University of Passau
Faculty of Computer Science and Mathematics

Autonomous Vehicles:

Wireless Networking for Cooperative Maneuvering

8th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS)

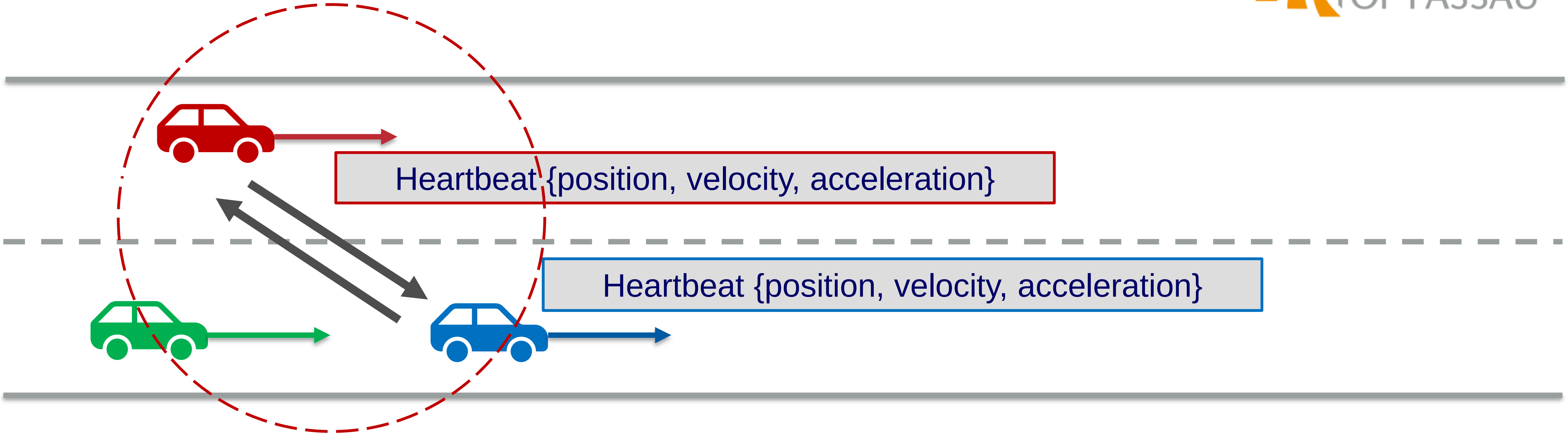
28 April 2022 – Chair of Reliable Distributed Systems – Prof. Dr. Alexey Vinel

"Generalized self-driving is a hard problem, as it requires solving a large part of real-world AI. Didn't expect it to be so hard, but the difficulty is obvious in retrospect"

Elon Musk, July 2021

Foto: Aly Song/Reuters

Step 1. Cooperative Awareness

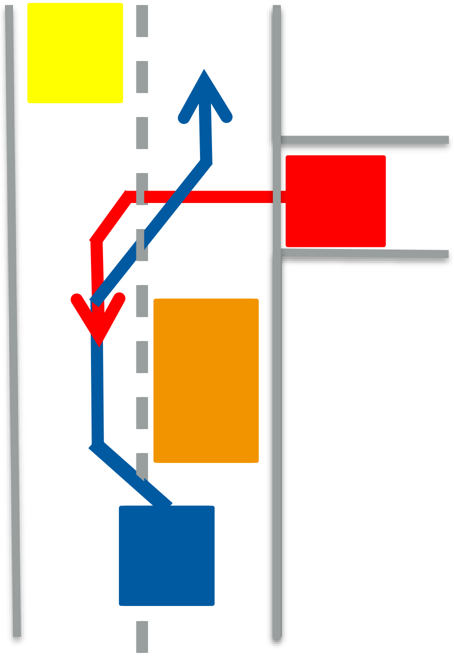


Idea. Each vehicle always communicates its status to its neighbors in **heartbeat** messages

Cooperative awareness as a sensor

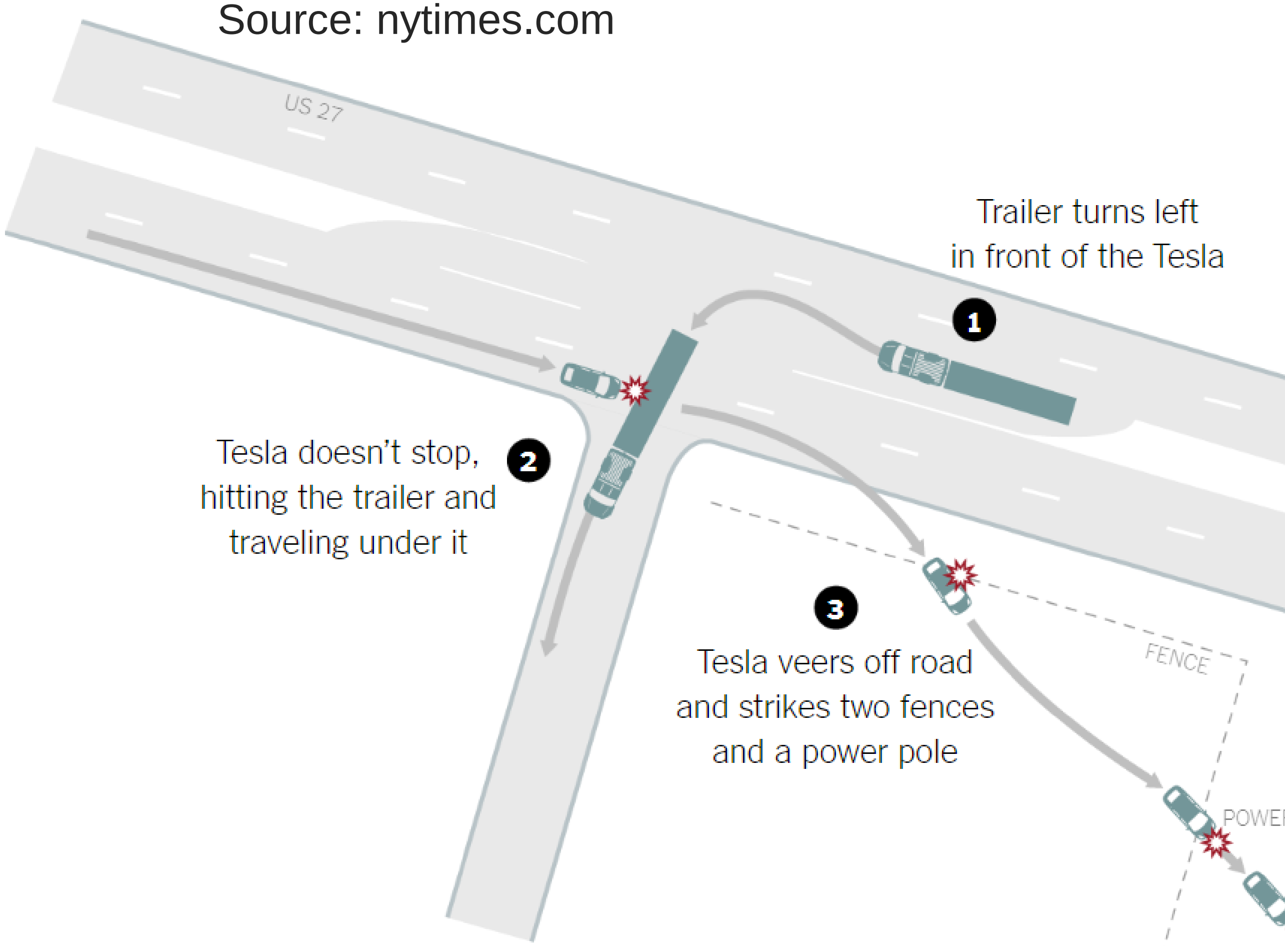
In cases when other sensors cannot "see" relevant vehicles, cooperative awareness enables these vehicles to **actively announce** their "presence"

How could cooperative awareness increase autonomous driving **safety**?



Scenario of 7 May 2016 Tesla crash

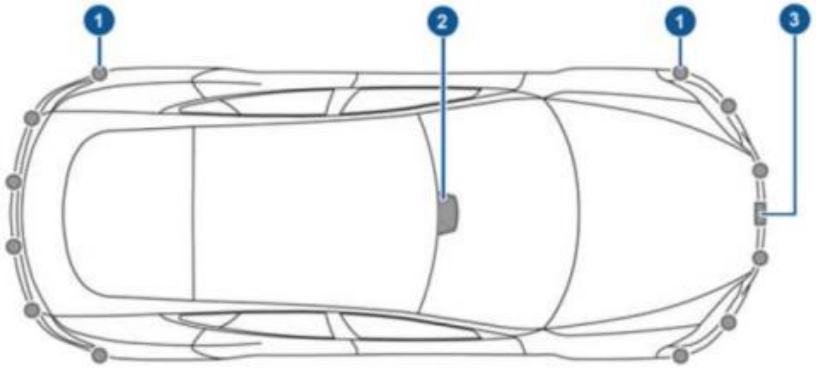
Source: nytimes.com



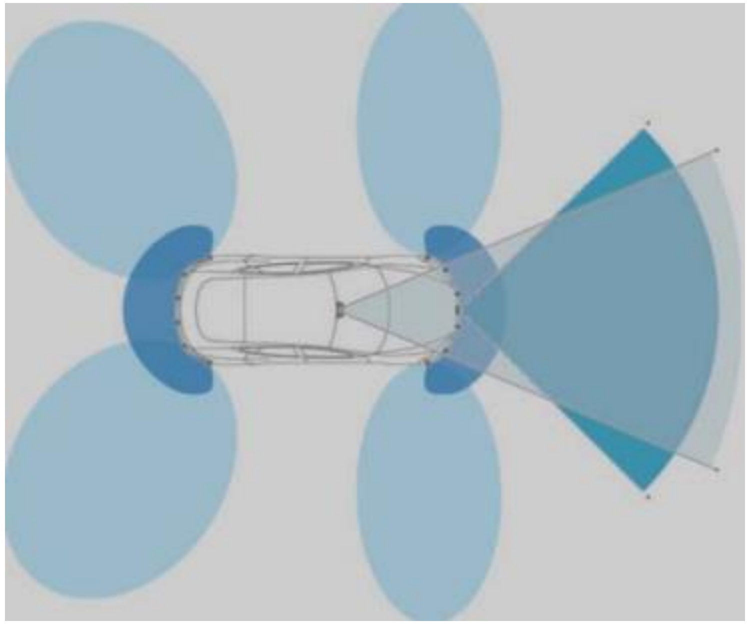
"Tesla driver took no braking, steering or other actions to avoid the collision"

https://static.nhtsa.gov/odi/inv/2016/INCLA-PE16007-7876.PDF

Sensors fields of view of 2016 Tesla Model S



1 – ultrasonic sensors 2 – camera 3 – radar



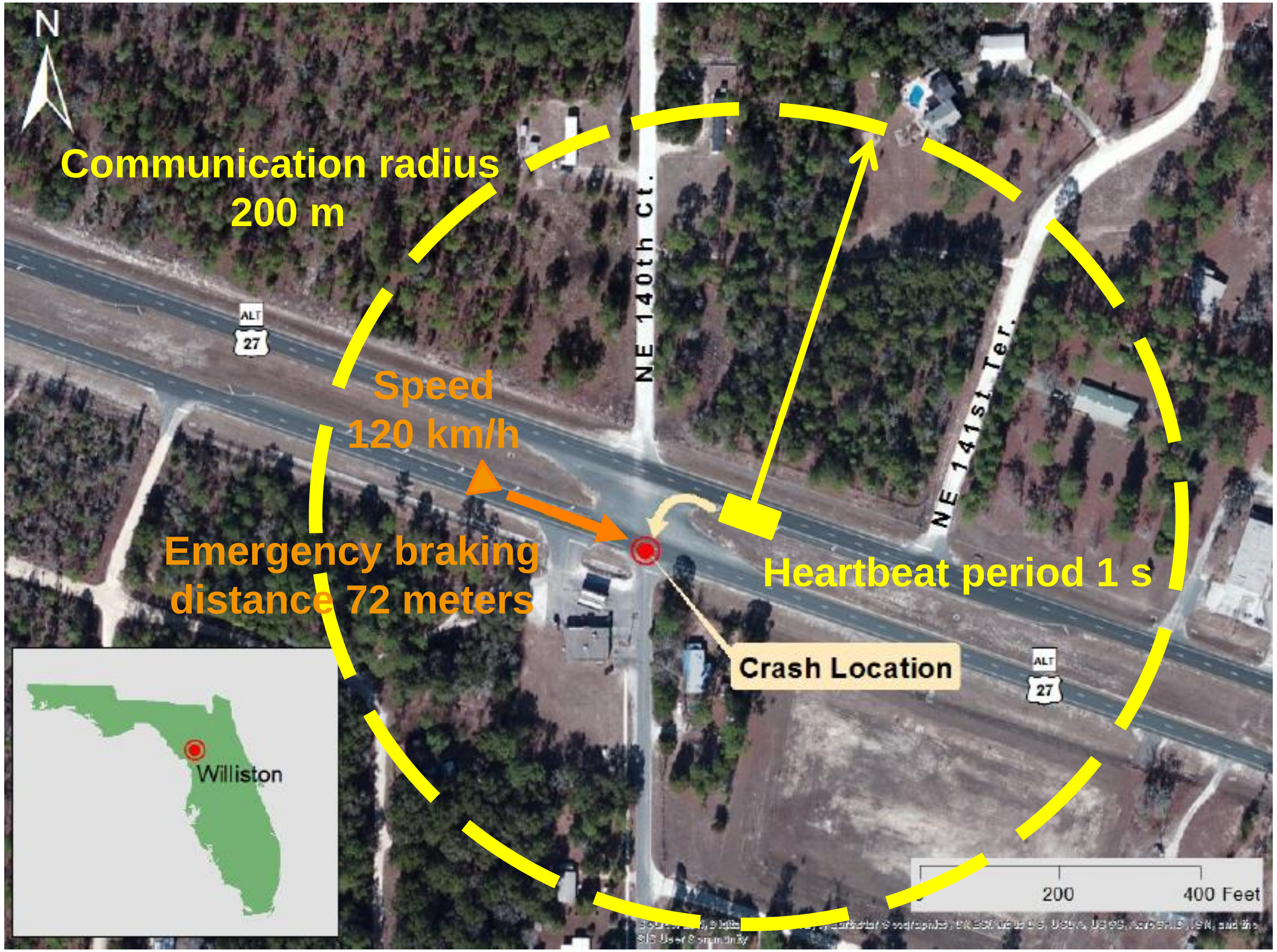
Sensors did not "see" the problem
"There was no record indicating that the Tesla's automation system identified the truck that was crossing in the car's path or that it recognized the impending crash. Because the system did not detect the combination vehicle – either as a moving hazard or as a stationary object – Autopilot did not reduce the vehicle's speed, the forward collision warning did not provide an alert, and the automatic emergency braking did not activate."

https://www.ntsb.gov/investigations/accidentreports/reports/har1702.pdf

The driver used the system improperly
"Tesla's Autopilot, require the continual and full attention of the driver to monitor the traffic environment and be prepared to take action to avoid crashes. Automated Emergency Braking systems have been developed to aid in avoiding or mitigating rear-end collisions."

Cooperative Awareness at 7 May 2016 Tesla Crash

Would cooperative awareness save the life?



Overtaking assistance

Real-time video is delivered from the camera at the windshield of the truck to the drivers of the cars behind

Better no help than such a help!

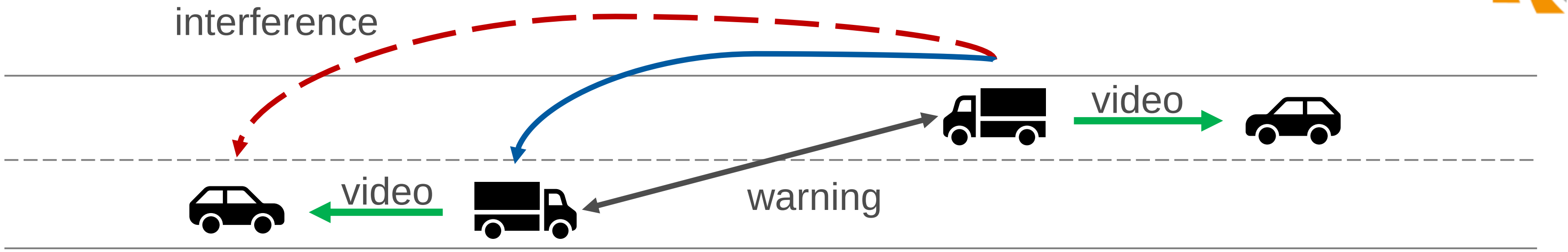
SENDER – Truck windshield camera

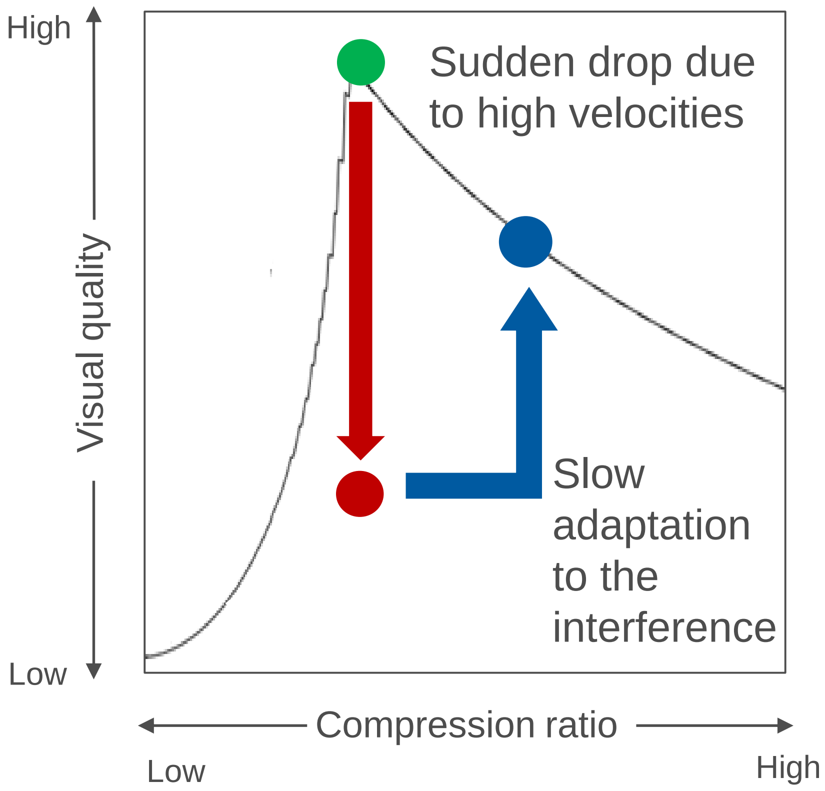
RECIEVER – Car dashboard display

The video is normally received with good quality,
but when there is an upcoming traffic, it gets worse or even freezes!

Belyaev, Vinel, Jonsson, Sjöberg
Live video streaming in IEEE 802.11p vehicular networks: demonstration of an automotive surveillance application, 2014

Predictive Quality of Service





Wireless channel throughput predictor

Video rate controller

Video encoder

Radio transmitter

SENDER
Truck windshield camera

RECIEVER
Car dashboard display

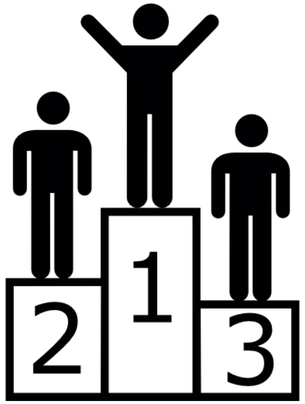
Non-signalized intersection passing

Two vehicles slow down to allow a third one to enter the traffic from the side road

Grand Cooperative Driving Challenge 2016

Halmstad University

Karlsruhe Institute of Technology



KTH Royal Institute of Technology

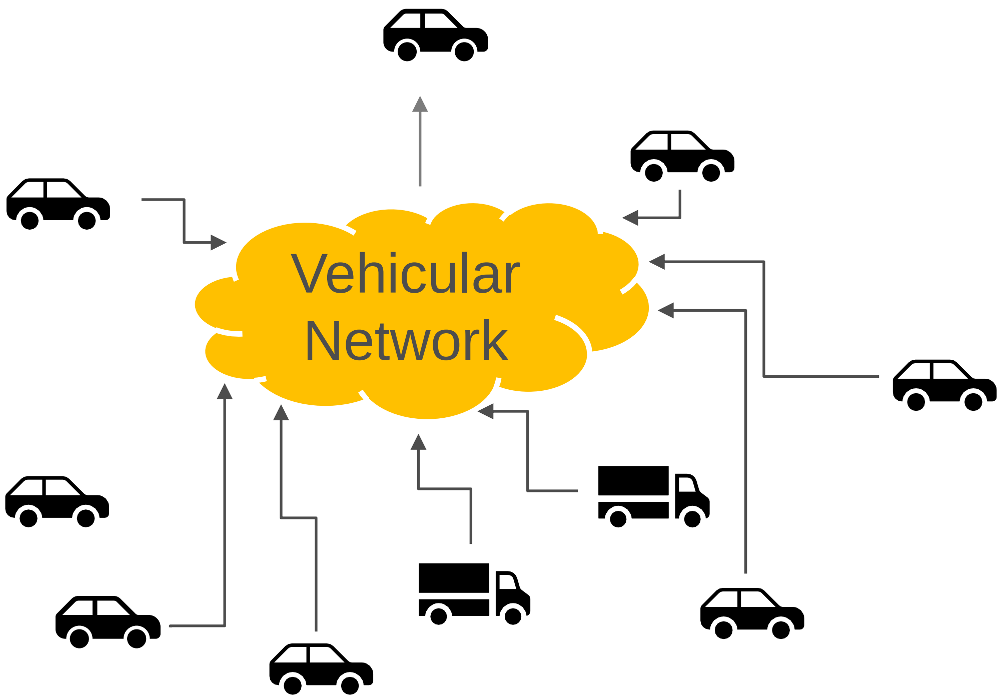
10 teams from EU

Receiver side congestion control

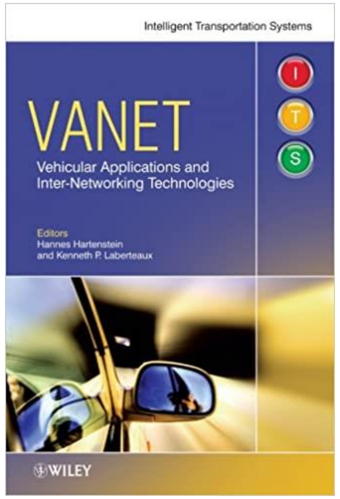
Rodríguez, Detournay, Vinel, Lyamin
An Approach for Receiver-Side Awareness Control in Vehicular Ad Hoc Networks, 2018

Bottleneck – Receiver

Receiver-side Awareness Control



GCDC2016 team Halmstad



Prof. Hannes Hartenstein
KIT

Sender-side Congestion Control

Bottleneck – Network

Step 3 (specific case): Cooperative Maneuvering

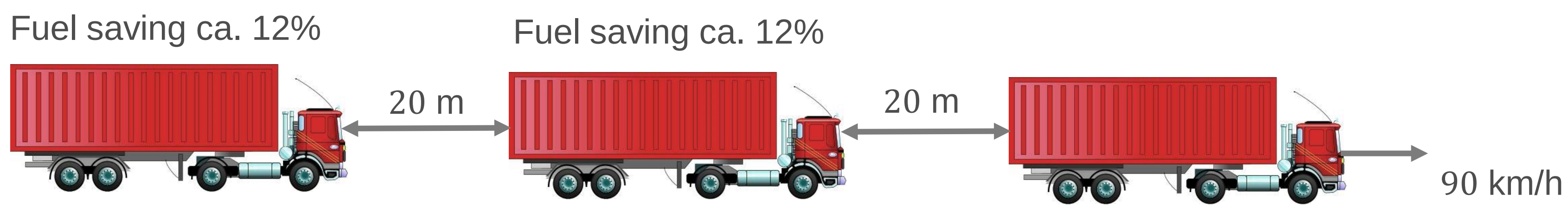
Vehicular platooning

Wirelessly connected trucks drive very closely together as one unit

Benefits of platooning

Nowadays drivers – Two-second rule

Platooning – EU ENSEMBLE 2021
DAF, DAIMLER, IVECO, MAN, SCANIA and VOLVO Group



To save fuel and reduce CO_2 emission

DIVE BRIEF

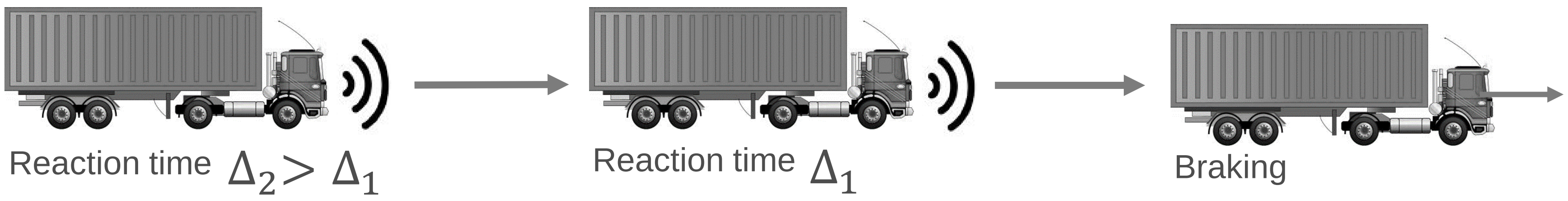
Daimler: There is 'no business case' for truck platooning

Published Jan. 8, 2019

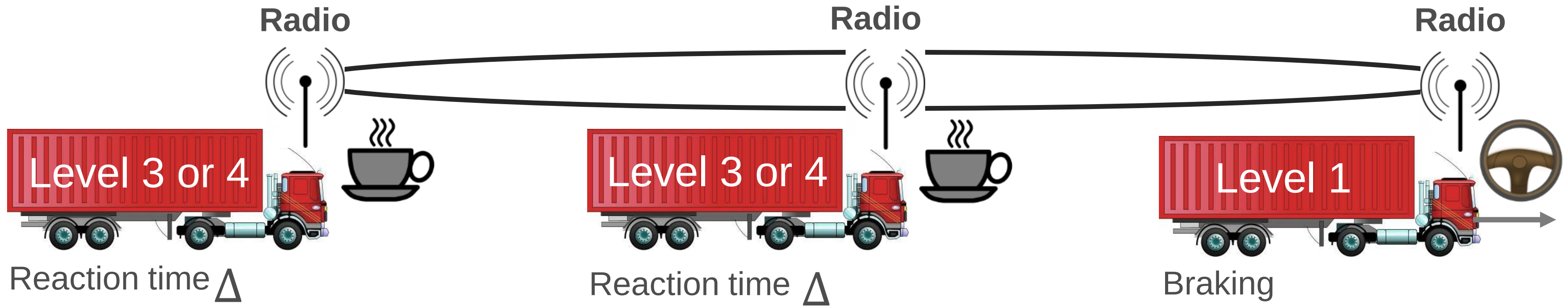
Edwin Lopez
Lead Editor

Benefits of platooning

”Autonomous” adaptive cruise control – ACC



Cooperative adaptive cruise control – CACC



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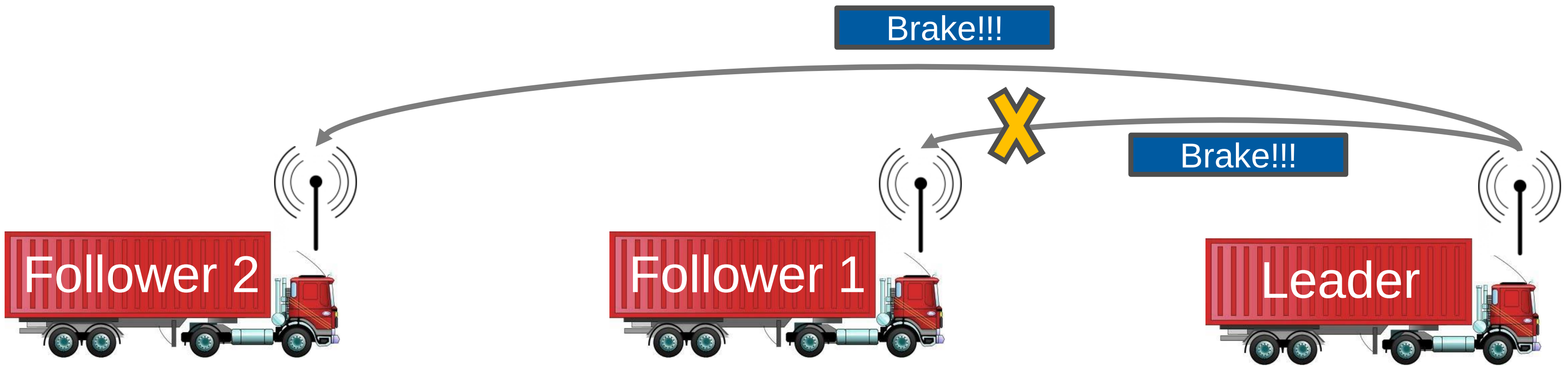
To reduce costs and improve road utilization

Is it safe to drive close?



Nelson, Lyamin, Vinel, Gustafson, Tufvesson
Geometry Based Channel Models with Cross- And Autocorrelation for Vehicular Network Simulations, 2018

Vehicular communications failures

ISO 26262
Functional safety

Radio
failed

ISO/SAE 21434
Cybersecurity
engineering

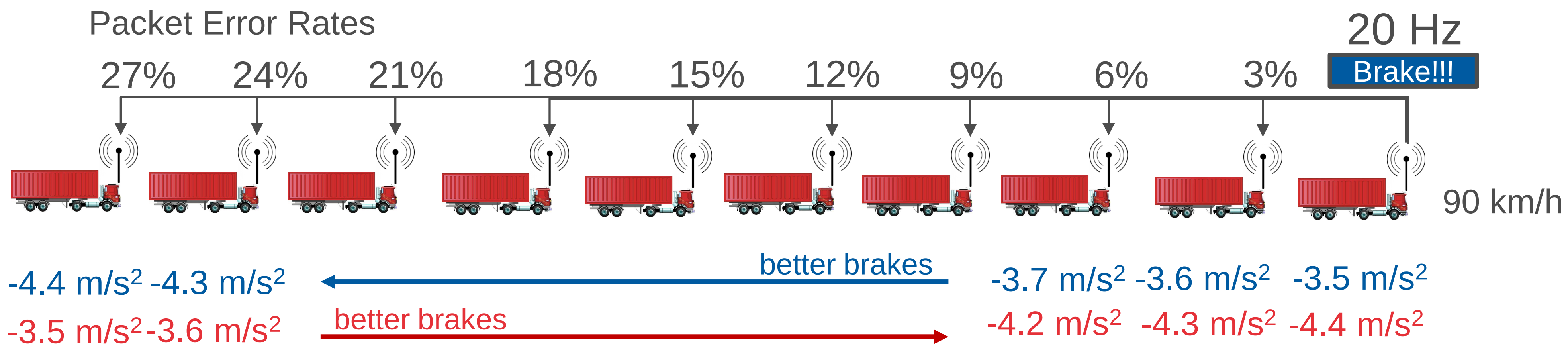
Network
hacked

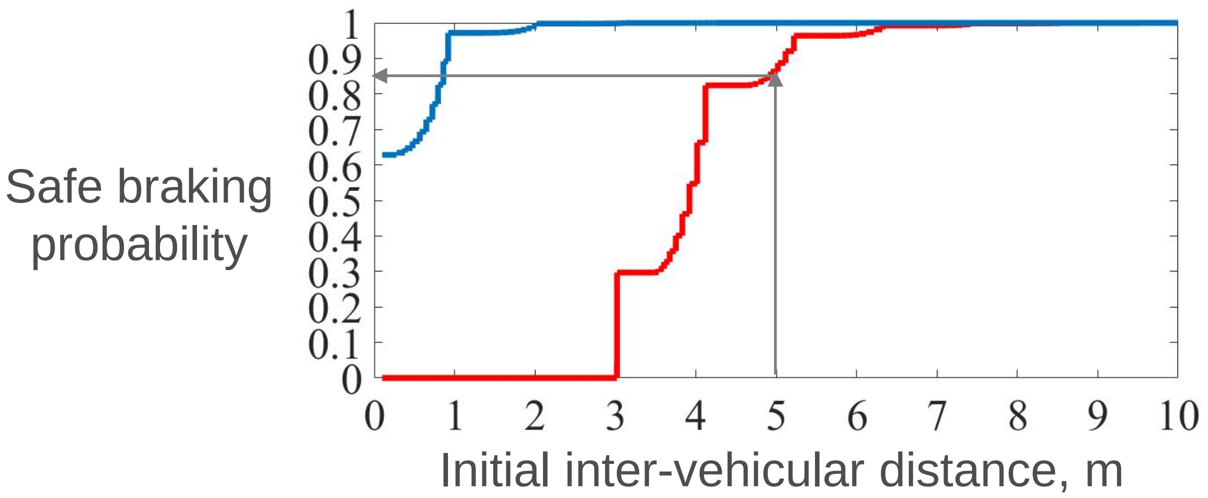
ISO PAS 21448
Safety of the
intended
functionality

Quality
worsened

Risk ~ Probability of crash × Severity of crash

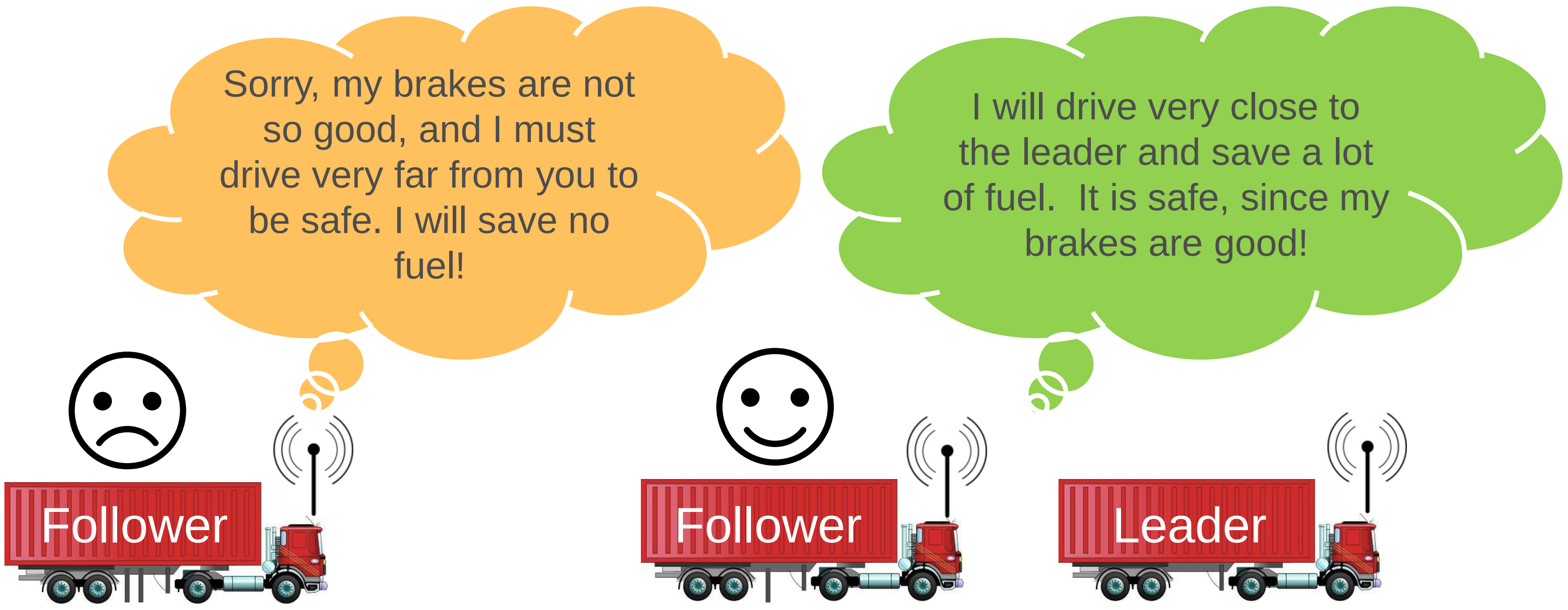
Safety Of Networked Autonomous Transportation Agents



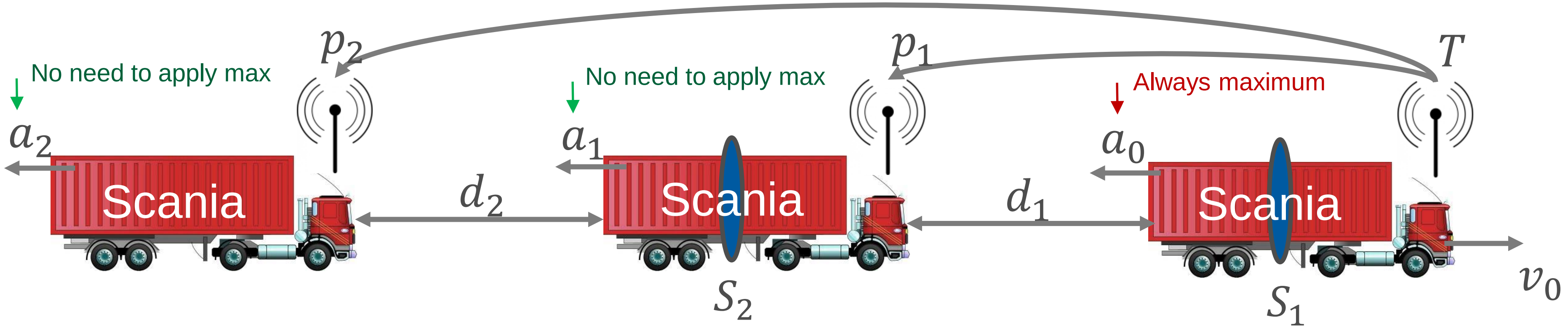


Thunberg, Lyamin, Sjöberg, Vinel
Vehicle-to-Vehicle Communications for Platooning: Safety Analysis, 2019

How to minimize the fuel consumption whilst being safe?



Mono-brand platooning (centralized)



$$J = \min \sum_{i=1}^{N-1} S_i d_i$$

s.t. $\quad 0 < a_i^* \le a_i \qquad d_i \ge 0$

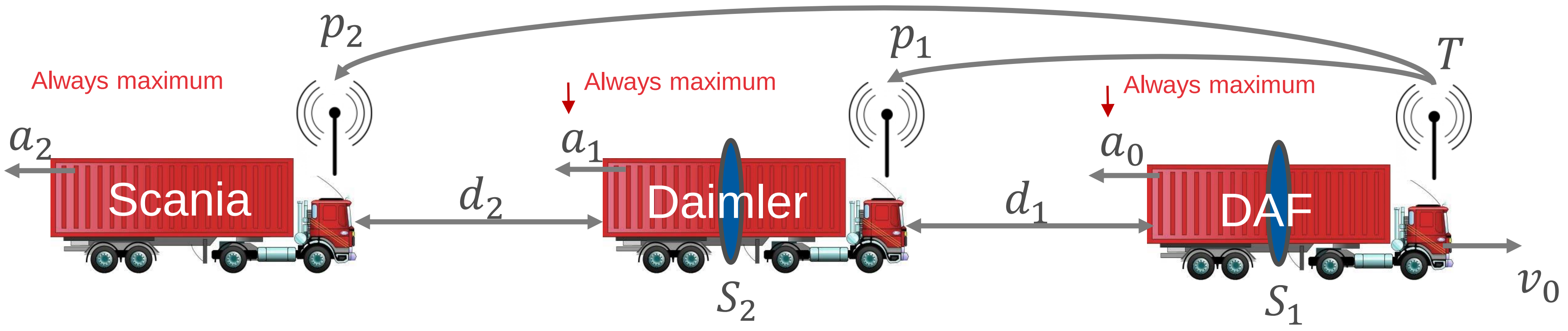
$$1 - p_i^{\lfloor \frac{\tau_i}{T} \rfloor} \ge Q^*$$

$$\tau_i \ge \min\{\frac{d_i}{v_0}, \frac{d_i}{v_0} + \frac{v_0}{2}(\frac{1}{a_i} - \frac{1}{a_{i+1}})\}$$

Notations

v_0 – initial platoon speed
a_i – maximal absolute decelerations
d_i – inter-vehicular distances
S_i – cross-sectional areas
N – number of platooning vehicles
T – emergency packet broadcasting period
p_i – packet loss probabilities
Q^* – required safety probability

Multi-brand platooning (distributed)



$J_1 = \min S_1 d_1$ | $J_2 = \min S_2 d_2$ | . . . | $J_{N-1} = \min S_{N-1} d_{N-1}$

Example

$N = 3$

$v_0 = 25$ m/s $S_1 = S_2 = 1$

$\boldsymbol{a_2 = 5.5}$ **m/s²** $\boldsymbol{a_1 = 7.5}$ **m/s²** $\boldsymbol{a_0 = 4.5}$ **m/s²**

$Q^* = 0.99999$

Centralized solution

$\boldsymbol{a_1^* = 4.9}$ **m/s²**

$d_1 = 8.1$ m $d_2 = 8$ m $\boldsymbol{J = 16.1}$ **m**

Distributed solution

$d_1 = 1.7$ m $d_2 = 30.2$ m $\boldsymbol{J = 31.9}$ **m**

Sidorenko, Thunberg, Sjöberg, Fedorov, Vinel, **Safety of Automatic Emergency Braking in Platooning**, 2022

Vehicular communications technologies

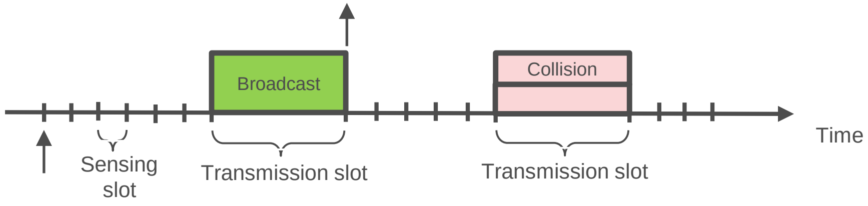
- IEEE 802.11p
  (integrated into 802.11-2016)
- IEEE 802.11bd
  (tbd Dec 2022)

- Rel14 Sidelink Communications
  - mode 3 „scheduled“
  - mode 4 „autonomous“
- Rel15 mmWave up to 52 GHz
- Rel16 platooning as one of the use cases

Uhlemann, **The Battle of Technologies or the Battle of Business Models?** 2018

Scalability of vehicular communications technologies

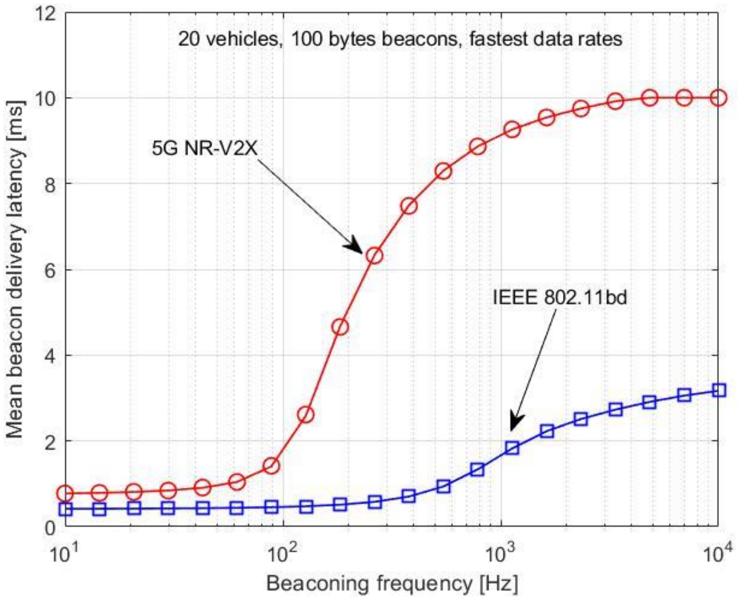
IEEE 802.11bd



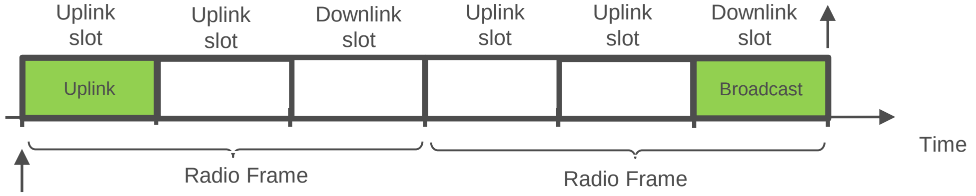
2-dimenstional Embedded Markov Chain $\{a(t), c(t)\}$

Number of active vehicles

Channel situation



5G NR-V2X

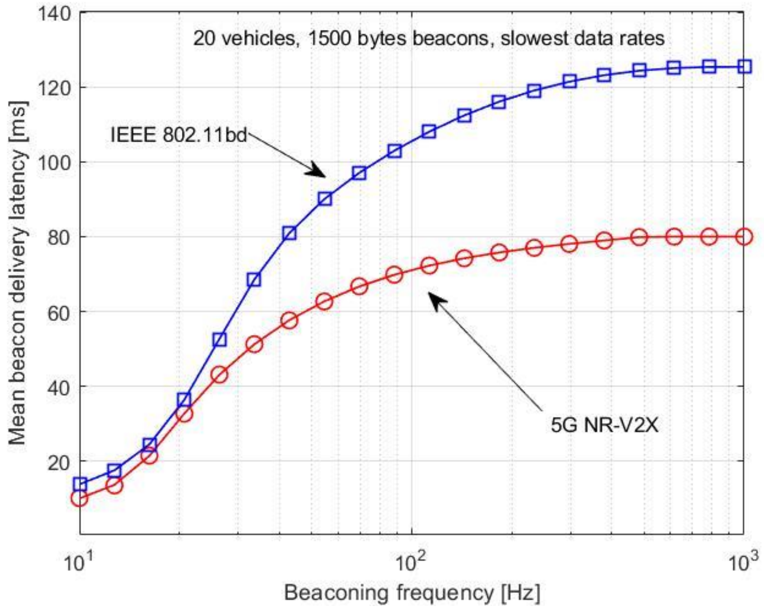


3-dimensional Markov Chain $\{a(t), b(t), s(t)\}$

Number of active vehicles

Number of packets at the base station

Slot index



Non-published 2021 extensions to

Vinel, **3gpp lte versus ieee 802.11p/wave: Which technology is able to support cooperative vehicular safety applications?** 2012

Autonomy Levels

Analytical and simulation models

Driver's hands on

Driver's eyes off

No driver

1 2 3 4 5

Driver's hands off

Driver's mind off

Real-world experiments

Closed-track experiments

Political statement on Autonomy Level 4

„Deutschland wird als erstes Land weltweit autonome Fahrzeuge aus den Forschungslaboren auf die Straße holen – heute sind wir diesem Ziel einen entscheidenden Schritt näher gekommen. Es freut mich sehr, dass das Kabinett den Weg frei gemacht hat für unser Gesetz zum autonomen Fahren.“

https://www.bmvi.de/SharedDocs/DE/Artikel/DG/gesetz-zum-autonomen-fahren.html

Andreas Scheuer, Febraury 2021