Railway Use Cases for NGV

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Authors:

Name	Affiliations	Address	Phone	email
Stephan Sand, Paul Unterhuber, Mohammad Soliman	German Aerospace Center (DLR)	Münchener Straße 20, 82234 Wessling, Germany	0049-8153-28-1464 0049-8153-28-2291 0049-8153-28-1990	stephan.sand@dlr.de paul.unterhuber@dlr.de mohammad.soliman@dlr.de
Andreas Lehner	German Aerospace Center (DLR), Intelligence on Wheels GmbH	Münchener Straße 20, 82234 Wessling, Germany Argelsrieder Feld 13 82234 Wessling, Germany	0049-8153-28-2804 0049-8153-2994023	andreas.lehner@dlr.de andreas.lehner@intelligence-on-wheels.de
Friedbert Berens	FBConsulting Sarl	21, Route de Luxembourg 6633 Wasserbillig Luxembourg	+4916097971846	friedbert.berens@me.com
Juan Moreno García-Loygorri	Universidad Politécnica de Madrid	Calle Nikola Tesla s/n 28031 Madrid (Spain)	+34 637931878	juanmorenogl@diac.upm.es

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

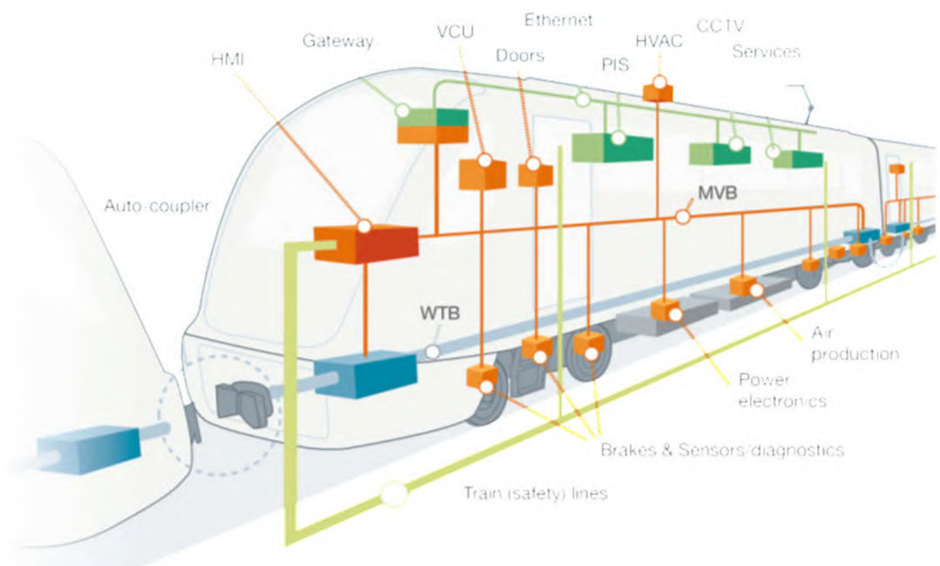
Railway terms

- **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



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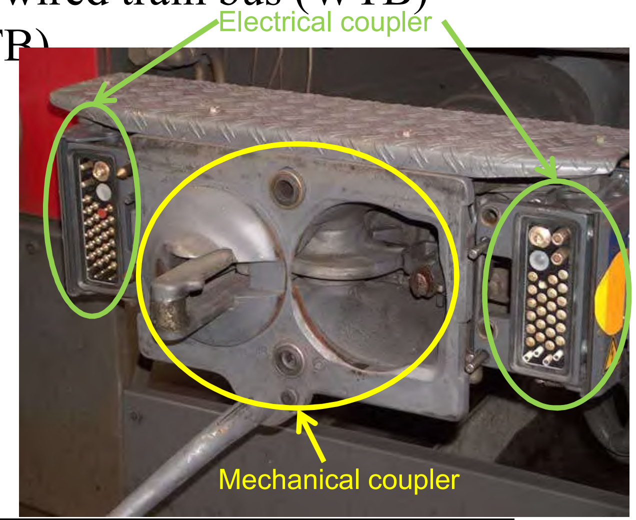
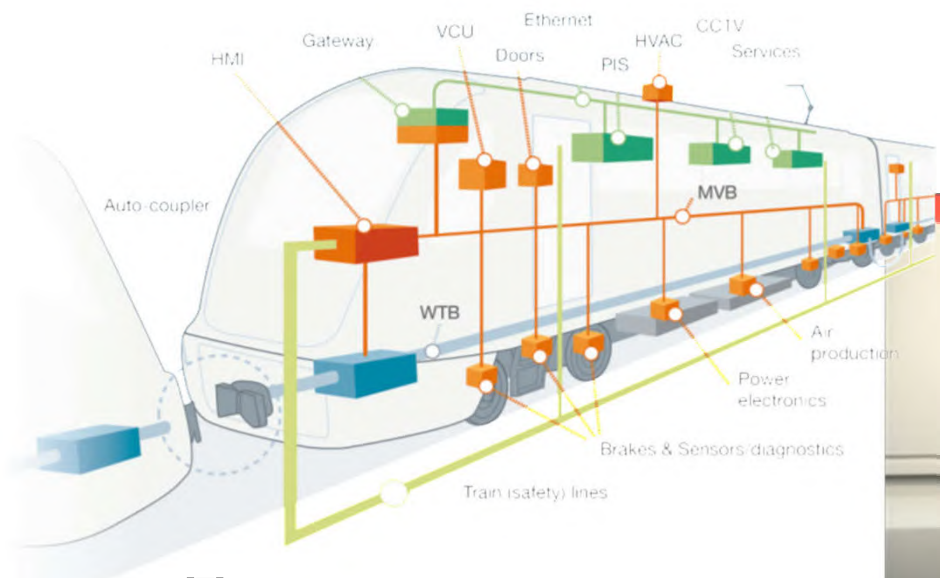


Use Case 1: Onboard Train

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



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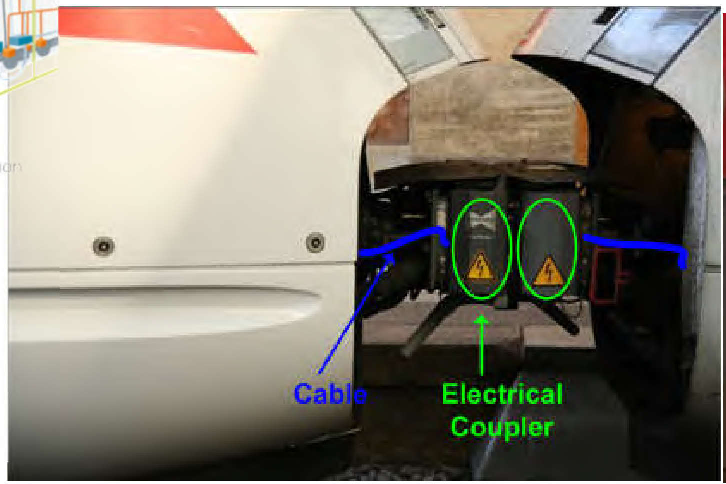
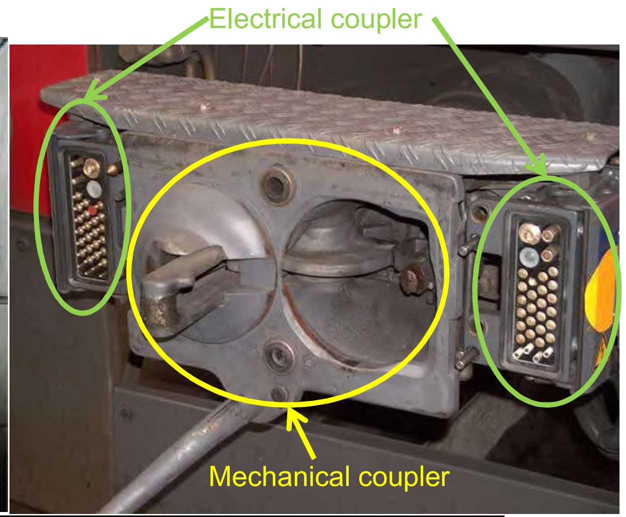
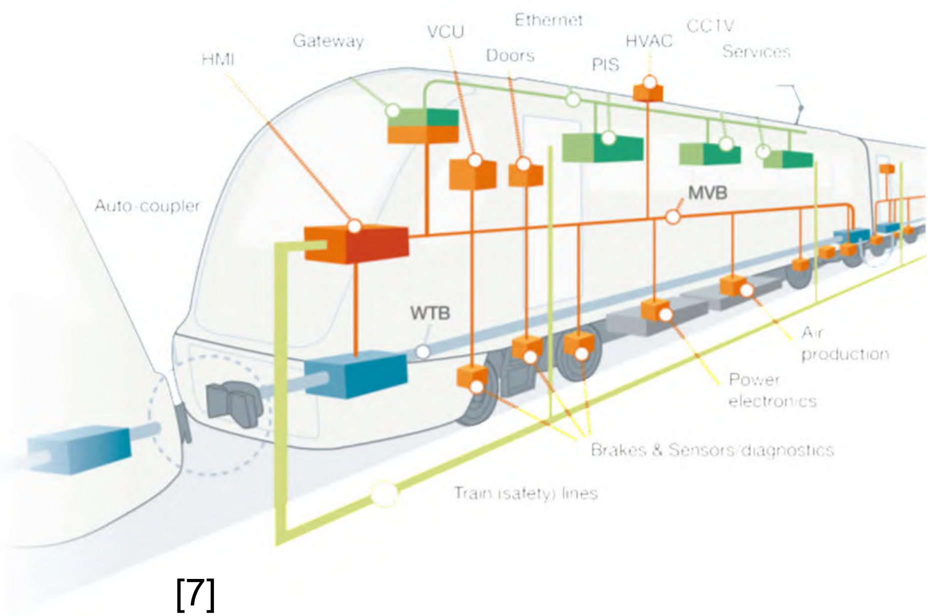
Mechanical stress at coupler leads to many connection failures!





Use Case 1: Onboard Train

- **Wireless Train Control and Monitoring System (TCMS) [5][6]**



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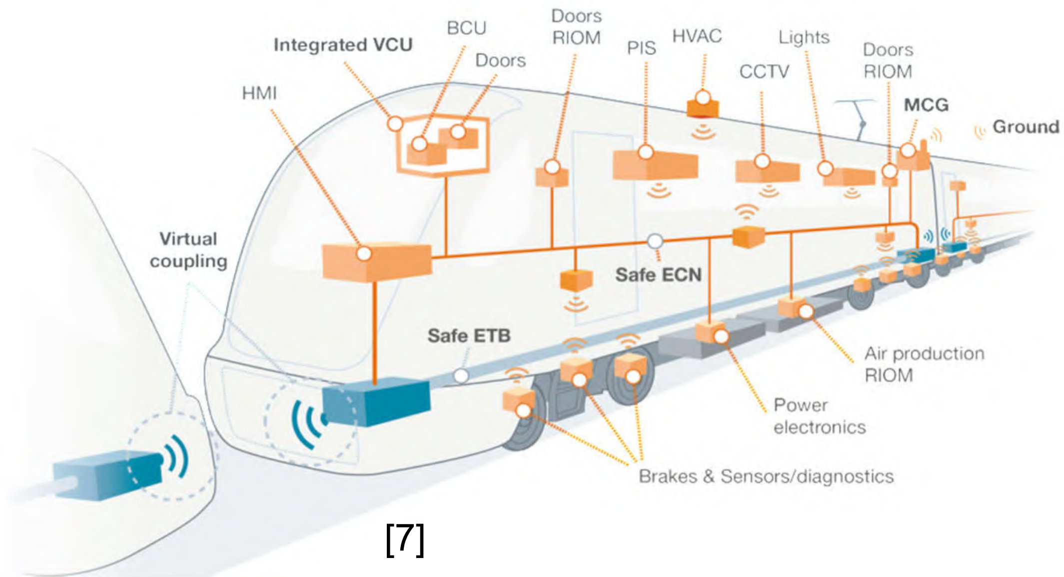

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Use Case 1: Onboard Train

- **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**

DOMAIN	DATA CLASS	DATA SIZE	DATA RATE NEED	CYCLE TIME	LATENCY [The latency should be between 0 and max]
		max	max	min	max
TCMS	Process	1432 [acc. IEC61375-2-3]	10Mbit/s	16ms	80ms [5 x Cycle Time min]
	Message	65388 [acc. IEC61375-2-3]	10Mbit/s	Not relevant [Message is not a periodic communication]	250ms
	Superv [Not relevant – slow PD]	Not relevant	10Mbit/s	50ms	250ms
	BestEffort e.g. for data upload/ download relevant	Not relevant	10Mbit/s	N/A	N/A
	Streaming [Not applicable]	N/A	N/A	N/A	N/A

Use Case 1: Onboard Train

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

DOMAIN	DATA CLASS	DATA SIZE	DATA RATE NEED	CYCLE TIME	LATENCY [The latency should be between 0 and max]
		max	max	min	max
TCMS	Process	1432 [acc. IEC61375-2-3]	10Mbit/s	40ms [from knowledge of expertise]	Between 3CycleTime and 7CycleTime [from knowledge of expertise]
	Message	65388 [acc. IEC61375-2-3]	10Mb/s	Not relevant [Message is not a periodic communication]	250ms
	Superv [Not relevant – slow PD]	Not relevant	10Mb/s	Not relevant	250ms
	BestEffort	Forbidden	Forbidden	Forbidden	Forbidden
	Streaming [Not applicable]	N/A	N/A	N/A	N/A

Use Case 1: Onboard Train

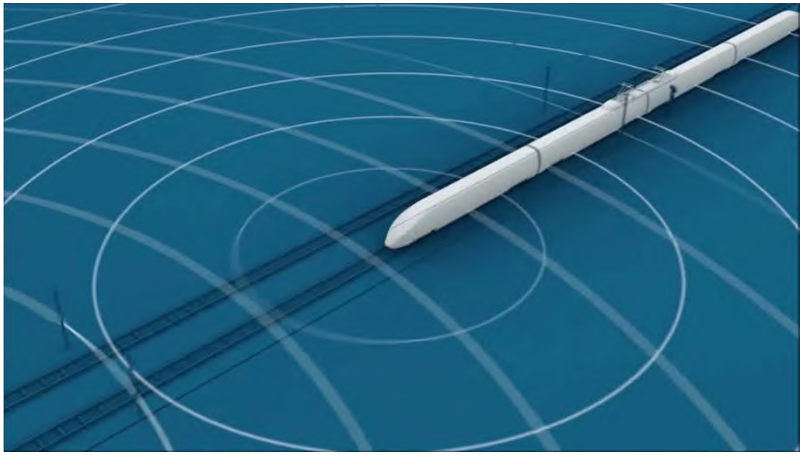
- **Train Control and Monitoring System (TCMS) [6]:**
  - Required bandwidth ~ 100 Mb/s in one train
  - 30 years innovation cycle
- **Operator oriented services**
  - Improve operational parameters of train, e.g. maintenance costs, vehicle availability, closed circuit television (CCTV)
  - Required 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

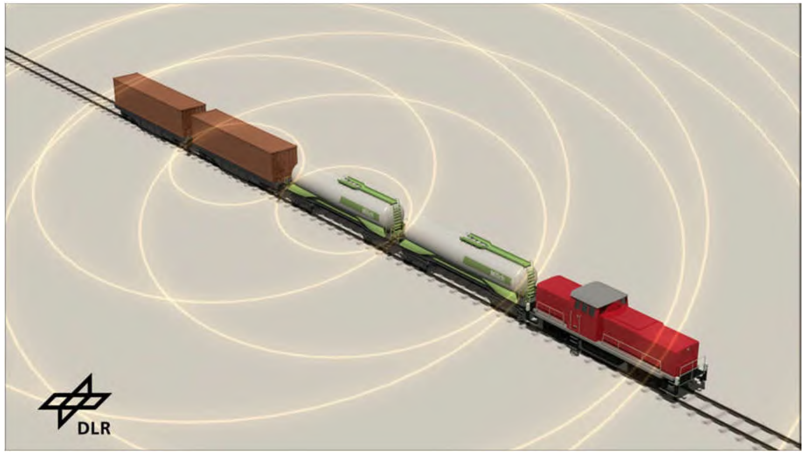


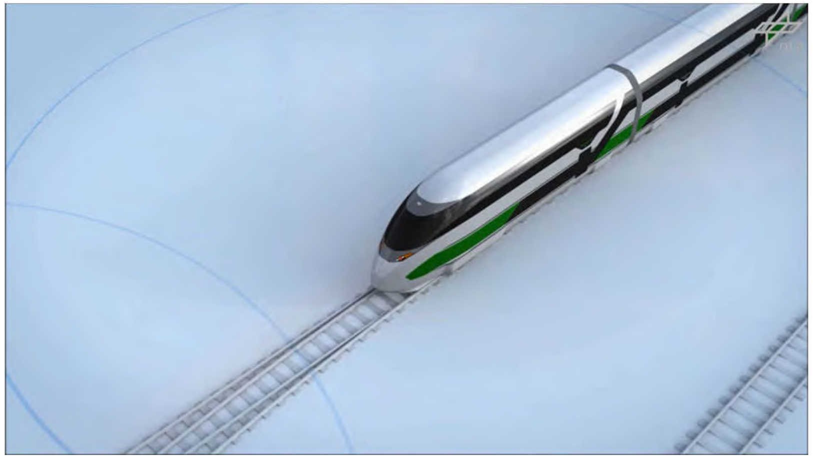
Autonomous train protection & operation (ATP/ATO)

Remote control, automatic coupling and train integrity [10]

Virtual coupling: Platooning [11]

Collision avoidance [9]



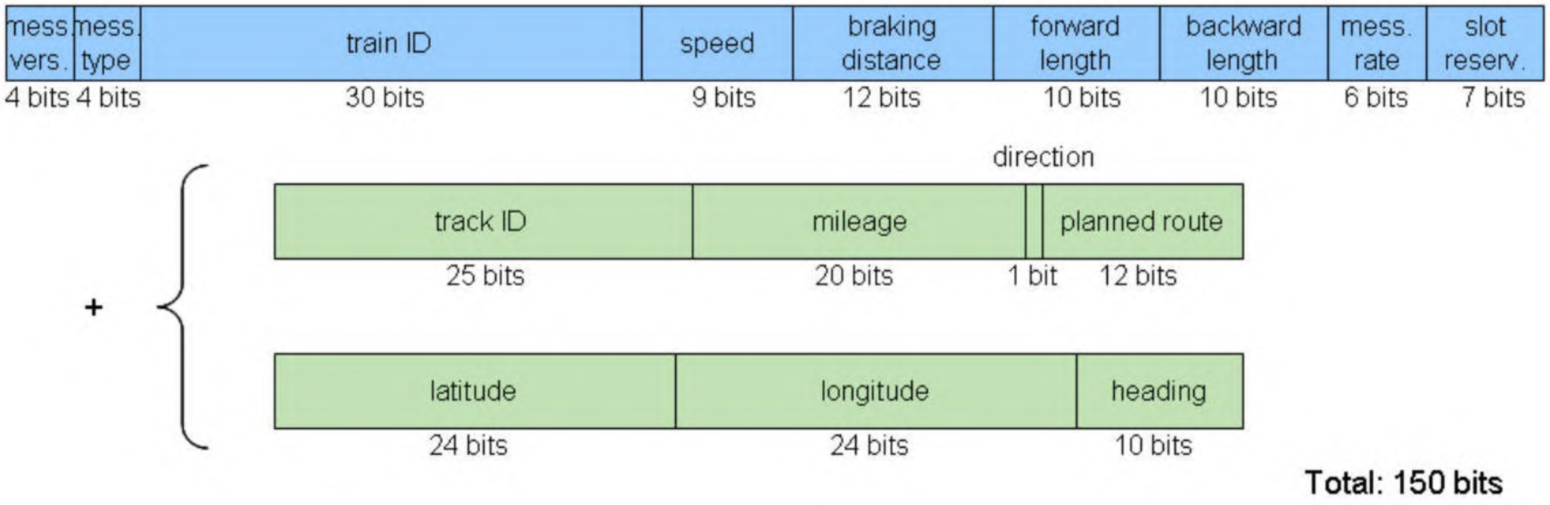


Use Case 2: Train-to-Train

Enabling Future Applications

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

- **150 bit message**



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**

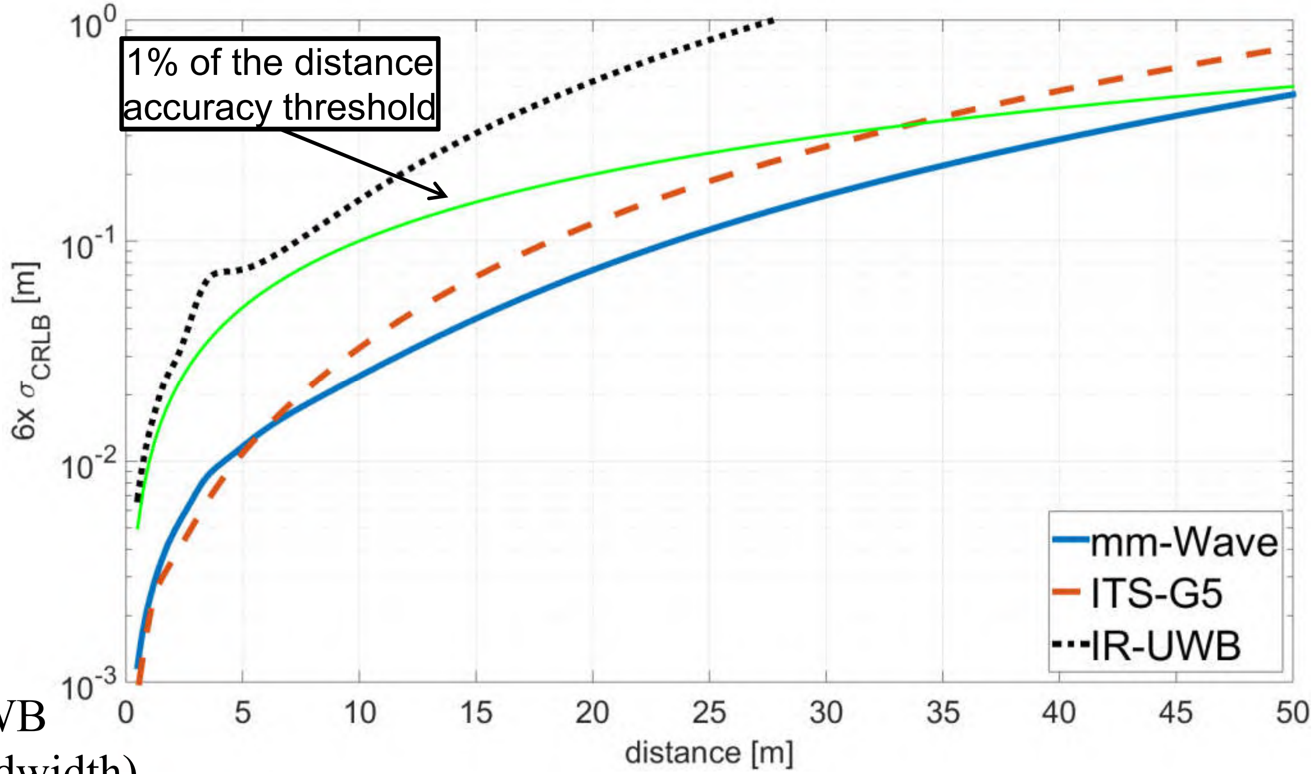
➔ Higher rates needed to include authentication and encryption also for stand alone system or autonomous operations

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**

Update-Delay Δt ($a_{max} = 1\ m/s^2$)	0.01 s	0.1 s	1 s	10 s
Position uncertainty $\lvert\Delta x\rvert_{max}$	0.5e-5 m	0.5e-2 m	0.5 m	50 m
Velocity uncertainty $\lvert\Delta v\rvert_{max}$	0.01 m/s = 0.036 km/h	0.1 m/s = 0.36 km/h	1 m/s = 3,6 km/h	10 m/s = 36 km/h

- **Message size 167 bytes**

➔ 13.36 kb/s for one train broadcasting to platoon

➔ 40.08/80.16/240.48 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

Scenario for Reference Train	Train-to-Trackside (Uplink)		Trackside-to-Train (Downlink)	
Critical Video Transmission	Yes	No	Yes	No
Future Evolution [Mbps]	7.42	3.46	4.38	0.42
Co-Existence / Mitigation [Mbps]	3.49	0.19	3.50	0.20

  - 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

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
  - 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)
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  - Signaling, operator oriented services, customer services (passenger information, …)
- **Use Case 4: Vehicle-to-Train**
  - Shared space in level crossings & shared spectrum

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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**