The projects CONNECTA-2 and Safe4RAIL-2 have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 826098 (CONNECTA-2) and No. 826073 (Safe4RAIL-2) respectively. The information and views set out in this document are those of the author(s) and do not necessarily reflect the official opinion of Shift2Rail Joint Undertaking. The JU does not guarantee the accuracy of the data included in this article. Neither the JU nor any person acting on the JU's behalf may be held responsible for the use which may be made of the information contained therein.

CONtributing to Shift2Rail's NExt generation of high Capable and safe TCMS. Phase 2

SAFE architecture for Robust distributed Application Integration in roLling Stock 2

Wireless TCMS at Backbone and Consist Levels

Igor Lopez, CAF igor.lopez@caf.net

Jérôme Härri, EURECOM jerome.haerri@eurecom.fr

Technical Seminar on Advanced Architectures and Components for Next-Generation TCMS

January 21st 2020, Brussels

Outline

- Introduction
- Wireless Train Backbone (WLTB)
  - Concept
  - Network Architecture and integration in NG-TCMS
  - Wireless Train Inauguration over WLTB
- Wireless Consist Network (WLCN)
  - Concept
  - Wireless Network Architecture and integration in NG-TCMS

Outline

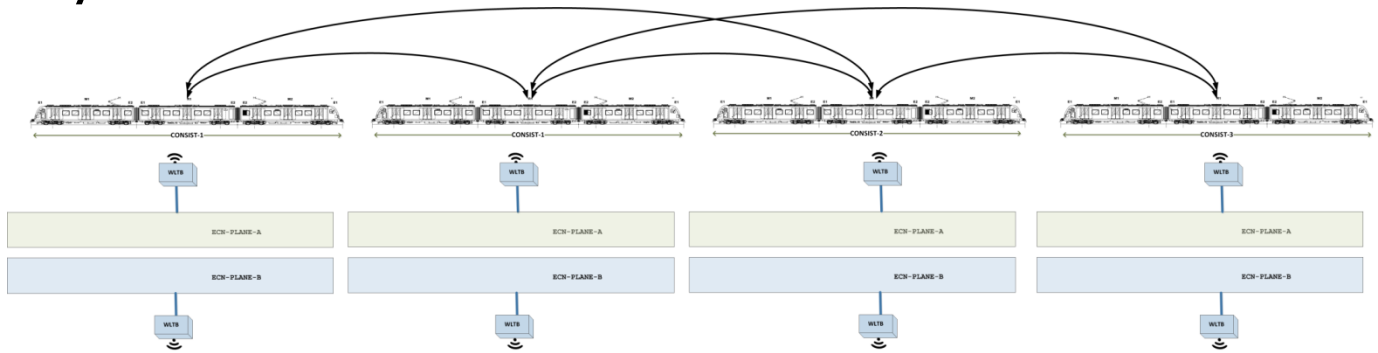
- Wireless Technology Selection
  - Candidates technologies for WLTB
  - Candidates technologies for WLCN
- Prototyping for CONNECTA-2 demonstrators

Introduction

- WLTB (WireLess Train Backbone) & WLCN (WireLess Consist Network)
- Provide wireless communication
  - between coupled consists
  - inside the consist/vehicle
  - in Operator-Oriented Services (OOS) and TCMS domains
  - between end devices, such as control units, displays, sensors, actuators, and smart devices
- Goal
  - Reduce cabling and connector failure/maintenance
  - Ease the installation of NG-TCMS systems in existing fleets

WLTB: Concept

- Substituting wired ETB (IEC 61375-2-5) by wireless communications
- Pre-requirements
  - Should be compatible with the NG-TCN architecture defined by CONNECTA WP3 which is an evolution of the existing IEC 61375-2-5.
  - Having in mind Wireless Safe Train Inauguration.
  - Maximum delays of 3 x Cycle Time.
  - Up to 860 meters.
  - Up to 32 consists.

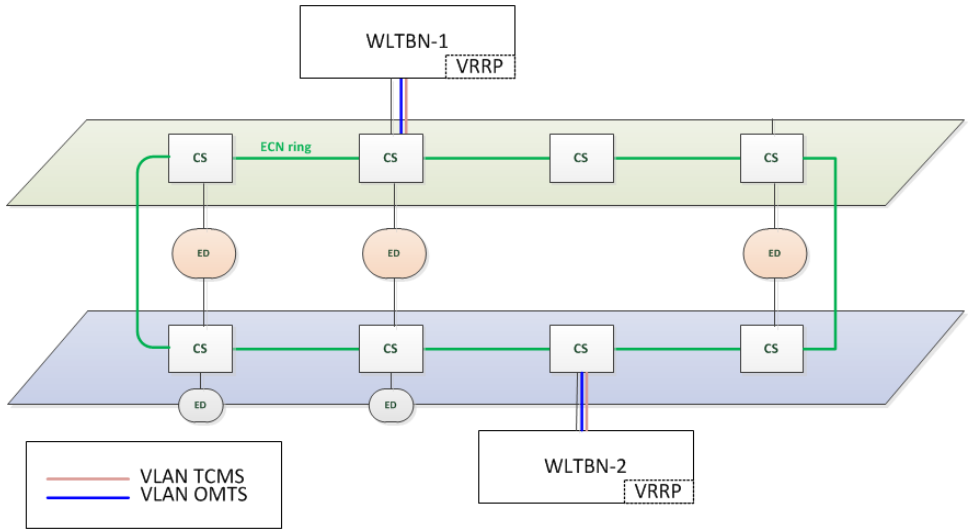


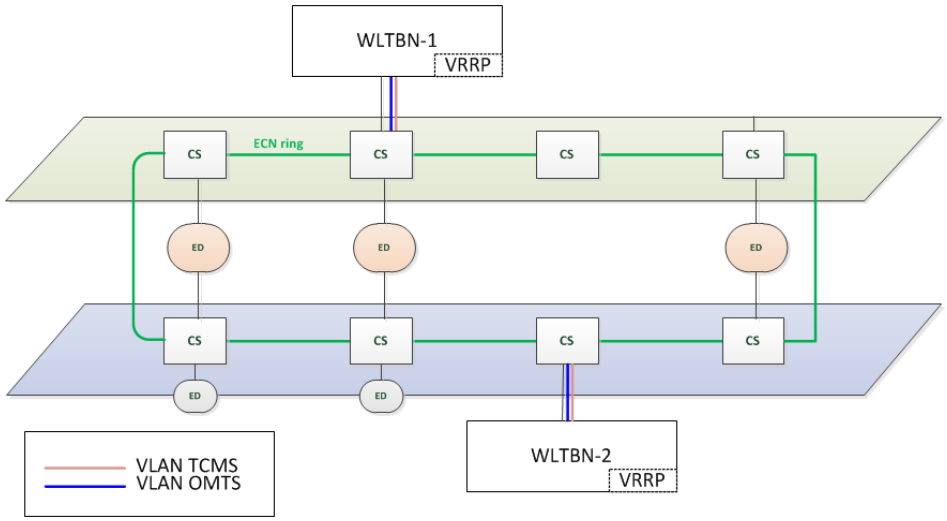
- Selected topology: <u>Mesh with multihop packet forwarding</u>

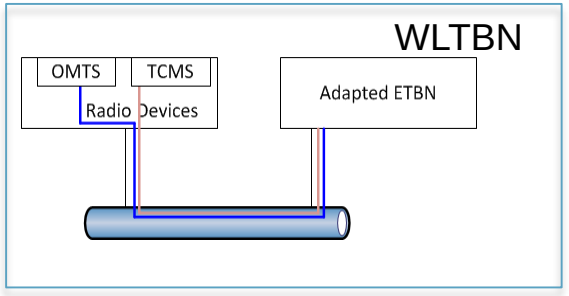
WLTB: Network Architecture and integration in NG-TCMS

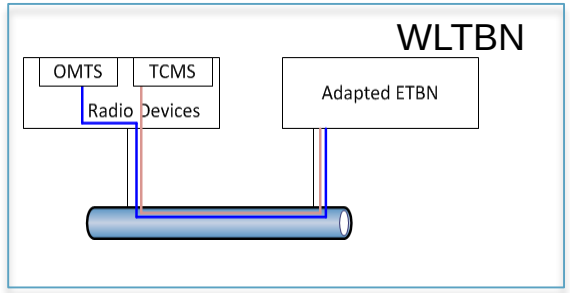
- WLTBN is divided in Adapted-ETBN (AETBN) and Radio Devices (RD)
  - AETBN
    - Railway specific functions: Inauguration, R-NAT, ECSP and TTDB Manager interface, etc.
    - Independent to underlying radio technology
    - Railway lifecycle
  - RD
    - Wireless networking specific functions: packet forwarding, secure association, secure data transmission, etc.
    - Adapted to the telecommunication evolution pace
- WLTBN splits two domains:
  - TCMS domain ➔ forwards through RD with low-latency and reliable capability
  - OMTS domain ➔ forwards through RD with high throughput capability

WLTB: Network Architecture and integration in NG-TCMS







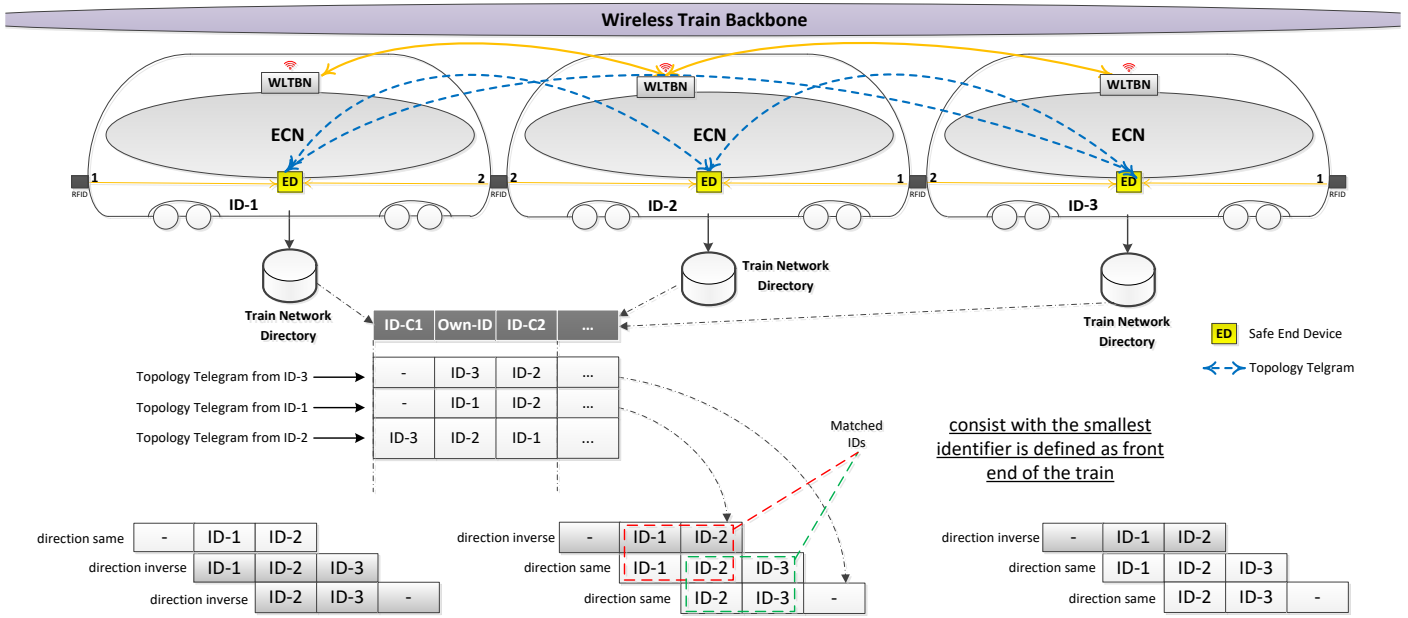


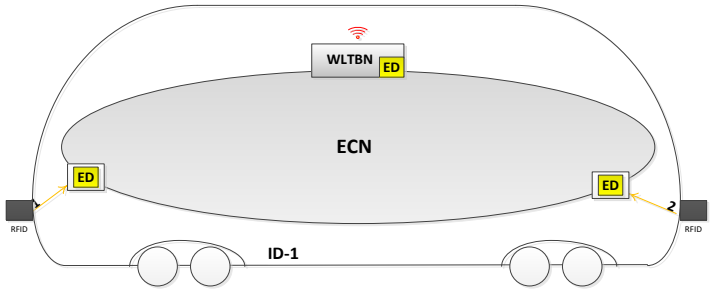
WLTB: Wireless Train Inauguration

- Divided in two phases:
  - Wireless Train Inauguration over WLTB → **WLTBN**
    - TTDP HELLO removed. Adjacent neighbour info retrieved from RFID transponders:
      - the consist identifier (consist id) of the local consist
      - the direction information (end in direction 1 or end in direction 2) of the local consist
      - the identifier of the WLTB and WLTBN
  - Train Inauguration Validator → **CCU**
    - From independent sensors: Train lines or independent RFIDs

WLTB: Wireless Train Inauguration

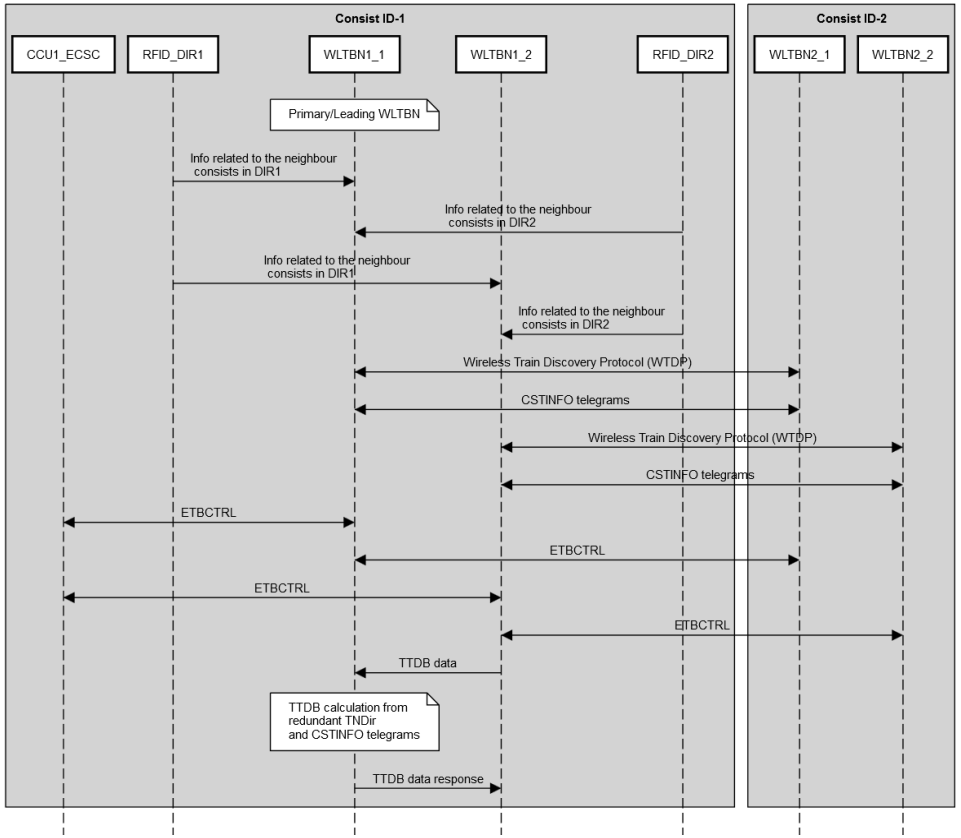
- Wireless Train Inauguration over WLTB → **WLTBN**
  - Adapted TOPO_FRAME (including info retrieved by RFIDs) with a cycle time of 40 ms.
  - Neighbour aliveness status implicitly with TOPO_FRAMEs.

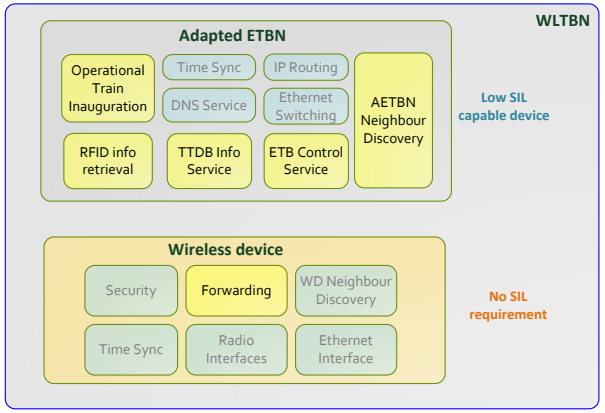


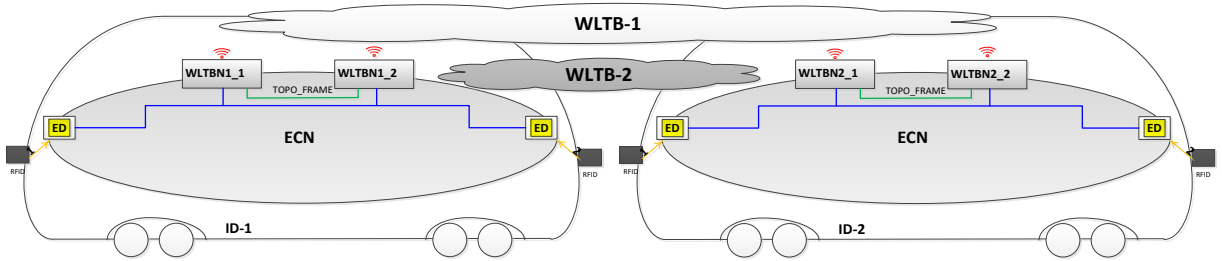


WLTB: Wireless Train Inauguration

- Example of wireless inauguration over redundant WLTBN:







WLCN: Concept

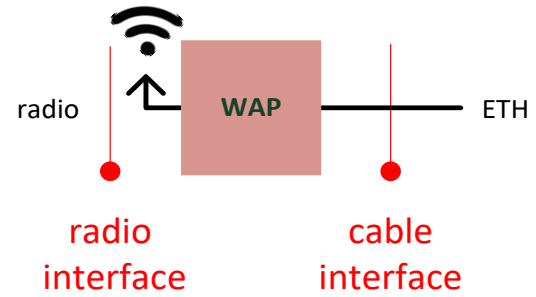
- Approach in CONNECTA-2
  - define additional general requirements for WLCN (input Roll2Rail and CONNECTA)
  - preselect suitable wireless technologies
  - support by complementary action / Safe4RAIL-2 to evaluate preselected wireless technologies in regard to requirements
  - select wireless technologies
  - specify WLCN with state of art wireless technologies
    - Define evolved Architecture (Roll2Rail, CONNECTA)
    - Define ED Interfaces
    - Evaluate Safety and Security Aspects

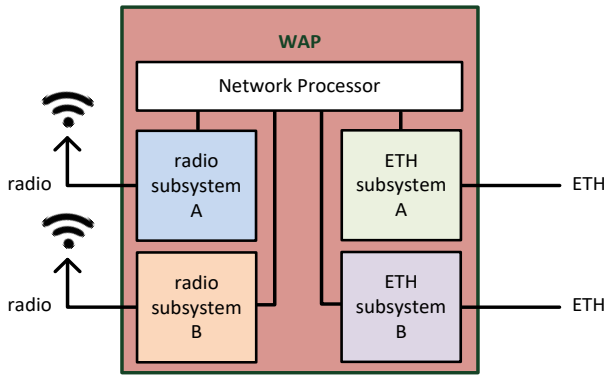
WLCN: Network Architecture and integration in NG-TCMS

- Assumption: A mix of technologies is used.
  Technology preferences: Wi-Fi, LTE, ZigBee (for sensors)

- WAP (Wireless Access Point) device provides access for wireless end devices to the consist network

- WAP may house different wireless technologies

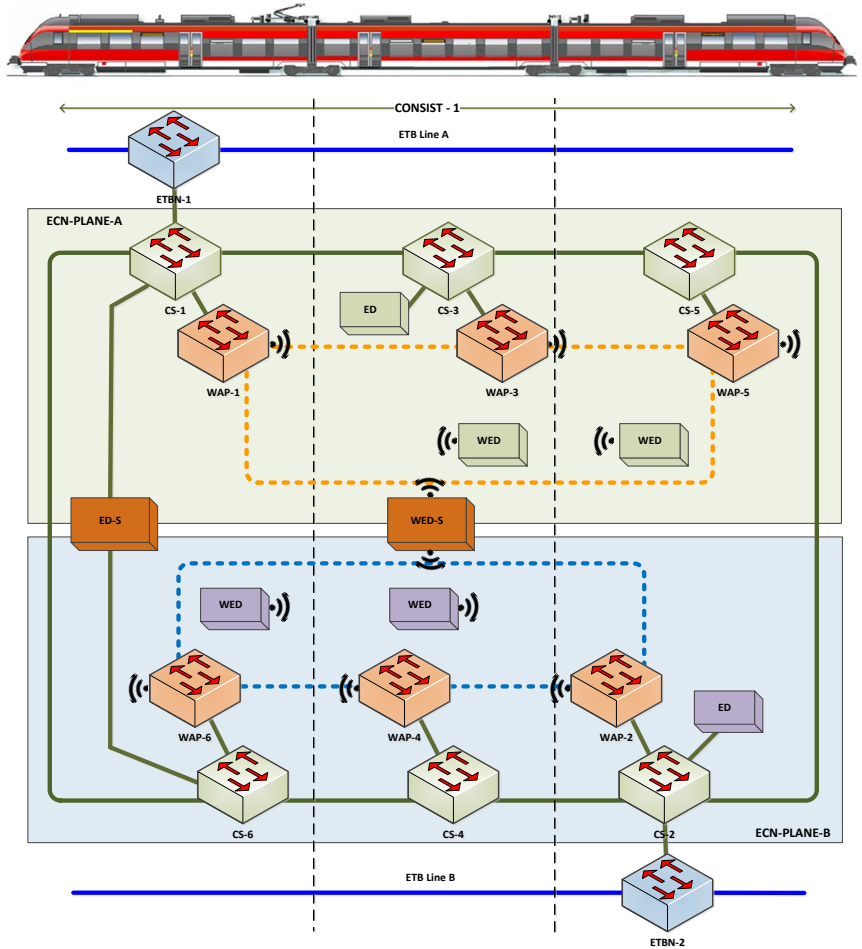




WLCN: Network Architecture and integration in NG-TCMS

State of the art:

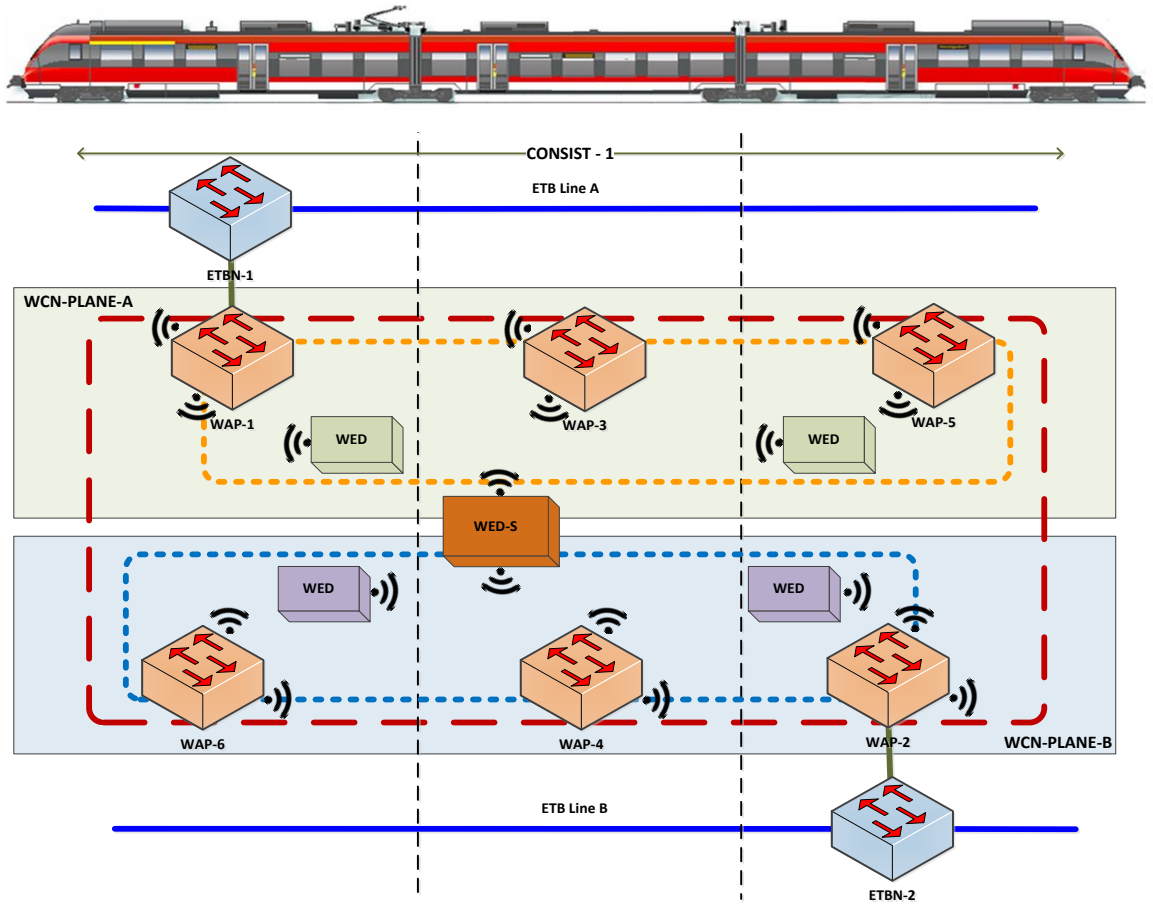
- ECN extended by WAP, constituting WLCN
  - WAP are added to the cable-based ECN, building the wireless network
  - each car contains WAP
  - each ECN plane has a separate WLCN
  - classic and safe wireless devices (WED) are connected to WAP
  - most practicable solution, various wireless technologies could be integrated/used



WLCN: Network Architecture and integration in NG-TCMS

Future:

- Fully WLCN (MESH)
  - Approach with a complete wireless ECN
  - all EDs are wireless (WED)
  - WAPs are using MESH technology according IEEE 802.11s,
    → using IEEE 802.11 technology
  - Approach with the most significant savings in cabling
  - Technical protection regarding security and network stability needed



WLTB: Wireless Candidates technologies

- **VLC and BLE** are unsuitable technologies for the WLTB considering a Mesh architecture. **BLE** is unsuitable due to low performance.
- **Wi-Fi** could be used for non-critical and high-data-rate WLTB traffic, but cannot support critical traffic.

OMTS

- **LTE V2X/D2D** could be used but need to merge D2D and V2X features, leading to 3GPP non-compliant systems. Irrespectively, it would need a deterministic scheduler to handle critical traffic.

TCMS

- **ITS-G5** could be used, but would need a deterministic scheduler to handle critical traffic.
- **NR V2X** offers better performances and mechanisms for deterministic scheduler. But, NR V2X rel. 16 is not ready yet.
- **DOT11BD** offers better performances than ITS-G5, but a same Listen-Before-Talk (LBT) MAC.

		WIRELESS TECHNOLOGIES						
REQUIREMENTS		*LTE-V2X [2,3]*	*ITS-G5 [1]*	*Wi-Fi [4,5,6, 7]*	*VLC [8,9,12]*	*BLE [10,11]*	*DOT11BD*	*NR V2X*
Max. Bit rate	100 Mbps per traffic type	27 Mbps	27 Mbps	(1) <2.4 Gbps (2) <6.5Gbps (mmWave)	LED dependent up (2Mbps-60Mbps)	up to 2Mbps	*estimation*: (1) <2-3Gbps (2) <20Gbps	*estimation*: (1) <2-3Gbps (2) <20Gbps
Max. Latency	16-500ms	50-100ms	1-20ms	(1) 1 - 20ms (2) 5-250ms	20-40ms	50ms-1000ms	*estimation*: (1) 1 - 20ms (2) 5-250ms	*estimation*: (1) 1 - 20ms (2) unknown
Medium Access	Deterministic	Mode 3: Deterministic Mode 4 Non-Deterministic;	Non-Deterministic	Non-Deterministic	Non-Deterministic	Deterministic	Non-Deterministic	Non-Deterministic (mode 2(b)) & Deterministic (mode 2(d))
Communication Range	up to 820m	300m-1000m	300m-1000m	(1) > 200m (2) < 2m	5m-20m	50m-200m	*estimation:* <1000m	*estimation:* <1000m
Group Communication	Multicast/Group	-	-	(2) DOT11y	-	Clustering	Multicast/groupcast	Multicast/groupcast
Mesh Capabilities	up to 32 nodes	-	Geonet/1609.3	DOT11s	-	inter-cluster	Geonet/1609.3	-
Freq. reuse	1 / car	SL-subpools (2-3)	-	ISM, mmWave	Directional	ISM	Carrier aggregation (Mx10Mhz)	SL-subpools (2-3)
Protect. against interferences	-	-	-	(1) DSSS+Freq Hopping (2) BeamForming	Beam Forming	Freq. Hopping	BeamForming	BeamForming

No single technology will meet whole set of requirements at once!

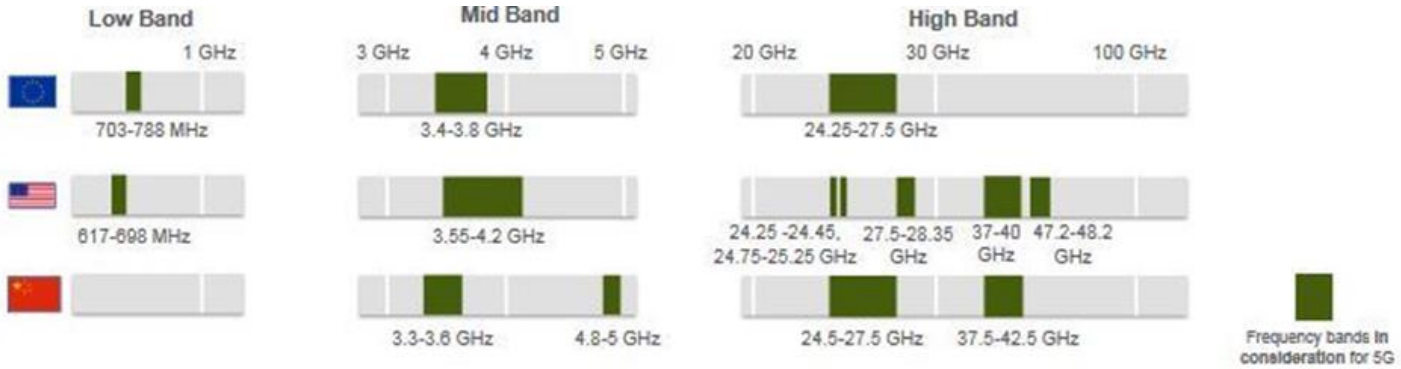
WLTB: Wireless Spectrum

GSM-R Frequencies

Uplink: **876MHz-880MHz** (4Mhz)
Downlink: **930MHz-934MHz** (4Mhz)

Spectrum for WLTB critical traffic needs strong lobbying… !!

ITS Band at 5.9GHz in EU for both LTE V2X and ITS-G5 [source: 5GCAR]s



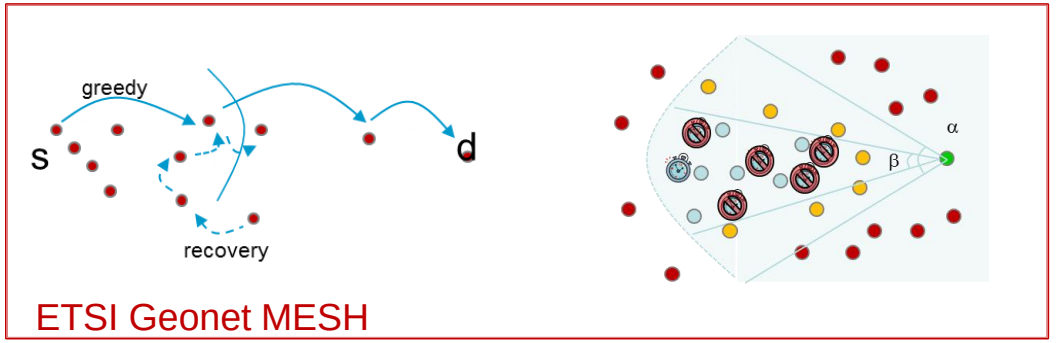
5G Frequency bands [source: 5GCAR]

3GPP Band Number	Uplink (MHz)	Downlink (MHz)	Duplex Mode	Combined with ITS Band
3	1710-1785	1805-1880	FDD	Yes
7	2500-2570	2620-2690	FDD	Yes
8	880-915	925-950	FDD	Yes
20	832-862	791-821	FDD	Yes

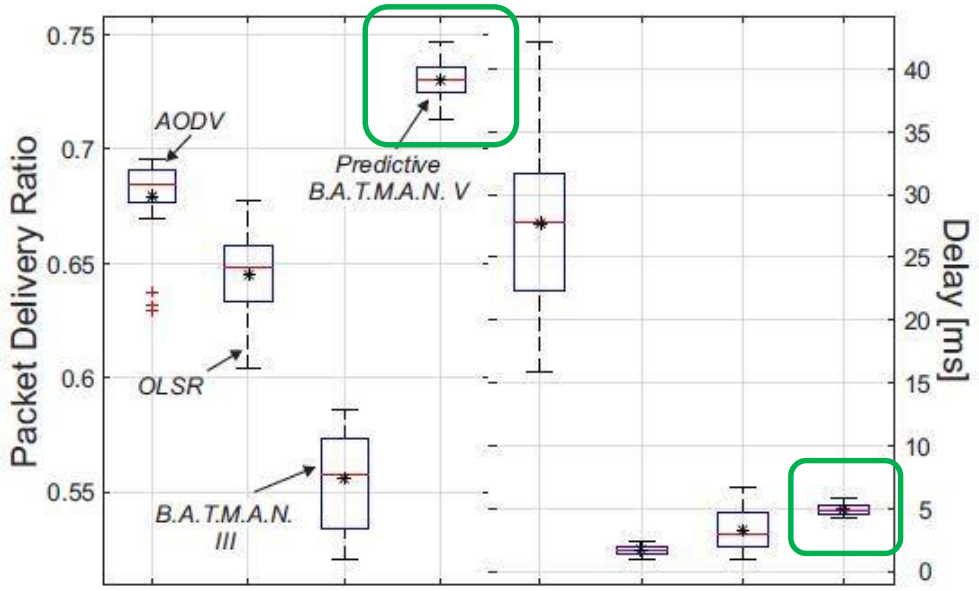
LTE Uu Frequency Bands (for LTE V2X mode 3)

WLTB: Mesh Candidates technologies

- **Reactive Ad-hoc MESH technologies** are unsuitable technologies for the WLTB due to delay.
- **Geographic (position-based) MESH technologies** are unsuitable technologies for the WLTB due to strong GPS requirement and to the native stateless approach. Notably, **ETSI Geonet** native stateless.
- **Proactive Ad-hoc MESH technologies** are most suitable technologies for the WLTB.
  - OLSR: defined at IETF, well used in the community. Candidate MESH technology for platooning in France (SCORE@F)
  - **B.A.T.M.A.N. improved version of OLSR. Large community in MESH WiFi.**
    - **L2 code availability**
- Challenge:
  - Security: ETSI ITS has a full security framework. Need to define such one for WLTB Mesh



ETSI Geonet MESH

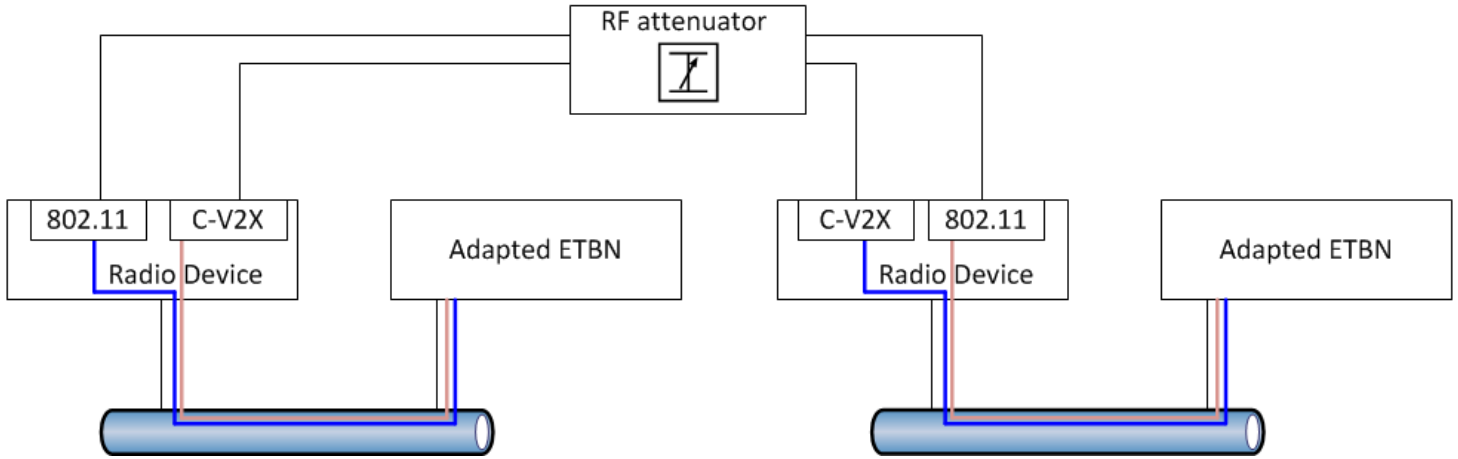


WLCN: Wireless Candidates technologies

- **ZigBee**, **WirelessHART** and **UWB** are unsuitable technologies for the WLCN. ABB's **WirelessHP** cannot be used either, due to the lack of a MAC layer implementation and **WISA** is no longer supported by ABB.
- **ECHORING** could be used for low-latency traffic, but WLCN data rate requirements should be relaxed. Several ECHORING networks should be deployed to cover all nodes in the WLCN.
- **Wi-Fi** could be used for non-critical and high-data-rate WLCN traffic, such as Audio/Video Data Streaming and Best Effort Data, as it is a high performance and non-deterministic technology. In order to use Wi-Fi for critical traffic, *a deterministic MAC layer should be added*, as has been done in **SHARP**.
- **LTE**, despite providing a deterministic access, does not provide enough data rate for Streaming Data traffic, and it does not provide sufficiently low latency for Process Data and Supervisory Data traffic in the WLCN.
- **5G** could be explored as an alternative, but further research would be required to confirm the specified latency values.

→ **<u>In near future no single technology will meet whole set of requirements at once!</u>**

Prototyping of WLTB: General

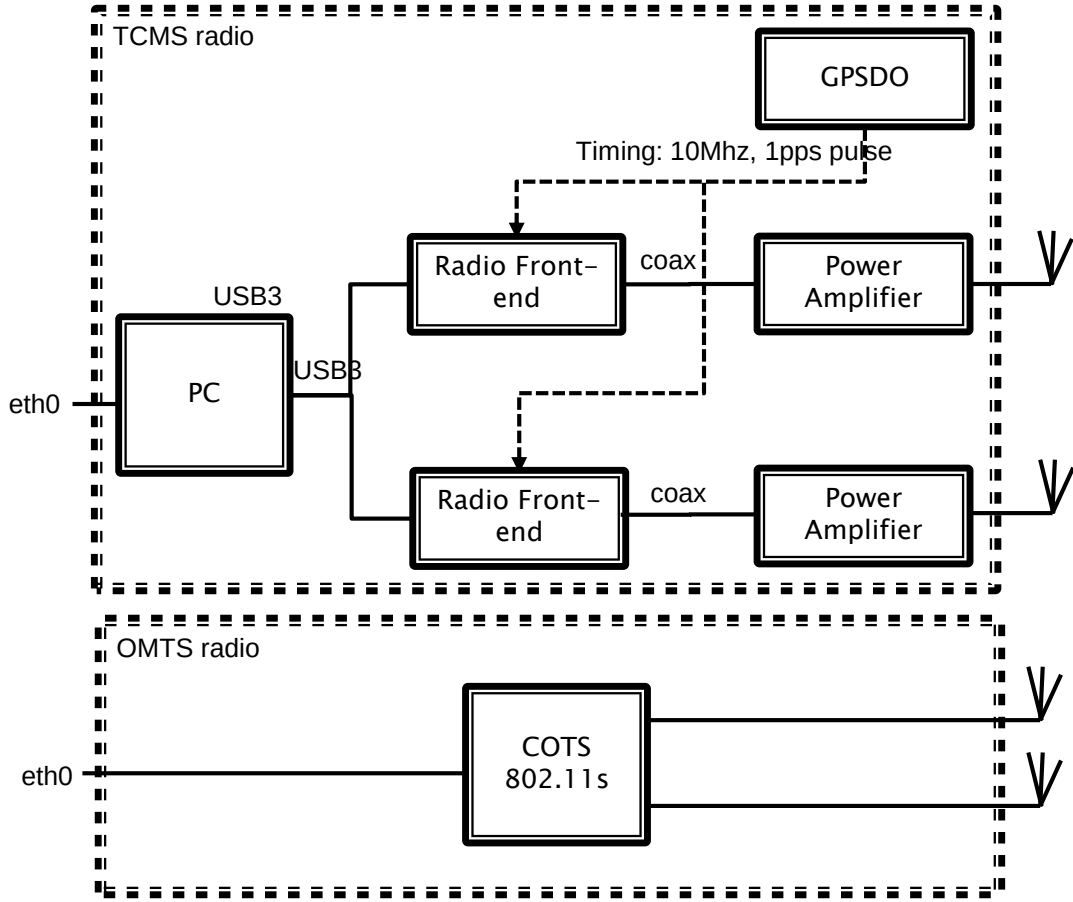


- 1 / 2 Adapted ETBN from CONNECTA-2
- 1 / 2 Adapted ETBN from Safe4Rail-2
- 2 / 4 C-V2X wireless devices from Safe4Rail-2
- 2 / 4 802.11s wireless devices from CONNECTA-2/Safe4Rail-2
- 1 / 2 RF attenuator from CONNECTA-2/Safe4Rail-2

Channel condition	Parameters to tune
Distance between WLTBNs	Attenuation[1]: • 87.70 dB of attenuation (i.e. 100 m). • 93.72 dB of attenuation (i.e. 200 m). • 97.25 dB of attenuation (i.e. 300 m). • 99.74 dB of attenuation (i.e. 400 m).
Tunnel	• Packet loss • Delay • Jitter
Open field	• Packet loss • Delay • Jitter
Underground station	• Packet loss • Delay • Jitter
Open air station	• Packet loss • Delay • Jitter

Prototyping of WLTB: Radio Devices

- WLTB Radio device specification for TCMS
  - 1 PC for LTE-V2X (L2) and B.A.T.M.A.N (L2)
    - Connection to AETBN via ETH
  - LTE-V2X rel.14
    - Mode 3: two radio front-ends (SL and UL/DL)
    - Mode 4: single radio front-end (SL)
  - GPSDO required for 10Mhz synch pulses
    - WLTB independent timing from AETBN
  - 5.9Ghz 10Mhz 23dBm power amplifier
- WLTB Radio device specification for OMTS
  - IEEE 802.11s

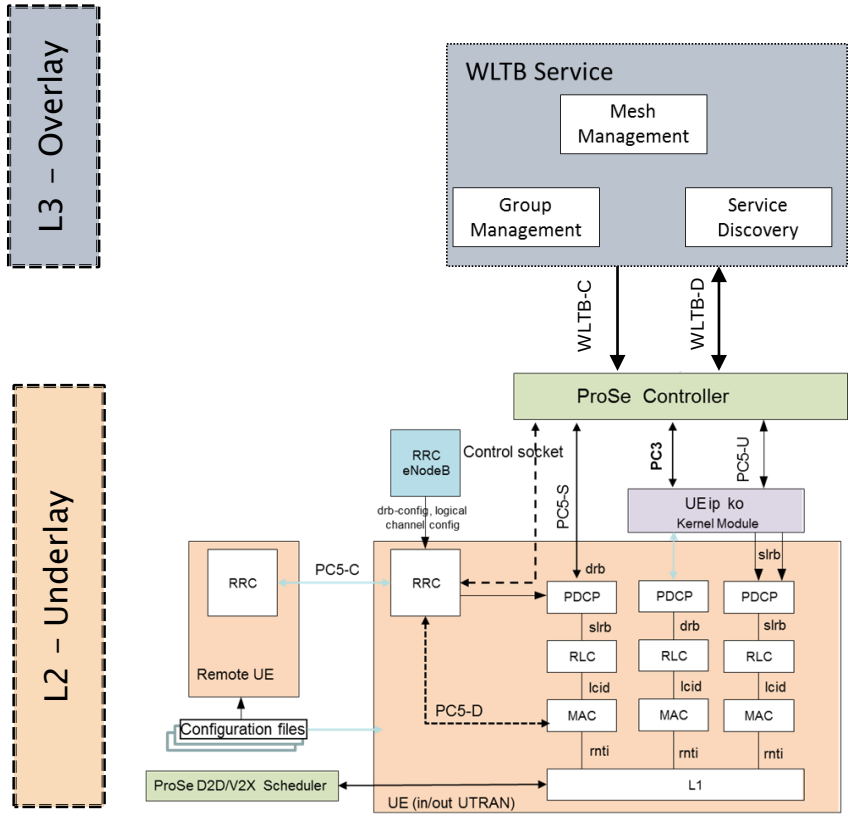


Prototyping of WLTB: TCMS Domain

- Overlay/Underlay approach
  - Underlay

DEMO

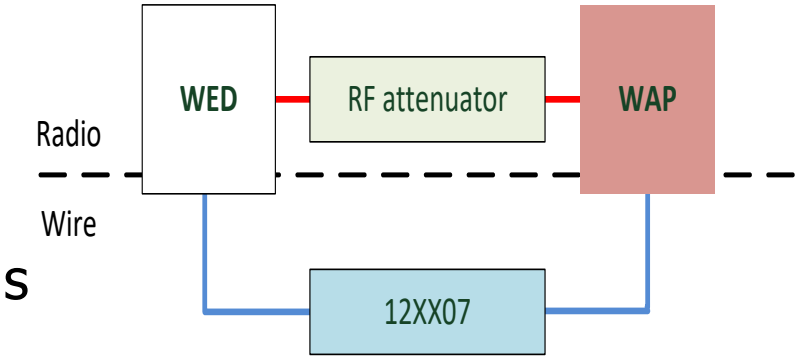
    - OpenAirInterface (OAI) SDR platform
      - LTE V2X L2 functions (sidelink, broadcast)
      - ProSe Controller configured for L2 (MESH)
      - QoS: LTE RB as function of the ProSe PPP
  - Overlay
    - Service discovery – Consist-2-Consist Communication
    - Group communication – Consist Management
    - Mesh Management – multi-hop
    - Security



Prototyping of WLCN

Define environment and test cases for WLCN to validate

- WLCN specification in general
- specific points like:
  - using wireless technologies in TCMS
    → deterministic behavior needed
    → fitting safety aspects
  - WAP positioning due to lacking propagation models
    → needed for train design



Proposed Testbed with RF attenuator and communication emulator 12XX07

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Coordinator:

CAF, Igor López

✉ igor.lopez@caf.net

✆ +34 943 189 241

Coordinator:

IKERLAN, Aitor Arriola

✉ aarriola@ikerlan.es

✆ +34 943 712 400