Cellular Vehicle-to-everything (C-V2X) Communication for Connected & Automated Vehicles

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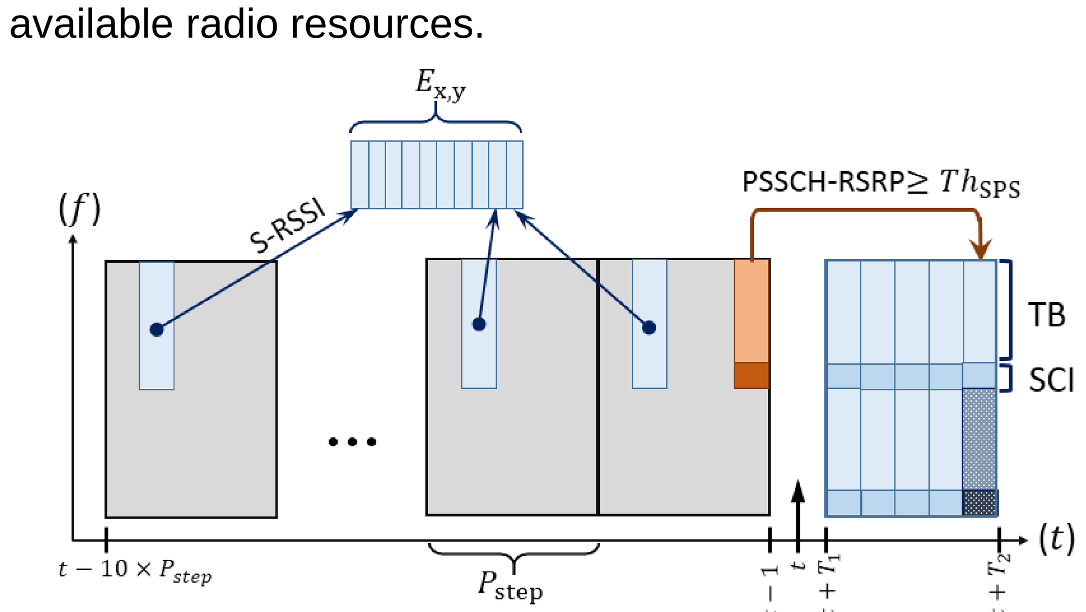
1. Overview

- **Vehicle-to-everything (V2X)** communication enables vehicles, roadside vulnerable users, and infrastructure facilities to communicate in an ad-hoc fashion.
- **Cellular V2X (C-V2X)**, which was introduced in the 3rd generation partnership project (3GPP) release 14 standard, has recently received significant attention due to its perceived ability to address the scalability and reliability requirements of vehicular safety applications.
- We investigate the C-V2X multiple access mechanism for **high-density vehicular networks**, as it can strongly impact the key performance indicators such as latency and packet delivery rate.
- Our simulation results indicate that a unified system configuration may be necessary for all vehicles, as it is mandated for IEEE 802.11p, in order to obtain the optimum performance.

2. Multiple Access (SB-SPS)

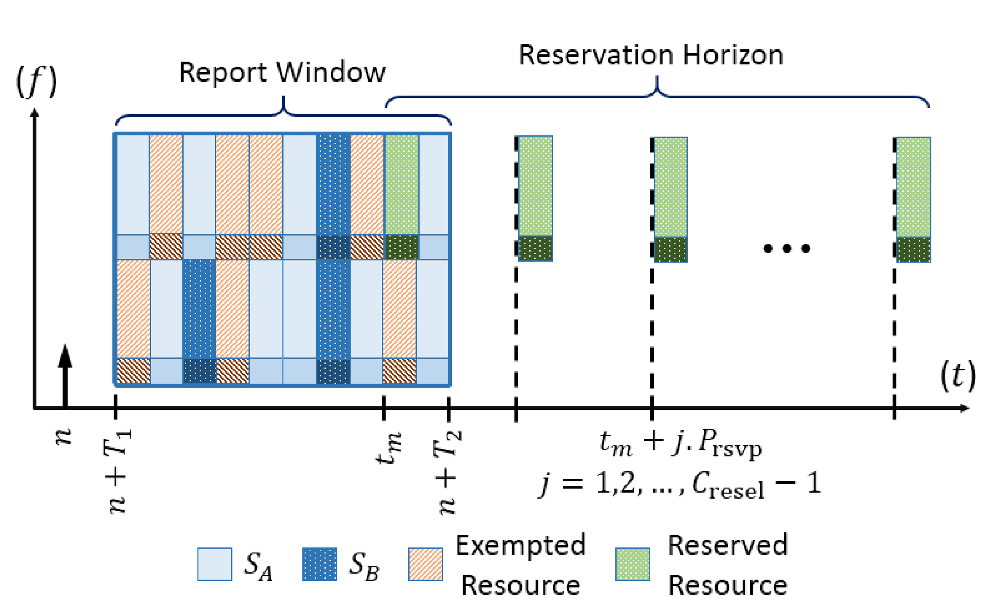
- The LTE sidelink mode-4 the **sensing-based semi-persistent scheduling (SB-SPS)**, which shrinks the available resources and significantly decreases the collision probability by limiting every UE to select resources from a narrowed-down set of available radio resources.



- The SB-SPS mechanism relies on channel sensing, exempting the previously-occupied resources (top figure) and sorting them by E-score, defined as follows

$$E_{x,y} = \frac{1}{10}\sum_{i=1}^{10}\left[\sum_{j=x}^{x+L_{subCH}-1} \mathrm{RSSI}_{(y-i.P_{step}),j}\right]$$

- Every node reserves its required radio resources in a semi-persistent fashion (bottom figure).

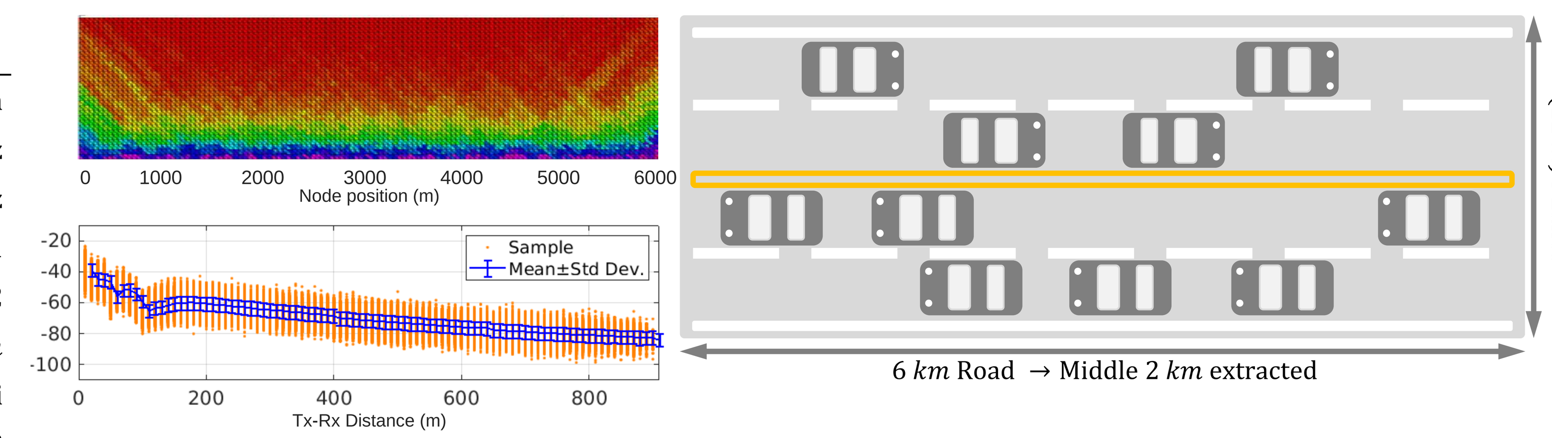


3. NSL C-V2X Simulator

We implemented a link-level event-based simulator using the ns-3 simulation environment. Our physical channel model is extracted from the field test data on the **FTT-A Fowlerville Proving Ground** in MI, USA. We conducted our studies on a platoon of vehicles in a straight highway where vehicles were arranged in 4 lanes in the stretch of $6\ km$ and with $3\ \mathrm{m}$ inter-lane spacing.

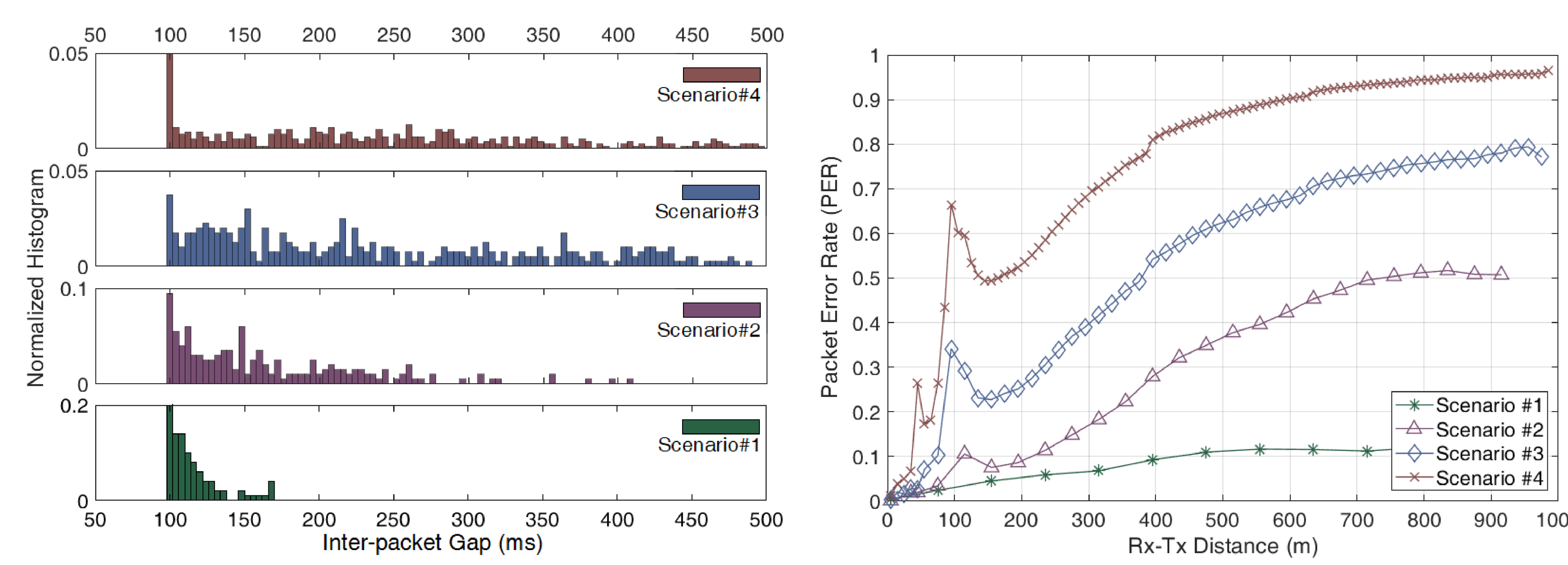
Simulation Parameters

Time (T_{sim})	20 s	Power (P_{TX})	23 dBm
Packet Size	190 B	Carrier Freq.	5.86 GHz
$1/T_{Gen}$	10 Hz	Bandwidth	10 MHz
MCS Index	5	Tx Antenna	1
$\{T_1, T_2\}$	$\{1, 100\}$	Rx Antenna	2
PSSCH RBs	20	Antenna h.	$1.5\ m$
P_{rsvp}	100 ms	Antenna G.	3 dBi
P_{step}	100 ms	Noise Figure	9 dB



(Left-top) Edge-effect (Left-bottom) Fowlerville Channel Model (Right) Vehicle mobility model

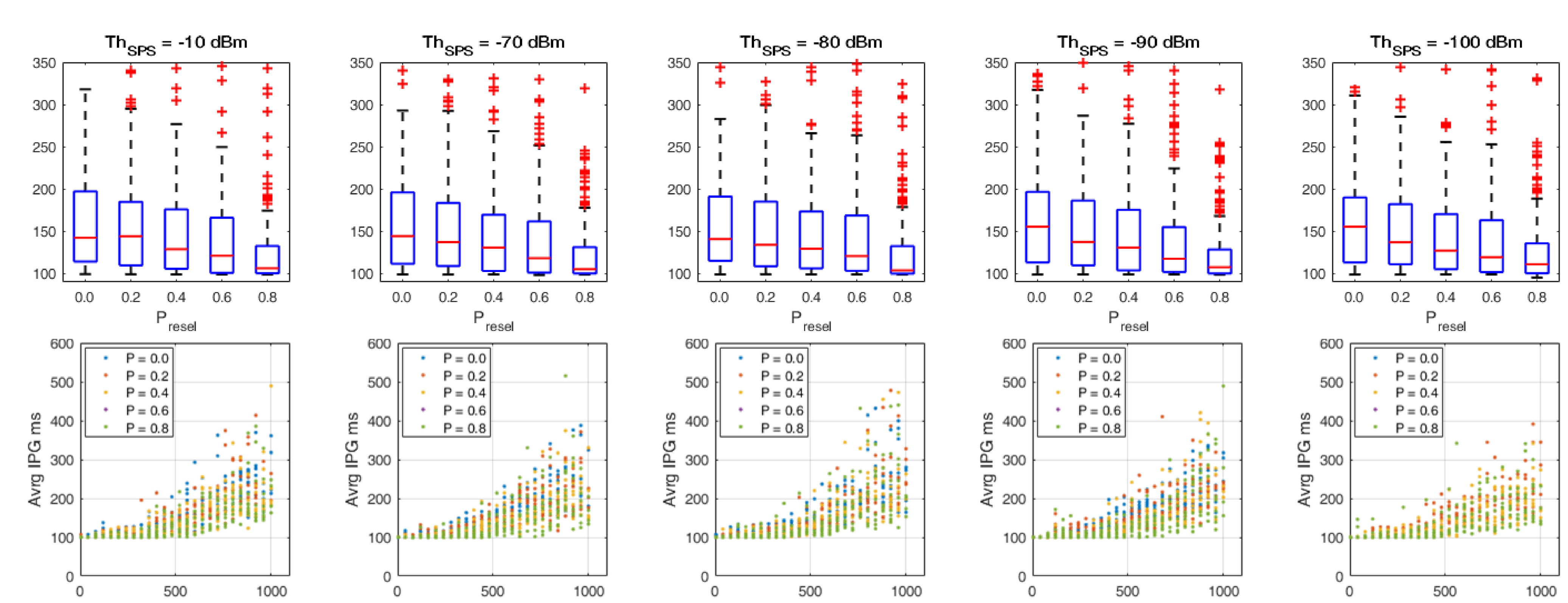
4. High-density Vehicular Scenarios: Analysis and Simulation Results



Vehicle Density

Scenario #1	12.5 v/km. lane
Scenario #2	25 v/km. lane
Scenario #3	50 v/km. lane
Scenario #4	100 v/km. lane

- Top figures: Network performance illustrated by **Packet Error Rate** (Right) and **Inter-packet Gap** (Left) for 4 vehicle scenarios.
- Bottom figures: The impact of tunable multiple access parameters on the network performance. IPG plotted versus distance (top row) and statistical distributions (bottom row)

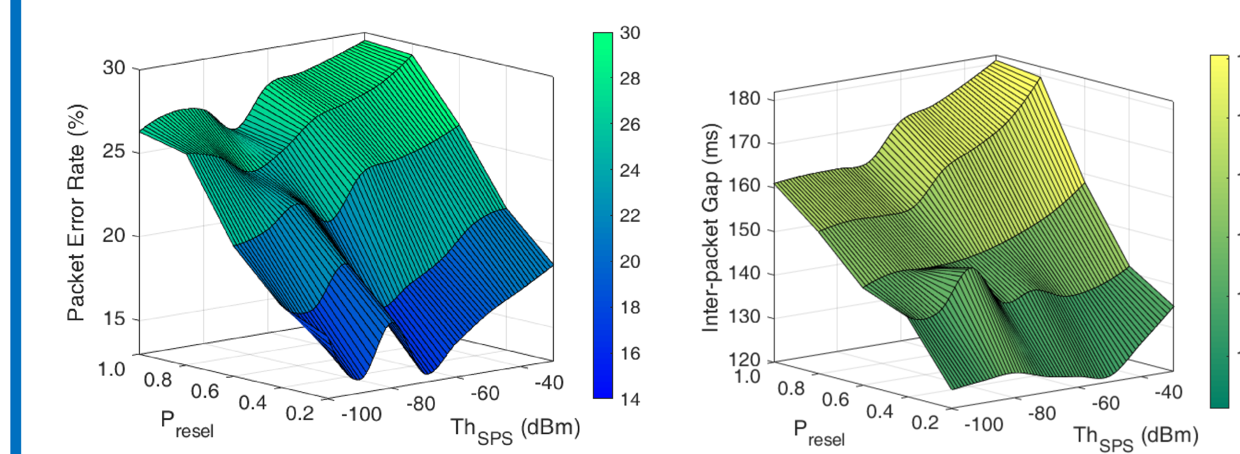


We thank to **Ford Motor Company, Research and Advanced Engineering (R&A)** for supporting this research project at the Networked Systems Lab (NSL), University of Central Florida. Related publications:

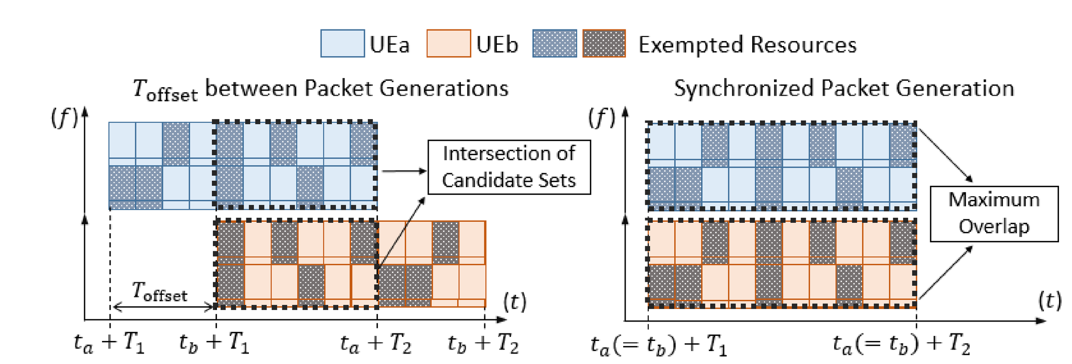
B. Toghi *et al.*, "Multiple Access in Cellular V2X: Performance Analysis in Highly Congested Vehicular Networks ," *2018 IEEE Vehicular Networking Conference (VNC 2018)*, Taipei, Taiwan

4. Analysis and Results (cont.)

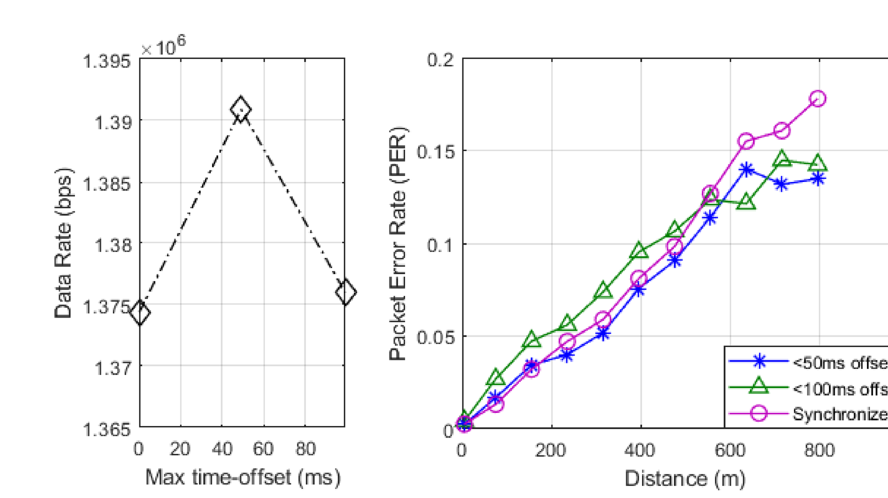
- The impact of two **MAC** (resource reselection probability P_{resel} and **PHY** (sensing power threshold TH_{SPS}) layer parameters on the multiple access performance is illustrated for packet error rate (Left) and inter-packet gap (Right)



- The 3GPP Release 14 standard mandates synchronized subframes among user equipments (UEs). Time synchronization is provided by GNSS. However, the packet generation time can be synchronous or asynchronous.



- The impact of the packet generation synchronization on broadcast throughput and packet error rate.



5. Concluding Remarks

- The **C-V2X communication** is being considered as a strong alternative for the vehicular communication technologies such as **DSRC**.
- Our results demonstrate the significance of the **parameter tuning** in the resource allocation mechanism to maximize performance and reliability in high-density networks.
- We conclude that the introduced parameters have to be regulated for all vehicles by application layer standards, similar to what has been defined for DSRC in **SAE J2945/1** standard.
- New workgroups are formed by the Society of the Automotive Engineers (SAE) to develop such standards for C-V2X; the current work progress is filed as **SAE J3161** standard.

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