Railway Use Cases for NGV

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Abstract

Railway use cases also relevant to NGV besides road vehicle use cases:

• **Use Case 1: Onboard Train**
  • Wireless train control and monitoring system (TCMS), operator oriented services, customer services (*passenger information services, connection to mobile hot spot for public internet*)

• **Use Case 2: Train-to-Train**
  • Autonomous train *protection & operation (ATP/ATO):* collision avoidance, remote control, automatic coupling and train integrity; virtual coupling (platooning)

• **Use Case 3: Train-to-Trackside**
  • Signaling, operator oriented services, customer services (*passenger information, …*)

• **Use Case 4: Vehicle-to-Train**
  • Shared space in level crossings & shared spectrum
Why Railways?

Definition of vehicle [1]:
A vehicle is a machine that transports people or cargo. Vehicles include
• wagons, bicycles, motor vehicles (motorcycles, cars, trucks, buses),
• railed vehicles (trains, trams),
• watercraft (ships, boats),
• amphibious vehicles (screw-propelled vehicle, hovercraft),
• aircraft (airplanes, helicopters) and spacecraft.
Why Railways?

Current situation in road traffic:
- Very efficient use of roads
- EU: 75% of freight, 82% of passengers
- Many accidents, traffic jams, less energy efficient

Current situation in railways:
- Very safe and energy efficient
- EU: 18% of freight, 8% of passengers
- Inefficient use of railways due to old and national safety system
Why Railways?

Current situation in road traffic:

- Large Market: 1.3 billion motor vehicles, 1.35 trillion $ trade (2015)

Current situation in railways:

- Small Market: 6.2 million rail vehicles, without freight cars only 0.7 million, 167 billion $ (2015)

Society and politics: Shift traffic from road to rail [4]

- Need for highly efficient and safe railway operation with less infrastructure
- Reliable low-latency communications and ranging essential
Railway terms

- Rail vehicle: Wagon, railcar, locomotive, …
- Consist: a single vehicle or a group of vehicles that cannot be uncoupled

- Train: composition of one or a set of consists or rail vehicles that can be operated as an autonomous unit
Use Case 1: Onboard Train

• **Train Control and Monitoring System (TCMS) state-of-the-art [5][6]**
  - Inside rail vehicle or consist: Multifunction vehicle bus (MVB) or Ethernet consist network (ECN)
  - Connecting multiple vehicles: wired train bus (WTB) or ethernet train backbone (ETB)
  - Between consists or wagons mechanical and electrical couplers
Use Case 1: Onboard Train

• Train Control and Monitoring System (TCMS) state-of-the-art [5][6]

Mechanical stress at coupler leads to many connection failures!

[7]
Use Case 1: Onboard Train

- Wireless Train Control and Monitoring System (TCMS) [5][6]
Use Case 1: Onboard Train

- **Train Control and Monitoring System (TCMS) Data classes [6]:**
  - Process data= small dimension data (byte or bit) that are sent periodically [8]
  - Message data= differ from process data for bigger size and not sent periodically [8]
  - Supervisory data= as message data, not periodically, used for supervision and inauguration process [8]
  - Stream data= big amount of data sent continuously
  - Best Effort data= data rate and delivery time depend on traffic load
Use Case 1: Onboard Train

- **Train Control and Monitoring System (TCMS) [6]:** Key performance attributes: Inside consist

<table>
<thead>
<tr>
<th>DOMAIN</th>
<th>DATA CLASS</th>
<th>DATA SIZE</th>
<th>DATA RATE NEED</th>
<th>CYCLE TIME</th>
<th>LATENCY [The latency should be between 0 and max]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Superv [Not relevant – slow PD]</td>
<td>Not relevant</td>
<td>10Mbit/s</td>
<td>50ms</td>
<td>250ms</td>
</tr>
<tr>
<td></td>
<td>BestEffort e.g. for data upload/download relevant</td>
<td>Not relevant</td>
<td>10Mbit/s</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Streaming [Not applicable]</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Use Case 1: Onboard Train

- **Train Control and Monitoring System (TCMS)** [6]: Key performance attributes: Inside train

<table>
<thead>
<tr>
<th>DOMAIN</th>
<th>DATA CLASS</th>
<th>DATA SIZE</th>
<th>DATA RATE NEED</th>
<th>CYCLE TIME</th>
<th>LATENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Message</td>
<td>65388 [acc. IEC61375-2-3]</td>
<td>10Mb/s</td>
<td>Not relevant [Message is not a periodic communication]</td>
<td>250ms</td>
</tr>
<tr>
<td></td>
<td>Superv</td>
<td>Not relevant</td>
<td>10Mb/s</td>
<td>Not relevant</td>
<td>250ms</td>
</tr>
<tr>
<td></td>
<td>BestEffort</td>
<td>Forbidden</td>
<td>Forbidden</td>
<td>Forbidden</td>
<td>Forbidden</td>
</tr>
<tr>
<td></td>
<td>Streaming</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Submission: Stephan Sand, German Aerospace Center (DLR)
Use Case 1: Onboard Train

- **Train Control and Monitoring System (TCMS) [6]:**
  - Required bandwidth ~ 100 Mb/s in one train
  - 30 years innovation cycle

- **Operator oriented services**
  - Improve operational parameters of train, e.g. maintenance costs, vehicle availability, closed circuit television (CCTV)
  - Required bandwidth ~ 1-10 Gb/s in one train
  - 10 years innovation cycle

- **Customer services**
  - Passenger comfort, e.g. public internet, passenger info portal; customer’s own devices, WiFi
  - Required bandwidth ~ 1-10 Gb/s in one train
  - 5 years innovation cycle
Use Case 1: Onboard Train

• **Overview**
  • Safety critical and for efficient operation
  • Wireless train control and monitoring system (TCMS)
  • Operator oriented services (CCTV, maintenance)

• **Deployment time line >2025**

• **Requirements**
  • For a speed of 400 km/h and distance of 500m, NGV provides at least a data rate of 100 Mbps and latency of 1 ms and supports reliability (SIL2/3)

• **Limitations**
  • Communication range “onboard” train to avoid interference with other trains
Use Case 2: Train-to-Train
Enabling Future Applications

Autonomous train protection & operation (ATP/ATO)

Remote control, automatic coupling and train integrity [10]

Collision avoidance [9]
Use Case 2: Train-to-Train
Enabling Future Applications

Autonomous train protection & operation (ATO): Collision avoidance [9]

- 150 bit message

<table>
<thead>
<tr>
<th>mess vers type</th>
<th>train ID</th>
<th>speed</th>
<th>braking distance</th>
<th>forward length</th>
<th>backward length</th>
<th>mess. rate</th>
<th>slot reserv</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 bits 4 bits</td>
<td>30 bits</td>
<td>9 bits</td>
<td>12 bits</td>
<td>10 bits</td>
<td>10 bits</td>
<td>6 bits</td>
<td>7 bits</td>
</tr>
</tbody>
</table>

- track ID: 25 bits
- mileage: 20 bits
- planned route: 1 bit 12 bits
- latitude: 24 bits
- longitude: 24 bits
- heading: 10 bits

Total: 150 bits
Use Case 2: Train-to-Train  
Enabling Future Applications

Autonomous train operation (ATO): Collision avoidance [9]

• 150 bit message (excl. authentication and encryption)
• Dense train station /shunting yard: 200 static & 25 moving trains, 
  update rates 0.2 Hz static & 1 Hz moving train
  ➔ Minimum message rate = 200 · 0.2 Hz + 25 · 1 Hz = 65 Hz
• System data rate = 150 bit · 65 Hz = 9.75 kbit/s
• Communication range 5 km for 2 km breaking distance of train @ 200 km/h (~125 mph)
• Sufficient for informing train driver as safety-overlay in addition to other safety measures
  ➔ Higher rates needed to include authentication and encryption also 
  for stand alone system or autonomous operations
Use Case 2: Train-to-Train
Enabling Future Applications

Autonomous train operation (ATO): Remote control, automatic coupling and train integrity [10]

- Communication and ranging for control
- Ranging accuracy 1% of actual distance
- 6-sigma of Cramér–Rao lower bound (CRLB)
- ITS-G5 (802.11p, 10 MHz), IR-UWB and mm-Wave (both 500 MHz bandwidth)
Use Case 2: Train-to-Train
Enabling Future Applications

Virtual coupling: Platooning [12]
• Demonstration at Innotrans 2018 by Siemens, Bombardier, CAF
# Use Case 2: Train-to-Train

Enabling Future Applications

## Virtual coupling: Platooning [12]
- **Trains per platoon:** 3/6/18 in rural/suburban/urban
- **Message rate** 10 Hz

<table>
<thead>
<tr>
<th>Update-Delay $\Delta t$ ($a_{max} = 1 \text{ m/s}^2$)</th>
<th>0.01 s</th>
<th>0.1 s</th>
<th>1 s</th>
<th>10 s</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Position</strong> uncertainty $</td>
<td>\Delta x</td>
<td>_{max}$</td>
<td>0.5e-5 m</td>
<td>0.5e-2 m</td>
</tr>
<tr>
<td><strong>Velocity</strong> uncertainty $</td>
<td>\Delta v</td>
<td>_{max}$</td>
<td>0.01 m/s = 0.036 km/h</td>
<td>0.1 m/s = 0.36 km/h</td>
</tr>
</tbody>
</table>

- **Message size** 167 bytes
  - $13.36 \text{ kb/s}$ for one train broadcasting to platoon
  - $40.08/80.16/240.48 \text{ kb/s}$ for 3/6/18 trains per platoon in rural/suburban/urban
Use Case 2: Train-to-Train

- **Overview**
  - Safety critical and for efficient operation
  - Autonomous train protection & operation (ATP/ATO): collision avoidance, remote control, automatic coupling and train integrity; virtual coupling (platooning)

- **Deployment time line >2030**

- **Requirements**
  - For a relative speed of 500 km/h (with directional antennas 800 km/h) and distance of 2000 m, NGV provides at least a data rate of 1 Mbps, a ranging accuracy of 1% of distance, and latency of 10 ms as well as supports reliability (SIL2)
Use Case 3: Train-to-Trackside

- **Signaling: Safe operation of trains**
  - European Train Control System (ETCS)
    - GSM-R, future railway mobile communication system (FRMCS) using LTE/5G or WLAN
    - FRMCS traffic analysis [13]: ETCS, ATO, telemetry, remote control, critical video transmission
  - Positive Train Control (PTC) [14]
  - Communication Based Train Control (CBTC) [15]
    - Application standard
    - 802.11b/g or LTE @ 1.8 GHz as well as proprietary solutions @ 5.9 GHz, e.g. based on 802.11a with 5MHz channels

<table>
<thead>
<tr>
<th>Scenario for Reference Train</th>
<th>Train-to-Trackside (Uplink)</th>
<th>Trackside-to-Train (Downlink)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Video Transmission</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Future Evolution [Mbps]</td>
<td>7.42</td>
<td>3.46</td>
</tr>
<tr>
<td>Co-Existence / Mitigation [Mbps]</td>
<td>3.49</td>
<td>0.19</td>
</tr>
</tbody>
</table>

| Critical Video Transmission                  | Yes                        | No                            |
| Future Evolution [Mbps]                      | 7.42                       | 3.46                          |
| Co-Existence / Mitigation [Mbps]             | 3.49                       | 0.19                          |

- Positive Train Control (PTC) [14]
- Communication Based Train Control (CBTC) [15]
  - Application standard
  - 802.11b/g or LTE @ 1.8 GHz as well as proprietary solutions @ 5.9 GHz, e.g. based on 802.11a with 5MHz channels
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- **Signaling: Safe operation of trains**
  - European Train Control System (ETCS)
    - GSM-R, future railway mobile communication system (FRMCS) using LTE/5G or WLAN
  - Positive Train Control (PTC) [14]
  - Communication Based Train Control (CBTC) [15]
    - Application standard
    - 802.11b/g or LTE @ 1.8 GHz as well as proprietary solutions @ 5.9 GHz, e.g. based on 802.11a with 5MHz channels
  - Remote train operation in degraded mode for autonomous train operation (ATO)

- **Issues:**
  - In urban areas capacity problems
  - Dedicated links (link setup, link loss) to access points/base stations
  - Broadcast to multiple access points for redundancy, lower latency
Use Case 3: Train-to-Trackside

• **Overview**
  • Safety critical and for efficient operation
  • Signaling of European Train Control System (ETCS), Positive Train Control (PTC), Communication Based Train Control (CBTC), Remote train operation in degraded mode for autonomous train operation (ATO)

• **Deployment time line >2025**

• **Requirements**
  • For a speed of 400 km/h and distance of 2000 m, NGV provides at least a data rate of 100 Mbps (50 Mbps without critical video), absolute position accuracy of 2 m cross and 0.5 m along track with at least 99% reliability, and latency of 100 ms as well as supports reliability (SIL4)
Use Case 4: Vehicle-to-Train

- **Shared space: Level crossings**
  - Basic safety message/ CAM
  - Long breaking distance of trains compared to cars, e.g. 250m @ 100 km/h (62 mph) compared to 50m
  → Need for increased communication range

- **Shared spectrum**
  - EC Mandate for regulation:
    - Shared spectrum use of 5.9 GHz ITS band between V2X and urban rail communications
    - Spectrum segregation not an option
Use Case 4: Vehicle-to-Train

• **Overview**
  • Safety critical and for efficient operation
  • Shared space at level crossings, shared spectrum for 5.9 GHz ITS band between V2X and urban rail communications

• **Deployment time line >2020**

• **Requirements**
  • For a relative speed of 500 km/h and a distance of 2000 m, NGV provides at least a data rate of 1 Mbps, a ranging accuracy between 5% and 10% of distance, and a latency of 100 ms, as well as supports reliability (SIL2)

• **Limitations**
  • Interference between V2X and T2X limited while enabling safe cooperation
Summary

Railway use cases also relevant to NGV besides road vehicle use cases:

- **Use Case 1: Onboard Train**
  - Wireless train control and monitoring system (TCMS), operator oriented services, customer services (*passenger information services, connection to mobile hot spot for public internet*)

- **Use Case 2: Train-to-Train**
  - Autonomous train protection & operation (ATP/ATO): collision avoidance; remote control of automatic coupling and train integrity; virtual coupling (platooning)

- **Use Case 3: Train-to-Trackside**
  - Signaling, operator oriented services, customer services (*passenger information, …*)

- **Use Case 4: Vehicle-to-Train**
  - Shared space in level crossings & shared spectrum
References

2. Source wikipedia https://commons.wikimedia.org/wiki/File:Autobahn_A8_bei_Holzkirchen.JPG
3. Source wikipedia https://commons.wikimedia.org/wiki/File:Gleise_zu_Z%C3%BCrich_HB_2010.jpg
References


12. Source Javier Goikoetxea’s tweet https://twitter.com/goikotrains/status/1038396656507670528


Straw Poll

Question: use cases relevant for NGV?

• Y/N/Need more information: 27/0/18
Straw Polls

Question: Do you agree to adopt the “Onboard Train” use case on slide 14 as one of NGV use cases?
• Y/N/A: 10/8/15

Question: Do you agree to adopt the “Train-to-Train” use case on slide 21 as one of NGV use cases?
• Y/N/A: 21/2/7

Question: Do you agree to adopt the “Train-to-Trackside” use case on slide 24 as one of NGV use cases?
• Y/N/A: 12/4/14

Question: Do you agree to adopt the “Vehicle-to-Train” use case on slide 26 as one of NGV use cases?
• Y/N/A: 24/0/10