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

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
Performance evaluation of convoys

- 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)

- Measures how many vehicles receive the convoy messages (reliability)
  - 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

The NCR = 66%
Communication delay

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

  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)

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

- \( t_d \): 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

<table>
<thead>
<tr>
<th>EC Call</th>
<th>FP7-ICT-2013-10</th>
<th>EU Funding</th>
<th>Project Start-End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of action</td>
<td>Project budget</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 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

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