AUTONET2030 COMMUNICATIONS:
V2X FOR COOPERATIVE AUTOMATED DRIVING

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AutoNet-2030 Final Event
AstaZero, Sandhult, Sweden
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History of V2X communications

- European projects, academia and industry contribute to EU standards for V2X communication.
- Large-scale Field Operational Tests (FOTs) validate V2X standards

**Standard Development (e.g. ETSI TC ITS)**

- **GeoNet**
- **Safespot**
- **COMeSafety**
- **CoVeL**
- **Score@f**
- **simTD**
- **PRE-DRIVE C2X**
- **DRIVE C2X**
- **eCoMove**
- **AutoNet2030**

**Year**

- ‘07
- ‘08
- ‘09
- ‘10
- ‘11
- ‘12
- ‘13
- ‘14
- ‘15
- ‘16

- **Mandate M/453**
- **Research Prj.**
- **FOT Prj.**
- **Standards released for Day-1 use cases**
Convergence between stand-alone vehicle automation and cooperative V2X communications
• EU projects AutoNet2030, AdaptIVe, Companion, i-Game

Key to develop and demonstrate cost-efficiency and performance of Cooperative Automated Driving opposed to pure stand-alone AD.

Keep overall system complexity low – stand-alone automated driving is already complex enough
Selected AutoNet2030 use-cases (1)

4 Freeway use-cases

1. Convoy Driving
2. Merging
3. Splitting
4. Cooperative Lane Change

... key use cases for experiments.
Selected AutoNet2030 use-cases (2)

1 Urban use-cases
   – Cooperative Intersection Control
Communication requirements

1. Functional requirements
   – **Cooperative sensing** - *cyclic* broadcast of data
     • Ego-vehicle data: position, speed, acceleration, etc. (10 Hz)
     • Perception data: Occupancy grid (2 Hz)
     • Control data: Target trajectory, speed & acceleration, group composition (2 Hz)
   – **Cooperative maneuvering** –
     *event-based* uni-/broadcast of data

2. Delay requirements
   – End-to-end delay < 100 ms for high dynamic data
   – End-to-end delay < 500 ms for maneuver negotiation
AutoNet2030 V2X extensions: CCCS

- **Cooperative Convoy Communication Service**: periodic convoy messages
  - Message transmission frequency can be freely chosen
  - Content:
    - car ID
    - timestamp
    - position
    - speed
    - heading
    - lane number
    - headway
    - vehicle state

- They allow convoy vehicles to perform cooperative maneuvers
- Characteristics
  - Limited communication range
  - Packet losses
  - Latency
**AutoNet2030 V2X extensions**

**Joint effort** between *AutoNet2030* and *AdaptIVe* projects resulted in:

1. New and extended Facilities-layer messages
2. Reliable BTP and GN routing algorithm to improve geo-broadcast communication
3. Validation through field experiments and simulation

![AutoNet2030 Architecture Diagram](http://www.autonet2030.eu/)

**Full specification available at:**

- **CLCS** = Cooperative Lane Change Service
- **CCCS** = Cooperative Convoy Communication Service
- **CICS** = Cooperative Intersection Control Service
- **CPS** = Cooperative Perception Service
- **RBTP** = Reliable BTP

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1. **Node coverage ratio (NCR)**
   - Measures how many convoy vehicles receive the convoy messages
   - \[ \text{NCR} = \frac{\text{\# Rx vehicles in the convoy}}{\text{\# vehicles in the convoy}} \]
   - Reasons for lost messages: path loss and collisions

2. **Communication delay**
   - Average latency of convoy messages (transmission + propagation + processing delays)
   - \[ \text{Delay} = t_{\text{Rx}} - t_{\text{Tx}} \]

3. **Global transmission rate**
   - Total number of transmitted convoy messages per second
   - \[ \text{Rate} = \frac{\text{\# vehicles in the convoy}}{\text{interval between Tx of convoy messages}} \]
Simulation framework for performance evaluation of CAD

- A simulation tool specifically designed for cooperative automated driving (CAD) does not exist to date
- Different simulator types can be used for the simulation of V2X networks:

<table>
<thead>
<tr>
<th>Simulator</th>
<th>Pros</th>
<th>Cons</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network simulator</td>
<td>Accurate network model for V2X communication</td>
<td>Simplistic vehicle mobility</td>
<td>ns-2, ns-3, OMNeT++</td>
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<td></td>
<td>Good scalability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic simulator</td>
<td>Realistic vehicle mobility</td>
<td>Simplistic V2X communication</td>
<td>SUMO, Aimsun</td>
</tr>
<tr>
<td></td>
<td>Good scalability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle simulator</td>
<td>Even more realistic vehicle mobility</td>
<td>Simplistic V2X communication</td>
<td>Webots, V-REP, USARSim</td>
</tr>
<tr>
<td></td>
<td>Great visual interface</td>
<td>Poor scalability</td>
<td></td>
</tr>
</tbody>
</table>
Bidirectionally-coupled simulation for CAD

1. Combine two simulators → **joint simulation framework**
   - Advantages of both simulator types:
     realistic vehicle mobility and accurate V2X network model
   - Allows to evaluate the impact of the vehicle movements on the V2X network and vice versa

2. Traffic simulator + network simulator
   - Realistic vehicle mobility and good scalability
   - Examples: Veins (SUMO + OMNeT++), iTetris (SUMO + ns-3)

3. Vehicle simulator + network simulator
   - Very realistic vehicle mobility for “small” scenarios
   - Our approach: **Webots + ns-3**
Performance evaluation

• Evaluate performance of convoy communications using Webots/ns-3 bi-directionally coupled simulator

• Simulation scenario
  – Ring-shaped freeway with 8 lanes and 2 km length
  – Convoy size: from 6 to 32 vehicles
  – Propagation: multi-slope log-distance with Nakagami fading
  – PHY/MAC layer: IEEE 802.11p/ITS-G5
  – All convoy vehicles transmit periodic convoy messages
  – 160 vehicles in the convoy’s vicinity send periodic CAMs
  – 10 simulation runs with 30 s duration and 95% confidence intervals
Performance evaluation

Node coverage ratio: reliability

\[ \text{NCR} = \frac{\# \text{Rx vehicles in the convoy}}{\# \text{vehicles in the convoy}} \]

Communication delay: latency

\[ \text{Delay} = t_{\text{Rx}} - t_{\text{Tx}} \]
Contribution to standards

2 Work Items in WG1 (Application Requirements and Services)

- Definition, use cases, requirements, recommendation on technical specifications targeting at extending the release 1 standards (CAM, DENM, GN, ITS-G5 etc.) to support Platooning & C-ACC applications

1. TR 103 298 - Platooning pre-standardization study
   • Rapporteur: Ms. Sjöberg (Volvo Technology Corporation)
   • Status: WI Adopted by Technical Committee.

2. TR 103 299 - C-ACC pre-standardization study
   • Rapporteur: Ms. Lan (Hitachi Europe)
   • Status: Early draft of Technical Report

AutoNet2030, AdaptIVe and i-GAME are contributing to the above work items.
Conclusions

1. AutoNet2030 project extended state-of-the-art of V2X communications for CAD

2. Contributed to European standardization process

3. Validation by experiments and simulations

4. Assessed performance of convoy communications by coupled vehicle and network simulator
Selected publications

1. *Network of automated vehicles: The AutoNet2030 vision*, A. de La Fortelle et al., ITS World Congress & Exhibition, 2014

2. *Enhancements of V2X communication in support of cooperative autonomous driving*, L. Hobert et al., IEEE CommMag, 2015


4. *Greedy algorithms for information dissemination within groups of autonomous vehicles*, I. Llatser et al., IEEE Intelligent Vehicles (IV) Symposium 2015

Thank you!
Any questions?

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Requirements for CCCS

- Ultra-high reliability
- Low/bounded latency
- Low message overhead
- Security and privacy
- New use cases

New use cases
Bidirectionally-coupled simulation

- **Webots** simulates movement of the convoy vehicles and triggers message transmissions

- **ns-3** simulates the V2X networking stack, including the wireless channel, IEEE 802.11p PHY and MAC, GeoNetworking and messaging protocols

- A **communication plugin** manages the information exchange between Webots and ns-3
Performance evaluation

Global transmission rate: channel congestion

\[
\text{Rate} = \frac{\# \text{ vehicles in the convoy}}{\text{Tx period of convoy messages}}
\]

Data age: freshness of data

Time since the last received convoy message was generated