Case for Connected Autonomy and Implications for 5G Systems

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Do real-world autonomous vehicles need to be connected?
Historical precedence

- There have been various conceptual approaches toward driverless cars:
  - Smartification of roads/infrastructures
  - Smartification of vehicles
  - Combination of both

- Smartification of roads
  - California Partners for Advanced Transit and Highways (PATH) program, the “DEMO 97” program demonstrated the platooning of eight AVs guided by magnets embedded in the highway and coordinated with vehicle-to-vehicle (V2V).
An “autonomous system” has the authority/capability to make decisions on its own.

According to the dictionary definition of autonomous systems, at the first glance, for many, “Connected Autonomous Vehicles” sounds like an oxymoron!

But, can autonomous vehicles actually operate without interaction (i.e., Communications) with their environment?
Autonomous Vehicles – Key Functions

1. Where am I (positioning of ego-vehicle)?

2. What are the objects around me (perception)?

3. What should I do next (control)?

Even most radical opponents of CAVs do not object that all the above functions require some form Communication (passive or active) with the outside entities. The controversial questions is whether active communication can play a bigger role?
Generic Implementation of Autonomous Function

Sensing

Perception (own state and environment)

Control
Implementation Localisation and Perception

Observation

Estimation (semantically called perception)

It is known from estimation theory that the accuracy of estimation algorithms significantly improves when the number of independent observations.
Example: Cooperative object classification

- Comparison of the performance of cooperative perception with the state of the art demonstrate very promising results on synthetic data.

Cooperative performance improvement:
- Experiment 1: ~15%
- Experiment 2: ~37%
Safe and efficient control requires not only passive sensing, but also interactive communications (for example for coordination with other road users (Predictive Control)).
Addressing the Misconception

Connected/Cooperative Autonomy
IS NOT about control of ego-system from the outside.

Connected/Cooperative Autonomy
Is mainly about creating platforms and frameworks for autonomous vehicles to assist each other and benefit from the support of infrastructures to significantly improve accuracy of sensing, quality of perception and robustness of autonomous control.

The right question is perhaps, what level and horizon of communications is sufficient/helpful for autonomous vehicles?
## Nominal Performance of Existing Technologies

<table>
<thead>
<tr>
<th>Feature</th>
<th>IEEE 802.11p</th>
<th>WiFi</th>
<th>UMTS</th>
<th>LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Rate</td>
<td>3-27 Mbps</td>
<td>6-54 Mbps</td>
<td>2 Mbps</td>
<td>Up to 300 Mbps</td>
</tr>
<tr>
<td>Latency</td>
<td>10ms</td>
<td>10ms</td>
<td>50-100ms</td>
<td>10ms</td>
</tr>
<tr>
<td>Setup Time</td>
<td>0</td>
<td>3-5 seconds</td>
<td>100ms up to seconds</td>
<td>50 – 100ms</td>
</tr>
<tr>
<td>Coverage</td>
<td>Intermittent</td>
<td>Intermittent</td>
<td>Ubiquitous</td>
<td>Ubiquitous</td>
</tr>
<tr>
<td>Mobility Support</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td>V2V Broadcast</td>
<td>Native</td>
<td>Native</td>
<td>Through server</td>
<td>Through server</td>
</tr>
<tr>
<td>I2V Broadcast</td>
<td>Native</td>
<td>Native</td>
<td>MBMS</td>
<td>eMBMS</td>
</tr>
</tbody>
</table>
Performance of Existing Technologies (2)

- Existing wireless communication technologies demonstrate a **nominal latency in the range of 5-10ms in load free conditions** excluding service setup time and hand-off delay.

- The average latency in **moderately loaded conditions** is reported to be about **1s for 802.11p and 200ms for LTE networks** with the **spikes of well above 1-2s**.
Implications for Communication Systems

**Connected Autonomy Aspect**
- Enabling Cooperative Driving
- Supporting Perception Systems
- Supporting Cooperative Sensing

**Technical requirements**
- **Capacity**
  - 4G: 100 Mbps (2010)
  - 5G: 10 Gbps (2020)
- **Low Latency**
- **High Reliability**

**Constraints**
- Cost Effective
- Environment Friendly
- Safe/Secure

Figure source: Qualcomm
Thank you for your kind attention.

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