Enhanced C-V2X Mode-4 Subchannel Selection

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Contents

Figure 1:Connected world

Background

- 3GPP[1] proposed in Release 14, two novel schemes to support sidelink vehicular communications
  - C-V2X *mode-3* (centralized)
  - C-V2X[2] *mode-4* (distributed)

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[2] C-V2X: Cellular Vehicle–to–Everything
[3] D2D: Device–to–Device communications

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- C-V2X *modes* are based on LTE-D2D[3] technology, where similar communication modalities were proposed.

- However, in LTE-D2D (introduced for public safety) the ultimate objective is to prolong batteries lifespan (at the expense of compromising on latency).

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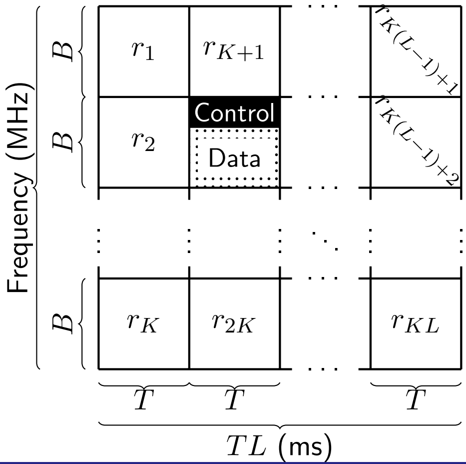
Sidelink Subchannels



- T: duration of a subframe
- K: number of subchannels per subframe
- L: total number of subframes for allocation
- B: subchannel bandwidth

C-V2X Mode-4 Scenario

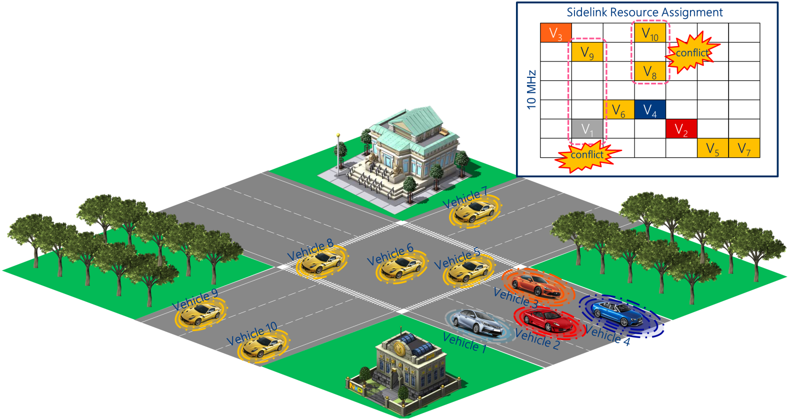


Figure 2:C-V2X Mode-4 Scenario

C-V2X Mode-4 Operation

- Vehicles typically exchange **cooperative awareness messages (CAMs)**[6].

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- Vehicles autonomously reserve a subchannel on a semi-persistent basis[7] to add predictability.

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Semi-Persistent Scheduling (SPS) Principle

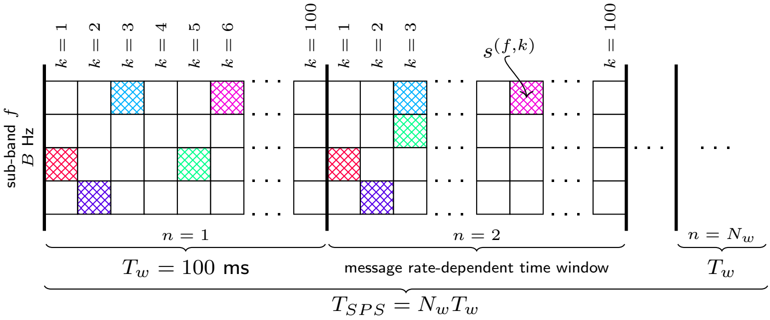

Figure 3:SPS operation principle

Mode-4 Scheduling

- The scheduling scheme in C-V2X *mode-4* consists of the following stages.
  - **Power sensing** in each subchannel
  - **Subchannel ranking**
  - **Subchannel selection** for semi-persistent transmissions
  - (Optional) Random retransmissions

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- A vehicle autonomously reserves a subchannel on a semi-persistent basis to add predictability.
- Thus, vehicles can understand the subchannels utilization patterns and reduce the number of packet collisions.

Mode-4 Scheduling

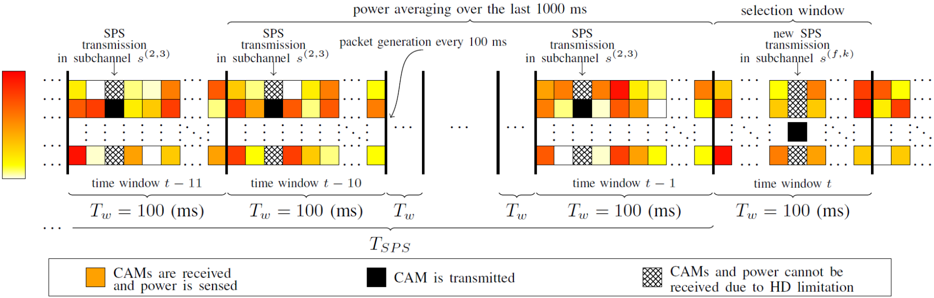

Figure 4:Scheme with joint SPS scheduling and random retransmissions

Power Sensing

$$\varepsilon_i^{(n,f,k)} = \begin{cases} \displaystyle\sum_{\substack{j=\{u|v_u\in\mathcal{V}^{(n,k)}\}\\ u\neq i}} I_p P_j \frac{G_t \cdot G_r}{\mathcal{X}_{ij}^{(n)} \cdot PL_{ij}^{(n)}} + P_\sigma, & \text{if } (*) \\ \infty, & \text{otherwise} \end{cases} \quad (1)$$

where $(*) : k = \{m \mid \mathcal{S}_i^{(n)} \cap \{s^{(1,m)}, \ldots, s^{(F,m)}\} = \emptyset\}$
$P_j = P_T$: transmit power from vehicle v_j.
$PL_{ij}^{(n)}$: path loss between vehicles v_i and v_j.
$\mathcal{X}_{ij}^{(n)}$: correlated shadowing between vehicles v_i and v_j.
$\mathcal{V}^{(n,k)}$: Set of vehicles that use the any subchannel in subframe k.

Exponentially-Weighted Moving Average

When $\alpha = 1$, the power averaging is compliant with the standardized linear average proposed by 3GPP. The proposed average power is given by

$$\tilde{\varepsilon}_i^{(n,f,k)} = \frac{\sum_{l=1}^{10} \alpha^l \varepsilon_i^{(n-l,f,k)}}{\sum_{l=1}^{10} \alpha^l}, \qquad (2)$$

where $\alpha \leq 1$ is an exponential weighting factor.

Simulation Parameters

Table 1: Simulation parameters

Description	Symbol	Value	Units
Number of RBs per subchannel (per subframe)	-	30	-
Number of sub-bands	F	3	-
Number of subchannels per sub-band	-	100	-
Number of subchannels	-	300	-
CAM message rate	Δ_{CAM}	10	Hz
CAM size	M_{CAM}	190	bytes
MCS	-	7	-
Transmit power per CAM	-	23	dBm
Transmit power per RB	P_T	6.67	mW
Effective coded throughput (24 CRC bits)	ρ	0.9402	bps/Hz
Throughput loss coefficient [?]	λ	0.6	-
SINR threshold	γ_T	2.9293	dB
Distance between Tx and Rx	D_x	50-300	m
Scheduling period [?]	T_{SPS}	0.5-1.5	s
Antenna gain	G_t, G_r	3	dB
Shadowing standard deviation	$\mathcal{X}_\sigma$	7	dB
Shadowing correlation distance	-	10	m

Vehicular Traces

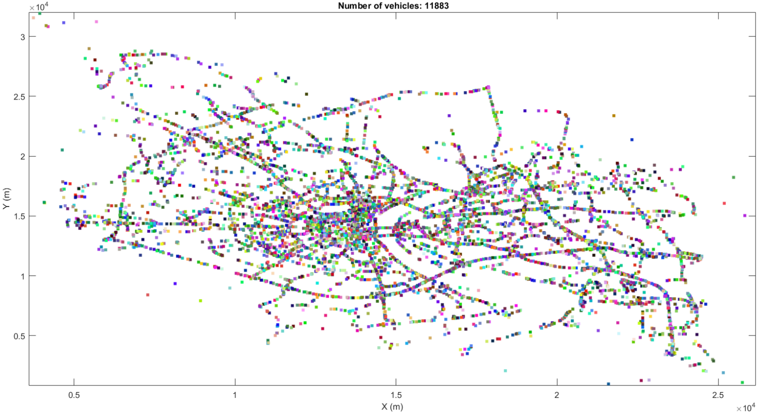

Figure 5:Real vehicular traces

Simulations

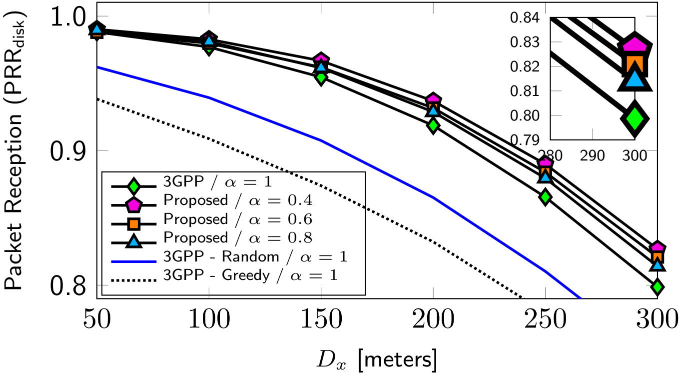

Figure 6:PRR_{disk} for an urban scenario with $p_{keep} = 0$

Simulations

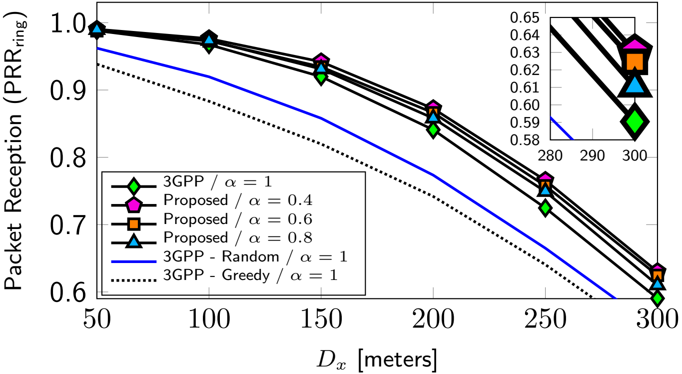

Figure 7:PRR$_{ring}$ for an urban scenario with $p_{keep} = 0$

PRR Degradation Origin

Distance	PRR (Disk)	HD-SF (Disk)	HD-SC (Disk)	Propagation (Disk)	CCI (Disk)	IBE (Disk)	PRR (Ring)	HD-SF (Ring)	HD-SC (Ring)	Propagation (Ring)	CCI (Ring)	IBE (Ring)
50	98.8194	0.1262	0.1050	0.0000	0.8664	0.0830	98.8194	0.1262	0.1050	0.0000	0.8664	0.0830
100	97.7037	0.2167	0.1093	0.0031	1.5919	0.3753	96.7375	0.2952	0.1131	0.0058	2.2195	0.6289
150	95.4630	0.3354	0.1076	0.0799	2.9353	1.0788	91.9840	0.5197	0.1036	0.1990	5.0226	2.1711
200	91.8708	0.4291	0.1025	0.6057	5.0871	1.9048	84.0963	0.6320	0.0916	1.7436	9.7441	3.6924
250	86.5511	0.5163	0.1017	2.3065	7.8852	2.6392	72.4718	0.7469	0.1005	6.8081	15.2899	4.5828
300	79.8627	0.5623	0.1148	5.5492	10.7124	3.1986	59.0403	0.7051	0.1553	15.6443	19.5148	4.9402

Figure 8:Classification (in percentage) of missed/undecodable packets - Urban scenario with $\alpha = 1$ and $p_{keep} = 0$

- PRR: packet reception ratio
- HD-SF: errors due half-duplex impairment in the same subframe
- HD-SC: errors due half-duplex impairment in the same subchannel
- Propagation: errors due to path-loss and shadowing
- CCI: errors due to co-channel interference
- IBE: errors due to in-band emissions

Conclusions

- In this work, we have presented link-level simulation results on the recently introduced technology C-V2X Mode 4.
- A new power averaging idea based on exponential weighting was proposed. It was shown that this modification improves the performance of the distributed scheduling C-V2X.
- In addition, the nature of each type of conflict was classified. We have observed that most of the packet errors are due to either CCI or IBE.
- **Future work:** Decentralized channel congestion control approaches will be studied in order to improve the performance of this distributed technology.

Questions

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