X2Rail-2

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1 Executive Summary

This document is focused on functional architecture and interfaces specifications for on-board train integrity, as output from Task 4.3, and candidate technologies selection, as output from Task 4.4. Also train length determination is addressed as output from Task 4.6.

Section 6 describes OTI functional architecture for passenger and freight scenarios in relation to OTI Product Classes defined in D4.1.

Section 7 addresses interface specification at application level, protocol level and physical level. At application level the interface specification is derived from the OTI functional requirements. A detailed description is provided for each proposed input/output in relation with target scenario and OTI functionality specified in D4.1. At protocol stack level four alternative solutions have been evaluate. An high level analysis have been considered about applicability of communication solutions defined in Adaptable Communication Services and FRMCS for OTI context in freight applications. Communication over new generation TCMS has been explored in relation to passenger scenarios. Solutions from DEWI/SCOTT projects are considered in relation to freight context. Finally the applicability of euro-radio protocol is evaluated. At physical level different alternatives are considered both about peer-to-peer communication or network oriented solutions.

Section 8 focuses on ETCS backward compatibility scenario ensuring full compliancy to CR940 with a unidirectional communication between OTI and ETCS limited to train integrity status consisting in three possible values: unknown, confirmed or lost.

Section 9 includes an analysis of candidate technologies as output of Task 4.4. A qualitative comparison analysis among defined OTI product classes is reported in relation to overall life cycle including installation impart and maintenance implications. Wireless technologies are evaluated and possible options for applicability to OTI context are provide. Finally general guidelines for energy harvesting application to freight application domain are provided.

Section 10 contains the conclusions for overall topics specified and analysed.

Appendix A includes OTI contribution to system level analysis.

Appendix B includes an example for Virtual Coupling Applicative Messages in relation to assumption reported in D4.1.

Appendix C refers to redundancy for OTI DEVICES.

Appendix D includes the results of communication analysis respect to EN50159.

Appendix E reports the traceability matrix between the requirements specified in D4.1 (Ref. [1]) and requirement specified in this document D4.2.

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3 Abbreviations and acronyms

Abbreviation / Acronyms	Description
ACS	Adaptable Communication System
CFM	Communication Functional Module
CoAP	Constrained Application Protocol
COTS	Commercial Off-the-Shelf component
CRC	Cyclical Redundancy Check
DMI	Driver Machine Interface
ER	Euro-radio
ETCS	European Train Control System
EVC	European Vital Computer
FRMCS	Future Railway Mobile Communication System
FSM	Finite State Machine
GPS	Global Positioning System
GSM-R	Global System for Mobile-Railways
IEEE	Institute of Electrical and Electronics Engineers
IMU	Inertial Measurement Unit
ISO	International Standards Organization
IP	Internet Protocol
IPs	Innovation Programmes
IPsec	Internet Protocol Security
MQTT	Message Queuing Telemetry Transport
MVB	Multifunction Vehicle Bus
OBU	On-board Unit
OCN	On-board Communication Network
OCP	On-board Communication Protocol
OTI	On-board Train Integrity
OTI-I	Module for on-board train integrity monitoring
OTI-L	Module for on-board train length determination
OTI-M	On-board Train Integrity Master Device
OTI-S	On-board Train Integrity Slave Device
PDU	Protocol Data Unit
QoS	Quality of Service
RBC	Radio Block Centre
RCS	Radio Communication System
RFID	Radio Frequency Identification
RSSI	Received Signal Strength Indicator
SFM	Safe Functional Module
SoM	Start of Mission
TCMS	Train control and monitoring system
TCP	Transmission Control Protocol
TDs	Technical Demonstrators
TMS	Traffic Management System
TIU	Train Interface Unit
UDP	User Datagram Protocol
WMC	Wayside Maintenance Center
WSN	Wireless Sensor Network

4 Background

The present document constitutes Deliverable D4.2 “Functional architecture & Interfaces specifications & Candidate technologies selection” in the framework of the Project titled “Enhancing railway signalling systems based on train satellite positioning, on-board safe train integrity, formal methods approach and standard interfaces, enhancing traffic management system functions” (Project Acronym: X2Rail-2; Grant Agreement No 777465).

5 Objective

This document contains description of:

- Functional Architecture Specification for On-Board Train Integrity based on the application scenarios (e.g. Passenger and Freight) defined in D4.1 [1]
- OTI Interface specification, including ETCS - OTI interface based on functional requirements defined in D4.1 [1];
- Candidate Technologies selection

Scope of Work for X2Rail-2 WP4 is to define requirements for On-Board Train Integrity and train length determination functionalities.

ETCS rules to manage train integrity information inside Position Report messages and RBC rules to manage the received train integrity information is out of the scope of WP4.

In general the operational rules, as example managing emergency situations in case of loss of integrity, are out of the scope of WP4.

6 Functional Architecture Specification

This section contains the functional architecture specification based on the functional requirement and application scenarios defined in the D4.1 [1] (i.e. passenger scenarios and freight scenarios).

Functional architecture described in the following takes into account the most relevant differences among OTI product classes defined D4.1 [1]. As example “wired” or “wireless” is remarked in the considered on-board communication networks for classes 1 and 2. Presence of ETCS at both train cabins is considered for class 1. Specific implementation choices for definition of physical architecture are part of product specification in D4.4 [45].

6.1 Functional Architecture for OTI Product Class 1

This section depicts examples referred to OTI Product Class 1 with train integrity criterion consisting in liveliness of the communication between OTI Master and OTI Slave.

An example for functional architecture in passenger scenario application is depicted in Figure 6-1. Main features for this configuration consist in:

- fixed train composition;
- ETCS equipment available in front cabin and at train tail (e.g. high speed trains);
- OTI Master and OTI Slave modules implemented as external devices, located respectively in front cabin and at train tail and connected to the ETCS equipment.
- wired on-board communication network for communication between OTI Master in front cabin and OTI Slave at train tail;

Configuration/Maintenance Operator depicted in Figure 6-1 refers to diagnosis, configuration and maintenance functionalities (see D4.1 section 6.2.4.11).

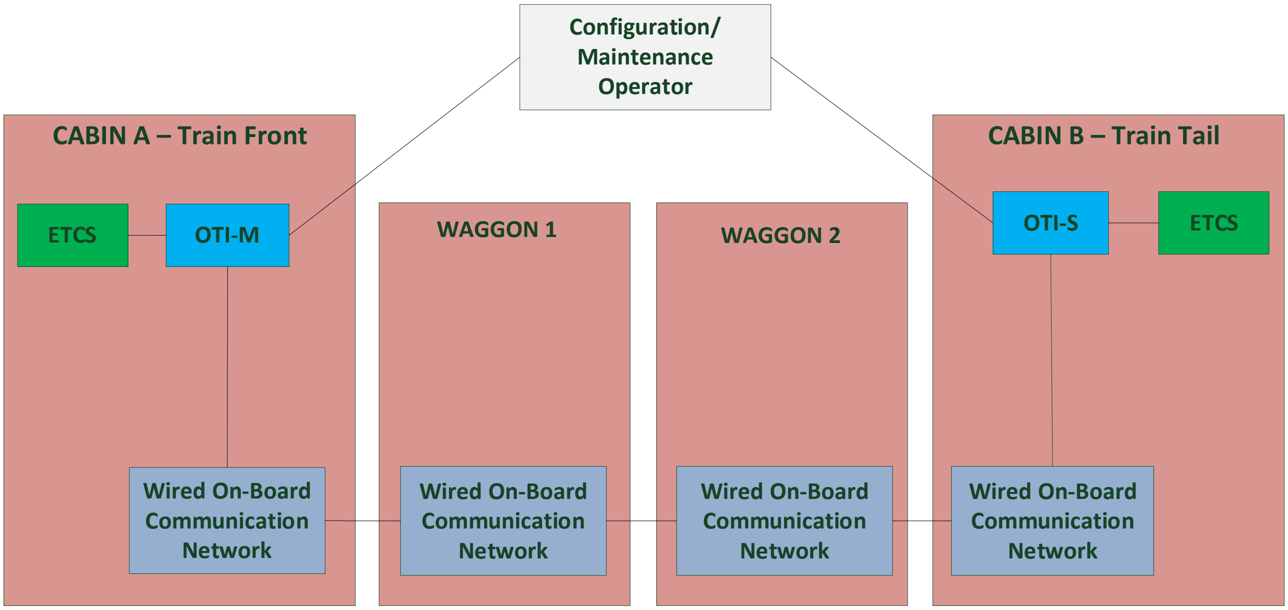

Figure 6-1: Functional Architecture for Passenger Scenario

Another example for functional architecture in passenger scenario application is depicted in Figure 6-2, referring to central ETCS (e.g. urban/sub-urban). Main features for this configuration consist in:

- fixed train composition;
- one central ETCS equipment to manage front cabin and train tail;
- OTI Master and OTI Slave modules implemented as external devices, located respectively in front cabin and at train tail and connected to ETCS equipment. Note that OTI role (Master or Slave) depends on active cabin.
- wired on-board communication network for communication between OTI Master in front cabin and OTI Slave at train tail.

Configurator/Maintenance Operator interfaced with OTI devices is also depicted in Figure 6-2.

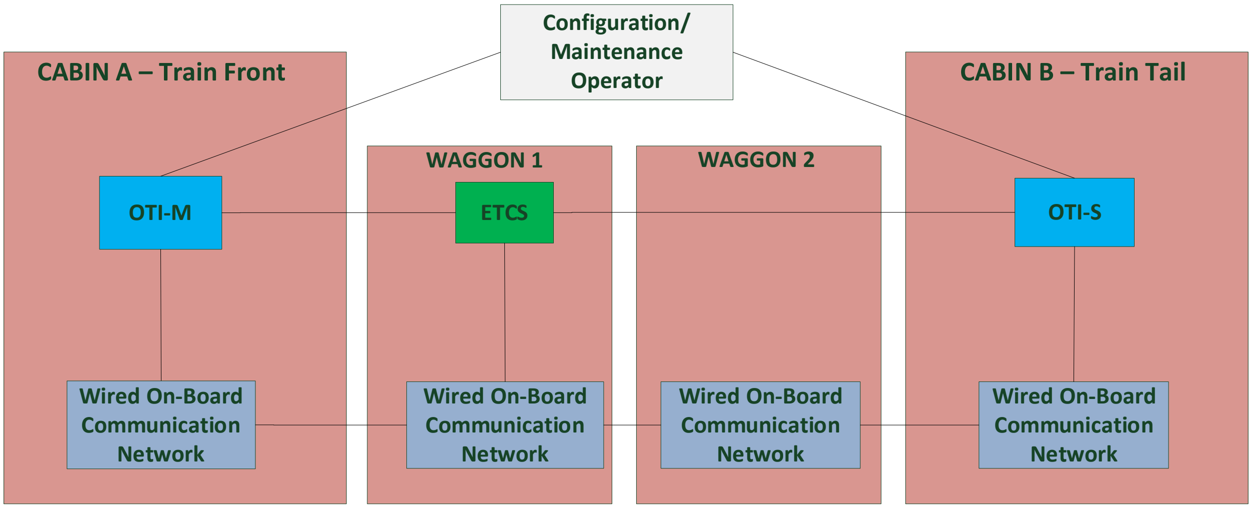

Figure 6-2: Functional Architecture for Passenger Scenario in Central ETCS configuration

An alternative example includes peer-to-peer connection between ETCS and OTI-M and between ETCS and OTI-S that can change their role depending on active cabin.

Another example for functional architecture in passenger scenario application is depicted in Figure 6-3. Main features for this configuration consist in:

- fixed train composition;
- ETCS equipment available only in front cabin;
- OTI Master and OTI Slave modules implemented as external devices, located respectively in front cabin and at train tail. Only OTI Master is connected to ETCS equipment;
- wired on-board communication network for communication between OTI Master in front cabin and OTI Slave at train tail;

Configurator/Maintenance Operator interfaced with OTI devices is also depicted in Figure 6-3.

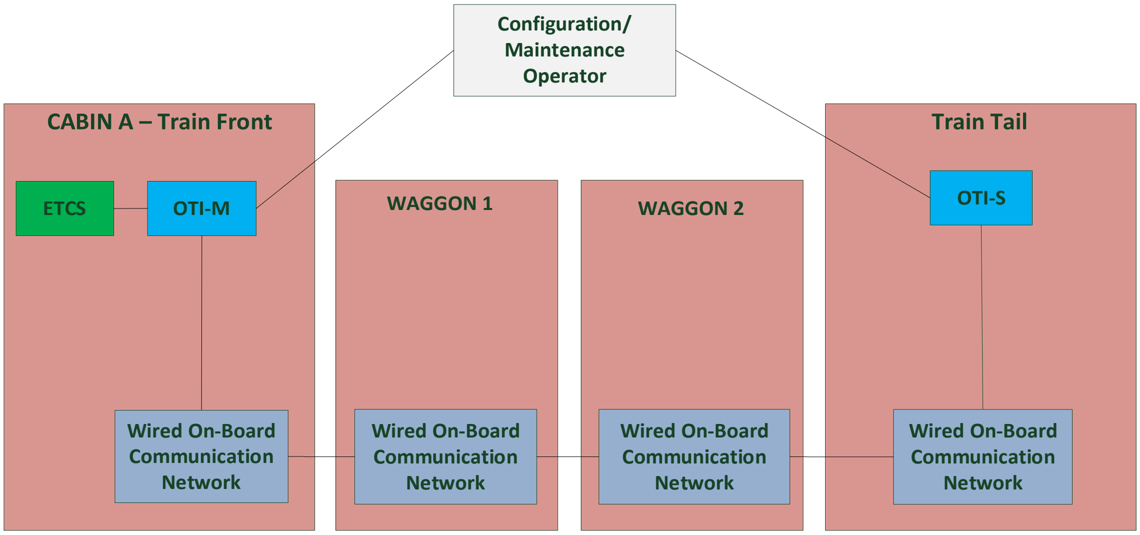

Figure 6-3: Functional Architecture for Passenger Scenario with ETCS only in front cabin

Another example for functional architecture in passenger scenario application is depicted in Figure 6-4 referring to high-speed applications with OTI functionality hosted inside ETCS platform, independent from ETCS core. Main features for this configuration consist in:

- fixed train composition;
- ETCS equipment available in front cabin and at train tail (e.g. high speed trains);
- OTI Master and OTI Slave modules implemented as SW module hosted inside ETCS platform.
- wired on-board communication network for communication between OTI Master in front cabin and OTI Slave at train tail.

Note that even though OTI functional module is physically hosted in the ETCS platform, it is independent and external respect to ETCS core.

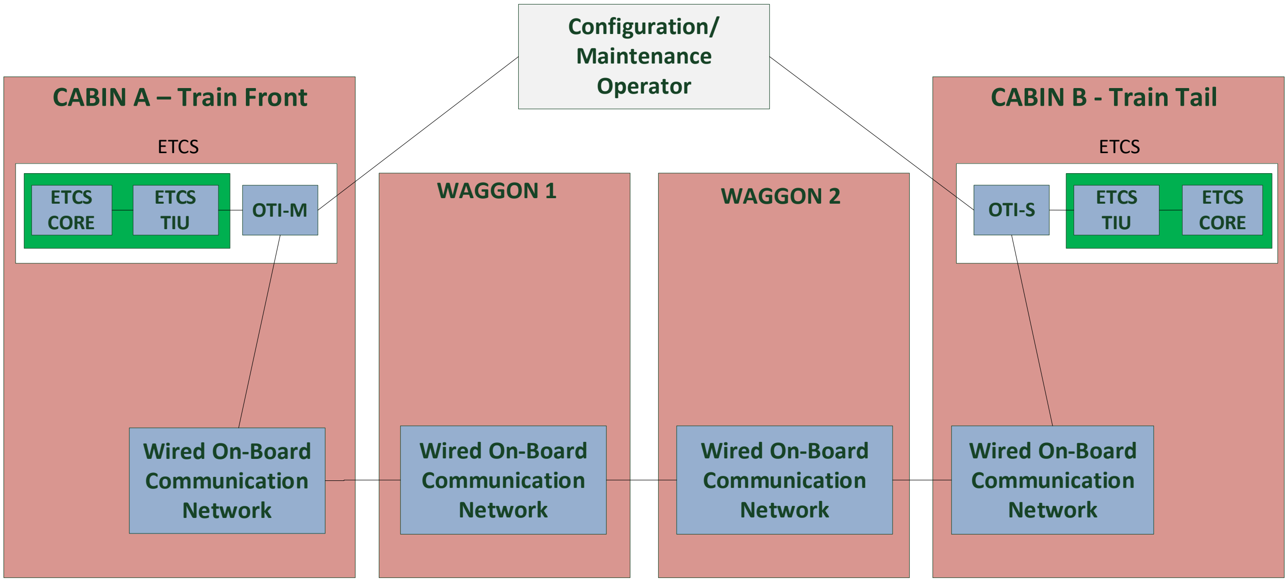

Figure 6-4: Functional Architecture for Passenger Scenario with OTI hosted in ETCS platform

Another example for functional architecture in passenger scenario application is depicted in Figure 6-5 referring to passenger applications with OTI Master functionality hosted inside ETCS platform, independent from ETCS core, and OTI Slave as external device located at train tail. Main features for this configuration consist in:

- fixed or variable train composition;
- ETCS equipment available only in front cabin;
- OTI Master functionality implemented as SW module hosted inside ETCS platform;
- OTI Slave device implemented as external device located at train tail;
- wired on-board communication network for communication between OTI Master in front cabin and OTI Slave at train tail;

Note that even though OTI functional module is physically hosted in the ETCS platform, it is independent and external respect to ETCS core.

Note that in new generation trains the intentional coupling/uncoupling events provided by the rolling stock is equivalent for OTI-M to START command that triggers OTI system reconfiguration for a new train composition. This event avoid further driver involvement to generate manually the START command after completing a new train composition. In this case the functional architecture block diagram includes also interface between OTI and rolling stock.

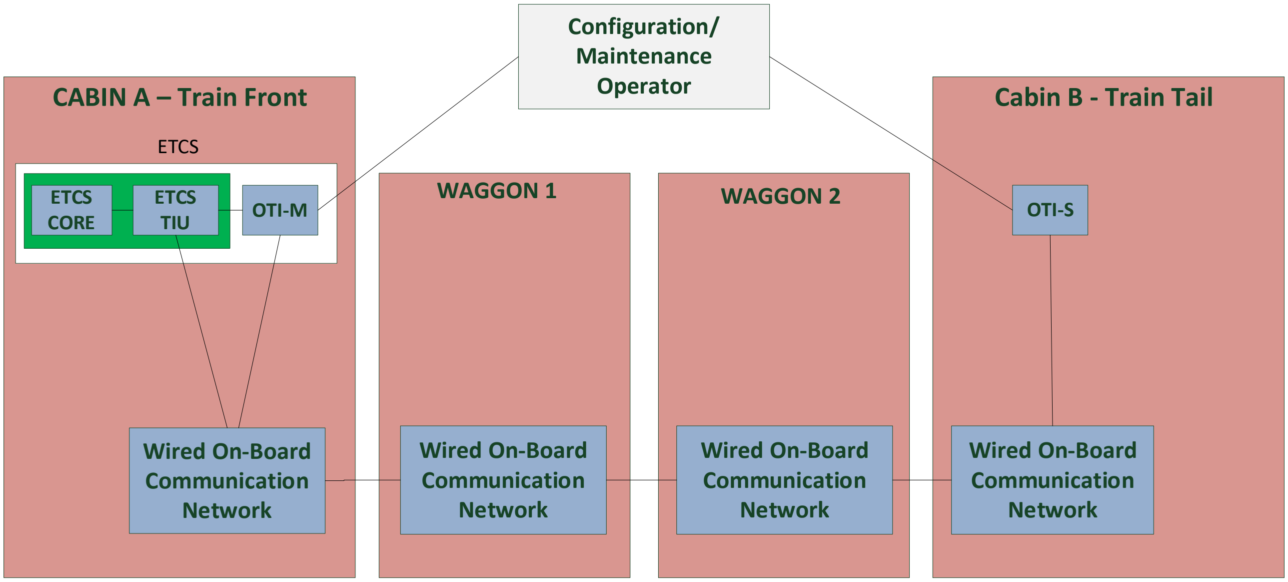

Figure 6-5: Functional Architecture for Passenger Scenario with OTI-M hosted in ETCS platform

6.2 Functional Architecture for Product Class 2

This section depicts examples referred to OTI Product Class 2 with train integrity criterion consisting in comparing kinematic data from OTI Slave at train tail and kinematic data from OTI Master at front cabin.

An example for functional architecture in freight scenarios is depicted in Figure 6-6. Main features for this configuration consist in:

- variable train composition;
- only one ETCS equipment available in the front cabin;
- wireless on-board communication network by using the technology available in the market as COTS or as output from other TDs or already selected in other TDs or IPs; the verification of the suitability of this technology for implementing the OTI functions will be carried out in the context of the OTI development;
- OTI Master device implemented as external device, located in front cabin and connected to ETCS equipment;
- OTI Slave device present at least at train tail or optionally also in all waggons and connected to OTI Master device by means of wireless on-board communication network.
- Kinematic sensors used by OTI Slave at train tail to acquire train tail movement status, provided to OTI Master for comparison with front cabin movement.

Configurator/Maintenance Operator and Wayside Maintenance Centre interfaced with OTI devices are also depicted in Figure 6-6.

Note that OTI Slave devices are also connected to a TAIL sensor to identify position inside the train. This sensor is not optional and is relevant for pairing process between OTI Master and OTI Slave at train tail, as described in D4.1 [1].

In OTI Product Class 2, the train integrity monitoring criterion consists in verifying train tail kinematic data to check that last waggon is regularly advancing in a coherent way respect to the front cabin.

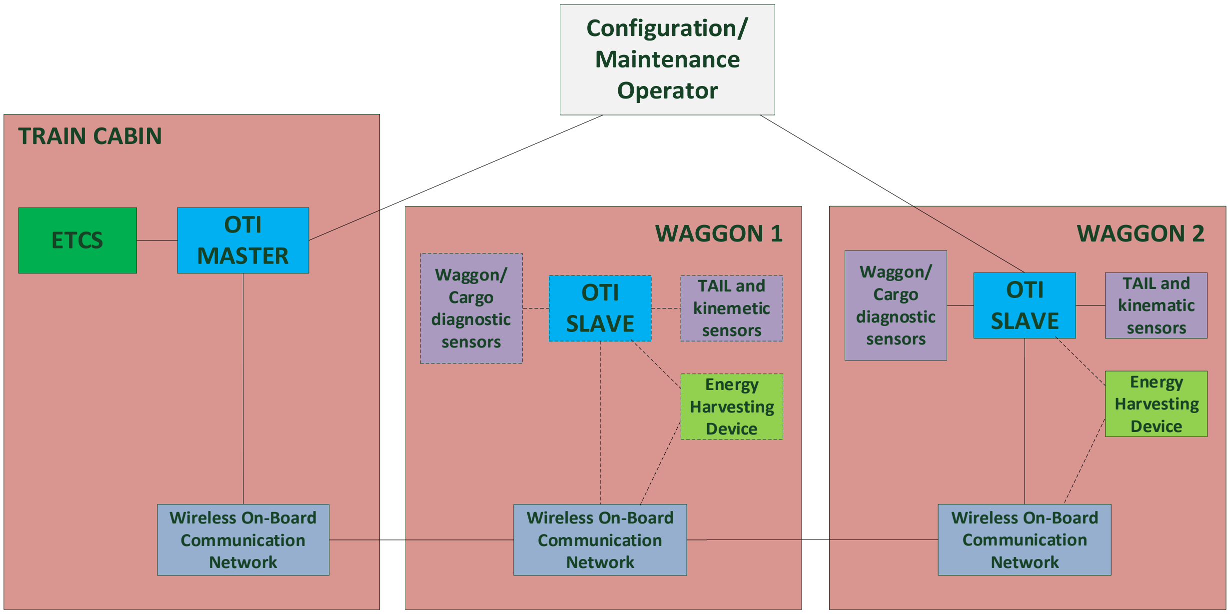

Figure 6-6: Functional Architecture for Freight Scenario with OTI Product Class 2

Note that:

- waggon / cargo diagnostic sensors are not part of the OTI slave device. In general also the TAIL sensor is an external sensor, however the possibility to integrate TAIL sensor inside OTI is part of product specification phase
- further options for cargo/waggon diagnosis consists in including direct radio link between OTI Slave and OTI Master in case of unavailable on-board communication network
- development of radio technology is outside the scope of the TD 2.5 – On Board Train Integrity.

Note that freight application domain is also addressed by OTI Product Class 1 with wired communication. In this case, Figure 6-6 is based on a wired communication network.

Note that functional architecture in Figure 6-6 depicts a case with an OTI device for each waggon. Another case for consists in OTI Slave device only at train tail.

As remarked in D4.1 [1], installing an OTI device in each waggon implies a higher investment cost respect to the installing only an OTI device at train tail and in front cabin. Therefore to increase the interest of the freight operator, also waggon/cargo diagnostic functionalities have been considered in connection with a Wayside Maintenance Centre.

Note that above considered example addresses old generation freight waggons without any train line. In case wired communication is available and ETCS is present in both train cabins, the OTI Product Class 1 can be applied to freight applications.

6.3 Functional Architecture for OTI Product Class 3

On-board configuration Product class 3 is composed of an OTI device in front cabin with Master role connected to ETCS and an OTI device in each waggon with Slave role. OTI devices communicate over a wireless on-board network. In this case, the train integrity criterion consists in communication liveliness and separation detection between adjacent waggons. Network topology discovery techniques are used to determine train composition both for train integrity monitoring and train length determination. Interaction with trackside is considered to mitigate the risk of errors in train composition determination that would results in partial monitoring of train integrity (e.g. OTI fault in an intermediate waggons would prevent discovering the subsequent waggons). For this reason the train composition is also acquired by trackside and compared with discovered train composition with confirmation procedure that involves also the train driver on a dedicated OTI dashboard.

An example for functional architecture in OTI Product Class 3 is depicted in Figure 6-7Figure 6-6. Main features for this configuration consist in:

- variable train composition;
- only one ETCS equipment available in the front cabin;
- wireless on-board communication network;
- OTI Master device implemented as external device, located in front cabin and connected to ETCS equipment;
- OTI Slave devices present in all waggons and connected to OTI Master device by means of wireless on-board communication network;
- separation sensor for each waggon to detect separation between adjacent waggons.

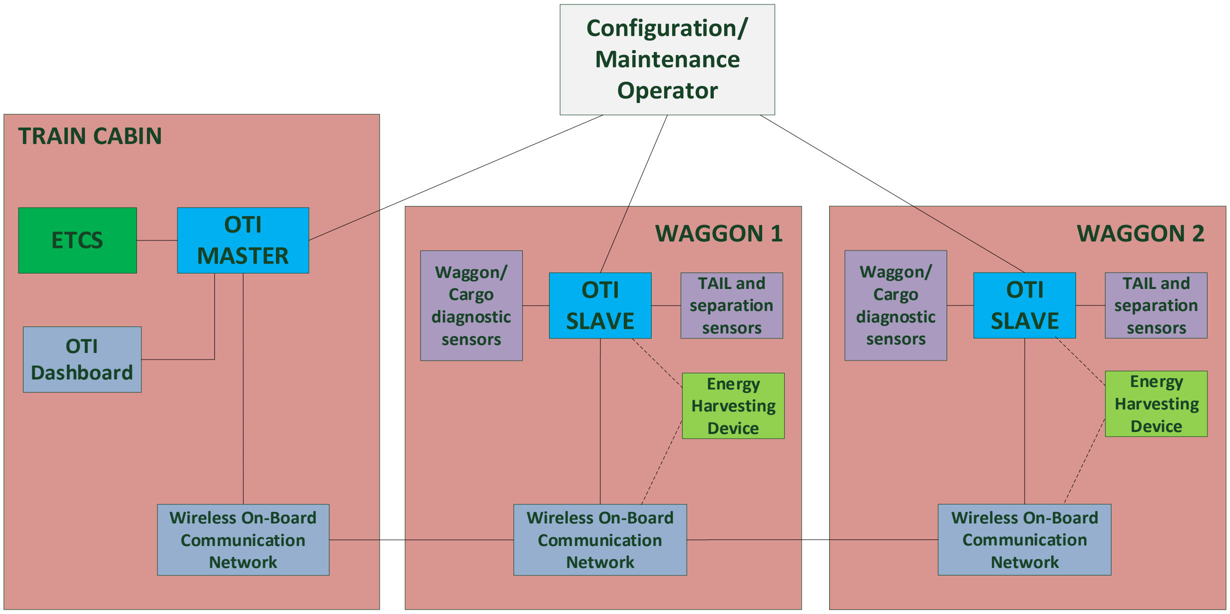

Figure 6-7: Functional Architecture for OTI Product Class 3

6.4 Functional Architecture for ETCS backward compatibility

ETCS backward compatibility is intended as compliancy to ETCS BL3 R2 specified in [2][3][4]. In this case OTI provides to ETCS only train integrity status and train length. Other information needed to OTI device are managed independently from ETCS-OTI interface.

An example for functional architecture suitable for ETCS backward compatibility is depicted in Figure 6-8. Main features for this configuration consist in:

- OTI Master device implemented as external device, located in front cabin and connected to ETCS equipment;
- Interface with an OTI Dashboard to managed the interface with the driver (i.e. lamps for Train integrity status and OTI device status; buttons for Start/reset commands):
- Interface with the rolling stock to acquire the cabin status, necessary to define the OTI role (i.e. master or slave).

Configurator/Maintenance Operator interfaced with OTI devices is also depicted in Figure 6-8.

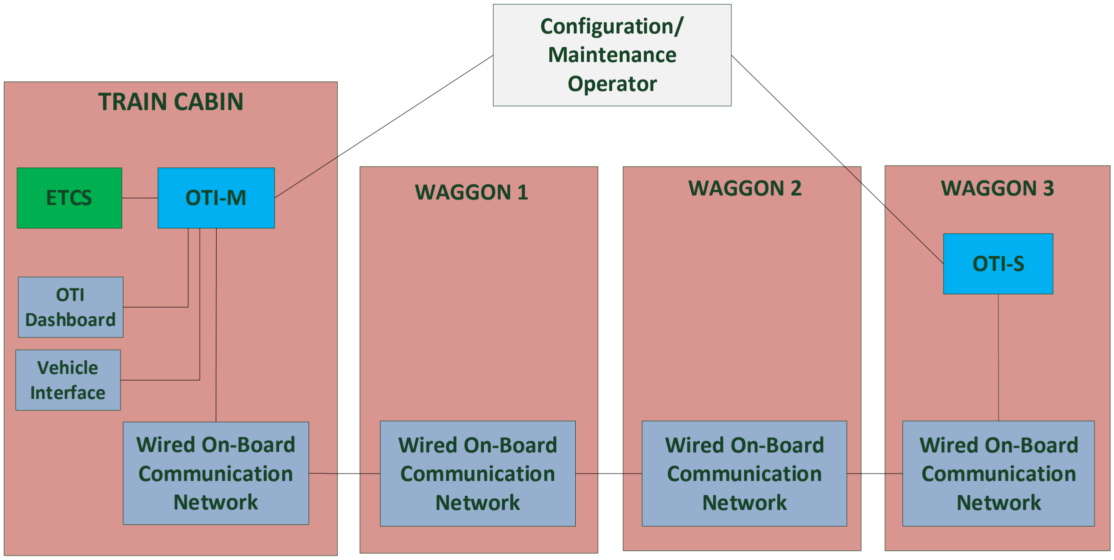

Figure 6-8: Functional Architecture for ETCS backward compatibility

Note that OTI dashboard and Vehicle Interface are introduced in relation to ETCS backward compatibility scenario described in details at section 8. As example OTI dashboard shows OTI status and includes start/reset buttons for train composition phase. Vehicle interfaces provides cabin status for OTI role assignment.

Note that also the wireless communication is applicable to “ETCS backward compatibility” scenario.

6.5 Relations between Train Integrity and Train Length

In general, train integrity monitoring function is referred as OTI-I and train length determination function is referred as OTI-L. These two functions interact for the following three aspects:

- OTI-L provides the train length to the ETCS and to OTI-I;
- OTI-I may use train length from OTI-L as input for train integrity criterion (e.g. Product Class 2);
- OTI-I provides train integrity information after that OTI-L provided train length (i.e. train length is used as trigger event to enable OTI-I communication to ETCS).

General assumption is that OTI-I and OTI-L are hosted within same equipment and OTI-L / OTI-I communication is referred to internal to the same equipment.

Sequence diagrams reported in the following depicts examples for basic interface (i.e. for ETCS backward compatibility) and enhances interface.

6.5.1 Examples for basic interface

Sequence diagrams reported in this sections refers to existing ETCS interface that includes acquisition of the following information:

- Train length
- Train integrity status

Additional information (e.g. OTI status, start/reset commands) are managed by an external OTI dashboard as described at section 6.4 for ETCS backward compatible scenario.

In the following sequence diagrams OTI-I refers to train integrity monitoring functional blocks and OTI-L refer to train length determination functional block.

Example depicted in Figure 6-9 refers to a nominal case with OTI-L an OTI-I working regularly. The OTI dashboard is used to generate start command and to show OTI status. Determined train length is shown to the driver and confirmed.

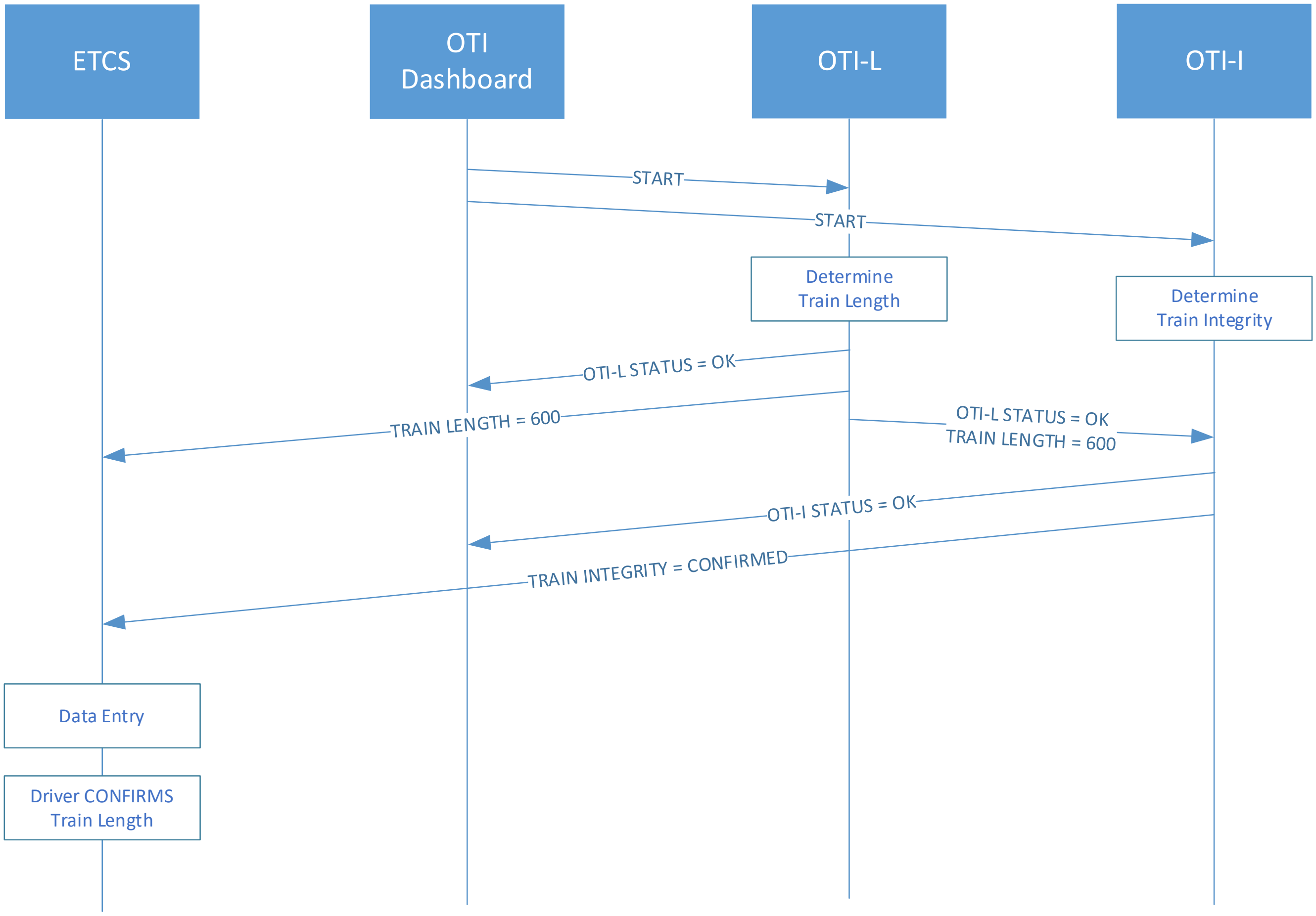

Figure 6-9: Example 1 for basic interface

Example depicted in Figure 6-10 refers to a faulty case with OTI-L not working regularly. The OTI dashboard is used to generate start command and to show OTI status. In this case OTI-I evaluates train integrity independently from train length value that driver has entered with ERTMS/ETCS data entry procedure. Note that considered situation is an exception that is managed by the driver according to the operation rules of each Infrastructure Manager.

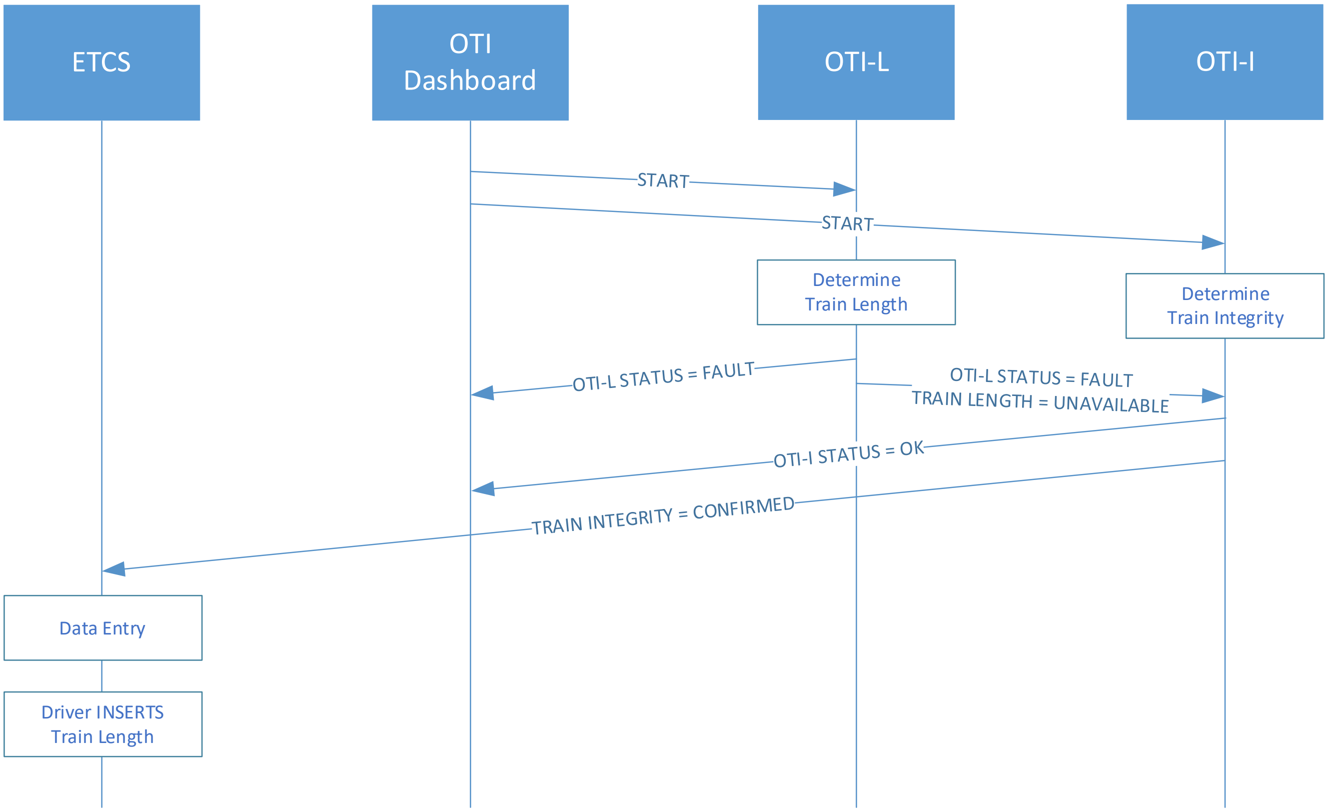

Figure 6-10: Example 2 for basic interface

Note that train composition determination may be used by OTI-L or OTI-I to determine train length or train integrity status, depending on OTI Product Class. In following examples OTI-I does not use train composition to evaluate train integrity status, therefore OTI-I interaction with OTI Dashboard is not required.

Example depicted in Figure 6-11 refers to an exceptional situation with train driver changing, within ERTMS/ETCS data entry procedure, the train length value provided by OTI-L. In this case the driver overrides the OTI-L that need to be disabled with a RESET command. Note that considered situation is an exception that is managed by the driver according to the operation rules of each Infrastructure Manager.

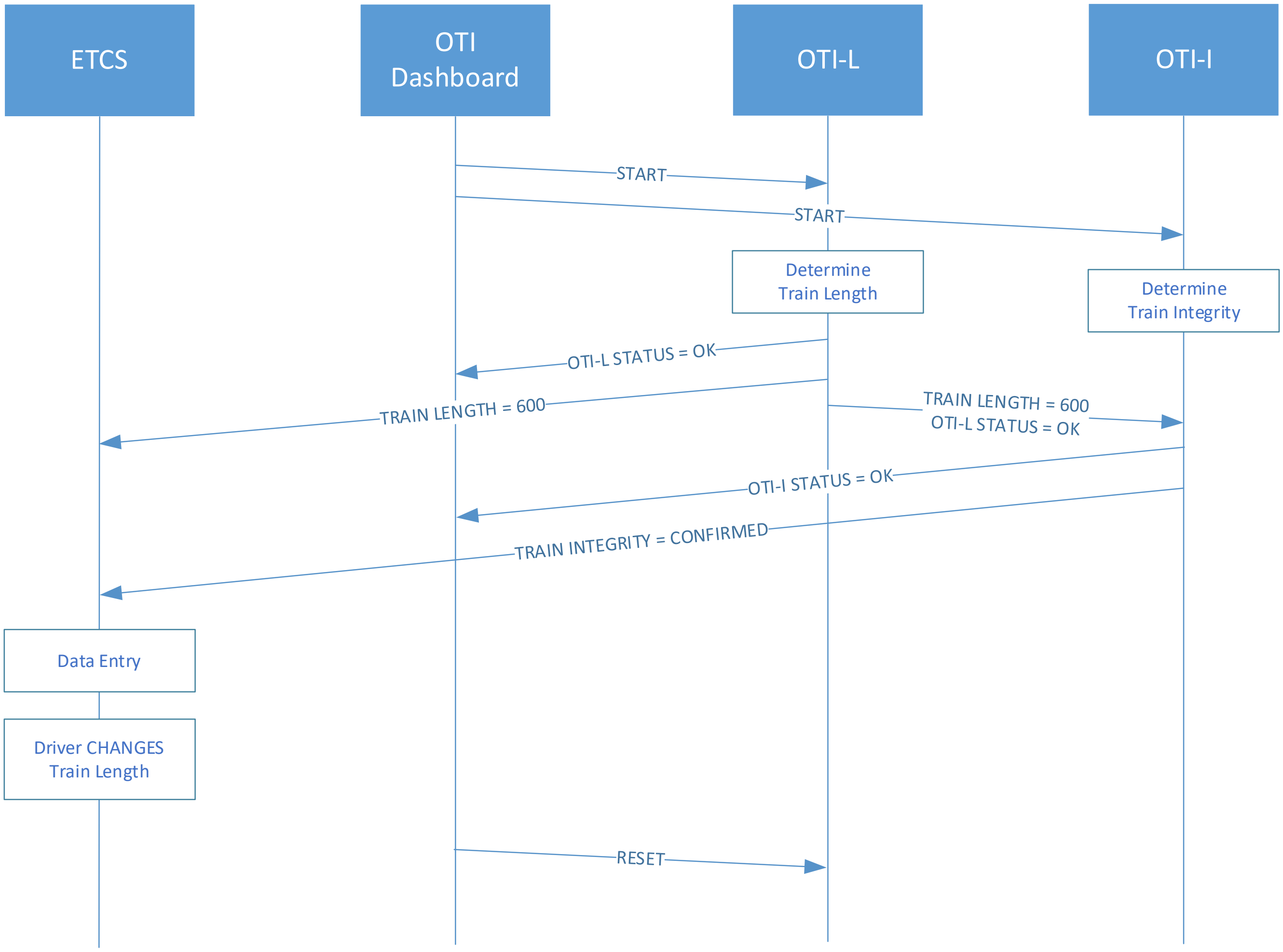

Figure 6-11: Example 3 for basic interface

Example depicted in Figure 6-12 refers to a nominal situation with OTI-L providing train length to ETCS and train driver confirming train length values proposed during the ERTMS/ETCS data entry procedure.

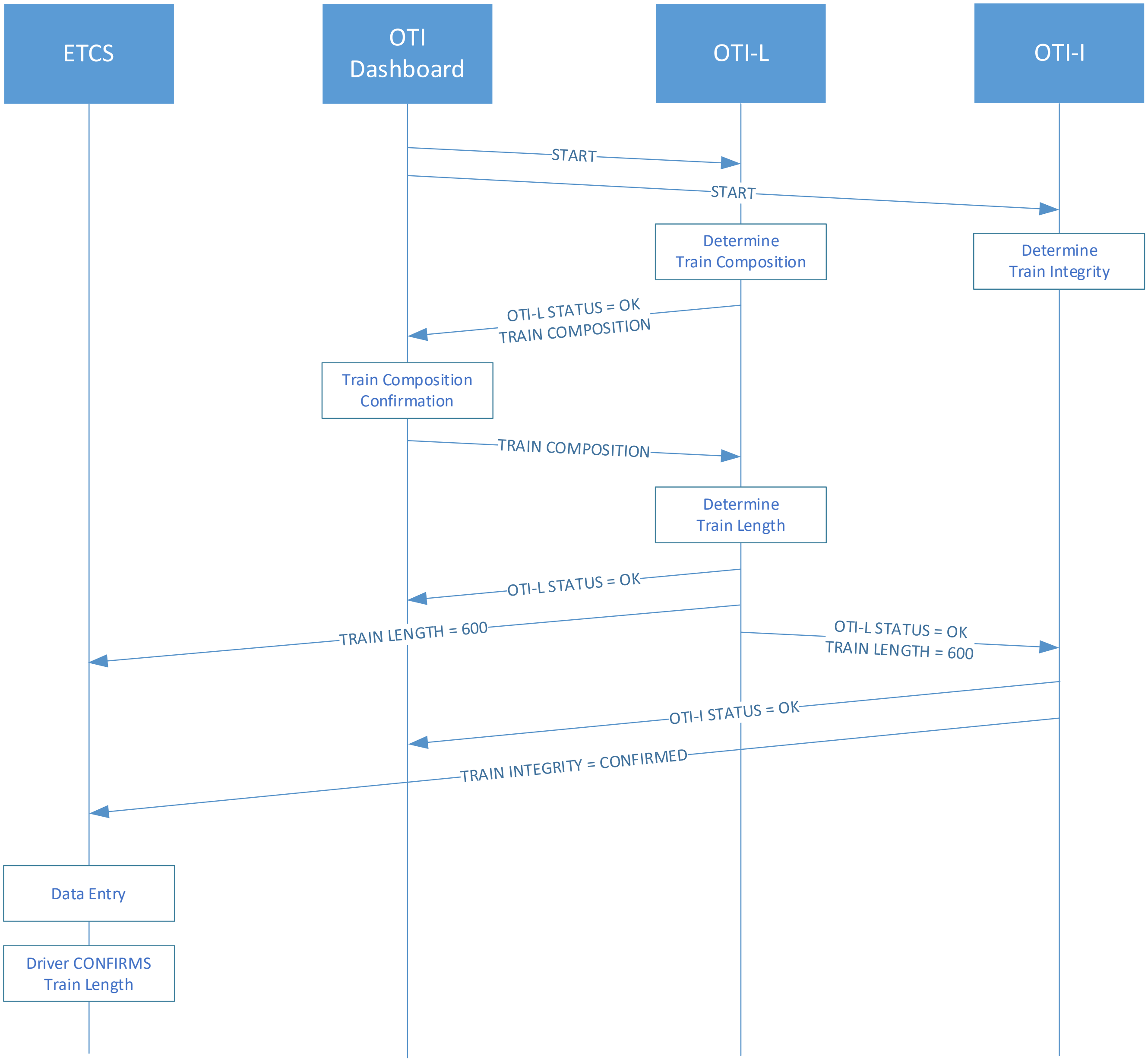

Figure 6-12: Example 4 for basic interface

Example depicted in Figure 6-13 refers to an exceptional situation with train driver changing, within ERTMS/ETCS data entry procedure, the train length value provided by OTI-L. In this case the driver overrides the OTI-L that need to be disabled with a RESET command.

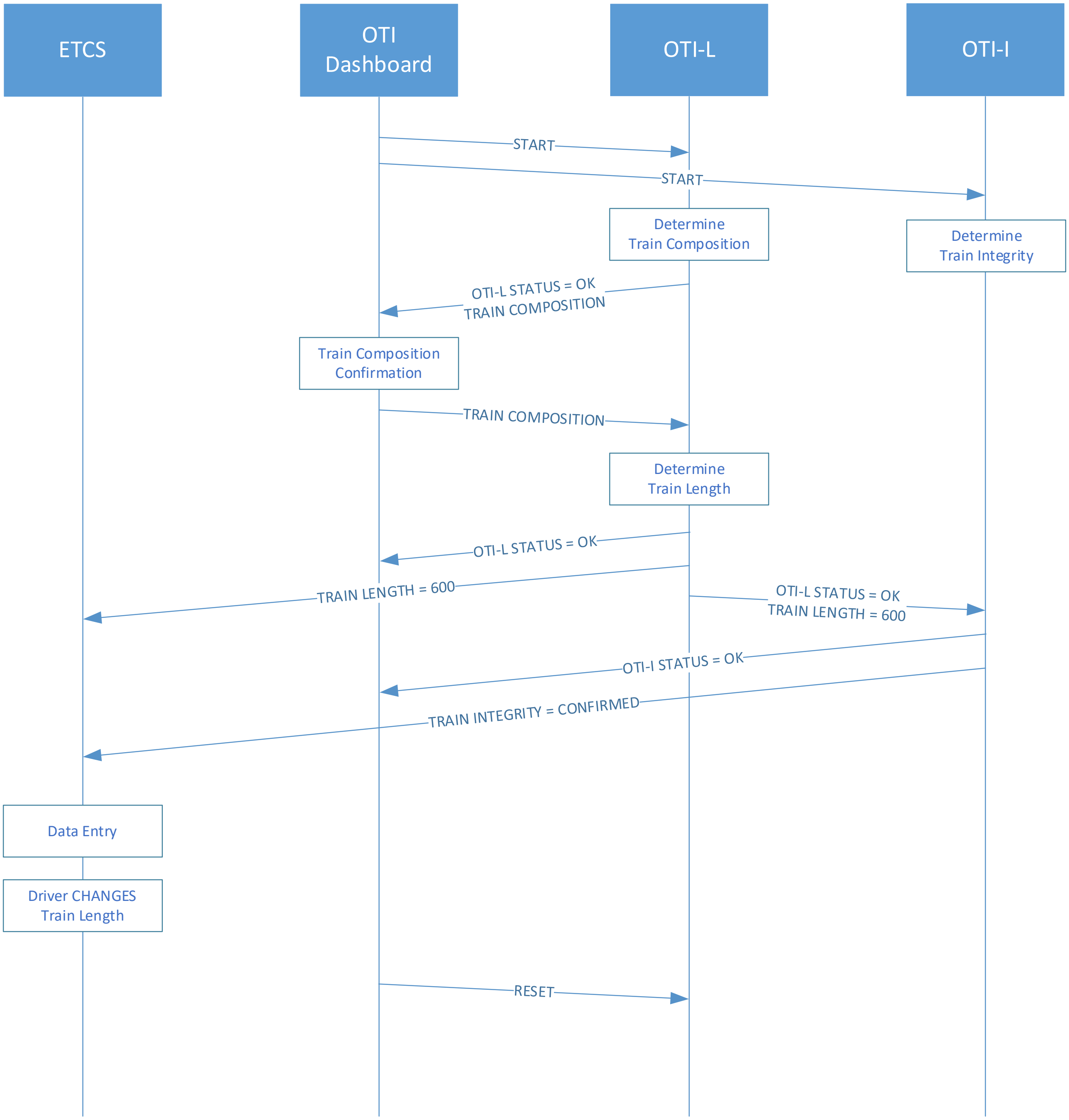

Figure 6-13: Example 5 for basic interface

6.5.2 Examples for enhanced interface

Sequence diagrams reported in this sections refers to a new ETCS interface managing the following information:

- Train length
- Train integrity
- Status of Train Length functional block (OTI-L)
- Status of Train Integrity functional block (OTI-I)
- Start and Reset commands

In general, OTI with enhanced interface does not requires interactions with the driver (e.g. start/reset command are managed by ETCS; OTI status is provided directly to ETCS). An exception is train composition confirmation on OTI dashboard.

Note that train composition determination may be used by OTI-L or OTI-I to determine train length or train integrity status, depending on OTI Product Class. In some cases, to mitigate the risk of errors in train composition determination, the OTI dashboard is also depicted for a confirmation. In following examples OTI-I does not use train composition to evaluate train integrity status.

Example depicted in Figure 6-14 refers to a nominal case for enhances interface with START command generated by ETCS. In this case OTI-L determines train length that is confirmed by the driver during the ERTMS/ETCS data entry procedure.

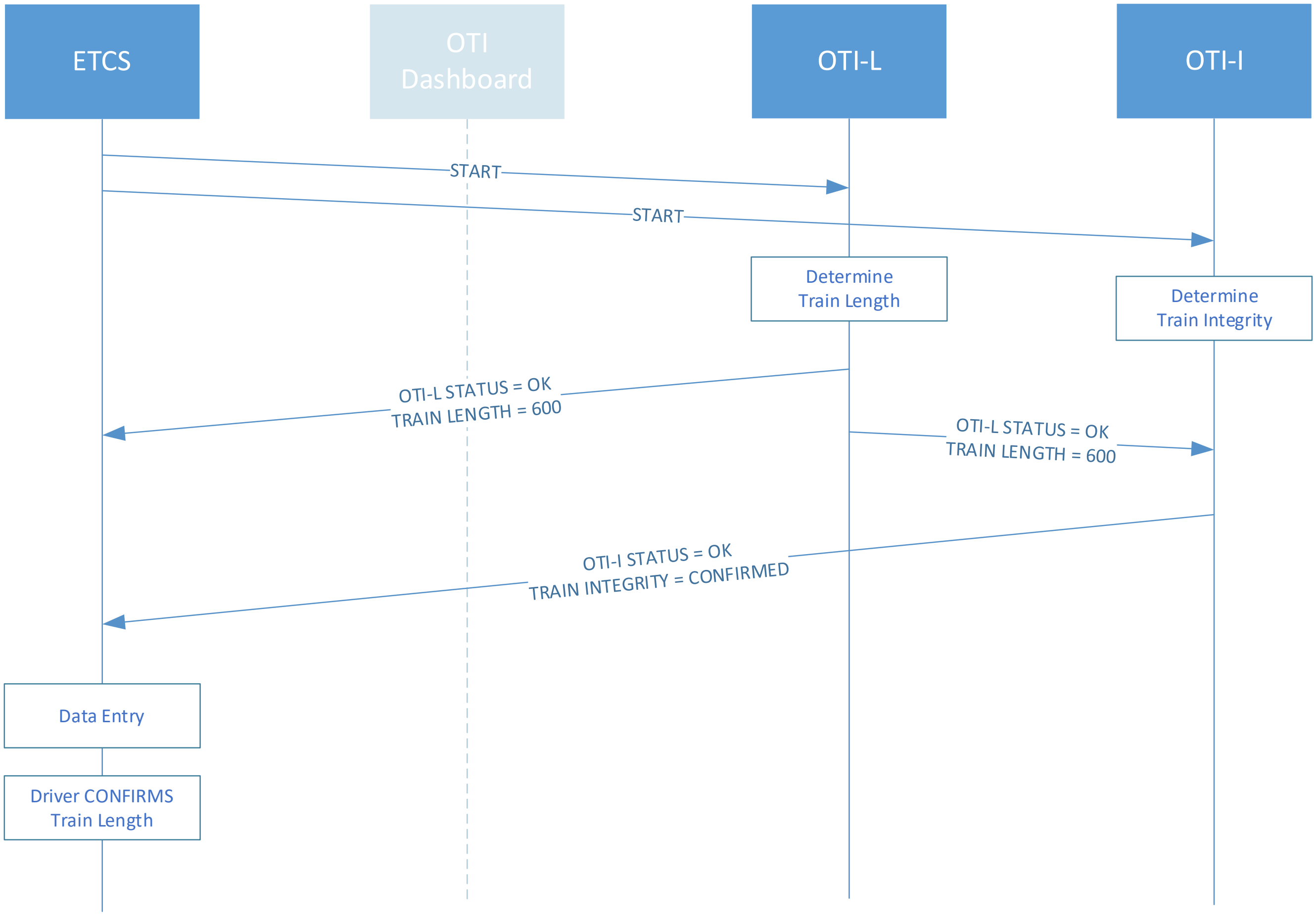

Figure 6-14: Example 1 for enhanced interface

Example depicted in Figure 6-15 refers to a fault in OTI-L functionality and train driver entering manually train length during the ERTMS/ETCS data entry procedure.

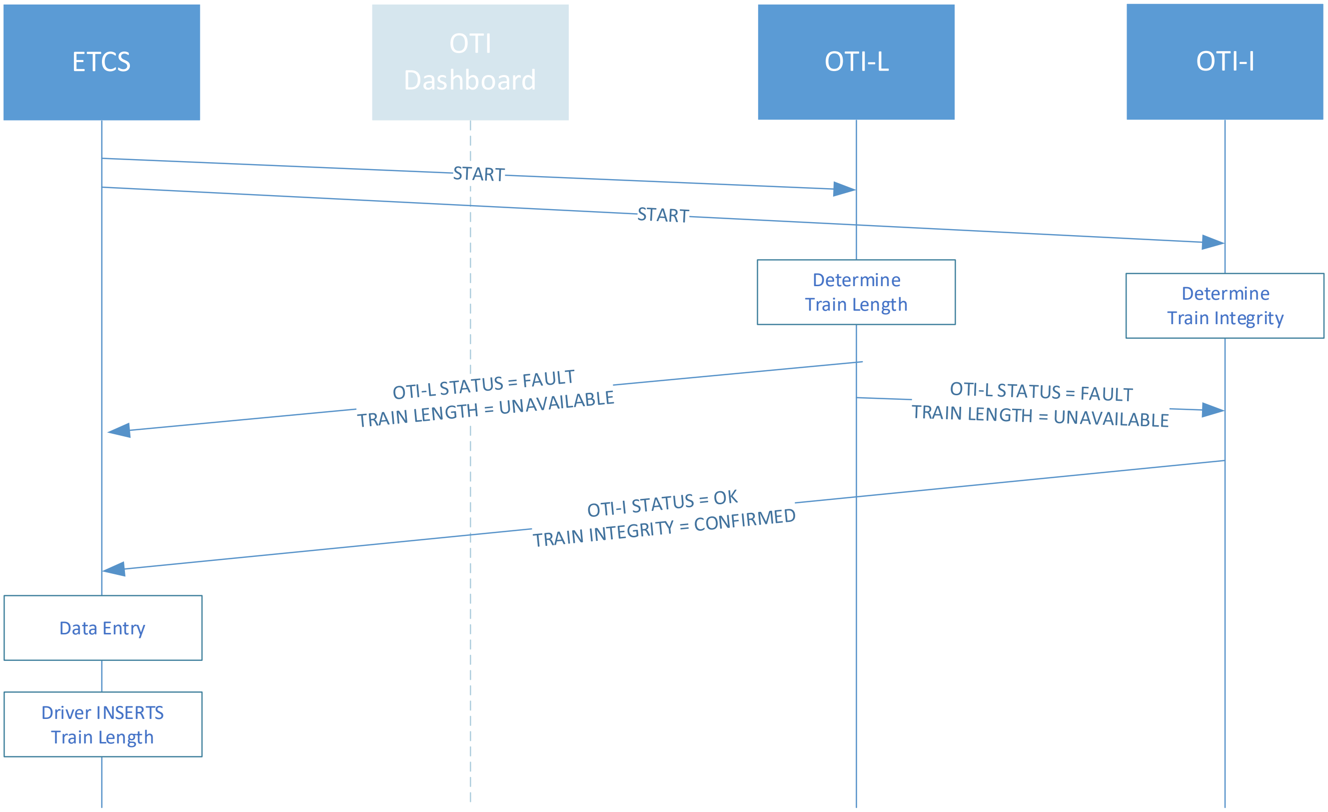

Figure 6-15: Example 2 for enhanced interface

Example depicted in Figure 6-16 refers to an exceptional situation with train driver changing, within ERTMS/ETCS data entry procedure, the train length value provided by OTI-L. In this case ETCS overrides the OTI-L that need to be disabled with a RESET command.

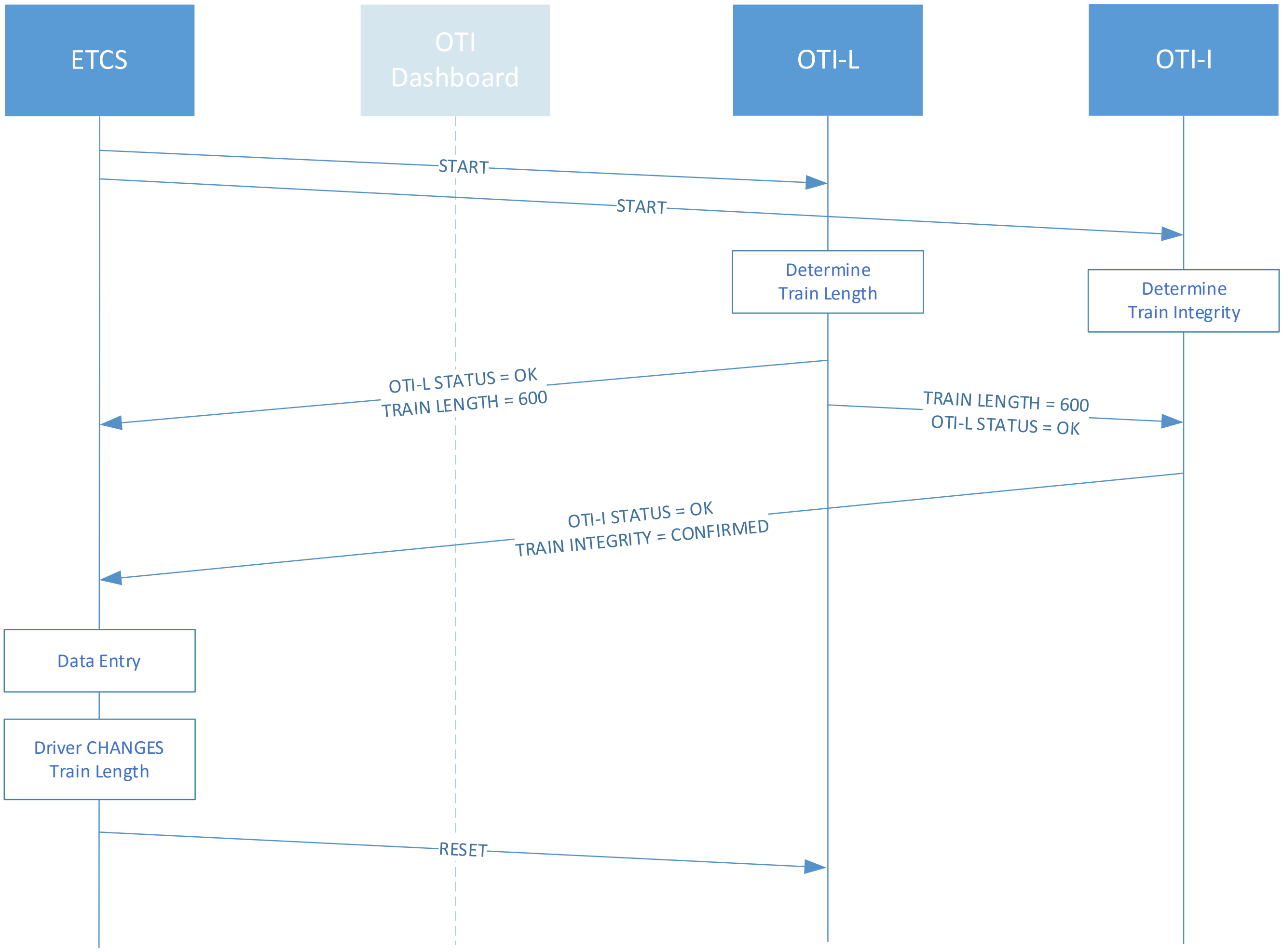

Figure 6-16: Example 3 for enhanced interface

Example depicted in Figure 6-17 refers to a nominal situation with OTI-L providing train length to ETCS and train driver confirming train length values proposed during the ERTMS/ETCS data entry procedure. Examples considered in Figure 6-17 and Figure 6-18 manages the train composition confirmation on a separate OTI dashboard. Optionally this aspect could be managed by ETCS within ETCS DMI, however the impact on existing specifications would be relevant.

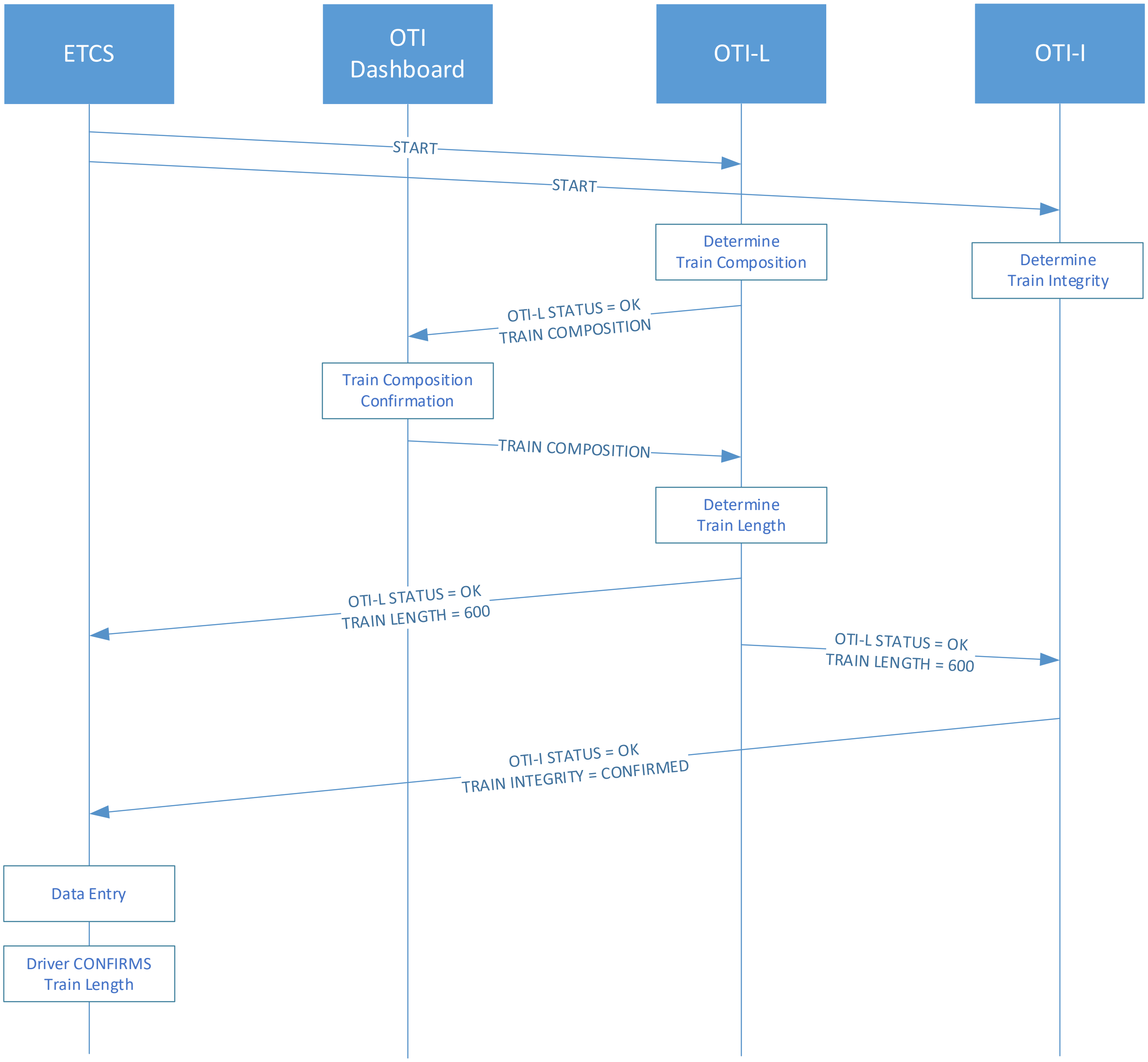

Figure 6-17: Example 4 for enhanced interface

Example depicted in Figure 6-18 refers to an exceptional situation with train driver changing, within ERTMS/ETCS data entry procedure, the train length value provided by OTI-L. In this case ETCS overrides the OTI-L that need to be disabled with a RESET command.

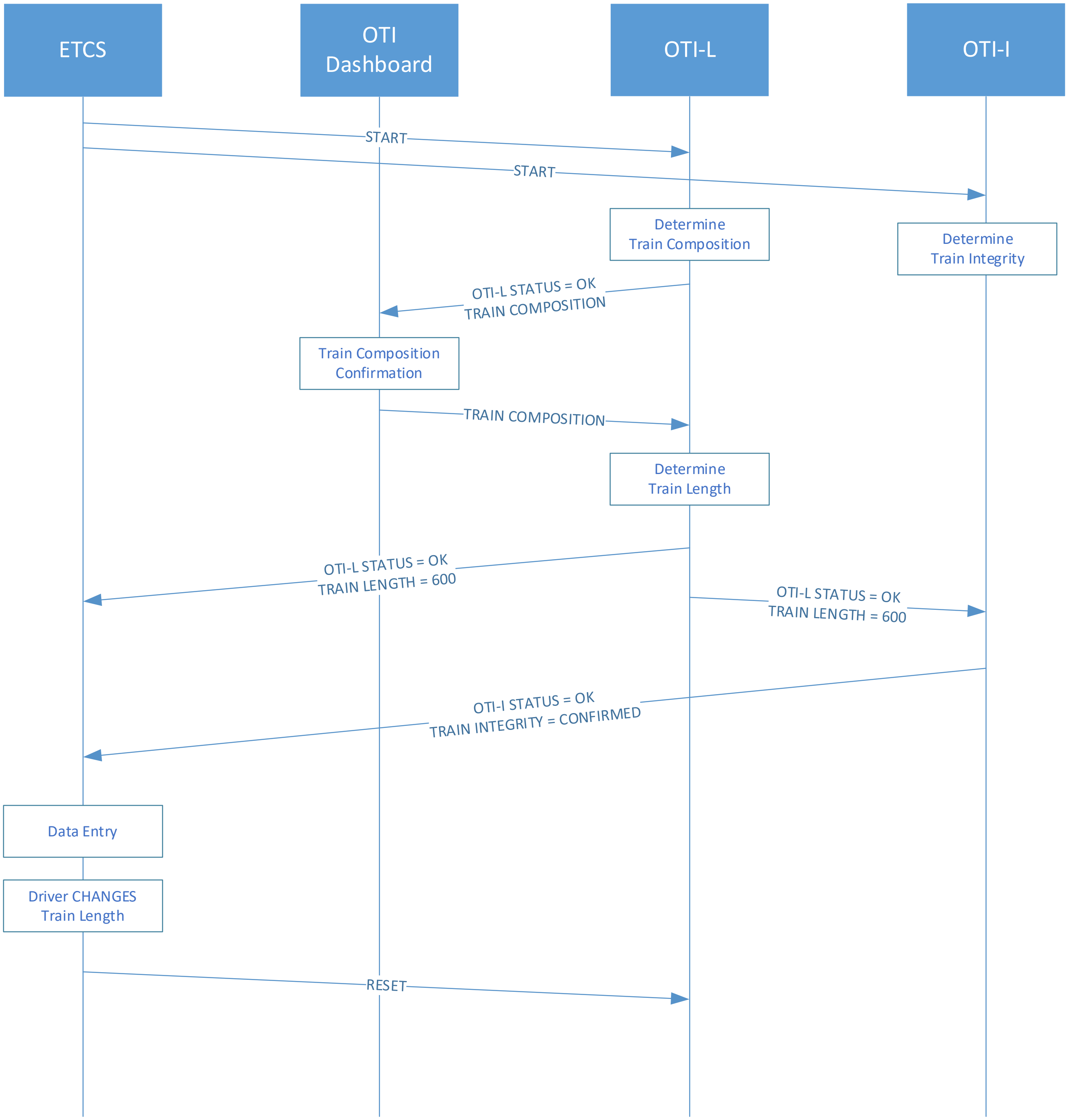

Figure 6-18: Example 5 for enhanced interface

6.5.3 Examples for train joining/splitting

This section described train joining/splitting procedures. In considered examples, the rolling stock (e.g. new generation trains) generates intentional coupling/uncoupling events equivalent to START command that triggers OTI system reconfiguration for a new train composition thus avoiding further driver involvement to generate START command (see par 7.2.1 and Table 7-1). Note that only OTI Slaves answer to identification request messages generated by OTI-1. OTI-3 changes its role later on, when the train driver set as non-active the ETCS-2 cabin. The scope of the diagram is to show the events triggered by coupling event. Note that examples reported in Figure 6-19 and Figure 6-20 are applicable to basic and enhances interface, whereas Figure 6-21 and Figure 6-22 refers to enhances interface.

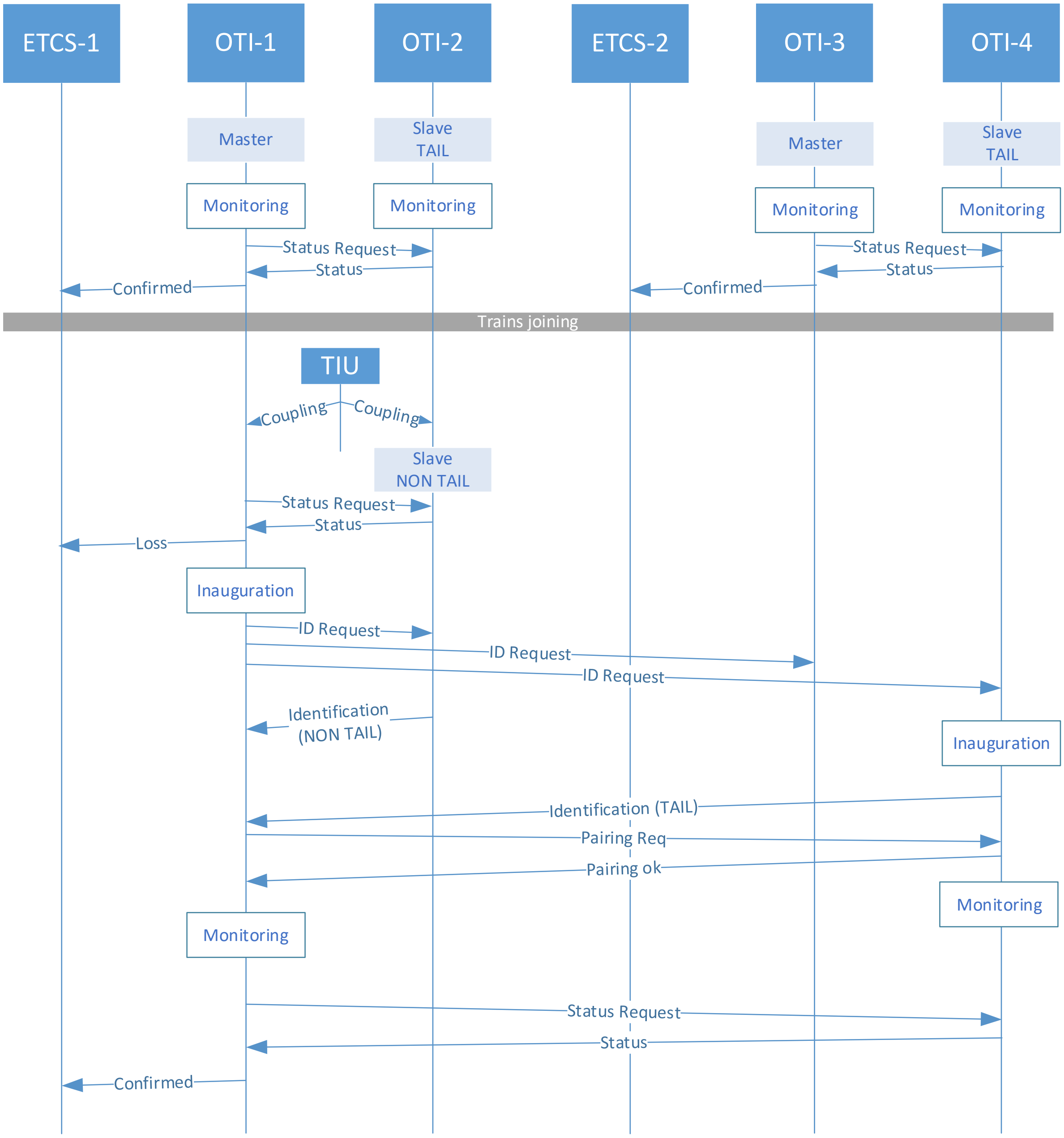

Figure 6-19: Example for trains joining

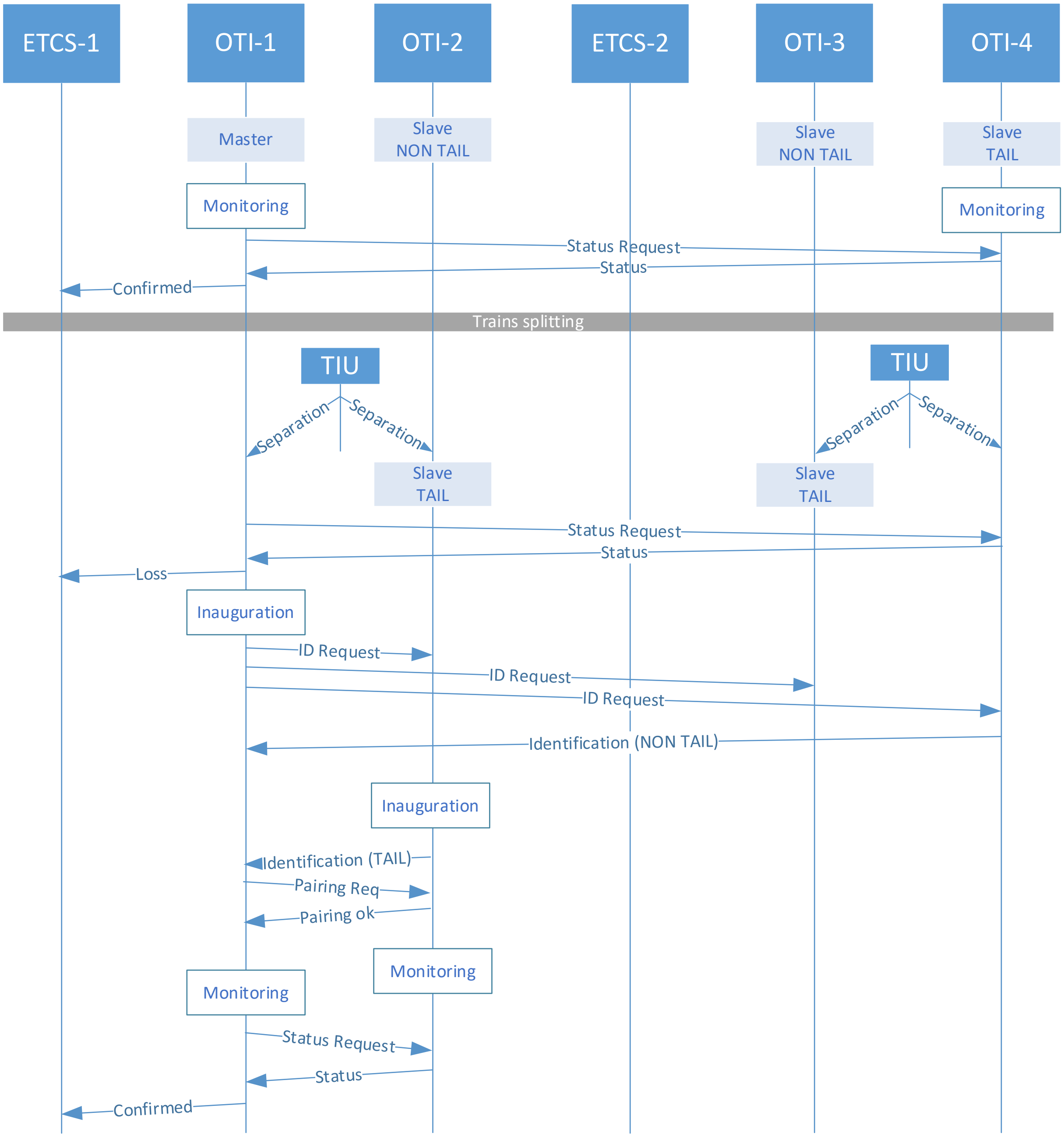

Figure 6-20: Example for train splitting

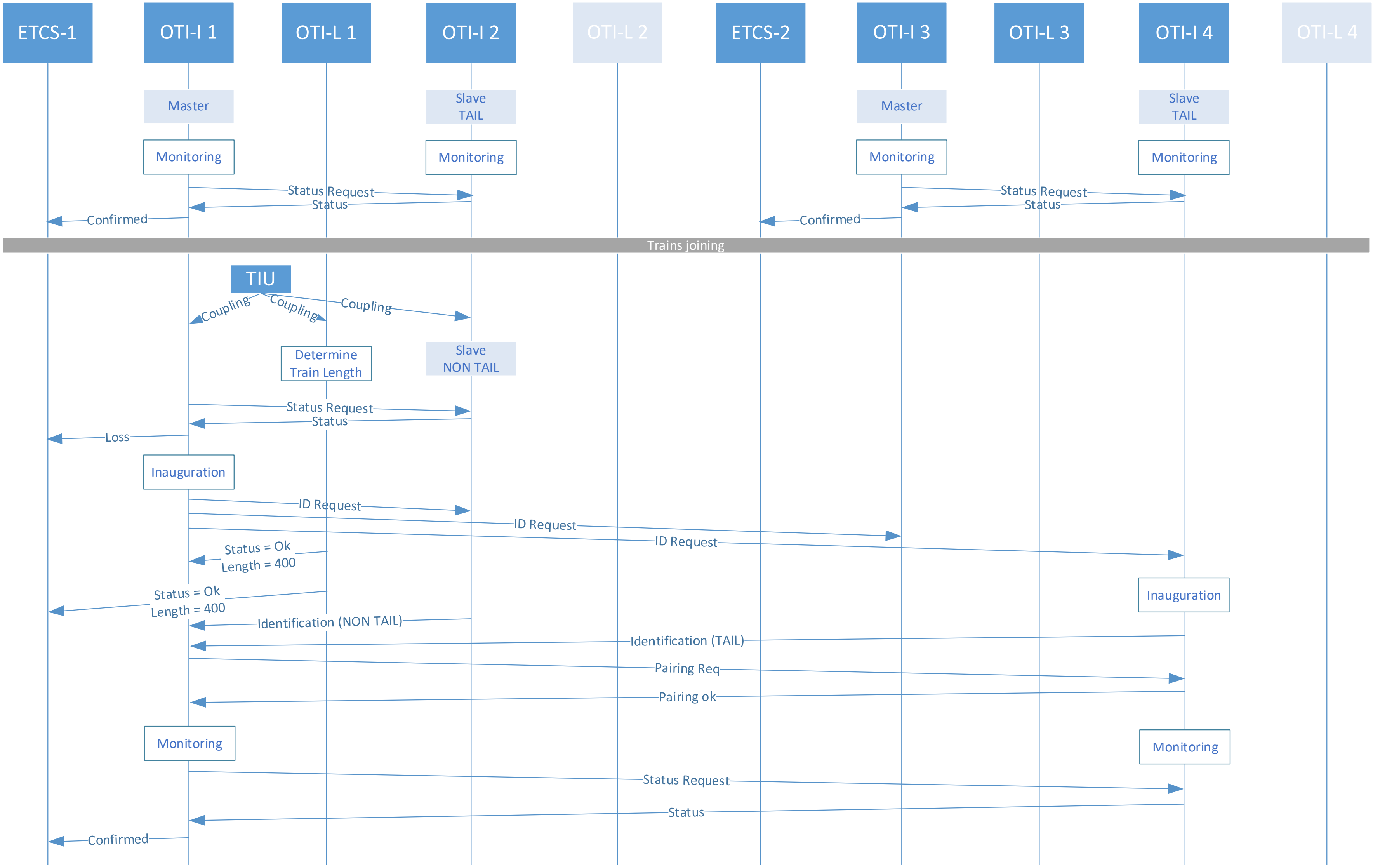

Figure 6-21: Example 2 for train joining

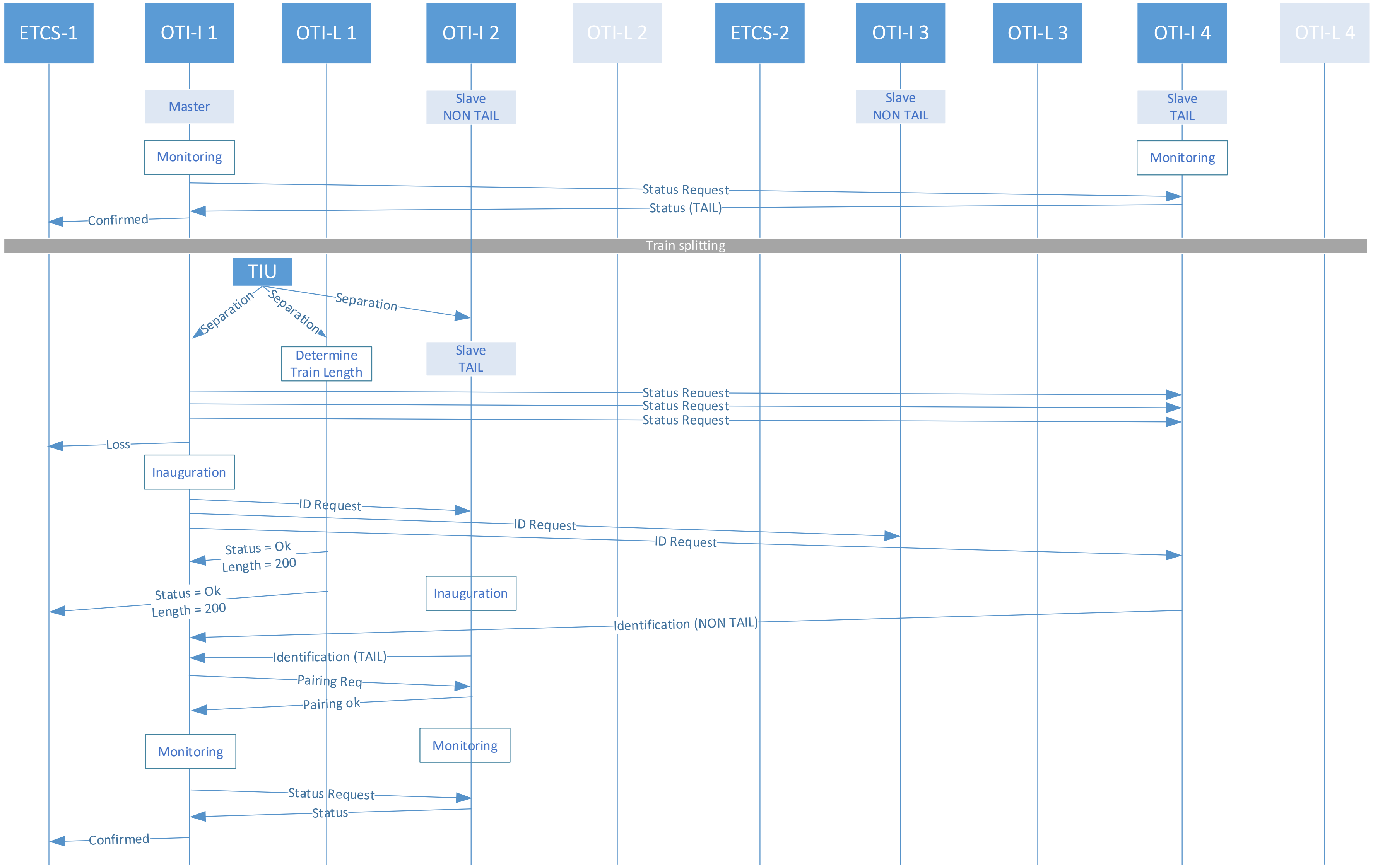

Figure 6-22: Example 2 for train splitting

6.6 Time Reference

In general, entities involved in train integrity monitoring and train length determination uses data provided by different sources with different time references. In the example depicted in Figure 6-22, odometry data for Product Class 2 or balise messages for train length determination area acquired by ETCS equipment installed in different cabins with time reference referred to their respective power-on.

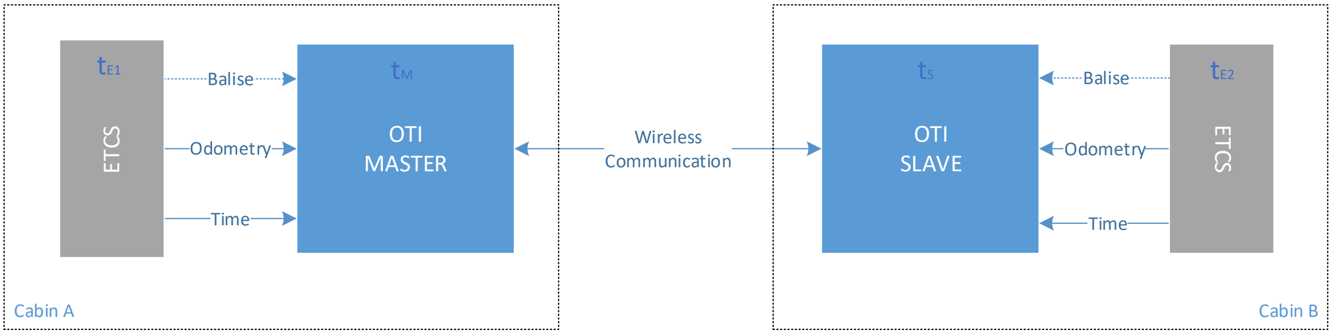

Figure 6-23: Time reference in OTI applications

To allow comparing data provided by different source, a general time reference has to be introduced. Possible options includes time reference from TCMS for new generation trains, time reference service provided by ACS gateway, time reference service provided by OTI System. A possible example for an independent time reference managed by OTI system consist in implementing an NTP server in OTI Master. In this case other entities involved in train integrity monitoring and train length determination can acquire time reference from OTI Master.

7 Interface Specification

7.1 Introduction

Interface specification is derived by functional requirements specified in D4.1 [1] that includes uses cases identification and hazard analysis. Basic principles related to OTI-I and OTI-L functionalities and examples of interactions as sequence diagrams are reported at section 6.5. Functionalities related to each input/output information are quoted at section 7.2 and section 7.3. Traceability matrix between interface specification and functional requirements is reported in Appendix E.

Block diagram depicted in Figure 7-1 summarizes the communication links related to OTI functionality and current regulations or OTI deliverables that describe them. At OTI level, the present document contains specification for communication between OTI Master and OTI Slave modules and includes also new proposal for OTI Master and ETCS interface respect to existing Subset 034 [3] and CR940 [4] to implement specified functionalities in D4.1 [1].

Note that power supply interface and other interfaces for maintenance/configuration purpose are not depicted in Figure 7-1. Finally, the On-board Communication Network (OCN) can be wired or wireless.

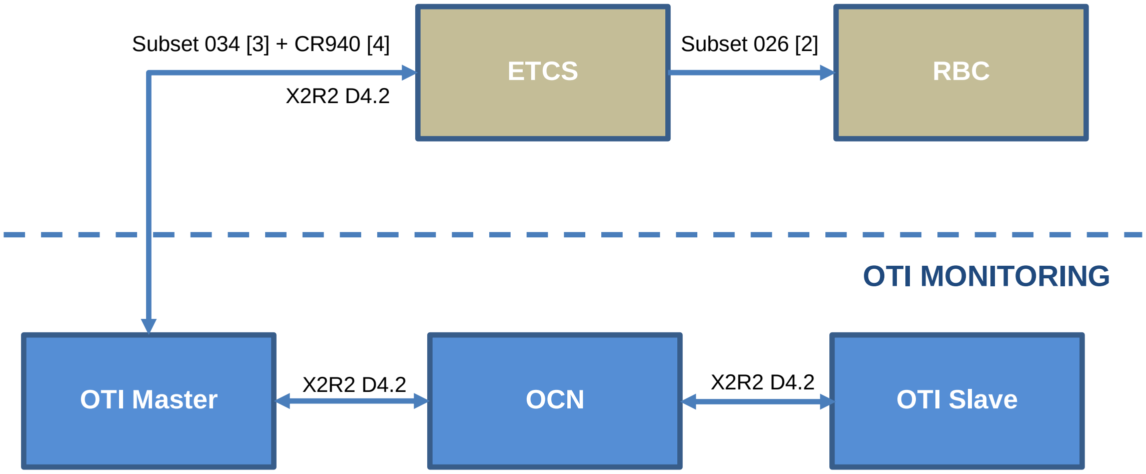

Figure 7-1: Functional Interfaces

Note that according to Subset034 [3] and CR940 [4] the OTI-ETCS interface consists in a unidirectional communication from OTI to ETCS to provide train integrity status with three possible values: unknown, confirmed or lost. The direction from ETCS to OTI is used in case ETCS backward compatibility is not mandatory.

The analysis performed in D4.1 identified reference scenarios and high level functionalities, as example:

- Master-ship phase was defined to assign OTI role (i.e. Master or Slave);
- Inauguration phase was defined to allow OTI Master identifying OTI Slave at train tail and to pair with it;
- Monitoring phase was defined for train integrity monitoring.

This information have been used as inputs to specify OTI FSM in D4.1 and to propose subsequently a general interface between OTI and ETCS to manage the following situations:

1. Train with both cabins equipped with ETCS or trains with a central ETCS configuration implies the acquisition of active cabin information to define OTI role in master-ship phase (i.e. Master or Slave).
2. Supporting train joining/splitting implies managing start/reset commands to stop the monitoring phase and to restart the inauguration phase.
3. In general closing and opening again the desk to change OTI role implies performing again the Start of Mission and re-establishing the communication with RBC. This procedure, performed during a train mission in an intermediate station after removing/adding some passenger cars, implies delays in train mission. For this reason alternative solutions have been suggested to trigger the restart of master-ship phase (e.g. new train length entered by the driver is also provided to OTI).

Therefore start/reset command or train length from ETCS are proposed as alternative solutions to restart master-ship and inauguration phases.

In general the functional specification and related interface is designed to support also product class 2 that uses a train integrity criterion based on comparing kinematic data of train tail and front cabin. For this specific case the odometry data transmission from ETCS to OTI Master has been considered. An alternative approach consists in embedding safe odometry within OTI device with a higher complexity and cost.

The functional specification and related interface are also designed to support potential adoption of GNSS based technologies for train integrity monitoring in product class 2. For this case the train length entered by the driver has been also provided to OTI as input to compare measured train length, determined with GNSS, with the train length entered by the driver. In this case the physical enlargement and shortening of train length due to pushing and pulling movements should be taken into account. Train length determination functionality has been introduced in X2R2 WP4 with an amendment thus avoiding potential driver errors in inserting train length within the ERTMS/ETCS data entry procedure. The use of train length inserted by the driver in class 2 with possible GNSS applications was originally considered when train length determination functionality was not specified. This general case have been left among the possibilities in case the train length determination functionality is not available. In general OTI-L provides train length to ETCS that shows the value to the driver for confirmation. For generality, the train driver is allowed to override (i.e. change) the value provided by OTI-L thus allowing to manage exceptions or special cases.

In general OTI-I term is used in relation to on-board train integrity functionality and OTI-L is used in relation to train length determination functionality.

The “train length determination” functionality requires additional messages exchanged between OTI-L/OTI-I and ETCS including:

- OTI-L function status (i.e. OK or FAULT) → from OTI-L to ETCS and OTI-I. Additional information in case of OK (i.e. ACTIVE, RESET)
- Train length value → from OTI-L to ETCS and OTI-I
- Train length Status (i.e. INIT, AVAILABLE, NOT AVAILABLE) → from OTI-L to ETCS and OTI-I
- Euro-balise Identified → from ETCS to OTI-L
- Train length Validity (i.e. Validated, To Be Revalidated) –> from ETCS to OTI-I to manage the exception case of train length override (i.e. train driver changes, during the ERTMS/ETCS data entry procedure, the train length value provided by OTI-L).

Note that euro-balise message is considered in relation to the specific implementation based on distance measurements. More specifically train length is evaluated as travelled distance between balise detection with ETCS in front cabin and ETCS at train tail. In this case a richer ETCS-OTI interface is required, therefore not applicable to basic interface for ETCS backward compatibility.

For a general analysis these commands are proposed in section 7.4.1 to support a possible future improvement of ETCS-OTI interface that would imply also changes to Subset 026[2], Subset 034[3] and CR940 [4].

Proposing a change request to ETCS specifications [2][3][4] implies a long process and need to be supported by detailed analysis, simulations or experimental evidences.

For this reason also a scenario with full compliancy to Subset034 [3] and CR940 [4] has been considered in section 8 with unidirectional OTI-ETCS communication limited to train integrity status. In this scenario all other commands (e.g. cabin status, start/rest commands) are managed with other OTI interfaces.

7.2 Logical interfaces On-Board Train Integrity

This section contains the communication interface specification related to context depicted in Figure 7-2.

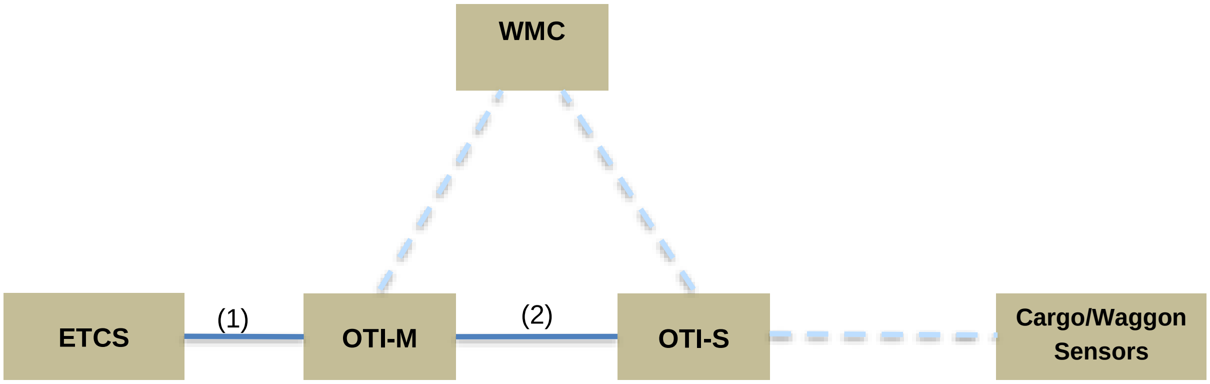

Figure 7-2: OTI communication interfaces

The focus is on the following interfaces:

1. ETCS – OTI Master (SUBSET 034 [3] plus this document)
2. OTI Master – OTI Slave

This document addresses above quoted interfaces at application level, protocol stack level and physical level.

Note that the other interfaces represented with dotted lines in Figure 7-2 are related to diagnostic functionalities introduced in D4.1 [1] and are out of scope of this analysis and consequently not included in this document.

7.2.1 Logical Interface OTI Master

This section describes the logical interfaces (Input/Output) required and provided by OTI Master module to implement the functionalities specified in D4.1 [1] .

The Table 7-1 contains the list of functional input for OTI Master derived from high-level functionalities identified in D4.1 [1] sec. 6.2.4.11: (i) mastership for role identification, (ii) inauguration for OTI Slave at train tail identification and paring with OTI Master, (iii) train integrity monitoring. Refer also to §7.1 of this document.

For each “INPUT” a short reference to the related “Functionality” is reported in the table, the “Source” is also specified (i.e. ETCS or TIU or OTI SLAVE or Driver) and finally the “Type” of input is reported (i.e. VITAL or NON VITAL). In relation to Driver as source, clarifications are reported at section 8.

Functional interface specification has been designed on the basis of reference scenarios and functional requirements defined in D4.1.

START/RESET commands have been introduced to start OTI device and to manage OTI reconfiguration when train composition changes with the following alternatives:

- train cabin activation/deactivation generated by the rolling stock
- Start/Reset commands generated by train driver by means of OTI dashboard (e.g. start/reset buttons)
- Start/Reset commands generated by ETCS with OTI enhanced interface
- Coupling/uncoupling event generated by the rolling stock (equivalent to Start command)
- Train length inserted manually by the driver (equivalent to Start command)

Note that odometry data have been added as input for OTI device in relation to product class 2 with wireless interface. In this case the train integrity criterion implies comparing kinematic data from train tail and front cabin. Finally, Train length has been added as input for OTI device in case GNSS-based train integrity.

In general the interface specification is designed in a general to support implementation for all product classes with different technological solutions.

INPUT	Functionality	Source	Type
Cabin Status	MASTERSHIP	ETCS / TIU	VITAL
OTI Slave Identification	INAUGURATION Role of the OTI Slave (Tail or non-Tail)	OTI Slave	VITAL
Slave Pairing Ack	INAUGURATION Completing pairing procedure with OTI Slave at train tail.	OTI Slave	VITAL
Start / Reset command	INAUGURATION	ETCS / Driver	VITAL
OTI Slave Status	MONITORING	OTI Slave	VITAL
Status Request	MONITORING Providing train integrity information on ETCS request.	ETCS	VITAL
Odometry	MONITORING Train Integrity monitoring in wireless communication scenario based on kinematic data monitoring (e.g. train position, train speed).	ETCS / kinematic sensors	VITAL
Train Length	MONITORING OTI system configuration Train Integrity monitoring in wireless communication and GNSS scenario for Product Class 2.	ETCS / OTI-L	VITAL
Train Length Status, OTI-L status	MONITORING Trigger events enabling communication with ETCS	OTI-L	VITAL

INPUT	Functionality	Source	Type
Train Length Validity	MONITORING manages the exception case of train length override	ETCS	VITAL
Coupling/Uncoupling	INAUGURATION Equivalent to START trigger event in relation to OTI system re-configuration for a new train composition.	TIU	VITAL
Cargo/Waggon Diagnostic Data	DIAGNOSIS Optional Cargo/Waggon diagnosis.	OTI Slave	NON VITAL
Train Composition	Train Composition determination	WMC	VITAL

Table 7-1: OTI Master – Logical Interface – List of Input

Cabin Status refers to MASTERSHIP high level functionality for role assignment (i.e. OTI MASTER or OTI SLAVE).

OTI Slave Identification refers in general to the “role” of the OTI slave device to identify if it is located at the train tail or not for INAUGURATION high level functionality.

Slave Pairing Ack refers to INAUGURATION high level functionality and allow to complete pairing procedure with OTI Slave at train tail.

Start and **Reset** commands refer to INAUGURATION high level functionality to support train joining/splitting scenario.

OTI Slave Status refers to MONITORING high level functionality and represents the information necessary to OTI Master to apply the train integrity criteria (e.g. communication liveliness in Product Class 1 or train tail coherent movement respect to front cabin in Product Class 2).

In general OTI device provides periodic train integrity information to ETCS. In case of long reporting periods, the **Status Request** command is exported to ETCS to allow requesting train integrity status before an End of Mission thus updating the position of train tail and related track occupation. The train integrity reporting period is smaller than 5 seconds, therefore "status request" command is not necessary in general. Anyway, for more generality, the status request command was included inside the interface to provide more flexibility in case of longer reporting periods (e.g. due to power limitations in energy harvesting applications).

Odometry data are used by OTI Master in MONITORING high level functionality in case of wireless communication. In this case kinematic information about front cabin and train tail are used by train integrity criterion consisting in verifying coherent movement of train tail respect to front cabin, as explained at section 7 in D4.1 [1].

Train Length, Train Length Status and OTI-L status are used for different purposes:

- in INAUGURATION high level functionality as trigger event in case of train joining/splitting (refer to section 7 in D4.1 [1]);
- in MONITORING high level functionality for Product Class 2 with GNSS localization to compare measured train length, based on satellite technologies, respect to the input provided by train driver during data entry procedure;
- In MONITORING high level functionality to enable communication with ETCS after that OTI-L determined and provided to ETCS the train length.

Train Length Validity is provided by ETCS to OTI-I to manages the exception case of train length override (i.e. train driver changes, during the ERTMS/ETCS data entry procedure, the train length value provided by OTI-L).

Coupling/Uncoupling event generated in new generation trains after changing train composition is equivalent to START trigger event to reconfigure OTI system.

Cargo/Waggon Diagnostic Data refers to DIAGNOSIS high level functionality and represents optional information not related to on-board train integrity.

Additional description shall be reported inside the document to provide evidence about reasons for introducing start/reset commands, odometry data and train length.

The Table 7-2 contains the list of functional output provided by OTI Master.

For each "OUTPUT" a short reference to the related "Functionality" is reported in the table, the "Destination" is also specified (i.e. ETCS, TIU, Driver or WMC) and finally the "Type" of output is reported (i.e. VITAL or NON VITAL). In relation to Driver as destination, clarifications are reported at section 8.

Train Composition is acquired by trackside for diagnostic purposes or for comparison with train composition determined by OTI system in Product Class 3. In second case this input need to be vital.

OUTPUT	Functionality	Destination	Type
Identification Request	INAUGURATION Identification Phase	OTI Slave	VITAL
Master Pairing Request	INAUGURATION Pairing with OTI Slave at train tail	OTI Slave	VITAL
Train Integrity Request	MONITORING	OTI Slave	VITAL

OUTPUT	Functionality	Destination	Type
	OTI Slave status request		
Train Integrity Status	MONITORING Unknown, Confirmed or Lost	ETCS	VITAL
OTI-I status	DIAGNOSIS	ETCS / Driver	VITAL
Cargo/Waggon Diagnostic Data / Alarms	DIAGNOSIS Optional Cargo/Waggon diagnosis	WMC / Driver	NON VITAL

Table 7-2: OTI Master – Logical Interface – List of Output

Identification Request and **Master Pairing Request** refer to INAUGURATION high level functionality (as described in D4.1 [1]) to identify the OTI Slave located at train tail.

Train Integrity Request refers to MONITORING high level functionality.

Train Integrity Status refers to MONITORING high level functionality and provides to the ETCS the status of the train integrity with three possible values (i.e. Confirmed, Lost, and Unknown).

OTI-I status refers to DIAGNOSIS high level functionality and provides to ETCS the status of OTI-I sub-system status (i.e. OK or Fault).

Cargo/Waggon Diagnostic Data / Alarms refers to DIAGNOSIS high level functionality and are optional information not related to on-board train integrity.

See contribution to system level analysis reported in Appendix A in relation to L3 SoM and TIMS override.

7.2.2 Logical Interface OTI Slave

This section describes the logical interfaces (Input/Output) required and provided by OTI Slave module to implement the functionalities specified in D4.1 [1] . The Table 7-3 contains the list of functional input required by OTI Slave.

For each “INPUT” a short reference to the related “Functionality” is reported in the table, the “Source” is also specified (i.e. Tail Sensor or Diagnostic sensor) and finally the “Type” of input is reported (i.e. VITAL or NON VITAL).

INPUT	Functionality	Source	Type
Cabin Status	MASTERSHIP	TIU / ETCS	VITAL
Terminal Waggon	INAUGURATION OTI Slave Localization	TIU / Tail Sensor	VITAL
Start / Reset command	INAUGURATION	ETCS / Driver	VITAL
Identification Request	INAUGURATION Identification Phase	OTI Master	VITAL
Master Pairing Request	INAUGURATION Pairing Phase	OTI Master	VITAL
Status Request	MONITORING Train Integrity monitoring	OTI Master	VITAL
Odometry	MONITORING Train Integrity monitoring in wireless communication scenario.	ETCS / kinematic sensors	VITAL
Cargo/Waggon diagnostic data	DIAGNOSIS Cargo/Waggon diagnosis	Diagnostic sensors	NON VITAL

Table 7-3: OTI Slave – Logical Interface – List of Input

Cabin Status refers to MASTERSHIP high level functionality for role assignment (i.e. OTI MASTER or OTI SLAVE).

Terminal Waggon refers to INAUGURATION high level functionality and allows the OTI Slave to localise itself at train tail.

Start and **Reset** commands refer to INAUGURATION high level functionality to support train joining/splitting scenario.

Identification Request and **Master Pairing Request** refer to INAUGURATION high level functionality as described in D4.1 [1].

Status Request refers to MONITORING high level functionality.

Odometry data are used by OTI Slave in MONITORING high level functionality in case of wireless communication.

Cargo/Waggon diagnostic data refers to DIAGNOSIS high level functionality and are optional information not related to on-board train integrity.

The Table 7-4 contains the list of functional output provided by OTI Slave.

For each “OUTPUT” a short reference to the related “Functionality” is reported in the table, the “Destination” is also specified (i.e. OTI Master or WMC) and finally the “Type” of output is reported (i.e. VITAL or NON VITAL).

OUTPUT	Functionality	Destination	Type
OTI Slave Status	MONITORING Train Integrity monitoring	OTI Master	VITAL
Slave Identification	INAUGURATION Role of the OTI Slave (Tail or non-Tail)	OTI Master	VITAL
Slave Pairing Ack	INAUGURATION Pairing	OTI Master	VITAL
Cargo/Waggon Diagnostic Data	DIAGNOSIS Optional Cargo/Waggon diagnosis.	OTI Master	NON VITAL
Cargo/Waggon Diagnostic Data/Alarms	DIAGNOSIS Optional Cargo/Waggon diagnosis.	WMC	NON VITAL

Table 7-4: OTI Slave – Logical Interface – List of Output

OTI Slave Status refers to MONITORING high level functionality. This information, provided to OTI Master, is essential for Train Integrity monitoring. In Product Class 1 this information is limited to a liveliness message. In Product Class 2 this information includes train tail kinematic data.

OTI Slave Identification refers to INAUGURATION high level functionality and provides to the OTI Master the “role” of the OTI slave device (if it is located at the train tail or not).

Slave Pairing Ack refers to INAUGURATION high level functionality and allow to complete pairing procedure with OTI Master.

Cargo/Waggon Diagnostic Data and **Alarms** refer to DIAGNOSIS high level functionality and are optional information not related to on-board train integrity monitoring.

Note that train composition, optionally determined for OTI Product Class 3, is confirmed by the driver through OTI Dashboard.

7.2.3 Master – Slave Inauguration Phase

This section describes the “Inauguration” phase between the OTI Master and OTI Slave.

As reported in [1], the Inauguration phase consists of two steps:

a) Identification: this step consists of identifying the OTI modules connected to On-board Communication Network (OCN);
b) Pairing: during this step the OTI Master sends a pairing request to OTI module located at train tail;

The following Figure 7-3 reports the messages exchanged between OTI Master and OTI Slave during the Inauguration Phase (refer also to [1]) in nominal conditions (that’s no delay, no corruption introduced by the communication network):

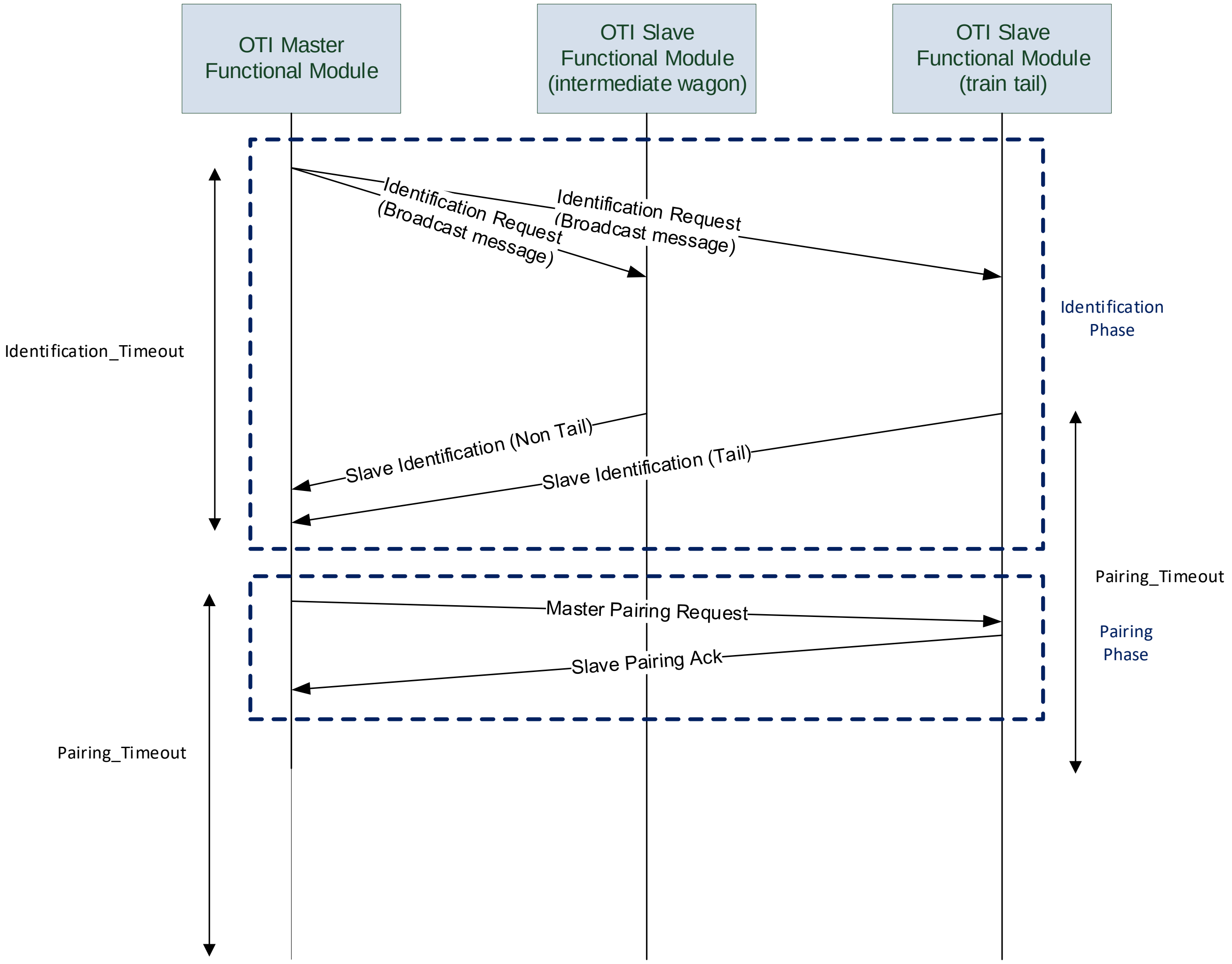

Figure 7-3: Inauguration Phase: messages exchanged between OTI Master and OTI Slave

The following Table 7-5 reports the messages exchanged during the Inauguration phase:

Message	Sender	Receiver	Description
Master Identification Request	OTI Master	All OTI Slave	Message sent by OTI Master in broadcast to all OTI Slave connected to the OCN
Slave Identification Ack	All OTI Slave	OTI Master	Message sent by all OTI Slave to OTI Master. This message includes the information of the OTI localisation (TAIL/Non TAIL)
Master Pairing Request	OTI Master	OTI Slave (Tail)	Pairing request sent by OTI Master only to OTI Slave TAIL
Slave Pairing Ack	OTI Slave (Tail)	OTI Master	Pairing Ack sent by OTI Slave TAIL to OTI Master

Table 7-5: List of messages exchanged during the Inauguration Phase

The following Table 7-6 explains the meaning of the two time-out reported in Figure 7-3:

Time-out	Description
Identification_Timeout	This timer is used by OTI Master. It is activated when the "Master Identification Request" message is sent. If this timer expires and the "Slave Identification Ack" message from OTI Slave TAIL is not received, then the OTI Master can resend the "Master Identification Request" message and re-start this timer. "Slave Identification Ack" message received after this time will be rejected by OTI Master.
Pairing_Timeout	This timer is used by OTI Master and OTI Slave. *OTI Master:* OTI Master activates this timer after sending the "Master Pairing Request" message. If the OTI Master does not receive the "Slave Pairing Ack" message before expiring this timer, it resends the "Master Identification Request" message. *OTI Slave:* The OTI Slave TAIL activates this timer after sending the "Slave Identification Ack" message. If the OTI Slave TAIL does not receive the "Master Pairing Request" message before expiring this timer, it won't accept anymore this message and it will wait for a new "Master Identification Request" message. (See the note reported after Figure 7-8. If an iteration mechanism is implemented also for the Pairing procedure, then this timer shall be restarted). In general different values for OTI Master and OTI Slave timeout can be used.

Table 7-6: Time-out used during the Inauguration phase

7.2.3.1 Examples of communication faults during the Inauguration phase

This section reports some examples of communication faults between OTI Master and OTI Slave during the Inauguration phase.

Example 1: Fault during the Identification procedure (Figure 7-4)

In this example, the OTI Master sends the “Master Identification Request” message but does not receive the “Slave Identification Ack” message from the OTI Slave TAIL or receives this message after the timer “Identification_Timeout” has expired.
Note: the OTI Master can send the “Master Identification Request” message a finite number of attempts or indefinitely. It is implementation issue.

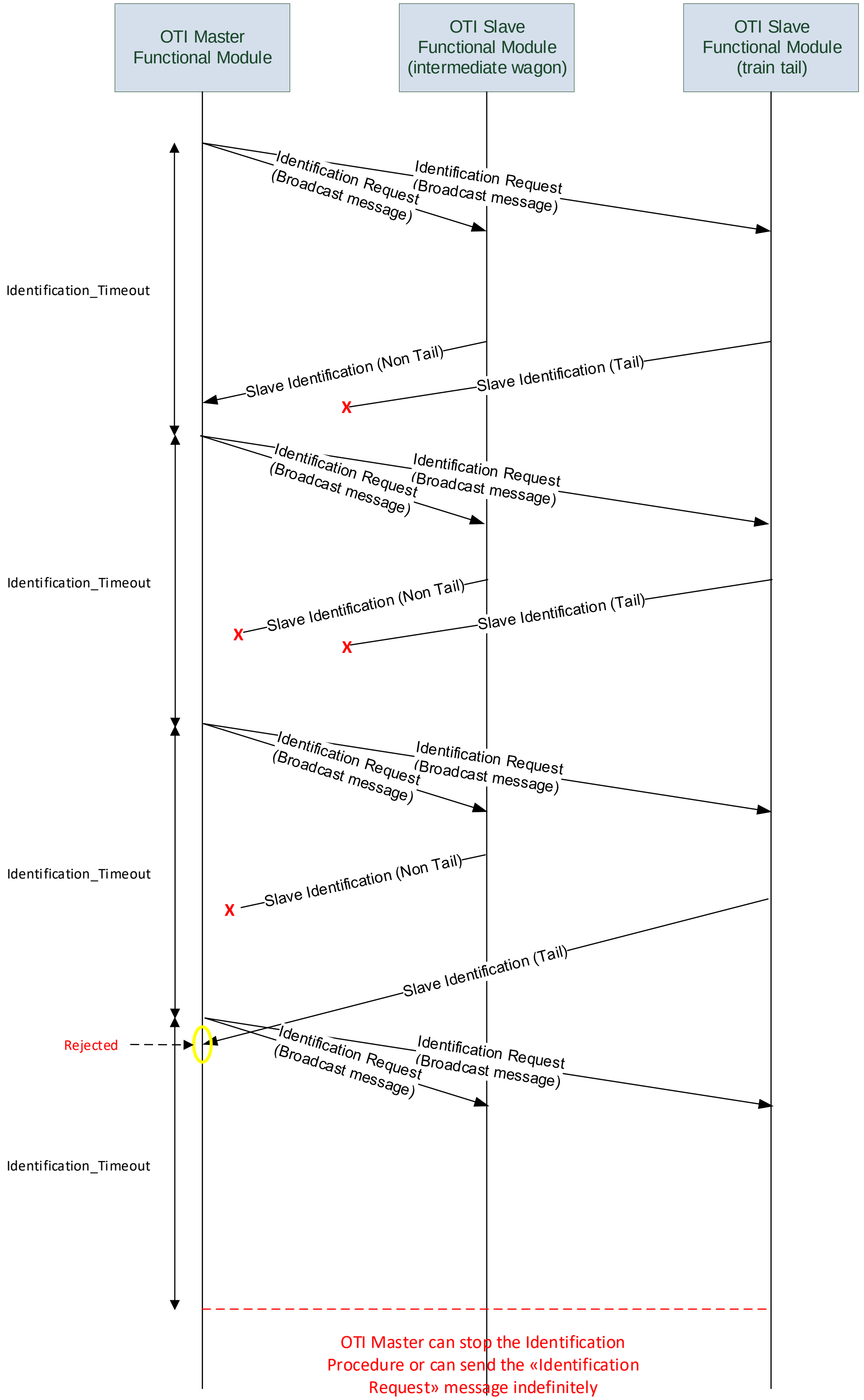

Figure 7-4: Example 1: Communication Fault during the Identification Procedure

Example 2: Fault during the Identification procedure (Figure 7-5)

In this example, the OTI Master sends the “Master Identification Request” message and receives two “Slave Identification Ack” messages from two OTI Slave with TAIL information (e.g. due to a fault of intermediate OTI Slave) before the timer “Identification_Timeout” has expired. In this case, the OTI Master sends again the “Master Identification Request” message.

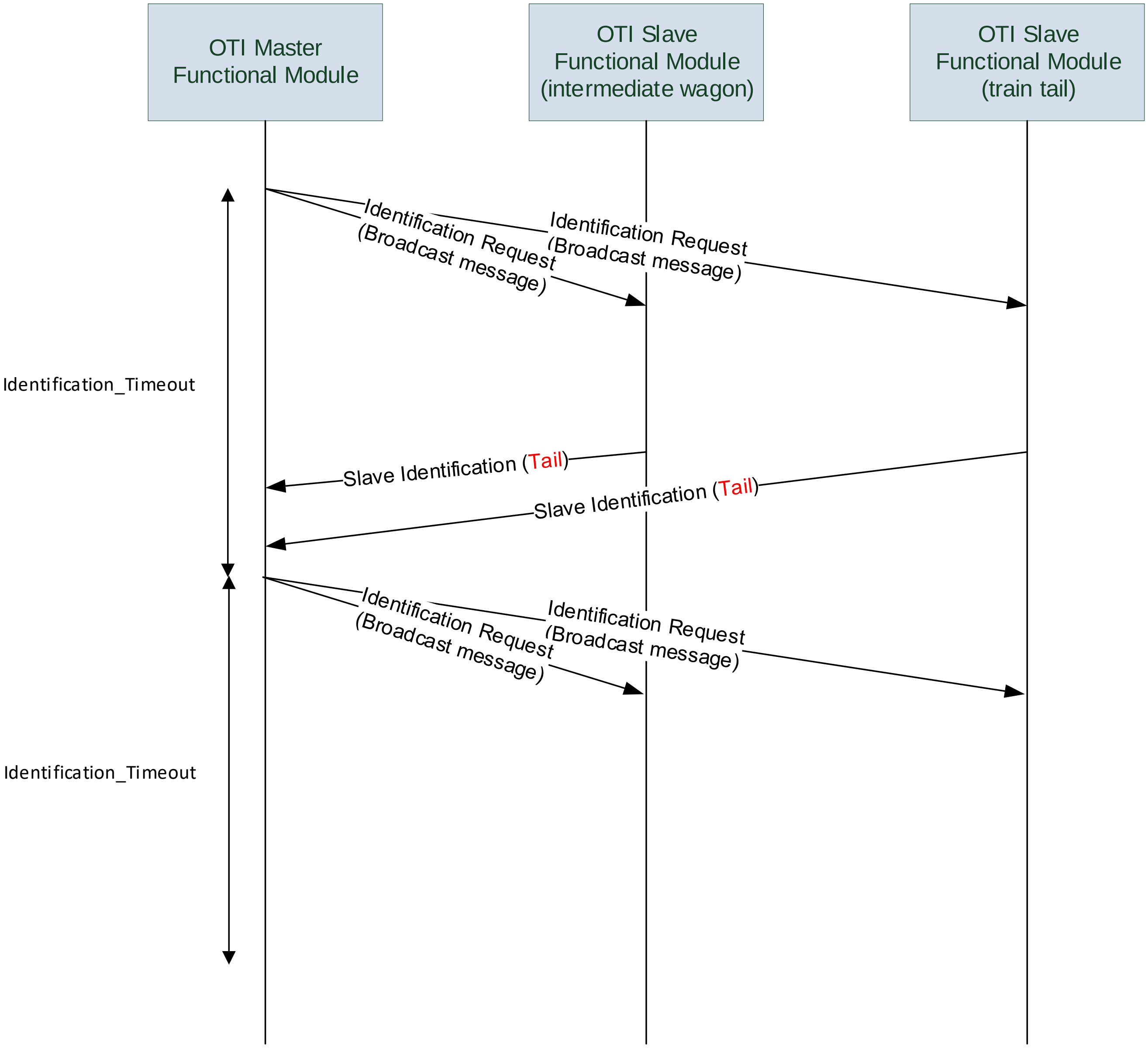

Figure 7-5: Example 2: Communication Fault during the Identification Procedure

Example 3: Fault during the Pairing procedure (Figure 7-6)

In this example, the OTI Master receives the “Slave Identification Ack” message sent by the OTI Slave TAIL and starts the Pairing procedure sending the “Master Pairing Request” message but the OTI Slave

TAIL does not receive it (or receives and rejects a corrupted message). If the “Pairing_Timeout” expires, the OTI Slave will wait for a new “Master Identification Request” message.

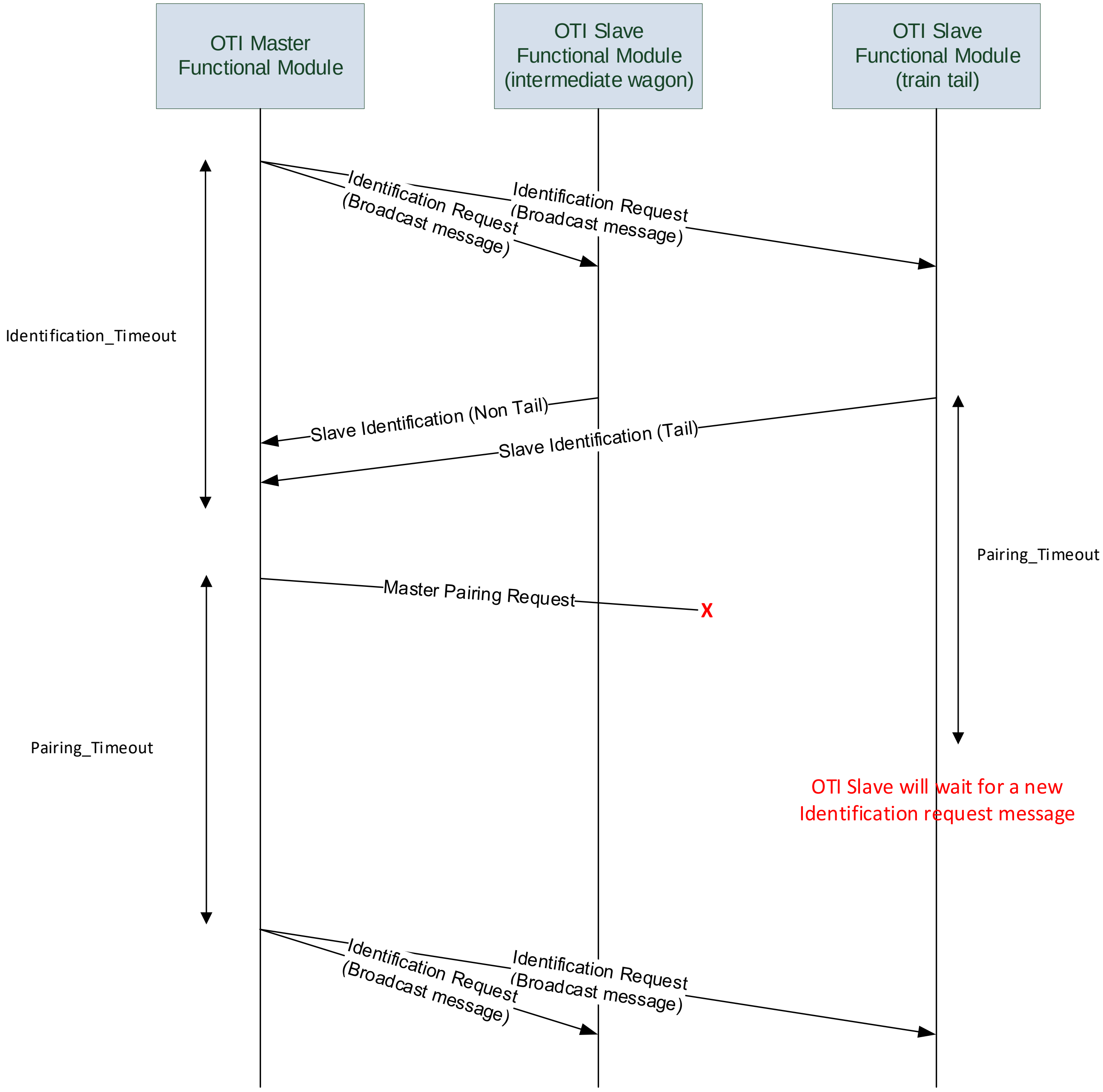

Figure 7-6: Example 3: Communication Fault during the Pairing Procedure

Example 4: Fault during the Pairing procedure (Figure 7-7)

In this example, the OTI Slave TAIL has received the “Master Pairing Request” message and has sent the “Slave Pairing Ack” message but this message is not received or is received corrupted by OTI Master. When the “Pairing_Timeout” expires, the OTI Master sends a new “Identification Request” message. Note: the OTI Slave will always accept a new “Master Identification Request” message.

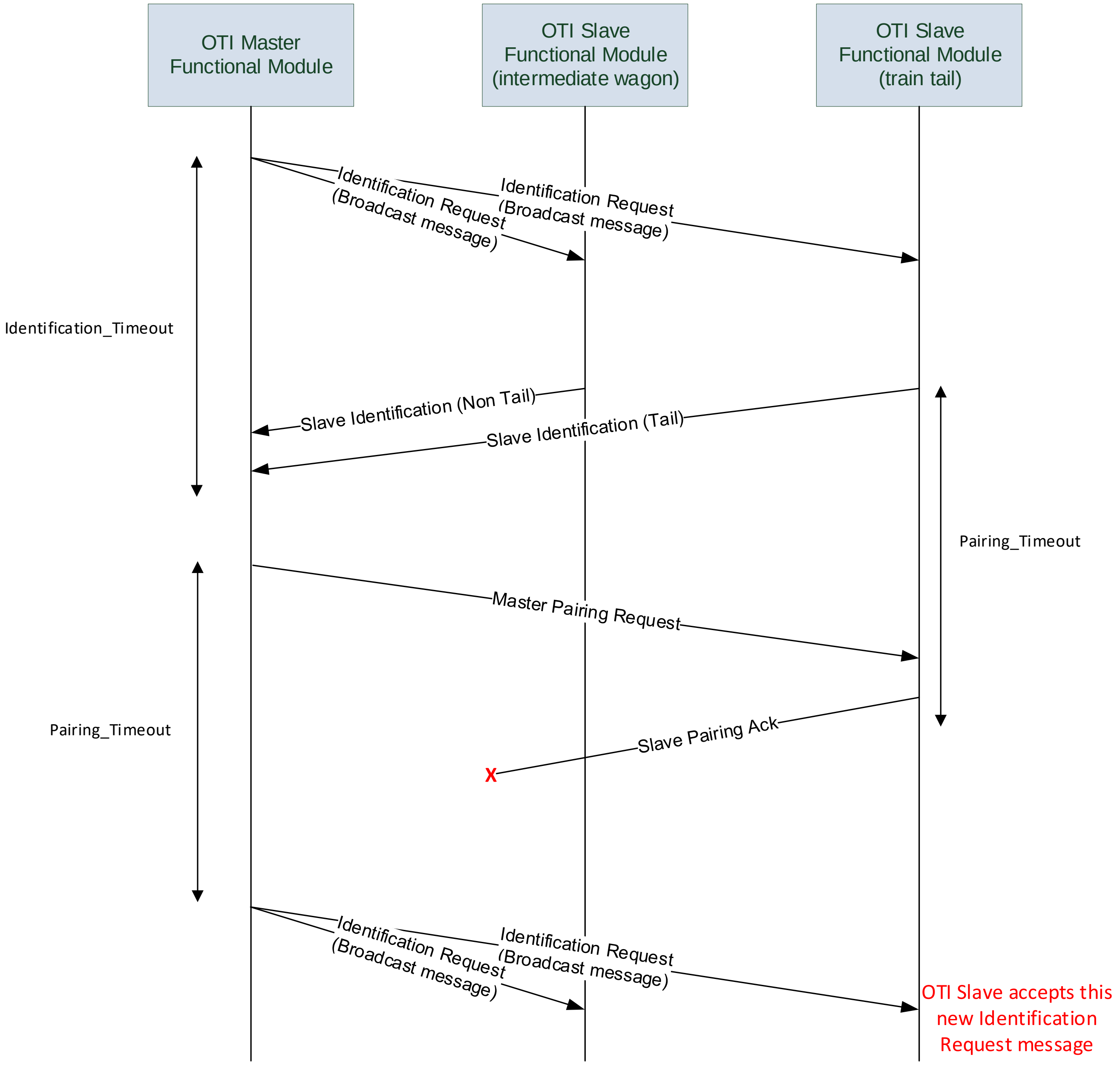

Figure 7-7: Example 4: Communication Fault during the Pairing Procedure

<u>Example 5: Fault during the Pairing procedure</u> (Figure 7-8)

In this example, the OTI Master receives the “Slave Identification Ack” message sent by the OTI Slave TAIL and starts the Pairing procedure sending the “Master Pairing Request” message but the OTI Slave TAIL receives it when the “Pairing_Timeout” is expired. The OTI Slave will wait for a new “Master Identification Request” message.

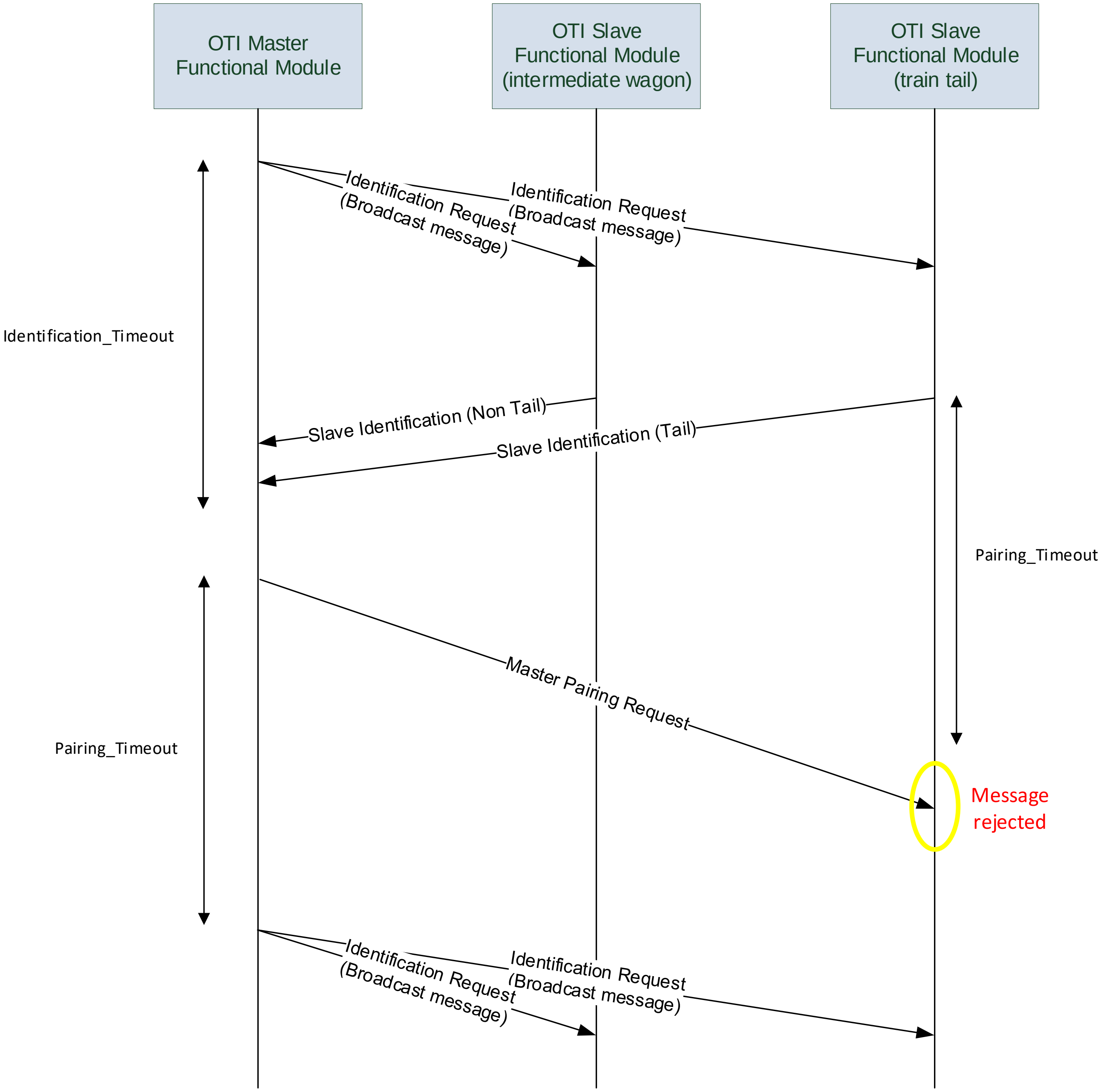

Figure 7-8: Example 5: Communication Fault during the Pairing Procedure

Note: an iteration mechanism for the Pairing procedure can be defined similarly to Identification procedure.

7.2.3.2 Inauguration phase with cellular communication networks

In case of wireless communication (e.g. cellular networks) that allows OTI master communication with OTI Slave in other trains, the identification request message sent in broadcast is no more applicable.

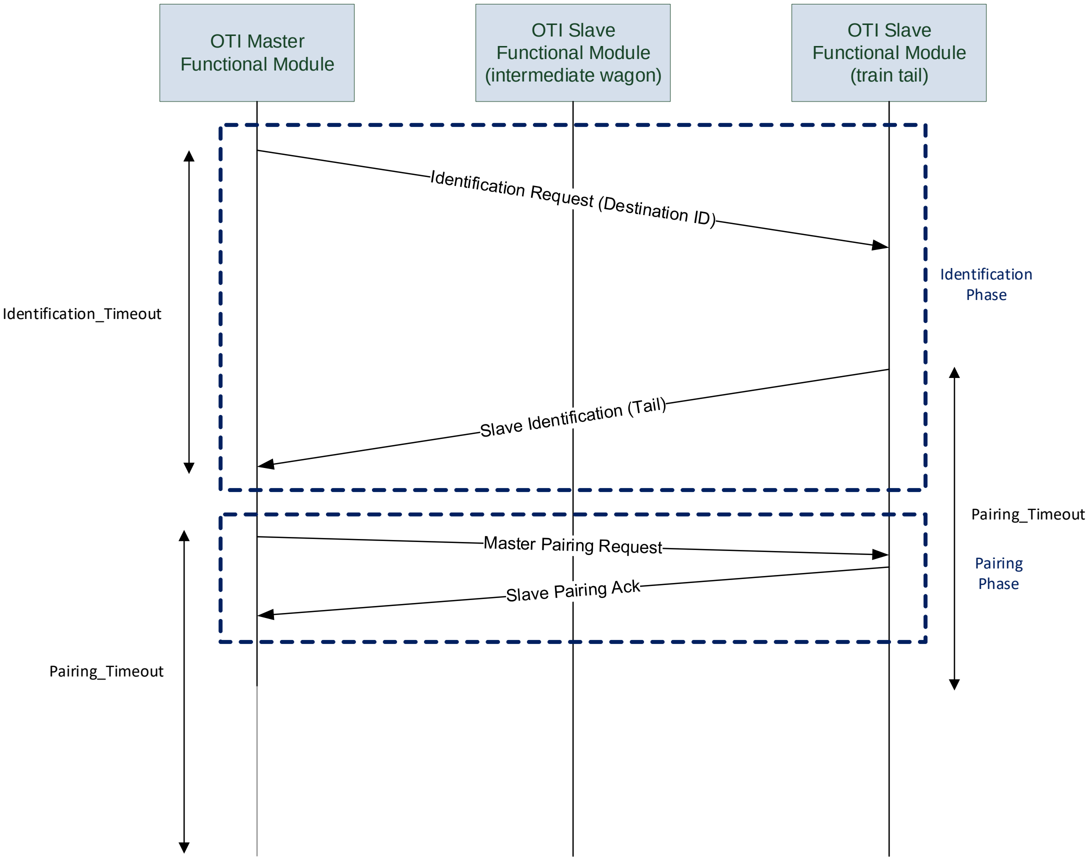

Figure 7-9: Example 6: Pairing Procedure in cellular communication networks

In this case OTI Master need to know in advance the identified of OTI Slave to be contacted for pairing. For fixed composition trains this information can be a configuration parameter, whereas for variable composition trains this information need to be provided by an external entity.

7.3 Logical Interfaces Train Length determination

This section described the logical inputs and logical outputs for OTI-L functionality as specified in D4.1 [1]. Train length determination basic principles includes the following aspects:

- Train length is determined before starting the mission
- Determined train length is provided to ETCS for validation within the ERTMS/ETCS data entry procedure
- Train integrity monitoring is activated after that train length has been determined.

Note that in general train driver can override, within ERTMS/ETCS data entry procedure, the train length provided by OTI-L to manage exceptions or special cases.

In general, logical interfaces are defined by including input and output data required for all possible product level solutions, including as example euro-balise detection for distance measurement. In general, train length determination at product level in addressed in D4.4 [45] and D4.6 [61].

INPUT	Functionality	Source	Type
Status Request	Train Length determination	ETCS for OTI enhanced interface	VITAL
Start/Reset command	OTI system configuration	Driver for OTI Basic Interface ETCS for OTI enhanced interface	VITAL
Coupling	OTI system configuration Train Length determination	TIU	VITAL
Euro-balise Identifier	Train Length determination	ETCS for OTI enhanced interface	VITAL
Odometry	Train Length determination	ETCS for OTI enhanced interface	VITAL

Table 7-7: OTI-L – Logical Interface – List of Inputs

Status Request command refers to ETCS requests for OTI-L status and determined train length.

Start and **Reset** commands refer to start and stop the train length determination in relation to train joining/splitting procedures. Reset command is also used by train driver or ETCS to reset OTI-L when train driver changes, within ERTMS/ETCS data entry procedure, the provided train length value.

Coupling input is acquired from the rolling stock and used as trigger event to recalculate the train length after a train joining/splitting procedure.

Euro-balise Identifier and **Odometry** are acquired from ETCS to determine optionally train length based on travelled distance between front cabin and train tail based on balise detection.

OUTPUT	Functionality	Destination	Type
OTI-L status	OTI-L sub-system status	ETCS / OTI-I	VITAL
Train Length Status	Train Length determination	ETCS / OTI-I	VITAL
Train Length	Train Length determination	ETCS / OTI-I	VITAL

Table 7-8: OTI-L– Logical Interface – List of Outputs

OTI-L status refers to OTI-L subsystem status.

Train Length Status refers to the status of train length determination (i.e. available, non-available).

Train Length refers to determined train length.

Note that OTI-I uses OTI-L status, train length status and train length for two reasons:

- Enabling the OTI-I communication to ETCS after that OTI-L has determined and provided train length to ETCS
- Optional use of train length in OTI Class 2 as input parameter for train integrity monitoring

Note that train composition, optionally determined for train length determination, is confirmed by the driver through OTI Dashboard.

7.4 Communication protocols

Several protocols are available for on-board communication and an analysis shall be performed respect to OTI communication requirements specified in D4.1 [1].

The general approach for safe communications consists in a non-vital part implementing lower protocol layers and a vital part implementing safety related layer. Figure 7-10: depicts approach reported in [5].

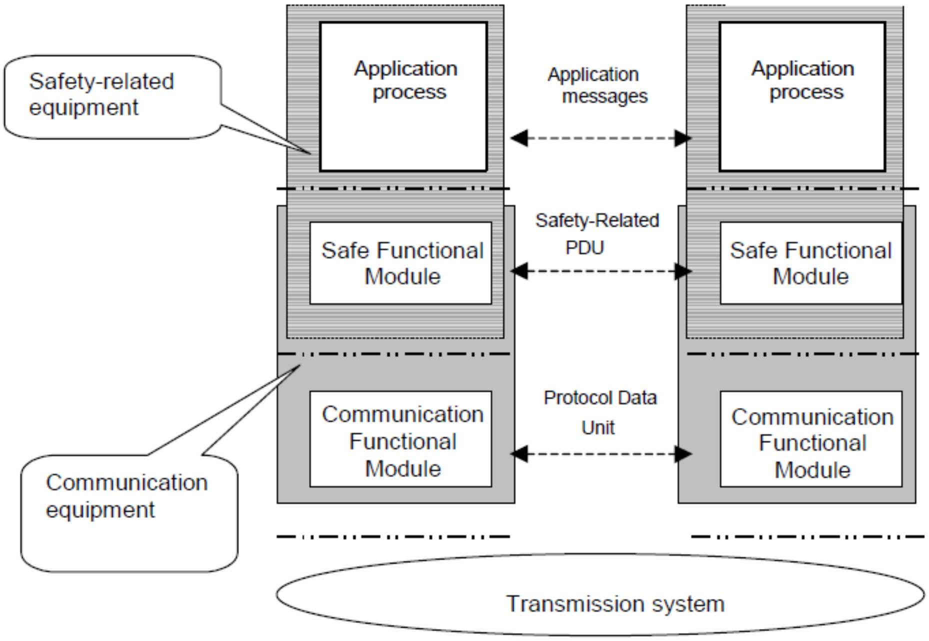

Figure 7-10: Protocol stack safety approach

In the following sections, the communication interface is analysed and described at application level, protocol level and physical level.

7.4.1 Application level

This section describes the applicative messages exchanged between ETCS and OTI Master for Enhanced Interface and the messages exchanged between OTI Master and OTI Slave.

In general the OTI device (master or slave), as described in D4.1 [1], shall also check the consistency of the messages received. Refer to §7.4.1.9 for more details.

Some fields introduced in the exchanged messages are necessary to provide protection against the communication threats described in [6]. Appendix D includes the threats/defences matrices as reported in [6].

Figure 7-11 depicts the information exchanged between OTI system and ETCS equipment.

As described in the FSM in D4.1 [1], the OTI-I module has three different phases:

- Master-ship
- Inauguration
- Monitoring

In “Mastership phase” the start command is used to determine the role (i.e. master or slave). In other phases the reset command is used to reconfigure OTI system (e.g. in case train compositions changes).

In “Inauguration phase”, there is no exchange of information. In “Monitoring phase” the Train Integrity information is provided to ETCS. In general, OTI device provides also its status to ETCS.

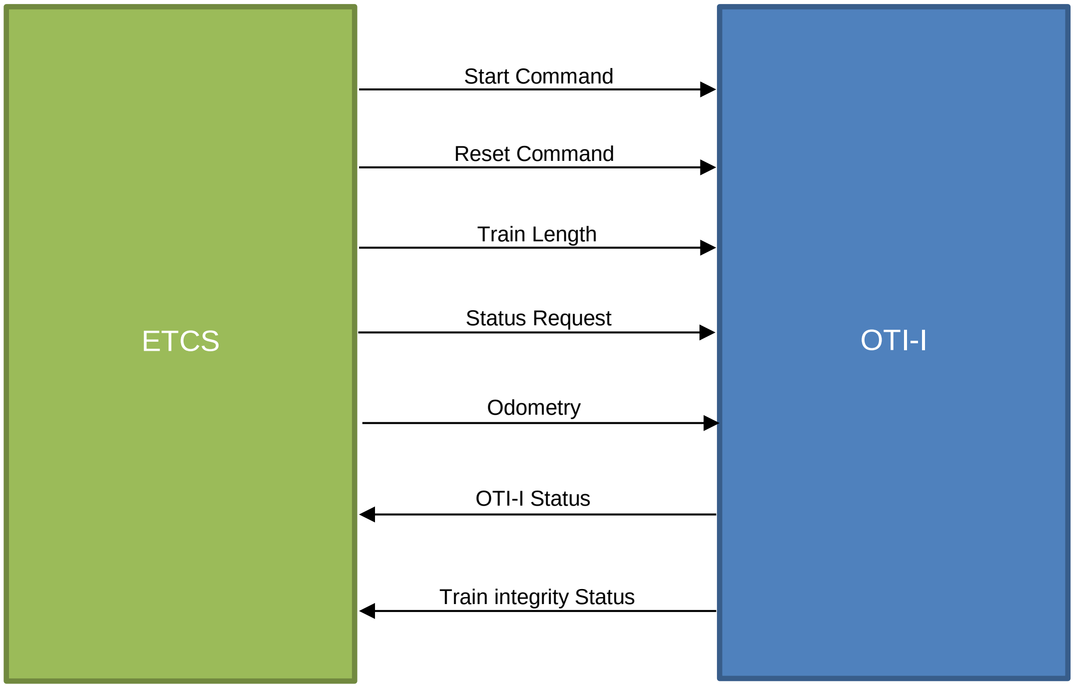

Figure 7-11: ETCS – OTI-I functional interface

Note that train length from ETCS to OTI has been originally introduced for OTI-I for two purposes:

- Trigger event to reconfigure OTI system for a new train composition (i.e. new train length entered by the train driver during ERTMS/ETCS data entry procedure)
- Optional input for Product Class 2 as train integrity monitoring criterion. In this case the attribute validity has been included in relation to train length validation during ERTMS/ETCS data entry procedure.

Information exchanged between ETCS and OTI-L include start and reset commands, odometry and euro-balise identifier are optionally used as input parameters for train length determination, determined train length and device status.

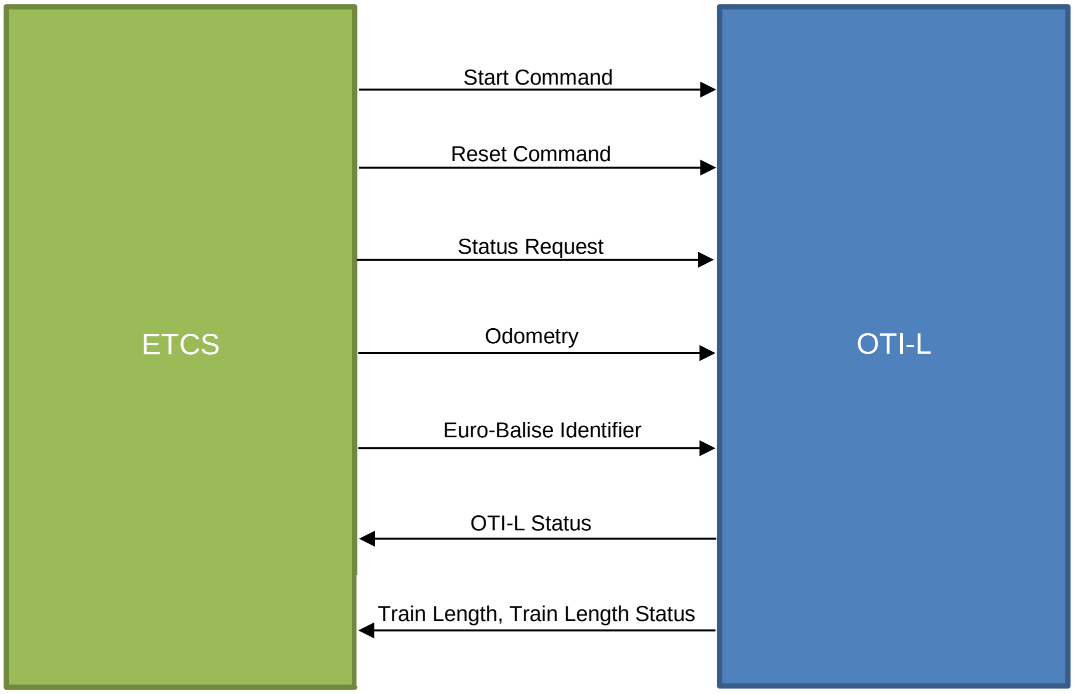

Figure 7-12: ETCS – OTI-L functional Interface

Figure 7-13 represents the information exchanged between OTI Master and OTI Slave.

During the “inauguration” phase the exchanges messages refers to identification request, pairing request and related answers. In “monitoring” phase the exchanges messages includes train integrity status, Slave status and optionally also cargo/waggon diagnostic data.

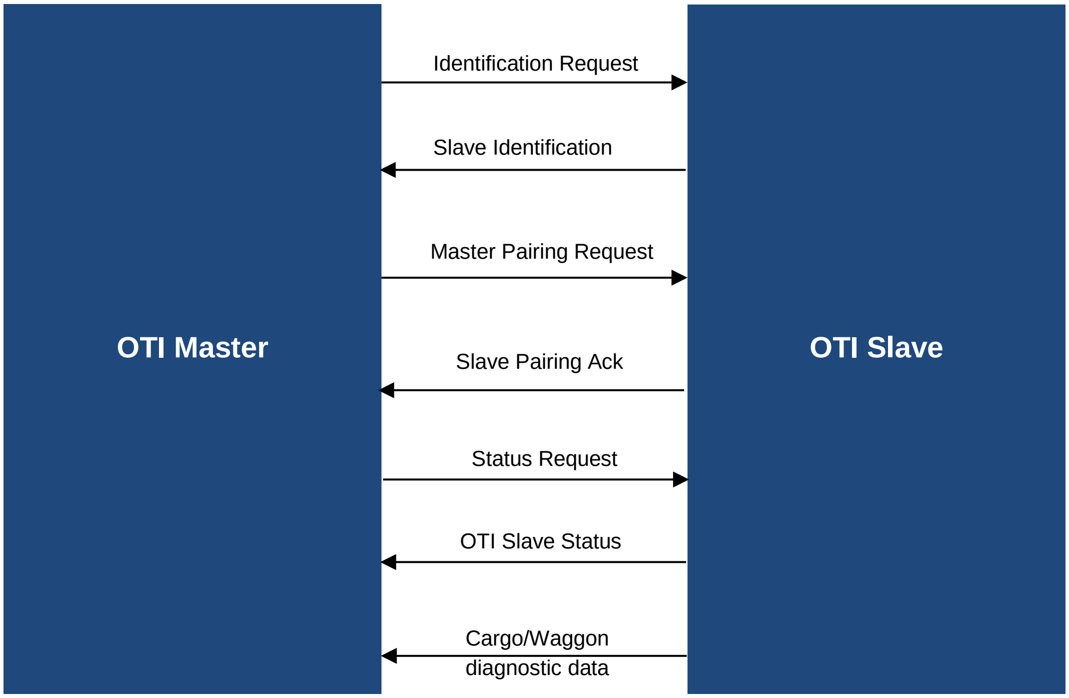

Figure 7-13: OTI Master - OTI Slave interface

7.4.1.1 List of application level messages

This section provides application level messages list related to ETCS, OTI-I and OTI-L communication and OTI Master-OTI Slave communication for train integrity and train length determination functionalities. Note that in Table 7-9 OTI Master and OTI Slave are referred to OTI-I functionality. In general OTI-I and OTI-L are independent function hosted within the same physical equipment. Each message structure is defined in subsequent sections.

Message description	Source	Destination	Identifier
ETCS message to OTI-I	ETCS	OTI-I	0x07
OTI-I message to ETCS	OTI-I	ETCS	0x08
ETCS message to OTI-L	ETCS	OTI-L	0x10
OTI-L message to ETCS / OTI-I	OTI-L	ETCS / OTI-I	0x09
Master Identification Request	OTI MASTER	OTI SLAVE	0x01

Master Pairing Request	OTI MASTER	OTI SLAVE	0x03
Master Status Request	OTI MASTER	OTI SLAVE	0x05
Slave Identification Ack	OTI SLAVE	OTI MASTER	0x02
Slave Pairing Ack	OTI SLAVE	OTI MASTER	0x04
Slave Status	OTI SLAVE	OTI MASTER	0x06
Balise Message	OTI SLAVE	OTI MASTER	0x12
Slave diagnostic message	OTI SLAVE	OTI MASTER	0x11

Table 7-9: List of application level messages

7.4.1.2 Messages between ETCS and OTI

The Interface between ETCS and OTI is bidirectional. Each exchanged message is described as following.

Note that same variables name of ETCS-RBC messages have been adopted also for OTI messages. Anyway there is no relation between OTI messages and ETCS-RBC messages.

7.4.1.2.1 Message from ETCS to OTI

Considering the I/O list defined in the § 7.2.1, an example of applicative message from ETCS to OTI-I is depicted in Table 7-10.

Field	Variable	Description	Size
1	***NID_MESSAGE***	Message Identification Number (ID = 0x07).	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. NID_ENGINE if the source is the ETCS)	48 bits
5	***ID_DESTINATION***	Identifier of the receiver of the message (e.g. identifier of the OTI Master module)	48 bits
6	***Time***	ETCS time	3 byte
7	***ETCS_Command***	Start/Reset/Status request commands	4 bits
8	***Train_Position***	Train position of front cabin	12 byte
9	***Train_Speed***	Train speed of front cabin	3 byte
10	***Train_Acceleration***	Train acceleration of front cabin	3 byte
12	***Train_MovDir***	Train movement direction of front cabin	2 bits
12	***Train_Length***	Optional input for OTI-I	12 bits

13	***Train_Length_validity***	Status of train length validation during ERTMS/ETCS data entry procedure in relation to override case (see note below)	2 bits
14	***SPARE***	Future use	4 byte
15	***CRC***	CRC calculation	6 byte
16	***Padding data***	Padding bits	10 bits

Table 7-10: "ETCS – OTI-I" message

Note: Validity is referred to the expectional case that train driver changes, during the ERTMS/ETCS data entry procedure, the train length provided by OTI-L.

Field	**Variable**	**Description**	**Size**
1	***NID_MESSAGE***	Message Identification Number (ID = 0x10).	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. NID_ENGINE if the source is the ETCS)	48 bits
5	***ID_DESTINATION***	Identifier of the receiver of the message (e.g. identifier of the OTI Master module)	48 bits
6	***Time***	ETCS time	3 byte
7	***ETCS_Command***	Start/Reset/Status request commands	4 bits
8	***Balise_Message***	Balise message	30 bits
9	***SPARE***	Future use	4 byte
10	***CRC***	CRC calculation	6 byte
11	***Padding data***	Padding bits	4 bits

Table 7-11: "ETCS – OTI-L" message

7.4.1.2.2 Message from OTI - ETCS

Applicative message from OTI-I to ETCS, considering the I/O list defined in the § 7.2.1, is reported in Table 7-12.

Field	**Variable**	**Description**	**Size**
1	***NID_MESSAGE***	Message Identification Number (ID = 0x08).	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bit
3	***SEQ_NUMBER***	Sequence Number of the message	32 bit
4	***ID_SOURCE***	Identifier of the source of the message (e.g. identifier of the OTI Master module)	48 bit
5	***ID_DESTINATION***	Identifier of the receiver of the message (e.g. identifier of the ETCS)	48 bit
6	***Time***	OTI device time	3 byte

7	***OTI-I_Status***	OTI-I sub-system status	4 byte
8	***OTI_Role***	Role of the OTI Device (Master/Slave)	2 bit
9	***Train_Integrity_Status***	Train Integrity status.	2 bit
10	***Train_Integrity_Latency***	Latency about *Train_Integrity_Status* information	1 byte
11	***SPARE***	Future use	4 byte
12	***CRC***	CRC calculation.	6 byte
13	***Padding data***	Padding bits	2 bit

Table 7-12: “OTI-I – ETCS” message

Note: when a confirmation of integrity (ETCS side) is received from OTI Master, this does not necessarily mean that the train is complete at the moment that the confirmation is received, but rather that the train was known to be complete at some time before the confirmation of integrity was received. This time will depend on the properties of both the OTI device and the interface. In general, Latency aspects need to be considered at system point of view to respect the safety level of Train Integrity monitoring function. This aspect is addressed at sections 7.4.1.4 and 7.4.1.5.

Communication between OTI-L and OTI-I shall comply with EN50159 [6].

Field	Variable	Description	Size
1	***NID_MESSAGE***	Message Identification Number (ID = 0x09).	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. identifier of the OTI-L module)	48 bits
5	***ID_DESTINATION***	Identifier of the receiver of the message (e.g. identifier of the ETCS)	48 bits
6	***Time***	OTI device time	3 byte
7	***OTI-L_Status***	OTI-L sub-system status	3 byte
8	***Train_Length_status***	Status for train length information	2 bits
9	***Train_Length***	Train length	12 bits
10	***SPARE***	Future use	4 byte
11	***CRC***	CRC calculation.	6 byte
12	***Padding data***	Padding bits	0 bits

Table 7-13: “OTI-L – ETCS” message

Note that the message reported in Table 7-13 is also provided from OTI-L to OTI-I.

7.4.1.3 Messages between OTI devices

The interface between OTI-M and OTI-S, during the “Inauguration” phase, has the scope to identify the OTI modules connected to On-board Communication Network (OCN) and to pair OTI Master in front cabin and OTI slave at train tail.

While during the “Monitoring” phase, implements a master-slave communication protocol aimed at exchanging liveliness messages, status messages and diagnostic messages. The Identified approach consists in adopting a master slave communication with OTI Slave generating messages only as answer to explicit requests from OTI Master. Note that assigning liveliness and time management to lower layer of protocol stack introduced relevant constrains to protocol stack and to on-board communication network.

7.4.1.3.1 Message OTI Master - OTI Slave “Inauguration Phase”

Considering the Table 7-14 and Table 7-15 here are shown typical examples of the messages sent by OTI-M to OTI-S during the Inauguration phase:

Master Identification Request

Field	Variable	Description	Size
1	***NID_MESSAGE***	Message Identification Number (ID = 0x01)	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. identifier of the OTI Master module)	48 bits
5	***ID_DESTINATION***	Identifier of the receiver of the message (e.g. identifier of the OTI Slave module)	48 bits
6	***OTI_Role***	Role of the OTI Device (Master/Slave)	2 bits
7	***SPARE***	Future use	4 bytes
8	***CRC***	CRC calculation.	6 bytes
9	***Padding data***	Padding bits	4 bits

Table 7-14: “OTI Master - OTI Slave” message in Inauguration phase - Identification Request

Master Pairing Request

Field	Variable	Description	Size
1	***NID_MESSAGE***	Message Identification Number (ID = 0x03)	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. identifier of the OTI Master module)	48 bits
5	***ID_DESTINATION***	Identifier of the receiver of the message (e.g. identifier of the OTI Slave module)	48 bits
6	***OTI_Role***	Role of the OTI Device (Master/Slave)	2 bits
7	***SPARE***	Future use	4 bytes
8	***CRC***	CRC calculation.	6 bytes
9	***Padding data***	Padding bits	4 bits

Table 7-15: “OTI Master - OTI Slave” message in Inauguration phase - Pairing Request

7.4.1.3.2 Message OTI Master - OTI Slave “Monitoring Phase”

Considering the I/O list defined in the §7.2.2, the applicative message from OTI-M to OTI-S is reported in Table 7-16.

Master Status Request

Field	Variable	Description	Size
1	***NID_MESSAGE***	Message Identification Number (ID = 0x05).	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. identifier of the OTI Master module)	48 bits
5	***ID_DESTINATION***	Identifier of the source of the message (e.g. identifier of the OTI Slave module)	48 bits
6	***OTI_Role***	Role of the OTI Device (Master/Slave)	2 bits
7	***SPARE***	Future use	4 bytes
8	***CRC***	CRC calculation	6 bytes
9	***Padding data***	Padding bits	4 bits

Table 7-16: “OTI Master - OTI Slave” message in Monitoring phase

7.4.1.3.3 Message OTI Slave - OTI Master “Inauguration Phase”

Considering the Figure 7-13 here are shown typical examples of the messages exchanged sent by OTI-S to OTI-M during the Inauguration phase:

Slave Identification Ack

Field	Variable	Description	Size
1	***NID_MESSAGE***	Message Identification Number (ID = 0x02)	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. identifier of the OTI Slave module)	48 bits
5	***ID_DESTINATION***	Identifier of the receiver of the message (e.g. identifier of the OTI Master module)	48 bits
6	***OTI_Role***	Role of the OTI Device (Master/Slave)	2 bits
7	***OTI_Position***	Information about OTI Slave device (Tail, Non Tail)	2 bits
8	***SPARE***	Future use	4 bytes
9	***CRC***	CRC calculation.	6 bytes
10	***Padding data***	Padding bits	2 bits

Table 7-17: “OTI Slave - OTI Master” message in Inauguration phase – Slave Identification

Slave Pairing Ack

Field	Variable	Description	Size
1	***NID_MESSAGE***	Message Identification Number (ID = 0x04)	1 byte

2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. identifier of the OTI Slave module)	48 bits
5	***ID_DESTINATION***	Identifier of the receiver of the message (e.g. identifier of the OTI Master module)	48 bits
6	***OTI_Role***	Role of the OTI Device (Master/Slave)	2 bits
7	***OTI_Position***	Information about OTI Slave device (Tail, Non Tail)	2 bits
8	***SPARE***	Future use	4 bytes
9	***CRC***	CRC calculation	6 bytes
10	***Padding data***	Padding bits	2 bits

Table 7-18: "OTI Slave - OTI Master" message in Inauguration phase – Slave Pairing Ack

7.4.1.3.4 Message OTI Slave - OTI Master "Monitoring Phase"

An example of applicative message from OTI-S to OTI-M, considering the I/O list defined in the §7.2.2, is reported in Table 7-19.

Slave Status

Field	Variable	Description	Size
1	***NID_MESSAGE***	Message Identification Number (ID = 0x06).	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. identifier of the OTI Slave module)	48 bits
5	***ID_DESTINATION***	Identifier of the receiver of the message (e.g. identifier of the OTI Master module)	48 bits
6	***Time***	OTI device time	3 byte
7	***OTI_Role***	Role of the OTI Device (Master/Slave)	2 bits
8	***OTI_Position***	Information about OTI Slave device (Tail, Non Tail or unknown)	2 bits
9	***OTI_Device_Status***	Information about the OTI Device	4 bytes
10	***Train_Position***	Train tail position	12 byte
11	***Train_Speed***	Train tail speed	3 byte
12	***Tran_Accelerarion***	Train tail acceleration	3 byte
13	***Train_MovDir***	Train tail movement direction	2 bits
14	***Train_Slide_Slip***	Attribute for odometry data from wheel sensors	2 bits
15	***Satellite localization based information***	Satellite localization information	20 bytes
16	***SPARE***	Future use	4 bytes
17	***CRC***	CRC calculation	6 bytes
18	***Padding data***	Padding bits	6 bits

Table 7-19: "OTI Slave - OTI Master" message

Note that satellite localization is a generic field defined to host GNSS information for those products based on it.

7.4.1.3.5 Message OTI Slave - OTI Master “Balise Message Request”

The message reported in Table 7-20 includes the balise message request from OTI Master to OTI Slave. The balise message is provided to OTI Slave by ETCS located in non-active cabin. This information is used by OTI Master for train length determination.

Field	Variable	Description	Size
1	***NID_MESSAGE***	Message Identification Number (ID = 0x13).	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. identifier of the OTI Master module)	48 bits
5	***ID_DESTINATION***	Identifier of the source of the message (e.g. identifier of the OTI Slave module)	48 bits
6	***OTI_Role***	Role of the OTI Device (Master/Slave)	2 bits
7	***SPARE***	Future use	4 bytes
8	***CRC***	CRC calculation	6 bytes
9	***Padding data***	Padding bits	4 bits

Table 7-20: “OTI Master - OTI Slave” balise message request

7.4.1.3.6 Message OTI Slave - OTI Master “Balise Message”

The message reported in Table 7-21 includes the balise message that OTI Slave receives from ETCS at train tail. This information is used by OTI Master for train length determination.

Field	Variable	Description	Size
1	***NID_MESSAGE***	Message Identification Number (ID = 0x12).	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. identifier of the OTI Slave module)	48 bits
5	***ID_DESTINATION***	Identifier of the receiver of the message (e.g. identifier of the OTI Master module)	48 bits
6	***Time***	OTI device time	3 byte
7	***OTI_Role***	Role of the OTI Device (Master/Slave)	2 bits
8	***OTI_Position***	Information about OTI Slave device (Tail, Non Tail or unknown)	2 bits
9	***Balise_Message***	Balise message	30 bits
10	***SPARE***	Future use	4 bytes
11	***CRC***	CRC calculation	6 bytes
12	***Padding data***	Padding bits	4 bits

Table 7-21: “OTI Slave - OTI Master” balise message

7.4.1.3.7 (Optional) Diagnostic Message OTI Slave - OTI Master

An example of diagnostic message from OTI Slave to OTI Master, considering the I/O list defined in the §7.2.2, is reported in Table 7-22.

Note that proposed size for cargo/waggon diagnostic data is to be defined after detail definition of technological solutions in D4.4 [45].

Slave_Diagnostic_Message

Field	Variable	Description	Size
1	***NID_MESSAGE***	Message Identification Number (ID = 0x11).	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. identifier of the OTI Slave module)	48 bits
5	***ID_DESTINATION***	Identifier of the receiver of the message (e.g. identifier of the OTI Master module)	48 bits
6	***Time***	OTI device time	3 bytes
7	***OTI_Role***	Role of the OTI Device (Master/Slave)	2 bits
8	***OTI_Position***	Information about OTI Slave device (Tail, Non Tail or unknown)	2 bits
9	***OTI_Device_Status***	Information about the OTI Device	4 bytes
10	***Cargo/Waggon info***	Cargo/Waggon diagnostic information	28 bytes (TBC)
11	***SPARE***	Future use	4 bytes
12	***CRC***	CRC calculation	6 bytes
13	***Padding data***	Padding bits	2 bits

Table 7-22: Diagnostic Message OTI Slave - OTI Master

7.4.1.4 Latency in ETCS-OTI communication

This section contains general evaluation of ETCS-OTI communication latency and train integrity information freshness.

Figure 7-14 depicts a communication example with OTI Master generating periodic train integrity messages to ETCS with period T_OTIM_COMM. In this case the time integrity confirmation received by ETCS at T_3 refers to an information acquired in T_2. In this case, the general worst-case communication latency can be considered as composed of T_OTIM_COMM period and ETCS-OTI communication latency:

WORST_CASE_LATENCY = T_OTIM_COMM + ETCS-OTI communication latency

The first part (i.e. T_OTIM_COMM) is fixed and known in advance, whereas the second part can be variable and depends on the specific communication link adopted.

An option to evaluate the ETCS-OTI communication latency consists in using time-stamp in train integrity messages, however this imply a safe clocks synchronization procedure between ETCS and OTI.

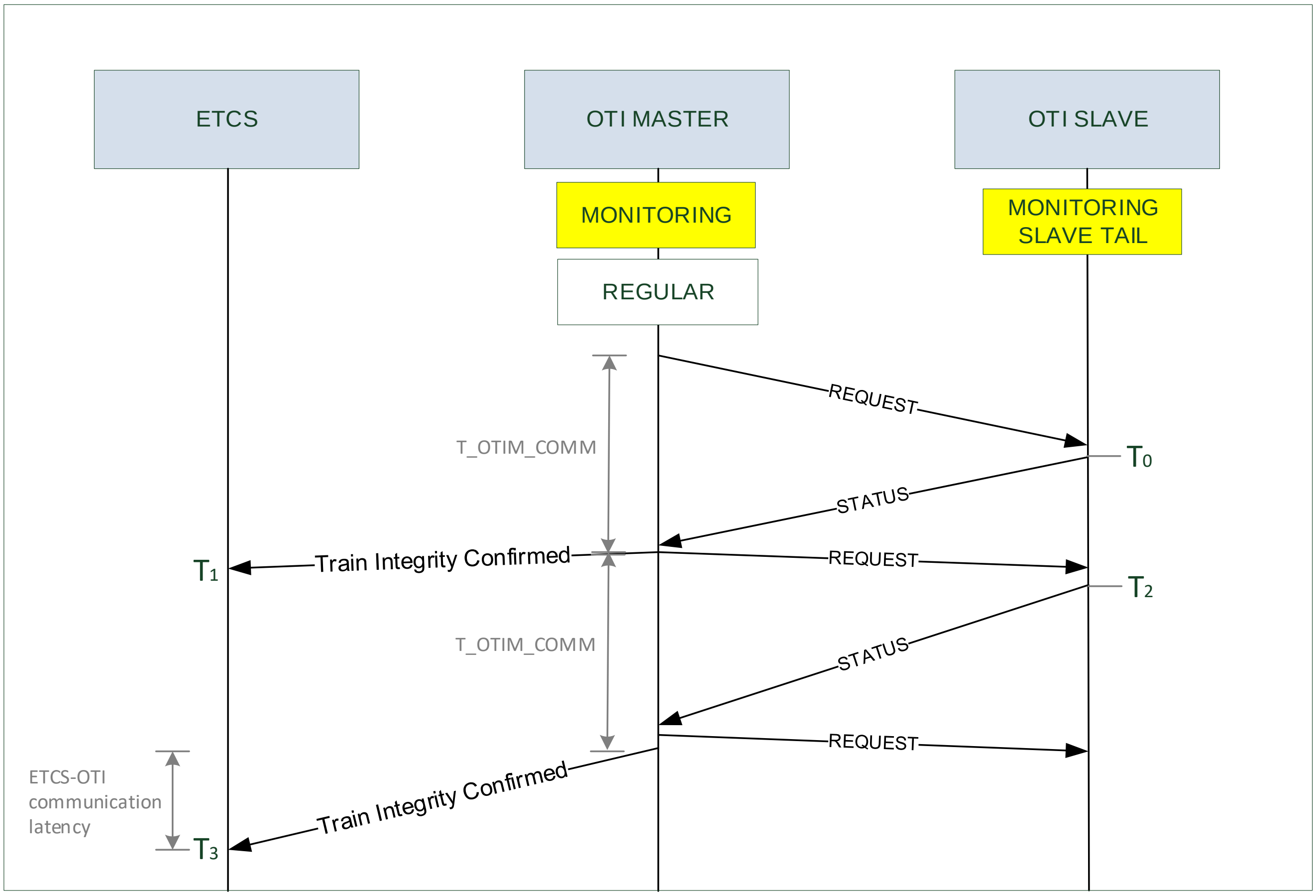

Figure 7-14: Communication latency in ETCS-OTI interface – Example 1

Figure 7-15 depicts a communication example with ETCS generating periodic requests to OTI Master with period T_ETCS_COMM.

In this case, the time integrity confirmation received by ETCS at T_4 refer to an information acquired in T_0. In this case, the general worst case communication latency can be considered as composed of T_OTIM_COMM period and T_ETCS_COMM period:

WORST_CASE_LATENCY = T_OTIM_COMM + T_ETCS_COMM

In this case, no time stamp is needed inside train integrity messages and no safe clock synchronization procedure is required.

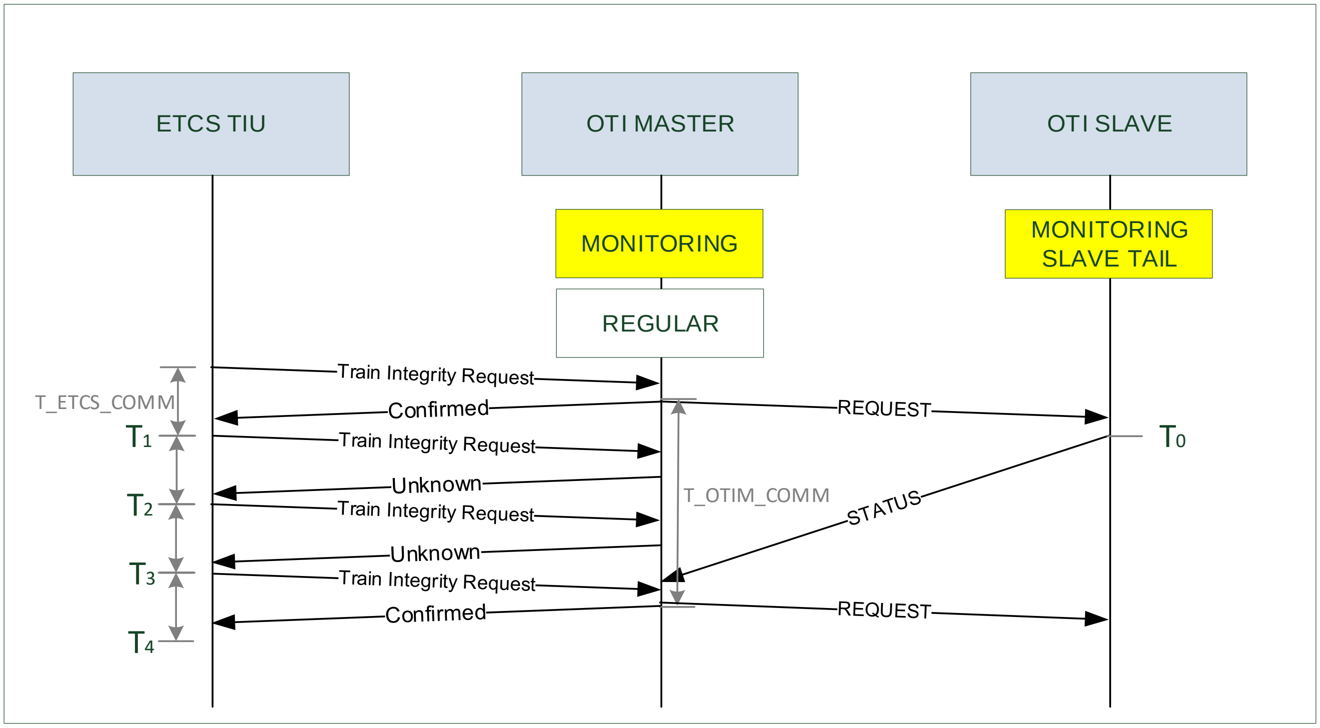

Figure 7-15: Communication latency in ETCS-OTI interface - Example 2

In general, the WORST_CASE_LATENCY should be considered by ETCS when a train integrity information is received. The acceptable values of the WORST_CASE_LATENCY range from 1 to 5 seconds. More in general also the train integrity detection time of OTI device should be taken into account by ETCS.

7.4.1.5 Latency in train integrity information

CR940 [4] specifies how ETCS calculates safe train length, based on last received train integrity confirmation, and how this information is provided to RBC within the Position Report message together with train integrity status. As long as train integrity is unknown, the position of train tail position remains at the location of last received train integrity confirmation.

In general, to calculate the safe train length defined in CR940 [4], ETCS need to keep into account also the latency of train integrity confirmation. This latency is intended as the time elapsed between the train integrity confirmation detection at train tail and its delivery to ETCS.

Possible options to manage the latency of train integrity confirmation are reported in the following:

1) The Train Integrity system provides a timestamp with train integrity information sent to the EVC. Note that this would change the nature of the interface.

Option A) Timestamp in OTI messages.

- ➢ Cons: This requires clocks synchronization mechanism among ETCS, OTI-Master, OTI Slave with additional exchange of messages.
- ➢ Pro: ETCS knows the time of each confirmation event thus maximizing performances and therefore line capacity.

Option B) Additional parameter in OTI-ETCS message related to information latency.

- ➢ Pro: no clocks synchronization required between ETCS and OTI.
- ➢ Pro: ETCS knows the latency of each confirmation event thus ensuring good performances in terms of line capacity.

2) ETCS makes a global allowance for the latency of train integrity information, for example 5 seconds. This would unnecessarily reduce performance on a railway where trains with a wired solution for train integrity are used.

- ➢ Pro: No changes to the nature of ETCS-OTI interface as defined in Subset-034.
- ➢ Cons: This would unnecessarily reduce performance on a railway where trains with a wired solution for train integrity are used.

3) Each EVC is configured with a value for train integrity latency, which is therefore train-specific.

- ➢ Pro: No changes to the nature of ETCS-OTI interface as defined in Subset-034.
- ➢ Pro: No performances reductions.
- ➢ Cons: This would require additional safety assessment for each on-board specific application.

Based on currently identified options and in relation to pro and cons, the outcome of the analysis is that:

- In terms of ETCS backward compatible interface, the options 3 appears as the most appropriate to ensure best performances in terms of line capacity.
- As non-ETCS backward compatible interface, the options 1-B ensures good performances in terms of line capacity with limited impact at ETCS level.

7.4.1.6 Definition of variables of applicative messages

This section describes the variables used in applicative messages defined in previous sections. In general, the guidelines for defining variable’s structure are derived from Subset 026 [2].

7.4.1.6.1 BALISE_MESSAGE

Name	Balise Message		
Description	Identifier of last balise		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
30 bits			
10 bits – NID_C	0	1023	Numbers
14 bits - NID_BG	0	16382	Numbers
3 bits - N_PIG	0	7	Numbers
3 bits - N_TOTAL	0	7	Numbers

7.4.1.6.2 ETCS_COMMAND

Name	ETCS Command		
Description	ETCS commands to OTI device		
Length of variable	**Minimum Value**	**Maximum Value**	**Resolution/formula**
4 bit			
Special/Reserved Values	0	No command	
	1	Start command	
	2	Reset command	
	3	Status request	
	4÷15	Invalid	

7.4.1.6.3 ID_DESTINATION

Name	Destination Identification		
Description	Identification of the destination of the message		
Length of variable	**Minimum Value**	**Maximum Value**	**Resolution/formula**
48 bits	1	2^{48} - 1	Integers
Special/Reserved Values	0	Used for broadcast message	

7.4.1.6.4 ID_SOURCE

Name	Source Identification		
Description	Identification of the source of the message		
Length of variable	**Minimum Value**	**Maximum Value**	**Resolution/formula**
48 bits	1	2^{48} - 1	Integers

7.4.1.6.5 L_MESSAGE

Name	Message length		
Description	L_MESSAGE indicates the length of the message in bytes, including all fields defined in the message.		
Length of variable	**Minimum Value**	**Maximum Value**	**Resolution/formula**
10 bits	0	1023	1 Byte

7.4.1.6.6 NID_MESSAGE

Name	Message identifier		
Description	Message identifier. Regards defined values of NID_MESSAGE		
Length of variable	**Minimum Value**	**Maximum Value**	**Resolution/formula**

8 bits	0	255	Numbers
Special/Reserved Values	0x01	Master Identification Request [From Master to Slave]	
	0x03	Master Pairing Request [From Master to Slave TAIL]	
	0x05	Train Integrity Request [From Master to Slave]	
	0x02	Slave Identification Ack [From Slave to Master]	
	0x04	Slave Pairing Ack [From Slave TAIL to Master]	
	0x06	OTI Slave Status [From Slave TAIL to Master]	
	0x07	ETCS Status Request [From ETCS to Master]	
	0x08	Train Integrity Message [From OTI Master to ETCS]	
	0x09	ETCS Ready for separation [see Appendix B]	
	0x10	ETCS Separation Confirmed [see Appendix B]	
	0x11	Diagnostic Message [From OTI Slave to OTI Master]	

7.4.1.6.7 OTI-I_Status

<table>
<tr><td><i>Name</i></td><td colspan="3">Status of OTI-I sub-system</td></tr>
<tr><td><i>Description</i></td><td colspan="3">Include information about the OTI-I device, e.g. OTI-I status, OTI-I FSM Status (i.e. Mastership, Inauguration, Monitoring), OTI sub-state, Energy Harvesting information, Wireless Interface information.
This field has the following structure:<table>
<tr><th>Byte</th><th>Bit 7</th><th>Bit 6</th><th>Bit 5</th><th>Bit 4</th><th>Bit 3</th><th>Bit 2</th><th>Bit 1</th><th>Bit 0</th></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table></td></tr>
<tr><td><i>Length of variable</i></td><td><i>Minimum Value</i></td><td><i>Maximum Value</i></td><td><i>Resolution/formula</i></td></tr>
<tr><td>4 bytes</td><td></td><td></td><td></td></tr>
<tr><td><i>Special/Reserved Values</i></td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="3">Byte 1<table>
<tr><td>Bit 7</td><td rowspan="4">OTI State</td></tr>
<tr><td>Bit 6</td></tr>
<tr><td>Bit 5</td></tr>
<tr><td>Bit 4</td></tr>
<tr><td>Bit 3,2,1,0</td><td>Spare</td></tr>
</table></td><td>0000xxxx</td><td colspan="2">OTI State - Mastership</td></tr>
<tr><td>0001xxxx</td><td colspan="2">OTI State – Inauguration</td></tr>
<tr><td>0010xxxx</td><td colspan="2">OTI State – Monitoring</td></tr>
<tr><td rowspan="8">Byte 2<table>
<tr><td>Bit 7</td><td rowspan="7">OTI sub-state</td></tr>
<tr><td>Bit 6</td></tr>
<tr><td>Bit 5</td></tr>
<tr><td>Bit 4</td></tr>
<tr><td>Bit 3</td></tr>
<tr><td>Bit 2</td></tr>
<tr><td>Bit 1</td></tr>
</table></td><td>0000000x</td><td colspan="2">Mastership substate - SLAVE</td></tr>
<tr><td>0000001x</td><td colspan="2">Mastership substate – MASTER</td></tr>
<tr><td>0000010x</td><td colspan="2">Inauguration substate – IDENTIFICATION</td></tr>
<tr><td>0000011x</td><td colspan="2">Inauguration substate – PAIRING</td></tr>
<tr><td>0000100x</td><td colspan="2">Monitoring Master substate – INITIALIZATON</td></tr>
<tr><td>0000101x</td><td colspan="2">Monitoring Master substate – REGULAR</td></tr>
<tr><td>0000110x</td><td colspan="2">Monitoring Master substate – NON-REGULAR</td></tr>
<tr><td>0000111x</td><td colspan="2">Monitoring Master substate – LOSS</td></tr>
</table>

Bit 0	OTI device status	0001000x	Monitoring Slave substate – MONITORING NON TAIL
		0001001x	Monitoring Slave substate – MONITORING TAIL
		xxxxxxx0	OTI sub-system Status – OK
		xxxxxxx1	OTI sub-system Status – KO
Byte 3		xxxxxxxx	Energy Harvesting info. (e.g. status and percentage of stored energy)
Byte 4		xxxxxxxx	Wireless Interface info (e.g. status and level of received signal)

7.4.1.6.8 OTI-L_Status

<table>
<tr><td><i>Name</i></td><td colspan="3">Status of OTI-L sub-system</td></tr>
<tr><td><i>Description</i></td><td colspan="3">Include information about the OTI-L device, e.g. sub-system status (i.e. OK, fault), FSM State (i.e. Idle, Running), Energy Harvesting information, Wireless Interface information.
This field has the following structure:
<table>
<tr><td>Byte</td><td>Bit 7</td><td>Bit 6</td><td>Bit 5</td><td>Bit 4</td><td>Bit 3</td><td>Bit 2</td><td>Bit 1</td><td>Bit 0</td></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table></td></tr>
<tr><td><i>Length of variable</i></td><td><i>Minimum Value</i></td><td><i>Maximum Value</i></td><td><i>Resolution/formula</i></td></tr>
<tr><td>3 bytes</td><td></td><td></td><td></td></tr>
<tr><td><i>Special/Reserved Values</i></td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="6">Byte 1
<table>
<tr><td>Bit 7</td><td rowspan="3">OTI-L State</td></tr>
<tr><td>Bit 6</td></tr>
<tr><td>Bit 5</td></tr>
<tr><td>Bit 4,3,2,1,0</td><td>Spare</td></tr>
</table></td><td>00xxxxxx</td><td colspan="2">OTI-L FSM Status – Idle (INIT)</td></tr>
<tr><td>11xxxxxx</td><td colspan="2">OTI-L FSM Status – Idle (RESET)</td></tr>
<tr><td>01xxxxxx</td><td colspan="2">OTI-L FSM Status – Running/Unknown (ACTIVE)</td></tr>
<tr><td>10xxxxxx</td><td colspan="2">OTI-L FSM Status – Running/Known (ACTIVE)</td></tr>
<tr><td>xx0xxxxx</td><td colspan="2">OTI-L sub-system status – Regularly working (OK)</td></tr>
<tr><td>xx1xxxxx</td><td colspan="2">OTI-L sub-system status - Fault (FAULT)</td></tr>
<tr><td>Byte 3</td><td>xxxxxxxx</td><td colspan="2">Energy Harvesting info (e.g. status and percentage of stored energy)</td></tr>
<tr><td>Byte 4</td><td>xxxxxxxx</td><td colspan="2">Wireless Interface info (e.g. status and level of received signal)</td></tr>
</table>

7.4.1.6.9 OTI_Position

Name	OTI Position		
Description	Identify the position of the OTI Slave (tail, not tail or unknown)		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
2 bits	0	3	Integers
Special/Reserved Values	0	Unknown	
	1	Tail	
	2	Non Tail	
	3	Spare	

7.4.1.6.10 *OTI_Role*

Name	Role of OTI device		
Description	Specifies the role of the OTI device (Master or Slave)		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
2 bits	0	3	Integers
Special/Reserved Values	0	Unknown	
	1	Master	
	2	Slave	
	3	Invalid	

7.4.1.6.11 *SEQ_NUMBER*

Name	Message Sequence Number		
Description	Sequence number of the message sent by OTI device or ETCS. Refer to §7.4.1.8		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
32 bits	0	2^{32} - 1	integers

7.4.1.6.12 *Time*

Name	Time		
Description	ETCS time in seconds from power-on		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
3 Byte	0	2^{24} - 1	1 s

7.4.1.6.13 *Train_Integrity_Status*

Name	Qualifier for train integrity status		
Description	Qualifier, identifying the train integrity information availability.		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
2 bits	0	3	
Special/Reserved Values	0	Train integrity status unknown	
	1	Train integrity confirmed	
	2	Train integrity lost	
	3	Invalid	

7.4.1.6.14 *Train_Integrity_Latency*

Name	Train integrity latency

Description	Latency of train integrity status		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
8 bits	0	$2^8 - 1$	1 s

7.4.1.6.15 Train_Length

Name	Train length		
Description	Train length information		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
12 bits	0	4095	1 m

7.4.1.6.16 Train_Length_Status

Name	Qualifier for train length status		
Description	Qualifier, identifying the train length information availability.		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
2 bits	0	3	
Special/Reserved Values	0	Not Available	
	1	Init	
	2	Available	
	3	Invalid	

7.4.1.6.17 Train_Length_Validity

Name	Qualifier for train length validity		
Description	Qualifier, identifying the train length information validity in relation to ERTMS/ETCS data entry procedure. This attribute is referred to the case that train driver changes, during ERTMS/ETCS data entry procedure, the train length value provided by OTI-L.		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
2 bits	0	3	
Special/Reserved Values	0	Not Available	
	1	Validated	
	2	To Be Revalidated	
	3	Invalid	

7.4.1.6.18 Train_MovDir

Name	Train Movement		
Description	Direction of train movement in relation to the Active Cabin		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***

2 bits	0	3	
Special/Reserved Values	0	Reverse	
	1	Nominal	
	2	Unknown	
	3	Spare	

7.4.1.6.19 Train_Acceleration

Name	Train Acceleration		
Description	Train acceleration (respect to direction of movement)		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
3 bytes			
Byte 1: Train Position	0	255	1 dm / s^2
Byte 2: negative error	0	255	1 dm / s^2
Byte 3: positive error	0	255	1 dm / s^2

7.4.1.6.20 Train_Position

Name	Train Position		
Description	Train position (absolute travelled distance)		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
12 byte			
Byte 1÷4: Train Position	0	2^{32} - 1	1 m
Byte 5÷8: negative error	0	2^{32} - 1	1 m
Byte 9÷12: positive error	0	2^{32} - 1	1 m

7.4.1.6.21 Train_Speed

Name	Train speed		
Description	Train speed		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
3 byte			
Byte 1: Train Length	0	255	1 m/s
Byte 2: negative error	0	255	1 m/s
Byte 3: positive error	0	255	1 m/s

7.4.1.6.22 Train_Slide_Slip

Name	Train_Slide_Slip

Description	Attribute for odometry data acquired by wheel sensors		
Length of variable	**Minimum Value**	**Maximum Value**	**Resolution/formula**
2 bits	0	3	
Special/Reserved Values	0	Nominal (no slide/slip)	
	1	Slide	
	2	Slip	
	3	Not Applicable (in case odometry data are not provided by wheel sensors)	

7.4.1.7 CRC calculation

The CRC field of the messages described in §7.4.1.1 and §7.4.1.3 shall be calculated taking into account the variables as described in the following Table 7-23:

NID_Message	Message	Fields to take into account for CRC calculation
0x07	ETCS Status Request [From ETCS to Master] (7.4.1.2.1)	NID_MESSAGE L_MESSAGE SEQ_NUMBER ID_SOURCE ID_DESTINATION Time ETCS_Command Train_Position Train_Speed Train_Acceleration Train_MovDir Train_Length Train_Length_validity SPARE
0x08	Train Integrity Message [From OTI Master to ETCS] (7.4.1.2.2)	NID_MESSAGE L_MESSAGE SEQ_NUMBER ID_SOURCE ID_DESTINATION Time OTI-I_Status OTI_Role Train_Integrity_Status Train_Integrity_Latency SPARE

0x01	Master Identification Request [From Master to Slave] (7.4.1.3.1)	NID_MESSAGE L_MESSAGE SEQ_NUMBER ID_SOURCE ID_DESTINATION OTI_Role SPARE
0x03	Master Pairing Request [From Master to Slave] (7.4.1.3.1)	NID_MESSAGE L_MESSAGE SEQ_NUMBER ID_SOURCE ID_DESTINATION OTI_Role SPARE
0x05	Train Integrity Request [From Master to Slave] (7.4.1.3.2)	NID_MESSAGE L_MESSAGE SEQ_NUMBER ID_SOURCE ID_DESTINATION OTI_Role SPARE
0x02	Slave Identification Ack [From Slave to Master] (7.4.1.3.3)	NID_MESSAGE L_MESSAGE SEQ_NUMBER ID_SOURCE ID_DESTINATION OTI_Role OTI_Position SPARE
0x04	Slave Pairing Ack [From Slave TAIL to Master] (7.4.1.3.3)	NID_MESSAGE L_MESSAGE SEQ_NUMBER ID_SOURCE ID_DESTINATION OTI_Role OTI_Position SPARE

0x06	OTI Slave Status [From Slave TAIL to Master] (7.4.1.3.4)	NID_MESSAGE L_MESSAGE SEQ_NUMBER ID_SOURCE ID_DESTINATION Time OTI_Role OTI_Position OTI_Device_Status Train_Position Train_Speed Tran_Accelerarion Train_MovDir Satellite localization based information SPARE
0x11	Diagnostic Message [From OTI Slave to OTI Master] (7.4.1.3.7)	NID_MESSAGE L_MESSAGE SEQ_NUMBER ID_SOURCE ID_DESTINATION Time OTI_Role OTI_Position OTI_Device_Status Cargo/Waggon info SPARE

Table 7-23: Fields to take into account for CRC calculation

For CRC calculation, the generator polynomial for SIL 4 communication defined in §10.1.3 of [60] shall be used.

7.4.1.8 Sequence Number

The variable SEQ_NUMBER defined in the messages of §7.4.1.3 shall be managed as follows:

1) When the OTI Master sends the first “Master Identification Request” message, the SEQ_NUMBER shall be set to 0 and shall be increased of 1 unit for each new message sent by OTI Master [$\text{SEQ\_NUMBER}_{(\text{N Message})} = \text{SEQ\_NUMBER}_{(\text{N-1 Message})} + 1$];
2) The OTI Slave shall set the value of the SEQ_NUMBER variable equal to the value of the SEQ_NUMBER of the last message sent by OTI Master and received by OTI Slave;
3) When the SEQ_NUMBER reaches the maximum value as defined in 7.4.1.6.11, it shall be re-initialised to 0;

The value to be assigned to the variable SEQ_NUMBER defined in the messages §7.4.1.1 depends on the adopted solution for the communication between ETCS and OTI Master.

7.4.1.9 Criteria of consistency

The following sections specify the criteria for the acceptance of the messages received by OTI devices.

7.4.1.9.1 OTI Master Data checks

When the OTI Master receives a message sent by OTI Slave shall perform the following checks:

1. The variables included in the messages shall have one of the possible values defined in § 7.4.1.6;
2. The value of the ID_SOURCE field received in the messages “Slave Pairing Ack” and “OTI Slave Status” shall be equal to the value sent by the OTI Slave TAIL in the “Slave Identification Ack” message;
3. The value of the ID_DESTINATION field shall be equal to the OTI Master ID;
4. The value of the ID_POSITION field received in the messages “Slave Pairing Ack” and “OTI Slave Status” shall be equal to “TAIL”;
5. The value of the OTI_ROLE field shall be equal to “SLAVE”;
6. The SEQ_NUMBER shall be equal to the SEQ_NUMBER of the sent message (see §7.4.1.8);
7. The CRC field shall be correct (see §7.4.1.7).

If one of these checks fails, the OTI Master shall reject the message.

7.4.1.9.2 OTI Slave Data checks

When the OTI Slave receives a message sent by OTI Master shall perform the following checks:

1. The variables included in the messages shall have one of the possible values defined in § 7.4.1.6;
2. The value of the ID_SOURCE field received in the messages “Master Pairing Request” and “Train Integrity Request” shall be equal to the value sent by the OTI Master in the “Master Identification Request” message;
3. The value of the ID_DESTINATION field shall be equal to the OTI Slave ID (with the only exception for the “Master Identification Request” message where the “ID_DESTINATION” is set to “0”);
4. The value of the OTI_ROLE field shall be equal to “MASTER”;
5. The CRC field shall be correct (see §7.4.1.7).

If one of these checks fails, the OTI Slave shall reject the message.

7.4.2 Protocol level

This section contains the analysis of different solutions for protocol stack considering:

- Communication solutions defined in TD2.1 Adaptable Communications
- Communication solution defined in FRCMS
- Communication solution defined in Connecta
- Communication solution defined in DEWI/SCOTT projects
- Euro-radio over TCP/IP [5]

The analysis reported at section 7.4.2.1 evaluates the applicability of communication solutions defined in Adaptable Communication Services as wireless communication for freight context with OTI Product Class 2. In general freight application domain includes also the case of wired communication (e.g. with automatic couplers) addressed by OTI Product class 1.

The specific use case considered at section 7.4.2.1 refers to OTI application to ETCS L3 that implies availability of track-side commutation networks for train to ground communication. Other wireless technologies to address other uses cases are described at section 9.

7.4.2.1 Solution defined in TD2.1 Adaptable Communication

Within the Shift2Rail project, especially in IP2, TD2.1 has addressed the issues related to communication systems for signalling. Within this context, meetings were held to understand what has already been developed or ideas developed within TD2.1 could be useful for the management of radio communications for the specific TD2.5 train integrity project.

The conclusions reached during the various meetings are reported in this chapter. The interaction between TD2.1 and TD2.5 cannot be considered completed, but what is reported offers a state of the art that becomes a good starting point for the considerations to be made within TD2.5 and future cooperation between the two TDs.

The Adaptable Communication System (ACS) developed within the TD2.1 can offer a series of services for wireless communication between OTI master and OTI slave.

Starting from the assumption that the Train Integrity is an On Board function responsible for verifying the completeness of the train, while the train is in operation. The scope of work consists concretely in monitoring the status of the train’s tail (i.e. last waggon is regularly advancing in a coherent way in relation to the movement of the remaining train).

Main goals related to the Train Integrity include:

(i) autonomous localisation of the train tail without interaction with trackside equipment;
(ii) safe detection (SIL-4) of train interruption, filtering false alarms conditions;
(iii) capability to establish a wireless communication between the tail and the front cabin, in order to transfer the confirmation of integrity, without any trackside network support, in the case of absence of a hardwired train communication line;
(iv) innovative solution to supply the required power for OTI equipment in freight convoy, where the solution will involve both the generation of energy and its storage.

In general, the four different S2R application domains influence the assessment and selection of the communication technology used for enabling the required exchange of data.

For example, trains fully equipped with a TCMS network can leverage the available wireline communication (typically based on Ethernet) to enable the messaging between train head and train tail for train integrity. In case a wireline connection is available, the choice for connecting the OTI devices should be straightforward and a wireless system should not be used.

For other train classes, including freight trains, it can be expected that no wireline connectivity is available and as such a wireless communication system becomes necessary to enable the exchange of data to derive the train integrity status.

The next two sections (§7.4.2.1.1 §7.4.2.1.2) offer a view of the possible approaches to managing a wireless connection. In fact, there are two macro families of solutions. Use a device-to-device approach or use an external infrastructure that is often already present along the line.

The section §7.4.2.1.3 contains some considerations in adopting the ACS platform also for the communications necessary for the Train Integrity function.

7.4.2.1.1 Device to Device communication or Direct mode (off-net)

From a wireless communication perspective different device-to-device technology options are available. Examples include Wi-Fi Direct, 802.11p, LTE D2D, 5G C-V2X, Zigbee, Bluetooth. For most of these technologies the maximum distance between devices range from 100 to 200 meters if high packet reception ratio (higher than 50%) is required to comply with train integrity requirements.

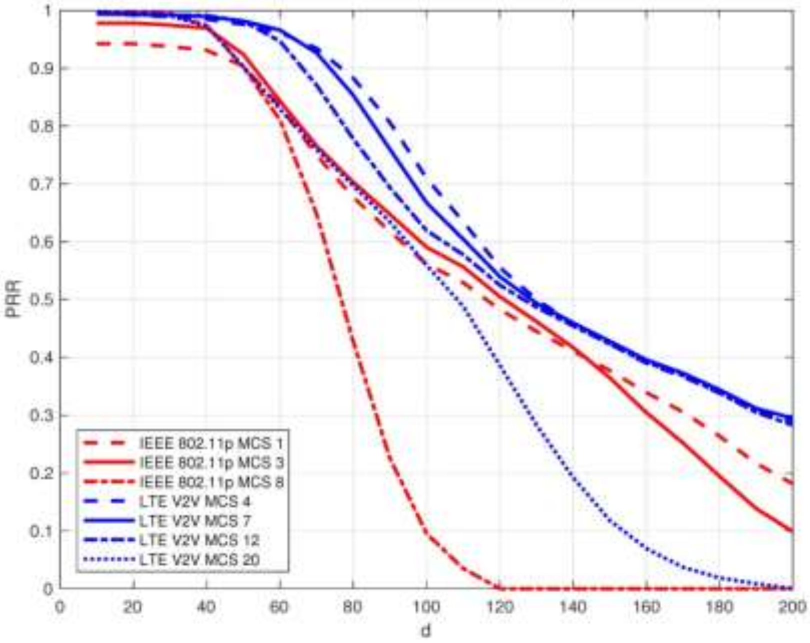

Figure 7-16: Packet reception rate (PRR) per distance (d) in meters for IEEE 802.11p and LTE V2V

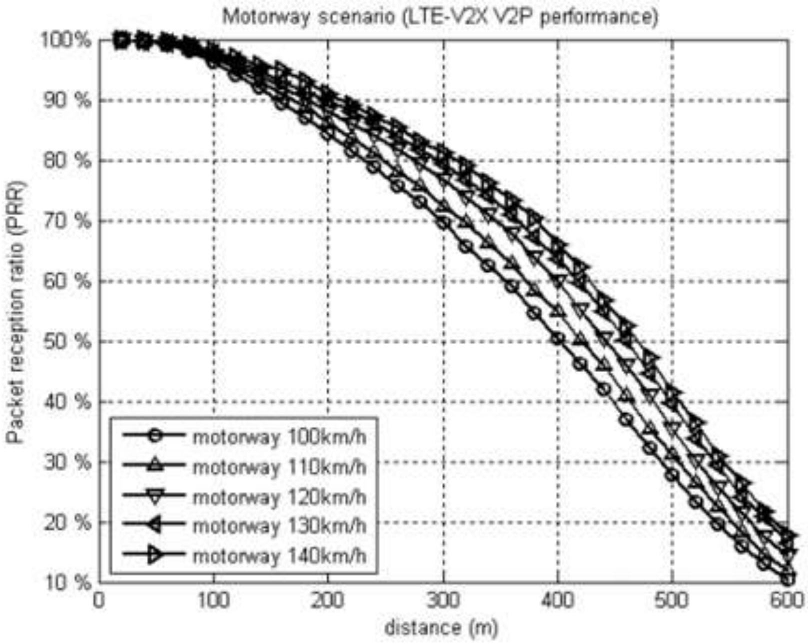

Figure 7-17: LTE-V2P performance in 6-lane motorway scenario

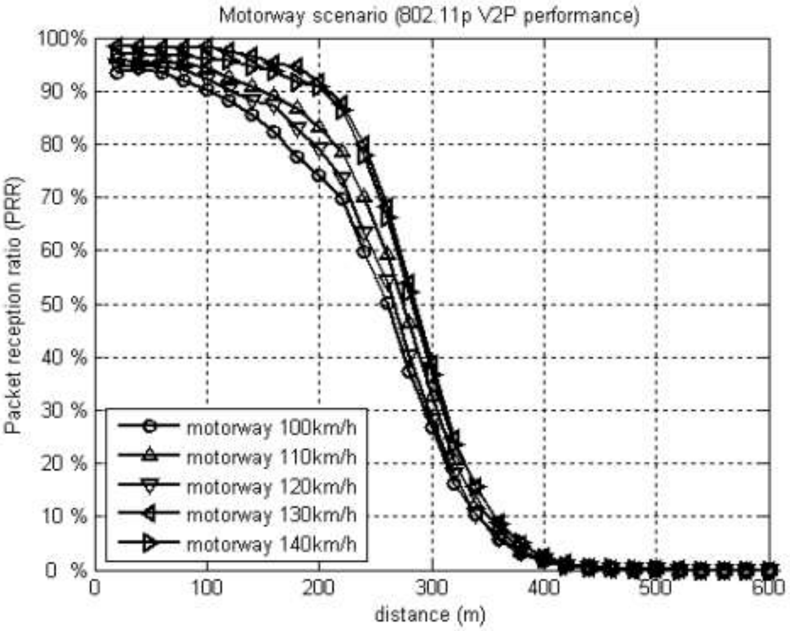

Figure 7-18: 802.11p V2P PRR performance in 6-lane motorway scenario

In consequence it becomes challenging to support train integrity functionality for long trains (e.g. freight trains with length >1km). An alternative approach could be considered to equip every waggon with a communication device to relay the communication from the head to the tail of the train, which would overcome the issue of maximum distance and at the same time provides new options in terms of using low-power short distance communication devices.

Another challenge for using device to device communication is linked to the discovery phase at setup time. Once the On Board train integrity (OTI) devices are initialized a broadcast operation is used to collect information about other OTI devices in proximity. Based on the information received the master OTI at the head of the train and the relevant slave OTI at the tail of the train are computed.

In case other trains are nearby and respond to broadcasts from initializing OTI devices, it becomes complex to identify only the OTI devices belonging to the same train.

7.4.2.1.2 Infrastructure based cellular communication (on-net)

The exchange of data between the onboard train integrity (OTI) devices could also be done by using the trackside cellular infrastructure. In other words, the OTI devices sends data to the network and the network transfers the data to the target OTI device. Even if the train integrity application does not require wireless infrastructure, the functions in the network would be able to deliver key advantages.

1. Low power cellular devices (LTE-M, NB-IoT, etc.) enable reliable communication options for low throughput applications with limited power requirements;
2. The Train integrity application is typically tied to ETCS Level 3 support on the track which implies that cellular network coverage and in consequence train-to-trackside communication is available;
3. The centralized ACS/FRMCS functions can be leveraged to safely identify the OTI devices on the same train using the mandatory device registration as well as information sources in the network (e.g. TMS, ETCS, ..);
4. FRMCS requirements foresee peer to peer communication latency lower than 100ms (see. 3GPP TR 22.889)

In summary the trackside-based communication infrastructure provides essential advantages and overcomes some of the challenges for train integrity in terms of connectivity for long trains as well as the safe determination of OTI master and slave.

7.4.2.1.3 Application Implications from ACS

Applications have to interface with the ACS and perform the required procedures to leverage communication services.

1. Each application (On Board or trackside) represents a communication user (ACS user or FRMCS user), which is linked to a predefined default identity.
2. Each application has to register with the ACS / FRMCS with a defined identification and authentication procedure before any communication services can be used.
3. An application can optionally register additional logical identities, which will be associated with the application and as such can be used by other users as the destination address to set up the communication link. Example: On-Board ETCS.{train-running-number}.{network}.{country}
4. The application requests a new communication link from the ACS / FRMCS using a destination address (other user or application) and the needed communication characteristics (average and guaranteed throughput, latency, max. error rate, other QoS parameters, etc)
5. Once the communication link is set up by ACS / FRMCS the application can use an IP connection combined with any transport layer protocol (UDP, TCP, SCTP, etc).

6. During communication the application can instruct the ACS / FRMCS to change the communication characteristics (e.g. different QoS) or terminate the connection.

In general the ACS offers a standardized control interface to manage the communication requests and supports plain IP connectivity for the user plane without additional constraints. At the same time the ACS hides any technology selection or management procedures from the applications and makes generic communication services available according to the application needs.

ACS gateway has been defined for train to ground communication, however it is also suitable for train to train communication (i.e. OTI Master – OTI Slave communication).

7.4.2.2 Train Integrity communications considered in FRMCS project

As one of the key building blocks for ETCS, GSM-R is a successful rail radio communication technology not only in Europe but also worldwide. GSM-R as well as telecom standards in general are dependent on the telecom industry evolution cycles. Since the end of support for GSM-R is planned by 2030 onwards, studies for a successor to GSM-R has been launched as soon as 2012 by the consortium, named Future Rail Mobile Communications System (FRMCS).

So far, the FRMCS project delivered the User Requirements Specifications (URS) focusing mainly on rail communication needs as a basis for the development of the GSM-R successor.

Main activities of FRMCS working groups can be summarised as follows:

- The maintenance and evolution of User Requirements Specifications,
- The production of Functional and System Principle Use Cases, necessary for the development of the corresponding functional and technical standards within telecom standardization Bodies in ETSI Technical Committee for Rail Telecommunications (ETSI TC-RT) and the 3rd Generation Partnership Project Technical Specifications Groups (3GPP TSG) and in particular the Service and System Aspects (SA),
- The definition of migration strategies from GSM-R to FRMCS with their associated impacts in terms of traffic analysis and frequency spectrum requirements.

OTI is seen from the FRMCS as an application associated with a FRMCS user residing in the train. It is one of many onboard application use cases captured in the 3GPP technical report TR 22.889, which is submitted into 3GPP Rel.16 stage 1 and will be worked by stage 2 and stage 3 to identify the technical solution and details to address the requirements. If the use case is processed in 3GPP Rel.16 the relevant stage 2 documents become available mid 2019 and stage 3 documents beginning of 2020.

According to the OTI use case, both communication types are foreseen based on 3GPP functionalities:

- “Off-network” communication: In this case, FRMCS System establishes a communication between the authorised FRMCS Users at the train. The data communication for train integrity requires the QoS class which matches the application category of “CRITICAL DATA” within the FRMCS system. The FRMCS system establishes the bearer service required for the data communication. The FRMCS System verifies if the FRMCS Users are authorised to use the train integrity application. The FRMCS Users are exchanging continuously information about the train integrity until the end of the mission. The entire train integrity communication will be recorded.

- “On-network” communication: On demand by the FRMCS Users (train integrity entities), the FRMCS System establishes a communication between the authorised FRMCS Users at the train and the ground. The data communication for train integrity requires the QoS class which matches the application category of CRITICAL DATA (according to FRMCS specification) within the FRMCS system. The FRMCS system establishes the bearer service required for the data communication. The FRMCS System verifies if the FRMCS Users are authorised to use the train integrity application. The FRMCS Users are exchanging continuously information about the train integrity until the end of the mission. The entire train integrity communication will be recorded.

Studied wireless communication alternatives for some OTI applications (e.g. freight train) assume low-power consumption devices. This factor should be considered for a proper selection of wireless network and respecting protocols. FRMCS embraces low-energy cellular systems based on LTE-M (machine to machine communication) or NB-IoT (narrow band Internet of Things) and further enhancements introduced with 5G.

More technical information beyond the current User Requirements Specification (URS) document will be made available by UIC (FRMCS coordinator) in the course of 2019 and 2020. At the beginning of 2019 the Functional Requirements Specification (FRS) document will be provided as draft version followed by the System Requirements Specification (SRS). In 3GPP the FRMCS activities are covered by the FS_FRMCS studies and the MONASTRY work items.

7.4.2.3 Solution defined in Connecta

The following subsections are intended to explain the protocol stack related to current TCMS in relation to Train Real-Time Data Protocol and Safe Data transmission Protocol.

7.4.2.3.1 Train Real-Time Data Protocol (TRDP)

This section provide description for Real-Time Data Protocol with a general introduction, a description for lower layers, communication identifier, process data protocol and data messages.

7.4.2.3.1.1 Introduction

The Train Real-Time Data Protocol (TRDP) is a network protocol for communication over IP-based networks on trains, and it is part of the Train Communication Network (TCN). The protocol was developed by the IEC Working Group TC9 / WG43, and standardized in IEC61375-2-3, under the coordination of the 'Train Communication Network Open Source Special Interest Group' (TCNOpen). TCNOpen is an open source initiative founded by the railway industry partners, with the aim of jointly developing key components for the next railway communication standards.

This protocol is executed by a TRDP layer which is placed on top of the TCP/UDP transport layer (Figure 7-19:), allowing the exchange of TCN **Process Data (PD)** and TCN **Message Data (MD)** between train devices (door controls, screens, air conditioners...) over ETB (Ethernet Train Backbone). TRDP could also be used within the ECN (Ethernet Consist Network) communication.

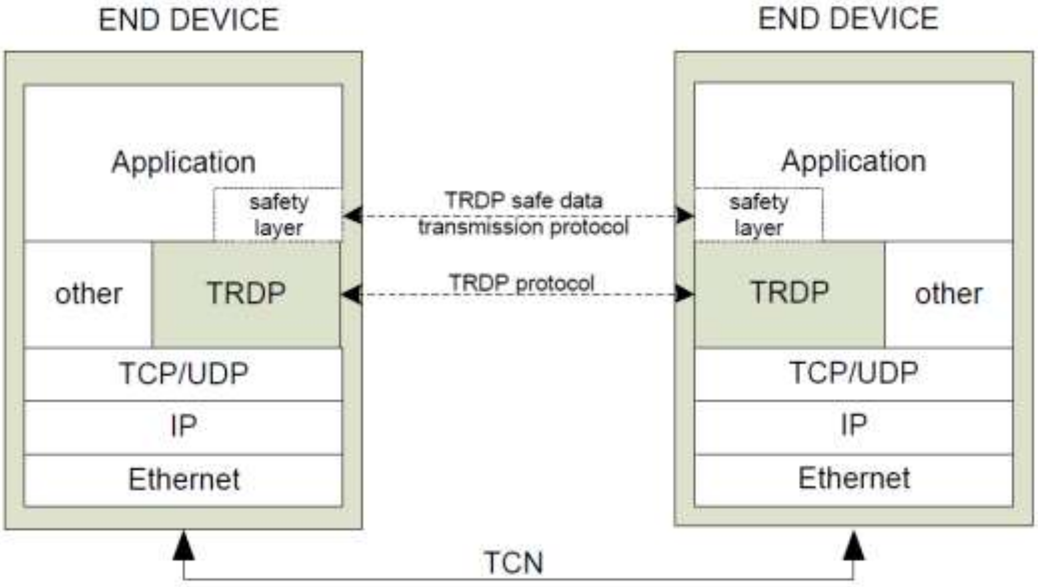

Figure 7-19: Overview of TRDP protocol stack

The TRDP layer shall provide services for process data and message data communication to the TRDP user at upper layer (application) as shown in Figure 7-20:. This service interface (service primitives) is defined in an abstract way in order not to restrict implementations.

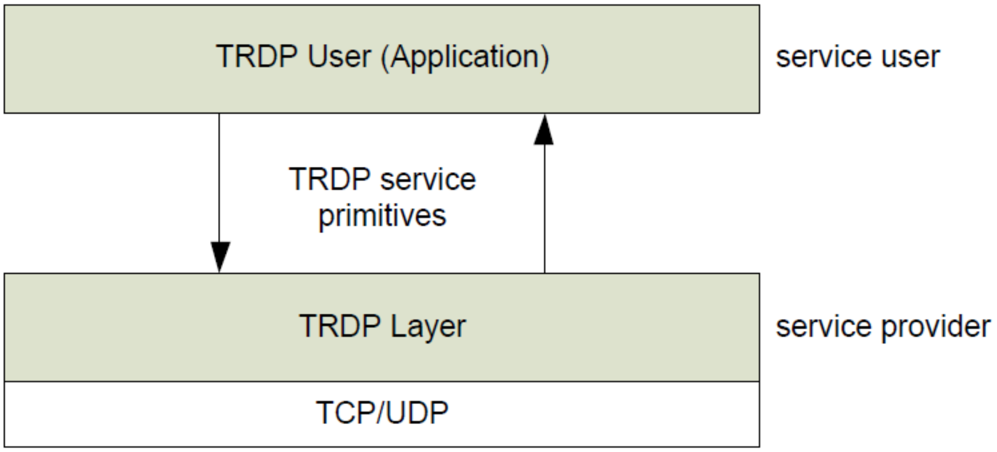

Figure 7-20: Interaction between TRDP user and TRDP layer

TRDP layer may optionally be extended by a **safety layer,** which provides safe end-to-end data transmission of safety critical process data and message data between any two end devices in the network (**Safe Data Transmission** protocol, **SDTv2**).

All TRDP data on the wire is defined as big-endian and byte alignment. Possible marshalling of user data needs to be done by a specific service primitive called from application layer before calling the TRDP service primitives to send data. Similarly, a possible unmarshalling of user data needs to be done at application level after receiving data from the TRDP layer.

7.4.2.3.1.2 Lower Layer

I) Data Link Layer

TRDP uses the ETB as defined in IEC 61375-2-5 for data communication within trains.

II) Network Layer

TRDP is based on IP for data exchange between functions located in different consists of a train. IP addressing of functions and devices is also defined in IEC 61375-2-5. It must be remarked that IP address assignments may change after train inaugurations.

Data transfer between ETB and ECN is provided by a gateway functionality of the ETBN (ETB node), as defined in IEC 61375-2-5. As a recommendation, this gateway should only transfer data between ETB and ECN if the data are consistent with the actual train backbone view and operational train view. The filtering of inconsistent data within the ETBN reduces the probability that inconsistent data are transferred to the destination. Nonetheless, it does not release the destination from the responsibility to check the consistency by itself.

III) Transport Layer

TRDP uses the services of the UDP and TCP transport layer protocols for data communication. On the one hand, TRDP process data shall be sent with UDP, whose packet size shall be restricted to the size of one Ethernet frame. On the other hand, TRDP message data may be sent with UDP or TCP. The choice shall be done by the user when the message data transfer is invoked. Note that message data packets exceeding the Ethernet MTU (Maximum Transmission Unit) in size can be transmitted by TCP in order to avoid problems with packet fragmentation. However, TCP restricts to point-to-point communication.

For interoperable data communication, the destination port assignments (well-known ports) defined in Table 7-24 shall be used.

Protocol	Destination Port
Process Data	20548
Message Data (UDP)	20550
Message Data (TCP)	20550

Table 7-24: UDP/TCP port assignments

Depending on the type of data to be exchanged and its associated transport layer protocol, the following guidelines should be followed:

- For receiving any process data telegrams and for receiving UDP message data notification, request and confirm telegrams, the well-known port shall be used.
- For receiving UDP message data reply telegrams, the port the related request was sent from shall be used.
- For sending any process data telegrams and for sending UDP message data notification, request and confirm telegrams, a private source port different from the well-known port shall be used.
- For sending UDP message data reply telegrams, any source port different from the one the request was received from can be used.
- TCP connections shall be established between a source port different from the well-known port and the well-known port as destination.
- NOTE:
    - Using different well-known port numbers may be allowed for project specific purposes.
    - The used well-known port numbers should be given as a configuration parameter to the communication stack.

7.4.2.3.1.3 Communication Identifier

All TRDP communication is using a so called Communication Identifier (ComId) transmitted in the header of each PDU (Protocol Data Unit). The ComId forms, together with the source IP address, a unique identifier of the PDU within the train.

The ComId is application dependent, but it must be remarked that the ComIds 1 to 999 shall not be used by the application, since they are reserved for specific use (some examples are provided in Table 7-25).

comId	Description
1	ETBCTRL telegram
2	CSTINFO notification message
3	CSTINFOCTRL notification message
10	TRDP Echo
31	TRDP – statistics request command
35	TRDP – global statistics data
130	ETBN – control request
131	ETBN – status reply

Table 7-25: Reserved ComIds

Note that ComId shall be set to zero in the following cases:

- For PDUs with unspecified user dataset.
- In message data confirmation messages.
- In message data error messages.

7.4.2.3.1.4 Process Data

The TRDP Process Data (PD) protocol defines the exchange of PD-PDUs for the transfer of process data. The communication partners in a process data transfer can have different roles:

- **Publisher:** The source of process data.
- **Subscriber:** The sink of process data.
- **Requester:** Requesting the publisher(s) to publish its process data.

TRDP process data shall be **cyclically transmitted, or transmitted on request,** between a publisher and one or many subscribers using a connectionless and unconfirmed TRDP service.

Publisher and requester coincide in push communication patterns, whereas a subscriber may also be a requester in pull communication patterns. Essentially, data exchange patterns initiated by a data source (an application instance producing user data) are called push patterns, whereas data exchange patterns initiated by a data sink (an application instance consuming user data) are called pull patterns.

I) Push communication pattern

Process data exchange shall support the following push communication patterns, as defined in IEC 61375-1:

- Point to point, cyclic without acknowledge, source knows the sink (Figure 7-21: PD push pattern (point to point)Figure 7-21:).
- Point to multipoint, cyclic without acknowledge, source knows the sink (Figure 7-22:).
- Point to multipoint, cyclic without acknowledge, source does not know the sink (Figure 7-22:).

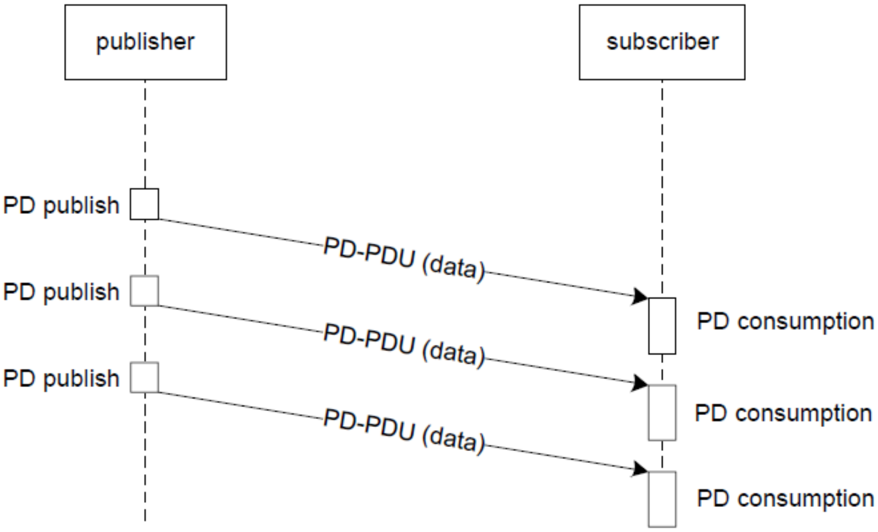

Figure 7-21: PD push pattern (point to point)

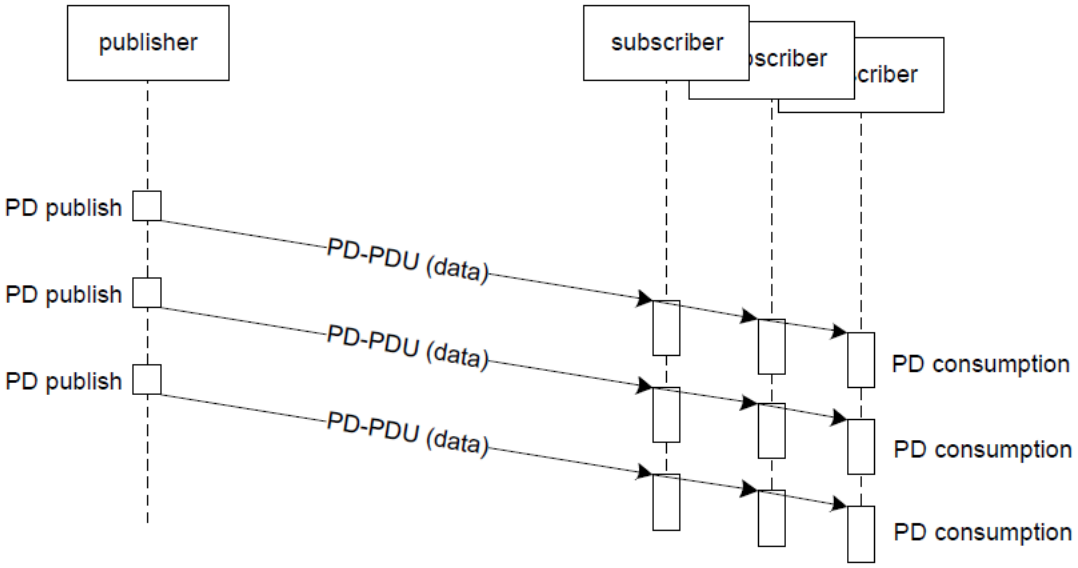

Figure 7-22: PD push pattern (point to multipoint)

II) Pull communication pattern

Process data exchange shall support the following pull communication pattern, as defined in IEC 61375-1:

- Point to point, without acknowledge, sink knows the source (Figure 7-23:).
- Multipoint to point, without acknowledge, sink does not know the source (Figure 7-24:).
- Point to multipoint, without acknowledge, sink knows the source (Figure 7-25:). Here, one dedicated subscriber is requesting the known publisher to send its PD-PDU.
- Multipoint to multipoint, without acknowledge, sink does not know the source (Figure 7-26:). Here, one dedicated subscriber is requesting one or multiple unknown publisher to send their PD-PDU.

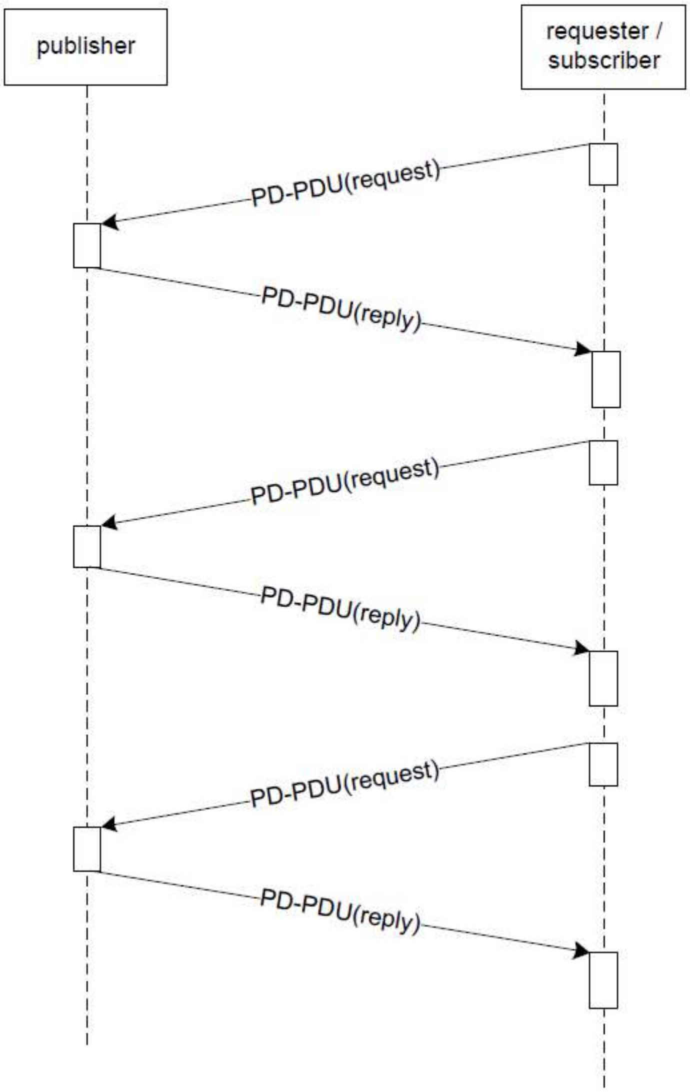

Figure 7-23: PD pull pattern (point to point)

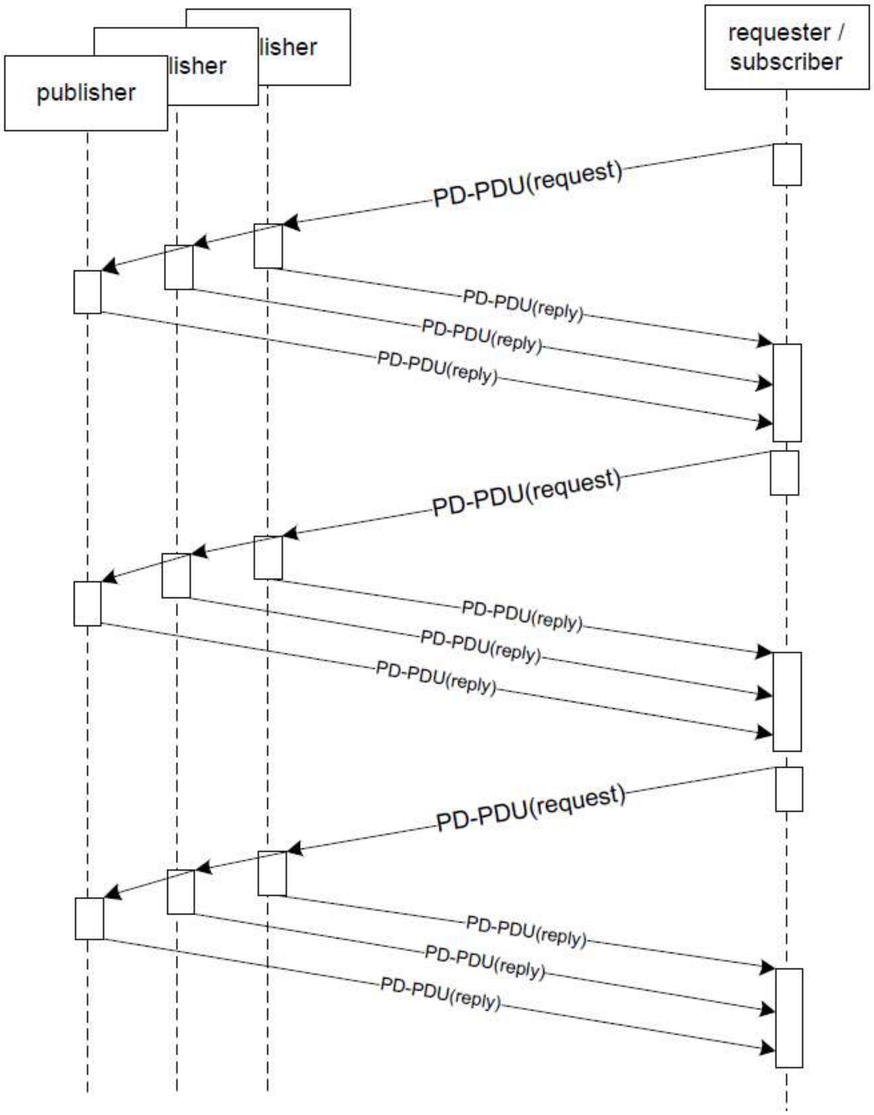

Figure 7-24: PD pull pattern (multipoint to point)

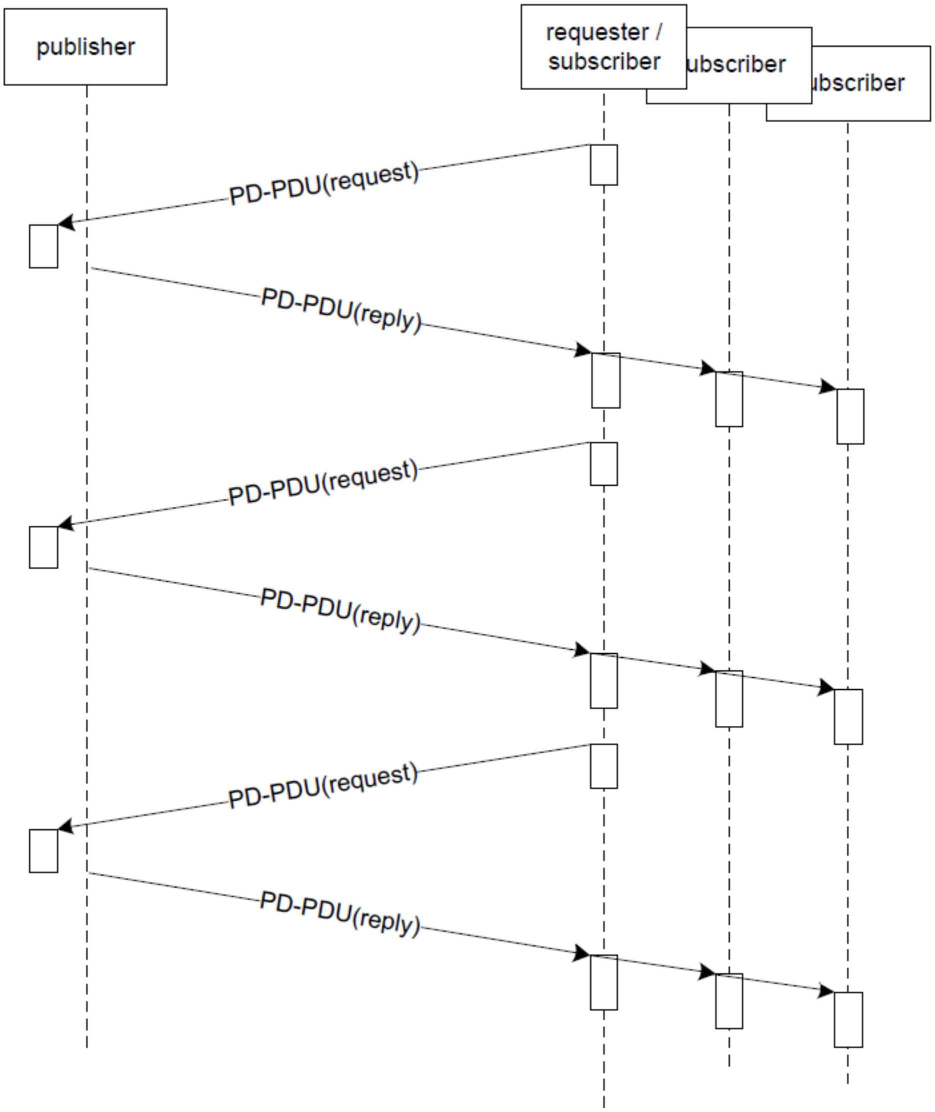

Figure 7-25: PD pull pattern (point to multipoint)

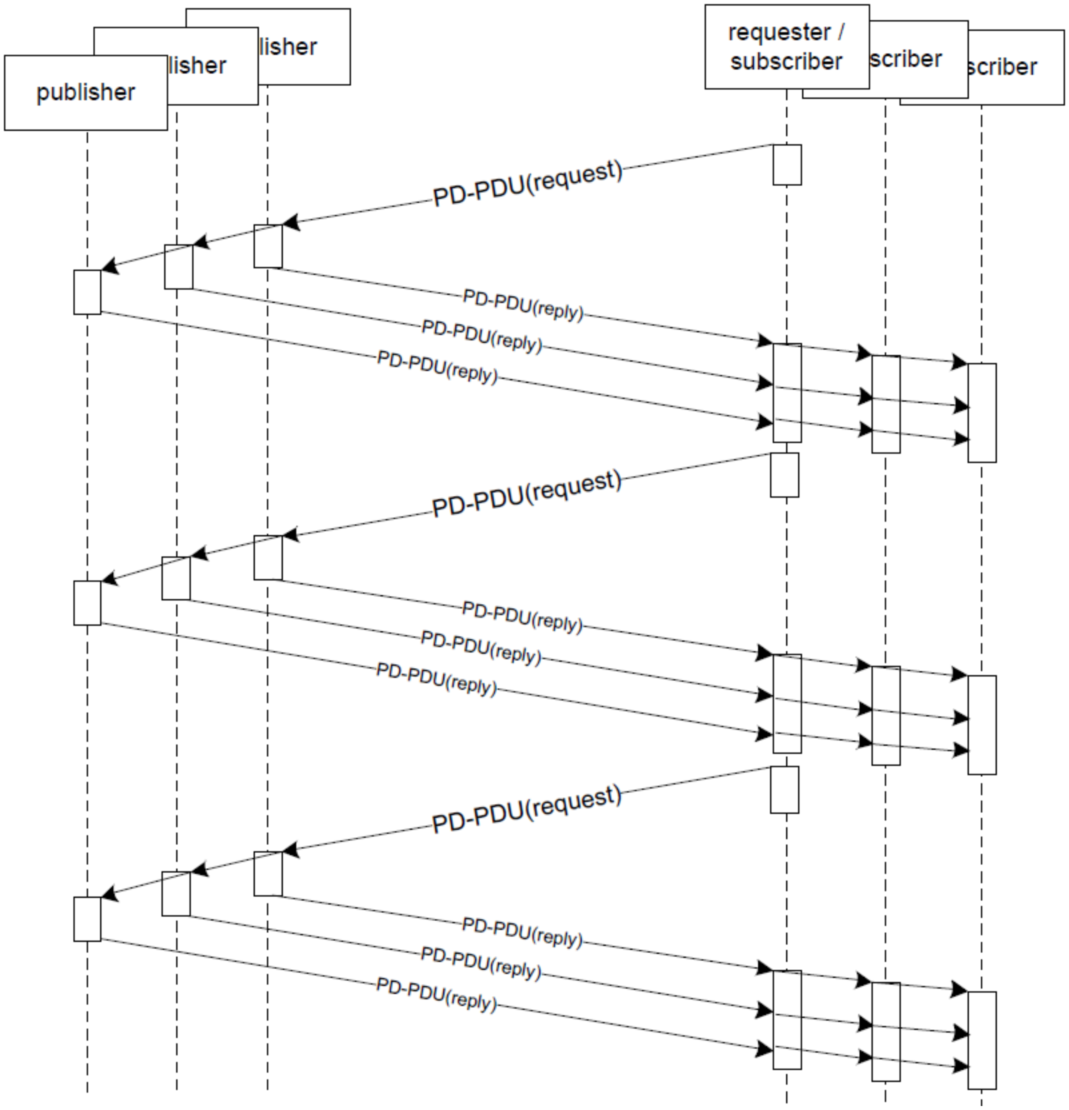

Figure 7-26: PD pull pattern (multipoint to multipoint)

III) PD-PDU

The structure of a PD-PDU is defined in Figure 7-27:, with additional explanation given in Table 7-26.

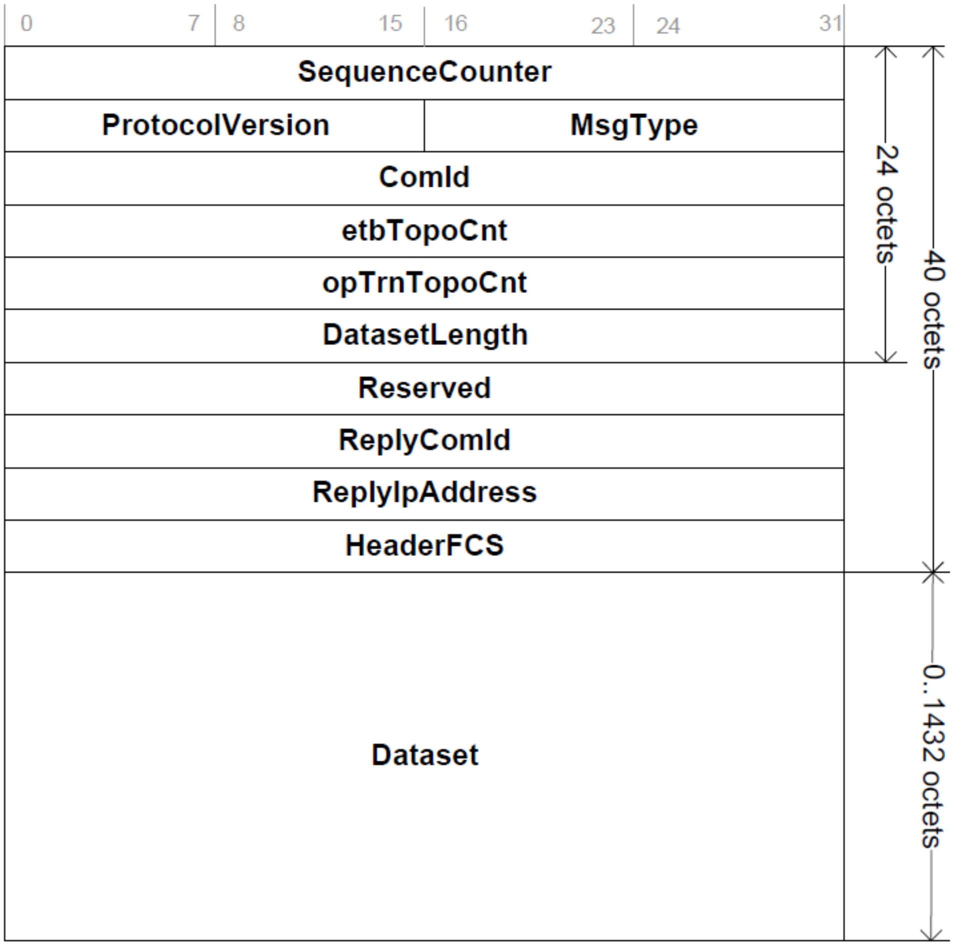

Figure 7-27: PD-PDU

Parameter	Description	Value
sequenceCounter	The sequence counter: • Shall be managed for sending process telegrams per ComId/MsgType at each requester/publisher. • Shall be managed (stored) for received process telegrams per SourceIPAddr/ComId/MsgType at each publisher/subscriber. • Shall be incremented with each sending of the process telegram. Telegrams sent in parallel via different subnets are sent with the same sequence counter to detect duplication at receiver side. • Can be used for communication layer surveillance (PD sending). A surveillance that the application is still updating its process data (user data) can be done via the safe data transmission protocol (SDTv2) or can be implemented by the application (e.g. via a life sign).	Computed, start value 0.

protocolVersion	The protocol version shall consist of: • Higher significant octet: mainVersion, incremented for incompatible changes. • Lower significant octet: subVersion, incremented for compatible changes.	Fixed (e.g. ‘0102’H = protocol version 1.2).
msgType	Type of the telegram: • ‘Pr’ = PD Request • ‘Pp’ = PD Reply • ‘Pd’ = PD Data • ‘Pe’ = PD Data (Error)	‘5072’H (‘Pr’) ‘5070’H (‘Pp’) ‘5064’H (‘Pd’) ‘5065’H (‘Pe’)
comId	Identifier of the user dataset.	Set by user.
etbTopoCnt	The ETB topography counter: • Shall be used (train addressing) as defined in IEC 61375-2-5. • Shall be set by the user. • Shall be set for all communication over the ETB. • Shall be set if a valid opTrnTopoCnt is set. • Optional in all other cases. Shall be set to 0 (= invalid) if not used.	0 – 2^{32}-1, Set by user.
opTrnTopoCnt	The operational train topography counter: • Shall be set by the user. • Shall be set for communication between functions which use information from the operational train directory (e.g. side selective operations). • Shall be set when the source device used the operational train directory to retrieve the destination IP address. • Optional in all other cases. Shall be set to 0 (= invalid) if not used.	
datasetLength	The dataset length: • Shall be the length of the user data set in number of octets without padding octets. • Shall be the primary information about the user data size.	0 – 1432, Computed.
reserved01	Reserved for future use	Set to 0.
replyComId	The requested ComId: • Shall be used only in a PD request. • Shall be used as ComId in the reply. • If set to 0, the ComId of the request shall be used for the reply. • If set to 0, and the ComId of the request is also set to 0, the reply shall be sent as an unspecified PDU.	Set by user in PD request, in other telegram types set to 0.
replyIpAddress	The reply IP address: • Shall be used only in a PD request. • Shall be used as destination IP address in the reply. • If set to 0, the source IP address of this request shall be used for the reply.	Set by user for request, otherwise set to 0.
headerFCS	The header frame check sequence: • Shall be calculated for the PD-PDU header. • Shall not include the headerFCS itself.	

dataset	The user data set. If the user data length is not a multiple of 4 octets, octets with a value of 0 shall be appended until a multiple of 4 octets is reached (padding bytes).	

Table 7-26: PD-PDU parameters

7.4.2.3.1.5 Message Data

The TRDP Message Data (MD) protocol defines the exchange of MD-PDUs for the transfer of message data. The communication partners in a message data transfer can have different roles:

- **Caller:** The source of message data in push communication patterns, or the sink of message data in pull communication patterns.
- **Replier:** The source of message data in pull communication patterns, or the sink of message data in push communication patterns.

Hence, TRDP process data shall be **transmitted on request** between a caller and one or many repliers over a confirmed TRDP service.

Since it is thought only for real-time message data, the length of a telegram is limited to 64 kBytes. The caller is sending a request message with or without user data to the replier(s), and the replier(s) will send a reply message with or without user data in return, if required by the caller (i.e. a caller shall be able to define by the request type whether a reply is expected or not). Then, the caller shall quit reception of the reply by sending a confirmation, if required by the replier (i.e. a replier shall be able to define by the reply type whether a confirmation of its reply is expected or not).

It must be highlighted that this gives a guaranteed transfer of data as the caller/replier is notified about the correct reception and processing of the message data.

Therefore, three message data transfer options shall be provided by TRDP (Figure 7-28:):

- Request without reply (‘notification’).
- Request with reply but without confirmation (‘request without confirmation’).
- Request with reply and confirmation (‘request with confirmation’).

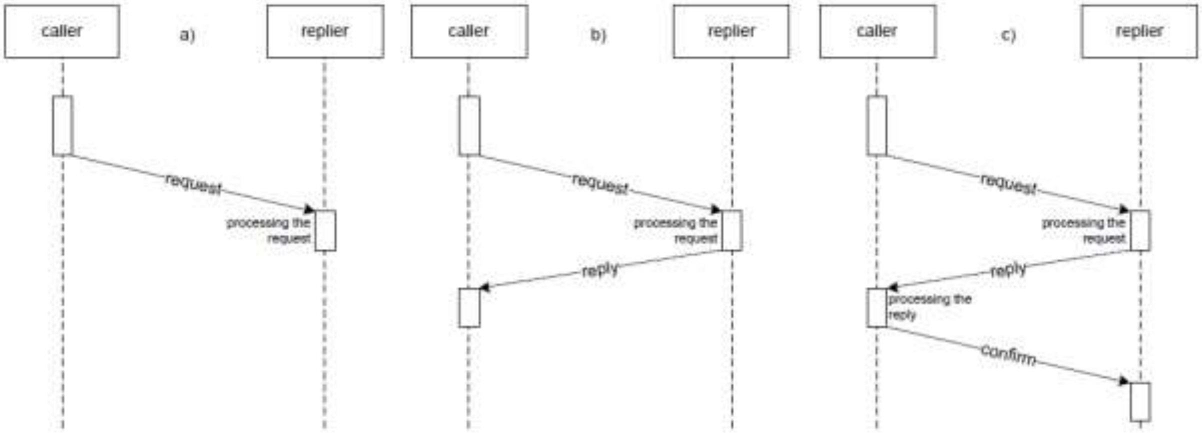

Figure 7-28: Message data transfer options

As previously mentioned, TRDP shall provide two mechanisms to transfer message data (via UDP and via TCP), but the different service primitives of the two possibilities shall not be mixed.

I) Push communication pattern

Message data exchange shall support the following push communication pattern, as defined in IEC 61375-1:

- Point to point, sporadic with acknowledge, source knows the sink.
- Point to point, sporadic without acknowledge, source knows the sink.
- Point to multipoint, sporadic with acknowledge, source knows the sink.
- Point to multipoint, sporadic without acknowledge, source knows the sink.
- Point to multipoint, sporadic with acknowledge, source does not know the sink.
- Point to multipoint, sporadic without acknowledge, source does not know the sink.

II) Pull communication pattern

Message data exchange shall support the following pull communication pattern, as defined in IEC 61375-1:

- Point to point, sporadic with acknowledge, sink knows the source.
- Point to point, sporadic without acknowledge, sink knows the source.
- Point to multipoint, sporadic with acknowledge, sink knows the source.
- Point to multipoint, sporadic without acknowledge, sink knows the source.
- Point to multipoint, sporadic on first acknowledge, sink does not know the source.
- Point to multipoint, sporadic without acknowledge, sink does not know the source.

III) MD-PDU

The structure of an MD-PDU is defined in Figure 7-29:, with additional explanation given in Table 7-27.

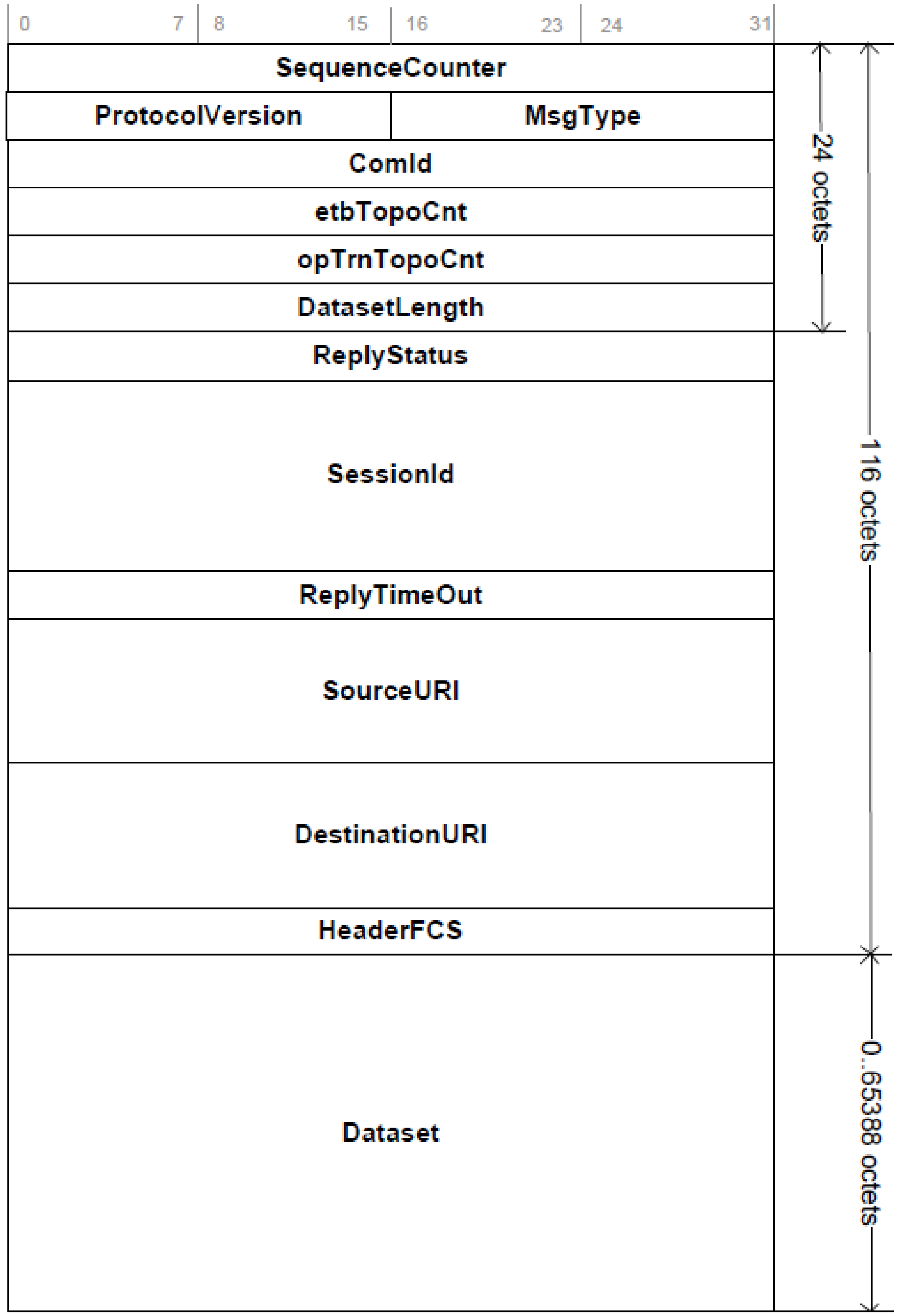

Figure 7-29: MD-PDU

Parameter	Description	Value

sequenceCounter	The sequence counter: • Shall be incremented with each repetition of the message (return to 0 on overflow). • Shall be returned with the reply message.	Computed, start value 0..
protocolVersion	The protocol version shall consist of: • Higher significant octet: mainVersion, incremented for incompatible changes, • Lower significant octet: subVersion, incremented for compatible changes.	Fixed (e.g. ‘0102’H = protocol version 1.2).
msgType	Type of the telegram: • ‘Mn’ = Notification (Request without reply) • ‘Mr’ = MD Request with reply • ‘Mp’ = MD Reply without confirmation • ‘Mq’ = MD Reply with confirmation • ‘Mc’ = MD Confirm • ‘Me’ = MD error	‘4D6E‘H (‘Mn’) ‘4D72‘H (‘Mr’) ‘4D70‘H (‘Mp’) ‘4D71‘H (‘Mq’) ‘4D63‘H (‘Mc’) ‘4D65‘H (‘Me’)
comId	Identifier of the user dataset.	Set by user.
etbTopoCnt	The ETB topography counter: • Shall be used (train addressing) as defined in IEC 61375-2-5. • Shall be set by the user. • Shall be set for all communication over the ETB. • Shall be set if a valid opTrnTopoCnt is set. • Optional in all other cases. Shall be set to 0 (= invalid) if not used.	0 – 2^{32}-1, Set by user.
opTrnTopoCnt	The operational train topography counter: • Shall be set by the user. • Shall be set for communication between functions which use information from the operational train directory (e.g. side selective operations). • Shall be set when the source device used the operational train directory to retrieve the destination IP address. • Optional in all other cases. Shall be set to 0 (= invalid) if not used.	
datasetLength	Length of the user data set in number of octets without padding octets.	0 – 65388, Computed.

replyStatus	The status value shall be set by the replier to report the execution result of a request message or by the caller sending a confirmation. The execution result is supplied by the replying application and transmitted to the requesting application in addition to the reply message itself. In case of a TRDP error reply (‘Me’) the value is supplied by TRDP: • –1: reserved • –2: session abort • –3: no replier instance (at replier side) • –4: no memory (at replier side) • –5: no memory (local) • –6: no reply • –7: not all replies • –8: no confirm • –9: reserved • –10: sending failed	< 0: NOK = 0: OK > 0: user reply status
sessionId	The session identification: • Shall identify a “request-reply” or a “request-reply-confirm” session which is composed of a caller session and a reply session. • Shall identify a “request-error” session when the replier’s TRDP layer returns an error message. • Shall be computed at caller side and reused at replier (listener) side. • Shall be used at caller side to relate a reply or error message to the original request message. • Shall be used at replier side to identify a retransmission of the request in case the reply message was not received and to identify the confirm message.	Computed.
replyTimeout	The reply timeout value shall be set to define the expected reply time (in µs) in a “request-reply” session. Shall be set to 0 for 'Mn', 'Mp', 'Mc' and 'Me' type telegrams.	1 – 2^{32}-1 0: infinite time
sourceURI	The source URI: • Shall be used for functional addressing. • Shall be a null terminated string. • Filling bytes at the end shall be set to 0. • Shall contain only the “user part” without “host part” and “@”. • May be an empty string (all 0).	
destinationURI	The destination URI: • Shall be used for functional addressing. • Shall be a null terminated string. • Filling bytes at the end shall be set to 0. • Shall contain only the “user part” without “host part” and “@”. • May be an empty string (all 0).	

headerFCS	The header frame check sequence: • Shall be calculated for the MD-PDU header. • Shall not include the headerFCS itself.	
dataset	The user data set. If the user data length is not a multiple of 4 octets, octets with a value of 0 shall be appended until a multiple of 4 octets is reached (padding bytes).	

Table 7-27: MD-PDU parameters

7.4.2.3.2 Safe Data Transmission protocol (SDTv2)

This section provide description for Safe Data Transmission protocol including introduction, vital data packet, safe data source, safe data sink and safety analysis.

7.4.2.3.2.1 Introduction

TRDP layer may optionally be extended by a **safety layer,** which provides safe end-to-end data transmission of safety critical (vital) process data and message data between any two end devices in the network. For this purpose, Safe Data Transmission protocol (SDTv2) provides a safe communication path between a Safe Data Source (SDSRC) and one or several Safe Data Sinks (SDSINK). This safe communication path is called "SDTv2 channel" (Figure 7-30:), which starts and ends at safe applications, and covers the entire path along from the SDSRC application to the SDSINK application(s). This includes the Train Communication Network (TCN), as well as the communication layers related to the TCN which reside on the Safe End Devices (ED-S) hosting the safe application, both of which are considered not trustable from a safety point of view.

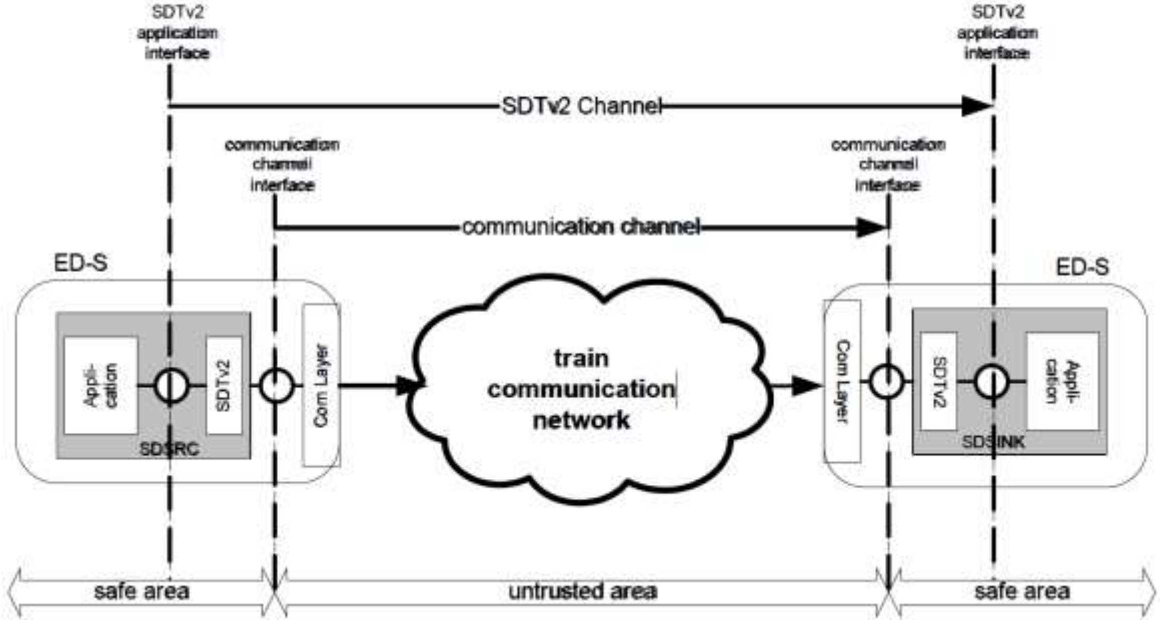

Figure 7-30: SDTv2 channel

An ED-S may contain one or a number of SDSRCs or SDSINKs, respectively. SDSRC and SDSINK itself can be described as a composition of the safe application and the SDTv2 protocol layer, which provides two interfaces:

- The communication channel interface is defined by the communication technology underneath (i.e. TRDP), and it is the interface where SDTv2 protocol data units (called Vital Data Packets (VDP)) are sent to or received from the TCN.
- The SDTv2 application interface, which is product specific, is the place where safety related process data are put to or get from the application.

The SDTv2 layer, on SDSRC side, has mainly the task to add protocol information to form a VDP, which is necessary for a safe transfer of those data over the network, prior to sending. On SDSINK side, the SDTv2 layer validates received VDPs, and if validation is successful, contained vital data are exposed in the SDTv2 application interface.

As in the case of TRDP, all data within SDTv2 shall be transmitted in big-endian format, and all data structures used within SDTv2 shall be naturally aligned.

7.4.2.3.2.2 Vital Data Packet

A SDSRC shall encapsulate safety critical data in a Vital Data Packet (VDP) before transmission. VDPs transferred over ETB (ETB-VDP) are **transmitted within the user data part of a TRDP process data telegram.** A VDP may also be transmitted within the user part of a TRDP message data telegram, but with some restrictions.

The structure of an ETB-VDP is defined in Figure 7-31, with additional explanation given in Table 7-28.

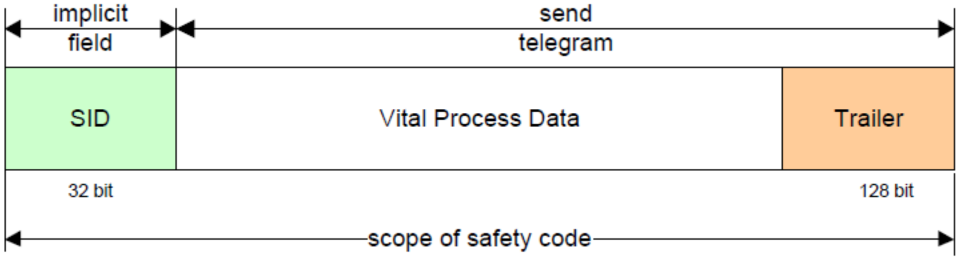

Figure 7-31: ETB-VDP

Parameter	Description
Source identifier (SID)	All sources of safety related data (SDSRC) shall be identified by a SID. It is a unique identification of the VDP within the train wide network, both in space (different SDSRC have different SID) and time (SID of SDSRC must change after train inaugurations changing the train topology). The SID shall be an unsigned32 value which is computed as a SC-32 signature of a data structure containing the following parameters, which ensures its uniqueness: • User defined Safety Message Identifier (SMI), which shall be unique within a consist. • Version of the SDTv2 protocol. • Unique consist identifier • Safe Topograph Counter (STC), which is a unique identification of the actual train composition.
Vital process data (VPD)	User defined data set with safe and non-safe process data (padding bytes may be necessary to have a total length of a multiple of 4 octets).
Trailer with check parameters	These parameters are used by the SDSINK receiver to verify the correctness of a received VDP. It includes: • UserDataVersion, i.e. the version of the vital process data part. • Safe Sequence Counter (SSC), which is incremented each time a new VDP is generated and stored to the communication channel interface. • SafetyCode: SC-32 cyclic redundancy code (CRC). It is computed over VDP, starting with most significant byte of VPD up to the SSC (seed value: SID).

Table 7-28: ETB-VDP parameters

7.4.2.3.2.3 Safe data source (SDSRC)

A safe data source is intended to produce VDPs, meaning that the VDPs are generated and are subsequently passed to the communication layer for transmission. It must be remarked that VDPs shall not be produced if the end device hosting the SDSRC is not a safety device.

There is an application aimed at safe data preparation, i.e. responsible for providing the vital process data to be sent with SDTv2. Two input data classes are distinguished:

- Continuous data: Those data are characterized by changing their value more or less continuously over time (e.g. speed signal). Only samples of those data need to be transmitted. After sampling, the sampled data value is kept constant until the next sample (sample and hold principle).
- Discrete data: Those data are characterized by changing their value on event (example: doors close/open signal). All different values of those data need to be transmitted, because otherwise

safety related information might get lost. The application shall ensure that all value changes of a discrete input data item (signal) are sampled and that the samples are kept stable in the SDTv2 application interface.

It is convenient to have redundant SDSRCs. The redundancy principle is to have two redundant source devices (SDSRC-A and SDSRC-B) forming one redundancy group. The input signal is read by both source devices, but only one device (redundancy leader) is actively sending VDPs to the sink (SDSINK), while the other device (redundancy follower) is not sending. Both source devices supervise each other, and if the redundancy follower detects a failure of the redundancy leader, it starts actively sending to SDSINK (Figure 7-32:).

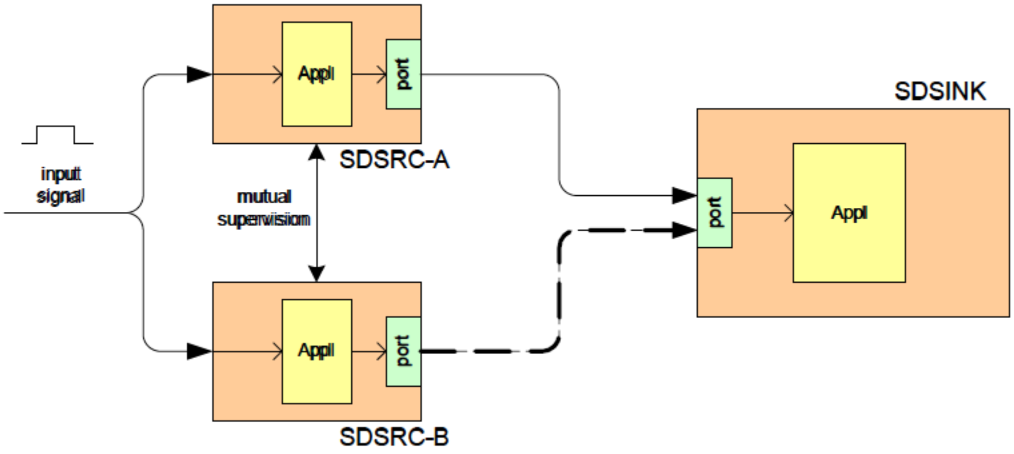

Figure 7-32: Redundancy group (example with 2 SDSRCs)

7.4.2.3.2.4 Safe data sink (SDSINK)

A safe data sink is intended to receive ("sample") VDPs, in order to validate them and to expose received process data in the SDTv2 application interface. "Sampling" of VDPs in this context means that the most recent VDP is read from the communication channel interface. Each received VDP can be classified as follows:

- Duplicate VDP: A received VDP is considered a duplicate if it is identical to the VDP received before.
- Correct VDP: A received VDP is considered correct if:
  - SafetyCode is correct (computed SafetyCode value is identical to the SafetyCode value contained in the VDP);
  - UserDataVersion is correct (equals the expected user data version value).
- Initial VDP: A received VDP is considered initial in one of the following cases:
  - It is not a duplicate;
  - It is the first correct VDP received after power-up/reset;
  - It is the first correct VDP received after a communication loss;

    - It is a correct VDP, but where the SafetyCode evaluation has been done with the alternative SID of the redundant SDSRC (a VDP with a different SID may be received when a redundancy shift occurs within a SDSRC redundancy group).
- Fresh VDP: A received VDP is considered fresh if:
    - It is correct;
    - The VDP is not the initial VDP;
    - The SID of the VDP is identical to the initial SID;
    - It is a real successor to the initial or fresh VDP received before.
- Valid VDP: A received VDP is considered valid if it is a fresh VDP or a duplicate of the fresh VDP received before. In all other cases, it shall be considered invalid.
- Discarded VDP: Discarding a VDP means not to expose its data to the application.

SDSINK is also in charge of checking VDP integrity, filtering those VDPs which are not correct. After a power-up, reset, redundancy shift or a loss of safe communication, the receiver waits for the reception of an initial VDP, which is used to synchronize the SDSINK with the SDSRC. Nevertheless, receiving the initial VDP is not sufficient to indicate the reception of valid and safe data to the application. This will be done only with the next received fresh VDP, which matches the “window of expected SSC“. This window defines a range of allowed SSC values which have to be matched by the VDPs following the initial VDP, in order to ensure that the received VDPs are in correct sequence. This window is shifted to the right with each received VDP, so subsequent VDPs need to match the shifted window. In the example of Figure 7-33:, a VDP with SSC = 09 has been received. The next VDP is expected to have a SSC in the range of 09 to 13. If the next received VDP has a SSC of 09, it will be a duplicate of the previously received VDP. If it has a SSC of 10 to 13, it will be a fresh VDP. All VDPs matching the window are called “valid”, but only those with a new SSC value are called “fresh”. After receiving the VDP with SSC = 10, the window is shifted by one covering now the range of 10 to 14.

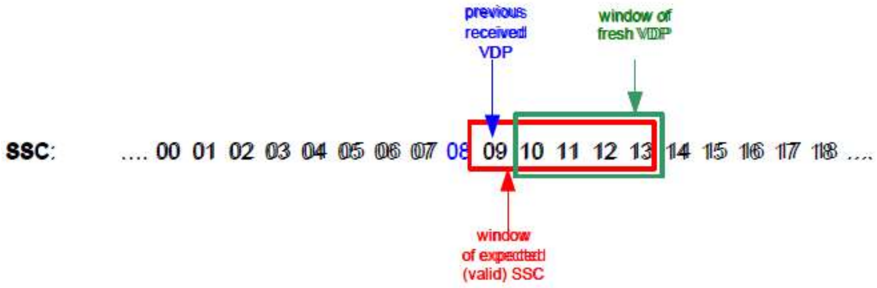

Figure 7-33: VDP integrity check (example)

Besides, SDSINK is also able to detect two redundant active SDSRCs (both sending VDPs) by means of checking the “guard time”, which starts with the reception of an initial VDP. If a VDP with a SID different from the expected one is received during that time, SDSINK will assume that both redundant SDSRCs became active and shall indicate loss of communication safety. Such an event is called "guard time violation".

7.4.2.3.2.5 Safety analysis

A safety analysis performed in CONNECTA concluded that **SDT protocol is capable of guaranteeing a safety integrity level SIL4 (SDTv4)** if the structure of the VDP is modified as follows (there are two possible alternatives):

- Variant 1: Use of small safety frames with a maximum payload of 8 bytes (note that reducing the amount of safety related data within a safety frame could also reduce the error probability). In this case, the CRC computation has to be executed once by using the same polynomial as the computation of the SID.
- Variant 2: Use of large safety frames with a maximum payload of (PDU-Size – Trailer) bytes. In this case, the CRC computation has to be executed twice by using a second suitable generator polynomial. When choosing the polynomials, care should be taken that at best the polynomials have no common factors.

7.4.2.4 Euro-radio over TCP/IP [5]

The EN50159 [6] defines the reference architecture for safety-related systems using open transmission systems.

A safety system designed in conformity to this architecture can be used by application processes to exchange safety-related and non-safety related information with remote application processes using the services of the Radio Communication System (RCS).

RCS is part of the Open Transmission System along with the Open Network (public or railway owned), as established by EN50159 [6] and depicted in the Figure 7-10: of the following document.

It is composed by two components:

- Safety Functional Module (SFM), that encompasses the functionalities of the safety-related transmission system.
- Communication Functional Module (CFM) that provides the functions of the communication system based on circuit switched bearer services of GSM-R PLMN.

The EURORADIO, as safety communication protocol, is compliant with this RCS architecture. The protocol level communicates with its neighbouring levels through different interfaces:

- The lowest level interface, is interposed between RCS and the chosen transmission medium; it is composed by a user plane, that deals the transferring of user data, and a control plane, that take care of connection management.
- The second interface, optional and not required for ERTMS level 1 Radio Infill unit, interfaces non-safe applications or support applications and the Communication Functional Module.
- The third Interface is a service interface between safe applications (e.g. ATP/ATC) and SFM (safety layer).

The coordinating function of the CFM covers the OSI layer 4 (Transport layer), layer 3 (Network layer) where performs routing, and layer 2 (Data Link layer) where can handle GSM-R modems and fixed network. At the Transport layer the X.224 protocol for connection mode transport service is used; it also ensures the interoperability with remote entities.

The safety services of SFM provide safe connection setup, and safe data transfer during the connection lifetime.

In particular, the Safe Service (SaS) user exchanges data with the SaS provider and the safe data transfer takes care of data integrity and data authenticity. These safe services are accessed by means of safe service primitives with their corresponding parameters at the Safe Service Access Point (SaSAP).

An example of a protocol stack is the use of Euro-radio over TCP/IP is shown in Figure 7-34:.

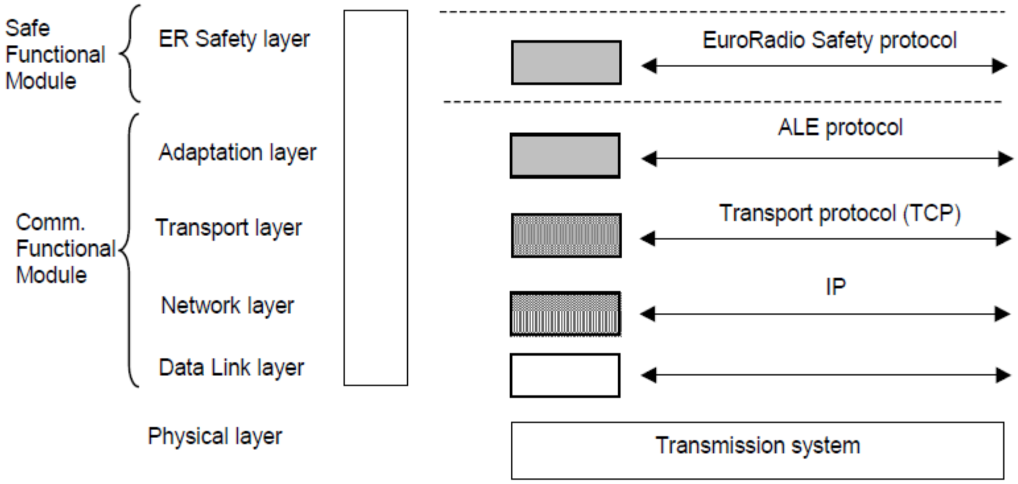

Figure 7-34: Protocol Stack of Euro-radio over TCP/IP

Its applicability to the OTI monitoring function, based on the communication between OTI-M and OTI-S modules, is reported in Figure 7-34.

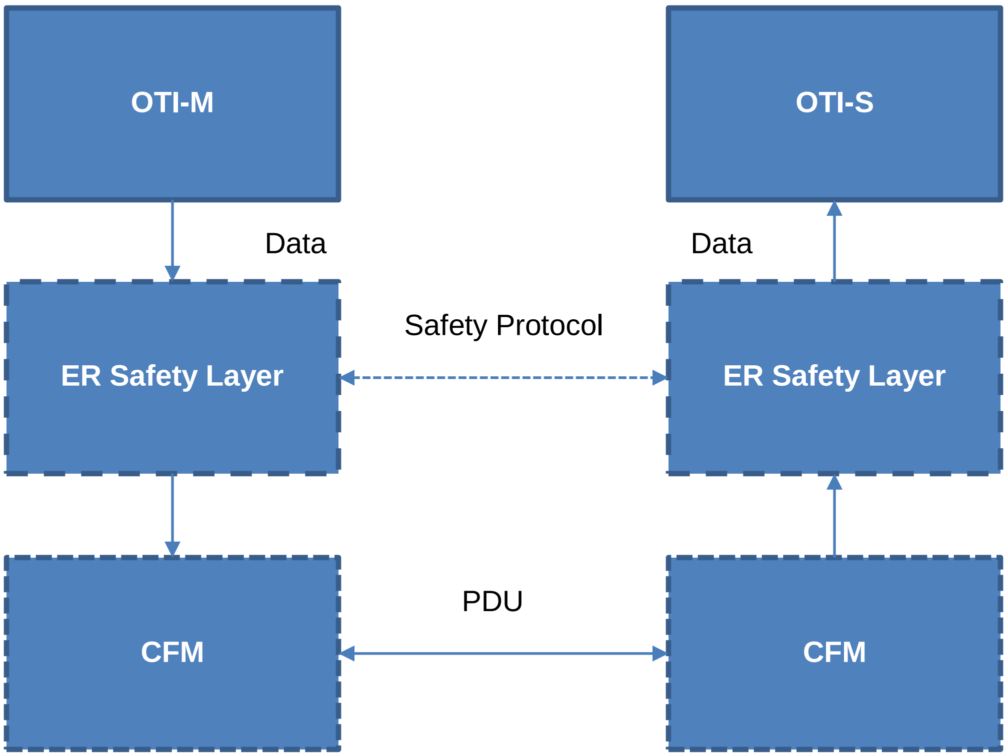

Figure 7-35: Model of Euro-radio protocol for OTI Monitoring function

The OTI Master module can be considered as a safety user, installed in the head of the train, which communicates with its OTI Slave module(s) (other safety user(s)) through one or more safe service access points by means of the safe service primitives, implemented by Euro-radio (ER) Layer.

The peer safety entities support safe connection exchanges by means of safety protocol data units (PDU).

These protocol exchanges use the services of the transport layer via one Transport Connection (TC) through one transport service access point (TSAP) inside the CFM module.

Based on these exchanges of data (PDU) the two safety users (OTI master and OTI slave module) can monitor the communication vitality and check the train integrity functionality.

An example of Master-Slave communication based on the Euro-radio protocol over TCP/IP is shown in Figure 7-35. Request and ACK messages exchanged between Master and Slave modules are sent through Euro-radio protocol over TCP/IP while the parameters T_OTIM_I, T_OTIM_COMM, T_OTIM_L and T_OTIM_R are configuration parameters. Detailed description of master slave communication is reported in D4.1 [1].

7.4.2.5 New rail digitalisation services - Solution defined in IP5 for Freight Environment

This solution propose looking forward the evolution of the rail services, taking into account the objective of Shift2Rail focused on research, innovation and market-driven solutions by accelerating the integration of new and advanced technologies. With rail digitalization on the horizon, it is important to consider protocols in which may be possible to integrate not only current services, but the future ones.

New market perspectives should be analysed to boost the rail supply industry's competitive edge, guaranteeing safety and security. Furthermore, looking to the future of railway technologies, it is important to set the focus on wireless communication protocols.

DEWI [46] [16] and SCOTT [9] projects focus on Train Integrity (and other rail services) have analysed several protocols for all layers in OSI model. To define the distribution, access and transport layer, for current and new rail services (On-Board and On-Track services); and different Sensor Network solutions, these projects make use of the Semantic Sensor Network Ontology [47] for describing sensors and their observations, the involved procedures, the studied features of interest, the samples used to do so, and the observed properties, as well as actuators.

The works from DEWI and SCOTT are been used in IP5 FR8RAIL project [9] for the communication stack protocol, ontology, data model and interface definition. The ontology defined in IP5 for freight services is considered an input for the Canonical Data Model of S2R for freight rail environment.

Thinking in the future integration of several services which complement the On-Board Train Integrity service, it is recommended the use of open standard protocols which facilitates broader adoption of new technologies. In this context, messaging protocols such as AMQP or MQTT are gaining relevance in several fields related to future deployments in an IoT environment. Furthermore, the AMQP/MQTT standards, which are proposed as the most suitable candidates for session and application layers, are fully compliant and recommended for IoT solutions (WSN and actuators) by the AIOTI[1] and follows the main structure of ISO/IEC 29182 – Sensor Network Reference Architecture [48].

In addition, AMQP offers several benefits, such as reliability, safe delivery of messages, secure connection or extensibility. This last benefit has an actual importance looking forward to compatibility and scalability in future developments of new standards and protocols. AMQP also complies with interoperability. As an example, the Interoperable Train Control (ITC) group integrated in the American Association of Railroads (AAR), is developing a communications messaging standard using AMQP [49] to support interoperability.

It is important to identify which protocols in the OSI lower layers can comply with application and presentation layers. Moreover, the integration of OTI functionalities in a more complex system that allocates other functionalities and guarantees safety and security is one of the main challenges of the current rail innovative projects. For this reason it is important to define a protocol level which covers the new market perspectives and also accomplish the time to market requirements. In the figure below, the protocol stack used in IP5 is proposed following the OSI model:

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[1] AIOTI: Alliance for Internet of Things Innovation

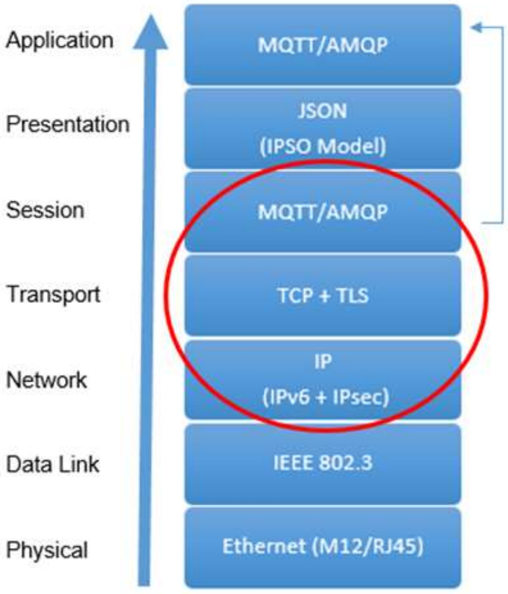


Figure 7-36: Protocol Stack

First of all, for physical layer, M12 encoded Ethernet cable is the hardware selected to be deployed as a connector for the interface. For data link layer, IEEE.802.3 protocol will be used at the link level communication since it is currently the most used standard in the industry.

For OSI level 3 (network layer), IPv6 protocol has been selected in FR8RAIL. The use of IPv6 allows for possible connections towards the Internet in the future. Additionally, IPv6's implementation of the IPsec functionality in every connection increases the overall security of the system. Moreover, IPv4 is still chosen, besides IPv6, to comply with the current IPv4 requirements as it is widely deployed.

In the transport layer, TCP has been chosen to comply with level 5 and 7, because MQTT and AMQP has been developed to best perform over TCP. To reach extra security, TLS protocol is included in this layer as it is recommended by the MQTT standard.

The transport layer has to support the protocols developed in the session and application layer. The application layer focus on MQTT (Message Queuing Telemetry Transport) and AMQP (Advanced Message Queuing Protocol), which also implements functionalities in session level, covering both layers and accomplish safety conditions. The use of MQTT or AMQP depends on the interface definition:

- Cargo/Waggon sensors to OTI Slave -> MQTT
- OTI Slave to OTI Master -> MQTT or AMQP

7.4.2.5.1 Standards and regulations

For the specification of the Sensor Network for Train Integrity purposes, the following standards were analysed:

- ERTMS/ETCS SubSet-026 [2]: where the functional requirements on Safe Rear Train End reporting include the Train Integrity information. Specifically, the following subsections and requirements of the subset have been taken into account for the Sensor Network specification:

- SubSet-026-5 section 5.4: The ERTMS/ETCS on-board equipment shall request the driver to enter/revalidate the Train Data that requires driver validation.
- SubSet-026-5 section 5.14.2: If the ERTMS/ETCS on-board equipment which was supervising the train before splitting has not performed an end of mission for splitting, the driver must modify the Train Data such that it fits with the new train composition after splitting.
- SubSet-026-5 section 5.14.3: If a former leading ERTMS/ETCS on-board equipment remains leading and there was no end of mission, the driver must modify the Train Data such that it fits with the new train composition.
- SubSet-026-3 Requirement 3.13.3.1.1 "For trains with variable composition (loco hauled trains), the brake characteristics can vary together with the composition of the train. In this case, it is not convenient to pre-program the brake parameters necessary to calculate the braking curves. The only practical way to obtain the correct values for the current train composition is to include them into the data entry process by the driver."
- SubSet-026-8 Requirement 8.5.2: "Train to Track radio message" Message 129 Validated Train Data:

Field No.	Variable/Packet	Remarks
1	NID_MESSAGE	
2	L_MESSAGE	
3	T_TRAIN	
4	NID_ENGINE	
5	Packet 0 or 1	
6	Train data	Train - track packet type 11.

Table 7-29: Validated Train Data Message

- CENELEC EN50159 [6]: Classification of the communications between devices (Backhaul)

7.4.2.5.2 MQTT

MQTT protocol has been chosen for defining interfaces in IP5 FR8RAIL due to its high penetration in the industry concerning IoT networks. In this case, once the connection is established, the interface will be used to exchange “publish messages” in a safe way. These messages are defined in the MQTT specification [50] and they are composed of a header and a payload. The routing key is the first value and the publish message structure will be the following:

bit	7	6	5	4	3	2	1	0
Byte 1	Message type				DUP	QoS level		RETAIN
	0	0	1	1	0	0	1	0
Byte 2	Remaining length							
Len MSB	0	0	0	0	0	0	0	0
Len LSB	0	0	0	0	0	0	1	1
‘a’	0	1	1	0	0	0	0	1
‘/’	0	0	1	0	1	1	1	1
‘b’	0	1	1	0	0	0	1	0
ID MSB	0	0	0	0	0	0	0	0
ID LSB	0	0	0	0	1	0	1	0

Table 7-30: MQTT publish message header

An MQTT system consists of clients communicating with a server, often called a "broker". A client may be either a publisher of information or a subscriber. Each client can connect to the broker. Communication within MQTT is articulated through Topics. Senders and receivers must be subscribed to a common topic in order to be able to communicate.

These topics have a hierarchical architecture thanks to which we can establish father-children relationships. Considering this fact, when a MQTT client (node) is subscribed to a father topic, it will also receive the information provided by the children. To enable the data provision for children, while the subscription is done to the father, the multilevel wildcard “+” must be added.

The different involved nodes that belong to the WSN will be able not only to read the data from the sensor measurements but also to write on them as part of the actuators role. Each topic will be included in every measure it is used in, so keeping them short and concise will help to maintain the simplicity of the system. The fields of the header are explained below:

- Service and sub-service: Indicates the type of service. It is important to identify the service that remains essential within the Rail domain, looking ahead to new future services to be implemented and the scalability of the system. The subservice is a more specific identification for the MQTT packets into the service specified in the service field.
- Region and sub-region: This region indicates the location of a sensor or an OTI Slave.

- Source and sub-source: This field is used to indicate the owner of the source that reports the treated data.
- CRC: To foresight the security and safety analysis of the system which has to be performed, it is important to include a field for CRC calculation to detect unexpected changes on the data and verify the integrity of the data.

MQTT defines three levels of Quality of Service (QoS), which defines the level of message confirmation. Higher level of QoS are more reliable, but involve higher latency and have higher bandwith requirements.The QoS levels are the following:

- QoS 0: The broker/client will deliver the message once, without confirmation.
- QoS 1: The broker/client will deliver the message at least once, and requires confirmation.
- QoS 2: The broker/client will deliver the message exactly once by using a four step handshake.

Messages could be sent at any QoS level and clients may subscribe to topics at any QoS level, choosing the maximum QoS it will receive. For example, if a message is published at QoS 2 and a client is subscribed with QoS 0, the message will be delivered to the client in QoS 0. If another client subscribe to this topic with QoS, it will receie the message with QoS 2. In the same way, if a message is sent at QoS 0, and a client is subscribed with QoS 2, it will receive the message on QoS 0.

To guarantee the highest QoS level, QoS 2 has to be developed for brokers and clients. With this level neither the loss nor packets duplication is acceptable. On the other hand, the most reliable QoS level is also the slowest. QoS 2 should be used with specific clients that demand guaranteed delivery of messages over transmission speed. It has to be used in safety critical scenarios that cannot allow to lose messages or receive duplicate ones. However, for most of the deployments, QoS 1 seems to be sufficient.

All messages may be set to be retained, so the broker will keep the messages after sending to the subscribers. If a new subscription to this topic is created, the broker send this retained message to this new subscriber.

Another feature of MQTT is the support of message persistence, which is really useful when dealing with clients in a constrained environment. In normal environments, when a client which has started a session for subscribing or publishing topics lost the connection, the process starts again with the session establishment. This could be a disadvantage for systems with clients which have low processing power and intermittent connectivity. Due to the message persistence feature of MQTT, in a constrained environment, when a client connects to the broker, it can set the “Celan Session”

7.4.2.5.3 AMQP

AMQP is an open standard application layer protocol for message-oriented middleware which allows the reliable and safe exchange of messages between two parties, and it is broadly defined in ISO / IEC 19464 [51]. The main characteristics of AMQP [52] are:

- Message orientation
- Queuing
- Routing, including publisher-subscriber routines.
- Security

- Reliability

AMQP protocol has been also chosen due to its high penetration in the industry concerning IoT networks and future services that may be allocated in the OTI system. In AMQP case, once the connection is established, the interface will be used to exchange publish messages. Below is shown the general format of the AMQP frame composed by the frame header, payload and frame end. The frame payload format will depend on the frame type. The publish message header of AMQP is shown in the following figure:

Figure 7-37: AMQP publish message header

The publisher-subscriber structure explained for MQTT is also used by AMQP and it exists several topics to be subscribed by Producers-Publishers that send messages to the broker. These messages are stored in a queue until Consumers-Subscribers consume them.

OASIS group has given a definition of the AMQP protocol focusing on transport and messaging [53]. This definition introduces the AMQP network as a group of nodes connected via links. Nodes are named entities responsible for the safe messages exchanging.

The AMQP transport specification defines a peer-to-peer protocol for transferring messages between nodes in an AMQP network. In order for communication to occur between nodes in different containers a connection needs be established.

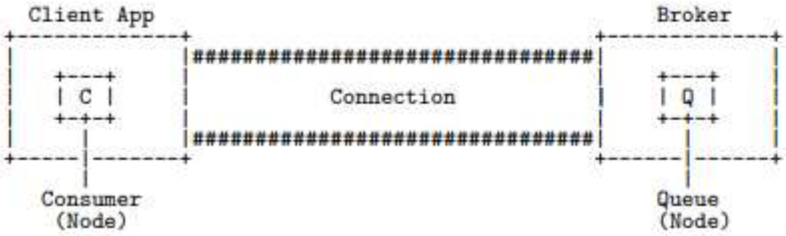


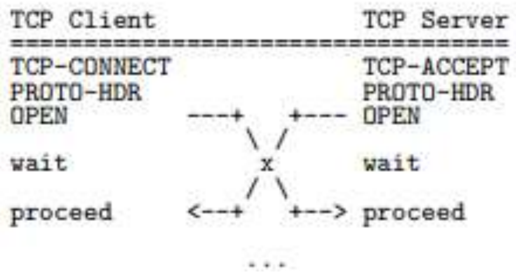
Figure 7-38: AMQP connection

An AMQP connection is divided into a negotiated number of independent unidirectional channels. Each frame is marked with the channel number indicating its parent channel, and the frame sequence for each channel is multiplexed into a single frame sequence for the connection. A single connection may have multiple independent sessions active simultaneously, up to the negotiated channel limit.

AMQP connections are divided into a number of unidirectional channels. A connection endpoint contains two kinds of channel endpoints: incoming and outgoing. This requires connection endpoints to contain two mappings. One from incoming channel number to incoming channel endpoint, and one from outgoing channel endpoint, to outgoing channel number.

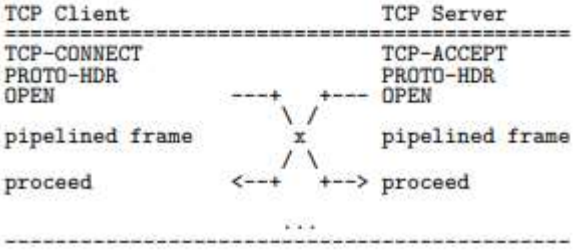
As examples of the messaging exchanges related to connection, the following sequences are presented:

- **Opening a connection**



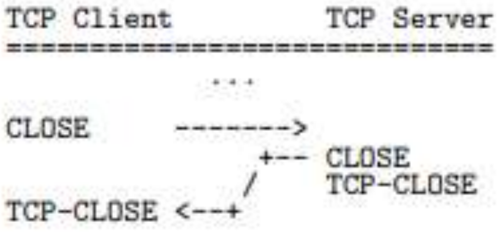
```
TCP Client              TCP Server
==================================
TCP-CONNECT             TCP-ACCEPT
PROTO-HDR               PROTO-HDR
OPEN        ---+   +--- OPEN
                \ /
wait             x      wait
                / \
proceed     <--+   +--> proceed

                ...
```

- **Pipelined Open**



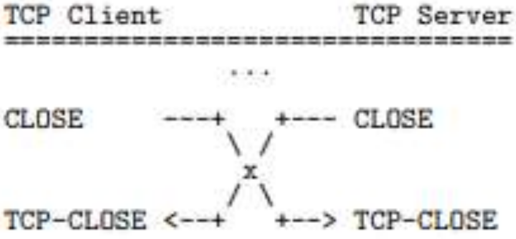
```
TCP Client                        TCP Server
============================================
TCP-CONNECT                       TCP-ACCEPT
PROTO-HDR                         PROTO-HDR
OPEN                 ---+   +---  OPEN
                         \ /
pipelined frame           x       pipelined frame
                         / \
proceed              <--+   +-->  proceed
                         ...
--------------------------------------------
```

- **Closing a connection**



```
TCP Client          TCP Server
==============================
           ...

CLOSE     -------->
               +-- CLOSE
              /    TCP-CLOSE
TCP-CLOSE <--+
```

- **Simultaneous Close**



```
TCP Client            TCP Server
================================
           ...

CLOSE     ---+   +--- CLOSE
              \ /
               x
              / \
TCP-CLOSE <--+   +--> TCP-CLOSE
```

When a message transference starts, a delivery-tag is assigned and used to track the state of the delivery while the message is been transferred. A delivery is considered unsettled at the sender/receiver from the point at which it was sent/received until it has been settled by the sending/receiving application. Each delivery must be identified by a delivery-tag chosen by the sending application. The delivery-tag must be unique amongst all deliveries that could be considered unsettled by either end of the link.

Once the message data reception is notified, the application processes the message, indicating the updated delivery state to the link endpoint as desired. Applications can classify delivery states as terminal or non-terminal depending on whether an endpoint will ever update the state further once it has been reached. Once the receiving application has finished processing the message, it indicates to the link endpoint a delivery state and an ACK is expected from the sending application.

7.4.2.5.4 Object Model

MQTT and AMQP protocol do not implement a functional presentation layer by default, so it is necessary to use a message structure for the producer and the broker exchange. In this context, and taking into account the future evolution of the system and the wide range of sensor networks, the JSON language is a good candidate as the data representation language within MQTT and AMQP. Although, for safety capabilities other file formats will be analysed (CBOR as an example), and their suitability will be studied.

Furthermore, in IP5 FR8RAIL project, to provide high-level interoperability between the sensors with other devices or services, the object model proposed is IPSO Smart Object. IPSO Objects are not based on the Constrained Application Protocol (CoAP), although this object model is based on Open Mobile Alliance Lightweight Specification (OMA LWM2M), which is a set of management interfaces built on top of CoAP. OMA LWM2M is used to develop an interoperable solution.

The main reason of the use of the IPSO Smart Objects is to set a common language and semantic for naming the different data that can be exchanged in the system. This alliance will be in charge of maintaining and updating the object and resource catalog.

7.4.2.5.5 Process Data

Several examples of communication based on the protocols defined on this section are shown below. Request messages have been exchanged using MQTT/AMQP.

The first example is related to the inauguration process. When the driver start the inauguration process, the requester/subscriber analyses the moving state of the train and can deny the inauguration process in case that the train is not stopped nor expecting for the inauguration. The exchange of messages is shown in the following figure:

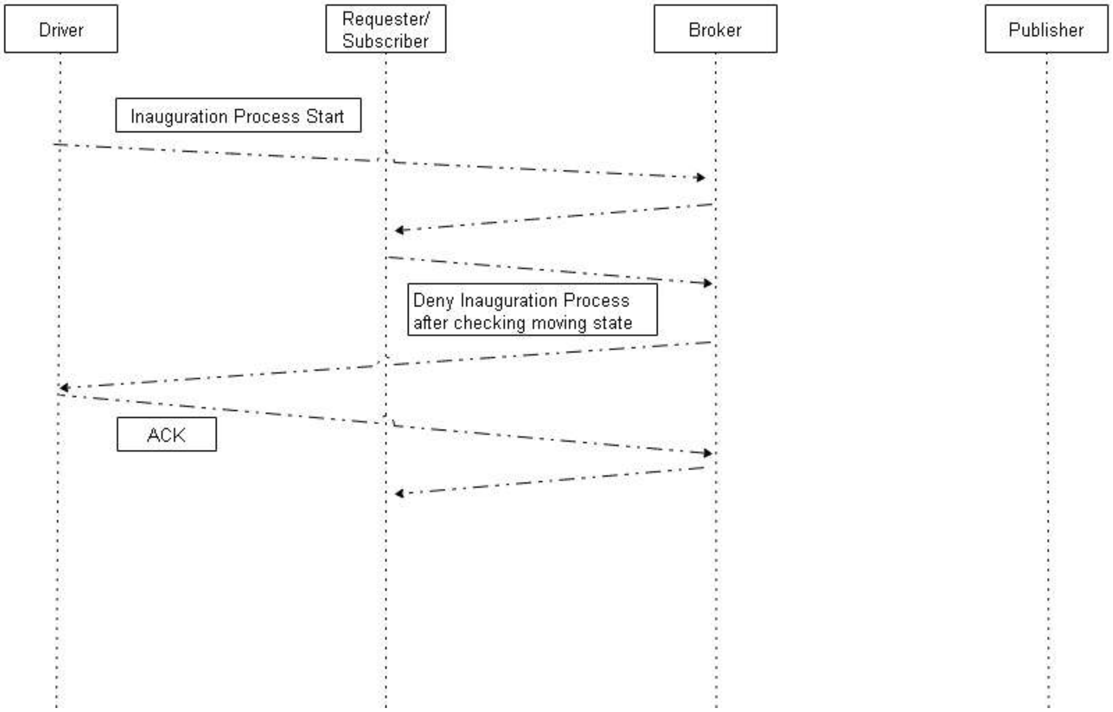


Figure 7-39: Inauguration Process Denied

In case the train is stopped and expecting for the inauguration process, the exchange of messages using the protocols defined along the previous sections is shown below:

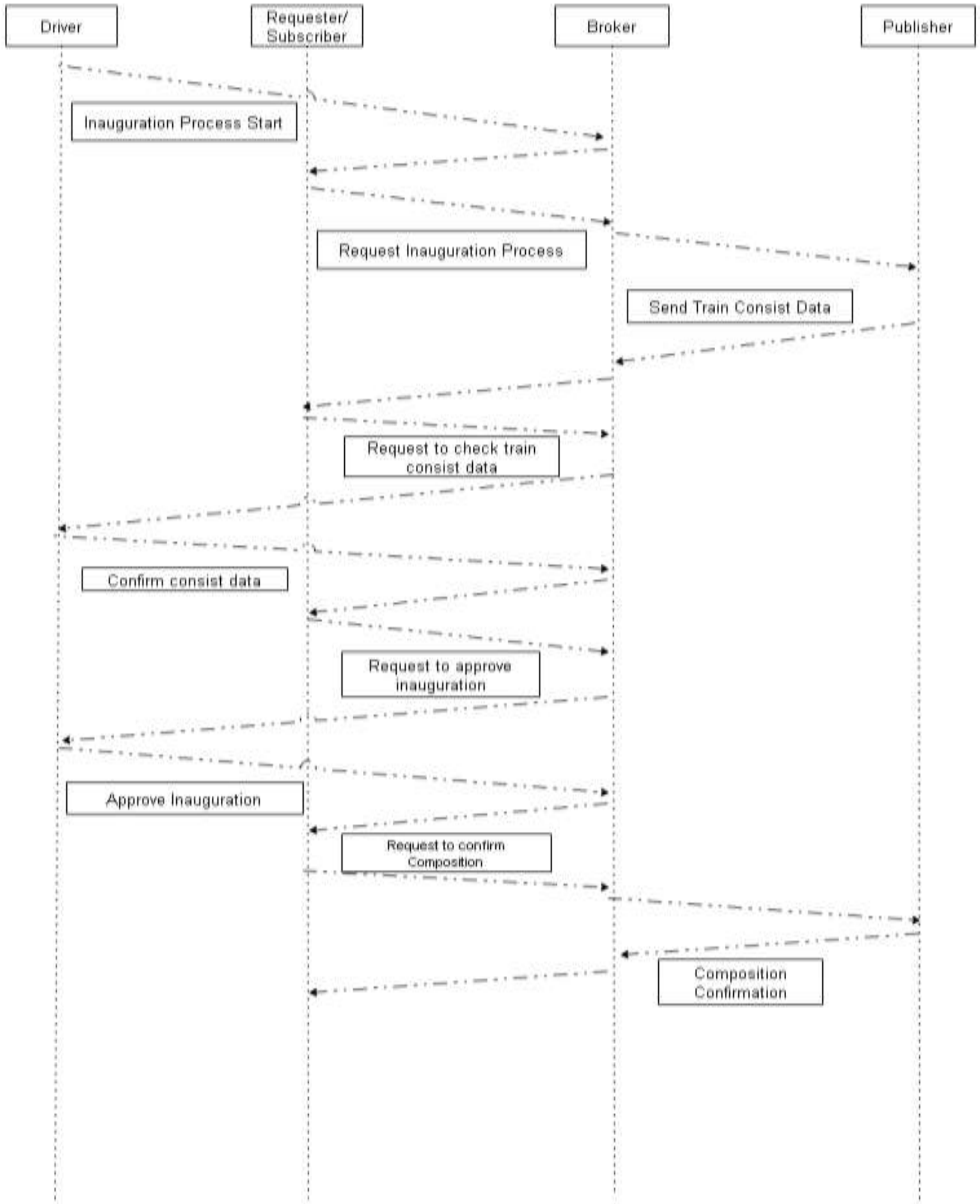


Figure 7-40: Example of Train Inauguration Process

An illustrative example of the train integrity process following the directives of the protocols already described is shown in the following figure:

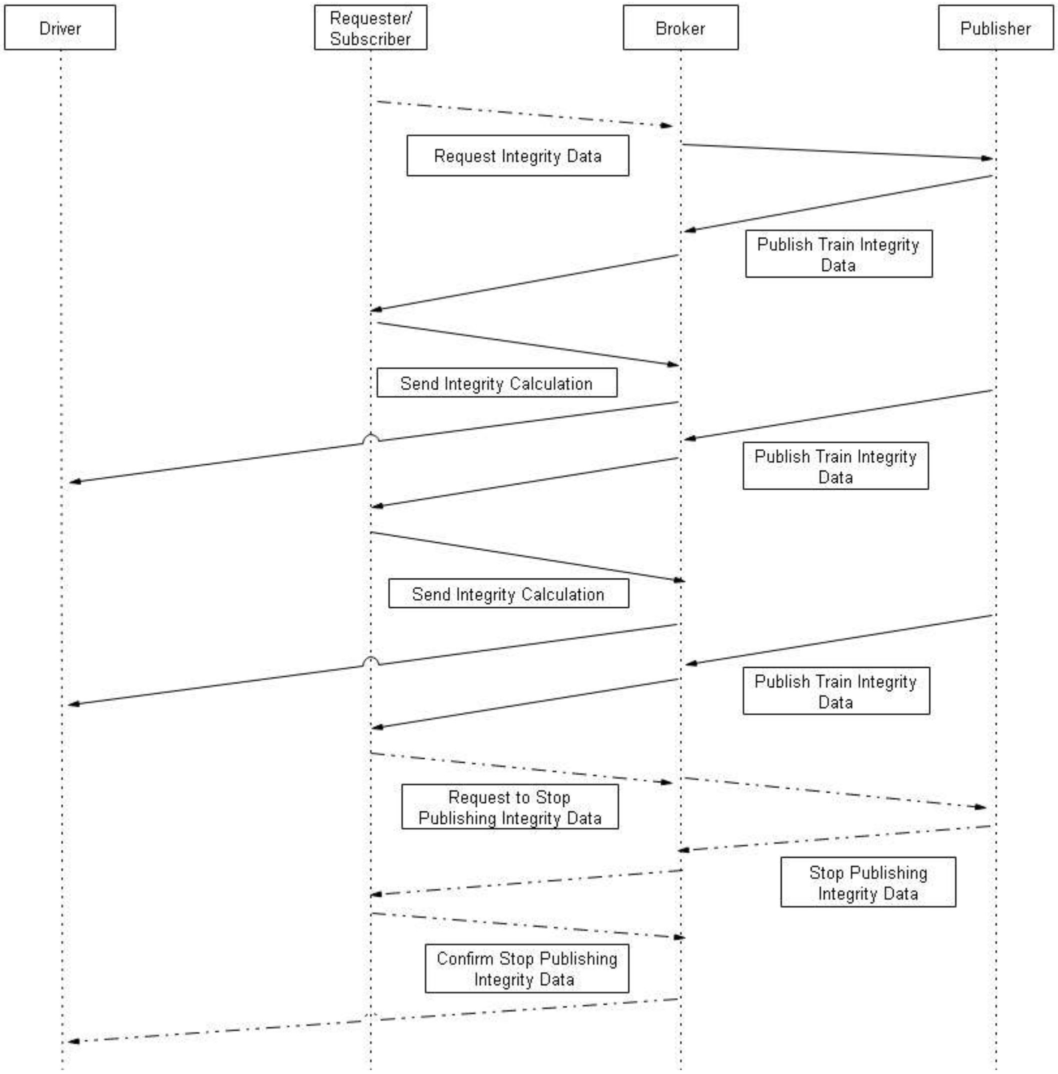


Figure 7-41: Example of Train Integrity process

7.4.3 Physical level

The On-Board system uses in general different wired physical buses to exchange information between different on-board sub systems for different purposes. Possible solutions for wireless communication are reported at section 9.

This section provides an analysis of different solutions for physical level in relation to their applicability to "**ETCS - OTI Master**" interface and "**OTI Master - OTI Slave**" interface.

In general all options considered in the following are suitable to support bidirectional messages exchange with a lacency less than 1 sec.

The physical wired buses used by on-board system are:

- PROFIBUS
- MVB BUS
- SERIAL LINE (RS232 and RS 485)
- DIGITAL I/O
- ETHERNET

The PROFIBUS is most used inside the on-board system (e.g. communication with BTM system, JRU system, etc.). PROFIBUS interface and related protocol stack are suitable for vital applications. Maximum speed of PROFIBUS communication is around 1,5 MBPs.

The MVB bus is used inside the on-board system and typically it is used for non-vital or diagnostic information.

Inside the on-board system also the serial lines are used, typically the serial lines used are the RS 232 and RS 485.

The RS 232 is a low cost interface but it supports lower speed for long distances. Higher speed (i.e. 115200 baud) can be achieved for short distances only.

The RS 485 use of differential signalling, maximum data transmission speed (100 Kbps) and distance up to 1200 meters are supported. It is immune to noise and the response time between reader and software is short when less than 32 controllers (or readers) are communicating on same data line.

Digital I/O are most used inside the on-board system as interface with the rolling stock. This interface is suitable for vital and non-vital applications and support acquisition or delivery of simple information (e.g. cabin status, train integrity status, TAIL/NON-TAIL information).

For new generation trains, ETHERNET interface and related infrastructure are available for wide range of applications.

Ethernet can be easily managed and connected using cheap industrial components. Ethernet cable for railway applications are also available. Ethernet is robust to the noise and support very high speed of communication. Ethernet infrastructure are already present in new generation trains. This interface is relatively inexpensive compared to other systems of connecting computers. All the nodes have same privileges; maintenance and administration are simple.

7.4.3.1 OTI Master - ETCS

As discussed in the paragraph above and quoted in SUBSET 119 [7], the use DIGITAL I/O interface is appropriate for the management of the interface between ETCS system and OTI Master module.

The OTI Master shall sent to the ETCS on-board the “Train Integrity status” as described the § 7.2.1 which has three possible values (i.e. confirmed, lost, unknown) then can be implemented with two VITAL OUTPUT according to Table 7-31 to ensure compliancy to ETCS backward compatibility scenario described in 8.

Vital output values	Train Integrity Status
High / High	unknown
Low / Low	unknown
High / Low	lost
Low / High	confirmed

Table 7-31: Interface with Vital Output to ETCS

More in general the ETCS-OTI functional interface specified in 7.2.1 and 7.2.2 implies a bidirectional exchange of messages. In general serial peer-to-peer communication or bus communication are suitable to support a bidirectional exchange of messages with a latency less then 1 sec.

As described in 7.4.3, as alternative to the use of the DIGITAL I/O for ETCS backward compatibility, the Ethernet is suitable to satisfy the needs of bidirectional exchange of messages with a latency less than 1 sec and is the most common solution present in new generation trains.

7.4.3.2 OTI Master – OTI Slave

As described in 7.4.3 Ethernet Interface satisfy the needs of an on-board network suitable to support bidirectional exchange of messages with a latency less than 1 sec.

7.5 Conclusion

This section considered the interfaces OTI Master - OTI Slave and ETCS – OTI Master with the general objective to support an interoperable specification by addressing the communication protocol and the physical level.

First step consisted in addressing the application level of the communication, based on functional requirements specified in D4.1 [1]. Then a second step addressed the protocol stacks by analysing communication services under specification and development (e.g. TD2.1, FRMCS, CONNECTA, SCOTT, DEWI and FR8RAIL) and existing solutions (i.e. euro-radio over TCP/IP) already implemented and currently in use. Finally, an analysis at physical level was considered.

In general, the results from experimental activities planned in X2Rail-2 and X2Rail-4 shall constitute a relevant input for the standardization proposal to be delivered as output from X2Rail-4.

The following two paragraphs contains a recap of the performed analysis in relation to OTI Master – OTI Slave interface and ETCS – OTI Master interface.

Proposed specification interface constitutes input guidelines for product specification and demonstrators implementation. Finally in X2Rail-4 a standardization proposal shall be specified.

7.5.1 Interface OTI Master-OTI Slave

In general a serial bus is required to support the functionalities specified in D4.1:

- role assignment (i.e. master or slave)
- device identification (i.e. OTI identifier)
- OTI Master pairing with OTI Slave at train tail (i.e. tail/non tail status)
- monitoring (i.e. liveliness messages or more general status message with kinematic data)

The alternative use of digital I/O lines would imply limitations in identification and pairing phase thus limiting the application to product class 1 and trains with fixed composition.

Physical interface proposed for serial communication is Ethernet with M12 coded connector. This solution could be implemented over an existing on-board network or a dedicated communication network. In general, the power supply for the on-board network should ensure an appropriate availability level. Alternative solutions could consists in adding converters from Ethernet to other communication mediums (e.g. Ethernet over power train lines).

In general, among the compared physical interfaces, Ethernet represents an interesting solution for its increasing presence in new generation trains and for the wide range of certified infrastructure products railway.

Analysed solutions included also new generation TCMS with SIL4 communication protocols under design and development for new generation trains.

In relation to communication protocols for open on-board network the compliancy to EN50159 [6] need to be considered. In this context the safety layer euro-radio represents a solution already available and certified. A general analysis of communication protocol compliancy respect to EN50159 [6] is available in Appendix D.

The analysis of Adaptable Communication Services defined in the context of TD2.1 considered:

- for OTI product class 1 (i.e. wired communication) the possibility to use the defined service of IP addressing scheme assignment
- for OTI product class 2 (i.e. wireless case) the possibility to use a public communication network or more in general a bearer independent solution.

In general, for wireless physical interfaces applicable to product class 2 refer to section 9.

7.5.2 Interface ETCS - OTI Master

Functionalities identified in D4.1 included also train joining/splitting phases that requires changing OTI configuration and therefore performing again the identification and paring procedure on start/reset commands.

To fully support the specified functionalities, the interface between ETCS and OTI Master need to be implemented with serial bus and bidirectional communication. Such hypothesis would imply changes to current specifications reported in CR940 [4] referring to a unidirectional interface between OTI Master and ETCS consisting in three possible values (i.e. unknown, confirmed or lost).

In this case of serial communication the Ethernet interface is proposed for uniformity with OTI-Master OTI-Slave interface. Alternative existing solutions incudes MVB or serial links RS485/RS422.

In case of digital communication two digital output (from OTI device to ETCS) is suitable to ensures full compliancy to current specification reported in CR940 [4].

8 ETCS backward compatibility

The assumptions for “ETCS backward compatibility” scenario consists in:

- ETCS equipment aligned to ETCS Baseline 3 Release 2 plus CR940 [4]
- wired or wireless on-board communication between OTI Master in front cabin and OTI Slave at train tail.

This scenarios is considered as “short term” or “first step” in OTI demonstrator implementation and testing plan. The aim is to avoid any impact on ETCS specifications, interfaces and safety case.

Figure 8-1: summarizes the functional interface for OTI context.

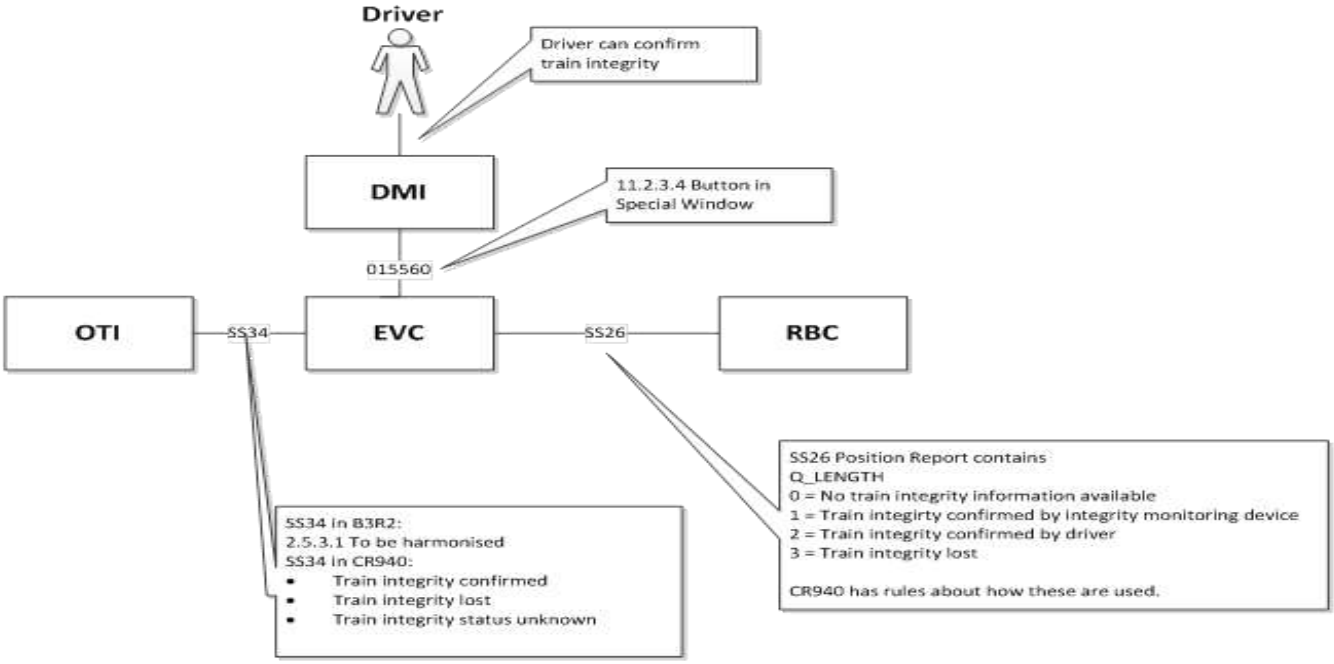


Figure 8-1: Functional Interfaces in Short Term Period

In general the ETCS-OTI communication defined at section 6 is bidirectional.

However in the ETCS backward compatibility scenario the communication between OTI and EVC is unidirectional.

The current DMI makes no provision to display OTI device status or Train Integrity status to the Driver. On the basis of the assumptions made above, a simplified interface specification is proposed in the following.

Figure 8-2: depicts the simplified interfaces for OTI Master functional block. More specifically only the train Integrity status is provided to the ETCS, whereas start/reset commands and status information refers to interface with the driver. This solution is applicable to all OTI product classes with wired and wireless communication, therefore suitable for all application domains, including freight.

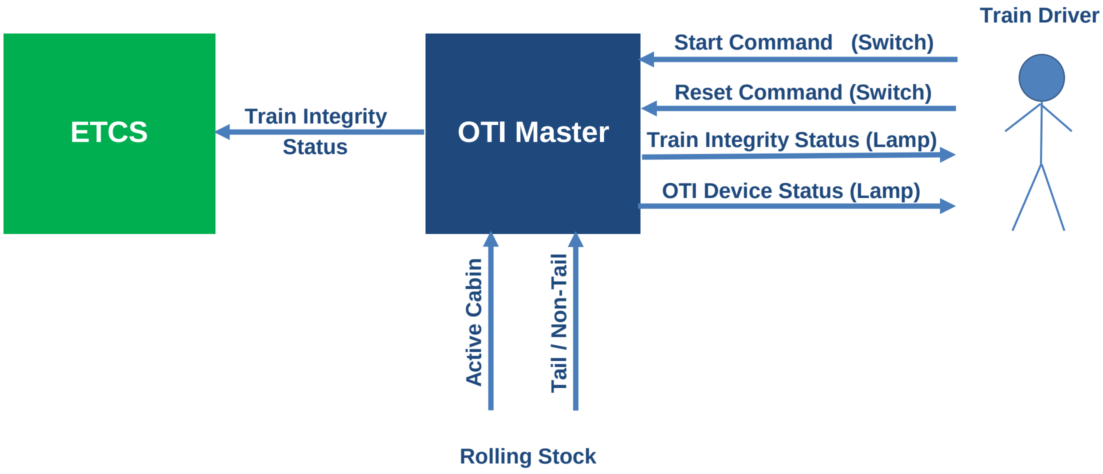


Figure 8-2: OTI Master functional interfaces in ETCS backward compatibility scenario

8.1.1 Application level Impact

8.1.1.1 Message from ETCS – OTI Master

The information from ETCS to OTI Master is not present, the communication is unidirectional and all other information are "external" to ETCS and are provided directly to OTI Master device from the train driver (i.e. start, reset commands) or from the rolling stock (i.e. cabin status, tail/non tail).

8.1.1.2 Message from OTI Master- ETCS

The information from OTI Master to ETCS is limited to train integrity information (i.e. confirmed, lost, unknown).

In case of physical interface implemented with N. 2 DIGITAL OUTPUT the values are the same reported at section 7.4.3.1.

In case of serial communication, the application level message differs from the message specified at (section 7.4.1.2.2 for the absence of the "OTI device status" information that is provided directly to the train driver.

8.1.1.3 Message from OTI Master- OTI Slave

The applicative messages between OTI Master and OTI Slave are the same defined at section § 7.4.1.3.1.

8.1.1.4 Message from OTI Slave- OTI Master

The applicative messages between OTI Slave and OTI Master are the same defined at section §7.4.1.3.4.

9 Candidate Technologies Selection

This section contains the analysis of candidate technologies in terms of compared analysis among OTI product classes, wireless on-board communication network, energy harvesting and energy storage, other sensors (e.g. tail/non-tail sensors). Final aim for comparison analysis consists in identifying guidelines for the product specification phase.

9.1 Product classes compared analysis

This section addresses a qualitative comparison analysis among the OTI product classes defined in D4.1 [1] with the aim of identifying general guidelines for subsequent OTI product specification.

9.1.1 OTI Product Classes

On the basis of performed analysis, the criteria identified to define OTI product classes include communication type (i.e. wired or wireless), availability of power supply and odometry at train tail, presence of ETCS equipment at train tail and implemented functionalities (i.e. train integrity monitoring, train composition determination, train length determination, cargo/waggon diagnosis).

In general, trains with wired communication network are addressed with Product Class 1 and trains with wireless communication network are addressed with Product Class 2. The difference consists in integrity criterion that in wired on-board network is based on communication liveliness, whereas in wireless on-board network requires verifying train tail coherent movement respect to front cabin. In fact, communication between train tail and front cabin could be present also after train splitting with limited distance of separated waggons in presence of wireless on-board network.

Note that in Product Class 2 the train length is assumed to be an input to OTI (i.e. train length entered by train driver during data entry procedure). The train length determination is currently addressed with Product Class 3 with OTI module installed in each waggon and including waggon length as configuration parameter. In this case the train integrity criterion includes status of separation sensors present in each waggon.

Note that loss of integrity detection with train at stand-still in case of wireless communication can be partially addressed by optional Product Class 3 by using separation sensors for each waggon.

In Product Class 1 the difference between A and B consists in availability of ETCS at train tail. Whereas in Product Class 2 and 3 the difference between A and B consists in availability of energy harvesting source. Note that the table includes for each class also the list of implemented functionalities.

Exceptions respect to defined product classes:

- MIXED train with passengers and freight waggons are included in Product Class 2 for Freight and requires a MIXED network (i.e. wired and wireless communication).
- New generation trains for passengers applications with wireless consist-to-consist communication are included in Product Classes 2 and 3.

RODUCT CLASS ID		SPECIFIC REQUIREMENTS		INTERCITY HIGH-SPEED	REGIONAL	URBAN SUB-URBAN	FREIGHT
1	A	COMMUNICATION	WIRED	X	X	X	X
		ETCS AT TRAIN TAIL	YES				
		TAIL ODO/POSITION SENSORS	NO				
		ENERGY HARVESTING	NO				
		FUNCTIONALITY	TRAIN INTEGRITY MONITORING				
	B	COMMUNICATION	WIRED	X	X	X	X
		ETCS AT TRAIN TAIL	NO				
		TAIL ODO/POSITION SENSORS	NO				
		ENERGY HARVESTING	NO				
		FUNCTIONALITY	TRAIN INTEGRITY MONITORING				

Table 9-1 - OTI product classes 1

RODUCT CLASS ID		SPECIFIC REQUIREMENTS		INTERCITY HIGH-SPEED	REGIONAL	URBAN SUB-URBAN	FREIGHT
2	A	COMMUNICATION	WIRELESS				X
		ETCS AT TRAIN TAIL	NO				
		TAIL ODO/POSITION SENSORS	YES				
		ENERGY HARVESTING	NO				
		FUNCTIONALITY	TRAIN INTEGRITY MONITORING CARGO/WAGGON DIAGNOSIS				
	B	COMMUNICATION	WIRELESS				X
		ETCS AT TRAIN TAIL	NO				
		TAIL ODO/POSITION SENSORS	YES				
		ENERGY HARVESTING	YES				
		FUNCTIONALITY	TRAIN INTEGRITY MONITORING CARGO/WAGGON DIAGNOSIS				

Table 9-2 - OTI product classes 2

For completeness of analysis, also the feasibility for delivering train length determination was considered. More specifically product class 3 was identified for this purpose. In this case an OTI device need to be installed in each waggon and need to be configured with identifier and length. Finally a train composition determination procedure is required to determine the train length. In general the implication at installation and maintenance level are relevant.

PRODUCT CLASS ID		SPECIFIC REQUIREMENTS		INTERCITY HIGH-SPEED	REGIONAL	URBAN SUB-URBAN	FREIGHT
3	A	COMMUNICATION	WIRELESS				X
		ETCS AT TRAIN TAIL	NO				
		TAIL ODO/POSITION SENSORS	YES				
		ENERGY HARVESTING	NO				
		FUNCTIONALITY	TRAIN INTEGRITY MONITORING TRAIN COMPOSITION DETERMINATION TRAIN LENGTH DETERMINATION CARGO/WAGGON DIAGNOSIS				
	B	COMMUNICATION	WIRELESS				X
		ETCS AT TRAIN TAIL	NO				
		TAIL ODO/POSITION SENSORS	YES				
		ENERGY HARVESTING	YES				
		FUNCTIONALITY	TRAIN INTEGRITY MONITORING TRAIN COMPOSITION DETERMINATION TRAIN LENGTH DETERMINATION CARGO/WAGGON DIAGNOSIS				

Table 9-3 – OTI product class with train length determination (product classes 3)

Note that CARGO/WAGGON diagnosis in OTI Product Class 2 and 3 is as an option functionality.

9.1.2 Comparison criteria

Identified criteria for product classes comparison analysis include OTI product complexity, installation constrains, operational and maintenance implications.

In the following a list of possible topics related to each criteria is reported:

- **PRODUCT**
  - SW Module hosted in ETCS platform or External Device
  - Wired Or Wireless Communication
  - Tail/Non Tail Identification
  - Tail Kinematic Data
  - Power Lines, batteries or Energy Harvesting devices
  - Fixed OTI device or Portable OTI device

- **INSTALLATION**
  - Wired Or Wireless Communication
  - Power Lines or Energy Harvesting devices
  - Tail/Non Tail Identification
  - Waggon Mechanical Constrains

- **OPERATIONAL**
  - Train Composition: Ensuring that last waggon is equipped with OTI device

- **MAINTENANCE**
  - SW Module hosted in ETCS platform or External Device
  - Wired Or Wireless Communication
  - Tail/Non Tail Identification
  - Batteries periodic maintenance

9.1.3 Result of qualitative comparison analysis

Results of this preliminary comparison analysis consists in evaluating from a qualitative point (i.e. Low, Medium, High) the effort for considered phases of product life cycle.

PRODUCT CLASS ID		SPECIFIC REQUIREMENTS		Product	Installation	Operational	Maintenance
1	A (*)	COMMUNICATION	WIRED	LOW	LOW	NONE	NONE (**)
		ETCS AT TRAIN TAIL	YES				
		TAIL ODO/POSITION SENSORS	NO				
		ENERGY HARVESTING	NO				
	B	COMMUNICATION	WIRED	MEDIUM	MEDIUM	LOW	MEDIUM
		ETCS AT TRAIN TAIL	NO				
		TAIL ODO/POSITION SENSORS	NO				
		ENERGY HARVESTING	NO				
2	A	COMMUNICATION	WIRELESS	MEDIUM HIGH	MEDIUM HIGH	LOW	MEDIUM HIGH
		ETCS AT TRAIN TAIL	NO				
		TAIL ODO/POSITION SENSORS	YES				
		ENERGY HARVESTING	NO				
	B (***)	COMMUNICATION	WIRELESS	HIGH	HIGH	LOW	HIGH
		ETCS AT TRAIN TAIL	NO				
		TAIL ODO/POSITION SENSORS	YES				
		ENERGY HARVESTING	YES				

Table 9-4 – Results about product classes comparison

(*) Product Class 1.A is intended as SW module hosted inside ETCS platform, independent from ETCS functionalities.

(**) Same maintenance of ETCS platform.

(***) Analysis performed by Moving Blocks identified 5 seconds as suitable value for OTI reporting period. Adoption of wireless communication and energy harvesting could imply longer reporting periods.

In general, also OTI Class 2 can be applied to trains equipped with ETCS on both train ends.

Product Class 3 has a complexity higher than Product Class 2, in fact each waggon need to be equipped with an OTI Slave device and related sensors for train separation detection. The benefit consists in for Product Class 3 consists in additional functionalities (e.g. train length determination, cargo/waggon diagnosis).

Note that this preliminary comparison analysis is considered as general guideline for OTI product specification.

9.2 Wireless on-board communication network

9.2.1 Introduction

The investigation on wireless sensors and transponder technologies performed in D4.1 Train Integrity Concept and Functional Requirements Specifications [1] presented a first approach of the possible candidates for the wireless technologies. In this chapter, these proposed technologies must be deeply analysed and compared among them.

In order to study which wireless technologies are most appropriate for the scope of the work that will be carried out in this project, the following subchapters will be presented:

- **Successful Implementation Cases:** In this subchapter, an analysis of different successful implementation cases in road/railway environment concerning proposed technologies will be performed.
- **Comparison between selected technologies:** In this chapter the proposed technologies will be characterized from the point of view of performance and general applicability, performing a comparison between them.
- **Technologies selection for Product Classes:** In this chapter, the proposed technologies must be analysed having into account the Product Classes.

9.2.2 Successful Implementation Cases and Current Use in Innovation Projects

This section aims to study the successful implementation cases and the current use in innovation projects of the wireless technologies proposed as candidates. In order to differentiate terrestrial technologies from satellite and mobile cellular networks, three subsections are created:

- **Terrestrial Wireless Technologies:** In this subsection, implementation cases and innovation projects concerning the following terrestrial wireless technologies are presented:
    - 802.11 family: 802.11a/b/c/g/n/ah and 802.11p
    - 802.15.4: ZigBee and 6LoWPAN
    - 802.16: WiMAX
- **Mobile Cellular Networks:** In this subsection, successful implementation cases concerning LTE are presented.
- **Satellite Technologies:** In this subsection, successful implementation cases concerning satellite technologies are presented.

9.2.2.1 Terrestrial Wireless Technologies

As exposed in D4.1 Train Integrity Concept and Functional Requirements Specifications [1], the proposed solutions concerning wireless terrestrial technologies, were 802.15.4 (ZigBee and 6LoWPAN), 802.11 family (focusing on 802.11p) and 802.16 (WiMAX).

ANT/ANT+ solution was also considered, but this technology is very new. In fact, the final ANT specification was performed in 2016, and for this reason, there are not railway physical implementation yet. It does not mean that this technology is not valid, but it is still in a first phase, so it is preferable to study other options with some implementation in the railway environment.

9.2.2.1.1 IEEE 802.11 Implementation Cases

The European Commission-funded project Safe Road Trains for the Environment (SARTRE) investigates the technologies for the safe platooning of road vehicles. In the context of this project, for V2V communication, the implemented communication protocol is 802.11p, using the 5.9 GHz channel. The main task achieved for V2V is the control and coordination of the platoon movement [8]. Furthermore, platooning control using IEEE 802.11p is an active challenge in vehicular networking and cooperative automated vehicles environment. A simulation campaign using Visible Light Communications (VLC) integrated with IEEE 802.11p was performed in 2016. The results of this study show that VLC combined with IEEE 802.11p could assure the safety of the overall system, considering the possibility of communication delays.

The SCOTT project from ECSEL [9] aims to extend the Internet of Things for different domains such as building and home, health or railway environment. SCOTT aims to provide cost-efficient solutions of wireless, end-to-end secure, trustworthy connectivity and interoperability to bridge the last mile to market implementation. Concerning this last one, the WP18, WP19 and WP20 of the SCOTT project (containing different rail Use Cases), leaded by INDRA, makes use of the IEEE 802.11p protocol for defining level 1 and level 2 communications of the entity-layered model described on this project. Furthermore, the use of IEEE 802.11p is studied forV2X capabilities. Furthermore, IEEE 802.11 a/b/g/n/ac is used in level 0 communications.

The ROLL2RAIL Project, within the S2R Initiative works, aims to develop key technologies and remove identified blocking points in the field of railway services, such as V2V and V2I/I2V communication. In the context of this project, a study of the railway environment characteristics is performed in order to create models to simulate radio communication technologies [10]. Concerning V2V communication, 802.11p is analysed and considered as the most appropriate solution in case that high data rates are not required.

The Short Range Devices/Maintenance Group (SRD/MG), as part of the Electronic Communications Committee (ECC) is working in the development of strategies, plans and implementation advice for the management of short range communications. In this context, when defining communications for the design of a CBTC system [11], 802.11p is selected as the most suitable technology.

Based on 802.11 family, Icomera [12] has developed a multi-technology platform to provide broadband Internet access in trains, combining Wi-Fi protocols deployed in the waggons with satellite and cellular technologies for the downlink and the uplink respectively. First tests of broadband on board trains in the world were performed in Sweden in September 2002. Using this platform, The Swedish train operator SJ currently offers Internet services on board using the works achieved with this multi-technology platform [13].

Between 2005 and 2007 SNCF in collaboration with Orange Labs [14], performed experimental tests relying Wi-Fi IEEE 802.11b/g for the implementation of train broadband communication in order to provide internet services to high speed passenger trains. The tested network was based on four access points located on bridges and pylons, covering an area of 13 km in Vendome, near Tours in France. This experimental solutions also offer a satellite complementary solution based on DVB-RCS using Multi-Frequency Time Division Multiple Access (MF-TDMA) which allows setting up the return link in order to optimize the required bandwidth for the fleet of trains.

9.2.2.1.2 IEEE 802.15.4 Implementation Cases

The ARTEMIS/ECSEL1 project DEWI (“Dependable Embedded Wireless Infrastructure”) [15] focuses on the area of wireless sensor/actuator networks and wireless communication. The Train Integrity Monitoring System proposed in DEWI is based on a WSN [16], which consist of the WSN Nodes (deployed on each waggon), the Coordinator and the Serial Gateway (both deployed on a locomotive). Each WSN Node measurements are send to the Coordinator, which compares the measurements from each node to detect the train integrity. In the test phase DEWI makes use of short-range technologies and corresponding standards from 802.15.4 such as ZigBee or 6LoWPAN.

Following the works started in DEWI project, SCOTT project [9] makes use of the 802.15.4 protocols for several purposes. Specifically, for level 0 communications of the entity-layered model may use 6LoWPAN protocol. In addition, mapping functional against physical entity models will make use of Message Queuing Telemetry Transport (MQTT) over ZigBee protocol.

IONX LLC and the rail freight operator Havelländische Eisenbahn (HVLE) has developed a solution based in 802.15.4 [17]. The solution was deployed on the HVLE freight trains, and IONX provides a low power wireless network. That network, built for IP compatibility, runs the entire length of the train and connect sensors on each waggon to the locomotive.

The Technical Innovation Circle for Rail Freight Transport (TIS Project) aims to firm up the innovation in the freight rail transport sector, and specially to develop the potential for innovative freight waggons. This project consists on representative of waggon manufacturers, waggon owners, suppliers, railway undertakings and customers and shippers, in order to draw up proposals for freight rail waggons development between 2012 and 2030 [18]. In the context of this project, the Requirements for Telematic and Sensor Technology document [19], several data transmission options are studied. Specifically, for wireless data transmission via local network within a networked train formation with a master node, both in the locomotive and in each waggon, ZigBee is given as example of one of most suitable technologies.

Several academic works also recommend the use of 802.15.4 as short-range technology in the railway environment. Alves dos Santos et al [20] developed a telemetric systems for monitoring and automation of railways using ZigBee protocol and Higuera et al [21] studied the feasibility of using low-power wireless technologies such as 802.15.4 and Bluetooth in high-speed railway scenarios for Madrid-Barcelona line in Spain. The conclusion which can be extracted of these studies were that 802.15.4 protocols (such as 6LoWPAN) and Bluetooth are suitable for train to ground connectivity up to train speeds of 305 km/h but ZigBee devices failed at speeds above 250 km/h.

9.2.2.1.3 IEEE 802.16 (WiMAX)

A solution based on WiMAX and cellular technologies has been developed by Nomad Digital and installed in several railway networks [22], such as the Southern Railway of Brighton, the Heathrow Express, the Virgin Trains in United Kingdom, and the UTA trains of Utah.

In order to evaluate the radio transmission in the railway environment, a study has been performed on the Shinkansen lines in Japan [23]. In this study, the different transmission methods have been compared and studied, using WiMAX technology as the main protocol. As a result of this research, could be verify that WiMAX transmission present some problems in tunnels because of the base stations distribution. While many base stations assured the communications along the Shinkasen line, in tunnel areas the communication was difficult due to WiMAX used a different frequency from train radio devices. Although this problem exists, this technology can be used in combination with broadband radio transmission in the conventional lines.

Also in Japan, in trains connecting Narita Airtport to Tokyo Center with a distance of 90 km, a WiMAX solution on 2.5 GHz [24] band was tested in 2009 achieving a maximum throughput of around 40 Mbit/s [25]. The Super Hitachi trains running from Tokyo to Iwaki with a distance of 200 km, make use of this network since 2012 [12].

9.2.2.2 Mobile Cellular Networks

In previous deliverable of WP4, Long Term Evolution (LTE) was the standard selected as the most suitable mobile technology for the purpose of the proposed works. 4G technologies were analysed and release 14 and 15 towards 5G was recommended to be considered for long range V2V communications.

Mistral Initiative, as part of Shift2Rail, introduces in D3.1 [26] the Mobile Network Operators (MNO) solution, based on re-using for mission applications the network infrastructure built for commercial services. This initiative uses the latest LTE auctions as reference for defining likely frequency fees, following the Systra report recommendations in the study about migration from GSM-R to other solutions concerning railway radio communication [27].

According to the Business Model analysed in D3.2 Report on Business Viability [28] urban and sub-urban areas presents large commercial LTE coverage, around 90-100%. Nevertheless, in rural areas, the coverage only can be reached around 50-80%. Therefore, for urban and sub-urban areas, LTE is one of the recommended technologies. The use of this technology enables vertical handover between different radio access technologies and could allow, in some cases, the use of public networks in place of or in conjunction with dedicated networks.

The study about video quality assessment for inter-vehicular streaming [29] aims to demonstrate the performance of IEE 802.11p, LTE and LTE Direct networks concerning real-time video streaming for V2V communication. In the context of this study, highways and congested urban road scenarios were modelled using Ricean and Rayleigh fading channel models respectively. The results shows that LTE Direct performance is quite better than IEEE 802.11p, and in turns, IEEE 802.11p performance is better than LTE.

In order to continue comparing 802.11 family with cellular technologies for long range communications, the study about Cooperative Awareness of Connected Vehicles [30] 802.11p and LTE for V2V are analysed for connected vehicles environment. As a result of the paper, LTE can achieve 10% better results in the packet reception radio and lower delays than for small packet transmission and 26% of improvement for large packet transmission over IEEE 802.11p. On the other hand, for large packet transmission, IEEE 802.11p guarantees lower delays and present robustness at limited distances.

9.2.2.3 Satellite Technologies

Concerning already existing application of GEO satellite based communication, the 3InSat Demonstration Project [31] was also mentioned in D4.1 Chapter 6.3.4.1 [1]. This project was developed to demonstrate, test and verify a new satellite-based subsystem.
The tests were carried out on the RFI Cagliari-Olbia line in Sardinia with a length of 300 km and a speed up to 130 km/h. The EURORADIO over IP protocol defined in the UNISIG subset 037 [5] was tested both in terrestrial and satellite solution presented in this project. The test results shows that the performances of the network are compliant with the requirements established for low traffic lines.

SAFETRIP Project [32] has explored new opportunities and innovative services for V2V and V2I/I2V communication, using satellite and complementary terrestrial technologies thanks to the DVB-SH standard. The Final Report Summary [33] presented the results of the demonstration which took place at the S-Band Workshop organised by the European Space Agency (ESA), showing the high efficiency of the SAFETRIP architecture with optimal data rates.

IRIDIUM solution, also studied in D4.1 [1], is based in Iridium NEXT, a second-generation satellite network, consisting of 66 active satellites. These satellites will incorporate features such as data transmission [34] for V2V and I2V/V2I communication. The constellation provides L-band data speeds of up to 1.5 Mbit/s and High-speed Ka-Band service of up to 8 Mbit/s.

Other solution [35] is based in the use of satellite technologies with satellites in Low Earth Orbit (LEO) combined with a SigFox terrestrial network using the 868 and 915 MHz ISM bands. With the use of terrestrial networks, latency can be controlled under 10 ms.

9.2.3 Comparison between selected technologies

The following technologies were described in D4.1 Train Integrity Concept and Functional Requirements Specifications Chapter 6.3.1 and in the previous chapter its implementation cases and uses in innovation projects has been analysed:

- 802.11a/b/g/n/ac
- 802.11p
- 802.15.4
    - ZigBee
    - 6LoWPAN
- WiMAX
- LTE
- Satellite Technologies

Due to these technologies are proposed as the most suitable wireless technologies for the purpose of WP4 works, and in order to establish a comparison among them from the point of view of performance and general applicability, the most important features of terrestrial technologies and satellite communications are presented below:

Features	**802.11a/b/g/n/ah**	**802.11p**	**ZigBee**	**6LoWPAN**	**WiMAX**
Link Type	Master/Client Point to multipoint	Master/Client Point to multipoint	Master/Client Point to multipoint	Star Point to multipoint Cluster Tree	Master/Client Point to multipoint
Data rate	11-1000 Mbit/s	Up to 200 Mbit/s	20/40 kbit/s for ISM band 250 kbit/s for 2,4 GHz	20/40 kbit/s for ISM band 250 kbit/s for 2,4 GHz	Up to 350 Mbit/s
Range	Up to 1 km	Up to 300 m	10 – 75 m	10 – 75 m	Up to 50 km
Throughput	5 – 600 Mbit/s	0,1 – 100 Mbit/s	1-50 kbit/s	1-50 kbit/s	1-50 kbit/s

Frequency	2,4 / 3,7 / 5,0 GHz	ISM band	ISM band 2,4 GHz band	ISM band 2,4 GHz band	2,4 GHz ISM 2,5-2,7 GHz lic. 5,8 GHz unlic. 10,5 GHz lic.
Channel Bandwith	20, 40 and 80 MHz	10 MHz	2 MHz ISM band 5 MHz 2,4 GHz band	2 MHz ISM band 5 MHz 2,4 GHz band	3.5 MHz 5 MHz 7 MHz 10 MHz
Latency	1-10 ms	1-10 ms	10 ms	10 ms	50 ms
Security	WPA2 (128 AES)	128 AES-CCM	128 AES	128 AES	Extensible authentication protocol
Internet Protocol	IPv4 IPv6	IPv6	IPv4 IPv6	IPv6	IPv4 IPv6
Spectrum Use	Public	Unlicensed	Public	Public	Public/Licensed/ Unlicensed

Table 9-5: Terrestrial Technologies Comparison [1] [33] [42] [43]

Features	**Geo-L (3InSAT)**	**Geo-S (Safetrip)**	**LEO L + Ka (IRIDIUM)**	**LEO with ISM (Airbus D&S)**
Orbit	GEO	GEO	LEO	LEO
Band	L	S	L+Ka	L + ISM
Range	300 km	Europe	Europe	50 km
Speed	130 km/h	130 km/h	-	-
Data Rate	492 kb/s	2.2 Mb/s	1.5-8 Mb/s	1kb/s
Latency	>100 ms	>100 ms	>100 ms	<10 ms

Table 9-6: Satellite Technologies Comparison

From the tables and the analysis of the implementation cases, the following conclusions can be extracted:

- Concerning satellite communication, besides the high latency that this technology generates, it is important to consider the problem of the shadows in the environment. In places with high density of mountains and tunnels, the use of satellite communications is quite inefficient. On the other hand, the low cost of the receiver devices deployment, makes satellite technology a good candidate when it is combined with terrestrial or cellular technologies which cover the shadowed area.
- For short range communications and low data rate, ZigBee and 6LoWPAN seems to be the most suitable technologies due to its low consumption and its robustness and security. However, as exposed on Chapter 9.2.2.1.2, ZigBee has some failures in high speed trains (up to 250 km/h). Moreover, 6LoWPAN allows different types of link configuration, as cluster or tree, which presents an advantage over ZigBee.

- IEEE 802.11p is also recommended for short and medium range communications. Several studies shows that this technology, although is unlicensed, has optimum performance in the railway environment.
- In general terms, 802.11 family and WiMAX are suitable for long range communications and when high data rate is needed. Train integrity sensors does not need to transmit high amount of data and WiMAX has a high latency in comparison with 802.11 or 802.15.4 and it is becoming obsolete due it not has the support of big companies and it is not been used in current innovation projects. Furthermore, the successful cases and uses in innovation projects shows that 802.11 family is more advisable for railway environment. Therefore, for long range communications, 802.11 family is preferred.
- Concerning cellular technologies, LTE is a good candidate for long range communications as it is presented on subchapter 9.2.2.2 and the future deployments in railway environment are pointing towards the use of incoming cellular technologies. Nevertheless, release 14/15 and 5G technologies are in a very early stage of the specification. In D4.1 [1], it was exposed that the use of high frequency requires more radio links in order to maintain a good coverage, so it implies high CAPEX costs.

Making use of the highlighted technologies, three candidate network topologies have been defined to provide wireless communication for existing waggons, both passengers and freight trains:

- The first solution presents an approach with one WSN per trainset. Each integrity node establish wireless communication with of its adjacent waggon node. The following figure illustrates this solution:

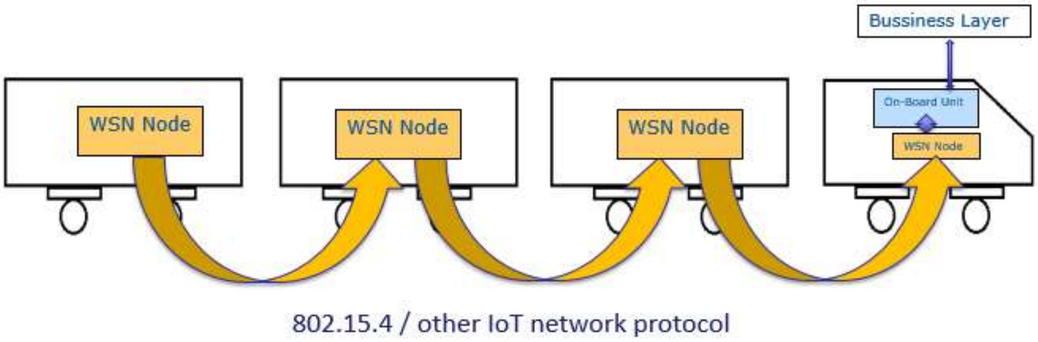


Figure 9-1: Train Integrity WSN Solution I

Despite this solution is easy to deploy and presents low power consumption, it has one disadvantage: the high dependence of the waggon length. The WSN Node has to establish communication with the previous and the following waggon and the waggon length could increase the distance covered by the communications, forcing to add more nodes for coverage reasons, increasing the complexity and reducing the theoretical availability of the solution.

- A second solution is proposed in order to avoid the problem of waggon separation. It is shown in the following figure:

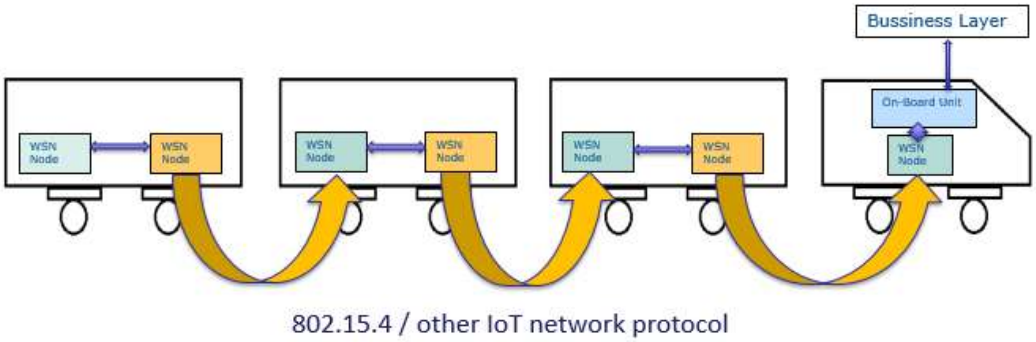


Figure 9-2: Train Integrity WSN Solution II

This solution includes two sensor per waggon. The communication between the nodes inside the waggon can be performed with wired or wireless methods. In this way, the sensor nodes only have to tackle the distance between the end of one waggon and the beginning of the adjacent waggon. Thus, this second solution is not waggon dependant and it allows developing fast communications for integrity and train length data along the composition.

- In order to enhance the previous solutions and increase the data rate, the third solution is presented in the following figure:

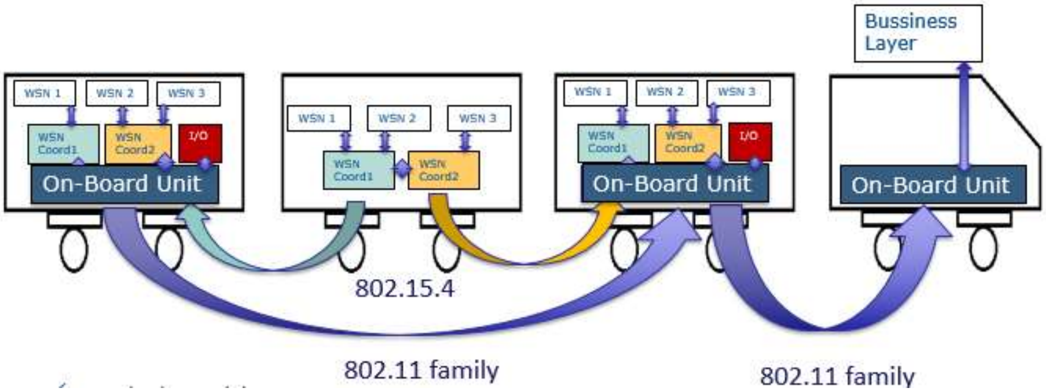


Figure 9-3: Train Transponder solution

This approach is based on transponder solution in each waggon to be able to distribute and transport different WSN capabilities. WSNs hubs integrate the information collected in their own waggon (and adjacent waggons without electrification) and transmit it to the nearest On-Board Unit through 802.11 family protocols. The communication with sensors installed waggons without On-Board Unit will be performed with 802.15.4 family protocols. Furthermore, this transponder solution provides safety and security capabilities. I/O capabilities can be also implemented together with the possibility of allowing extra network communication such as LTE for other rail services.

The following table summarizes the advantages and disadvantages of each implementation, and the use of the wireless technologies recommended for these solutions:

Solution	Wireless Technologies	Waggon length impact	Data Rate	Waggon electrification	Deployment	Able to integrate future Rail Services
Train Integrity WSN solution I	802.15.4	Medium	Low	No	Easy	Low
Train Integrity WSN solution II	802.15.4	Low	Low	No	Medium	Low
Train Integrity Transponder solution	802.15.4 802.11 family	N/A	High	Need of electrification for waggons with On-Board Unit	Medium	High

Table 9-7: Train Integrity solutions comparison

9.2.4 Technologies selection for Product Classes

In the current subchapter, the proposed technologies solution are evaluated in terms of possible performance taking into account the different Product Classes depending on the identified on-board configuration. The comparison between OTI Product Classes performed in Chapter 9.1 is taken into account when making the wireless technology selection for each Product Class.

9.2.4.1 Product Class 1

On-board configuration Product class 1-A is composed of an OTI device per each train cabin, both devices are connected to ETCS and communicate each other over wired on-board network.

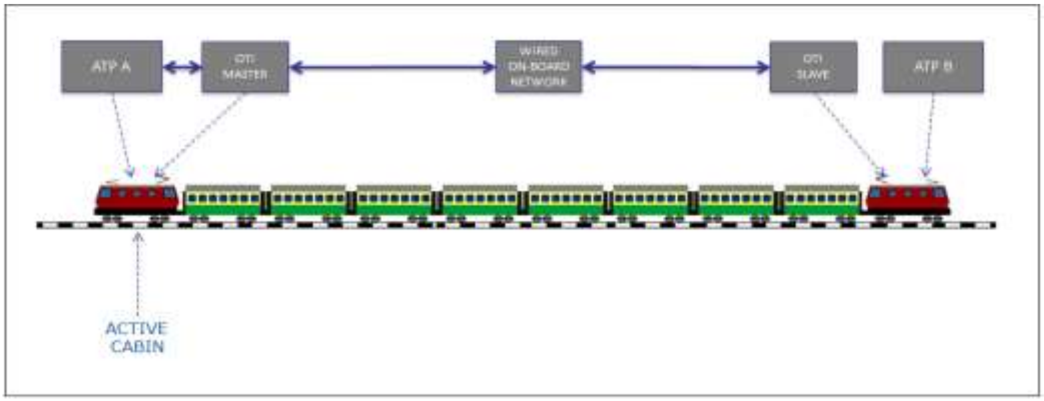


Figure 9-4: Product Class 1

Since the communication between devices is wired, none of the technologies discussed above apply in this case.

9.2.4.2 Product Class 2

On-board configuration Product class 2 is composed of an OTI device in front cabin with Master role connected to ETCS and an OTI device at train tail with Slave role. OTI devices communicates over wireless on-board network.

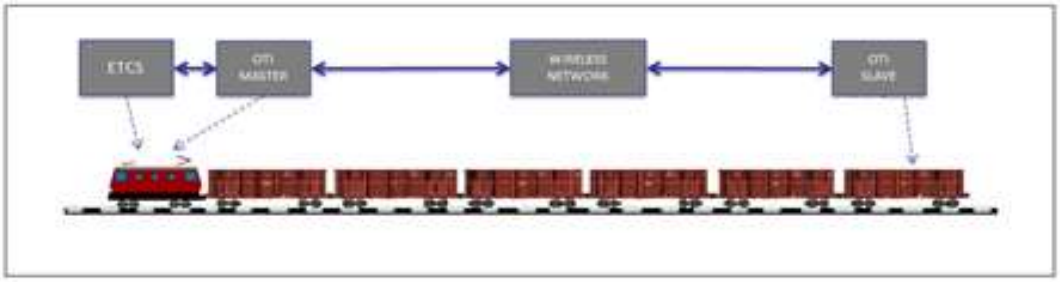


Figure 9-5: Product Class 2

This solution is high waggon length dependant and requires long coverage. The solutions that may apply in this case is 802.11 family, specifically 802.11p. In case that several wireless nodes are installed along the composition, in order to reduce OPEX/CAPEX costs, save power (in case of energy harvesting as Product Class 2B shows) and increase security, ZigBee or 6LoWPAN devices could be efficient due to it is not needed a high amount of data transmission.

9.2.4.3 Product Class 3

Product Class 3 refers to an on-board configuration with all waggons equipped with OTI device to support several functionalities such as:

- Determining train length.

- Detecting loss of integrity with train at stand-still by separation sensors installed in all waggon.
- Waggon/Cargo Diagnosis.

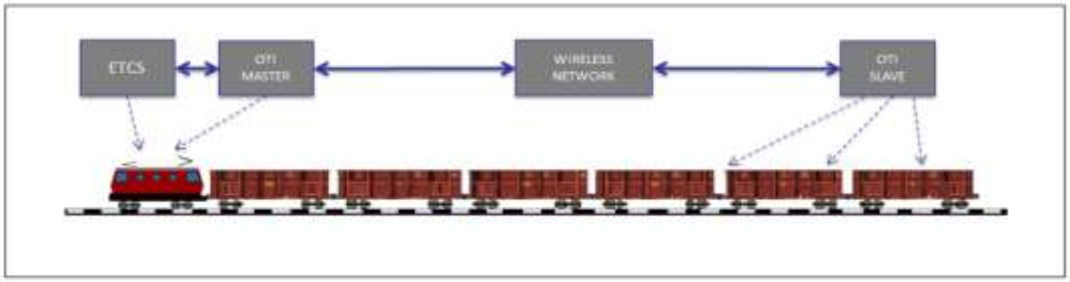


Figure 9-6: Product Class 3

Since each waggon will be equipped with an OTI Slave device, this device will gather the waggon data and processes to send it to the OTI Master along the backbone infrastructure, which acts as a concentrator of the amount of data sent by the slaves. Making use of 6LoWPAN or ZigBee, OTI devices can communicate with the correspondent OTI device of the adjacent waggons. It allows to implement a fast deployment solution with fast communication and with low power consumption needs.

Depending on the computing capacity of each OTI device, 802.11 family protocols can be used to provide a high bandwidth which allows to save the waggon length and transmit high amount of data to the OTI Master device, reducing the number of hops.

Furthermore, this approach provides safety and security capabilities. And by installing an OTI device in each waggon the possibility of allowing extra network connectivity such as LTE is provided.

9.3 Energy harvesting and energy storage

In this section, several solutions for energy harvesting and energy storage have been evaluated, taking into account the technology used for the harvester prototypes.

9.3.1 Vibration harvesters

In this subchapter, the solutions concerning for recovery or storage energy from motion and vibration are going to be studied.

The S2R Open Call named as Energy harvesting for signaling and communication systems (ETALON) will contribute to the enhancement of train integrity functionalities, providing a suitable energy supply for on-board train integrity and a robust radio communication system between vehicles that could be the basis for a train integrity check. The deliverable D4.2 of ETALON project [36] presents a design of vibration energy harvester product for bogie condition monitoring, and a proposed adaptation of displacement energy harvester concepts for rail.

The energy harvesters presented in ETALON project are suspension-based harvesters, which have been investigated for the recovery of the energy from motion and vibration induced by road/track disturbances. The following designs were proposed:

- Hybrid shock absorber
- Electromagnetic shock absorber
- Hybrid electromagnetic shock absorber
- Electromagnetic shock absorber
- Piezoelectric Harvester on a car damper

All the designs presented above lead to the design of a vibration energy harvester using suspended inertial mass and electrification generation. With this method, electromagnetic induction is exploited to covert vibration to electric potential.

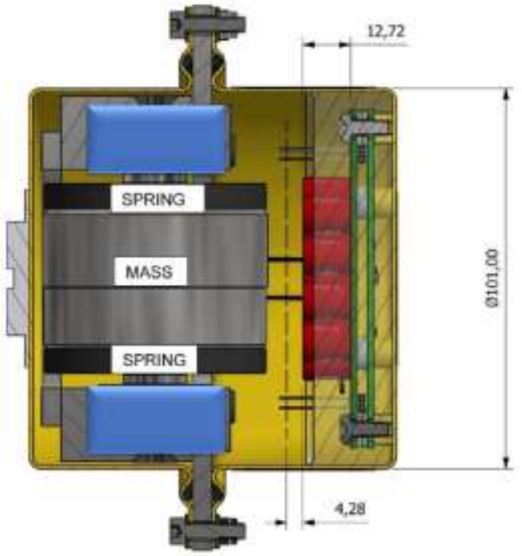


Figure 9-7: Vibration energy harvester example

This energy harvester can be fixed directly to the bogie or axle box. Vibration of the fixture moves a coil through a magnetic field, which is held in place inertially by a resonant, sprung mass. Efficiencies above 80% are possible, with adequate power supply design.

According to the deliverable submitted by ETALON, the harvesting solution supported on vibration energy harvesters could fit for OTI purposes, but the information provided seems to be insufficient to take into consideration for final decisions. Although this prototype seems to meet the OTI requirements, it has not been possible to demonstrate the performance of this devices, considering that the scope of ETALON does not cover the amount of development or adaptation work required for the harvester allocation.

In addition, even though the cost of development of this possible solution is less expensive than other existing solutions, OPEX costs might be increased as explained in the discussion chapter of D4.2 of ETALON project. The impact of fitting, configuring and maintaining a vibration energy harvesting near the wheelset has to be considered, as well as the impact on the wheelset maintenance operations. These disadvantages might be decisive when it comes to taking the most suitable solution for the energy harvesting issue.

The S2R Open Call named as INNOWAG aims to address the actual needs of rail freight for increasing its competitiveness and attractiveness. The deliverables D.1.1 [37] and D2.2 [38] of INNOWAG project, presents several vibration-based solution. The solution given in ETALON is also proposed in INNOWAG, which clearly specify that the estimated energy provided by this vibration-based prototype is not sufficient to power the communication hub, but it can power a Bluetooth sensor node mounted outside the waggon.

Furthermore, INNOWAG project presents a piezoelectric vibration energy harvesting developed in the ESZÜG project. This harvester is based on a clamped bending beam with a piezoceramic transducer. This piezoceramic transducer was developed as a prototype in INNOWAG project and tested in laboratory environment. The results of these tests have shown that the low vibration amplitudes make it not feasible for the project purposes.

9.3.2 Electromagnetic harvesters

Both ETALON and INNOWAG projects offer a harvesting solution based on electromagnetic devices. In this subchapter, these devices are studied.

First of all, in ETALON project, the On-Train Linear Generator is presented. This solution involves installing a linear generator in parallel with the suspension springs attached to the axlebox and the bogie frame. In this way, the suspension displacements induce a displacement between the components of the linear generator when the train is on the trip. The linear generator energy harvester is illustrated on the following picture:

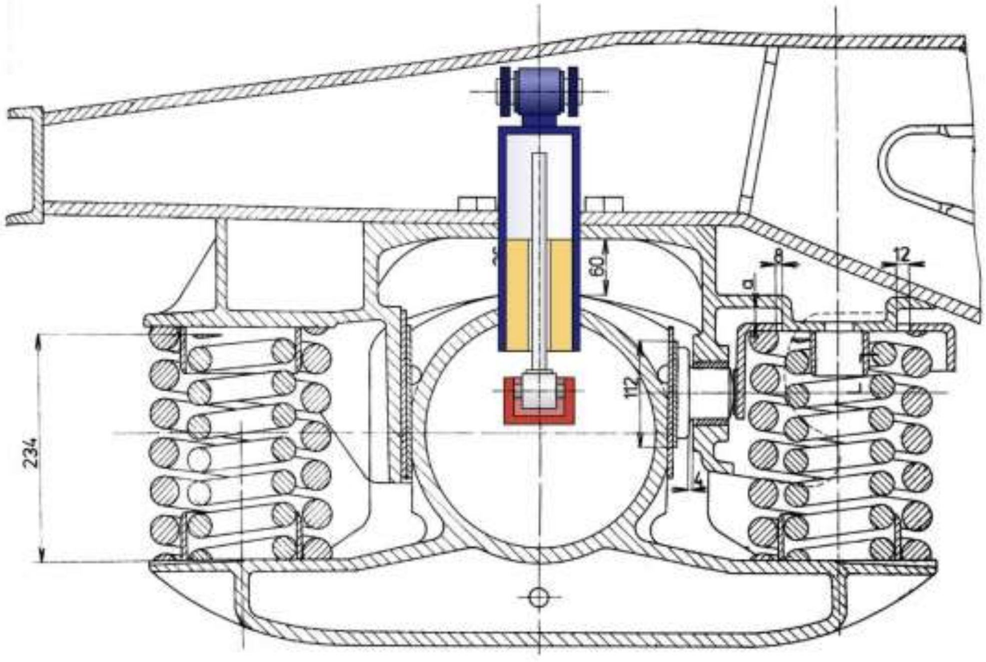


Figure 9-8: ETALON linear generator energy harvester design

Several simulations to estimate the power output of this harvester have been carried out by building the linear generator system in Matlab/SIMULINK. The results of the simulation is shown in Figure 9-9. The peak voltage obtained was around 2 V, with a peak power output of 4 W. The average power output is 0.2 W, as predicted in early stages of the simulation. This value is optimal to provide power to low power consumption devices, but when the speed is around 80 km/h. At lower speeds, the output is expected to be less. Finally, the vibration amplitude obtained is around 8 mm.

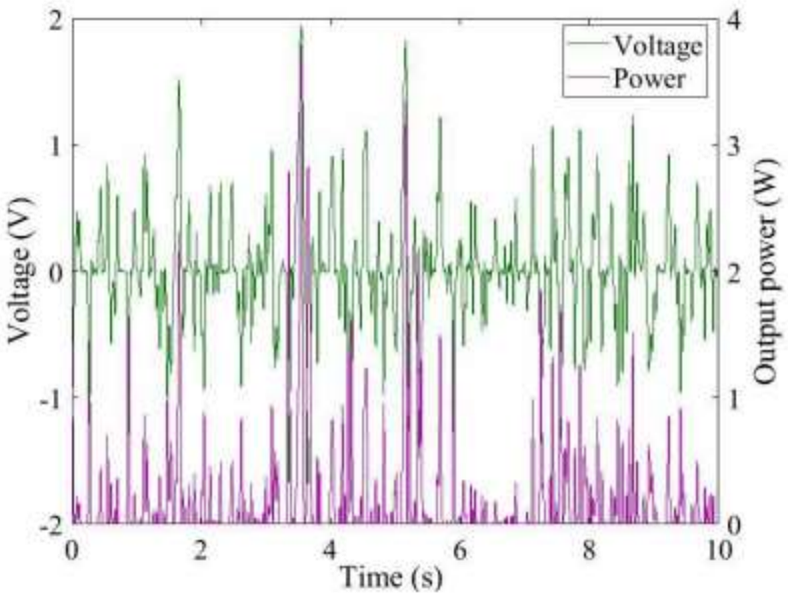


Figure 9-9: Estimated voltage and power output for the on-train linear generator harvester

Despite the mechanical components of the harvester has a long service life and minimal maintenance requirements, there are some disadvantages:

- Special mounting required, which may require modifications on the waggons and increase CAPEX costs.
- The design is at a very initial development phase and has not been proven in harvesting applications for a train integrity system.

In the other hand, INNOWAG project presents three kind of electromagnetic energy harvesting solutions:

- **Ambient RF energy harvesting**
    - Extracts usable energy from the ambient electromagnetic fields.
    - Antenna or array the antennas specifically designed to capture RF energy across a defined frequency range.
    - The advantages of this solution are the continuous energy harvesting and its availability.
    - The disadvantages are the location dependence and the low power density compared to piezoelectric harvesters.

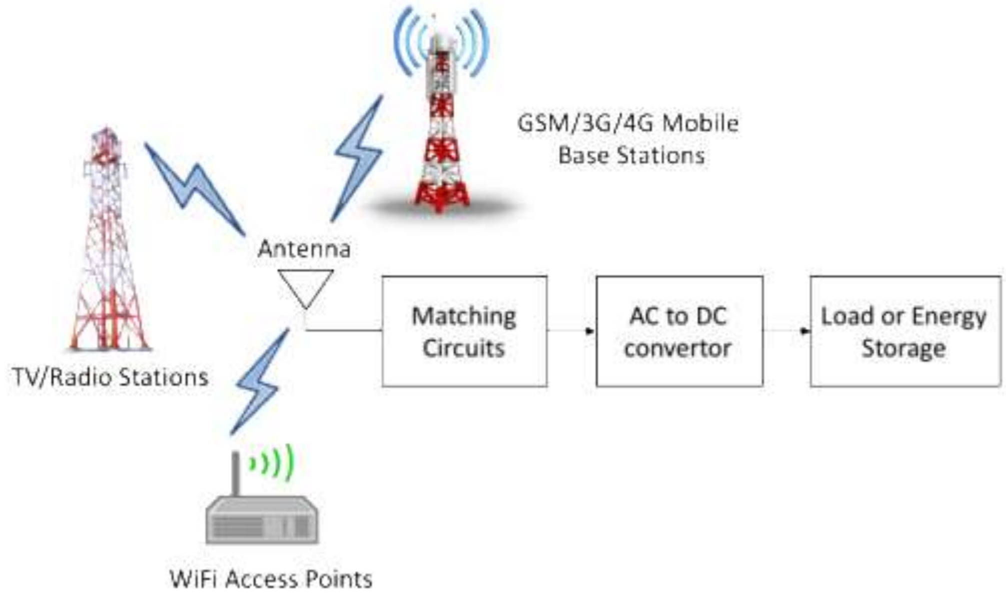


Figure 9-10: Ambient RF Harvester Diagram

- **Wireless power transfer technology**
    - Transmits radio frequency energy without wired link.
    - Converts electromagnetic field to a DC voltage to supply the electrical load.
    - The power obtained in this solution is limited by radio safety standards.
    - The power transfer efficiency is dependent of the radiation pattern of the antennas.

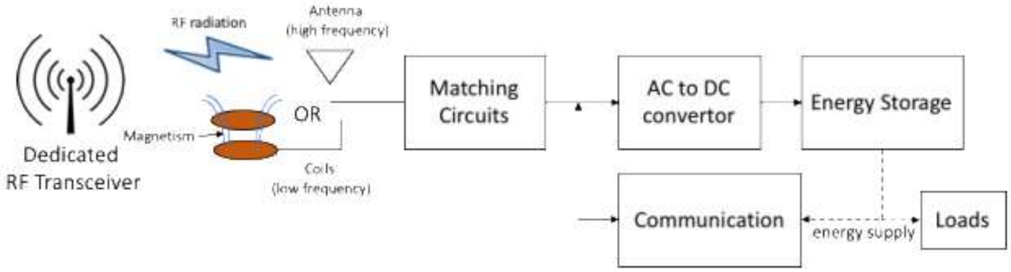


Figure 9-11: Wireless power transfer system diagram

- **Passive RFID sensor technology**
    - Integrates RF harvesting module into a RFID sensor tag.
    - Enables a longer read range and it is able to power a microcontroller and sensor circuits without needing an external power supply.
    - RFID technology is well-established in the market and available.

    - Capable to transmit sufficient power and offers benefits over other solutions due to the lack of range capability.
    - The performance and the communication robustness are worst when increasing the distance between the reader and the tag.
    - The reader requires high power consumption.

As a conclusion, after analysing ambient RF power, wireless power transfer and passive RFID technologies, INNOWAG proposes two architectures rely on passive RFID technology. Architecture 2 and 3 includes the installation of a RFID reader in the on-board communication hub.

INNOWAG project assures that this technology works well on railway environments. To strengthen this solution, can be studied a trackside reader which eliminates the high power consumption of the reader, as proposed on Architecture 4 of INNOWAG project. Dynamic testing is required to prove the viability of this solution.

9.3.3 Solar and wind harvesters

ETALON project analyses a solution for energy harvesting based on solar power tracking devices, giving as an example the Nexiot Globehopper. This device is equipped with rechargeable batteries, mobile data communication and GPS devices. This solution is designed to be used in individual waggons. It requires fast wireless network to transmit integrity messages from the end of the train to the locomotive. The disadvantage of this solution is that it does not have been proven in northern Europe at low temperatures.

On the other hand, INNOWAG project offers a harvesting solution based on photovoltaic effect, generating voltage when the photovoltaic cell is exposed to light [37]. It offers a good performance in outdoor deployments, generating a high rate of power compared to other solutions. The total energy harvesting can be increased by installing an array of panel on top of the waggon. Furthermore, the working life of these panels is up to 20 years, although it presents some degradation over this 20 years.

INNOWAG also presents harvesting solutions based on wind energy using turbines with several configurations. The most suitable solutions are the following:

- Conventional horizontal axis wind turbines
    - Energy output: 40 kWh/Month with an annual wind speed of 5.8 m/s.
    - Output voltage: 12, 24 and 48 VDC

Figure 9-12: Pole mounted wind turbine

- Vertical Axis Turbine
    - Energy output: 24 W at 8 m/s
    - Output voltage: 12, 24 and 48 VDC
    - Fully lubricated sealed bearing, which implies that no maintenance is needed.
    - Combined with solar power.

Figure 9-13: Vertical axis turbine

To sum up, INNOWAG project concludes that freight waggons are thought to carry loading goods and it reaches the limit of the structure gauges. In addition, it is not recommendable to deploy turbine generators on the top of the waggon. However, the possibility of using wind generators in mainlines has to be deeply studied.

In DEWI Project [40], an analysis of energy harvesting and energy supply techniques and sensors was performed, mixing solar and wind energy sources.

In rail domain applications, battery replacement may be difficult and expensive. Therefore, the use of ultra-low-power MCUs allows energy harvesters to extend the life of batteries. It is important because if the energy harvesting devices can accomplish the energy requirements of the embedded system, the system can become battery free.

In the context of DEWI project, a prototype for energy harvesting based on large solar panels and wind generators was designed and tested. The block diagram of this energy harvesting prototype is shown below:

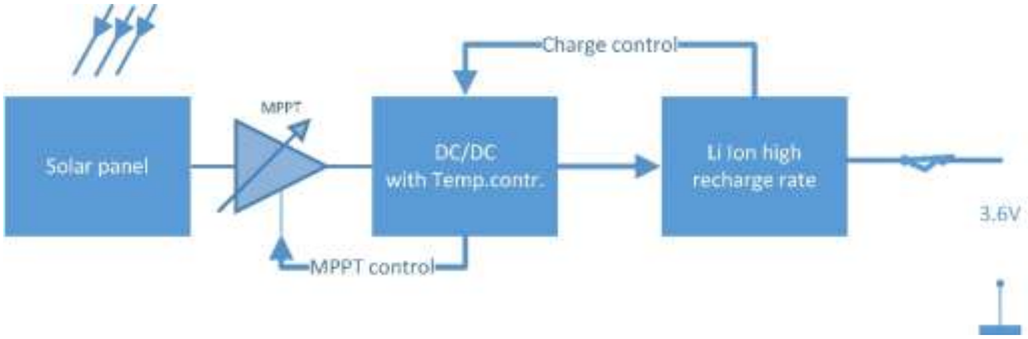


Figure 9-14: DEWI Project energy harvesting system block diagram

The energy harvesting system integrated the following elements:

- Solar panels
- Integrated circuit for energy harvesting/charging with maximum power point feature
- Solar panel temperature sensor
- 3.2 V Battery holder
- Battery temperature sensor connected to battery holder
- High side switch for battery protection from short circuit

The demonstrator was tested on a tourist train operating in Gulbene (Latvia). The distance for each trip was about 34 km, with an hour and a half duration. The weather conditions were rough, between 0º and -10ºC. For this reason, the installed devices had to accomplish an industrial operation range (-20 to 60 ºC). Furthermore, the test were carried out in November, when the low solar radiation and shortness of daylight time sets the most critical scenario for energy harvesting testing. In fact, during the test development, the temperature was about 0ºC and it was snowing.

Figure 9-15: DEWI Project energy harvesting system

The results of the tests were satisfactory. The energy harvesting system was able to feed the integrity sensors. The vertical design of harvesting surfaces provided energy supply during the continuous tests time without voltage losses or instabilities of energy supply.

On this way, DEWI harvesting solution has been proved as one of the candidates that suits better to the characteristics of the train integrity issue. However, other solutions might be explored and used.

9.3.4 Energy Storage

According the information and requirements provided in D4.1 of X2R2 WP4, the energy harvesting system needs a storage that provides energy also with train at stand-still. Furthermore, this storage has to guarantee power supply availability also in case of vehicle at stand-still for 13 months in case of Product Class 2B (REQ 7.4.6).

In ETALON and INNOWAG project, several energy storage solutions have been analysed. As a result of the study of these works, the following comparative table is presented, based on INNOWAG D2.2 and ETALON D4.2:

Type	Density	Degradation	Charge/ Discharge	Cost	Leakage	Duty Cycle
Capacitor	Very low	Electrolytic	High	Low	Low	High
Supercapacitor	Low	Electrolyte Loss	High	High	High	Medium
NiMH rechargeable	High	Charge/Discharge cycles	High	Low	Low	Low

Lithium rechargeable	Very High	Charge/Discharge cycles	Medium	High	High	Low
Hybrid Layer Capacitor (HLC)	Medium	Electrode Loss	Low	Very High	Very Low	Medium

Table 9-8: Energy storage devices comparison

The appropriate storage method depends on the energy harvester selected:

- For high output harversters such as wind and solar panels, optimal performance may be reached with low levels of activity and amounts of energy can be discarded if the vehicle is running. For these solutions, capacitors and supercapacitors can be used.
- For lower output devices such as vibration-based harvesters, more storage may be required in order to avoid discarding energy. Lithium rechargeable and NiMH rechargeable (as low cost solution) may be the best candidates.

9.4 IMU sensors

Taking into consideration the state of the art of sensors analysed in D4.1 of X2R2 project, the following sensors are considered as the most suitable options, among others:

- Accelerometer
- GPS
- RFID

In consequence, in the following subchapters, several examples of suitable devices will be presented and analysed, concerning the sensors previously selected.

9.4.1.1 Accelerometer

Accelerometer sensor is thought to provide acceleration data of each waggon. As it was explained in D4.1 [1] the accelerometer sensors have to accomplish energy harvesting requirements:

- Voltage: 3.3 V
- Current 3.27mA
- Power Consumption < 9W

Furthermore, the accelerometer total error has to be under 1mg.

Analysing the power and no functional requirements of the available sensors and the works performed in DEWI project several accelerometer could shape up as the best options.

The accelerometer analysed provides 12-bit output resolution. The accelerometer has to accomplish with the first energy harvesting requirement in terms of voltage. Its dimensions has to make this device appropriate for easy installation on the waggon.

The accelerometer also accomplish current requirements for different operation modes. In measurement mode, acceleration data is read continuously and the accelerometer consumes less than 3 µA across its entire range of output data rates of up to 400 Hz.

Concerning temperature constrains, the temperature range is -50ºC to +150ºC.

In summary, the accelerometer sensor is appropriate for using in the WP4 works because of its high sensitivity (with 1mg resolution) and low power. Furthermore, its low noise features fits perfectly for train vibration detection.

9.4.1.2 GPS sensor

One of the possible solution for train integrity studied on D4.1 [1] was based on the combination of accelerometer and GPS in order to provide position and RSSI. The technical constraints for the GPS were established according the following parameters:

- Velocity error < 1-3km/h
- Position error < 2.5m

In addition, the energy harvesting requirements for GNSS and RSSI established in previous deliverable were the following:

- GNSS
  - Voltage 3.3V
  - Current 545mA
  - Power Consumption 1.8W
- RSSI
  - Voltage 3.3V
  - Current 3.27mA
  - Power Consumption 825mW

Analyzing the power and no functional requirements of the available sensors and the works performed in DEWI project, the GPS receivers shaping up as one the best options.

These GPS receivers analysed present the following characteristics:

- Operating temperature: -40C to +85C (industrial level)
- Operating humidity: Max. 85%
- Operable at 3.3V
- Current 24mA
- UART interface at CMOS level
- Position accuracy: <2.5 m
- Time to first fix for hot start: <1s

In summary, these GPS receivers seems to be appropriate for using in the WP4 works because it fits the technical and energy harvesting constrains.

9.4.1.3 Radio-Frequency Identification (RFID)

RFID technology was proposed on D4.1 [1] as a good candidate to provide train integrity through train composition, by checking integrity data through active RFID links. Active RFID provides enhanced capabilities with the potential to improve railway operations.

A first approach solution could be the adding of a RFID reader full compliant with the requirements. In this context, UHF RFID readers shaping up as one the best options.

The main features of these RFID readers are the following:

- Able to be reprogrammed
- Able to read multiple tags in a simultaneous way.
- UHF tags can be read over a greater distance that HF or LF
- Ease of use with embedded projects

These features makes this RFID reader able to use in WP4 works in combination with other sensors.

9.5 Tail/Non-Tail sensors

Among all the possible installation options related to devices, it could be required sensors at each waggon which may be categorised as tail/non tail sensor in order to offer a solution for train tail localization.

Several solutions can be adopted. One of them is the detection of the train tail position using satellite positioning systems. However, it seems not be enough to guarantee the full coverage of the signal during the trip, due to the signal shading caused by tunnels and the topography. For this reason, it is necessary to complement this satellite solution with a system based on tail/non tail sensors.

Except for Product Class 1A, the rest of Product Classes do not contemplate the possibility of having ETCS at train tail. Furthermore, Product Class 1B does not present availability of odometry or position sensors at train tail. In a generic way, the OTI Slave module acquires the status of train tail and provide collected information to OTI Master Module on the locomotive.

Tail/non tail determination has to be included at design phase. In this manner, OTI Slaves located in intermediate waggons behave as OTI Slave non tail, and OTI Slaves at train tail behaves as OTI Slave tail. Furthermore, OTI Master only pairs with OTI Slave tail for train integrity monitoring, checking its status to evaluate train integrity. In case of coupling scenarios, the previous tail waggon of the front train will behave as an OTI Slave non tail when the coupling is complete, and the OTI Master module will establish communication with the new OTI Slave tail of the back train. Therefore, the OTI Slave devices are connected to a tail/non tail sensor which identifies the position inside the train, in case of not ETCS in the waggon at tail, specifically in freight scenarios.

For this purpose, several solutions can be studied. First of all, in deliverable D3.2 [40] from ETALON project, the distance sensor DWM1001 is presented. This device makes use of Two-Way Ranging Real Time Localization System (TWR RTLS) and it is composed of an accelerometer and tow integrated antennas for UWB and BLE. It also offers data encryption for network connectivity, which allows the deployment of security capabilities.

The device can be configured in two modes:

- Anchor: Device defined as the objective of the measurement.
- Tag: Device that requires the measurement.

The distance sensor can be used to measure a distance between two devices, one configured as anchor and the other as tag. In this way, this device can be set up as the tail sensor when it do not detect other devices behind. This distance sensor is fully compliant with IEEE 802.15.3 standard, one of the selected standards according chapter 9.2.4.

The WSN composed by the single nodes concerning the distance sensors is also able to assess the integrity of the train by periodically checking of the distance between the coupled waggons. It could be used as a complementary method to ensure train integrity. For this purpose, for each node it is necessary to define the interface with the following distance sensor to establish if it is tail or non tail sensor, and compare the distance to ensure that an integrity loss has not occur.

Concerning power consumption of the distance sensor, it is important to remark as established in ETALON project, that most of the time, this module would stay in a low consumption state and it can be powered with a 2.8-3.6 V voltage range. When the device is set as active, the current consumption is established around 6 mA and in idle mode the consumption reaches 13 mA. In the following figure is shown the current consumption of the module in detail:

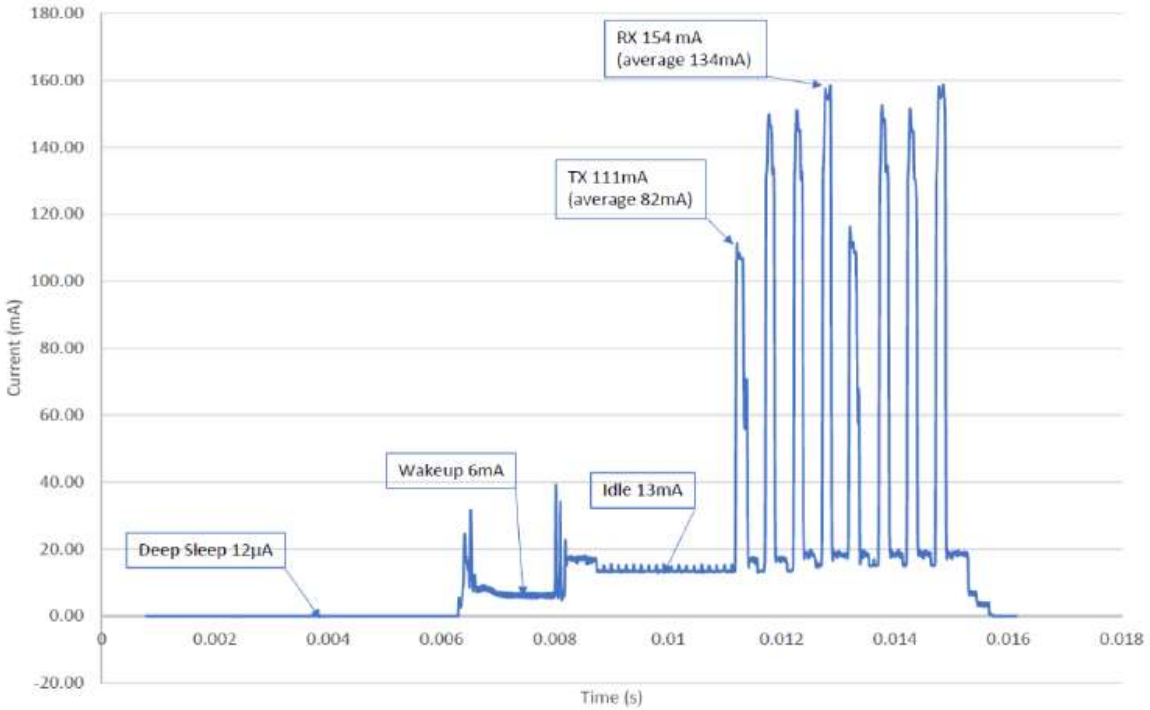


Figure 9-16: Distance sensor power consumption

The time required to activate the sensor and perform the measurement is around 9ms, which it is enough to figure out if the OTI Slave is tail/non tail.

INNOWAG proposes several solutions for real-time localisation and waggon identification based on different technologies. Due to the characteristics of the system developed on this WP, only available technologies for on-board systems are evaluated in this sections. The technologies are the following:

- **RFID**
  - As each RFID tag has its own identification code, when the reader sends request to the tag, it will response with this code.
  - In this way, with dynamic RFID tags it is possible to identify the device as tail or on tail during the inauguration process. Also, the value of this tag can be modified during the trip if necessary.
  - Advantages:
    - Low costs for tags
    - Tags can be self-powered
    - Resistant to environmental factors
  - Disadvantages:
    - Limited communication range
    - Security weaknesses with other devices working at the same frequency
    - RFID readers present a high energy consumption.

- **GPS technology via satellite navigation**
  - The satellite navigation system measures the distance to a satellite by calculating the amount of time to receive a transmitted signal form the satellite. With this distance, the position can be determined.
  - This method could be useful to establish the position of a waggon in regard to the locomotive, so it is possible to know if the waggon is at the tail.
  - Advantages:
    - Worldwide coverage
    - Low Cost solution
    - High accuracy
    - Easy integration
  - Disadvantages:
    - Unavailability in shadowing areas such as tunnels or forests.
    - Interference of weather conditions.
    - Limited by train speed.

- **Dead reckoning localisation**
  - Process of calculating the position based of a known fixed point, in this case, the head of the train.
  - If the distance between the waggon and the head is known, it is easy to figure out if the sensor is located at the tail.
  - Dead reckoning devices:
    - Odometers based on pulse counter.
    - Tachometers based on eddy-current sensors.
    - Doppler radar systems based on radar.
    - Inertial systems based on accelerometers and gyroscopes.
  - Advantages:
    - Resistant to environmental factors
    - High availability on movement
    - Easy integration
  - Disadvantages:
    - Low accuracy due to cumulative errors
    - High costs.

- **Radiolocation**
  - Calculates the time to communicate between on-board devices and a number of radio stations.
  - Uses the global communication systems such as GSM.
  - Advantages:
    - No extra hardware needed if radio communication is available as the data medium.
  - Disadvantages:
    - Unavailability far from the base station.
    - Less accuracy than GPS technology.

To sum up, after analysing all the different options, INNOWAG project selects as the most feasible a combination of the GNSS module with an odometer or an inertial system, which guarantees the availability in shadowed areas.

In DEWI project [REF 4.1], the GPS sensors used to detect the integrity failure can be used to identify if the waggon is at the train tail or in an intermediate waggon. The DEWI GPS positioning solution installed in every waggon monitors the distance between waggons and train’s cabin. If the distance between the head and the tail is known, it is easy to identify each waggon as tail or non tail.

The operational requirements used in DEWI to evaluate the performance of this GPS sensor are the following:

- Feasibility of installation in different location
- Easy installation, start-up and maintenance
- Low Power Consumption
- Accuracy in measurements
- Long-Term Robustness and Reliability
- Long term stability in measurements
- Compatibility with Track Maintenance Tasks
- Fixed and portable nodes

Taking into account these requirements, GPS sensors used in DEWI and described in the previous chapter offer a good performance. However, the high consumption of the GPS makes it less appropriate for being used as a tail/non tail sensor. Furthermore, this solution is not recommended in areas with high density of tunnels.

Another feasible solution for the implementation of tail/non tail sensors is based in End of Train (EOT) devices. These devices are mounted on the end of the train and commonly they are used for providing a visible indication of the tail with a red light. However, smart end of train devices send back data to the locomotive via radio-based telemetry. Therefore, if it is possible to establish communication with the rest of OTI Master and OTI Slaves, EOT devices can be used as tail/non tail devices. Several EOT devices has been analysed and presented below:

- **Guardian End of Train Device (Progress Rail)**
    - Transmit real-time information from the end of the train, contributing to improve safety and security
    - Powered by air turbine and long duration batteries.
    - Mounted outside the waggon and is able to operate in conditions around - 40ºC.
    - Easy deployment.

Figure 9-17: Guardian EOT Device

- **SRA End-of Train Device (Siemens)**
    - Apart from indicating the tail of the train, this device provides information regarding conditions at the tail, such as brake pipe pressure, movement or battery condition.
    - Includes a GPS receiver used to determine location and speed, and this information is stored.
    - Powered by air generator which keep the battery charged.
    - Easy deployment.

Figure 9-18: SRA EOT Device

- **Trainlink End of Train (Wabtec)**
    - Provides tail information about brake pipe pressure, motion status, battery condition and marker light status.
    - Powered by long life air generator.
    - GPS tracking is available, but it need an special deployment of external antennas with based tracking tools.
    - High CAPEX costs and complex deployment for tail/non tail purposes.

Figure 9-19: Trainlink EOT device

- **EOTD Rear Unit (EMS Railtech)**
    - Designed to give train control over rail operation, with continuous display of the brake line pressure.
    - Tracking based on satellite and GSM, with integrity and status of the train available.
    - Powered by air generator with long life batteries.

Figure 9-20: EOTD Rear Unit

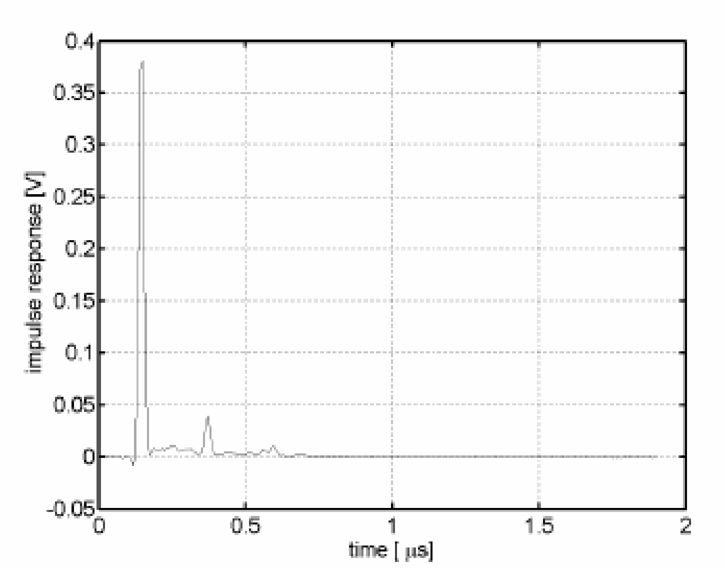
TIS project [41] study the feasibility of a sensitive multichannel GNSS receiver in parallel with GPS for waggon localisation within a composition. To ensure speed and robust tracking, the receiver can offer additional GNSS functionalities such as A-Galileo. However, the project is still unfinished and tests have been not carried out yet, but it is important to follow the advances of this project in order to evaluate if this solution could be feasible for tail/non tail sensors.

9.6 Powerline solution for wired communications

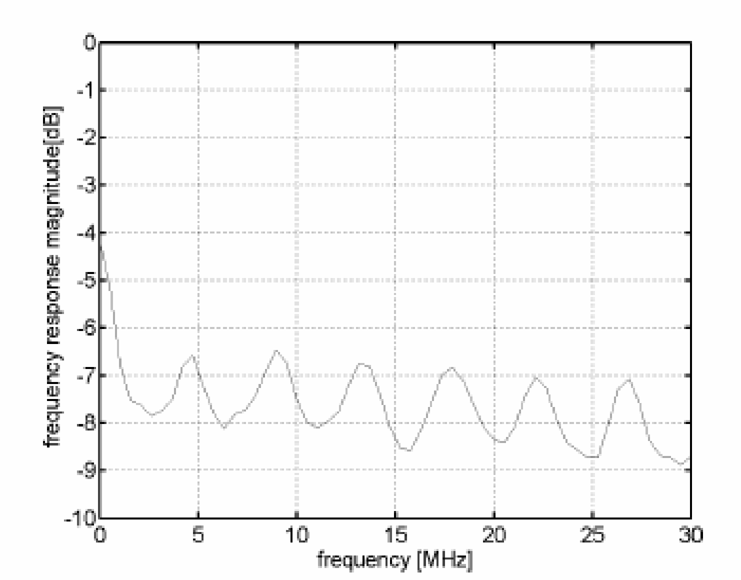
Nowadays, there are several old generation trains with electrification in which wired solutions for communications are not implemented. In this context, it is necessary to search for solutions which take advantage of the cabling already existing in the trains, as train power lines, in order to save costs. This is an important issue because, as it was mentioned on chapter 9.2.4 of the current deliverable, Product Class 1 is restricted to wired communications through one OTI device per each train cabin connected with ETCS. The scope of the candidate technologies selection related to communications is focused on wireless technologies, but taking into account this Product Class 1, it is necessary to address wired communication issues to this analysis.

Convoyed waves over train power lines becomes very important to be considered as a possible solution. Furthermore, current and future railway systems require a high number of electronic devices to be allocated in the cabins and communication has to be safe and secure along the train composition. In a wired environment, it requires dedicated wired networks which increase high CAPEX costs which are unacceptable from a market point of view, for old generation trains. The irruption and progress of power line communications (PLC) for data transmission in the last decade open a new way for communication applications focused on transportation, and also in railway environment.

In this context, the use of Broadband Power Line (BPL) by the paper from Barnada et al. [54], which presents a first approach to the design of a PLC system on-board. It introduces a solution based on the use of train power lines to develop the communications without complex hardware/software implementation, which makes it interesting from the point of view of saving costs. Based in a remote control and a communication line composed by conductors, cables and connection boxes, it is possible to guarantee the transmission of information continuity along the train composition. Concerning the characterization of the PLS channel, the paper focuses on the simulation of the channel's behaviour to obtain the parameters of the multiconductor. These parameters take into account the dependence on the frequency, relevant in 1Mhz-30Mhz range (OFDM). The results of the simulation are the following, considering different parameters:



9.19: Time domain impulse response circuit in the cable trunking [54]



9.20: Time domain impulse response circuit in the cable trunking [54]

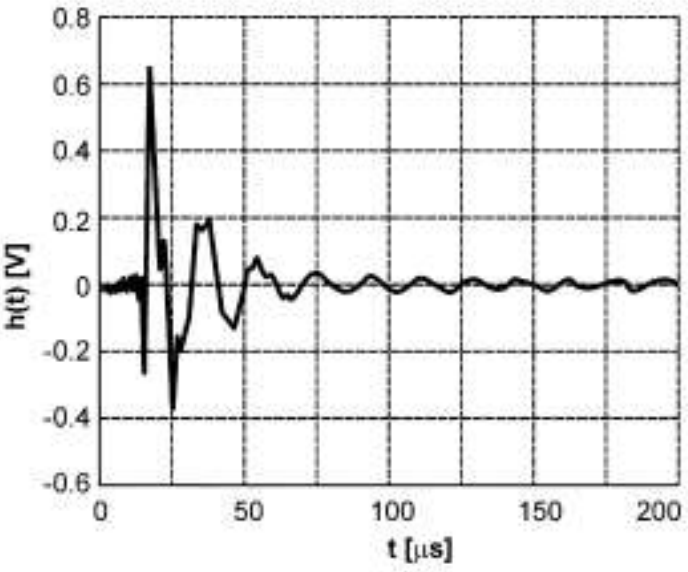
The conclusions of the Barnada et al. study shows the good performance of PLC on-board solution. However, the conductors could act as noise source for the transmission over the cable, and crosstalk has to be investigated.

In this line of work, Russo et al. [55] define a communication alternative solution for non-critical devices, applying it for Passenger Information System devices. The transmission of information is performed with PLC, which provides the interface with a band-pass filter to avoid nose interferences. Using the installed power cables, it is possible to provide a full solution of audio and video media for passengers and it was tested in Trenitalia trains. The proposed solution covers all the OSI layers at low speed PLC and physical and data link layers at high speed.

The experimental results shows that the system is able to communicate with wayside infrastructure via GSM/GPRS and is able to locate the train position with a GPS module. Furthermore, the availability of coaxial cables provides robustness and complete redundancy. However, this system has not been developed during the last decade, and it can be considered obsolete opposite to other proposed solutions.

Another paper, from Karols et al. [56] investigates mass transit power line channels (MT-PLC) to support a solution for train control system. The availability of power traction lines in a railways network makes it very interesting to be used as the communication alternative to other wired implementations. The study includes the development of a stochastic model based on the deterministic channel modelling performed also in the paper. Channel simulation and emulation are considered to evaluate the system performance. The results of the simulation, in a frequency range of 50-500 kHz and a sampling frequency fixed to 1.5 MHz, shows that the speed of amplitude fluctuations increases with frequency, depending on the Doppler filters. Furthermore, channel transfer functions are correlated over time and frequency intervals. The width of this correlation intervals correspond to the width of the Doppler spectrum.

The channel impulse response resulting from the simulation is the following:

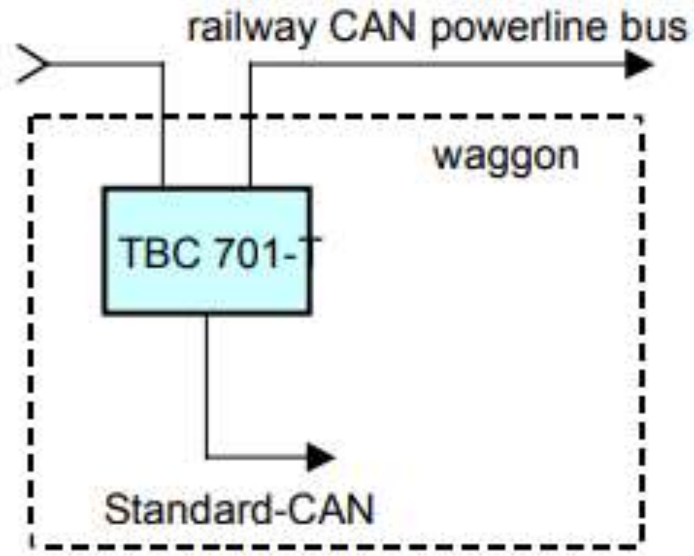


9.21: Channel impulse response [56]

The conclusions of the Karols et al. paper show the PLC over existing power supply lines as a good solution in environments that are not fair for wireless communication or an alternative solution to Ethernet link is needed. As a result of the study, a complete mass transit channel model is completed and main guidelines for building emulation hardware is presented. Moreover, the study considers that the channel adapted PLC system for power traction lines are prepared to be implemented in a railway environment.

Controller Area Network (CAN) powerline applications can be also used as a feasible solution, considering the need of adaptation of new system to old generation trains. In this context, two publications explore the use of this technology.

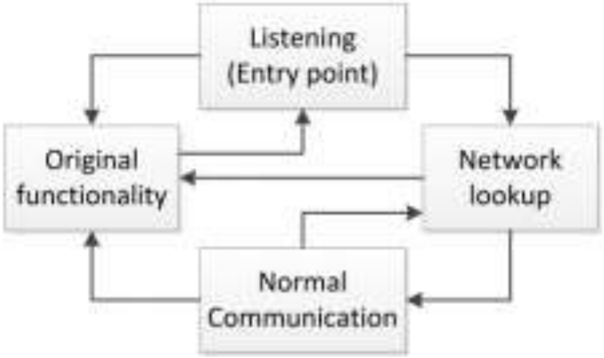
Beikirch et al. [57], proposes a CAN powerline solution for rolling stock. This interface offers a low cost and reliable communication medium to solve the deployment of high cost devices. The train couplers connect the internal CAN of every waggon onto the CAN powerline along the train, as shows the following figure:



9.22: Railway CAN Powerline bus [57]

The test results prove the success of CAN Powerline System for data transmission. However, additional tests for specification of bit rates and bus cable length could not be performed due to optimisation issues of the transceiver circuitry.

Other solution based on CAN was presented in Bécsi et al. [58]. The objective of this study was improving quality of service and reduce maintenance costs in the railway environment, presenting a solution based on data transfer via current existing interconnection. Using CAN communication through UIC 588 series cable and connector, could be theoretically implement a communication network along the composition able to transmit medium amount of data without needing a high investment in software/hardware. A network Look-Up algorithm presented in this study allows determining the order of the devices in the network, by enabling an automatic enumeration of the waggons, following the state diagram showed below:



9.23: Network State diagram for CAN based solution [58]

In the context of this study, two test have been performed to demonstrate the feasibility of this solution. Based on the results of these tests, it can be assumed that CAN communication can be applied in a safe manner on the current train interconnection solutions in wired railway environments.

A brief analysis of these solutions shows that the majority of the studies were performed at least ten years ago. Although PLC and CAN communication solutions are feasible for the implementation in old generation trains taking into account the results of the works, several issues have to be analysed.

First, these solutions do not guaranteed interoperability with all waggons of the market. For example, in freight market, the compositions changes in every trip and different kind of waggons from different manufacturers have to be connected. The solutions proposed are based in UIC cables, which is an extended standard within railway industry, but it is not the only one. LUL, HD or DIN VDE cables are being used in several waggons in the European railway market and accomplish with the industry standards [59]. So it is necessary to consider the performance of this solution and the possible interoperability and connection issues, which may increment the cost of the solutions.

Another important issue to be considered is the evolution of the communication devices and installation, both for wired and for wired communications concerning the cost. Ten years ago, the cost of these devices was too high, and other solutions like PLC or CAN communications were studied and recommended as feasible and appropriate for railway environments. However, the cost of installing and maintenance of current communication devices has been reduced last years, while PLC and CAN solutions cost has remaining practically the same than ten years ago. It implies that the installation of new communication devices should be recommended over the use of PLC concerning the costs of implementation and maintenance.

To sum up, the solutions based on convoyed waves over train power lines are feasible insofar as the railway context has not changed since ten years ago. However, nowadays could be considered as an obsolete technology taking into account the interoperability and the reduction of communication devices costs. Furthermore, there are not current solutions which may accomplish with the requirements concerning cost and interoperability and the current manufacturers are limited and they work in an oligopoly way, which triggers a high cost solution and highly provider dependant. Consequently, it makes much more recommendable to discard PLC solutions in favour of other wired and wired solutions as proposed in D4.1 and the current D4.2.

9.7 Conclusions

During this chapter, the candidate technologies selection has been presented and analysed. Concerning wireless on-board communication network, as it is explained in subchapter 9.2.3, for short range communications, ZigBee and 6LowWPAN are the most suitable technologies due to their low consumption and robustness and security. Moreover, IEEE 802.11p is recommended not only for short range communications, but also for medium range communications, according the implementation cases studied. For long range communications, IEEE 802.11 family protocols and LTE are the preferred candidates, due to their advantages regarding fast transmission of high amount of data. However, LTE release 14/15 and 5G technologies are still in a very early stage, and requires high CAPEX cost, so the usage of this solution has to be analysed in future stages of the work.

Taking into account the product classes compared in subchapter 9.1 and after analysing their requirements, a first approach for the selection of the wireless candidates can be given. In case of product Class 1, due to the communication between devices is wired, the technologies analysed did not apply in this case. Product Class 2 is highly dependent of the waggon length, so the best solution seems to be 802.11p. In case of several nodes installed along the composition, ZigBee and 6LowPAN can be good low consumption technology candidates to reduce costs. In case of Product Class 3 implementation, ZigBee and 6LowPAN should be useful for short range communications, but for long range communications, 802.11 family protocols may be used to provide a high bandwidth, reducing the number of hops.

Concerning energy harvesting solutions, the following table presents a summary of the analysed solutions:

Type	**Name**	**Amount of power**	**OPEX/CAPEX Costs**	**Feasibility**
Vibration harvesters	Vibration harvester using suspended inertial mass	Insufficient	High OPEX due to wheelset maintenance operations	Low feasibility for OTI purposes
	Piezoelectric vibration harvester	Low	Medium	The low vibration amplitudes make the solution not feasible for OTI purposes
Electromagnetic harvesters	On Train Linear Generator	High	Medium OPEX costs when special mounting is required	The design is at very initial development phase to consider the feasibility for OTI purpose

	Ambient RF energy harvesting	Low	Low	The availability and the continuous energy harvesting make it feasible. However, the low power density is an important disadvantage.
	Wireless power transfer technology	Limited by radio standards	Low	Feasibility and efficiency is dependant of the antenna radiation patterns
	Passive RFID sensor technology	High	High due to the need of a RFID reader installed on-track	The solution is feasible, but performance is worst when increasing the distance between the reader and the tag
Solar and wind harvesters	Nexiot Globehopper	High	High due to it is an individual waggon solution	Not proven yet in northern Europe at low temperatures
	Solution based on photovoltaic effect	High	Medium	Not proven yet
	Energy harvesting prototype from DEWI Project	Sufficient to feed integrity sensors	Medium	The solution provided energy supply during the continuous tests time without voltage losses or instabilities of energy supply

Table 9-5 – Results about energy harvesting solutions comparison

As it could be extracted from the previous comparison, vibration and electromagnetic are interesting solutions but may present insufficient amount of energy to power the OTI devices. These solutions may not be discarded, but in future phases of the implementation has to be deeply studied their feasibility.

Passive RFID solution is presented in INNOWAG as a good solution, but the cost of installing RFID readers on-track is too high, and for train integrity purposes, this costs is unacceptable. However, for complex systems (i.e. waggon On-Board Unit) that include train integrity features among other capabilities, this solution can to be analysed as proposed in INNOWAG project, but not as itself. Solar and wind harvesters can be useful, but the feasibility has to be proved.

To sum up the harvesting solutions, we can conclude that none of the presented solution accomplish all the criteria concerning capacities and they not guarantee the safety of the system. It is necessary to choose a mixed solution based in solar and wind harvesting as proposed in DEWI project and piezoelectric harvesting in case that the impact over the waggon design is not too critical. Anyway practical analysis in future stages of the work have to be performed to validate the use of this mixed solution.

Concerning Tail/Not-tail sensors, the solutions given in subchapter 9.5 have to be deeply studied in future stages of the work. The solutions selected are not mature enough in the context of this work package to give a final selection of candidates. Each technology has to be evaluated following the works to be performed in ETALON and INNOWAG, and updating the new market solutions that could be useful for OTI purposes.

Finally, several convoyed waves over power lines solutions have been analysed in order to take into account the existence of old generation electrified trains where Ethernet link is unavailable. Although these analysed solutions are feasible, they may be discarded attending to interoperability and cost criteria.

10 Conclusions

This report was focused on describing activities performed in side Task 4.3 and Task 4.6 in relation to functional architecture and interface specification. The analysis of candidate technologies selection, performed in Task 4.4, is also described as preliminary step for subsequent product specification.

At functional architectural level this reports presented solutions for passenger and freight scenarios including a focus on ETCS backward compatibility in relation to communication needs in different OTI product classes.

The interface specification was also analysed and defined in relation to ETCS-OTI communication link and also in relation to OTI Master and OTI Slave thus ensuring interoperability among products from difference suppliers. A specific effort was also spent in evaluating solutions to support ETCS backward compatibility (i.e. ETCS BL3 R2 [2] and CR940 [3][4]).

Interface specification explored application level, protocol stack and physical level. The first step consisted in defining high level functional interface on the basis of functional requirements and reference scenarios defined in D4.1 [1]. On these bases the structure for proposed application level messages have been reported. The protocol stack analysis included existing solution already available or under development in on-going projects focused on on-board communication solutions. Euro-radio over TCP/IP was considered as option already specified and applied in other railway applications. The applicability of communication services defined by Adaptable Communication TD2.1 and FRMCS was also considered. In this case the hypothesis of adopting cellular network is evaluated. The overall analysis included also the communication services offered by new generation TCMS.

Possible physical interfaces have compared and considered both about wired and wired communication. As example Ethernet is proposed as an interesting physical interface compatible with wide range of existing on-board communication infrastructures.

The ETCS backward compatibility analysis focused on delivering train integrity functionality ensuring compliancy to current ETCS-OTI functional interface specified in SubSet034 [3] and CR940 [4].

In this case only train integrity status is provided to ETCS, whereas other commands or information are managed independently. As example acquiring active cabin for OTI role assignment (master or slave) or acquiring start/reset commands in relation to train composition phase.

This report includes also results from candidate technology selection performed inside task 4.4. First analysis consisted in comparing the product classes in relation to product life cycle thus providing qualitative complexity figures taking into account product complexity, installation constrains, operational impact and maintenance implications. In conclusion OTI product class 2 referred to wireless technologies and energy harvesting addressing existing freight waggons resulted having an higher qualitative effort.

As wireless physical interface, a possible solution identified for OTI product class 2 includes 802.11 family, specifically 802.11p. In case that several wireless nodes are installed along the composition, in order to reduce OPEX/CAPEX, save power (in case of energy harvesting as Product Class 2B shows) and increase security, ZigBee or 6LoWPAN devices could be efficient due to it is not needed a high amount of data transmission.

General guidelines for applicability of energy harvesting solutions to freight application domain are provided.

Proposed interface specification and related explored technologies constitutes a guideline for OTI product specification. Note that compatibility to existing ETCS BL3 Rev2 + CR940 specifications have been considered in “ETCS backward compatibility” scenario. A proposal for standard interface specification shall be addressed in X2Rail-4.

In relation to train length determination, ETCS-OTI interface and OTI Master-OTI Slave interfaces has been enriched and relations between OTI-I functionality and OTI-L functionality has been described, based on functional requirements for train length determination functionality specified in D4.1 [1].

Finally this reports includes several annexes that extends the overall topics addressed in functional architecture and interface specification.

Appendix A addressed a system level functional analysis in relation to OTI override, OTI juridical data and SoM L3.

Appendix B reported application level messages related to the preliminary Virtual Coupling analysis reported in D4.1.

Appendix C evaluated redundancy implications for OTI devices.

Appendix D included the results of communication analysis respect to EN50159 both about opened and closed cases.

Appendix E reported the traceability matrix between the requirements specified in D4.1 (Ref. [1]) and requirement specified in this document D4.2.

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APPENDIX A X2R2 WP4 ON-BOARD CONTRIBUTION TO SYSTEM LEVEL ANALYSIS

This appendix notes includes, as examples, a contribution to system analysis in relation to three topics raised by EUG:

- Overriding of the TIMs by the driver
- Juridical data of the TIMs
- Possible review of ERTMS SoM PR to report the status of TIMs (e.g. it appears important to know as soon as possible if TIM is available for a train starting a mission in L3 or aiming to enter into a L3 area)

Preliminary proposal reported in the following shall be further analysed in X2Rail-4 in the context of Standardisation Proposal task.

A.1 Overriding of the TIMS

This sections analysis the possibility for the driver to override the TIMS functionality (e.g. due to faults). ETCS-OTI interface specified in CR940 [4] includes only train integrity information provided by OTI to ETCS. Additional OTI status information are required to inform the driver about the presence of OTI faults.

In relation to the DMI, the following options could be considered:

- Text message about OTI device fault
- Icon about train integrity status
- Override external OTI device
- Train integrity confirmed by the driver

At OTI product level, the implication consists in providing to ETCS information about OTI device status (e.g. regularly working or fault) by means of OTI-ETCS interface.

Interface specification was designed in a general way and includes OTI device status to allow the possibility to display train integrity status and OTI device status to the driver. Compliancy to ETCS BL3 and CR940 [2][4] was also taken in to account in ETCS backward compatibility scenario described at section 8. In this case the proposal consists in additional lamps in the dashboard directly connected to OTI device.

A.2 Juridical data of the TIMS

CR940 specifies to record only M_TRAIN_INTEGRITY_INFO (i.e. status of train integrity) as juridical data recorded by ETCS in relation to TIMS. A general criterion for identifying juridical data refers to information shown to the driver and driver actions. This section contains a preliminary analysis about other possible data related to TIMS functionality for a potential future enrichment of recorded data.

INFO IDENTIFIER	VALUES	TYPE OF DATA
TRAIN INTEGRITY STATUS	• Unknown • Confirmed • Lost	juridical data
OTI DEVICE STATUS	• Ok • Fault	diagnostic data
OTI FSM STATUS	• MASTERSHIP • INAUGURATION • MONITORING	diagnostic data
OTI FAULT	• OTI MASTER FAULT • OTI SLAVE FAULT • MASTER-SLAVE COMMUNICATION FAULT • ETCS-OTI COMMUNICATION FAULT	diagnostic data
TIMS OVERRIDE BY THE DRIVER	• Yes • No	juridical data

Table 11-1: Example of TIMS juridical and diagnostic data

In general the proposal consists managing juridical directly by ETCS and other data recorded for OTI diagnostic purposes.

Proposed information list allow clarifying on-board system behaviour, OTI device behaviour and driver behaviour during train mission. This topic shall be addresses, after laboratory and on-site experimental activities, at the end of X2R4 in the context of defining a Standardization Proposal.

A.3 SoM L3 and Position Report

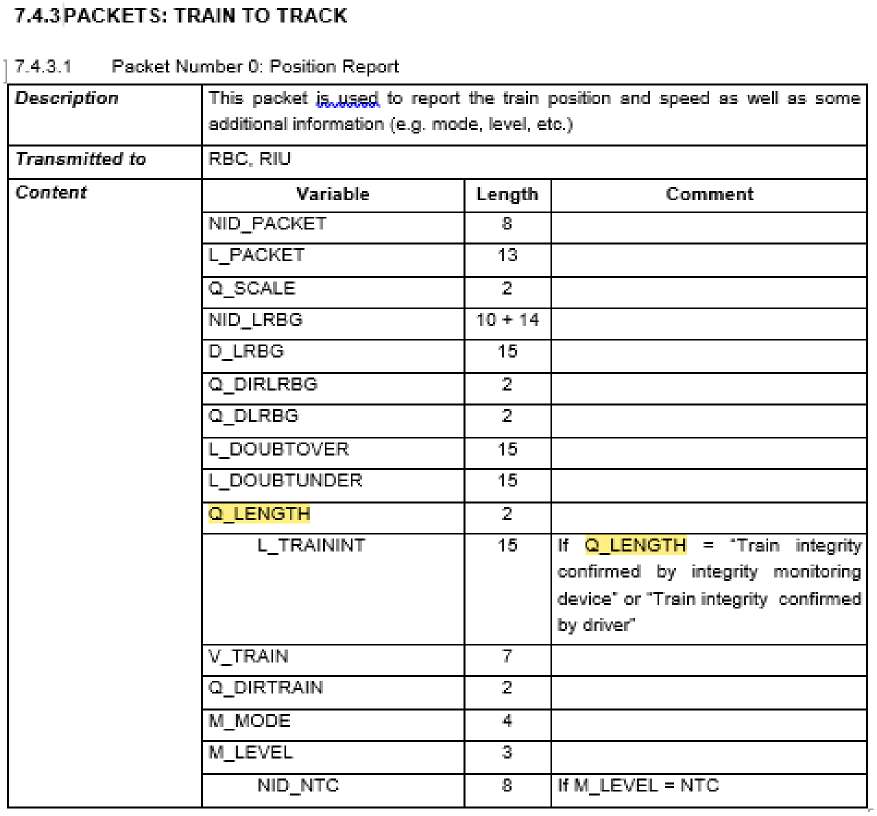
Considering the impact for an OTI monitoring system, this section contains an analysis for:

- Position Report message
- Start of Mission for Level 3
- Transition to a Level 3 area

A.3.1 Position Report

This section contains a proposal for enriching the Position Report message with TIMS status.

Current PR message (Table 11-2) includes Q_LENGTH variable (Table 11-3) related to the status of train integrity information.

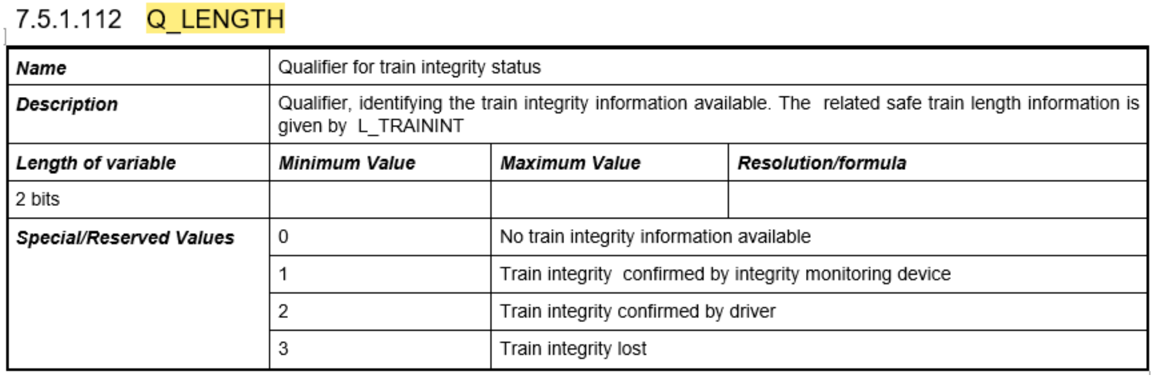


7.4.3 PACKETS: TRAIN TO TRACK

7.4.3.1 Packet Number 0: Position Report

Description	This packet is used to report the train position and speed as well as some additional information (e.g. mode, level, etc.)		
Transmitted to	RBC, RIU		
Content	**Variable**	**Length**	**Comment**
	NID_PACKET	8	
	L_PACKET	13	
	Q_SCALE	2	
	NID_LRBG	10 + 14	
	D_LRBG	15	
	Q_DIRLRBG	2	
	Q_DLRBG	2	
	L_DOUBTOVER	15	
	L_DOUBTUNDER	15	
	Q_LENGTH	2	
	L_TRAININT	15	If Q_LENGTH = "Train integrity confirmed by integrity monitoring device" or "Train integrity confirmed by driver"
	V_TRAIN	7	
	Q_DIRTRAIN	2	
	M_MODE	4	
	M_LEVEL	3	
	NID_NTC	8	If M_LEVEL = NTC

Table 11-2: Current Positon Report message



7.5.1.112 Q_LENGTH

Name	Qualifier for train integrity status		
Description	Qualifier, identifying the train integrity information available. The related safe train length information is given by L_TRAININT		
Length of variable	*Minimum Value*	*Maximum Value*	*Resolution/formula*
2 bits			
Special/Reserved Values	0	No train integrity information available	
	1	Train integrity confirmed by integrity monitoring device	
	2	Train integrity confirmed by driver	
	3	Train integrity lost	

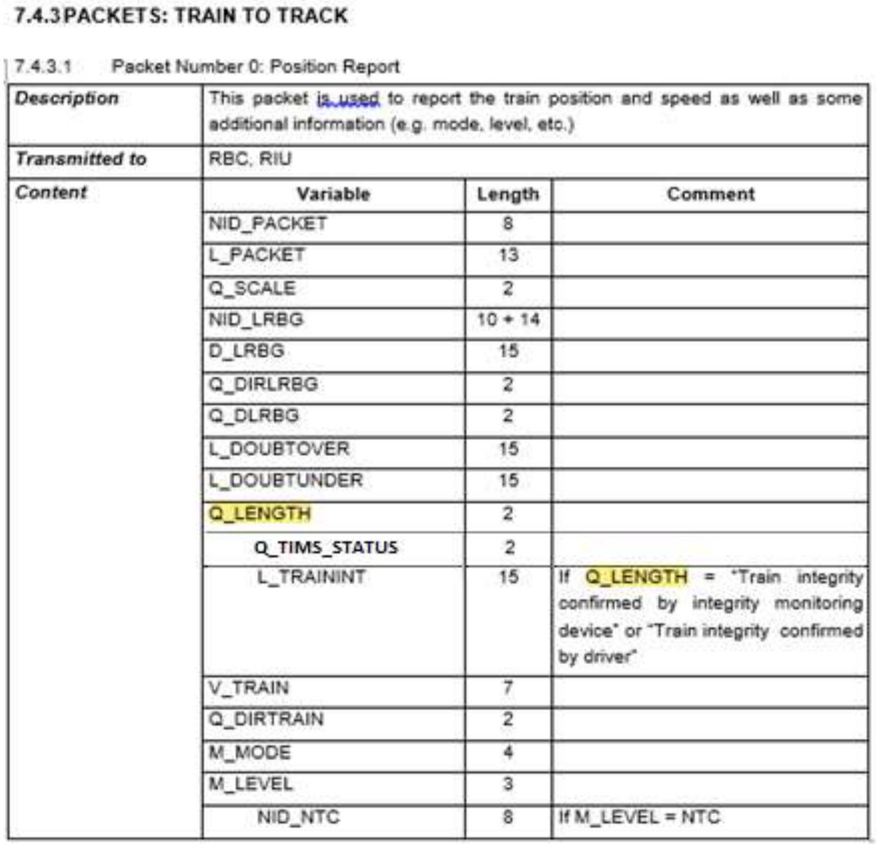
Table 11-3: Q_LENGTH variable

The proposal consists in adding Q_TIMS_STATUS variable (Table 11-4) inside the Position Report message (Table 11-5).

Name	Qualifier for TIMS status: Q_TIMS_STATUS		
Description	Qualifier, identifying the status for On-Board Train Integrity Management System		
Length of variable	**_Minimum Value_**	**_Maximum Value_**	**_Resolution/formula_**
2 bit			
Special/Reserved Values	0	NOT PRESENT	
	1	OK	
	2	FAULT	

Table 11-4: Q_TIMS_STATUS variable

ETCS-OTI interface specification described at section 6 includes also OTI device status (i.e. regularly working or in fault). Therefore the value for Q_TIMS_STATUS variable can be derived by information provided by OTI device.



7.4.3 PACKETS: TRAIN TO TRACK

7.4.3.1 Packet Number 0: Position Report

Description	This packet is used to report the train position and speed as well as some additional information (e.g. mode, level, etc.)		
Transmitted to	RBC, RIU		
Content	**Variable**	**Length**	**Comment**
	NID_PACKET	8	
	L_PACKET	13	
	Q_SCALE	2	
	NID_LRBG	10 + 14	
	D_LRBG	15	
	Q_DIRLRBG	2	
	Q_DLRBG	2	
	L_DOUBTOVER	15	
	L_DOUBTUNDER	15	
	Q_LENGTH	2	
	Q_TIMS_STATUS	2	
	L_TRAININT	15	If Q_LENGTH = "Train integrity confirmed by integrity monitoring device" or "Train integrity confirmed by driver"
	V_TRAIN	7	
	Q_DIRTRAIN	2	
	M_MODE	4	
	M_LEVEL	3	
	NID_NTC	8	If M_LEVEL = NTC

Table 11-5: Proposal for new Position Report message

In general "Unavailable" train integrity status doesn't allow to distinguish between unfitted or fault OTI device. Providing TIMS Status in PR message allows RBC being informed in advance about unavailability of TIMS functionality (unfitted or fault) thus informing Dispatcher/TMS how to manage this train according to Infrastructure Managers operational rules.

Similar evaluations are also valid for Packet Number 1 "Position Report based on two balise groups" [2].

A.3.2 Example for SoM Mission Level 3

Please note that the validity of proposed analysis is based on the assumption that TIMS is an enabling technology for ETCS L3. In general the possibility to have OTI also in L2 is under discussion.

As defined in SUBSET 026 a generic start of mission of Level 3 (L3) does not require the “availability” of an OTI monitoring system but only the availability of a Mobile Terminal on which the on-board can be registered.

A generic steps sequence done at the beginning consists in:

1. Power ON of entire system
2. Initialization Phase for equipment initialization (e.g. BTM, DMI, etc…)
3. SOM Procedure initiated by the driver

The flow chart of Start of Mission procedure, as reported in SUBSET 026, is depicted in Figure 11-1.

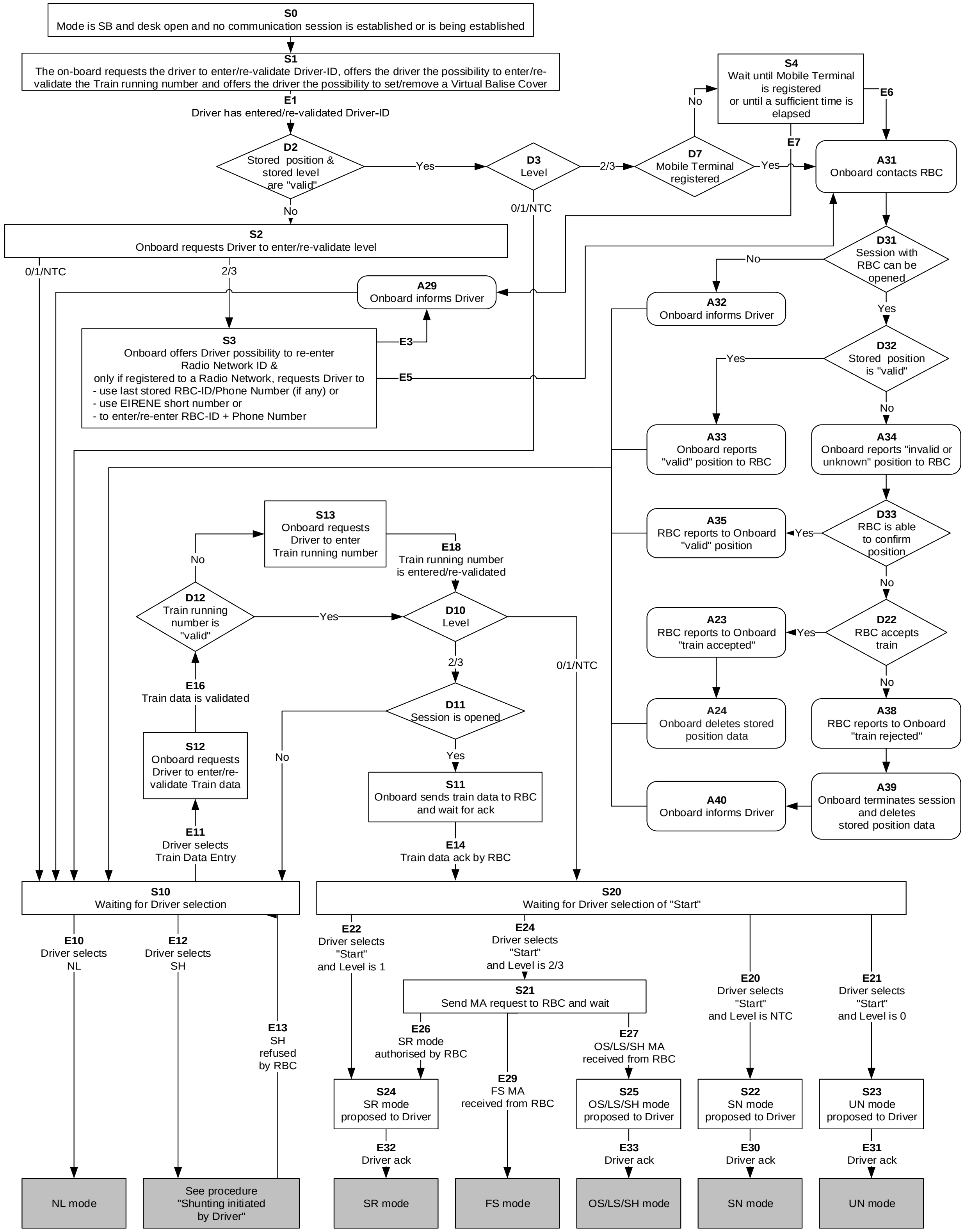


Figure 11-1: Flowchart for "Start of Mission"

In case of availability of an OTI Monitoring system, the step sequence done at beginning of a generic mission is still applicable, by including the OTI initialization.

In case Trackside Train Detection is not available, the Level 3 Start of Mission could be conditioned to the selection of Level 3 (L3) by the driver on the basis of “status” of OTI subsystem.

The status of OTI device reported to EVC, after the initialization is:

OTI Subsytem Status	**Meaning**	**Impact on DMI subsystem**
0	OTI not available (fault or not installed)	No Button “LEVEL 3” available to push
1	OTI available and correctly working	Button “LEVEL 3” available to push

Considering that, the flow chart of SOM modified could be the following Figure 11-2.

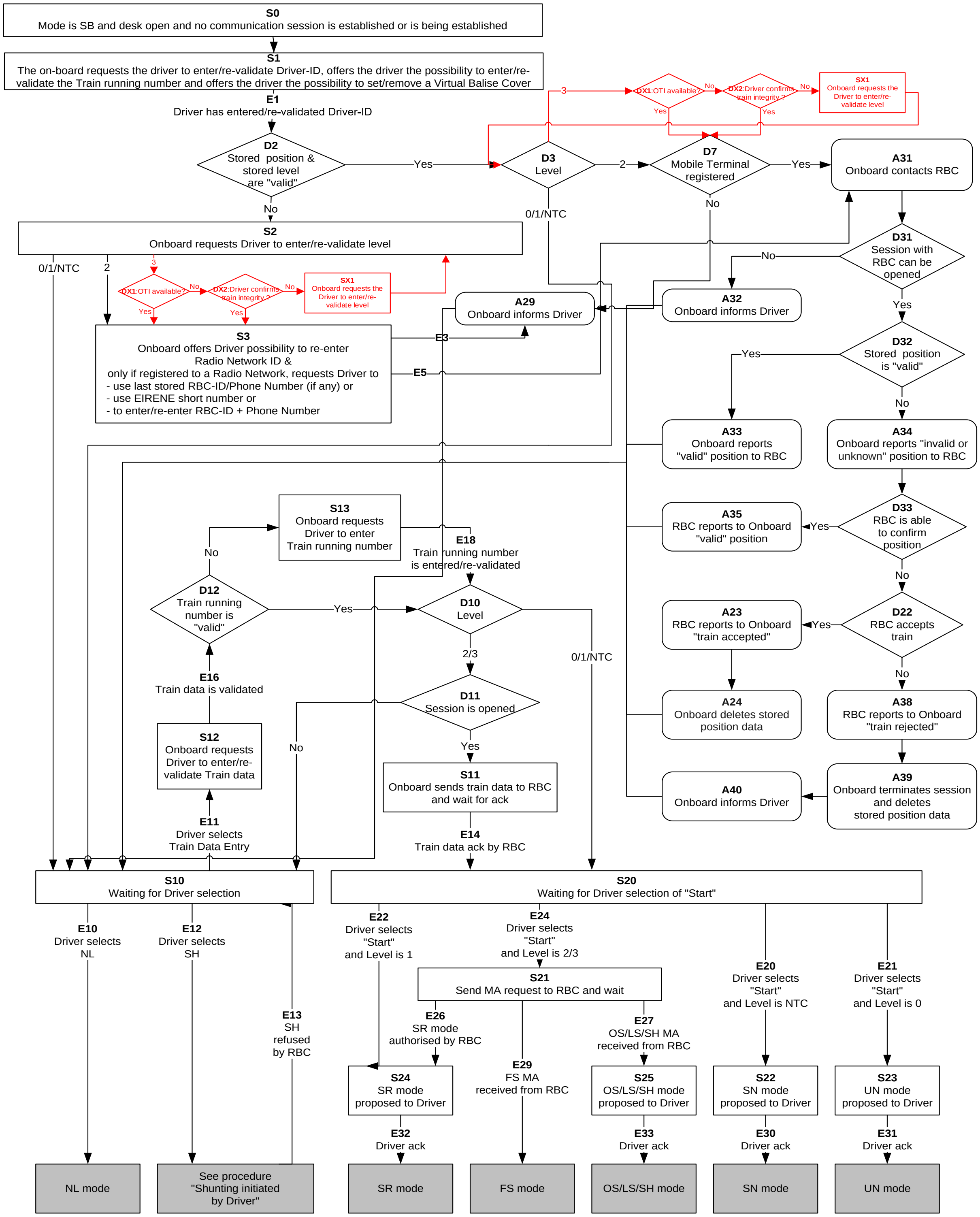


Figure 11-2: Flowchart for “Start of Mission” modified for OTI subsystem

Note: TD2.5 Scope of Work is limited to On-Board Train Integrity "external" functionality

Note that approach proposed consists in taking into account limitations of faulty functionalities. As example a fault in radio equipment deny transition to L2. Similar approach was applied in case of faulty TIMS. As reported above, the "Unavailable" train integrity information doesn't allow to distinguish between unfitted or fault OTI device.

In case train length is provided by OTI-L external functionality, its value is shown to the driver for confirmation. If OTI-L is not present or is in fault, the train driver shall insert manually train length within ERTMS/ETCS data entry procedure.

A.3.3 Example for Transition to Level 3 area

Additional conditions are needed about OTI device status in relation to the transition versus Level 3 area, to cover all the cases in which the on-board system perform a SOM in a level different from L3 (no check on OTI system availability is done) and during the mission can transit in a L3 area.

When from the trackside is received a level transition information, the ERTMS/ETCS on-board equipment shall select from the table the level with the highest priority, which is available for use by the on-board equipment.

The on-board equipment shall consider an ERTMS/ETCS level as "Available for use" as follows:

a) **Level 2**: the level is configured on-board and at least one Mobile Terminal is available on-board, i.e. the ETCS on-board has detected at least one Mobile Terminal in working condition, independently whether it is registered to a network or not.
b) **Level 3**: the level is configured on-board, at least one Mobile Terminal is available on-board, i.e. the ETCS on-board has detected at least one Mobile Terminal in working condition, independently whether it is registered to a network or not and the OTI subsystem is "available" and correctly working
c) **Level NTC:** the concerned National System is available on-board (if an STM is used, refer to SUBSET-035 for further details).
d) **Level 0 or 1**: always

Note that OTI external device provides train integrity information to OBU independently from ETCS level. Present analysis constitutes a contribution to system level analysis in relation to TIMS faults in case Trackside Train Detection is not present.

In general, driver confirmation for train integrity can be used in case OTI subsystem is in fault.

APPENDIX B VIRTUAL COUPLING APPLICATIVE MESSAGES

As described in D4.1, the Virtual Coupling concept is referred to the trains that running simultaneously and virtually coupled to the train in front and communicating and matching their speed to maintain safe splitting.

The figure below depicted a train that is split intentionally.

Case A refers to a train made up of two joined train-sets with an OTI master in active cabin (M1), OTI slave modules in intermediate waggons (S1, S2) behave as NON TAIL and an OTI Slave behaving as TAIL in last waggon (S3-T).

Case B refers to two split train-sets with independent ETCS and related OTI Master and Slave modules (i.e. M1 and S1-T for first train; M2 and S3-T for second train).

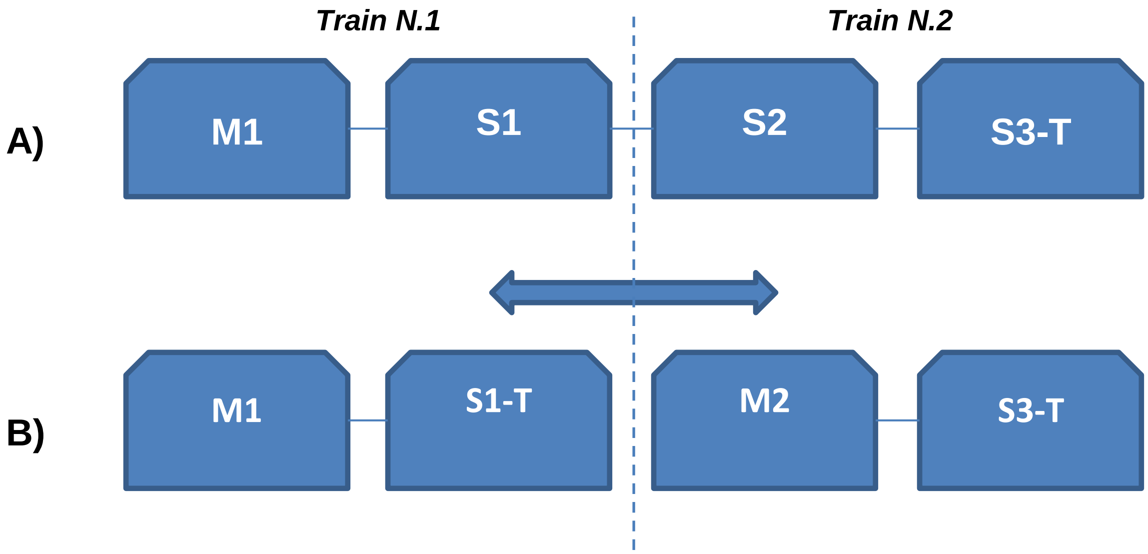


Figure 11-3: Train compositions during dynamic splitting

The applicative messages defined for the interfaces OTI-M and OTI-S, see the section 7.4.1.3, are still valid.

To cover, also, the cases in which two or more trains are coupled and then split more information need to be specified.

Case A

The information of train coupled can be acquired from ETCS point of view as two inputs with the following values:

- No Coupled unit detected
- Coupled unit detected

With the following coding:

Input 1	**Input 2**	**Meaning**
Coupled Information		
0	***0***	***Invalid situation***
0	***1***	***Coupled unit detected***
1	***0***	***No Coupled unit detected***
1	***1***	***Invalid situation***

Table 11-6: Coding of Coupled and not coupled train

This information shall be sent from ETCS to OTI Master so the message sent by ETCS to OTI-M can be as follows:

Field	**Variable**	**Description**	**Size**
1	***NID_MESSAGE***	Message Identification Number (ID = 0x07).	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. NID_ENGINE if the source is the ETCS)	48 bits
5	***ID_DESTINATION***	Identifier of the source of the message (e.g identifier of the OTI Master module)	48 bits
6	***ETCS_Information***	All the commands and information sent by ETCS to OTI-M	7 bytes
7	***SPARE***	Future use	4 bytes
8	***CRC***	CRC calculation	6 bytes
9	***Padding data***	Padding bits	6 bits

Table 11-7: "ETCS - OTI Master" message

The field ***ETCS_Information*** shall include also the status of the input to indicate if the train is coupled or not:

Byte	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
1	*Start_Cmd*	*Reset_cmd*	*ETCS_Status_Request*	*Spare*	*Spare*	*Spare*	*Spare*	*Spare*
2	*Train_Length*							
3					*Spare*	*Spare*	*Spare*	*Spare*
4	*Train_Speed*							*Spare*
5	*Train_Position*							
6								*Spare*
7	*Train_MovDir*		*Coupled Information*		*Spare*	*Spare*	*Spare*	*Spare*

Table 11-8: “ETCS - OTI Master” - ETCS_Information structure for coupled trains

The others messages between OTI-M and OTI-S module are still valid in the cases of train coupled.

Case B

In dynamic splitting the assumption is that the train is in operation and is “running”. The step sequences is shown in the figure below.

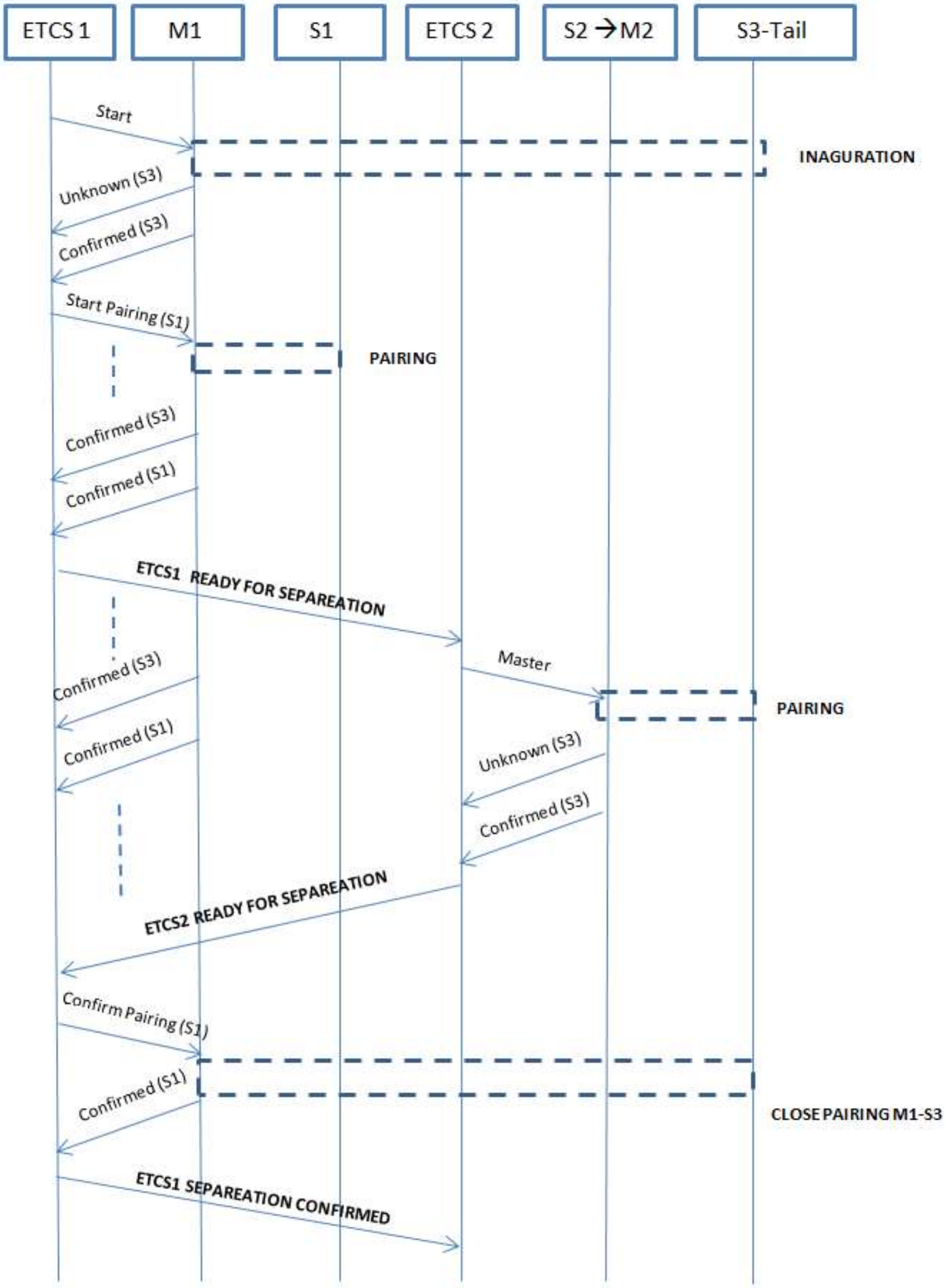


Figure 11-4: Dynamic Splitting

New kind of messages shall be defined:

- ETCS Ready for separation, exchanged between the two final ETCS equipment (NID_MESSAGE=0x09)
- ETCS Separation Confirmed, exchanged between the two final ETCS equipment (NID_MESSAGE=0x10)

ETCS READY FOR SEPARATION

The structure of this kind of message is the following:

Field	Variable	Description	Size
1	***NID_MESSAGE***	Message Identification Number (ID = 0x09 or ID=0x10)	1 byte
2	***L_MESSAGE***	Message length including everything (from field 1 to padding inclusive).	10 bits
3	***SEQ_NUMBER***	Sequence Number of the message	32 bits
4	***ID_SOURCE***	Identifier of the source of the message (e.g. identifier of the ETCS)	48 bits
5	***ID_DESTINATION***	Identifier of the source of the message (e.g. identifier of the ETCS)	48 bits
6	***READY for Separation***	Bit flag to indicated that the ETCSx is ready for the separation	1 bit
7	***Separation Confirmed***	Bit flag to indicated that the ETCSx separation is confirmed	1 bit
8	***CRC***	CRC calculation	6 bytes
9	***SPARE***	Future use	4 bytes
10	***Padding data***	Padding bits	4 bits

Table 11-9: "ETCSx- ETCSy" messages

The value of the field NID_MESSAGE is set to 0x09 for the message "Ready for Separation" and the "READY for Separation" field is set to 1.

While for the message "Separation Confirmed" the field NID_MESSAGE is set to 0x10 and the "Separation Confirmed" field is set to 1.

The new fields have the following structures:

Name	Ready for Separation		
Description	Ready for Separation		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
1 bit			
Special/Reserved Values	0	ETCS x not ready for the separation	
	1	ETCS x ready for the separation	

Name	Separation Confirmed		
Description	Separation Confirmed		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
1 bit			
Special/Reserved Values	0	ETCS x not separated	
	1	ETCS x separated	

APPENDIX C REDUNDANCY OF OTI DEVICES

The ETCS on-board shall be configured to define whether OTI subsystem (devices) components use redundancy.

The ETCS on-board shall be able to manage up to 4 OTI subsystem on Ethernet Interface, for each cabin (or for the Head and for the Tail) the 2 OTI are in complete redundancy:

- Each OTI is interfaced via two redundant Ethernet connections;
- Of two OTIs, one is active and the other is inactive (i.e. powered But not active for the communication).

In case of failure of the active OTI, the inactive OTI will become active.

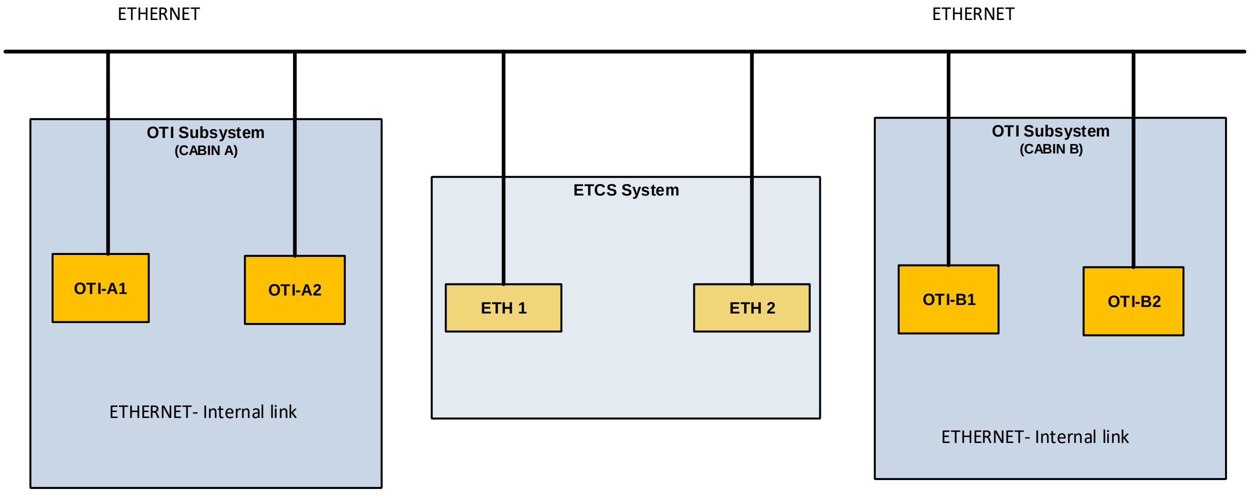


Figure 11-5: Example of OTI subsystem implementation in redundancy configuration

APPENDIX D THREATS – DEFENCES MATRICES

This appendix contains results of communication analysis respect to EN50159 [6] for close and open transmission system.

In general sequence numbers have been introduced in application level messages, timeouts are managed at application level, messages feedback are considered in inauguration procedure and in master-slave protocol, source and destination are considered in relation to inauguration procedure. Cryptographic techniques are considered at protocol stack level.

	Sequence Number	Time stamp	Timeout	Feedback message	Source and destination identifiers	Identification procedure	Safety code	cryptographic techniques
Repetition	X							
Deletion	X							
Insertion	X			X	X			
Re-sequencing	X							
Corruption							X	
Delay			X					
Masquerade								Not Applicable

Table 11-10: Close Transmission System

	Sequence Number	Time stamp	Timeout	Feedback message	Source and destination identifiers	Identification procedure	Safety code	cryptographic techniques
Repetition	X							
Deletion	X							
Insertion	X			X	X			
Re-sequencing	X							
Corruption							X	X
Delay			X					
Masquerade								X

Table 11-11: Open Transmission System

APPENDIX E TRACEABILITY BETWEEN D4.1 AND D4.2

This appendix reports the traceability matrix between the requirements specified in D4.1 (Ref. [1]) and requirement specified in this document D4.2.

The Table 11-12 includes four columns:

1) ID Requirement D4.1: this column reports the ID of the requirement specified in D4.1;
2) Text Requirement D4.1: this column reports the description of the requirement specified in D4.1;
3) ID Requirement D4.2: this column reports:
    a. the ID of the requirement specified in D4.2, or;
    b. a reference to a section of D4.2, or;
    c. “Not applicable” when a requirement of D4.1 is not traceable versus D4.2.

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
7.1 Functional Requirements Specification		
REQ_7.1.1	OTI monitoring functional module shall be composed of the following functional modules: OTI Master (OTI-M); On-board Communication Network (OCN); OTI Slave (OTI-S)	§6 Functional Architecture Specification
REQ_7.1.2	OTI monitoring functional module shall have a unique identifier OTI_ID.	§7.4.1 Application level All the messages exchanged between the OTI modules have an identifier of the sender (field ID_SOURCE) and of the receiver (field ID_DESTINATION).
REQ_7.1.3	OTI unique identifier OTI_ID shall be the MAC address of OTI communication interface.	Not Applicable
REQ_7.1.4	OTI monitoring functional module shall include its unique identifier inside each transmitted message.	§ 7.4.1 Application level All the messages exchanged between the OTI modules have an identifier of the sender (field ID_SOURCE) and of the receiver (field ID_DESTINATION). The same for the messages exchanged between OTI Master and ETCS
REQ_7.1.5	At power-on, the OTI monitoring functional module shall manage a master-ship assignment procedure to assume Master or Slave role.	Section §7.2 (in particular Table 7-1 and Table 7-3) specifies the logical interface of OTI module including the "Cabin Status" input. This input is used by OTI module during the Mastership assignment phase

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
REQ_7.1.6	After master-ship assignment procedure, the OTI monitoring functional module shall manage an inauguration phase composed of: (i) identification procedure and (ii) association procedure. Note that Identification procedure is aimed at identifying all OTI modules connected to the OCN.	Sections § "7.2.3 Master – Slave Inauguration Phase", § "7.4.1.3.1 Message OTI Master - OTI Slave “Inauguration Phase” and § "7.4.1.3.3 Message OTI Slave - OTI Master “Inauguration Phase” describe the Inauguration Phase
REQ_7.1.7	After identification procedure, the OTI monitoring functional module shall manage association procedure to pair OTI Master in front cabin and OTI Slave at train tail.	Sections § "7.2.3 Master – Slave Inauguration Phase", § "7.4.1.3.1 Message OTI Master - OTI Slave “Inauguration Phase” and § "7.4.1.3.3 Message OTI Slave - OTI Master “Inauguration Phase” describe the Inauguration Phase
REQ_7.1.8	Association procedure shall ensure that only one TAIL OTI Slave is present.	See Figure 7-5
REQ_7.1.9	After association procedure, the OTI monitoring functional module in monitoring state shall manage the communication between paired OTI Master and OTI Slave.	Sections § "7.4.1.3.2 Message OTI Master - OTI Slave “Monitoring Phase” and § "7.4.1.3.4 Message OTI Slave - OTI Master “Monitoring Phase” describe the Monitoring phase
7.1.1.1 OTI Master Master-ship State		
REQ_7.1.1.1.1	OTI monitoring functional module shall behave as OTI Master or OTI Slave based on cabin status information.	Section §7.2 (in particular Table 7-1 and Table 7-3) specifies the logical interface of OTI module including the "Cabin Status" input. This input is used by OTI module during the Mastership assignment phase
REQ_7.1.1.1.2	OTI monitoring functional module shall behave as OTI Master if connected to active cabin.	Section §7.2 (in particular Table 7-1 and Table 7-3) specifies the logical interface of OTI module including the "Cabin Status" input. This input is used by OTI module during the Mastership assignment phase
REQ_7.1.1.1.3	OTI monitoring functional module shall behave as OTI Slave if connected to a non-active cabin OR if cabin status is not available. Note: the OTI Module connected to a slave engine in NON LEADING mode shall behave as OTI Slave.	Section §7.2, in particular Table 7-1 and Table 7-3, specifies the logical interface of OTI module including the "Cabin Status" input. This input is used by OTI module during the Mastership assignment phase
7.1.1.2 OTI Master Inauguration State		

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
REQ_7.1.1.2.1	When the OTI Master transits to “Identification” state shall send an “Identification Request” as a broadcast message.	Section §7.2.3 Master – Slave Inauguration Phase
REQ_7.1.1.2.2	The OTI Master received the “Slave Identification” message from the OTI Slave TAIL shall send a “Pairing Request” message only to the OTI Slave TAIL.	Section §7.2.3 Master – Slave Inauguration Phase
REQ_7.1.1.2.3	The OTI Master shall interrupt and repeat the Identification procedure if it receives two or more “Slave Identification” messages from OTI Slave modules localized as “TAIL”. Note that a timer shall be defined before declaring completed the Identification phase. This timer shall be dimensioned based on the specific application. If this timer has expired and the OTI Master has not received the “Slave Identification” message from OTI Slave TAIL, then the OTI Master can restart the Identification procedure. For more details about communication between the OTI Modules refer to [7]	Section §7.2.3.1 Examples of communication faults during the Inauguration phase
REQ_7.1.1.2.4	REQ_7.1.1.2.4 The OTI Master in “Pairing” state shall accept the “Slave Pairing Ack” message only if: a) the message is consistent (see REQ_7.1.1.3.11) , AND; b) the message is sent by OTI Slave TAIL. If the conditions a) and b) are not verified, the OTI Master shall reject the message and shall transit to “Identification” state.	Definition of “consistent message” is provided in §7.4.1. §7.2.3.1 reports same examples of fault during the Inauguration phase but not this specific case.
REQ_7.1.1.2.5	If the OTI Master in “Pairing” state does not receive the “Slave Pairing Ack” message then it shall transit to “Identification” state.	§7.2.3.1
7.1.1.3 OTI Master Monitoring State		
REQ_7.1.1.3.1	Master Functional Module shall receive train tail status from OTI Slave Functional Module.	Section §7.4.1.3.4
REQ_7.1.1.3.2	OTI Master Functional Module shall check train tail status to verify train integrity. Note that train integrity criteria are reported at section 7.1.1.5.	Section §7.4.1.3.4 Message OTI Slave - OTI Master “Monitoring Phase” (this message is the answer of OTI Slave to the Request message sent by OTI Master

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
REQ_7.1.1.3.3	OTI Master Functional Module shall provide train integrity information to ETCS. Note: if the OTI Master exits from Monitoring state due to an event described in Table 7-2, then it shall send to ETCS the information of train integrity status “unknown”.	Section §7.4.1.2.2 Message from OTI Master - ETCS (field "Train_Integrity_Status")
REQ_7.1.1.3.4	OTI Master Functional Module shall manage the communication with OTI Salve Functional Module according to FSM depicted in Figure 7-13 and according to transitions reported in Table 7-4 and transition conditions reported in Table 7-5.	Not Applicable
REQ_7.1.1.3.5	(OPTIONAL) OTI Master Functional Module shall acquire waggon/cargo diagnostic messages from OTI Slave modules.	[Optional Requirement] Section §7.2.1 Logical Interface OTI Master => "Cargo/Waggon Diagnostic Data " are data input for OTI Master Section §7.4.1.3.4 Message OTI Slave - OTI Master “Monitoring Phase" (field "Cargo/Waggon info")
REQ_7.1.1.3.6	(OPTIONAL) OTI Master Functional Module shall determine train composition based on acquired waggon/cargo diagnostic messages from OTI Slave modules.	Not Applicable
REQ_7.1.1.3.7	(OPTIONAL) OTI Master Functional Module shall receive train composition from Wayside Maintenance Centre. Note that optional requirement related to train composition determination refers to two different cases: (i) OTI Slave provides composition data or (ii) Wayside Maintenance Centre provides train composition to OTI Master.	[Optional Requirement] Table 7-1
REQ_7.1.1.3.8	(OPTIONAL) OTI Master Functional Module shall provide waggon/cargo diagnostic data to a Wayside Maintenance Centre.	[Optional Requirement] Section §7.2.1 Logical Interface OTI Master, Table 7-2 => "Cargo/Waggon Diagnostic Data " are data output for OTI Master
REQ_7.1.1.3.9	(OPTIONAL) OTI Master Functional Module shall provide waggon/cargo diagnostic data to train Driver. Note that optional requirement related to providing cargo/waggon alarms to train Driver is aimed at reducing train Driver reaction time in case of emergencies.	See Table 7-2: OTI Master – Logical Interface – List of Output

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
REQ_7.1.1.3.10	(OPTIONAL) OTI Master Functional Module shall record waggon/cargo diagnostic data received from OTI Slave modules.	Not Applicable
REQ_7.1.1.3.11	A message shall be considered as consistent if compliant to communication protocol.	Section §7.4.1 Application level
REQ_7.1.1.3.12	N, M, T_OTIM_I, T_OTIM_COMM, T_OTIM_L, T_OTIM_R, T_STATUS_TAIL, T_MONITORING_PARAM shall be configuration parameters.	Not Applicable
REQ_7.1.1.3.13	Parameters N% or M% are intended as percentages of messages respect to overall messages received in a defined time-out	Not Applicable
REQ_7.1.1.3.14	Transition from INITIALIZATION to REGULAR is performed as soon as N% of Status consistent messages have been received by OTI-M	Not Applicable
REQ_7.1.1.3.15	Transition from LOSS to REGULAR is performed as soon as M% of Status consistent messages have been received by OTI-M	Not Applicable
REQ_7.1.1.3.16	In case OTI Master does not receive M% of consistent messages from paired OTI Slave within time-out T_OTIM_R, then OTI Master shall remain in LOSS state until a condition described in Table 7 2 is verified	Not Applicable
7.1.1.5 Train Integrity Criteria		
REQ_7.1.1.5.1	OTI Master Functional Module, in case of wireless communication network, shall consider train tail movement as “coherent“ if OTI Slave status is regular and one of the following conditions are verified: - difference between train tail position and front cabin position is equal to train length with a tolerance of POSITION_TOLERANCE; OR; - difference between train tail speed and front cabin speed is below a defined threshold SPEED_TOLERANCE, OR; - difference between train tail acceleration and front cabin acceleration is below a defined threshold ACCELERATION_TOLERANCE	Not Applicable

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
REQ_7.1.1.5.2	POSITION_TOLERANCE, SPEED_TOLERANCE and ACCELERATION_TOLERANCE shall be configuration parameters.	Not Applicable
7.1.1.6 Interfaces		
REQ_7.1.1.6.1	OTI Master Functional Module shall communicate with ETCS to acquire active cabin information and train length. Note: as depicted in Figure 7-9 and Figure 7-10, the OTI Module can acquire the cabin status information directly from TIU. This option permits the ETCS backward compatibility as explained in [7].	§7.2.1, Table 7-1 Cabin Status and Train Length are input for OTI Master
REQ_7.1.1.6.2	OTI Master Functional Module shall provide to ETCS the train integrity information according to CR940 [3] with the following three values: · Train integrity confirmed; · Train integrity lost; · Train integrity status unknown;	§7.2.1, Table 7-2 §7.4.1.2.2 OTI Master provides to ETCS the “Train Integrity Status” information
REQ_7.1.1.6.3	OTI Master shall communicate with OTI Slave at train tail for train integrity monitoring.	§7.2.1, Table 7-1, Table 7-2
REQ_7.1.1.6.4	OTI Master shall communicate with OTI Slaves for waggon/cargo diagnosis.	§7.2.1, Table 7-1, Table 7-2
REQ_7.1.1.6.5	OTI Master shall communicate with Wayside Maintenance Centre.	§7.2.1, Table 7-2
REQ_7.1.1.6.6	OTI Master shall provide to train Driver waggon/cargo alarms.	§7.2.1, Table 7-2
7.1.1.7 Safety Requirement		
REQ_7.1.1.7.1	OTI Master Functional Module shall be SIL4 in relation to master-ship management, inauguration phase and train integrity monitoring.	Not Applicable
REQ_7.1.1.7.2	The OTI Master shall not accept information received by other OTI modules configured as Master.	Not Applicable
REQ_7.1.1.7.3	In case of wireless communication, the OTI Master shall know the ID of OTI Slave with which a pairing procedure will be initiated.	Not Applicable
REQ_7.1.1.7.4	(optional) If the OTI modules manage diagnostic information, the communication protocol between OTI modules shall use different messages for diagnostic and train integrity information.	§7.4.1.3.2 §7.4.1.3.4 §7.4.1.3.7

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
REQ_7.1.1.7.5	Packets exchanged between the OTI modules shall include a field that specifies the OTI identifier (OTI ID) and the OTI role (Master / Slave TAIL / Slave Non TAIL).	§7.4.1.3 §7.4.1.6.3 §7.4.1.6.4 §7.4.1.6.9 §7.4.1.6.10
REQ_7.1.1.7.6	OTI identifier shall be unique for each OTI module	§7.4.1 Application level All the messages exchanged between the OTI modules have an identifier of the sender (field ID_SOURCE) and of the receiver (field ID_DESTINATION).
7.1.3 On-board Communication Network		
REQ_7.1.3.1	OCN shall be non-vital.	Not Applicable. [Will be taken in charge in deliverable D4.4 [45]]
REQ_7.1.3.2	OCN shall support messages exchange between OTI master module and OTI slave modules.	Not Applicable. [Will be taken in charge in deliverable D4.4 [45]]
REQ_7.1.3.3	OCN shall support communication for a maximum number of N OTI modules. Maximum number of OTI modules N depends on the specific application. Note: Maximum number of OTI modules to be defined taking into account the product class 2C with waggon/cargo diagnosis (e.g. some hundreds).	Not Applicable. [Will be taken in charge in deliverable D4.4 [45]]
REQ_7.1.3.4	OCN shall support messages exchange with a rate of T sec. Note that transmission rate T depends on the specific application. As example in passenger application, the rate could be around 1 sec and longer periods could be selected in freight applications.	Not Applicable. [Will be taken in charge in deliverable D4.4 [45]]
REQ_7.1.3.5	OCN shall support messages exchange with a size of S bytes. Note that message size S depends on the application message size and protocol stack overhead. As example application message for product class 1 shall include only OTI Slave status, whereas product class 2-B shall include cargo/waggon diagnostic information.	Not Applicable. [Will be taken in charge in deliverable D4.4 [45]]

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
REQ_7.1.3.6	OCN shall ensure a transmission latency less than L sec. Note that transmission latency L depends on the transmission rate. As example passenger application with master slave communication mechanism and transmission rate of 1 sec.	Not Applicable. [Will be taken in charge in deliverable D4.4 [45]]
REQ_7.1.3.7	OCN shall ensure communication between train tail and front cabin in LNOS situations in case of wireless communication.	Not Applicable. [Will be taken in charge in deliverable D4.4 [45]]
REQ_7.1.3.8	OCN shall provide high availability level. Note that availability level of communication network impacts on overall availability of on-board train integrity functionality and therefore on overall railway service availability and capacity.	Not Applicable. [Will be taken in charge in deliverable D4.4 [45]]
REQ_7.1.3.9	OCN shall avoid communication between peers from different trains.	Not Applicable. [Will be taken in charge in deliverable D4.4 [45]]
7.1.4 On-board Communication Protocol (OCP)		
REQ_7.1.4.1	OCP shall be implemented by OTI module.	§7.3
REQ_7.1.4.2	OCP shall be defined to support SIL4 communication.	§7.3
REQ_7.1.4.3	OCP shall comply with CENELEC 50159 [5].	§7.3 Appendix D
7.1.4.1 Application Layer		
REQ_7.1.4.1.1	OTI Master shall start communication with OTI Slave.	§7.2.3
REQ_7.1.4.1.2	OTI Master shall send liveliness REQUEST messages to OTI Slave.	§7.2.3.1
REQ_7.1.4.1.3	OTI Master shall send liveliness REQUEST after that T_OTIM_COMM timeout is expired.	§7.2.3.1
REQ_7.1.4.1.4	OTI Master shall wait for an answer from OTI Slave for a time T_OTIM_COMM defined as configuration parameter.	§7.2.3.1
REQ_7.1.4.1.5	OTI Slave shall answer to liveliness REQUEST from OTI Master with a liveliness STATUS message.	§7.2.3.1
7.1.5.1 OTI Slave Inauguration State		

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
REQ_7.1.5.1.1	The OTI Slave module “Non TAIL” shall not accept the Pairing Request Message sent by OTI Master.	Not Applicable
REQ_7.1.5.1.2	The OTI Slave TAIL in “Identification” state shall transit to “Pairing” state when the “Slave Identification” message is sent to OTI Master	Not Applicable
REQ_7.1.5.1.3	The OTI Slave TAIL in “Pairing” state shall transit to “Identification” state if an “Identification Request” message sent by OTI Master is received	Not Applicable
7.1.5.2 OTI Slave Monitoring State		
REQ_7.1.5.2.1	OTI Slave Functional Module Monitoring State shall behave according to FSM depicted in Figure 7-25.	Not Applicable
REQ_7.1.5.2.2	OTI Slave shall perform transition to TAIL state in case of last waggon.	Table 7-3 includes as OTI Slave input the “Terminal Waggon” information used to determine the position of the OTI Device
REQ_7.1.5.2.3	OTI Slave shall perform transition to NON TAIL state in case of intermediate waggon. Note that defining solutions to identify OTI Slave at train tail is part of D4.2 [7].	Table 7-3 includes as OTI Slave input the “Terminal Waggon” information used to determine the position of the OTI Device
REQ_7.1.5.2.4	OTI Slave in TAIL or NON TAIL status: - shall determine train tail status; - shall provide a status message to OTI Master as answer to each received request message; Note that in GNSS scenario, the OTI Slave status includes tail position and satellite coverage.	§7.2.2
REQ_7.1.5.2.5	OTI Slave in TAIL or NON TAIL status: - shall not provide any train integrity status to ETCS	Not Applicable
REQ_7.1.5.2.6	(OPTIONAL) OTI Slave in TAIL or NON TAIL status: - shall acquire waggon/cargo diagnostic data - shall provide periodic waggon/cargo diagnostic message to OTI Master each T_DIAG_DATA. Note that in general the diagnostic data shall be independent by train integrity monitoring data.	§7.2.2 §7.4.1.3.7
REQ_7.1.5.2.7	(OPTIONAL) T_DIAG_DATA shall be a configuration parameter.	Not Applicable

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
REQ_7.1.5.2.8	(OPTIONAL) OTI Slave shall determine identifiers of nearby OTI modules.	Not Applicable. Future application
REQ_7.1.5.2.9	(OPTIONAL) OTI Slave shall provide to OTI Master the identifiers of nearby OTI modules. Note that determination of nearby OTI slave identifier is aimed at allowing OTI Master to determine train composition.	Not Applicable. Future application
REQ_7.1.5.2.10	(OPTIONAL) OTI Slave shall provide waggon/cargo diagnostic data to Wayside Maintenance Centre. Note that optional requirement related to providing diagnostic data to Wayside Centre is referred to situation of unavailable communication with OTI Master	Table 7-4 specifies as output of OTI Slave versus the WMC the Cargo/Waggon Diagnostic Data/Alarms
REQ_7.1.5.2.11	(OPTIONAL) OTI Slave shall record waggon/cargo diagnostic data.	Not Applicable
7.1.5.3 Train tail status		
REQ_7.1.5.3.1	In case of wireless on-board communication network, the OTI Slave status message shall include odometry information: (i) position or (ii) speed or (iii) acceleration.	§7.4.1.3.4
7.1.5.4 Interfaces		
REQ_7.1.5.4.1	OTI Slave Functional Module shall communicate with OTI Master Functional module.	§7.2
REQ_7.1.5.4.2	OTI Slave Functional Module shall acquire odometry data.	Table 7-3 includes as input data for OTI Slave the odometry data
REQ_7.1.5.4.3	OTI Slave Functional Module shall communicate with wireless communication sensors.	Not Applicable
REQ_7.1.5.4.4	OTI Slave Functional Module shall communicate with waggon/cargo diagnostic wireless sensors.	Table 7-3 includes as input data for OTI Slave the waggon/cargo diagnostic data acquired via sensors
REQ_7.1.5.4.5	OTI Slave Functional Module shall communicate with Wayside Maintenance Centre.	This interface is included in §7, Figure 7-2 but it is out of scope of this document
REQ_7.1.5.4.6	OTI Slave Functional Module shall be powered also by energy harvesting sources.	Not Applicable
7.1.5.6 Safety Requirement		
REQ_7.1.5.6.1	OTI Slave Functional Module shall be SIL4 in relation to master-ship management, inauguration phase and monitoring state.	Not Applicable

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
REQ_7.1.5.6.2	Packets exchanged between the OTI modules shall include a field that specifies the OTI identifier (OTI ID) and the OTI role (Master / Slave TAIL / Slave Non TAIL). OTI identifier shall be unique for each OTI module.	§7.4.1.3 §7.4.1.6.3 §7.4.1.6.4 §7.4.1.6.9 §7.4.1.6.10
REQ_7.1.5.6.3	OTI identifier shall be unique for each OTI module	§7.4.1 Application level All the messages exchanged between the OTI modules have an identifier of the sender (field ID_SOURCE) and of the receiver (field ID_DESTINATION).
REQ_7.1.5.6.4	(optional) If the OTI modules manage diagnostic information, the communication protocol between OTI modules shall use different messages for diagnostic and train integrity information	§7.4.1.3.2 §7.4.1.3.4 §7.4.1.3.7
7.1.6.3 Requirements (VC)		
REQ_VC1:	(M) OTI Master shall receive pairing command from ETCS specifying OTI Slave ID.	Not Applicable
REQ_VC2:	(M) OTI Master shall pair with OTI Slave ID defined by ETCS.	Not Applicable
REQ_VC3:	(M) OTI Master shall manage double pairings on ETCS request.	Not Applicable
REQ_VC4:	(M) OTI Master shall stop a pairing on ETCS request.	Not Applicable
REQ_VC5:	(M) OTI Slave shall accept simultaneous pairing with two OTI Master.	Not Applicable
REQ_VC6:	(O) OTI Master shall determine train composition.	Not Applicable
REQ_VC7:	(O) OTI Master shall provide train composition information to ETCS	Not Applicable
8.7.1 Functional Requirements for Train Length		
REQ_8.7.1	The OTI-L shall implement the FSM depicted in Figure 8-32 and Figure 8-33, the transition conditions and actions described in Table 8-14 and Table 8-15.	§6.4 §6.5 §7.1 §7.3 §7.4.1 §7.4.1.1 §7.4.1.2.1 §7.4.1.3.5 §7.4.1.3.6 §7.4.1.6.1 §7.4.1.6.8 §7.4.1.6.15 §7.4.1.6.16 §7.4.1.6.17

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
REQ_8.7.2	Determined train length shall include a margin to keep into account potential train length variations due to train expansion.	Not Applicable
REQ_8.7.3	During the Start of Mission, the OTI-L shall provide to ERTMS/ETCS On-board the value of Train Length before the Driver performs the Train Data entry procedure.	§6.5.1 §6.5.2
REQ_8.7.4	The OTI-L shall provide the value of train length to the ERTMS/ETCS On-board only when it receives a trigger command (START/RESET).	§6.5.1 §6.5.2 §7.4.1.2.1
REQ_8.7.5	The OTI-L shall provide the train length value and OTI-L status to the OTI-I. OTI-L shall send this information to the OTI-I periodically.	§6.5.1 §6.5.2 §7.4.1.2.2
REQ_8.7.6	The OTI-I shall provide the status of train integrity to the ERTMS/ETCS On-board only when it has received a train length value from an external source if present.	§6.5.1 §6.5.2 §7.4.1.2.2
REQ_8.7.7	The ERTMS/ECTS On-board shall send to OTI-I the information of Train Length with the attribute of “validated” or “to be revalidated” (TBR).	§7.4.1.2.1
REQ_8.7.8	The OTI-I shall consider as “new” a Train Length value provided by ERTMS/ECTS On-board only if it is has been “validated” by the train driver.	§7.4.1.2.1
REQ_8.7.9	The ERTMS/ECTS On-board shall send to OTI-I the information of Train Length “validated” if Driver has validated it or Train Length has been received by an external source and no Driver validation is required.	§7.4.1.2.1
REQ_8.7.10	The ERTMS/ECTS On-board shall send to OTI-I the information of Train Length “to be revalidated” (TBR) in the following case: 1) as specified in UNISIG Subset – 026 (for example in case of a transition to Stand-by mode); 2) when the ERTMS/ETCS On-board sends the “Reset” Command to OTI-I; 3) when the ERTMS/ETCS On-board receives from the OTI-L the information of Train Lengh “Not Available”.	§7.4.1.2.1

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
REQ_8.7.11	When the OTI-I receives the train length value by OTI-L and the “validated“ train length value by ERTMS/ECTS On-board then it shall perform a check and verify if the values are equal or not. If this check fails then the OTI-I shall consider as correct the train length value provided by ERTMS/ECTS On-board.	§7.4.1.2.1
REQ_8.7.12	When train driver changes, during ERTMS/ETCS data entry procedure, the train length value provided by OTI-L, the ETCS shall reset OTI-L.	§6.5.1 §6.5.2 §7.4.1.2.1
8.7.2 Performance Requirements for Train Length		
REQ_8.7.13	During the Start of Mission, the OTI-L shall be able to provide to ERTMS/ETCS On-board the value of Train Length in one (1) minute starting from the switching on of all systems (ERTMS/ETCS on-board, OTI-I and OTI-L).	Not Applicable
8.7.3 Safety Requirements for Train Length		
REQ_8.7.14	The OTI-L and OTI-I shall manage the “START/RESET” commands via a vital input. If these commands are received via serial interface, then OTI-L and OTI-I shall comply with 50159 Standard.	§6.4
REQ_8.7.15	The Train Length evaluation function performed by OTI-L shall be safety-related. The Safety Integrity Level required is SIL4.	Not Applicable
REQ_8.7.16	The communication between the OTI-L and the ERTMS/ETCS On-board shall comply with 50159 Standard.	§7.4
REQ_8.7.17	If defined by the system architecture, the Train Interface Unit shall provide to the OTI system (OTI-L and OTI-I) the “START/RESET” command in a safe way. If this interface is based on serial communication, then it shall comply with 50159 Standard.	§6.4 §6.5.1 §6.5.2 §7.4
REQ_8.7.18	If defined by the system architecture, the ERTMS/ETCS On-board shall provide to the OTI system (OTI-L and OTI-I) the “START/RESET” command in a safe way. If this interface is based on serial communication, then it shall comply with 50159 Standard.	§6.4 §7.4

ID Requirement D4.1	Text Requirement D4.1	ID Requirement D4.2
REQ_8.7.19	The console used by Driver for “START/RESET” commands shall send this information via vital output. If this interface is based on serial communication, then it shall comply with 50159 Standard.	§6.4 §7.4
REQ_8.7.20	The communication between the OTI-L and the OTI-I shall comply with 50159 Standard.	§7.4 §7.4.1.2.2
REQ_8.7.21	ERTMS/ETCS On-board shall inform the Driver if an OTI-L equipment is connected to it or not. If an OTI-L is present but it is not able to provide the train length value (during the Start of Mission procedure or during a mission, e.g. after joining or splitting operation), then the ERTMS/ETCS On-board shall inform the Driver (e.g. OTI Dashboard, ETCS).	Not Applicable

Table 11-12: Traceability matrix D4.1 – D4.2