

Offloading Platooning Applications from 5.9 GHz V2X to Radar Communications: Effects on Safety and Efficiency

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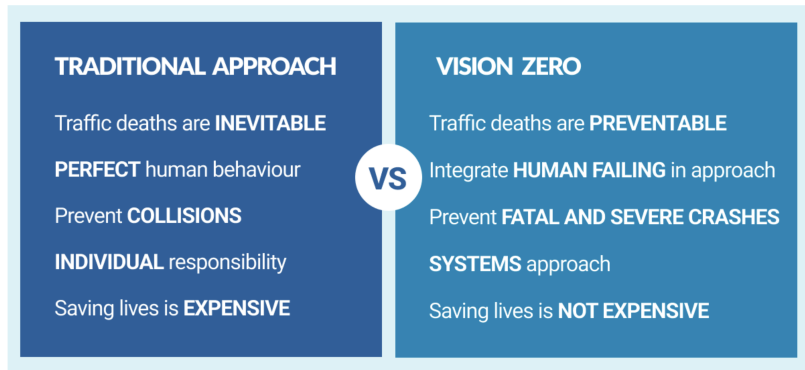
About me

- Affiliation: senior lecturer in applied mathematics at Halmstad University, Sweden

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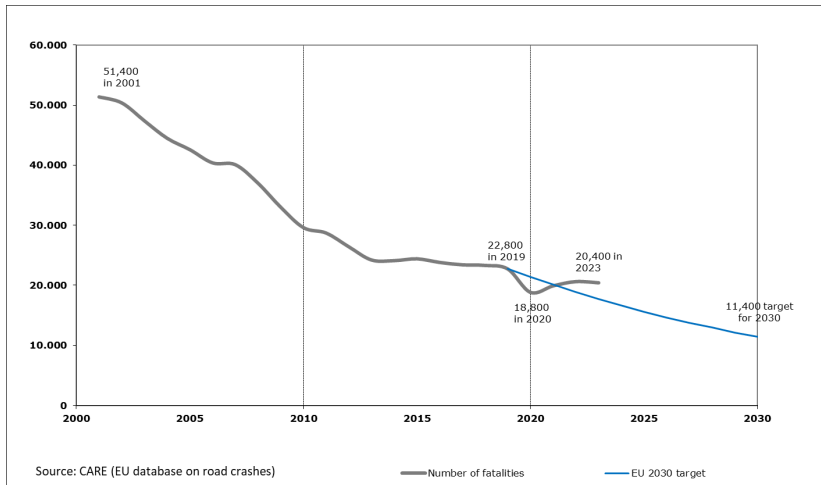
- Research interests: future mobility, transport flows, traffic simulations





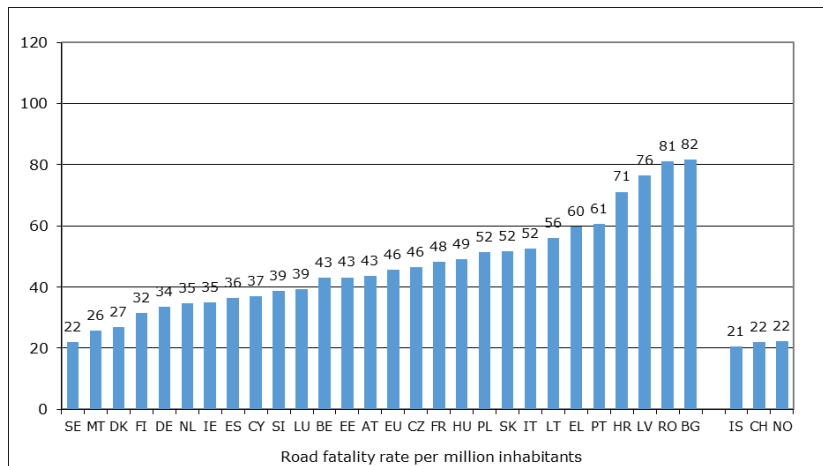
Source: Source: visionzeronetwork.org

Trend in the number of road traffic fatalities in the EU (2023)



Source: transport.ec.europa.eu

Number of road fatalities per million inhabitants by country (prelim. 2023)



Source: transport.ec.europa.eu

Collision matrix (all roads), 2022

ROAD TRAFFIC FATALITIES IN THE EU IN 2022

by road user and (other) 'main vehicle'
involved in the crash

IN A COLLISION WITH...

FATALITIES	PEDESTRIAN	BICYCLE	MOPED	MOTORBIKE	CAR	LORRY (<3.5T)	HEAVY GOODS VEHICLE (>3.5T)	BUS OR COACH	OTHER VEHICLE/ UNKNOWN	NO OTHER VEHICLE INVOLVED	TOTAL
PEDESTRIANS	1	25	21	112	2409	424	411	102	211	1	3715
CYCLISTS	10	51	12	33	921	158	210	37	76	501	2009
MOPED RIDERS	3	5	3	7	242	44	30	6	20	179	539
MOTORCYCLISTS	19	8	6	94	1442	241	162	28	81	1280	3361
CAR OCCUPANTS	7	7	3	20	2732	559	1450	122	257	4073	9210
LORRY (<3.5T) OCCUPANTS	1	0	0	0	114	87	201	8	16	286	713
HEAVY GOODS VEHICLE (>3.5T) OCCUPANTS	2	0	0	0	32	23	178	5	16	159	415
BUS OR COACH OCCUPANTS	0	1	0	0	15	3	6	4	4	45	78
OTHER/UNKNOWN	0	0	0	3	154	33	49	13	19	283	554
TOTAL	42	97	45	269	8061	1572	2697	325	680	6806	20 594



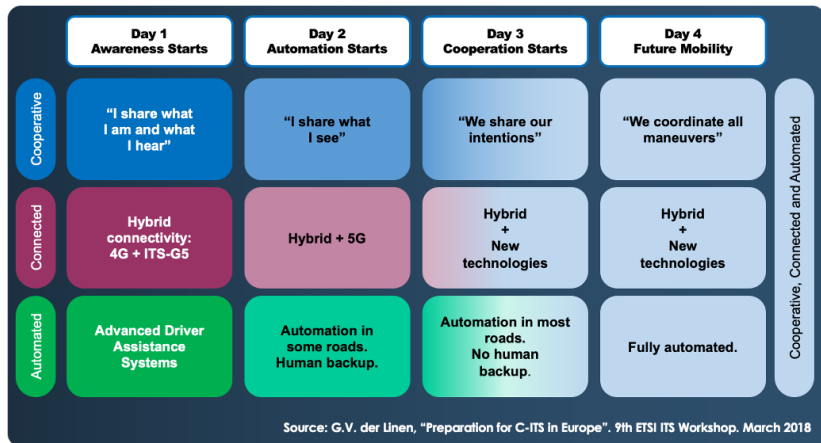
European Commission | Mobility and Transport

Methodological note: the data cover fatalities in single-vehicle crashes and crashes involving one or more traffic users. For the majority of fatal crashes, only one other vehicle is involved in the crash. For multi-vehicle crashes, the 'main vehicle' is the heaviest of the vehicles involved and the likely to be responsible for the most serious consequences. As a result, the figures in each column likely underestimate the number of cases a particular vehicle was involved in a crash. Source: EU CARE database on road crashes.

Data refer to the year 2022 except for IE (2019), LV and SE (2020), EL and MT (2021).

Source: transport.ec.europa.eu

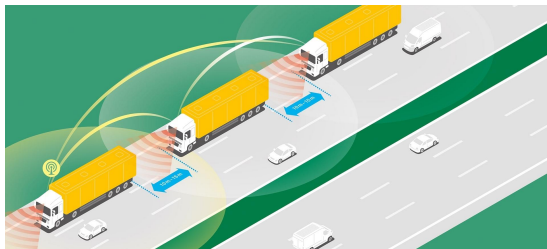
Cooperative, Connected and Automated Mobility



Cooperative, Connected and Automated Mobility

- Automated Mobility
- Cooperative Intelligent Transport System (C-ITS)
 - **Day 1:** Cooperative Awareness (CAMs), Decentralized Environmental Notification (DENMs)
 - **Day 2:** Collective Perception (CPMs)
 - **Days 3+4:** Maneuver Coordination (MCMs).

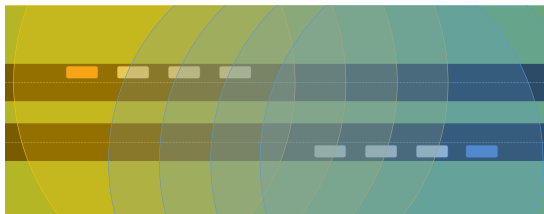
MC-example - platooning (PAMs + unicast PCMs)



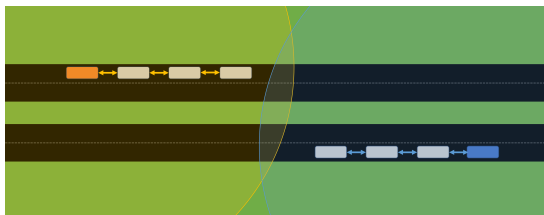
Source: rapp.ch

Network vs RadCom enabled platooning

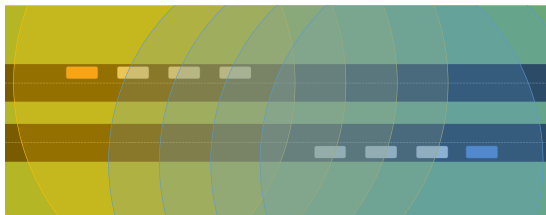
- WiFi-enabled platooning. Network nodes



- RadCom-enabled platooning. Network nodes



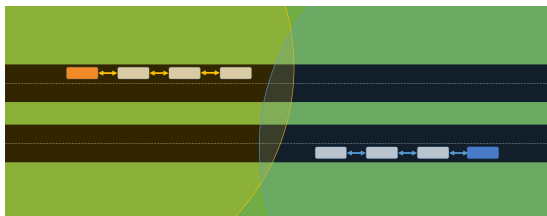
WiFi-enabled platooning



Feature	802.11p	802.11bd
Frequency bands	5.9 GHz	{5.9, 60} GHz
System bandwidth (at 5.9 GHz)	10 MHz	{10, 20} MHz
Data subcarriers (at 5.9 GHz)	48	48 & 52
MIMO	N/A	2 × 2 MIMO
Data rates (in 10 MHz)	3 to 27 Mbps†	Up to 39 Mbps
Relative veh. speed	252 km/h	500 km/h
mmWave (60 GHz)	Not supported	Supported
Localization	N/A	Supported

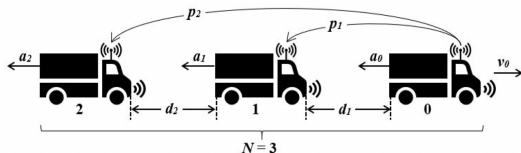
†Only 6 Mbps is typically used.

RadCom-enabled platooning (Preliminary results)



- Frequency — 76-81 GHz
- Bandwidth — 0.15-1 GHz
- Duty cycle — $\delta = 0.1$
- Capacity — $\delta \times 6.9$ Gbps [at 200 m]

Platooning scenario



- Safety metrics — probability to receive DENM

$$\underline{Q} = \prod_{n=1}^{N-1} C_{i-1,i} = \prod_{n=1}^{N-1} (1 - p_i^{\lfloor \frac{\tau_i}{T} \rfloor}), \quad C_{i-1,i} > 0.99999$$

- Receiving times

$$\tau_i = \tau_i(d_{1,\dots,i}, a_{1,\dots,i}, v_0)$$

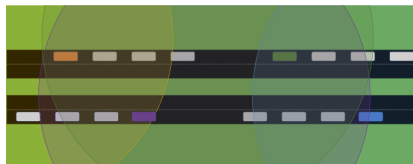
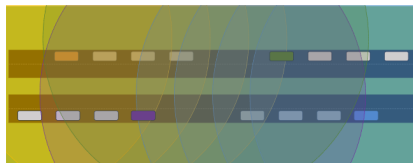
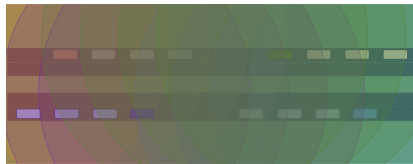
- Optimization for objective function

$$J = \sum_{i=1}^N A_i d_i$$

5.9 GHz Offloading to RadCom. PDR-Simulation

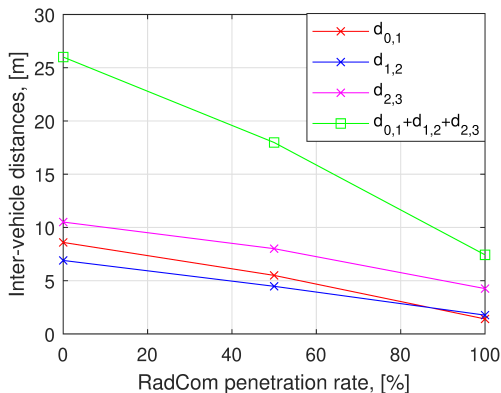
Artery (with Veins)

- Scenario:
5 km road with four lanes in each direction
- Density: 30 veh/km per lane
- PCMs are sent at 20 Hz
- Measurements are taken for 30 seconds
- Metrics:
Average packet delivery ratio (for the 30 messages)
- 3 RadCom penetration rates: 0%, 50%, 100%



5.9 GHz Offloading to RadCom

RadCom Penetration Rate	PDR	S-CBR	Latency
0%	0.6985	0.6176	136.80 ms
50%	0.7859	0.6119	109.57 ms
100%	0.9015	0.2217	1.45 ms



Thank you!

