TECHNISCHE UNIVERSITÄT DRESDEN

Vodafone Chair Mobile Communications Systems, Prof. Dr.-Ing. G. Fettweis

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# Vehicular Communication Performance in Convoys of Automated Vehicles

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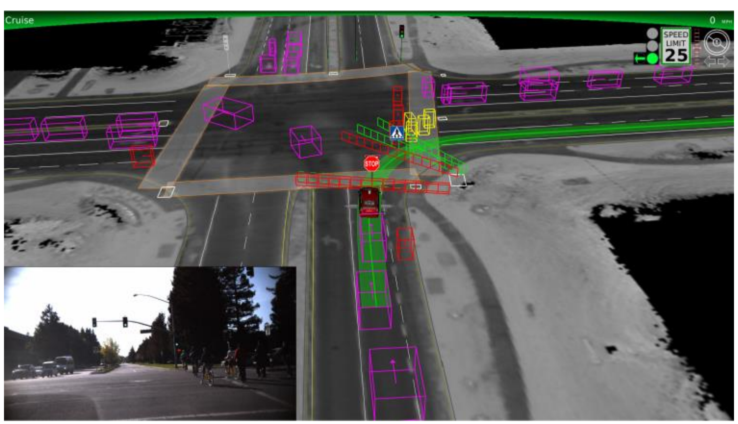
# Cooperative Autonomous Driving Systems (C-ADS)



- Autonomous vehicles and roadside units exchange information by means of V2X communications
  - Greatly improve safety and traffic efficiency
- C-ADS enable two key features
  - Cooperative sensing: allows vehicles to “see” behind obstacles
  - Cooperative maneuvering: vehicles share maneuver intentions

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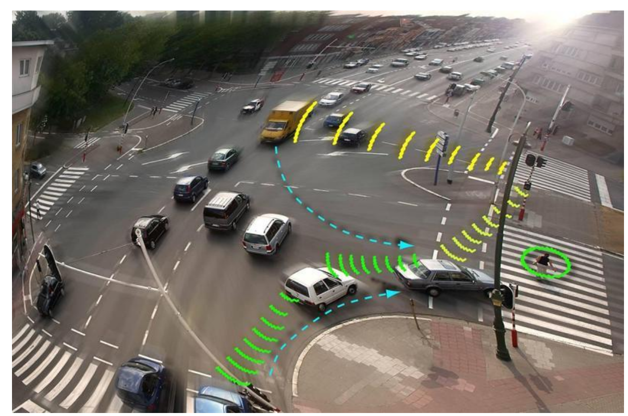


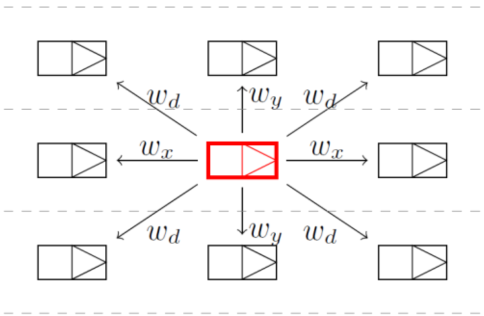
Imtech

L. Hobert, A. Festag, I. Llatser, L. Altomare, F. Visintainer and A. Kovacs, “Enhancements of V2X Communication in Support of Cooperative Autonomous Driving”, IEEE Communications Magazine, 2015.

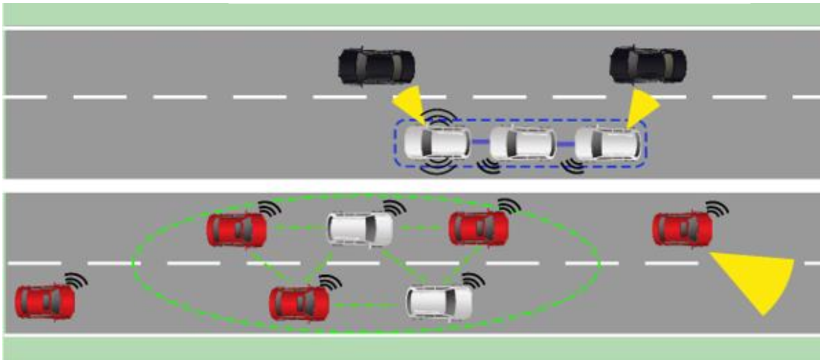
# Convoys of cooperative autonomous vehicles



- In order to drive cooperatively, vehicles are associated in convoys
  - Multi-lane groups of cooperative vehicles
  - Maintain a close distance and travel to a common destination
  - Fully distributed control mechanism




- Dynamic graph-based formation control
  - Guide individual vehicles to converge into a spatial formation
  - The convoy structure is modeled with a graph
    - Vertices: vehicles
    - Edges: relative vehicle positioning



# V2X communications in convoys



- Convoy vehicles send periodic **convoy messages** to all other convoy vehicles
  - Single-hop broadcast messages
  - Transmission frequency can be freely chosen
  - Content:

| | | | |
|---|---|---|---|
| car ID | clock | position | speed |
| heading | lane number | headway | vehicle state |

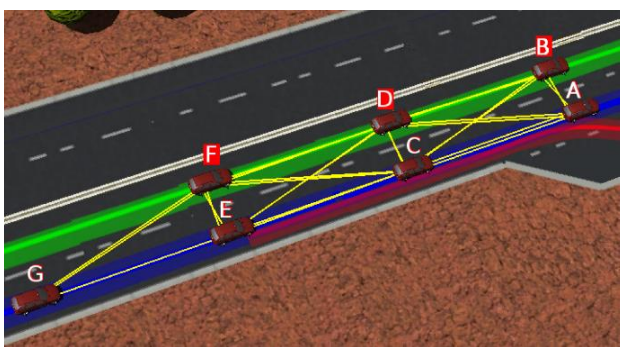
  - Transmitted via BTP / GeoNetworking / IEEE 802.11 OCB / ITS-G5
  - They allow convoy vehicles to perform cooperative maneuvers
    - Join/leave convoy
    - Lane change
    - Freeway merging
    - Change speed/headway

# Performance evaluation of convoys



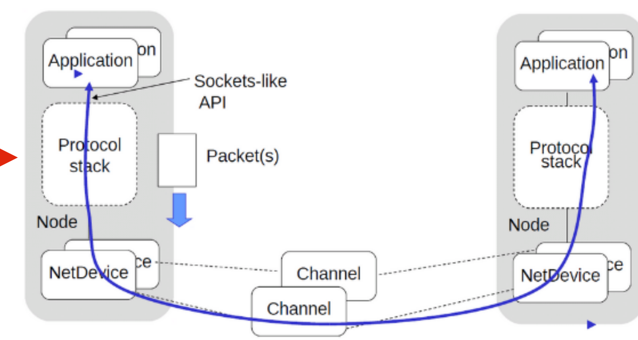
- Bidirectionally-coupled vehicle and network simulation framework
  - Webots: vehicle simulator with highly realistic vehicle dynamics
  - ns-3: network simulator with accurate V2X network model
  - Simultaneous execution of both simulators and information exchange via a communication plugin
  - ➢ Impact of V2X comm on the maneuvering performance of C-ADS

Webots




Communication plugin

ns-3



# Performance evaluation of convoys

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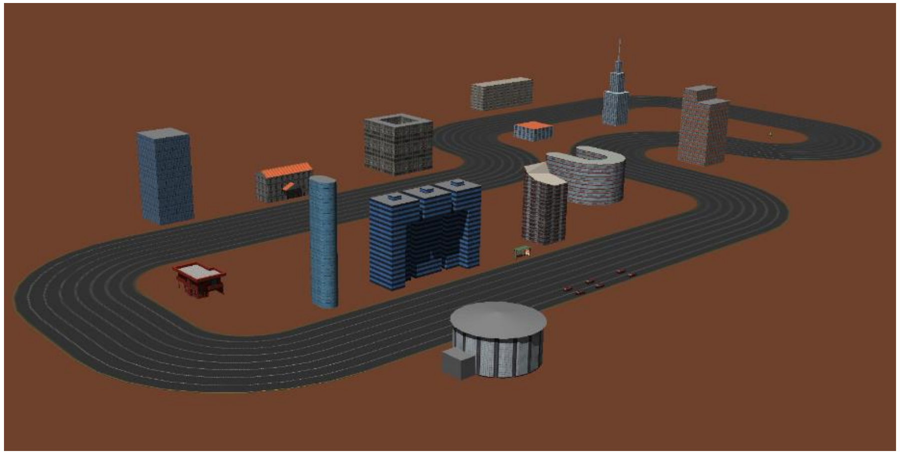
- Communication metrics allow to quantify the performance of convoy communications

Simulation scenario

- Ring-shaped freeway with 8 lanes and 2 km length
- **Convoy size**: from 6 to 40 vehicles
- **Convoy message transmission frequency**: from 0.5 to 15 Hz
- Propagation: multi-slope log-distance + Nakagami
- PHY/MAC layer: IEEE 802.11 OCB
- 160 vehicles near the convoy send periodic CAMs
- 10 simulation runs with 30 s duration



# Node coverage ratio (NCR)

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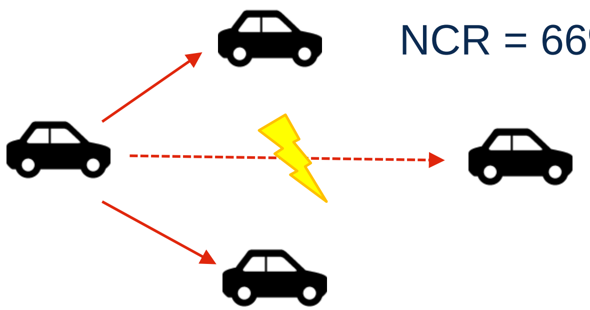
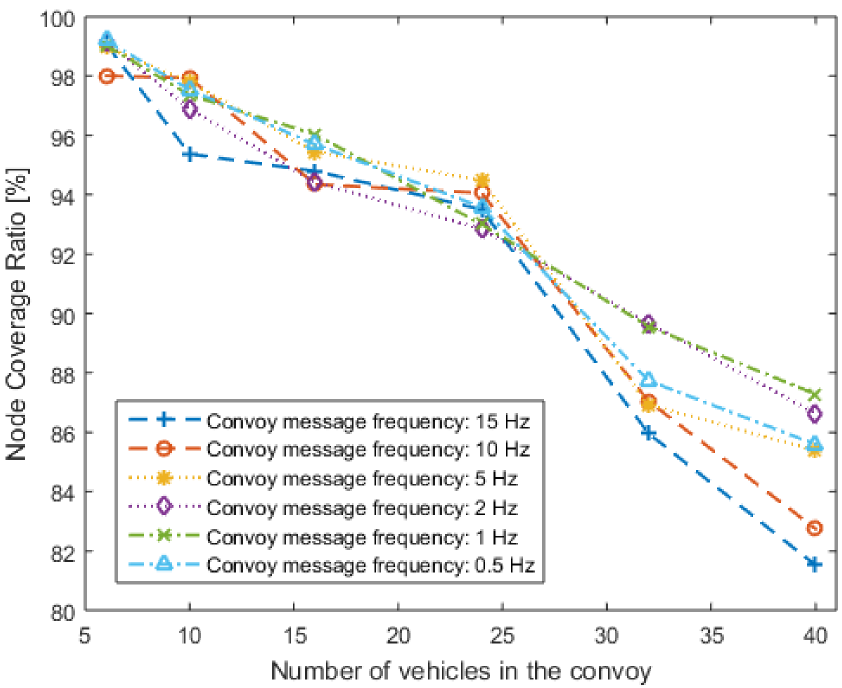
- Measures how many vehicles receive the convoy messages (reliability)
  - $\text{NCR} = \frac{\#\ \text{Rx vehicles in the convoy}}{\#\ \text{vehicles in the convoy}}$



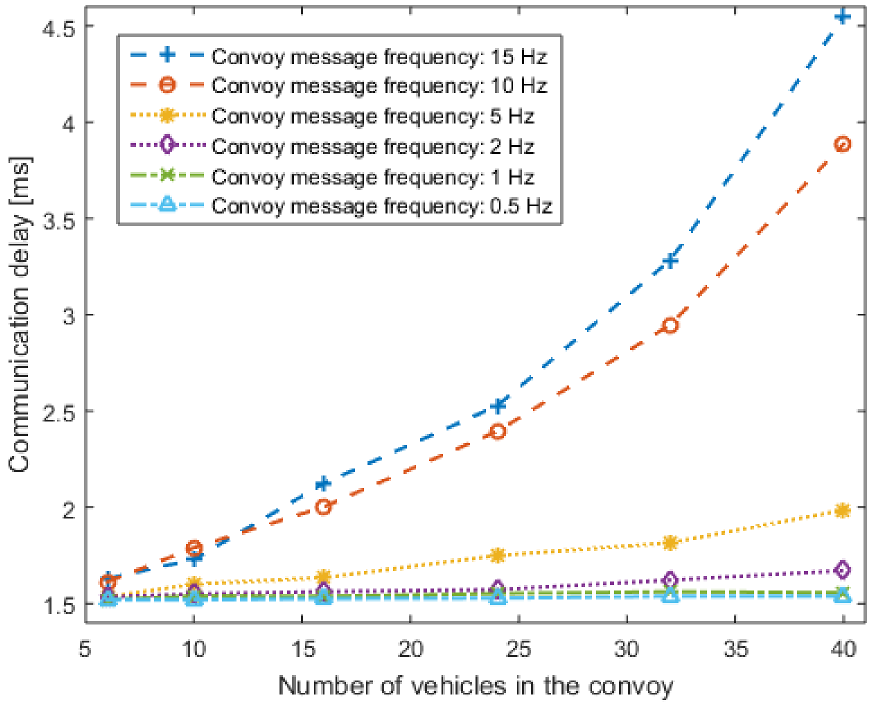




The NCR decreases as the convoy size grows

- It can be improved by lowering the transmission frequency of convoy messages

# Communication delay

- Average latency of convoy messages (transmission + propagation + processing delays)
  - $\text{Delay} = t_{\text{Rx}} - t_{\text{Tx}}$

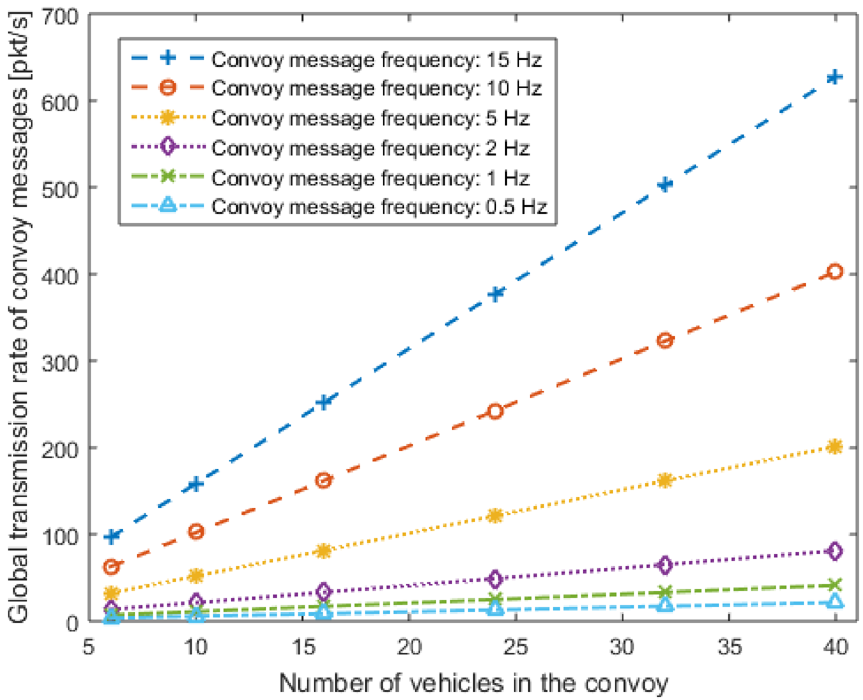



The delay increases for larger convoys and higher message frequency

- Remains below 5 ms in all tested scenarios

# Global transmission rate

- Total number of transmitted convoy messages per second (channel congestion)
  - $\text{Rate} = \frac{\#\ \text{vehicles in the convoy}}{\text{interval between Tx of convoy messages}}$



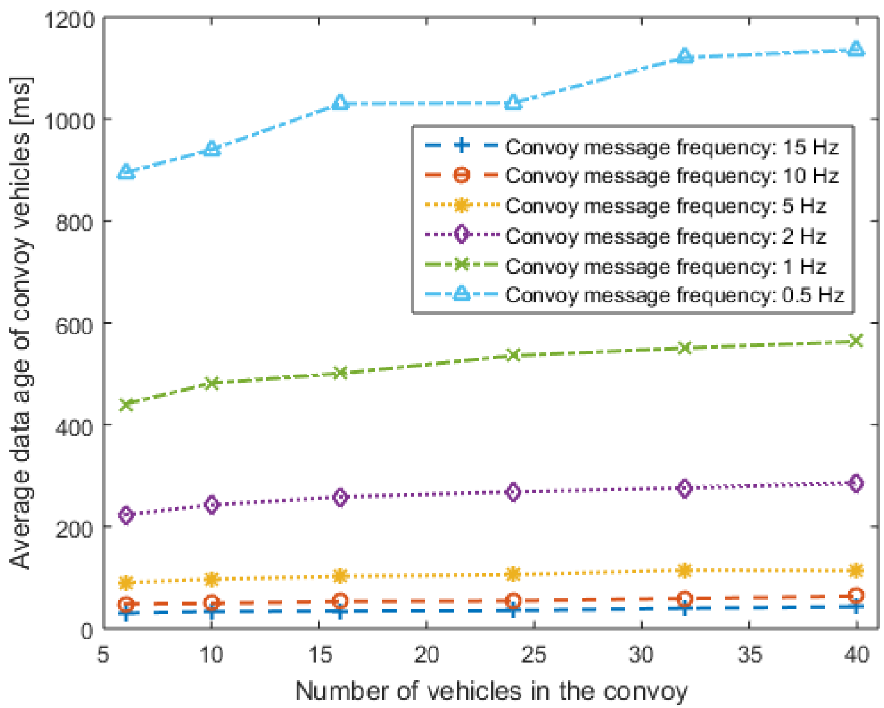

Directly proportional to the convoy size and the convoy message frequency

- The convoy communication performance degrades for high global transmission rates

# Data age



- Time since the last received convoy message was generated (freshness of data)


$$t_{age} \in \left[t_d, t_d + T(1 + N_p)\right]$$

$t_d$: communication delay
$T$: message transmission period
$N_p$: number of lost messages

Mainly determined by the convoy message frequency

- Convoy messages need to be transmitted frequently in order to maintain a low data age

# Conclusions



- Cooperative autonomous driving systems (C-ADS) allow vehicles to **increase their sensing range** and **maneuver coordinately** by means of V2X communications

- **Convoys** are groups of autonomous vehicles with decentralized control by means of **information exchange** among the convoy members

- The **convoy communication** parameters have a direct impact in the communication performance
  - Reliability, delay, channel congestion, data age

- Convoy communications need to be carefully designed in order to achieve the required performance **trade-off**
  - As a function of the number of cooperative vehicles (traffic congestion)

# AutoNet2030 general overview



| EC Call | FP7-ICT-2013-10 | | | |
|---|---|---|---|---|
| | **Type of action** | **Project budget** | **EU Funding** | **Project Start-End** |
| AUTONET 2030 | S/M Collaborative Project | € 4.59 m | € 3.35 m | 1st Nov. 2013-31st Oct. 2016 |

| | |
|---|---|
| **Partners** | ARMINES, BaseLabs, BroadBit Energy Tech., CRF, EPFL, Hitachi Europe, ICCS, TU Dresden, SCANIA. |
| **Target** | Automated Driving Technology supported by cooperative ITS |
| **Overall Approach** | To enable the convergence of pure sensor-based automation with cooperative V2X communications and decentralised maneuvering control algorithms |