Vehicle to X communication
complementing the automated driving system and more

Joerg Koepp
Market Segment Manager IoT
Rohde & Schwarz
What is new about Vehicle to vehicle communication?
The movement toward autonomous vehicles seems to be gaining traction

BMW will launch the electric and autonomous iNext in **2021**
Source: Elektrek, 2016-05-12

Ford CEO announces fully autonomous vehicles for mobility services by **2021**
Source: Reuters, 2016-08-16

Fully autonomous vehicles will be on the road before **2022**, says NVIDIA CEO
Source: Reuters, 2017-10-26
On the way to a future of autonomous driving

93% of all car accidents are caused by human errors

People spending more than 4 years of life in cars

People like to text, surf or just enjoy time on cars
The Internet of Cars or the value of hyper-connected vehicles: Use of several flavors of cellular IoT
Six levels of driving automation from “no automation” to “full automation”.

<table>
<thead>
<tr>
<th>Level</th>
<th>No Automation</th>
<th>Driver Assistance</th>
<th>Partial Automation</th>
<th>Conditional Automation</th>
<th>High Automation</th>
<th>Full Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver</td>
<td>Performs driving control at all times</td>
<td>Performs driving control at all times</td>
<td>Monitors all driving tasks at all times</td>
<td>Must be able to intervene (10s)</td>
<td>Not responsible to intervene</td>
<td>Might not be in the car</td>
</tr>
<tr>
<td>System</td>
<td>Doing support</td>
<td>Temporarily performs limited control</td>
<td>Temporarily performs complete control</td>
<td>Performs all tasks in certain scenarios</td>
<td>Performs all tasks in certain scenarios</td>
<td>Responsible at all times</td>
</tr>
</tbody>
</table>

SAE J3016 Level of Automation (LoA) SAE: Society of Automobile Engineers
Sensor fusion: Several types of external sensors

- **Rearward looking side cameras**
  - max distance: 100 m

- **Forward looking side cameras**
  - max distance: 80 m

- **Wide forward camera**
  - max distance: 60 m

- **Wide rear view camera**
  - max distance: 50 m

- **Ultrasonics**
  - max distance: 8 m

- **LIDAR**
  - max distance: ~100 m

- **Main forward Camera**
  - max distance: 150 m

- **Radar**
  - max distance: 160 m

- **Narrow Forward Camera**
  - max distance: 250 m
Autonomous and Cooperative Systems

Autonomous Systems
e.g. Pre-collision safety system

On-board sensors are used to detect objects (other vehicles, signs, pedestrians) around the vehicle **within the visibility range**

Cooperative Systems
e.g. Traffic hazard warning

Communication with infrastructure or other vehicle enables detection of objects and ‘events’ **outside the visibility range**

Enhanced safety systems leverage the coordinate use of both systems
V2x enabling cooperative applications

- Forward Collision Warning
- Blind Intersection Warning
- Cooperative driving (platooning)
- Emergency vehicle alert
Technology Solutions for Intelligent Transport Systems (ITS)

General awareness
Point-to-Multipoint continuous broadcast

Specific warning
Special message temporarily broadcasted

Reliability
Periodic message transmission; repetition frequency depends on importance

Availability
Decentralized system w/o central channel access coordination
ITS implementation for safety applications
ITS-G5 (ETSI EN 302 637 series), WAVE (IEEE 1609 series)

Basic Safety Message (BSM)
Vehicle status information
Optional event flags (SAE J2735, SAE J2945)

Cooperative Awareness Message (CAM)
Vehicle status information (ETSI EN 302 637-2)
Decentralized Environment Notification (DENM)
Information about specific event (ETSI EN 302 637-3)

E2e latency: 20 ms .... 500 ms
Repetition: 1 Hz ... 10 Hz,
Range: 300 m – 1 km
Speed: 250 km/h (absolute), 500 km/h (relative)
Car (Vehicle) to X, communication based on 802.11p Wi-Fi in a very challenging environment

802.11a signal with reduced rate:
- 802.11p is essentially based on the OFDM PHY
- 10 MHz bandwidth for robustness
- Carrier spacing reduced by $\frac{1}{2}$
- Symbol length is doubled, making the signal more robust against fading.
- Operates in the 5.8 GHz and 5.9 GHz frequency bands depending on regional regulations.
- No access point
ITS Example
CAM: Collision Risk Warning in Urban Area via ITS-G5

### Scenario

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>$V = 50 \text{km/h}$</td>
</tr>
<tr>
<td>Stopping Distance</td>
<td>$d_{\text{stop}} = 30 \text{m}$</td>
</tr>
<tr>
<td>CAM Repetition</td>
<td>200 ms</td>
</tr>
</tbody>
</table>

### Observation

- Probability of successful reception ($p \geq 99\%$): $l_{\text{coll}} \leq 97 \text{m}$
- Time to Collision: $TTC = 6 \text{s}$

Driver is informed 6s before collision, sufficient to come to complete stop if necessary.
ITS Example
DENM: Stationary Vehicle Warning via ITS-G5

Scenario

- Velocity: $V = 50 \text{km/h}$
- Stopping Distance: $d_{\text{stop}} = 30 \text{m}$
- DENM Repetition: 1s

Observation

- Probability of successful reception ($p \geq 99\%$): $l_{r1} \leq 83 \text{m}$
- Time to Collision: $TTC = 6s$

Driver is informed 6s before collision, sufficient to come to complete stop if necessary
## ITS approaches around the world – much more than just safety

<table>
<thead>
<tr>
<th>Region</th>
<th>Approach Type</th>
<th>Use Cases Specifications</th>
<th>Commercialization</th>
<th>Development Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Market driven approach w/ broad set of applications</td>
<td>&gt; 50 use cases specified by ETSI</td>
<td>Expected to follow phased approach</td>
<td>760MHz: Collision Avoid. 5.8GHz: ≈2000 ITS Spots</td>
</tr>
<tr>
<td>USA</td>
<td>Safety driven approach with core set of crash avoidance applications</td>
<td>Dep. of Transportations &amp; Industry develops &gt; 100 use cases Mandate expected*) 2019, starting 2021 (phase-in approach)</td>
<td></td>
<td>5.9 GHz, 7x10MHz, 30 MHz with additional 20 MHz for future use</td>
</tr>
<tr>
<td>China</td>
<td>Industry driven approach but orchestrated by government bodies</td>
<td>China ITS Industry Alliance and SAE China identified 40 ITS Use Cases</td>
<td></td>
<td>5.9 GHz, 3x10MHz + 2x10MHz</td>
</tr>
<tr>
<td>Japan</td>
<td>Industry driven approach supported by government departments</td>
<td>ITS system commercially available ITS applications mainly based on infrastructure 9 Development areas identified</td>
<td></td>
<td>@ 5.9 GHz, 7x10MHz</td>
</tr>
</tbody>
</table>

* Mandate expected in 2019, starting 2021 (phase-in approach)
18 use case have been studied in TR 22.885

- Forward Collision Warning
- Control Loss Warning
- V2V Use case for emergency vehicle warning
- V2V Emergency Stop Use Case
- Cooperative Adaptive Cruise Control
- V2I Emergency Stop Use Case
- Queue Warning
- Road safety services
- Automated Parking System
- Wrong way driving warning
- V2V message transfer under operator control
- Pre-crash Sensing Warning
- V2X in areas outside network coverage
- V2X Road safety service via infrastructure
- V2I / V2N Traffic Flow Optimisation
- Curve Speed Warning
- Warning to Pedestrian against Pedestrian Collision
- Vulnerable Road User (VRU) Safety
3GPP was analyzing three scenarios

1: D2D Sidelink (PC5)  
2: E-UTRAN Networking  
3: Combination of 1&2
Cellular Mobile Network – Preliminary Study before Release 14
Challenge: Point to Multipoint

How many vehicles can be served within a single cell?

Does the delay meet the requirements?

Messages replicated several times DL capacity sufficient?

Rural Deployment, 800MHz, Inter-Site Distance 6km

Urban Deployment, 2GHz, Inter-Site Distance 500m
Cellular Mobile Network – Preliminary Study before Release 14

Challenge: Geo-Messaging

- Delay: Does the delay still meet the requirement?
- Bottleneck: DL capacity

![Diagram showing measured minimum end-to-end latency with different components such as Geoserver, EPC, LTE (RAN + EPC), and Vehicle Application Layer RX/TX with latencies of 6ms, 21ms, 87ms, and 20ms respectively.]
Cellular Mobile Network – Preliminary Study before Release 14

Challenge: Network Coverage

- Messages for road safety must be received and transmitted at any time, anywhere
- 100% cellular network coverage expensive and hard to deploy

Taiwan around 80% 4G coverage
V2X communication architecture: V2V | V2N | V2I | V2P
Direct communication (PC5) or network communication (Uu)
Introduces V2X for out-of- and in- coverage communication in high speed scenarios to exchange vehicle status information and environment information
Rel. 14 work to enable vehicle to vehicle communication

## Adoption of LTE-D2D PC5 for V2V in a dedicated carrier

<table>
<thead>
<tr>
<th>In-coverage scenario w/ eNodeB scheduling (TM3)</th>
<th>Out-of-coverage scenario w/ distributed scheduling (TM4)</th>
<th>Reused channel structure of sidelink communication</th>
<th>DMRS extension to cope with relative speed of up to 500 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
<td><img src="image3" alt="Diagram" /></td>
<td><img src="image4" alt="Diagram" /></td>
</tr>
</tbody>
</table>

- **DMRS extension to cope with relative speed of up to 500 km/h**
- **Spectrum sensing and collision avoidance for distributed scheduling**
- **Introduction the concept of zones for transmission resources**
- **New arrangement of resources into resource pools (RPs)**
- **Time synchronization via GNSS**

In-coverage scenario with eNodeB scheduling (TM3):
- Uu
- PC5

Out-of-coverage scenario with distributed scheduling (TM4):
- Uu
- PC5

| Technology week | Taiwan | November 2017 | 24 |
Enhances V2X (eV2X) to support low latency, high data rate with transmit diversity in order to exchange sensor data, intention information and trajectory data.
V2x Phase III: 5G NR (Rel16+): Introduces New Radio (NR) to further increase data rate, support new spectrum, new numerology

<table>
<thead>
<tr>
<th>Reliability</th>
<th>100 ms</th>
<th>25 ms</th>
<th>10 ms</th>
<th>5 ms</th>
<th>3 ms</th>
<th>2 ms</th>
<th>1 ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>90.000 %</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>99.000 %</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>99.900 %</td>
<td></td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>99.990 %</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>99.999 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
</tr>
</tbody>
</table>

- CAM/DENM
- Platooning
- Sensor Sharing

**End to end latency**

- **Short Distance Platooning**: ✔
- **Remote Driving**: ✔

**Reliability Levels**
- **90.000 %**: Reliability 90.000 %
- **99.000 %**: Reliability 99.000 %
- **99.900 %**: Reliability 99.900 %
- **99.990 %**: Reliability 99.990 %
- **99.999 %**: Reliability 99.999 %

**Latency Levels**
- **100 ms**
- **25 ms**
- **10 ms**
- **5 ms**
- **3 ms**
- **2 ms**
- **1 ms**

**Challenging**
Rohde & Schwarz Supports 3GPP Cellular V2X Device Testing for Vehicle-to-Vehicle Connectivity

By AccessWire, October 19, 2017 10:10:00 AM EDT

The R&S CMW500 Wideband Radio Communication Tester Supports Cellular Vehicle-to-Everything (C-V2X) Signal Testing and Was Used to Successfully Test a Pre-Commercial Qualcomm® 9150 C-V2X Chipset

COLUMBIA, MD / ACCESSWIRE / October 19, 2017 / Rohde & Schwarz, a leading supplier of test and measurement equipment, is enabling vehicles to move to the next level of autonomy by providing initial support for cellular vehicle-to-everything (C-V2X) signaling testing. Rohde & Schwarz and Qualcomm Technologies, a subsidiary of Qualcomm Incorporated, have collaborated by using the R&S CMW500 wideband radio communication tester with a pre-commercial Qualcomm® 9150 C-V2X chipset, which supports 3rd Generation Partnership Project (3GPP) Release 14 specifications for PC5 based direct communications. The 9150 C-V2X chipset is a product of Qualcomm Technologies and operates in bands 460 and 47 for 5-8.5 GHz ITS spectrum.

Qualcomm is driving C-V2X towards commercialization

Chipset anticipated to be available for commercial sampling in the second half of 2018

- Supports C-V2X Direct Communications (V2V, V2I and V2P) for automakers and roadside infra providers
- Integrated GNSS support
- Pre-integrated with telematics unit for V2N operation
- Supports SIM-less operation
- Designed to work in ITS 5.9 GHz spectrum
- Designed for extended communication range and enhanced reliability
- Optimized for high vehicle density deployments
- Designed to empower vehicles, VRUs and RSUs
### 5G Automotive Association (5GAA) Members (September 2017)

#### Founding members

<table>
<thead>
<tr>
<th>Car Maker</th>
<th>Car Supplier</th>
<th>Telco Infrastructure</th>
<th>Chip Manufacturer</th>
<th>Operator</th>
<th>Telco Enabler</th>
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<tbody>
<tr>
<td>BMW GROUP</td>
<td>SAVARI</td>
<td>NOKIA</td>
<td>Intel</td>
<td>docomo</td>
<td>CETECOM</td>
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<td>DAIMLER</td>
<td>Valeo</td>
<td>HUAWEI</td>
<td>QUALCOMM</td>
<td>SoftBank</td>
<td>proXimus</td>
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<td>Audi</td>
<td>Bosch</td>
<td>ERICSSON</td>
<td>SKYWORKS</td>
<td>TELSTRA</td>
<td>Laird</td>
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<td>Ford</td>
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<td>ZTE</td>
<td>ROHM</td>
<td>SoftBank</td>
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<td>ZTE</td>
<td>Panasonic</td>
<td>Orange</td>
<td>SoftBank</td>
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<td>Continental</td>
<td>ZTE</td>
<td>LG</td>
<td>AT&amp;T</td>
<td>Keysight</td>
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<td>Volkswagen</td>
<td>Continental</td>
<td>ZTE</td>
<td>Infineon</td>
<td>China Mobile</td>
<td>JPM</td>
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<td>SAIC</td>
<td>Continental</td>
<td>ZTE</td>
<td>Analog Devices</td>
<td>China Mobile</td>
<td>JPM</td>
</tr>
</tbody>
</table>

**Technology week | Taiwan | November 2017**
5GAA organization

BOARD

EXECUTIVE COMMITTEE

GENERAL ASSEMBLY

WG1
Use Cases and Technical Requirements

WG2
System Architecture and Solution Development

WG3
Evaluation, Testbeds and Pilots

WG4
Standards and Spectrum

WG5
Business Models and Go-To-Market Strategies
Automotive Edge Computing Consortium

Industry leaders to form consortium for network and computing infrastructure of automotive big data
Aug. 10, 2017

DENSO Corporation, Ericsson (NASDAQ: ERIC), Intel Corporation, Nippon Telegraph and Telephone Corporation (NTT), NTT DOCOMO, INC., Toyota InfoTechnology Center Co., Ltd. and Toyota Motor Corporation today announced that they have initiated the formation of the Automotive Edge Computing Consortium. The objective of the consortium is to develop an ecosystem for connected cars to support emerging services such as intelligent driving, the creation of maps with real-time data and driving assistance based on cloud computing.

It is estimated that the data volume between vehicles and the cloud will reach 10 exabytes per month around 2025, approximately 10,000 times larger than the present volume. This expected increase will trigger the need for new architectures of

- Organization driven by Toyota and Eco-chain
- Edge computing to fulfill the requirements for small latencies.
- General trend also in Japan versus C-V2X with advantage to use existing infrastructure
- Automotive industry have interest to collect data for future business models, therefore preference of communication via BTS (PC5 only for non-coverage case).
Platooning – Why is latency (also commercially) relevant?

“road train“ with „electronic link“ to reduce aerodynamic drag and thus fuel consumption

Platooning: A cooperative method to enhance safety and efficiency

Technologies: radar, stereometric camera, V2X

The pressure field for a two-vehicle platoon with a spacing of 5, 10, and 20 m. The pressure coefficient represents a scaled deviation from the nominal air pressure.

- Fuel savings: 4-5% at 10 m distance
- Fuel savings: 8-9% at 3-6 m distance

Values vary for other References (up to 20% for 2nd truck on test track)

Reference: 2016 North American Council for Freight Efficiency

CONFIDENCE REPORT: Two-Truck Platooning

⇒ The distance is crucial for fuel reduction (even 1-2m if possible)
⇒ 5G URLLC
Resolution of the latency measurement system (at µsec-level)
Very low latency direct connection (< 5µs)

- + delay means Tx
- - delay means Rx, additional point is ACK
- In this screenshot both GPS clocks locked
- Latency measurement drift without GPS signal
  One GPS not locked (from t=200 sec), but since OXCO is very stable, no visible drift even after 300 seconds!
TUM FTM research project: Tele-operated driving

http://www.ftm.mw.tum.de/forschungsfelder/fahrerassistenz-und-sicherheit/teleoperiertes-fahren/
C-V2X latency measurement results
control, sensor, LIDAR and video IP packets from tele-operated vehicle

- Steps at multiples of 1 msec
- TTI is 0.5 msec
- Latency lower than LTE latency
- BTS f = 2.6 GHz

- Step structure in latency originate from distribution of large IP data packets over several TTIs
Rohde & Schwarz
your partner in testing
the connected car