TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair Mobile Communications Systems

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Vehicle-2-X Communication to Enable Autonomous Driving Systems

Motivation

- Most autonomous vehicles are based on **perception** subsystem (on-board sensors, e.g., camera, radar, lidar and GPS) and **control** subsystem
- Approach imposes some drawbacks:
  - Limited perception range and accuracy of on-board sensors
  - Complex integration (high cost) of sensors into current vehicles
- V2X communication allows the **exchange of information** among nearby autonomous vehicles by means of ad hoc networking
- Cooperative Autonomous Driving Systems (**C-ADS**) combine vehicular communication and autonomous driving to enable two key features:

Cooperative Sensing

- Increases sensing range of autonomous vehicles
- Allows cars to “see” behind obstacles and around corners

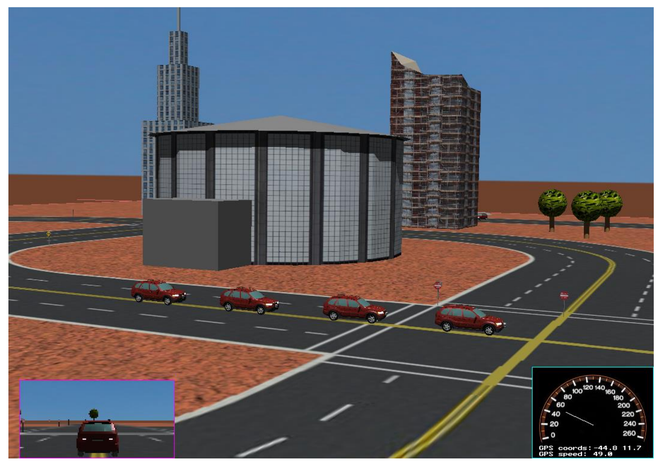
Cooperative Maneuvering

- Allows a group of autonomous vehicles to drive coordinately
- Enhances the safety and efficiency of maneuvers

- C-ADS are studied in several European R&D projects:
  - AutoNet2030, i-GAME, AdaptIVe, COMPANION

Convoys of Autonomous Vehicles

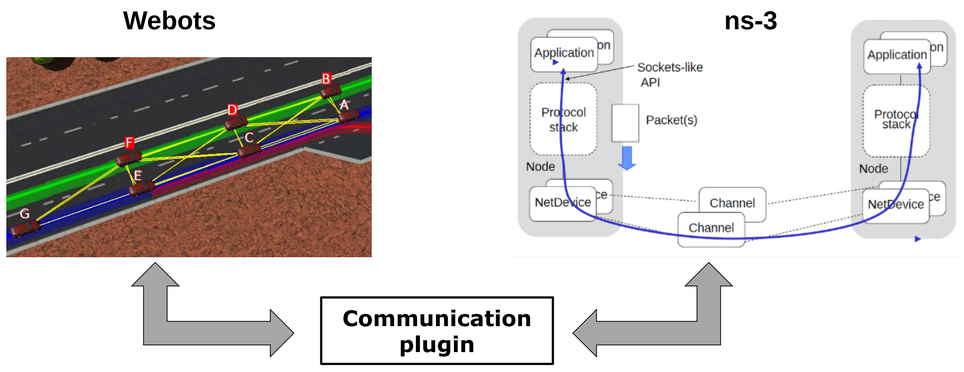
- Fast and reliable communication to support autonomous driving, in particular for **convoys** of autonomous vehicles:
  - Groups of autonomous cooperative vehicles in line
  - Maintain close distance and travel to a common destination
  - Fully distributed control mechanism
- Periodic transmission of single-hop broadcast **convoy messages** allows convoy vehicles to maneuver cooperatively
  - Vehicles exchange position, speed, heading and maneuver intentions
  - Each vehicle controller uses this information to steer the vehicle appropriately



- Convoys of autonomous vehicles require reliable and low-delay communications to ensure efficient and safe maneuvers

Testing Environments for V2X Communications

- 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
  - Study impact of V2X communication on the maneuvering performance of C-ADS

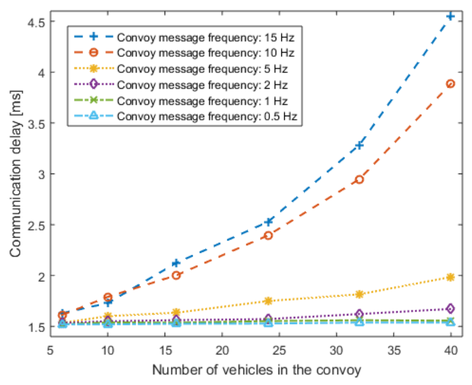


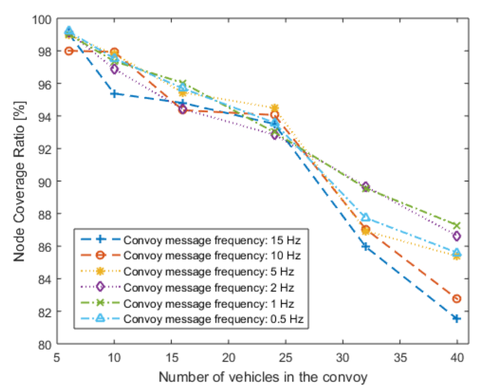
- Hardware testing with Cohda MK5 on-board units
  - Dual IEEE 802.11 radios, processor running V2X software stack and GNSS
  - Protocol stack for cooperative automated driving developed in AutoNet2030 project
  - PXI channel emulator allows a higher realism
  - Planned field trials on actual vehicles driving in a circuit

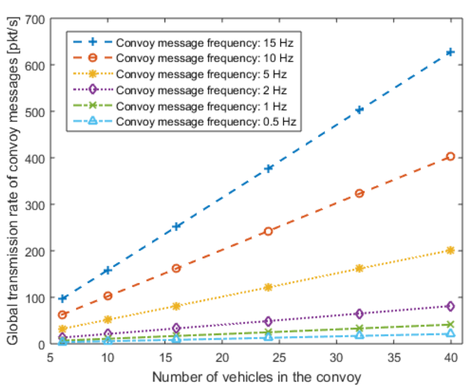
Performance Evaluation of Convoy Communications

- Use of coupled vehicle and network simulation framework
- Simulation scenario
  - Convoy of 6 to 32 cooperative autonomous vehicles driving on a highway
  - Propagation model: multi-slope log-distance with Nakagami fading
  - Transmission power and data rate from IEEE 802.11 OCB / ITS-G5
  - Average results of 10 simulation runs with 95% confidence intervals

- Main results
  - Node coverage ratio (reliability) of the convoy communications is lower in large convoys, unless the interval between transmissions of convoy messages is increased
  - Communication delay of convoy messages increases with convoy size and message frequency
  - Trade-off between node coverage ratio and communication delay of convoy messages







Selected Publications

- A. Festag: "Cooperative Intelligent Transport Systems standards in Europe", in IEEE Communications Magazine, 12(52), 2014
- A. Festag: "Standards for vehicular communication – From IEEE 802.11p to 5G", e & i, Springer, 132(7), 2015
- 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, vol. 53, no. 12, 2015
- I. Llatser, A. Festag, G. Fettweis: "Vehicular communication performance in convoys of automated vehicles", IEEE ICC 2016
- I. Llatser, S. Kühlmorgen, A. Festag, and G. Fettweis: “Greedy Algorithms for Information Dissemination within Groups of Autonomous Vehicles”, IEEE IV 2015
- S. Kühlmorgen, I. Llatser, A. Festag, G. Fettweis: "Performance evaluation of ETSI GeoNetworking for vehicular ad hoc networks", IEEE VTC2015-Spring
- S. Kühlmorgen, A. Festag, G. Fettweis: “Impact of decentralized congestion control on contention-based forwarding in VANETs”, IEEE Smart Vehicles 2016
- S. Kühlmorgen, A. Festag, G. Fettweis: "Exploiting distributed source coding for multi-hop routing in wireless ad hoc networks", IEEE VTC 2016-Spring

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