Wireless TCMS at Backbone and Consist Levels

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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: **Mesh with multihop packet forwarding**
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

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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.

Matched IDs

- Consist with the smallest identifier is defined as front end of the train
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.

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

- **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.

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**Note 1:** General assumptions for each technology (frequency band, environment (LOS/NLOS), evaluation methodology,..) are described in the cited papers.

**Note 2:** Performance of VLC technologies are assumed in a vehicular context and strongly depend on the receiver LED and modulation [11,12].

**Note 3:** The required WLTB communication range includes optional multi-hop forwarding.
**WLTB: Wireless Spectrum**

**GSM-R Frequencies**

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

**Spectrum for WLTB critical traffic needs strong lobbying...!!**

**5G Frequency bands** [source: 5GCAR]

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

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

**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
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.

→ **In near future no single technology will meet whole set of requirements at once!**
Prototyping of WL TB: 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

<table>
<thead>
<tr>
<th>Distance between WL TBNs</th>
<th>Attenuation:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>87.70 dB of attenuation (i.e. 100 m).</td>
</tr>
<tr>
<td></td>
<td>93.72 dB of attenuation (i.e. 200 m).</td>
</tr>
<tr>
<td></td>
<td>97.25 dB of attenuation (i.e. 300 m).</td>
</tr>
<tr>
<td></td>
<td>99.74 dB of attenuation (i.e. 400 m).</td>
</tr>
</tbody>
</table>

- Tunnel
  - Packet loss
  - Delay
  - Jitter

- Open field
  - Packet loss
  - Delay
  - Jitter

- Underground station
  - Packet loss
  - Delay
  - Jitter

- Open air station
  - Packet loss
  - Delay
  - Jitter

Attenuation calculated for Free Space Path Loss (FSPL) without antenna gains and a frequency of 5.8GHz.
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

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Prototyping of WLTB: TCMS Domain

- Overlay/Underlay approach
  - **Underlay**
    - 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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