Vehicle Connectivity in Intelligent Transport Systems: Today and Future

Prof. Dr. Ece Güran Schmidt - Middle East Technical University
• Intelligent Transportation Systems (ITS)
• Vehicle connectivity for ITS and infotainment
• Enabling technologies for connectivity: Today and future
• End-to-end connectivity architectures
• Real time connectivity application examples
• Conclusions
INTELLIGENT TRANSPORT SYSTEMS (ITS)

- Transport safety, comfort and efficiency
- Distributed computing and communication of ITS nodes:
  - Vehicles
  - Road Side Units
  - Mobile Devices
  - Pedestrians
  - Servers
  ➔ Cooperative ITS (C-ITS)

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Adopted from: http://www.toyota-global.com/innovation/intelligent_transport_systems/mobility
SELECTED VEHICLE CONNECTIVITY
ITS APPLICATIONS

3GPP TR 22.885 Technical Specification

V2V Safety [5.1-5.4, 5.7, 5.10, 5.12]
V2V/V2I Traffic Efficiency [5.5, 5.9, 5.15]
V2I Road Safety [5.6, 5.8, 5.14, 5.16]
V2P Road Safety [5.17, 5.18]

V2V message transfer under operator control [TR 22.885, 5.11]
V2X in areas outside network coverage [TR 22.885, 5.13]
VEHICLE CONNECTIVITY
INFOTAINMENT APPLICATIONS

Audi Q5 Infotainment

BMW ConnectedDrive

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USDOT extensive analysis of crash data from 2004 to 2008 result:
A fully implemented V2X system can address 4.5 million crashes (81% of all multi-vehicle unimpaired crash types)

Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application, Aug 2014

BUT: Customers are more interested and informed about infotainment than safety.
Connectivity Modes

C-ITS: Cooperative ITS
V2N: Vehicle to Network
V2I: Vehicle to Infrastructure
V2V: Vehicle to Vehicle
V2P: Vehicle to Pedestrian
OBU: On Board Unit
RSU: Road Side Unit

http://design.avnet.com/axiom/autorama-connecting-your-car-to-the-internet-of-tomorrow/

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ECU (Electronic Control Unit):
- Gets sensor inputs
- Computes outputs for actuators, motors, relays, LEDs

Contemporary vehicle:
- Up to 70 ECUs
- Tens of millions of lines of code
- ECUs connected by in-vehicle networks
Requirements from (ETSI) message properties:
- Latency ≤100msec
- Size ≤ 800 Bytes
- All vehicles periodically broadcast CAM messages at 1-10 Hz
- Event-triggered DENM messages

<table>
<thead>
<tr>
<th></th>
<th>IEEE 802.11p (DSRC-WAVE) 5.86–5.92 GHz</th>
<th>3GPP UMTS (3G) 700–2600 MHz</th>
<th>3GPP LTE (4G) 700–2690 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit rate</td>
<td>3–27 Mb/s</td>
<td>2 Mb/s</td>
<td>Up to 300 Mb/s</td>
</tr>
<tr>
<td>Range</td>
<td>Up to 1 km</td>
<td>Up to 10 km</td>
<td>Up to 30 km</td>
</tr>
<tr>
<td>Mobility support</td>
<td>Medium</td>
<td>High</td>
<td>Very high (up to 350 km/h)</td>
</tr>
<tr>
<td>Coverage</td>
<td>Intermittent</td>
<td>Ubiquitous</td>
<td>Ubiquitous</td>
</tr>
<tr>
<td>Latency</td>
<td>5 msec (V2V measured, 2016)</td>
<td>60 milliseconds (US, Jan 2017 measured)</td>
<td>10-30 milliseconds (US, Jan 2017 measured)</td>
</tr>
<tr>
<td>Broadcast</td>
<td>On control channel</td>
<td>Not supported</td>
<td>Cell Broadcast</td>
</tr>
</tbody>
</table>

CAM: Context Awareness Message
DENM: Decentralized Environmental Notification Message
**CONNECTIVITY FOR ITS: MORE ON DSRC-WAVE**

### Advantages
- Communication stack
- IEEE
  - Application (Safety/Non-safety)
  - Security Service
  - TCP/UDP
  - IPv6
- LLC
- WAVE Upper MAC
- WAVE Lower MAC
- WAVE PHY
- US Government mandate for all new light vehicles
- Reserved frequency
- Low cost hardware
- Low latency

### Disadvantages
- Short range: No V2N without RSU
- Poor performance under high vehicle density, mobility
- No evolution path for PHY/MAC layer range, reliability

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CONNECTIVITY FOR ITS: MORE ON LTE

Advantages
- QoS scheduling at base station
- Broadcast and multicast
- DENM can be supported better
- Can consolidate notifications

Disadvantages
- Cannot support continuous CAM messages with individual vehicle info
- No direct V2V support

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CONNECTION OPTIONS FOR ITS: V2X HETEROGENEOUS COMMUNICATIONS

- **DSRC:**
  - Low delay + cellular: good coverage, high mobility
  - V2V and V2I are realized by DSRC

- **Cellular network:**
  - Connects fragmented DSRC segments
  - Acts as a backup for V2V
  - Access network to the Internet for Infotainment
CONNECTIVITY OPTIONS FOR ITS: C(ELLULAR)-V2X

- **LTE Advanced Pro:**
  - Expected Latency of < 10 ms
  - Direct Communication (D2D) without base station with ProSe (Proximity Services)
- Expected 5G latency < 5 ms

Adapted from Nokia, Qualcomm
FUTURE CONNECTIVITY FOR ITS: C-V2X REALIZATION

November 2015: Real test in Deutsche Telekom’s live LTE network

Relative speed = 25 km/h

Integrated computing at the base station
E2E delay = 20ms

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E2E CONNECTIVITY

Requirements:
- Seamless connectivity
- Scalable
- Real-time E2E communication
- Mobility support

E2E CONNECTIVITY: ITCON

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Research project of METU conducted with automotive and telecom companies

- Web based application level data switching on ITCON server
- Seamless Communication among distributed applications and components
E2E CONNECTIVITY: ITCON REALIZATION

- OBU: SABRE for Automotive Infotainment Based on i.MX 6 Series running Android
- NW delay (w/o mobility): Cellular Access Delay + IP Network Delay.
- Expected E2E delay < 50 ms
  - Average IP ping delay within 300 km < 10 ms
  - LTE pro latency < 10 ms

Practical Application: Remote Vehicle Diagnostics
**E2E CONNECTIVITY: ITCON++**

**D2D/DSRC:** V2V, V2I

**Cellular:** V2N and Backing up D2D/DSRC messages

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Scheduling Lane Changes for Autonomous Vehicles (Ph.D Thesis, METU)

- Complete necessary lane changes before reaching an intersection
- Vehicles provide state and destination information to RSU
- RSU commands required speed/lane change maneuvers to vehicles
- Can be integrated into network-level traffic management
• Vehicle acts as a sensing, computing and communicating node of ITS
• End to end architectures are constructed with vehicle ECUs, vehicles, smart devices and servers as end nodes with seamless connectivity
• DSRC is an established low latency technology with its limitations
• Cellular communication standards are evolving very fast. Low latency, and continuous coverage are becoming possible.
• Real-time safety applications including cooperative autonomous driving will be enabled with low-latency, reliable V2V and V2I communication
• Regulators and vehicle manufacturers must agree on compatible connectivity standards that are implemented in all vehicles
FUTURE CONNECTIVITY FOR ITS: C-V2X with D2D

C-V2X without Base Station

US FCC: 3GPP Rel-12 is the next generation nationwide public safety network

- Motivated Direct Communication (D2D)

3GPP Rel-14: C-V2X enhancements for D2D

- High speeds and high Doppler
- High vehicle density
- Improved synchronization and low latency
- Proximal direct communications (100s of m)
- Latency-sensitive use cases, e.g. V2V safety