Scalability Analysis of Cellular V2X Communication for Connected & Autonomous Vehicles

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1. Overview

- **Cooperative vehicle safety (CVS)** applications are introduced to enhance safety end efficiency of intelligent transportation systems.
- In highly congested vehicular scenarios, a sophisticated **congestion control** solution is vital in order to maintain the network performance required for safety-related applications.
- Propose hybrid design for the **DCC-enabled C-V2X** and evaluate its performance in dense vehicular scenarios under heavy network load.
- Analyze the observations and highlight some important challenges and effects that result from the porting exercise. Based on the study, we share our conclusions on the applicability of DCC for C-V2X technology and identify directions for future study.

2. Congestion Control Alg

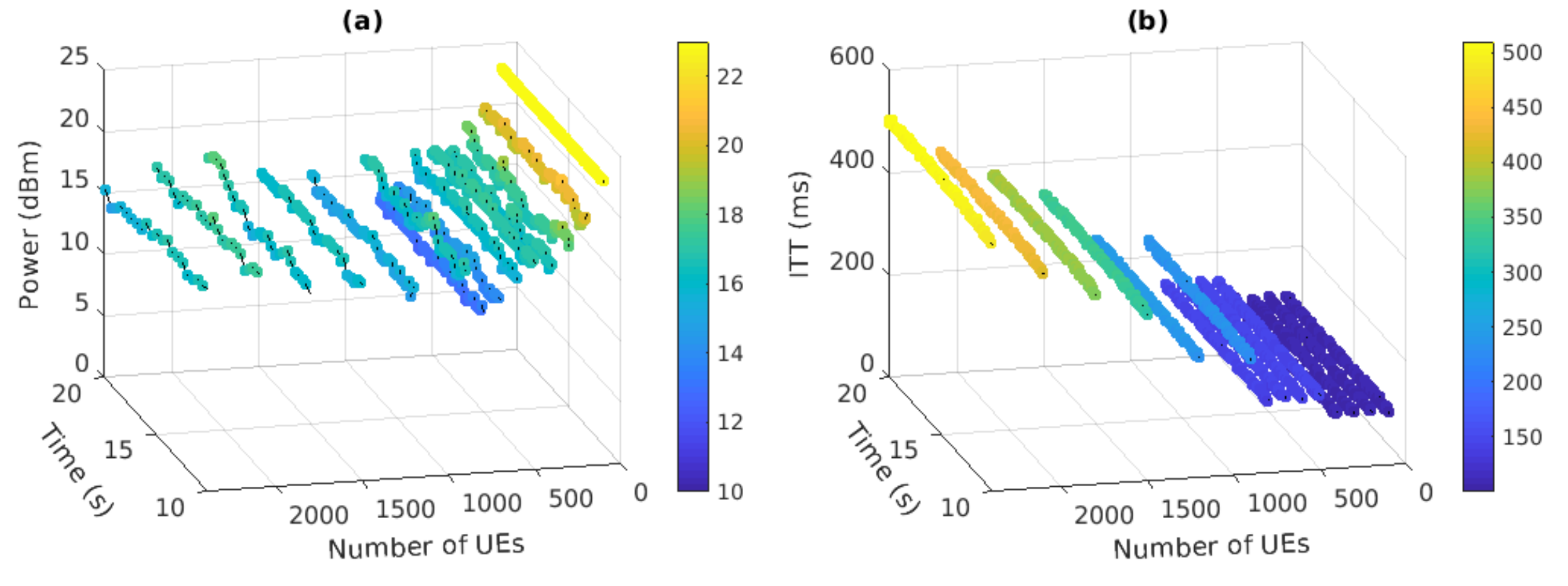
- Rate control algorithm determines the inter-transmit time (ITT) based on the measured vehicle density in its proximity, N_{STA}.

$$\mathrm{ITT} = \begin{cases} 100\,\mathrm{ms}, & N^S_{STA} \le \mathcal{B} \\ \frac{N^S_{STA}}{\mathcal{B}} \times 100\,\mathrm{ms}, & \mathcal{B} < N^S_{STA} < \frac{\mathrm{ITT}^{\max}}{100\mathrm{ms}}\mathcal{B} \\ \mathrm{ITT}^{\max}, & \frac{\mathrm{ITT}^{\max}}{100\mathrm{ms}}\mathcal{B} \le N^S_{STA}. \end{cases} \quad (1)$$

- The Stateful Utilization based Power Adaptation (SUPRA) scheme enables UEs to control their communication range and avoid excessive packet collisions based on channel busy percentage (CBP).

$$P_{k+1} = P_k + \eta \times \Big(g(\mathrm{CBP}) - P_k\Big)$$

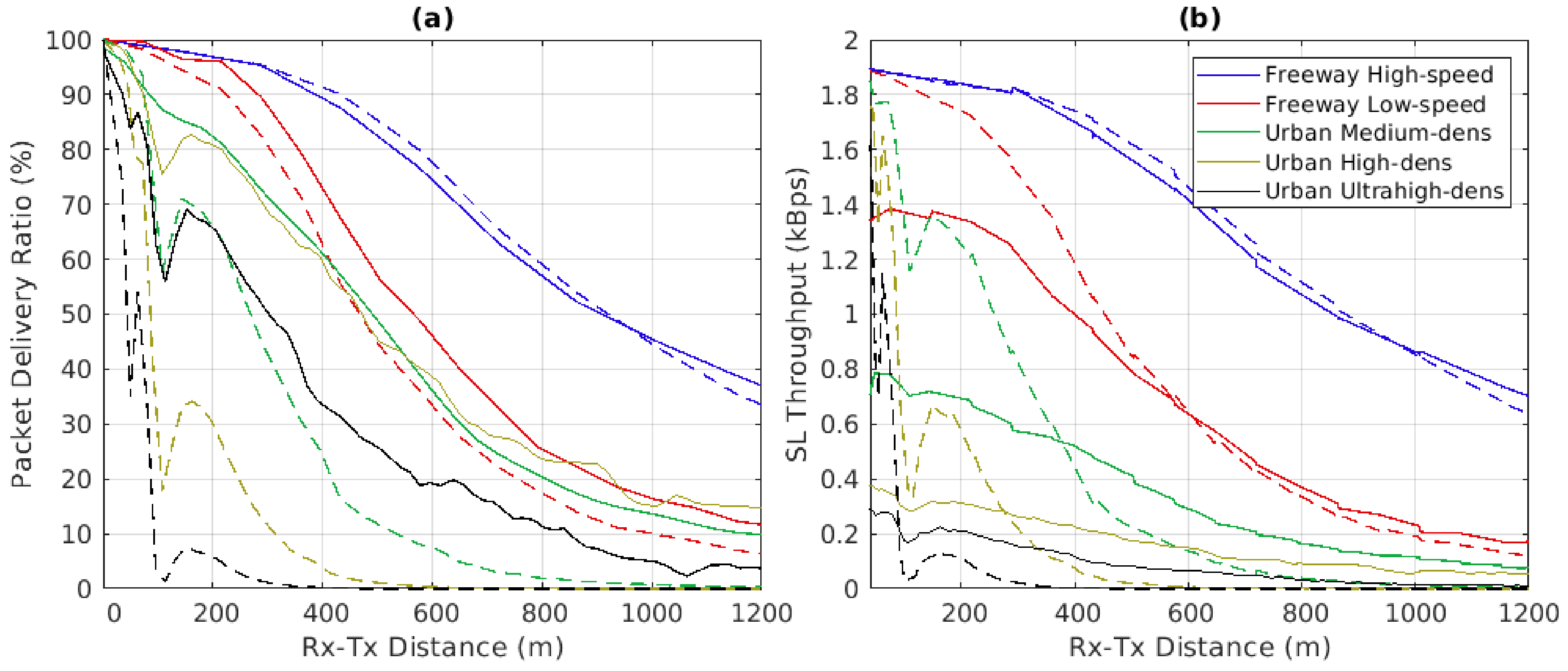
$$g(\mathrm{CBP}) = \begin{cases} P_{\max}, & \mathrm{CBP} < U_{\min} \\ P_{\min} + \left(\frac{U_{\max} - \mathrm{CBP}}{U_{\max} - U_{\min}}\right) & \\ \qquad \times (P_{\max} - P_{\min}), & U_{\min} \le \mathrm{CBP} < U_{\max} \\ P_{\min}, & U_{\max} \le \mathrm{CBP}. \end{cases} \quad (2)$$



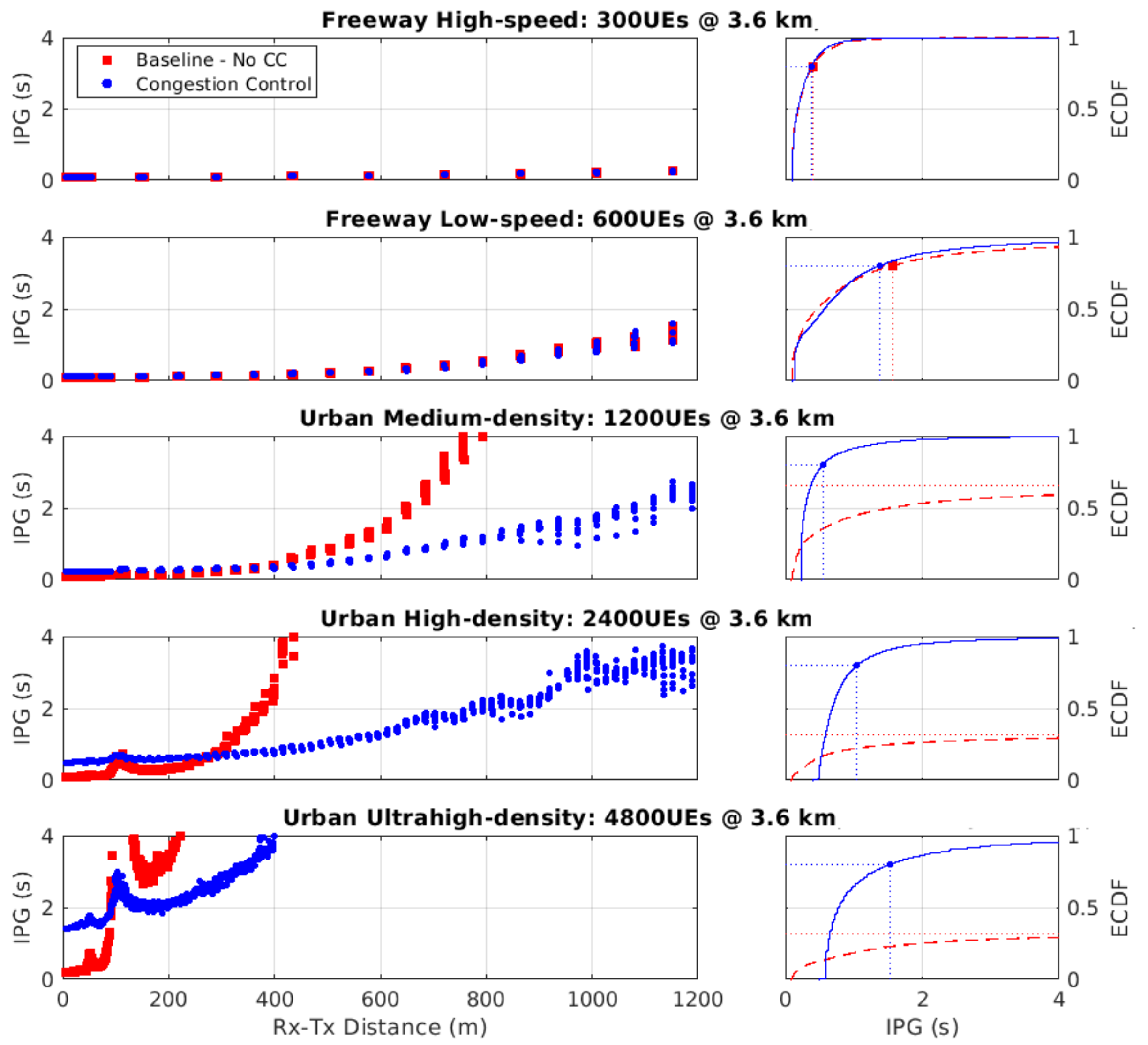
- Effect of node density on **(a)** Range Control, **(b)** Rate Control.

4. Scalability Study: Analysis and Simulation Results

- DCC mechanism does not intervene in the lowest density scenario, i.e., Freeway High-speed, due to the configured rate and range control parameters.
- The effect of DCC becomes noticeable in higher density scenarios, in which the baseline C-V2X degrades heavily as PDR drops to less than 10% in relatively near distances and UEs lose communication.



- Performance comparison of baseline (dashed) and DCC-enabled (solid) C-V2X in different density and mobility scenarios. Shown in terms of: **(a)** packet delivery ratio, **(b)** sidelink throughput



- Performance comparison of baseline (red squares) and DCC-enabled (blue circles) C-V2X in different density and mobility scenarios. **Left:** Average IPG vs. distance, **Right:** ECDF of IPG marked with 80th percentile.

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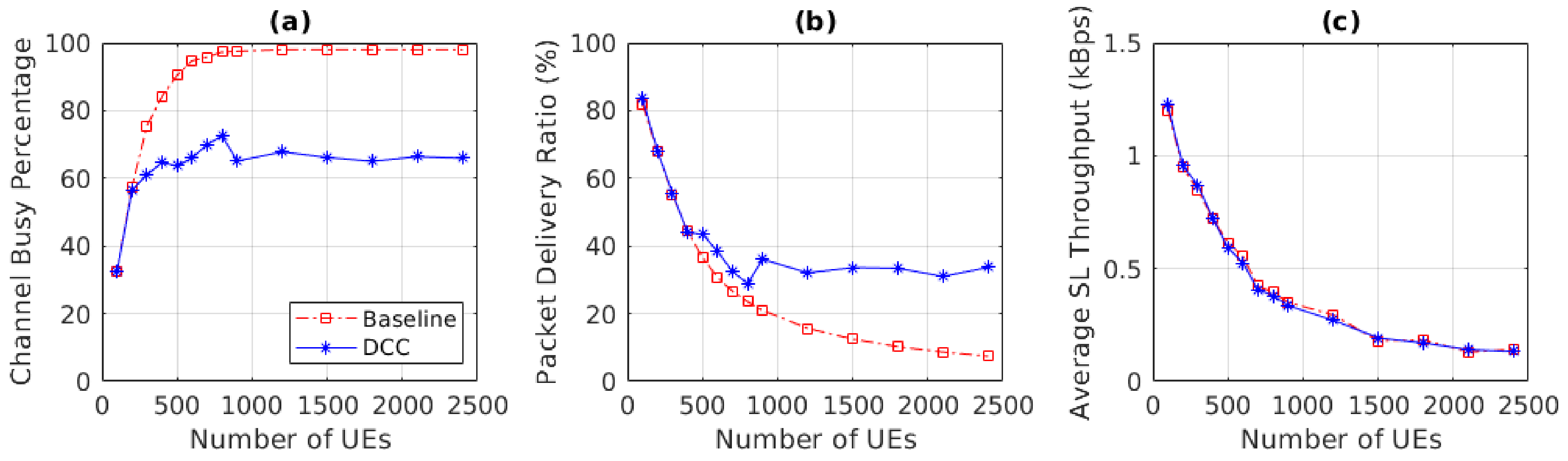
Related publications:

B. Toghi *et al.*, "Analysis of Distributed Congestion Control in Cellular Vehicle-to-everything Networks ," *2019 IEEE Vehicular Technology Conference (VTC-Fall 2019)*, Honolulu, HI

5. Impact of Tunable Params

- This figure summarizes the comparison between baseline and DCC-enabled C-V2X.
- **(b)** illustrates how DCC avoids communication degradation, in terms of PDR, compared to the baseline. Another noticeable point is, although Rate Control decreases the transmission rate in high density cases.
- **(c)** shows that the average SLT has not dropped, compared to baseline.



- **(a)** Throughput in near distances can be improved with compromise on PDR by employing a less aggressive Rate Control Scheme.
- **(b)** More aggressive Range Control schemes not only do not make an improvement but also downgrade the performance in far distances.
- **(c)** No significant performance change has observed via varying the MAC parameters.

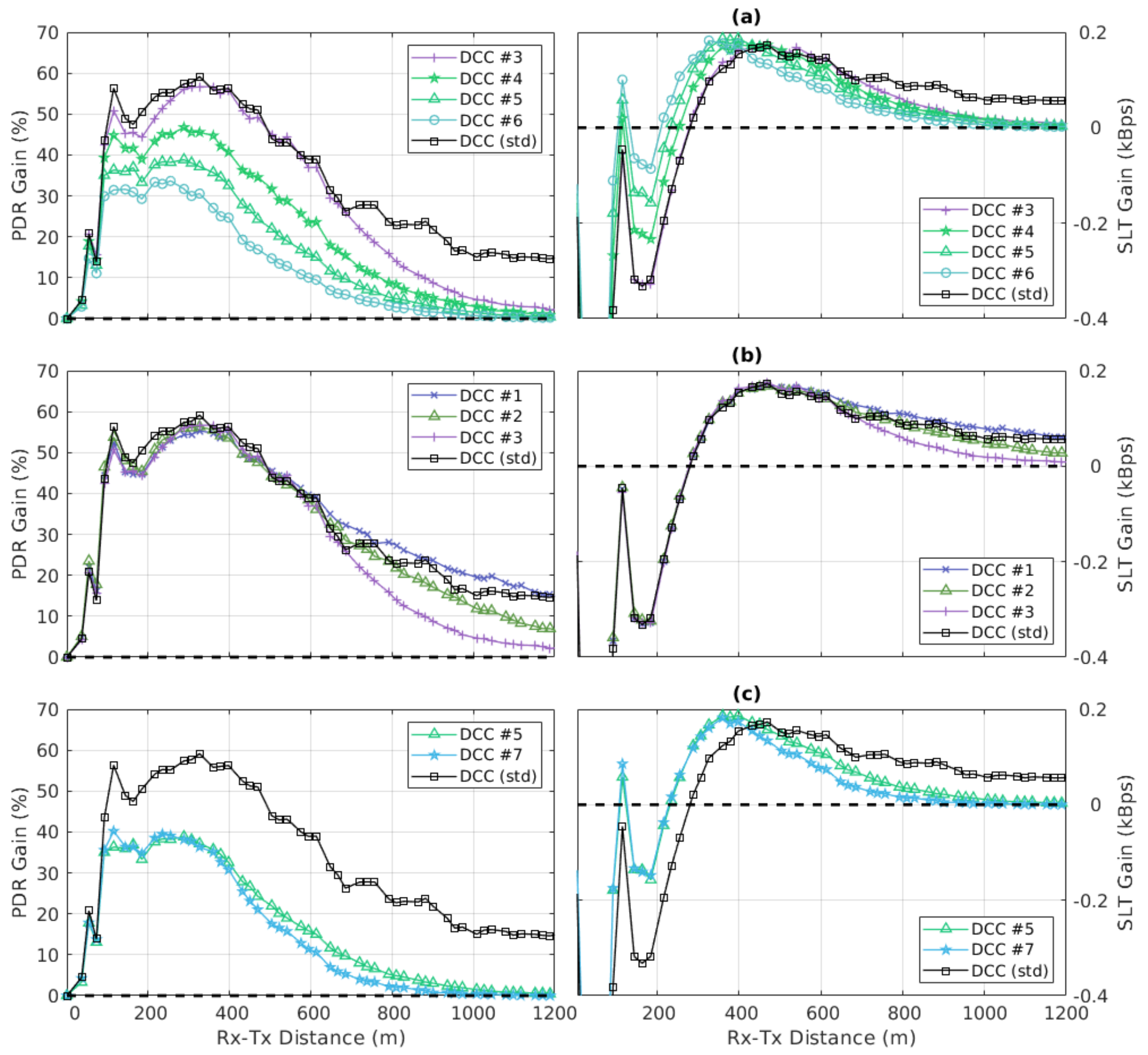
TABLE I: Simulation Parameters & Configurations

Time (T_{sim})	120 s	$\mathcal{B}$	25
Payload Size	190 B	η	0.5
MCS Index	5	$P_{\min}$	10 dBm
$\{T_1, T_2\}$	$\{1, 100\}$	$P_{\max}$	23 dBm
Carrier Freq.	5860 MHz	$U_{\min}$	50%
Bandwidth	10 MHz	$U_{\max}$	80%
$\mathcal{P}_{\mathrm{resel}}$	0.2	$\mathrm{ITT}^{\max}$	600 ms
SLRRC	∈[5, 15]	Th_{SPS}	-85 dBm

TABLE II: Test Congestion Control Schemes

DCC Scheme	$P_{\max}$	$P_{\min}$	$U_{\max}$	$U_{\min}$	$\mathcal{B}$
DCC #1	23dBm	23dBm	80%	50%	25
DCC #2	23dBm	10dBm	50%	30%	25
DCC #3	23dBm	5dBm	50%	30%	25
DCC #4	23dBm	5dBm	50%	30%	35
DCC #5	23dBm	5dBm	50%	30%	45
DCC #6	23dBm	5dBm	50%	30%	55
DCC #7[a]	23dBm	0dBm	50%	30%	45

[a] $\mathcal{P}_{\mathrm{resel}} = 0.2$, SLRRC∈[1, 5].



5. Concluding Remarks

- Previous studies have shown that DSRC requires a sophisticated congestion control mechanism to combat performance degradation in high density environments.
- DCC algorithm was standardized by SAE for DSRC to improve the performance under high network loads. Our own study so far indicates the same need for C-V2X.
- Proposed DCC-enabled design and evaluated the performance of transmission rate and range control components of DCC.
- Rate control has more significant impact on performance, compared to range control.

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