Presentation on behalf of the 5GAA

Cost–benefit analysis on cellular vehicle to everything (C-V2X)

5 December 2017 • Janette Stewart (Analysys Mason) & Alain Dunoyer (SBD Automotive)
Context for the study

Scope of the study
Research findings
Cost–benefit analysis
Results and recommendations
About Analysys Mason and SBD Automotive
The purpose of the study was to assess the net benefits of C-V2X use in Europe

- Vehicle to everything (V2X) will enable communication between vehicles (V2V), and between vehicles and infrastructure (V2I):
  - potential to provide enhanced information, complementing on-board sensors, enabling operation over a longer range

- C-V2X is designed to deliver V2X, with two modes of communication:
  - a direct vehicle-to-vehicle mode (‘PC5’), for V2V/V2I
  - a network communications interface, for vehicle-to-network (V2N) communication via mobile networks (‘Uu’)

- An existing short-range technology, IEEE 802.11p, is also designed to offer V2V/V2I services

- We were asked to examine qualitative evidence, and perform quantitative analysis to compare the net benefits of C-V2X with those of IEEE 802.11p
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There were three main elements to the study

1. Conduct primary research on C-V2X deployment
   - We interviewed 5GAA member companies, to gather evidence on planned C-V2X deployment, business models and cost assumptions.

2. Consider qualitative evidence
   - We gathered published evidence about C-V2X deployment (and its evolution to 5G) in Europe, including trials, deployment plans, potential business cases and socio-economic benefits.

3. Develop cost–benefit analysis
   - We developed scenarios and a cost–benefit model comparing C-V2X with IEEE 802.11p for V2V/I/N/P deployment in Europe.
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A key benefit of C-V2X is that it incorporates multiple modes of transmission

**PC5 Mode 3:** Network-assisted radio resource management

- GNSS time synchronisation
- eNodeB cellular base station
- Uu
- PC5

**PC5 Mode 4:** Distributed radio resource management

- GNSS time synchronisation
- Uu

Communication for management of radio resource

Communication related to use cases
C-V2X benefits include its evolution path to 5G, and potential for rapid economies of scale [1]

Future-proof, providing a progression to 5G

C-V2X will evolve to facilitate new capability in the 5G era. In the meantime, the dual modes of LTE C-V2X meet all the requirements of the automotive industry

Supports V2P communication

V2P may be needed for fully automated cars in urban areas. Although there are doubts that V2P can be achieved with IEEE 802.11p, V2P can be enabled using LTE smartphones (either via Uu, or PC5)

A wide range of business models are possible

Business models leveraging the multiple modes of C-V2X could include infotainment, traffic information, real-time mapping, telematics and data analytics. Network-based data analytics opportunities also exist (using data gathered via both Uu and PC5 interfaces)
C-V2X benefits include its evolution path to 5G, and potential for rapid economies of scale [2]

Economies of scale will develop more rapidly

Many automotive OEMs believe C-V2X will be less expensive to implement than IEEE 802.11p (and cheaper than a combination of IEEE 802.11p for V2V, plus cellular for V2N)

V2V and V2N modules can be combined in a single C-V2X chipset

This same integration between V2V and cellular is not expected for DSRC/ITS-G5, which will need dual/multiple chipsets in vehicles compared to potential for a single C-V2X chipset
## Research findings

We identified that C-V2X commercialisation is imminent, with several trials underway [1]

<table>
<thead>
<tr>
<th>Deutsche Telekom (DT), Continental, Fraunhofer, Nokia Networks</th>
<th>Real-time V2N2V (&lt;20ms latency)</th>
<th>Demonstrated on DT’s LTE network with MEC technology (Nov-15); and Nokia Networks in China (Nov-16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audi, DT, Huawei, Toyota, other automotive OEMs</td>
<td>C-V2X</td>
<td>Technical LTE-based field trial (Jul-16)</td>
</tr>
<tr>
<td>Audi, Ericsson, Qualcomm, SWARCO Traffic Systems, University of Kaiserslautern</td>
<td>C-V2X</td>
<td>Formed Connected Vehicle to Everything of Tomorrow (ConVeX) consortium (Jan-17) to demonstrate C-V2X (3GPP Release 14)</td>
</tr>
<tr>
<td>Ericsson, BMW, Deutsche Bahn, DT, Telefónica Deutschland, Vodafone, TU Dresden 5G Lab Germany, Federal Highway Research Institute (BAST), Federal Regulatory Agency (BNetzA)</td>
<td>C-V2X</td>
<td>Formed 5G-Connected Mobility consortium (Nov-16) to develop real-world application environment for 5G-based C-V2X</td>
</tr>
<tr>
<td>Vodafone, Bosch, Huawei</td>
<td>C-V2X (direct V2V)</td>
<td>LTE-based trial (Feb-17); aims to demonstrate very low latency, and differences from IEEE802.11 solutions</td>
</tr>
</tbody>
</table>
We identified that C-V2X commercialisation is imminent, with several trials underway [2]

<table>
<thead>
<tr>
<th><strong>Research findings</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>‘Towards 5G’ partnership</strong> (Ericsson, Orange, PSA Group, Qualcomm)</td>
</tr>
<tr>
<td><strong>UK Connected Intelligent Transport Environment</strong> (Vodafone, Jaguar LandRover)</td>
</tr>
<tr>
<td><strong>National Intelligent Connected Vehicle Testing Demonstration Base</strong>, Shanghai (China Mobile Communications, SAIC Motor, Huawei)</td>
</tr>
<tr>
<td><strong>Michigan, USA</strong> (Ford Motor Company, Qualcomm)</td>
</tr>
<tr>
<td><strong>5G showcase trials</strong>, South Korea (LG Electronics, Qualcomm)</td>
</tr>
<tr>
<td><strong>San Diego</strong> (Regional Proving Ground (AT&amp;T, Ford, Nokia, Qualcomm, supported by the San Diego Association of Governments))</td>
</tr>
</tbody>
</table>
Our interviews suggest possible commercial launch of C-V2X from 2020/2021

Overview of C-V2X timeline

- **LTE-based C-V2X specifications completed as part of 3GPP Release 14 (Dec 2016)**
- **Field testing / trials by OEMs (Q4 2017–2020 onwards)**
- **Interoperability tests/certification (2017–20)**
- **Commercial launch of C-V2X by OEMs (2020–22 onwards)**

- **3GPP Release 15 completion, including evolution of LTE-based C-V2X specifications (Sep 2018)**
- **3GPP Release 16 completion, including 5G-based C-V2X specifications (~2019)**

- **First commercial C-V2X chipsets (H1 2018)**
- **3GPP Release 14 completion (Jun 2017)**

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We modelled four scenarios, capturing different V2V/I technology choices

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<tr>
<th>Scenario 1: Base case</th>
<th>Scenario 2: 2020 EC mandate on V2V/V2I</th>
<th>Scenario 3: 2023 EC mandate on V2V/V2I</th>
<th>Scenario 4: Equitable 5.9GHz use</th>
</tr>
</thead>
</table>
| ▪ Automotive OEMs implement V2X in different timeframes, with some adopting IEEE 802.11p for V2V/I and others C-V2X  
  ▪ With limited incentive to replace roadside infrastructure, V2I is delayed (but C-V2X uses V2N)  | ▪ We assume that an EC mandate for C-ITS services to be supported in all new vehicle types from 2020 drives initial adoption of IEEE 802.11p  
  ▪ V2I requires extensive roadside infrastructure upgrades  | ▪ An EC mandate for support of C-ITS services in new vehicle types in 2023 rather than 2020 allows PC5 to develop, and automotive OEMs adopt this for V2V/V2I  
  ▪ V2I requires roadside infrastructure upgrades, but synergies within C-V2X (Uu) are exploited  | ▪ Similar to Scenario 1 we assume automotive OEMs make different technology choices for V2V/I, but with higher PC5 adoption due to greater certainty on spectrum access  |
We estimated C-V2X benefits using inputs on vehicles sold, take-up and unitary V2X benefit
V2X costs by technology are based on unit costs & timetable for infrastructure/in-vehicle roll-out

**Infrastructure take-up**
- RSU installed base
- Growth in RSU installed base
  - % replacement rate of RSUs
  - # of RSUs replaced/year
  - # new RSUs deployed/year
  - % of RSUs replaced/deployed with V2X capabilities
  - # of V2X-enabled replaced/new RSUs
  - Split of V2X-enabled replaced/new RSUs by tech.

**Infrastructure unitary costs**
- Capex/opex per V2X-enabled replaced/new RSU by tech.

**In-vehicle system unitary costs**
- # of vehicles sold/in use by service bundle by technology
- Capex/opex of in-vehicle systems per vehicle by technology
- Costs of in-vehicle systems by technology

**Total costs by technology**
Services represented in the model include warning, information and actuation/automation.

<table>
<thead>
<tr>
<th><strong>V2V</strong></th>
<th><strong>V2P</strong></th>
<th><strong>V2I/V2N</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Do not pass warning</td>
<td>Vulnerable road user protection</td>
<td>In-vehicle speed limits</td>
</tr>
<tr>
<td>Traffic jam ahead warning</td>
<td></td>
<td>In-vehicle signage</td>
</tr>
<tr>
<td>Slow or stationary vehicle warning</td>
<td></td>
<td>Probe vehicle data</td>
</tr>
<tr>
<td>Cooperative collision warning</td>
<td></td>
<td>Shockwave damping</td>
</tr>
<tr>
<td>Emergency brake light</td>
<td></td>
<td>Traffic signal priority requests</td>
</tr>
<tr>
<td>Hazardous location notification</td>
<td></td>
<td>Green light optimal speed advisory (GLOSA)</td>
</tr>
<tr>
<td>CACC (cooperative adaptive cruise control)</td>
<td></td>
<td>Traffic information for smarter junction management (e.g. signal violation,</td>
</tr>
<tr>
<td>Active breaking</td>
<td></td>
<td>traffic management)</td>
</tr>
</tbody>
</table>

**Warning**

**Actuation**

**Information**
By bunding services together we estimated vehicles sold by service bundle, per scenario

Share of vehicles sold with V2X systems by service bundle segment

<table>
<thead>
<tr>
<th>Vehicle service bundle segment</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2025</td>
<td>2035</td>
<td>2025</td>
<td>2035</td>
</tr>
<tr>
<td>Warning</td>
<td>0%</td>
<td>0%</td>
<td>75%</td>
<td>25%</td>
</tr>
<tr>
<td>Warning + information</td>
<td>81%</td>
<td>35%</td>
<td>25%</td>
<td>75%</td>
</tr>
<tr>
<td>Warning + information + actuation</td>
<td>19%</td>
<td>65%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

We also varied the technology adoption assumptions (i.e. IEEE 802.11p or C-V2X) by scenario. Unitary cost assumptions (i.e. economies of scale) are linked to the forecast technology adoption.
Assumptions on per-vehicle benefits of each C-ITS service were estimated from study inputs.

<table>
<thead>
<tr>
<th>Service</th>
<th>Category of impact</th>
<th>Urban</th>
<th>Rural</th>
<th>Motorway</th>
<th>Urban</th>
<th>Rural</th>
<th>Motorway</th>
<th>Urban</th>
<th>Rural</th>
<th>Motorway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do not pass warning</td>
<td>Safety</td>
<td>–</td>
<td>3%</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1%</td>
</tr>
<tr>
<td>Traffic jam ahead</td>
<td>Safety</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Slow/stationary vehicle</td>
<td>Safety</td>
<td>7%</td>
<td>3%</td>
<td>3%</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>GLOSA</td>
<td>Safety</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1%</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Selected examples only (full service list and unitary assumptions are in the published report).
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Benefits are highest in the equitable use scenario (4), due to V2V actuation + increased penetration.
Costs are highest in Scenario 2, where the largest deployment of RSUs is envisaged.

Results and recommendations
Net benefits* are highest in the equitable use scenario, using the multiple modes of C-V2X

* Net benefits = benefit – costs
Other impacts were the positive effect of C-ITS on jobs, road fatality reduction and SMEs

<table>
<thead>
<tr>
<th>Impact on jobs</th>
<th>Impact on SMEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ We estimate that up to an additional 220 000 jobs (direct and indirect) might be created in Europe by 2030</td>
<td>▪ SMEs could play a role in C-ITS installation/operation, and could benefit from lower operating costs, higher traffic efficiency and improved fuel consumption</td>
</tr>
<tr>
<td>▪ C-ITS could also have a positive impact on job quality</td>
<td></td>
</tr>
<tr>
<td><strong>Reduction in road fatalities</strong></td>
<td></td>
</tr>
<tr>
<td>▪ V2P specifically aims to protect pedestrians, cyclists and motorcyclists: C-V2X is well placed to deliver these services, leading to a reduction in fatalities among vulnerable road users</td>
<td></td>
</tr>
</tbody>
</table>
In summary, C-V2X benefits appear highest when its multiple usage modes are exploited

<table>
<thead>
<tr>
<th>Multiple C-V2X modes offer flexibility and net benefit gains</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Roadside infrastructure upgrades can be avoided by using cellular networks for the C-V2X Uu connectivity mode</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PC5 mode in smartphones will offer further benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ The ability for vehicles without an embedded V2V interface to use smartphone connectivity (PC5, or Uu) is a key benefit of C-V2X</td>
</tr>
<tr>
<td>▪ PC5 in smartphones will also enable V2P</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C-V2X technology integration can make deployment less expensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ C-V2X can reduce the cost of V2X/C-ITS deployment in Europe by offering cost efficiencies between its operating modes and exploiting synergies with mobile networks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Migration to 5G is also encouraged through C-V2X adoption</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ The automotive sector is predicted to generate among the highest economic benefits for Europe from 5G use – adopting C-V2X will facilitate the evolution to 5G</td>
</tr>
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Analysys Mason provides consulting and research services to the TMT industry

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- Digital transformation
- IoT
- Broadband
- Regulation and policy
- Transaction support
- Strategy and planning
- Virtualisation
- Smart energy
- Data centres
- Spectrum
- Media
- 5G
- Wireless networks
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