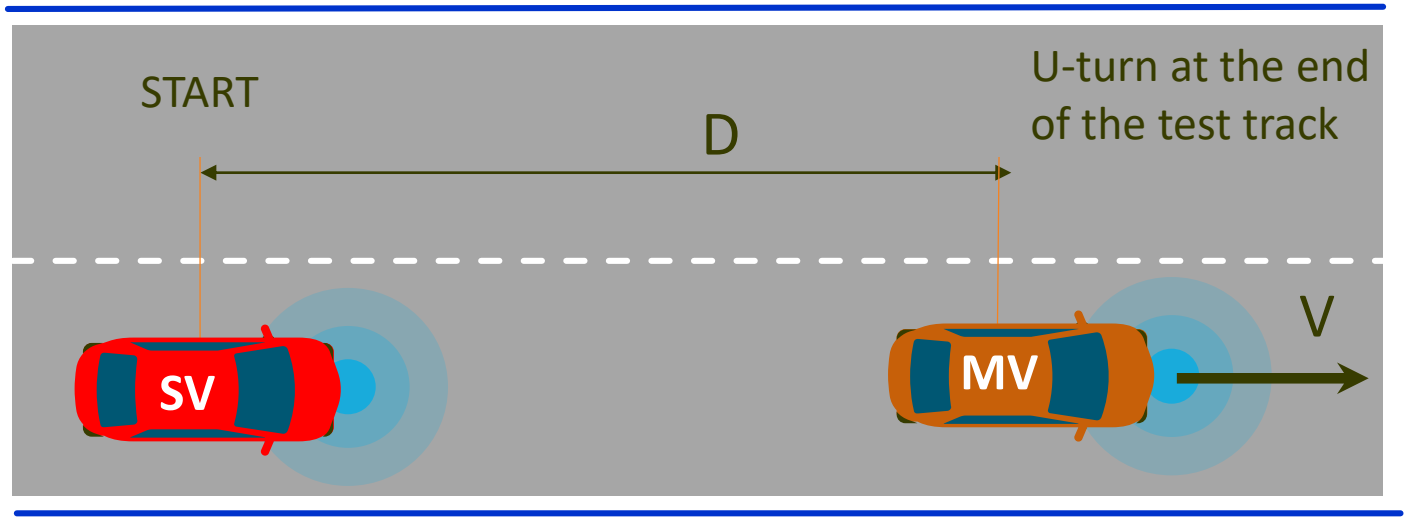
Measure radio performance under varying receive power conditions.



CV2X outperforms DSRC consistent with simulations.

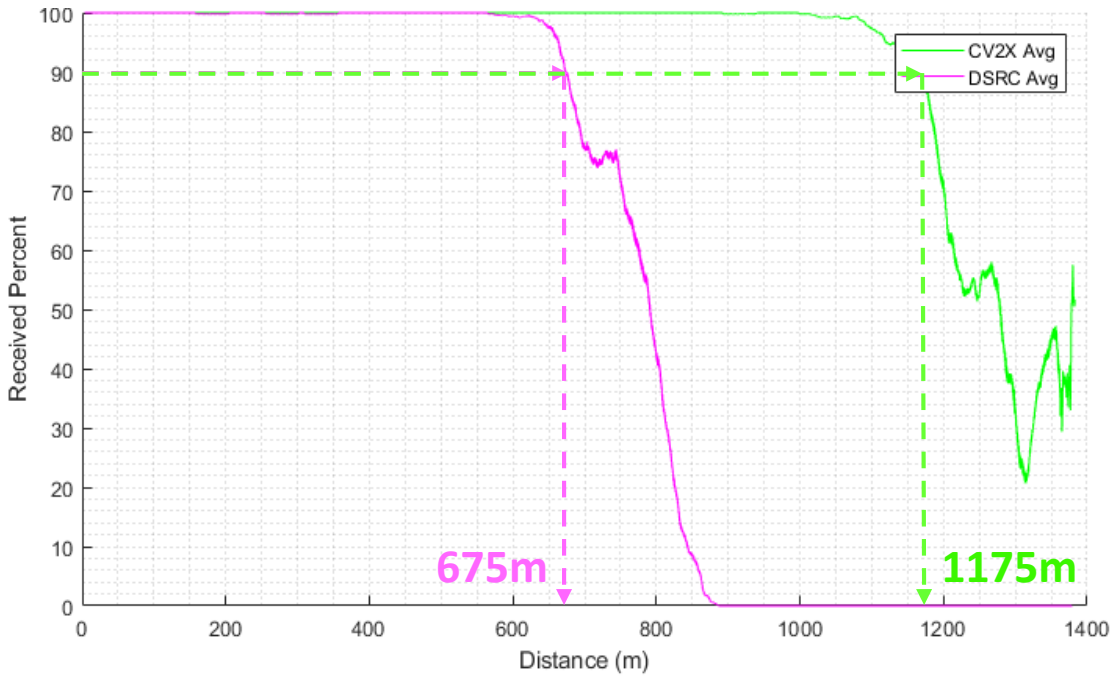
Line-of-Sight Field Test

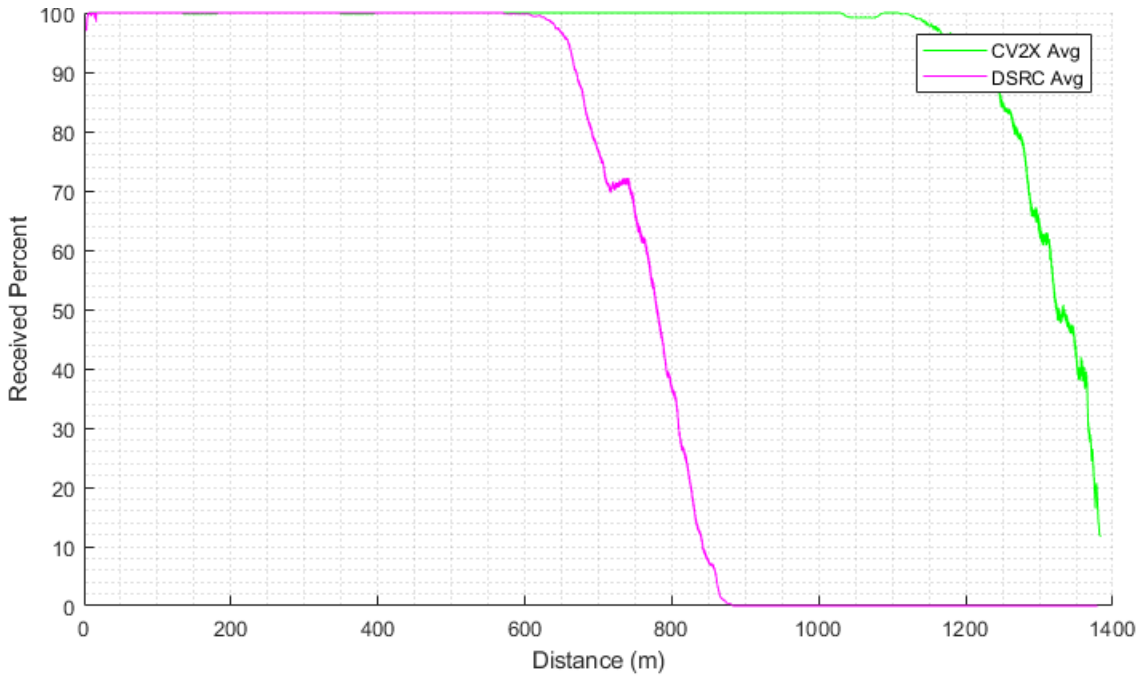
Purpose:
Assess baseline capability for V2V message exchange in line of sight (LOS).



Note: Equivalent transmit power was set at 11dBm for both DSRC and CV2X to fit measured range into the test track (1350m long) and to match the setting in previous tests by the industry.

Line-of-Sight Field Test Results



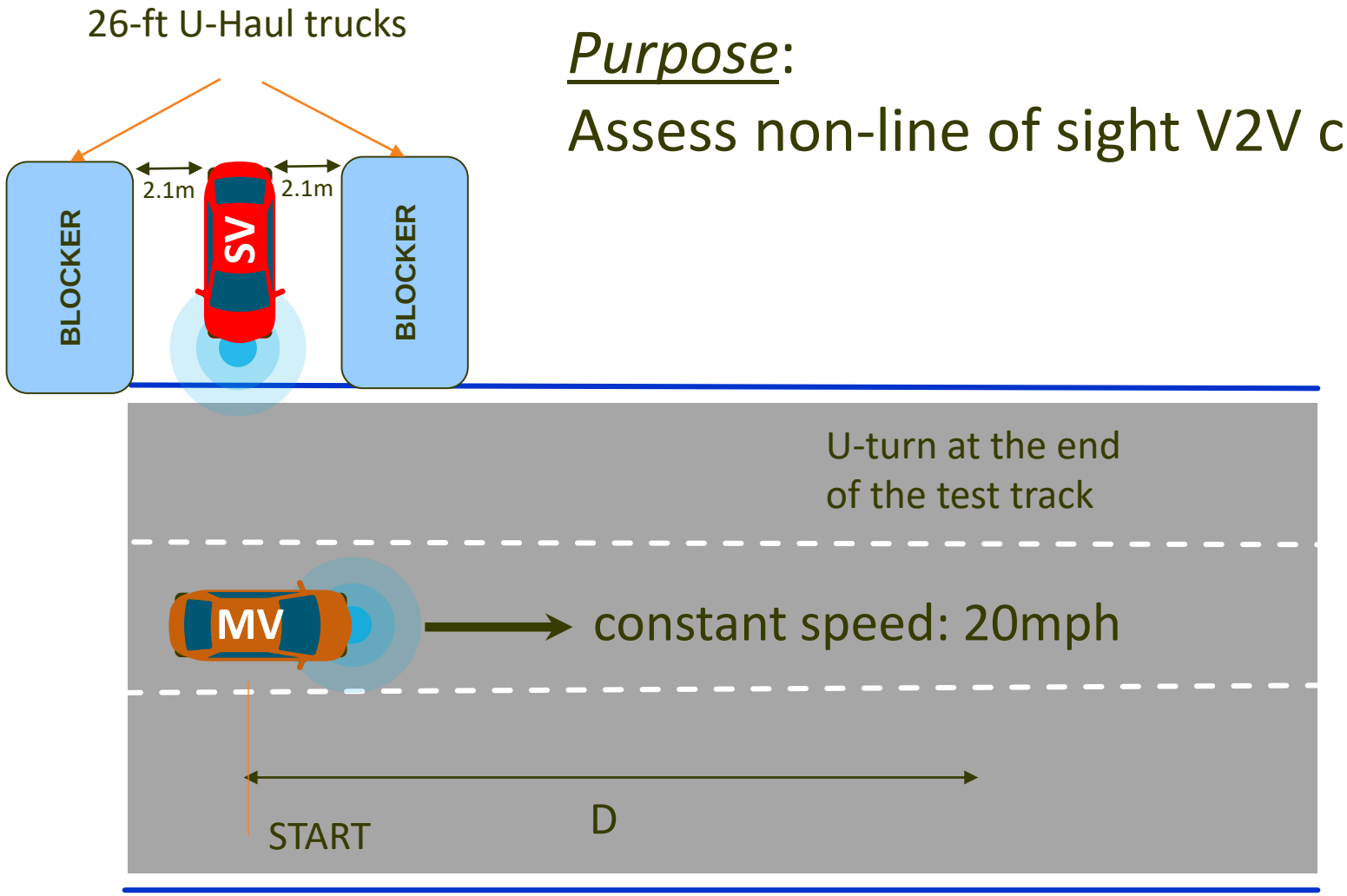


Stationary vehicle receiving
Moving vehicle transmitting and approaching

Stationary vehicle transmitting
Moving vehicle approaching and receiving

Significant baseline performance advantage consistent with Lab results.

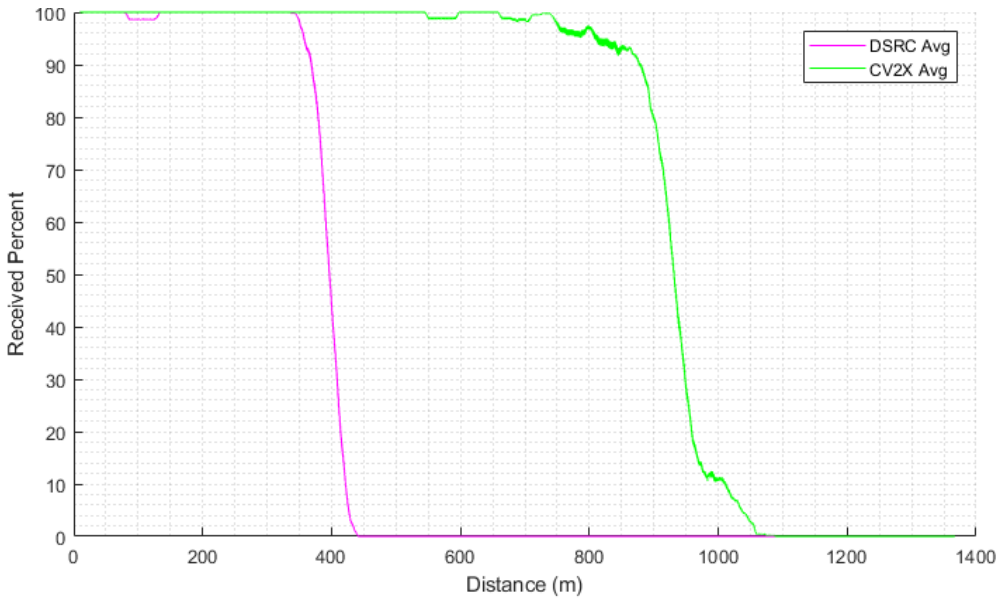
Intersection Test (Obstructed view)

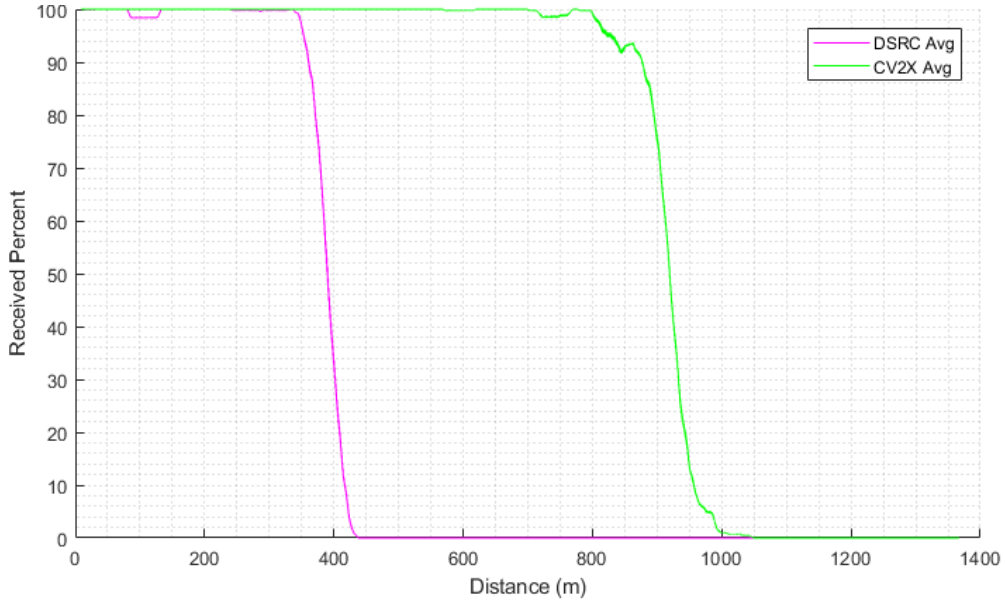


Purpose:

Assess non-line of sight V2V communication capability.

Intersection Test Results





Stationary vehicle receiving
Moving vehicle transmitting and approaching

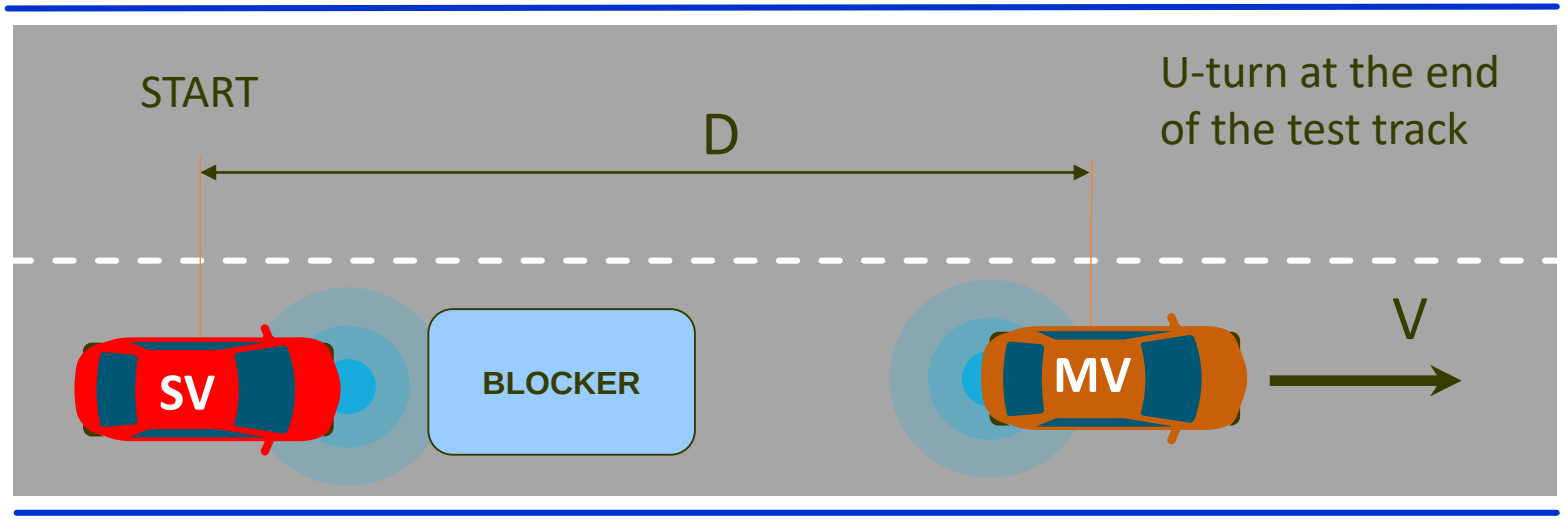
Stationary vehicle transmitting
Moving vehicle approaching and receiving

Significant performance advantage in obstructed view intersection.

5GAA Shadowing Test

Purpose:

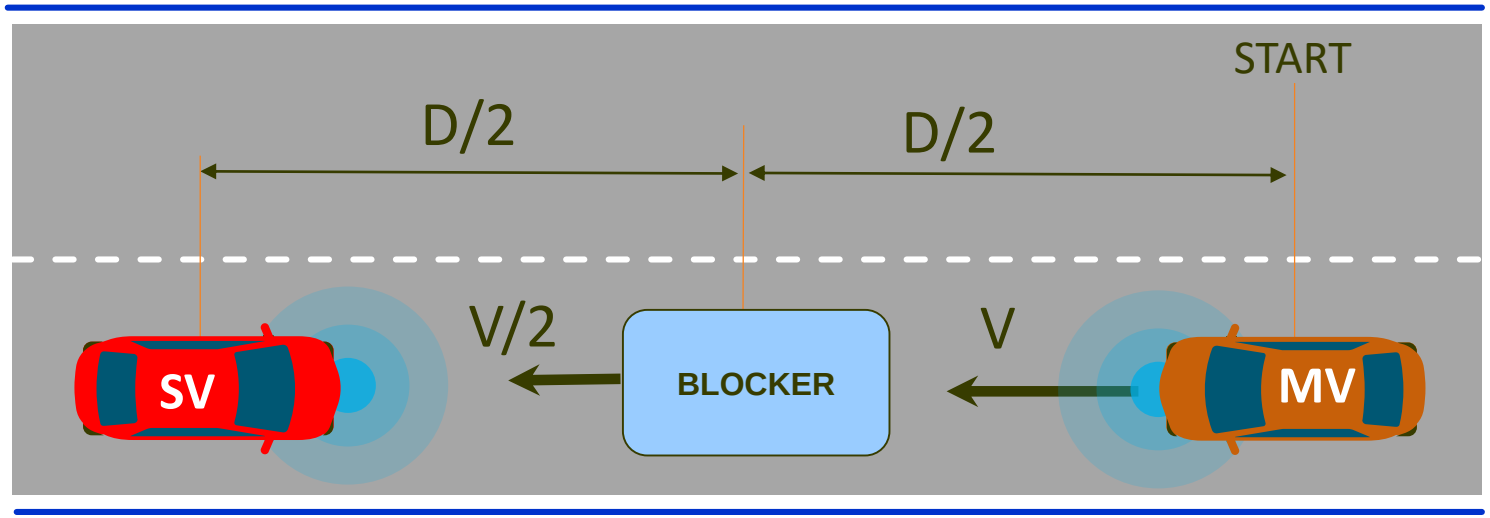
Assess capability for V2V message exchange in non-line of sight (NLOS) scenario with significant obstruction.

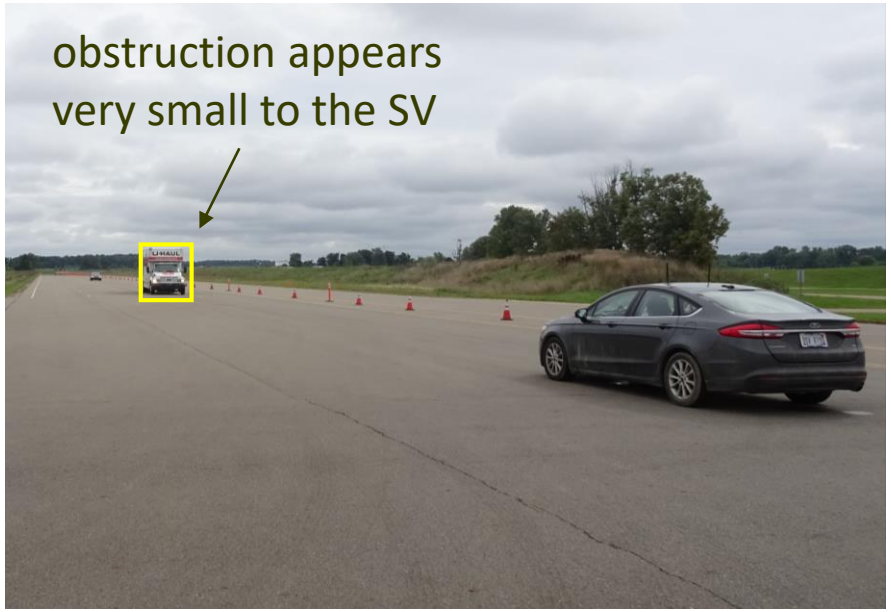


Note: The blocker is positioned in front of the stationary vehicle in order to create a significant (and constant) line of sight obstruction. **The Stationary Vehicle and Blocker remain motionless during the entire test**.

CAMP Shadowing Test

Purpose:
Assess V2V message exchange capability through obstruction in a highway queue-forming scenario.

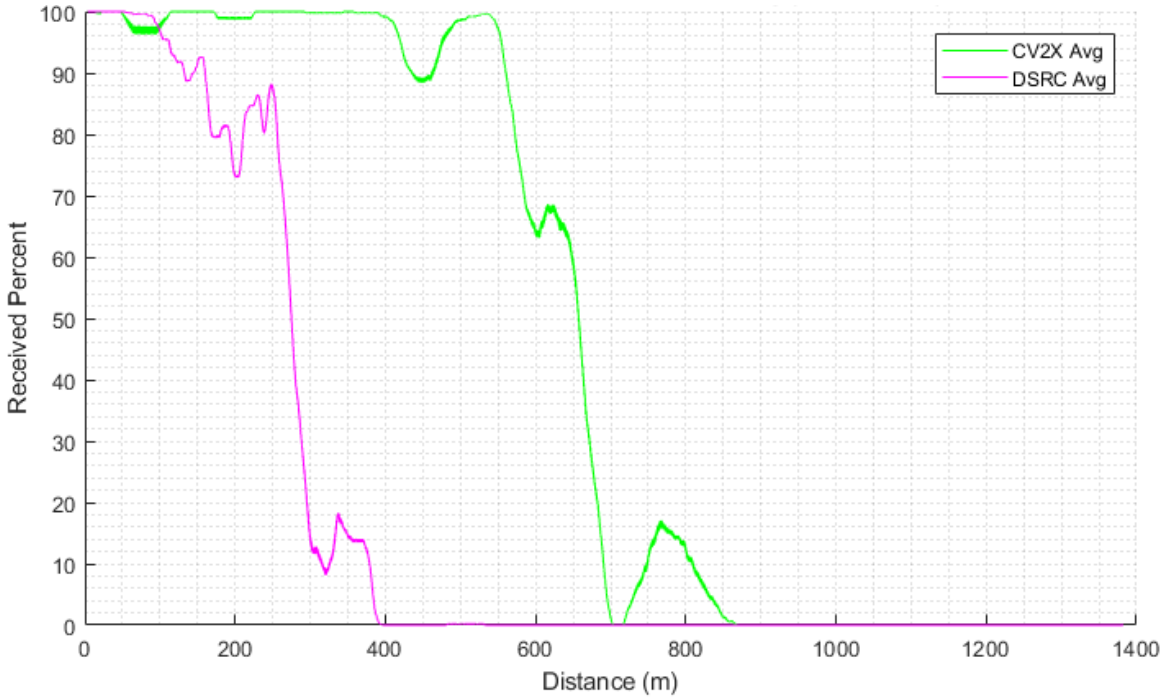




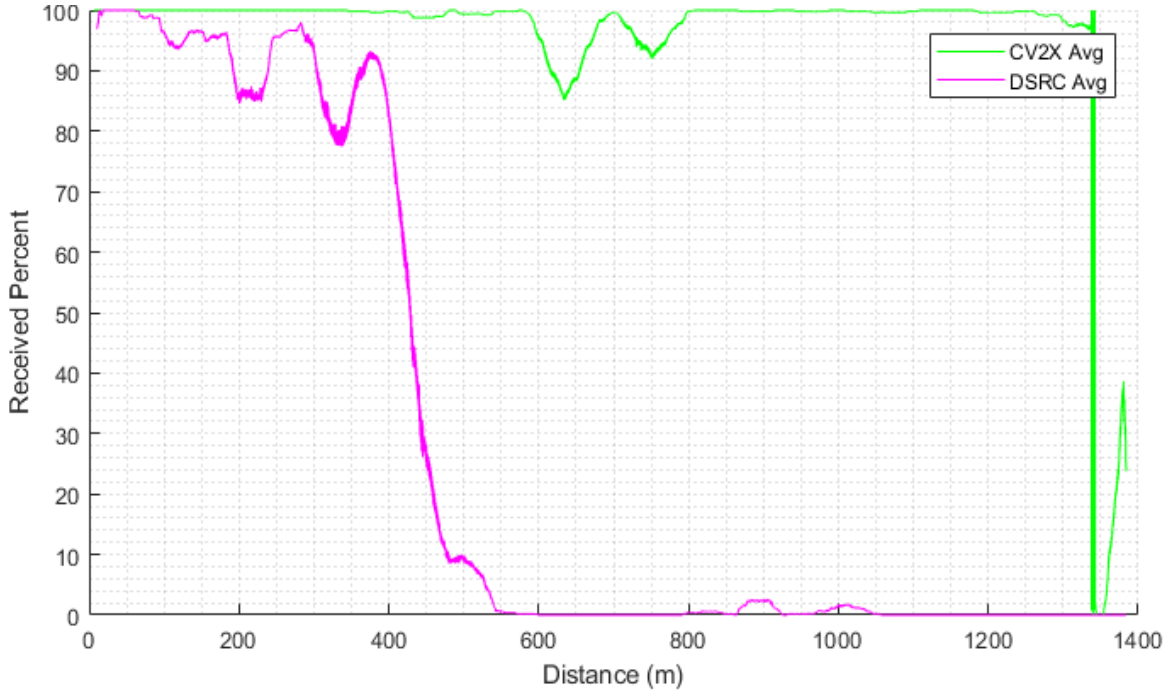
Note: In this test ***the effect of the blocker is negligible at maximum vehicle separation*** (obstruction appears very small to the SV)**.** As a result, the test will produce better range than the more demanding 5GAA shadowing test regardless of technology.

Shadowing Test results

5GAA shadowing test, Approach



CAMP shadowing test, Approach

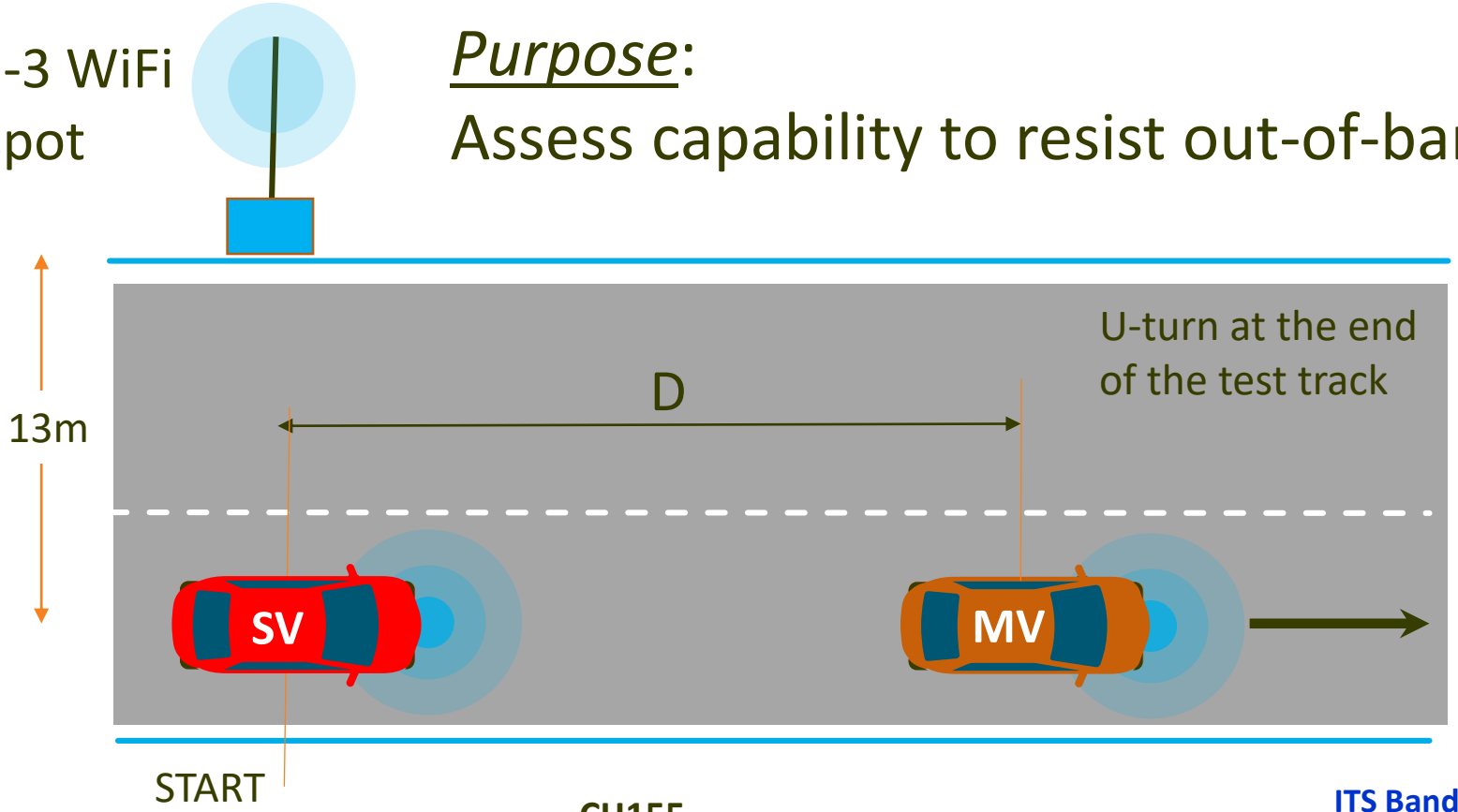


5GAA shadowing test is more demanding than the CAMP test.
CV2X outperforms DSRC in shadowing scenarios by large margin.

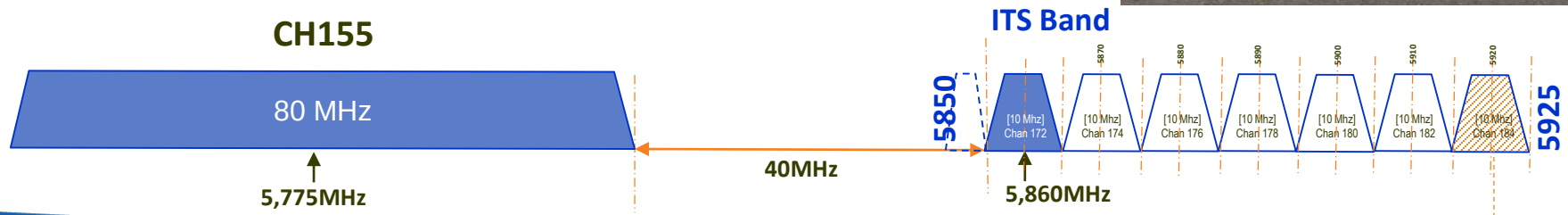
Line-of-sight UNII-3 Out-of-band Interference Test

U-NII-3 WiFi hot-spot

Purpose:
Assess capability to resist out-of-band interference.



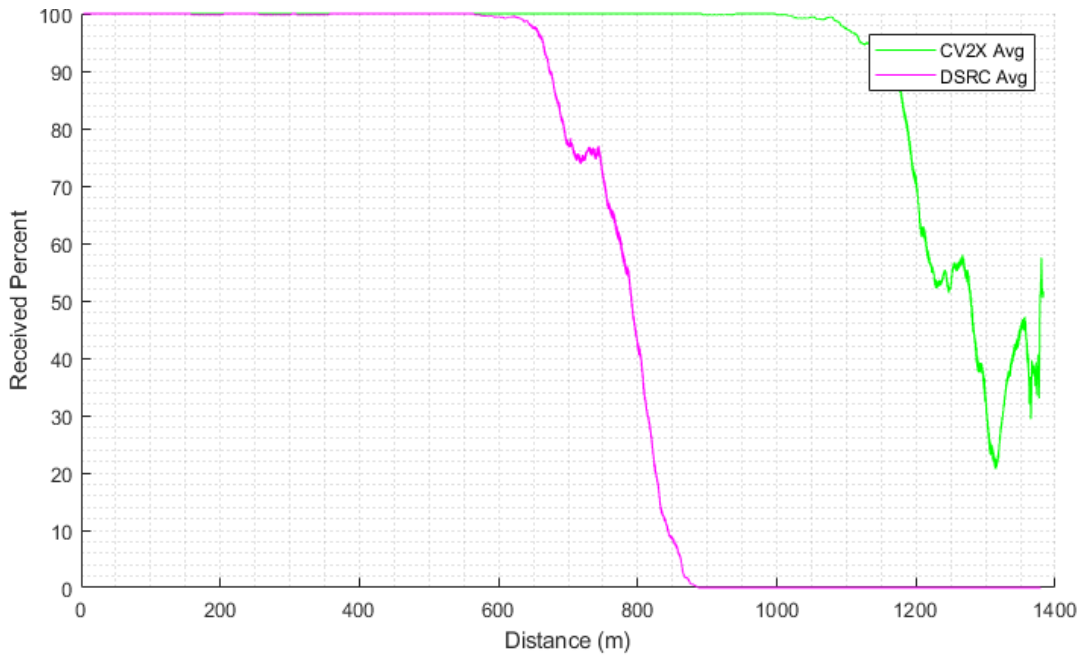
Parameter	Value
Tx Power	23 dBm
Utilization	76%



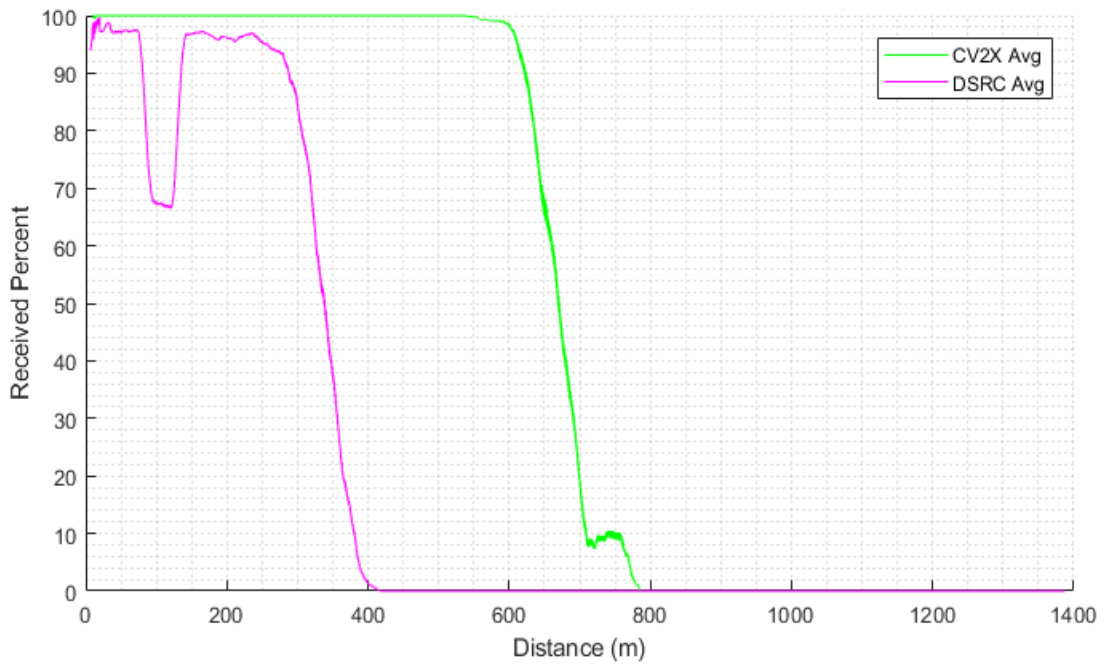
Both OBUs were operating in CH184 and the interferer was shifted from center frequency 5,775MHz to 5,835MHz

Line-of-sight UNII-3 Out-of-band Interference Test: Results

WiFi hot spot: OFF



WiFi hot spot: ON



Moving vehicle transmitting and approaching, Stationary vehicle receiving

CV2X is more resilient to UNII-3 interference than DSRC.

Latency Lab Results

Purpose:

Measure end-to-end latency at PRR > 90% in various lab tests.

Test	Technology	95%-ile IPG (ms)	95%-ile latency (ms)
Cabled Tx/Rx	CV2X	106	22* (with 20ms latency budget)
	DSRC	104	20
Congestion	CV2X	105	99* (with 100ms latency budget)

*In C-V2X, latency budget can be configured based on the application/situational need. The latencies remain bounded by the configured budget independent of the level of congestion.

Both CV2X and DSRC satisfy SAE J2945/1 requirements.

Technology benchmark summary

Congestion	**Lab** Cabled Congestion Control	Pass
Reliability	**Lab** Cabled Tx and Rx Tests	CV2X better
	Field Line-of-Sight (LOS) Range Tests	CV2X better
	Field Non-Line-of-Sight (NLOS) Range Tests	CV2X better
Interference	**Lab** Cabled Test with Simulated Co-channel Interference	CV2X better
	Lab Cabled Near-Far Test	Pass
	Field Co-existence with Wi-Fi 80 MHz Bandwidth in UNII-3	CV2X better
	Field Co-existing of V2X with Adjacent DSRC Carrier	Pass

CV2X radio technology consistently outperforms DSRC.

Field results summary

Test Procedure	Range at 90% Reliability	
	DSRC	CV2X
Line-of-Sight (LOS) Range	675m	1175m
Non-Line-of-Sight (NLOS) Blocker (5GAA)	125m	425m
Non-Line-of-Sight (NLOS) Blocker (CAMP)	400m (200m)[1]	>1350m (625m)
Non-Line-of-Sight (NLOS) Intersection	375m	875m
Co-existence with Wi-Fi 80 MHz Bandwidth in UNII-3	300m (75m)	625m
Co-existing of V2X with Adjacent DSRC Carrier	400m (100m)	1050m

CV2X radio technology consistently outperforms DSRC.

[1] Number in parenthesis indicate first drop below 90% reliability

Ford, Panasonic & Qualcomm CV2X demonstration in Colorado, August 2018

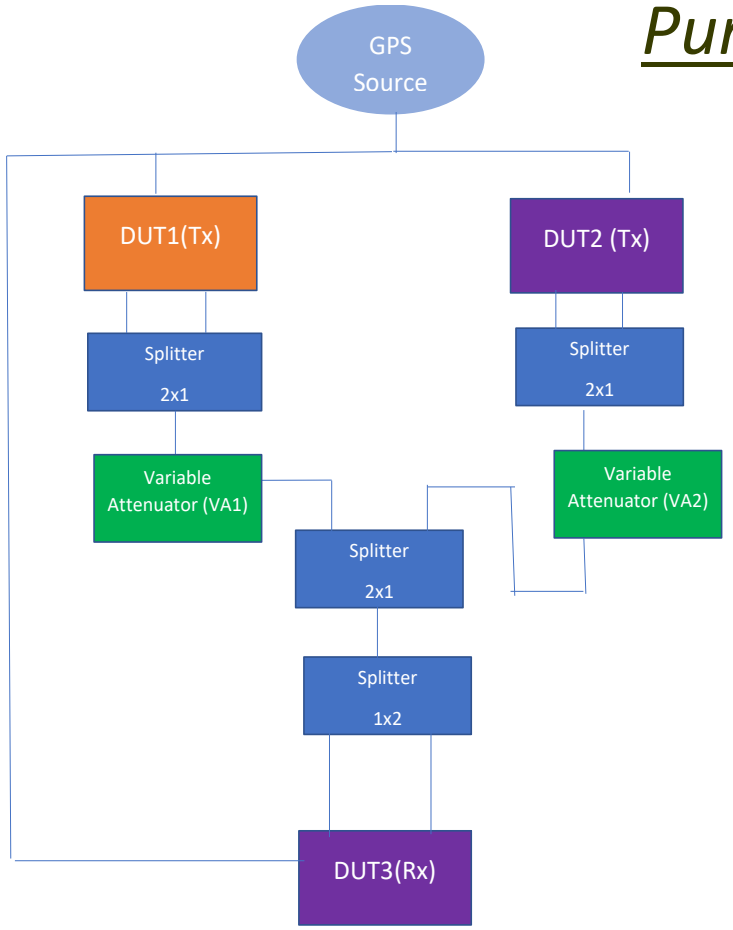
BMW, Ford, PSA, Qualcomm CV2X demonstration in Paris, France, July 2018

THANK YOU

Appendix

Cabled Near-Far Test

Purpose: Assess half-duplex C-V2X capability.

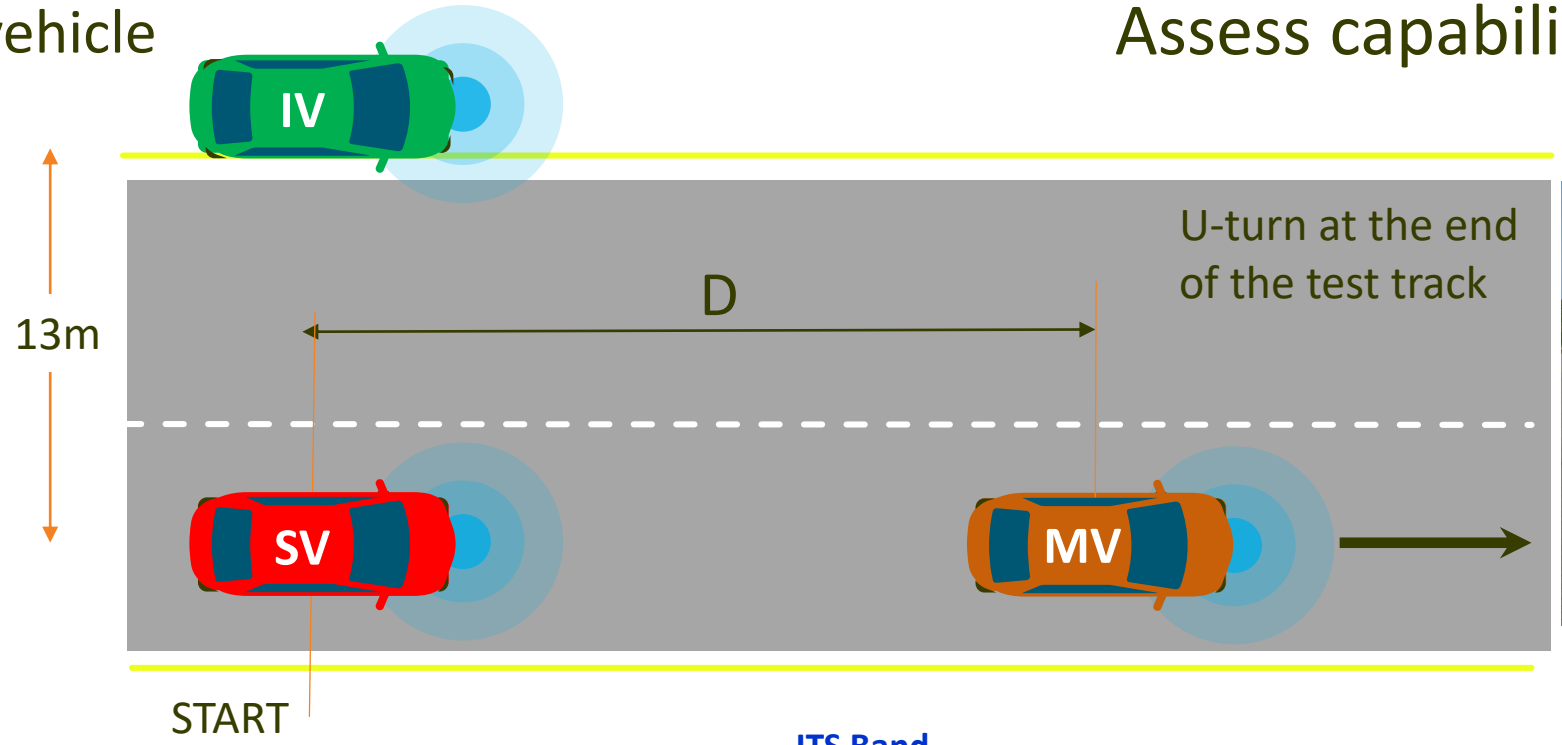


Attenuator Value (dB)	No. of Transmitted pkts (total for the 10 min test)		No. of Received pkts (total for the 10 min test)		PER % Calculated at Receiver (Device 3)	
	Transmit Device 1	Transmit Device 2	Received at Device 3 from Device 1	Received at Device 3 from Device 2	For Packets from Device 1	For Packets from Device 2
39	6000	6000	6000	6000	0.00	0.00
49	6000	6000	6000	6000	0.00	0.00
59	6000	6000	6000	6000	0.00	0.00
69	6000	6000	6000	6000	0.00	0.00
71	6000	6000	6000	6000	0.00	0.00
72	6000	6000	6000	5996	0.00	0.07
73	6000	6000	6000	5918	0.00	1.37
74	6000	6000	6000	5675	0.00	5.42
75	6000	6000	6000	4475	0.00	25.42
76	6000	6000	6000	2501	0.00	58.32
77	6000	6000	6000	699	0.00	88.35
78	6000	6000	6000	16	0.00	99.73
Device 1 TX Power (dBm)			21 dBm			
Device 2 TX Power (dBm)			21 dBm			

C-V2X copes well with transmissions in same time slot, different frequency.

Line-of-sight Adjacent Channel Interference Test

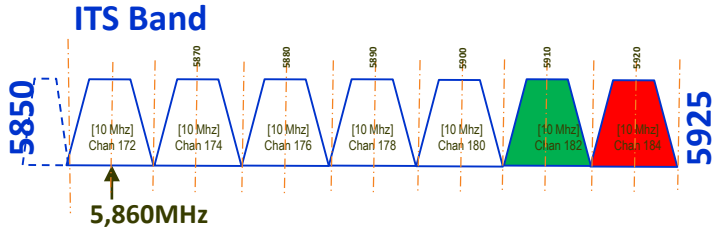
Interfering vehicle



Purpose:

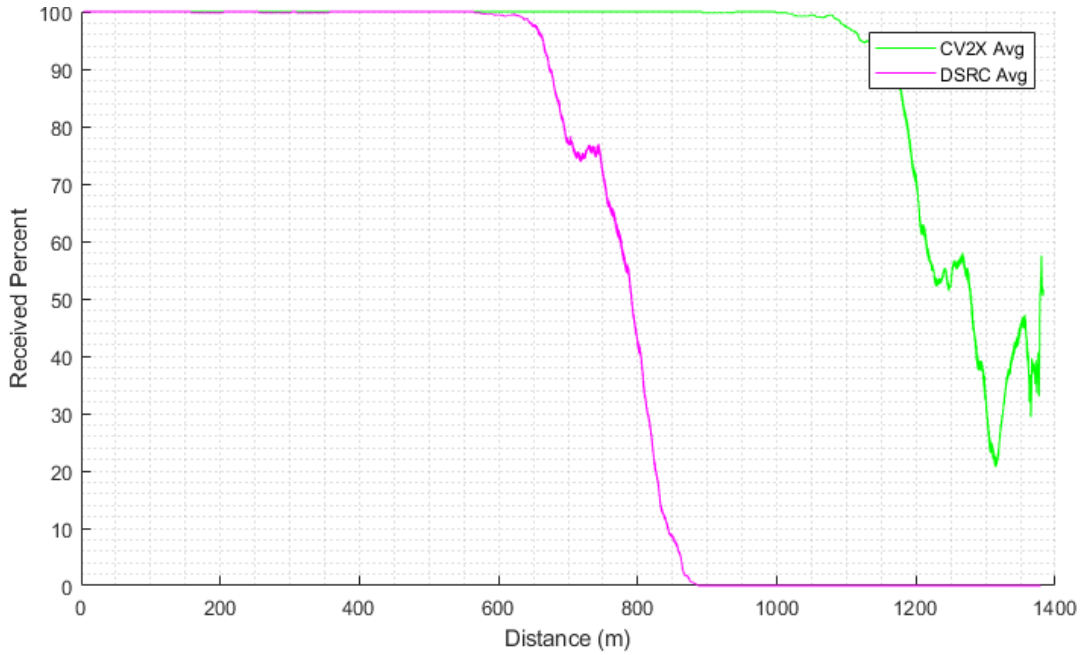
Assess capability to resist adjacent chanr

Parameter	Value
Tx Power	19 dBm
Utilization	96%

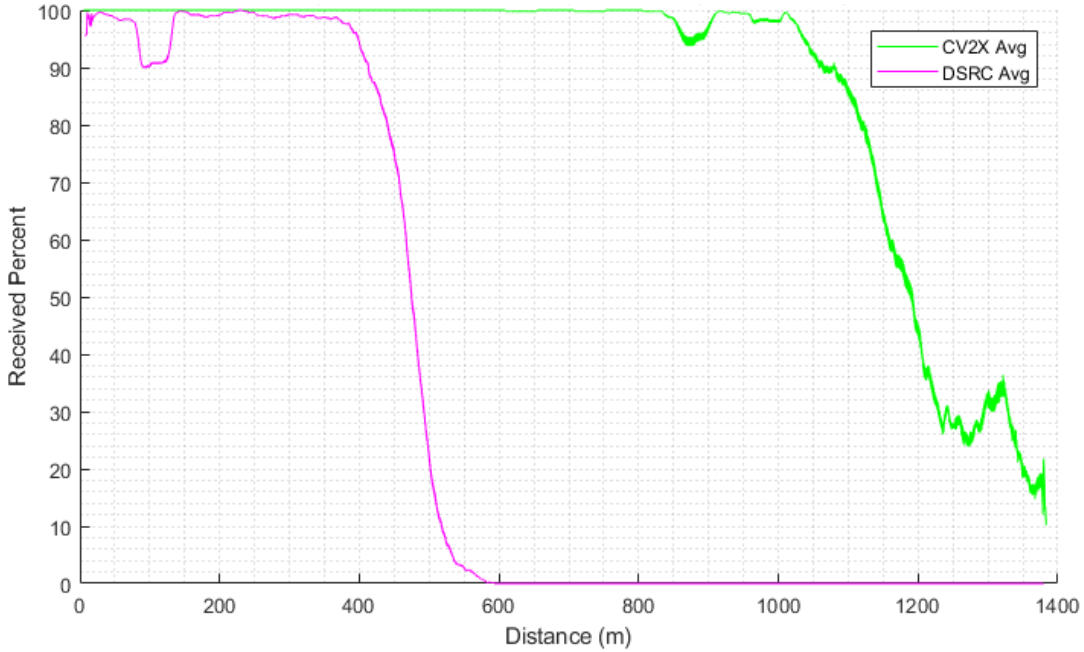


Line-of-sight Adjacent Channel Interference Test Results

Interference vehicle: OFF



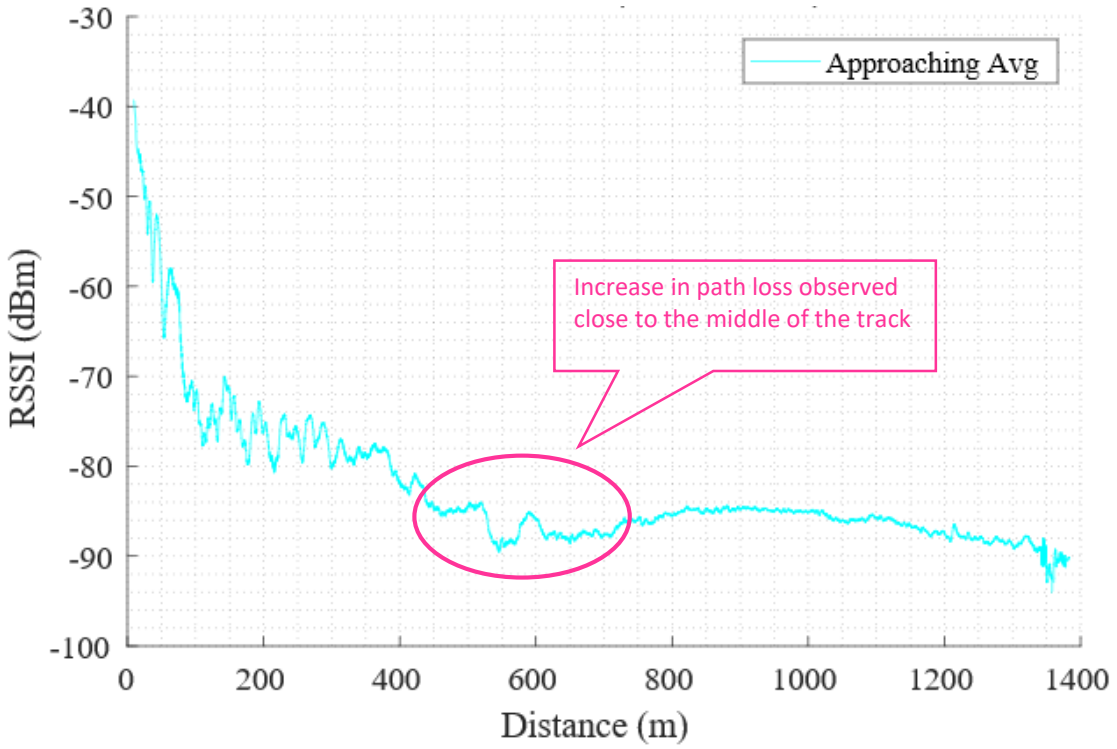
Interference vehicle : Transmitting

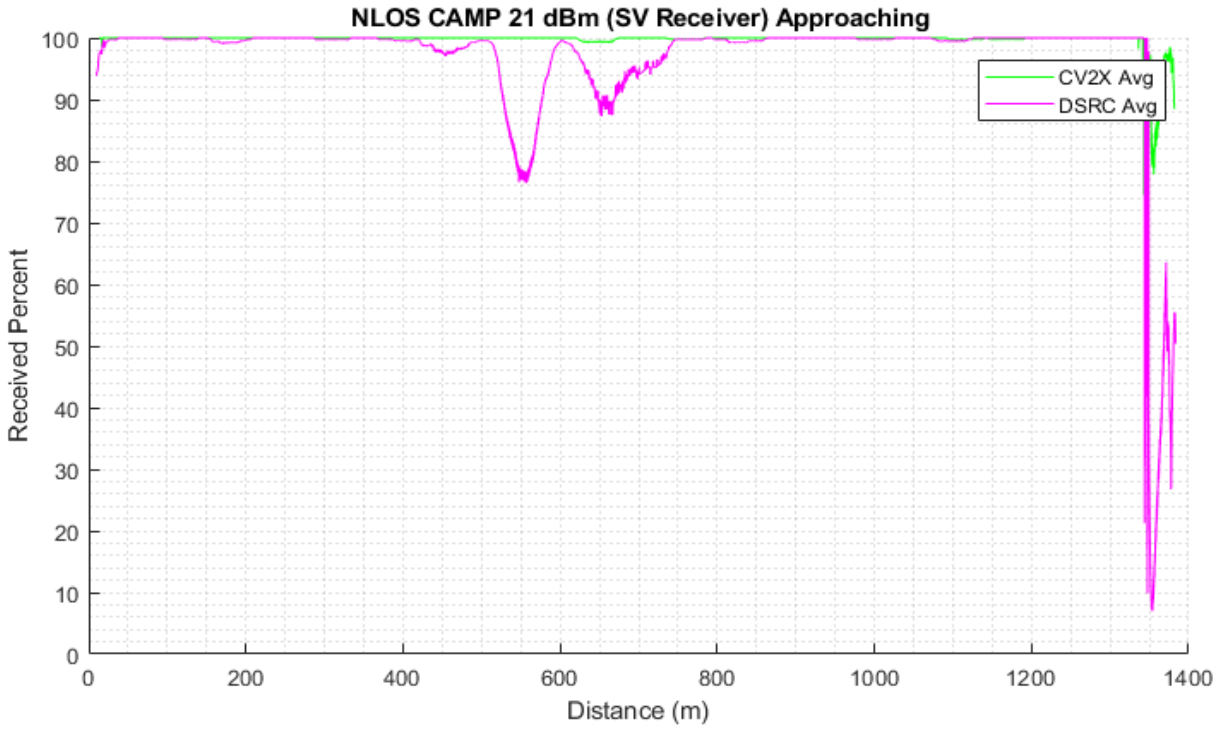


Moving vehicle transmitting and approaching, Stationary vehicle receiving

CV2X is more resilient to adjacent channel V2X interference than DSRC.

CAMP Shadowing Test Results (21 dBm)





Range for both technologies exceeds 1.4km at higher power
Drop in PRR consistent for both technologies