Cooperative, Connected and Automated Mobility (CCAM) – Challenges and Technical Enablers

IRACON – Final Workshop
Outline

— Motivation
— The road ahead
— 5GNetMobil & 5GCroCo projects
— Selected challenges and solutions for long-range C-V2X
— Summary & conclusion
Motivation

https://www.youtube.com/watch?v=rmjJkIlFMJ4
The road ahead

— **Goal is Autonomous Driving everywhere and anytime** (SAE Level 5)
— **Assisted Driving** is commercial reality today (SAE Level 1, 2)
— **Automated Driving** where Operational Design Domain (ODD) permits (SAE Level 3, 4)
— **But what does this mean for communication?**

**ASSISTED DRIVING**
- The driver is at the wheel and must constantly supervise the vehicle and intervene when necessary.
- The system provides steering, acceleration and braking support.

**AUTOMATED DRIVING**
- The system is able to cope with all dynamic driving tasks within its operational design domain (ODD) without driver supervision.
- It will transition to the driver, offering sufficient lead time, when these conditions are not met.
- The driver may perform non-driving related tasks.
- The driver must be promptly available for safe transition of control.

**AUTONOMOUS DRIVING**
- The system drives the vehicle under all conditions.
- No driver input is required.
- All vehicle occupants are effectively passengers.

Source: ACEA, “AUTOMATED DRIVING Roadmap for the deployment of automated driving in the European Union”, 12/2019

1) Society of Automotive Engineers
The road ahead

— Goal: Day 4 “maneuver coordination”!?  
— Today, we are somewhere between Day 1 and Day 2  
— Many vehicles still in “Day 0”  
— Can we go beyond Day 4?

Source: Joost Vantomme (Smart Mobility Director ACEA), “Towards cooperated, connected and automated driving in Europe Which connectivity?”, 10/2018
The road ahead

— Controlled airspace (e.g. North Atlantic) maximizes capacity and safety
— Similar for ships, e.g. around ports and the UK/France Channel
— Central control (not just steering) maximizes capacity thanks to its global situation awareness
— Communication becomes essential

The road ahead

- “…infrastructure is able to guide Automated Vehicles in order to optimize the overall traffic flow.”
- Today you cannot even trust the speed limit your navigation system shows
- Communication and trustworthy information is essential

<table>
<thead>
<tr>
<th>Level</th>
<th>Name</th>
<th>Description</th>
<th>Digital map with static road signs</th>
<th>VMS, warnings, incidents, weather</th>
<th>Microscopic traffic situation</th>
<th>Guidance: speed, gap, lane advice</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Cooperative driving</td>
<td>Based on the real-time information on vehicle movements, the infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimize the overall traffic flow.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>B</td>
<td>Cooperative perception</td>
<td>Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Dynamic digital information</td>
<td>All dynamic and static infrastructure information is available in digital form and can be provided to AVs.</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Static digital information / Map support</td>
<td>Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short term road works and VMS need to be recognized by AVs.</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>E</td>
<td>Conventional infrastructure / no AV support</td>
<td>Conventional infrastructure without digital information. AVs need to recognize road geometry and road signs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: ERTRAC, “Connected Automated Driving Roadmap”, 03/2019
5GNetMobil & 5GCroCo projects
5G NETMOBIL AT A GLANCE

5G NETMOBIL – 5G SOLUTIONS FOR FUTURE CONNECTED MOBILITY

SPONSOR  Federal Ministry of Education and Research
CALL  5G Tactile Internet within the german research program „IKT 2020 – Research for Innovation“
COORDINATOR  Bosch & Technische Universität
BUDGET  14.9 Mio. € (8,5 Mio. € Funding)
DURATION  01.03.2017 – 29.02.2020
CONSORTIUM

OEMs & Suppliers

Operators

Vendors

SMEs

Academic Organisations

VOLKSWAGEN

BMW GROUP

CLAAS

BOSCH

T

ERICSSON

acticom

HEUSCH-BOESEFELDT

Nokia

dresden elektronik

downhill

dte

Fraunhofer

TECHNISCHE UNIVERSITAT DRESDEN

TECHNISCHE UNIVERSITAT KAIERSLAUTERN

Fraunhofer Heinrich Hertz Institute

htw saar Forschungsgruppe Verkehrstelematik

5G NetMobil

07.02.2020
OVERVIEW

UC1
High Density Platooning

UC2
Off-Road Parallel Platooning

UC3
City Crossing Assistance for Vulnerable Road User (VRU) Protection

UC4
City Crossing by Smart Traffic Lights

UC5
Coexistence of Automotive Safety-Related and Consumer Infotainment Services
HOLISTIC ARCHITECTURE

Providing reliable, secure and robust communications that enable real-time control

- Radio Resource Management for Low Latency & High Reliability
- Hybrid V2X-Communication
- Network Slicing
- Agile Mobile Edge Cloud
- Predictive Quality of Service
- Multi-operator Networks
- Security
- New Communication Protocols and Message Formats

Communication Profiles

<table>
<thead>
<tr>
<th>Cellular</th>
<th>Direct</th>
</tr>
</thead>
<tbody>
<tr>
<td>(4G/5G) Unicast</td>
<td>(4G/5G) Assisted Ad-hoc</td>
</tr>
<tr>
<td>(4G/5G) Multi-/Broadcast</td>
<td>Sidelink IEEE 802.11p</td>
</tr>
<tr>
<td></td>
<td>Non-assisted</td>
</tr>
</tbody>
</table>
5G Large-Scale Trials

5G CroCo

Large-scale validation of 5G along France, Germany, and Luxembourg
Facts and Figures

• Coordinated by **CTTC**, Barcelona, Spain

• **24 partners** from **7 European Countries**

• Total project budget $\approx 17\text{M€}$ (EC Contribution $\approx 13\text{M€}$)

• Project duration: **36 Months** (Nov 2018 – Oct 2021)

• 3 CCAM key **use cases** to be trialled:
  1) Tele Operated Driving
  2) High Definition Map Generation and Distribution
  3) Anticipated Cooperative Collision Avoidance (ACCA)
Focus of the innovation

• **5G Technology** features
  • Cross-border/MNO/vendor/generation Operation
  • Mobile Edge Computing/Cloud (MEC)
  • 5G New Radio
  • Network Function Virtualization, Software Defined Networking & Network Slicing
  • QoS with Dedicated Bearers and QoS Prediction
  • Improved Positioning
• Recommendations for Regulation and Spectrum
• Identification of new business model opportunities
• Impact on standardization (3GPP, ISO, ETSI, SAE, ...)

5GCroCo Innovation Action
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5GCroCo Innovation Action
Selected challenges and solutions for long-range C-V2X
Challenges & solutions - geocasting

Challenge:
- Message must be received by vehicles in “destination area” (service dependent)
  ➔ must be at least sent to destination area (larger area OK)

Warning area specified in DENM\(^2\) message

Short-range solution:
- Radio communication range assures geographically limited dissemination (~100 – 1000 m)
- The challenge is often to reach an area larger than that ➔ multi-hop communication handled by GeoNetworking layer
  - Geographically Scoped Broadcast: elliptic or rectangular destination area
  - Topology Scoped Broadcast: max. number of rebroadcasts (zero for CAMs\(^1\))

Long-range solutions:
- IoT message queueing protocol handling it, e.g.:
  - Message Queuing Telemetry Transport (MQTT)
  - Advanced Message Queueing Protocol (AMQP)
- (Mobile) Edge Computing/Cloud ((M)EC) tightly coupled with set of cells and area they serve
  - Multimedia Broadcast Multicast Service (MBMS)

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1) CAM: Cooperative Awareness Message
2) DENM: Decentralised Environmental Notification Message
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1) CAM: Cooperative Awareness Message
2) DENM: Decentralised Enviromental Notification Message
Challenges & solutions – geocasting: (M)EC

Long-range solutions:
- (M)EC host tightly coupled with set of cells and area they serve
  - Not a default RAN feature, needs e.g. Selective IP Traffic Offload (SIPTO) to work
    - Fallback to central server possible
  - Inter-(M)EC communication needed when destination area “served” by multiple (M)EC hosts
  - Unicast: must track which vehicle is served by which (M)EC host (e.g. by listening to CAMs)
  - Same mechanisms used to “learn” the area served by a (M)EC host according to the cell coverage
  - Protocol stack can remain almost unchanged but UDP/IP must be used (encapsulation)

1) CAM: Cooperative Awareness Message
2) DENM: Decentralised Environmental Notification Message

Warning area specified in DENM\(^2\) message
Challenges & solutions – geocasting: IoT msg. queueing

Long-range solutions:
- IoT message queueing protocol handling it, e.g.:
  - Decouple application from mobile radio network geometries
  - Vehicle subscribes to the “topic” associated to its current area (“shapes” will be discussed in next slide)
  - Can subscribe to more areas to disguise position
- Solution 1: Message sent to all vehicles in subscription areas overlapping with destination area according to message content: 1, 2, 3
- Solution 2: Vehicles subscribe to areas and receive event originating from there (e.g. in front of them): 3
- Additional protocol, e.g. MQTT must be implemented, also in the vehicles
- TCP with connection established in uplink allows to easily overcome firewalls and NAT

1) CAM: Cooperative Awareness Message
2) DENM: Decentralised Enviromental Notification Message
3) NAT: Network Address Translation
Challenges & solutions – georeferencing

- GeoNetworking protocol allows (rotated) ellipse or rectangle
- Different services/messages have different ways for georeferencing, e.g.:
  - Single positions
  - List of positions
  - Position at road and distance from there (one or both directions)
- Geo information systems (GIS) / navigation systems
  - Quadtree
  - Open Location Referencing (OpenLR)
  - Navigation Data Standard (NDS)
Challenges & solutions – (M)EC

— Many associations and foundations work on (M)EC
  — 3GPP
  — Automotive Edge Computing Consortium (AECC)
  — 5G Automotive Association (5GAA)
  — Linux Foundation Edge (LF Edge)
  — ETSI MEC Industry Specification Group (ISG)
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“The guiding principle of network dimensioning has been to maximise the physical distance between the UE and the AS [Application Server], whilst delivering the required E2E latency and reliability for a given service.”

Source: NGNM; “5G Extreme Requirements: End-to-End Considerations”; Editors: Ilaria Thibault (Vodafone), Sophie Vrzic (Huawei); Aug. 2018
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Challenges & solutions – (M)EC

Known handover/selection:
- Radio handover
- Server selection (e.g. for load balancing / proximity)

New:
- Gateway (anchor point) selection/handover
Challenges & solutions – (M)EC

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4G EPC: Disconnect / Connect ➔ Vehicle Loses IP-Connectivity for some Time
Challenges & solutions — (M)EC

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— All handovers / reselections seamless and transparent for the application!?
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All handovers / reselections seamless and **transparent for the application!**?

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Help, my client disappeared!

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Who are you? I don’t know you.

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Why am I not getting the reply?
Challenges & solutions — (M)EC

Known handover/selection:
- Radio handover
- Server selection (e.g. for load balancing / proximity)

New:
- Gateway (anchor point) selection/handover

All handovers / reselections seamless and transparent for the application?

Features:
- Make-before-break gateway reselection
- Use multiple gateways for uplink
- Notify packet data network / Application Server
Challenges & solutions – QoS & charging

Challenges:
- Serve different classes of applications (e.g. infotainment / telematics + CCAM)
- Prioritize QoS data traffic over other data traffic
- Charge separately
- Keep complexity of communication unit / application in vehicle low

Solutions:
- Network Slicing: Needs 5G core; 4G slicing (DECOR\(^1\)) only allows one slice per UE
- Multiple APNs\(^2\): Results in multiple IP addresses per vehicle making the in-vehicle software complicated
- Dedicated bearers: Fulfill the requirements and put the effort to the MNO\(^3\), not the car manufacturer

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1) DECOR: Dedicated Core Network (aka DCN)  
2) APN: Access Point Name  
3) MNO: Mobile Network Operator  
4) BSS: Business Support System
Challenges & solutions – QoS & charging

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\(0\) Baseline: Infotainment / telematics over 4G/5G network

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1) Contract: MNO, C-ITS provider, and vehicle OEM / owner agree on **CCAM service delivery**

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4) Dedicated bearer for **CCAM services established automatically**; charged separately

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Summary & conclusion

- Starting with today’s 4G and emerging 5G networks CCAM can become reality
- Connectivity will initially be complementing on-board sensors
- Infrastructure providing connectivity must be reliable
  - End-to-end QoS incl. (M)EC
  - Hybrid (short- and long-range)

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Awareness Starts</td>
<td>Automation Starts</td>
<td>Cooperation Starts</td>
<td>Future Mobility</td>
</tr>
<tr>
<td></td>
<td>“I share where I am and what I hear”</td>
<td>“I share what I see”</td>
<td>“We share our intentions”</td>
<td>“We coordinate all manoeuvres”</td>
</tr>
<tr>
<td></td>
<td>Hybrid ITS G5/LTE-V + 3G/4G</td>
<td>Hybrid +5G</td>
<td>Hybrid + New technologies</td>
<td>Hybrid + new technologies</td>
</tr>
<tr>
<td></td>
<td>Advanced Driver Assistance System</td>
<td>Some Roads Human Back-up</td>
<td>Most Roads No Human Back-up</td>
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