D4.2 PART 3 - INTERFACE SPECIFICATION TRACKSIDE-TRACKSIDE

Executive Summary

This part of the report provides functional and non-functional requirements with interface specifications for track-to-track communication. This report is part 3 of D4.2 “Requirement specifications for Communication Report” which consists of five interconnected parts, as visualized in Figure 1. It is recommended to the reader to firstly read the top document of D4.2, to understand the context and main conclusions of this part of the deliverable.

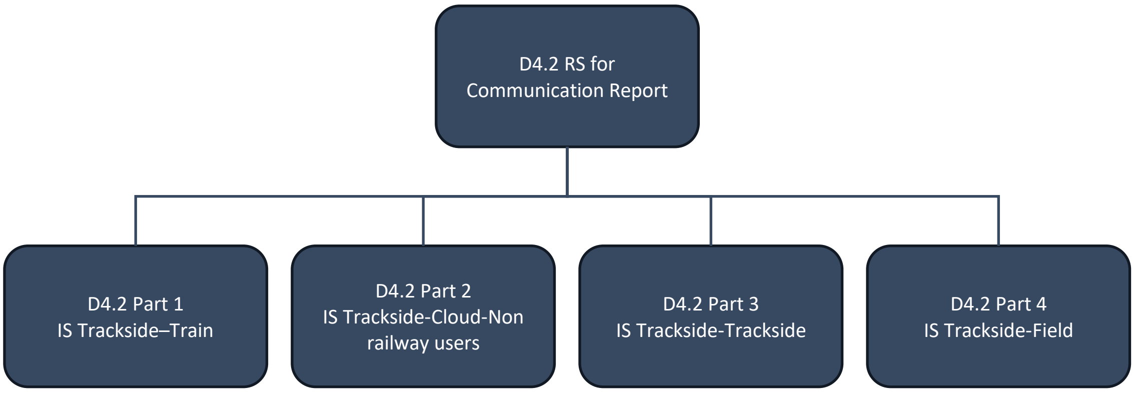

Figure 1: D4.2 Document Structure

The interface specification is influenced by the ISO (International Standards Organization) OSI-model (Open Systems Interconnection), describing the interface in different layers. However, the OSI model is not applied rigidly but should be viewed more as a conceptual framework.

Requirements from deliverable D2.2 [D2.2] have been used as top requirements for the development of this document. Those top requirements are referenced by citation in the document. Further considerations of safety and security aspects as well as cloud communication will be considered in the following work phase.

The utilized process for this deliverable was as follows: Use cases were defined discussed and amended through several rounds of iteration. From the use cases, system descriptions were developed, from which the final requirements were derived. A more detailed description can be found in Section 1.

The overall goal of this deliverable is to provide requirement specifications that could serve as guidelines to the development of solutions enabling cost reduction for regional railway lines. The guidelines are linked to the socio-economic goals developed in deliverable D2.3 [D2.3]. To do so, different railway system descriptions were developed that utilize e.g., wireless communication for adding new elements to existing brownfield deployments. Wireless communication is considered as one key enabler for cost reduction in regional lines. Please note that the suggested system descriptions may vary within the countries. They are not the focus of the requirements but should show where wireless connections could be included in the system.

1. Process

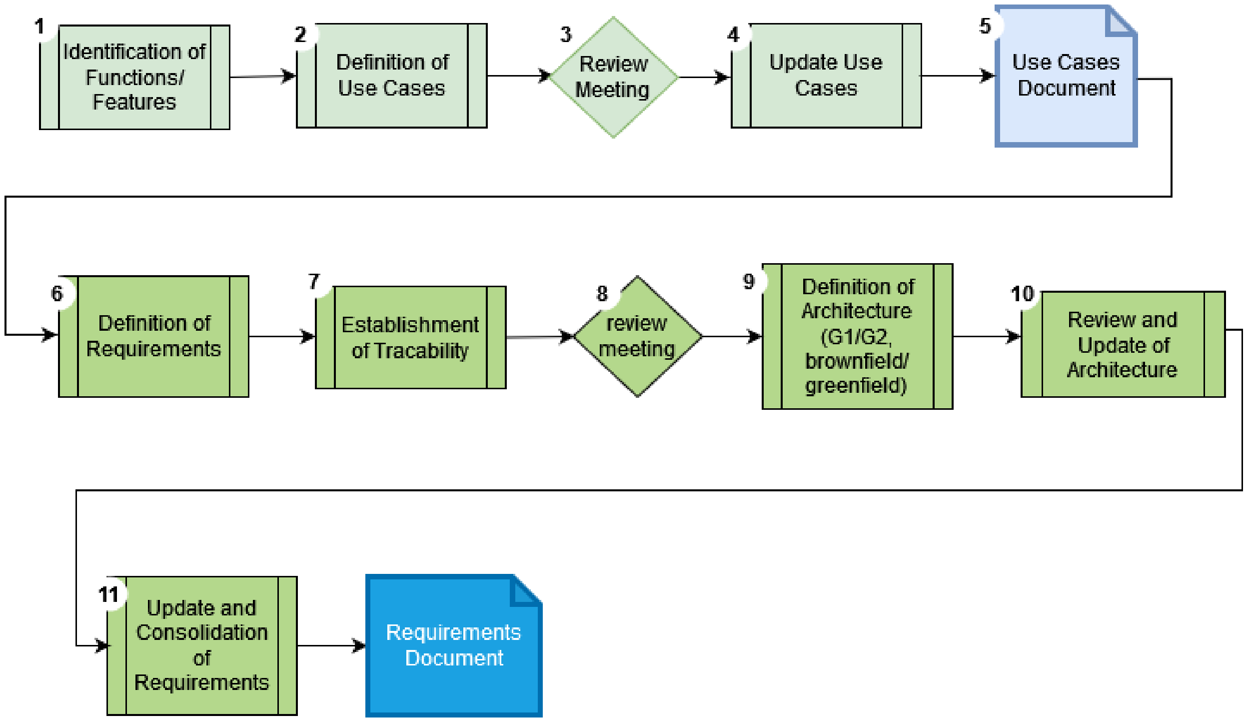

Figure 2: Work-flow process diagram

1. Identification of Functions/Features: In a first work field elements and their features have been investigated.
2. Definition of Use Cases: Based on the identification of features a draft list of use cases was defined [D4.4UC].
3. Review Meeting: In different review meetings the use cases were reviewed by other project partners.
4. Update Use Cases: Based on the feedback the use cases were updated.
5. Use Cases Document: Based on the consolidated use cases a use case document has been generated.
6. Definition of Requirements: Utilizing the use cases, requirements fitting to the use cases have been generated.
7. Establishment of Traceability: To allow traceability a link between WP2 requirements has been established. This allows the reader to understand if the requirement was newly generated or derived from already existing requirements e.g. the requirements from WP2.
8. Review Meeting: The produced requirements have been reviewed and checked for clarity and understandability.

9. Definition of Architecture: Based on the requirements, architectures have been developed that represent brownfield and greenfield deployments, as well as G1 and G2 lines.
10. Review and Update of Architecture: In review and update meetings the architecture has been revised and updated.
11. Update and Consolidation of Requirements: Based on further review comments the requirements have been further updated and consolidated.
12. Requirement Document: Finally, a requirement document was generated which is this present document.

2. Reuse of Shift2Rail results

For the architecture of G1 and G2 lines the concept of the smart wayside object controller (SWOC) of Shift2Rail (S2R) was utilized.
The concept of the Smart Wayside Object Controller has been introduced in the development of track-to-track system architecture. The results of 2 S2R projects X2Rail-1 and X2Rail-4 were studied and proved useful due to their comprehensive analysis of possible advantages of deploying wireless links for connection between spatially distributed trackside subsystems instead of laying optical or metallic cables. The possible cost savings, primarily CAPEX, are described in [X2R1D7.1].
Savings stem from the fact that both cost of the cables, especially for longer distances between communicating nodes are the case, and the cost of civil ground works are removed. Besides that the cost of periodical check along the line and risk of theft are removed, too. Although the main focus of the mentioned S2R results is directed to IXL to OC communication, the justification of wireless communication links deployment is valid also for RBC – RBC and IXL – IXL communication.
There should be also elevated the fact that the S2R analysis and the resulting requirement specifications cover also the needs to manage not only power but even the energy availability for the SWOC and also to remotely and properly supervise and manage these SWOC based distributed systems. See [X2R1.D7.2].
Therefore, these provisions also help to achieve CAPEX savings as the need for regular trackside inspection is considerably decreased.

3. System Description

In this chapter a non-exhaustive overview of system architectures for brownfield and greenfield deployments for G1 and G2 lines is shown. Infrastructure managers/operators can adapt these system architectures according to their needs. The reader is referred further to the architecture definition of [D2.1] that was developed together with WP4.

3.1 Track-to-track system description for G1 lines

The document relies on the general architecture presented in D2.1 (Figure 2/ [D2.1]). The specific architecture for RBC/RBC, IXL/IXL and IXL to OC communication for G1 lines for a *greenfield* deployment is shown in Figure 3.

In this architecture, a wireless communication link can be utilized for implementing the interfaces between backbone trackside CCS nodes:

- RBC to RBC.
- RBC to interlocking.
- interlocking to interlocking.
- interlocking to object controller (including smart wayside object controllers).

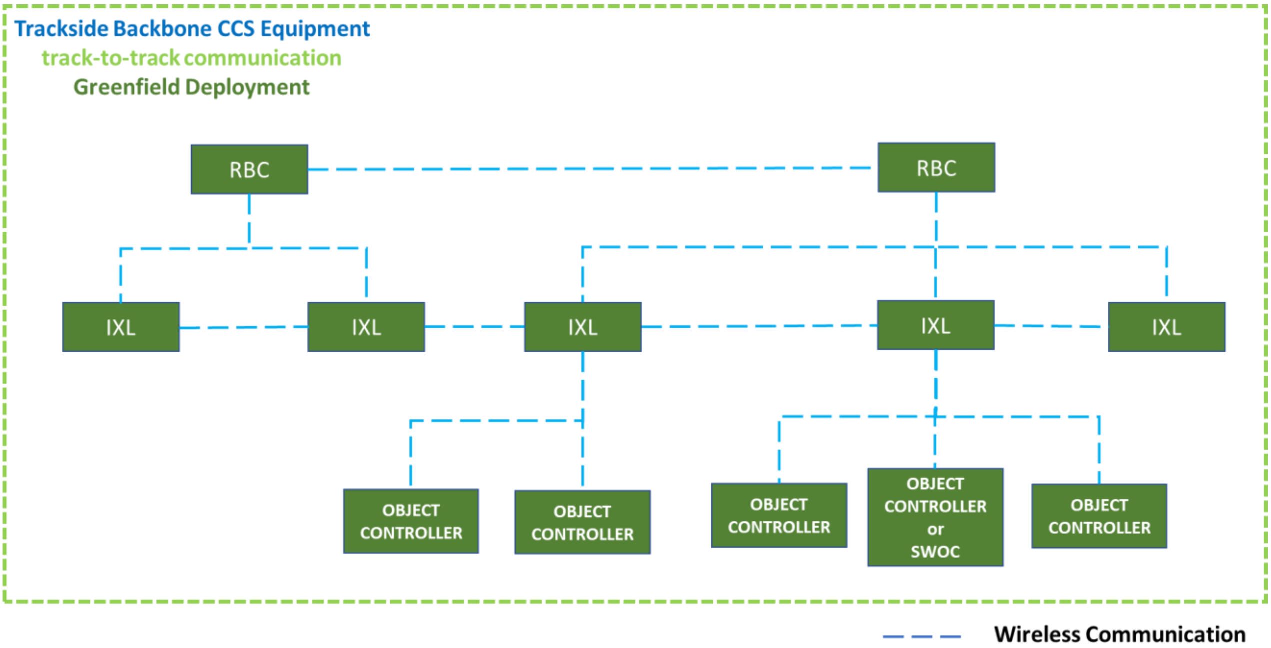

Figure 3: Envisioned RBC/RBC and IXL/IXL connection for G1 regional lines (Greenfield)

For *greenfield,* it is envisioned that the communication will be solely done wirelessly where appropriate. Please note that the use case RBC to IXL communication is not considered in this document.
S2R SWOC architecture definitions comprised in [X2R1.D7.2] were applied during the development of use cases and connections, especially the IXL – SWOC and SWOC – SWOC.

For a *brownfield* deployment shown in Figure 4 i.e., with existing installations, the RBCs and IXLs communicate with each other using wired connections, e.g., by copper or by fibre optic cables. In case of damaged cables, it should, however, be possible to allow replacing wired connections by wireless communication to reduce maintenance costs.

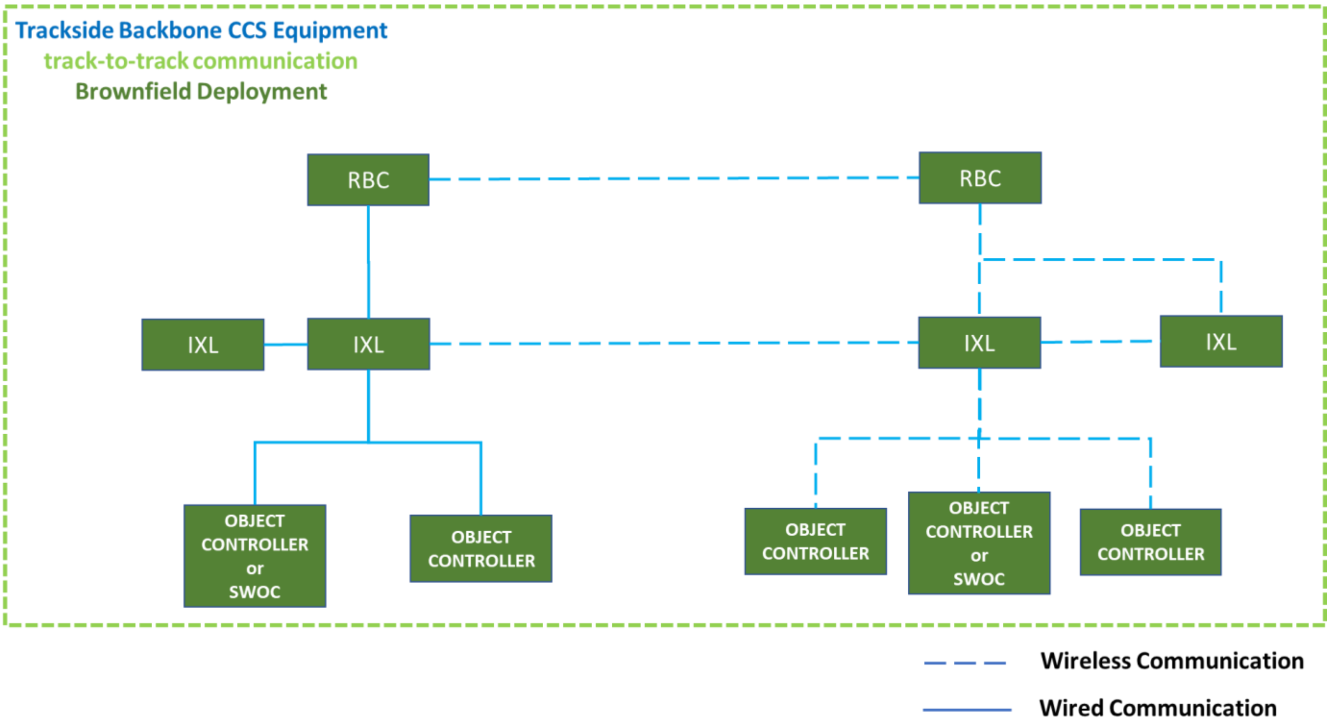

Figure 4: Envisioned RBC/RBC and IXL/IXL connection for G1 regional lines (Brownfield)

3.2. Track-to-Track system description for G2 lines

The conceptual architecture of G2 lines can be found in D2.2, Figure 13 in [D2.2]. In the case of G2 lines, a conceptual high-level architecture is considered. This has also an influence on the communication requirements.

In this case, a traffic management system (TMS)/centralized traffic control (CTC) is deployed. The CTC integrates the RBC and IXL functionality most of the times. Depending on the length of the railway line, a single TMS/CTC can be enough to control the complete line. The specific architecture for brownfield and greenfield deployment is considered in Figure 5.

In order to guarantee full compliance with requirements defined in the D2.2 and KPIs defined in D2.3, related to CAPEX and OPEX reduction, the expected target deployment scenario for G2 is the green field. The brownfield deployment scenario can be technically supported by the G2 concept, however, with lower expected magnitude of costs reduction.

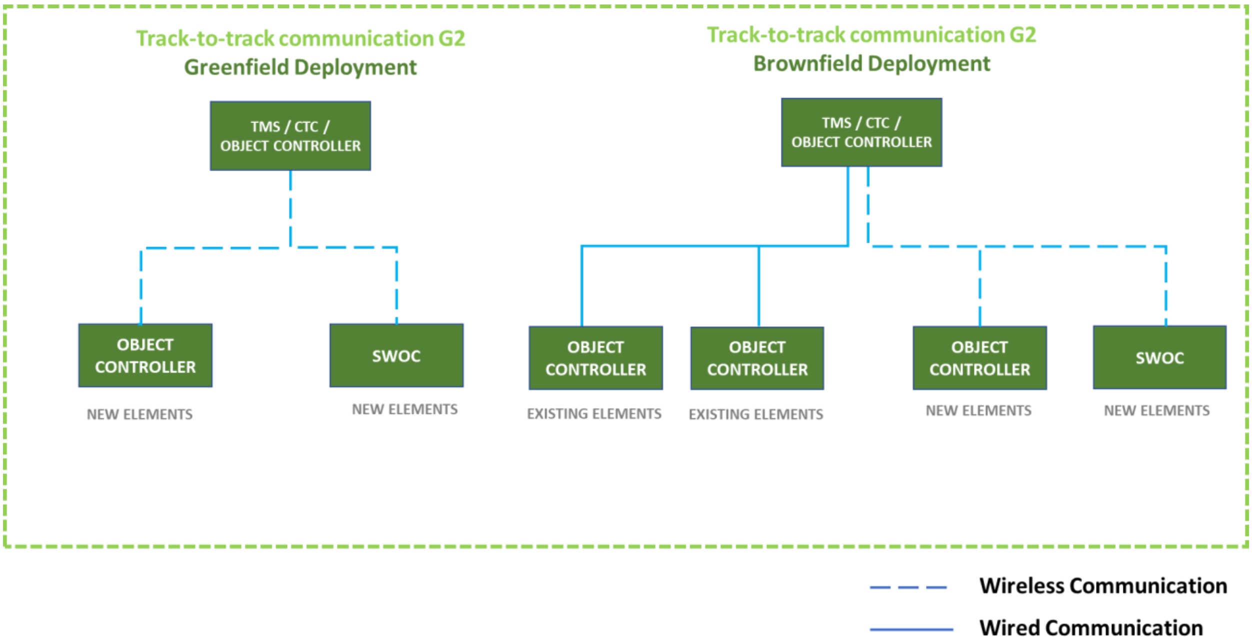

Figure 5: Envisioned TMS/CTC to object controller connection for G2 regional lines (Brownfield and Greenfield)

For a *greenfield* deployment, i.e., for the automatization of G2 railway lines with no previously existing installations, the deployment of an automatic signalling system will require the instancing of an integrated TMS/CTC and radio-controlled wayside object controllers (solar/battery powered), limited to those strictly required for the safety of the operations (i.e. point machines and level crossings).

These objects will be all communicating to the selected communication infrastructure. Specifically in this scenario the use of a wireless network can help to reduce costs.

Leveraging on the adoption of IP based standard protocols and data sharing through cloud (a concept developed in D4.3 of FP6), the proposed G2 lines deployments (both greenfield and brownfield) go into the direction of the implementation of "internet of railways things".
Reuse of achievements of S2R projects dealing with SWOC developments helped to define the communication architecture – see [X2R1.D7.2].

4. Communication system interface specification

It is in the scope of this section to characterise **the interface** between the signalling system and the track-to-track communication network, specifying the requirements the communication system must meet to be suitable for being directly connected to signalling systems from different vendors.

The envisioned communication system that G1 and G2 lines use for communicating between backbone trackside CCS nodes, either ETCS (RBC) equipment, or trackside equipment of the underlying signalling system (interlocking, object controllers), has a layered architecture. Specifically, for the trackside – trackside communication, deliverables of S2R projects comprising SWOC architecture and requirements specifications [X2R1.D7.2] have been partly reused. Also demonstrators of those S2R projects proved applicability of wireless technologies for those communication links.

The layers covered by this interface specification are generic and are shown in Figure 6. A functional description for the individual layers is given in the sections below. The track-to-track communication between backbone trackside CCS nodes is based on a protocol-layer stack as indicated in the figure.

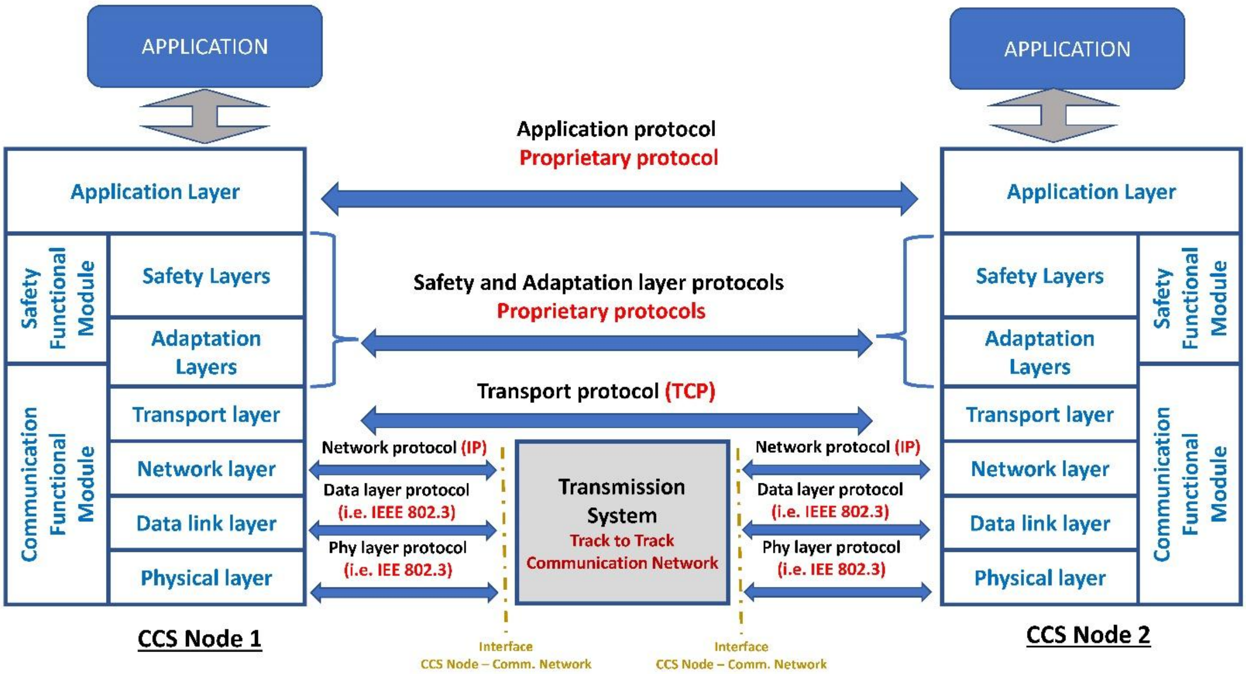

Figure 6: Protocol layer stack scheme

The protocols used for implementing the communication layers are the following:

- Application layer protocols are dependent on each equipment type and vendor
- Safety layer protocols are dependent on each equipment type and vendor
- The adaptation layer deals with the adaptation between the safety layer and the transport layer and provides the redundancy handling. Protocols in this layer are vendor dependent

- The transport layer protocol is TCP [RFC9293]. The retransmission function is provided by the normal mechanism of TCP.
- The network layer protocol is IP [RFC0791].
- The data link layer will not be specified by this specification.
- The physical layer will depend on the situation.

Only in the specific case of the RBC-RBC communication, application, safety and adaptation layers are specified by standards (Subset-039 and Subset-098, see [CCSTSI]).

Specifying the communication system is the target of this document. Currently, railway operators deploy optical wired networks (electrical copper networks in the past) for implementing the communication system for communicating between trackside elements. In this document a set of requirements are proposed to be tested using demonstrators in WP9 at later stages to ultimately be able to reduce CAPEX and OPEX.

5. Communication system for railway signalling systems specification

The scope of this section is to characterize the track-to-track communication network functionally and technically, referring to in-force standards (e.g. CSS TSI) that the system must meet for being applicable as a transmission system suitable for signalling systems from different vendors.

5.1. European Standard EN 50159

A characterization of the signalling system and its communication network is carried out in the ***EN 50159*** *Railway applications – Communication, signalling and processing systems – Safety-related communication in transmission systems* [EN50159]. This standard establishes the basic requirements necessary to achieve a secure communication between safety-related equipment connected to an open transmission system.

According to this standard, the transmission system consists of everything (hardware, software, transmission media, etc.) that may exist between two or more safety-related pieces of equipment connected to the transmission system. The transmission system can be open or closed depending on its characteristics.

The *EN 50159* standard classifies transmission systems into different categories according to their characteristics and identifies three categories of transmission systems C(B.1 Categories of transmission systems - Subclause 6.3):

- **Category 1**. Closed transmission systems, where all essential properties of the system are under the control of the safety-related system designer, and a simplified set of safety requirements can be defined.
- **Category 2**. Open transmission systems where, although the transmission is not fully under the control of the safety-related system designer, the risk of malicious attack can be considered negligible.
- **Category 3**. Open transmission systems where there is opportunity for malicious attack, and cryptographic defence measures are required.

The communication system used in railway signalling systems, as described in this document, are classified as open transmission systems because they do not meet the criteria for a closed transmission system. The classification of these systems varies based on their control and security characteristics:

- Private Systems with Full Control by the Infrastructure Manager (IM): Private networks such as Railway Mobile Radio (RMR) or dedicated Wi-Fi networks are generally classified as Category 2 if they are under the full control of the Infrastructure Manager (IM). In these cases, the IM oversees the entire network infrastructure, including its security measures, which helps mitigate the risk of malicious attacks.
- Public Systems: Public networks, such as public 5G networks, fall into Category 3 due to their open and accessible nature. These networks are exposed to a higher risk of malicious attacks and, therefore, require advanced cryptographic measures and comprehensive security protocols to ensure the integrity and confidentiality of the transmitted data.

Standard EN-50159 establishes the principal structure of a safety-related system using an open transmission system. This is illustrated in Figure 7 andFigure 8:

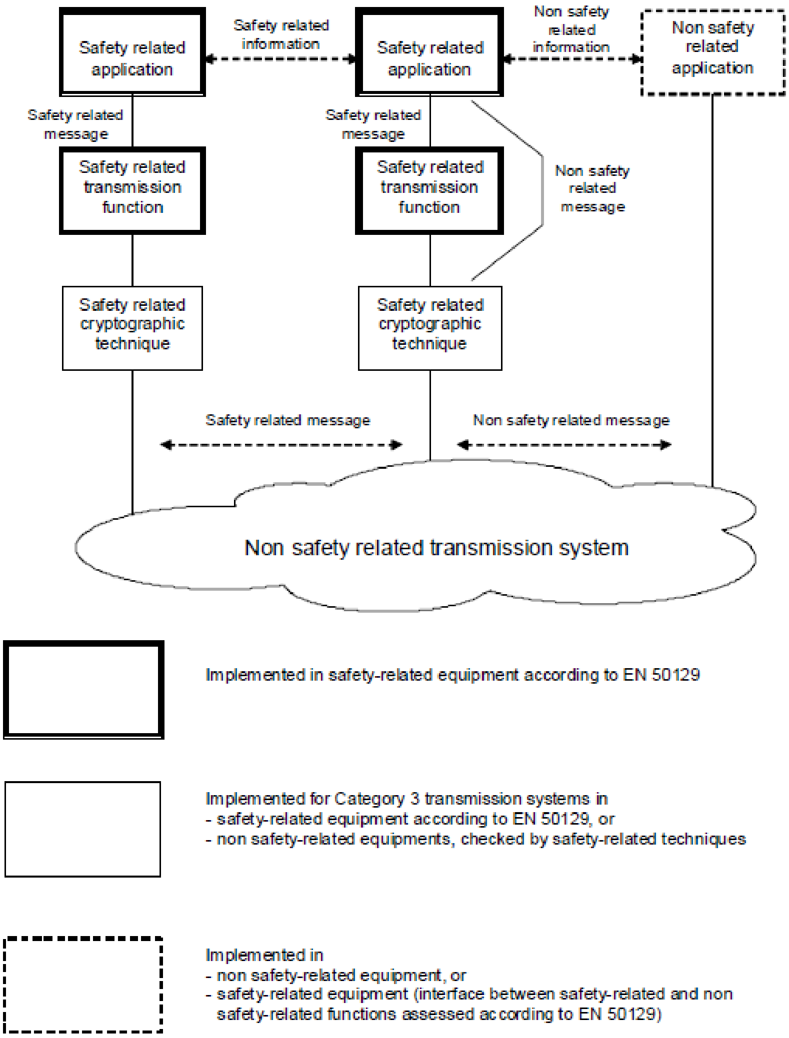

Figure 1 – Reference architecture for safety-related communication

The reference architecture is not intended to restrict implementations; different structures are possible, see examples in the informative Annex C and in particular Clause C.5 for non safety-related messages.

Figure 7: Safety-related communication. Source EN 50159 (2010)

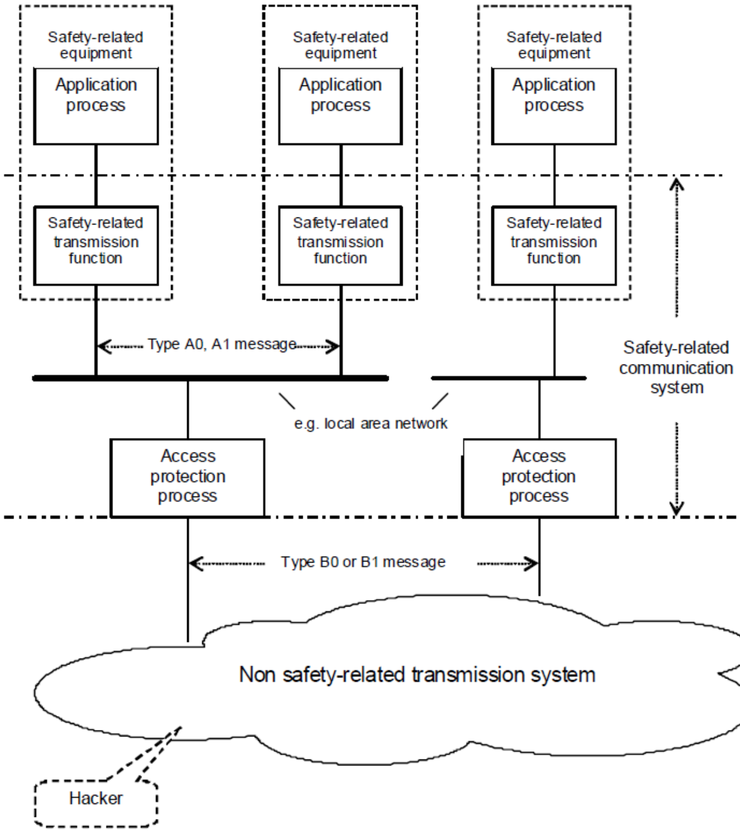

Figure C.3 – Use of a separate access protection layer

Figure 8: Open transmission system. Source EN 50159

In any case, no safety requirements shall be placed upon the non-trusted characteristics of the open transmission system. Safety aspects are covered by applying safety procedures and safety encoding to the safety-related transmission functions.

The EN-50159 standard establishes safety requirements that are generally implemented in the safety-related equipment, designed according to EN-50129. In certain cases, these requirements may be implemented in other equipment of the transmission system, as long as there is control by safety measures to meet the allocated safety integrity requirements.

Accordingly, for both G1 and G2 lines, the European Standard ***EN 50159*** *Railway applications – Communication, signalling and processing systems – Safety-related communication in transmission*, shall apply to the communication system used to communicate backbone trackside CCS nodes, either ETCS equipment or trackside equipment of the underlying signalling system.

5.2. RBC-RBC communication. Subset-098 and Subset-039.

For the specific use case RBC to RBC communication, the application, safety and adaptation layers are specified by the ERTMS ***Subset-098*** *RBC-RBC Safe Communication Interface (current version 4.0.0*) and ***Subset-039*** *FIS for the RBC/RBC Handover (current version 4.0.0*), see [CCSTSI]).

The Subset-098 document specifies the functional architecture and the protocols for the exchange of safety-related messages between RBCs via closed or open transmission systems.

The general structure of an RBC-RBC safe communication system is shown in Figure 9:

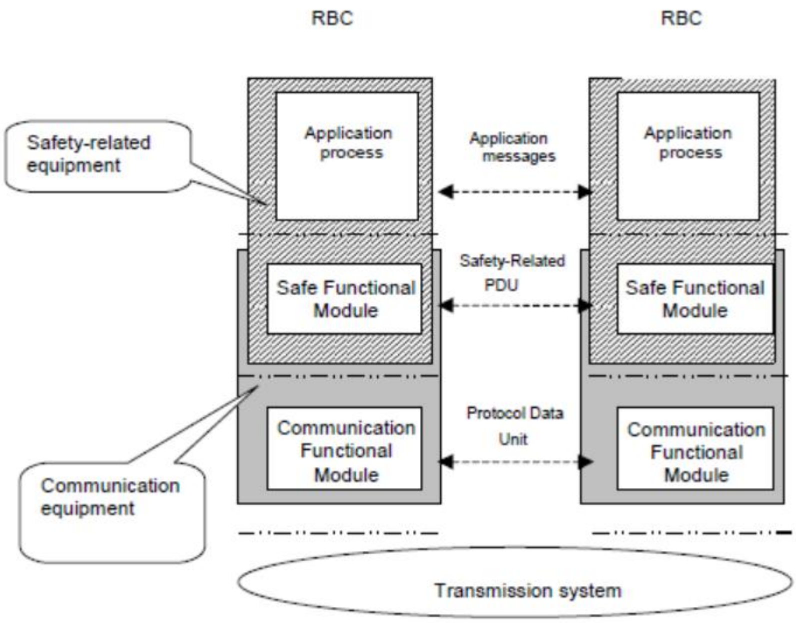

Figure 9: Structure of the RBC-RBC safe communication system. Source: Subset-098 by UNISIG

According to the subset-98, the RBC-RBC safe communication interface is layered. Protocols used for implementing the communication layers are the following:

- The application protocol for the transfer of the safety-related information is described by the specification for RBC-RBC handover [Subset-039].
- Safety layers in RBC-RBC interface are conformed by the Safe Application Intermediate (SAI) sub layer in addition to the Euroradio Safety Layer as specified by Subset-037-1-2.
- The adaptation layer deals with the adaptation between the safety layer (Euroradio Safety Layer) and the transport layer and provides the redundancy handling.
- The transport layer protocol is TCP [RFC9293]. The retransmission function is provided by the normal mechanism of TCP.
- The network layer protocol is IP [RFC0791].
- The data link layer will not be specified by this specification.
- The transmission system i.e. the (public or railway owned) network is out of scope for the specification (subset-98).

Referent to this, it is important to highlight that subset-98 does not establish neither a specific transmission system as mandatory neither the open network to use, being possible to use any transmission system able to support the transmission of the upper layers protocols.

The subset-98 also describes the functional interface requirements to be respected by any communication system to ensure interworking at the level of the transport and network protocols. The general features of the communication system are as follows:

- Reliable full-duplex transfer of railway application messages.
- Transparent transfer of user data. The content, format or coding of the information is not to be restricted. Interpretation of the data structure or its meaning is not needed to achieve data transfer.
- No constraints on user data, that is the protocol shall in no way constrain the type of data to be transferred.
- Efficient data transfer, the communication system shall support well-defined performance requirements including the transfer of large quantities of data at high speeds and with low latency.
- Open to different known and currently unknown applications.
- Support of physical link redundancy for availability purposes.

It will therefore be necessary that all these requirements are applicable to the communication network part of a signalling system.

Additionally, note that the Subset-039 document specifies the functional interface for the RBC/RBC communication to perform an RBC/RBC handover, enabling any pair of neighbouring RBCs compliant with it to be interconnected so that RBC/RBC handovers can be performed, independently of the functional characteristics, service performance and safety of the concerned RBCs, which are outside the scope of this document.

5.3. Commercial Solutions

Railway signalling systems require a communication network to enable connections between nodes located in different locations. Through the communication network, the signalling nodes are constantly interchanging data that is vital for the correct control of the railway line.

Designing a suitable communication system requires a previous technical characterization of the communication requirements on data rate, latency, packet loss rate of the signalling system. These technical communication requirements strongly depend on the signalling system vendor. Nowadays, there is no standardization for the communication channel for signalling, and each signalling system vendor designs its own protocol according to its and the infrastructure manager’s needs. Commonly deployed railway signalling systems being a proprietary solution specific from different vendors, there is very little information on the data rate requirements to fulfil adequate performance, making the complete characterisation of the communication system difficult.

Concrete requirements for wireless data rates, latencies and reliability are difficult to define. Upon reviewing technical specifications of data rates required in signaling networks from various major manufacturers or vendors, data rates in the same range (4kBit/s – 10Mbit/s) where observed.

Finally, signalling systems are usually limited by latency and availability, with the required data rate not being the bottleneck, as 4G, public 5G, private 5G, and Wi-Fi networks for objects close by generally offer much higher data rates.

In the signalling systems, some timeouts are defined to acknowledge the received updated and recent information about the progress of the railway operation. This means that, if the communication system is not fast enough, the railway application information may be overdue at the application layer.

5.4. EULYNX compatibility

Additionally, it is recommendable, at least for G1 lines, that the communication system specified in this document is compatible with the EULYNX architecture, defined at the current stage in *EULYNX Baseline Set 4 Release 2* documentation.

The EULYNX project aims to standardise interfaces and elements of the rail signalling systems in Europe, and to establish an architecture with long-term stable interfaces.

Specifically, the interfaces specified in the document "Specification of Point of Service-Signalling - Eu.Doc.100" [EU.Doc.100] can be of interest. The document specifies data rates for wireless communication links with a range from 15 kbit/s to 2 Mbit/s, with delays between 250 ms and 1300 ms, and packet loss rates below 1% to 5%, depending on the interface and use case.

In practical setups, the required wireless communication data rates depend on the specific deployment architecture and must be specified to meet customer requirements for reliability and availability. It is important to note that the requirements can vary significantly based on the deployment in question. Therefore, the wireless system should be adaptable enough to meet changing requirements.

6. Economic assessment of a communication system for railway signalling

In the context of FutuRe, an analysis of how **wireless connection between track and track/field devices** contributes to fulfil the SEO, was conducted. Also analyses of SWOC results, coming from S2R projects, showed the potential for CAPEX and OPEX savings – see [X2R1.D7.1]

To this end, FP6 Task 2.3 “KPI achievement monitoring” (see [D2.3]) was taken into account. The identified SEOs targets are

- **SEO5:** Overall reduction of OPEX and CAPEX. **KPI:** The overall reduction of OPEX and CAPEX is targeting 15%.
- **SEO8:** Reduced OPEX costs/km for trackside railway assets. **KPI:** Expected decrease by targeting 30%.

A quantitative evaluation of the achievement of these KPIs will be performed in WP9 after the demonstrator tasks have been concluded. The assessment will be based on the methodology, parameters (e.g. reduction of cabling length) provided D2.3 and compared with the D2.3/D2.6 baselines.

7. Top Functional and Non-functional requirements

In Table 1, a mix of top functional and non-functional requirements for track-to-track communication are listed. The requirements are linked to Deliverable D2.2 [D2.2].

If a requirement is derived from an existing one it is indicated in the column “Source” in the table, where the base requirement is noted.

Service operational requirements, service functional requirements, and rolling stock functional requirements are excluded from the deliverable.

Table 1: Consolidated Functional and Non-Functional Requirements

ID	Statement	Rationale	Source
FRCM 2.1	The wireless communication system shall enable the wireless transmission of CCS messages.	Operations supported by functional requirements.	[D2.2, FRCM 24]

ORCM 9.	The communication system shall be able to detect faults in the communication through fault detection mechanisms.	Equipping the wireless communication system with fault detection capabilities aligns with both OPEX and CAPEX considerations by reducing downtime, minimizing operational disruptions, and facilitating cost-effective maintenance through proactive fault identification	[D2.2]
SRCM 2.1	The wireless communication system shall be capable of supporting vital and non-vital communication.	Implementation of the operation statuses.	[D2.2, FRCM 1]
ORCM 2.1	The wireless communication system shall possess the capability to integrate and utilize public, private, and/or hybrid solutions infrastructure	Supports OPEX reduction by providing flexibility in choosing cost-effective solutions.	[D2.2, FRCM20]
SRCM 2.2	The wireless communication system shall possess the capability to support multiple and different wireless interfaces		[D2.2, ORCM 14]
NFRCM 2.1	The wireless communication system shall be scalable covering minimal regional line systems up to full equipped regional lines.	Supports OPEX reduction by facilitating cost-effective expansion.	[D2.2, NFRCM 1.]
NFRCM 2.2	The communication system should provide compatibility with installed infrastructure.	To reduce costs, the new systems should use as much as possible what is already present in terms of infrastructure.	[D2.2, NFRCM 2.]
NFRCM 3.	The wireless communication system shall be compatible with the application of the European Standard EN 50159.	Aligning with OPEX reduction, the system's compatibility with the European Standard EN 50159 streamlines compliance processes for railway applications, encompassing communication, signalling, and processing systems, specifically focusing on safety-related communication in transmission systems.	[D2.2]

NFRCM 2.3	The wireless communication system should allow fast and easy installation, detection/configuration, and connection of wayside systems.	Decrease CAPEX/OPEX by streamlining deployment processes.	[D2.2, NFRCM 5]
NFRCM 2.4	The wireless communication system should, use open standards.	OPEX reduction by fostering interoperability, minimizing vendor lock-in, and ensuring cost-effective adaptability to evolving technologies.	[D2.2, NFRCM 9]
SRCM 2.3	The wireless communication system for G1 lines shall be compatible with UNISIG Subset-098 and UNISIG Subset-039	Implementing an interoperable Safety Layer for all UDP-TCP/IP connections in the communication system aligns with both OPEX and CAPEX considerations by ensuring standardized safety protocols, reducing integration costs, and fostering long-term operational efficiency in a cost-effective manner.	[D2.2, NFRCM 12]
NFRCM 14	The wireless communication system shall support both, centralized and distributed energy system.	To decrease OPEX and CAPEX by providing flexibility in power infrastructure, minimizing installation costs, and ensuring adaptability to diverse energy supply scenarios cost-effectively.	[D2.2]
NRCM 2.5	The wireless communication system should assist to reduce the overall energy consumption.	To decrease OPEX by reducing energy costs, enhancing operational efficiency, and ensuring long-term sustainability in a cost-effective manner.	[D2.2, NFRCM 15]
NFRCM 2.6	The wireless communication system hardware and software should preferably utilize commercial off-the-shelf (COTS) solutions.	Costs Reduction. Easier implementation.	[D2.2, NFRCM 16]

SRCM 2.4	The wireless communication system shall facilitate compliance with industry regulations, national regulations, railways norms and railways standard rules.	Ensuring compliance of the wireless communication system hardware and software with railway norms and standards aligns with both OPEX and CAPEX considerations. This approach minimizes compliance-related risks, potential penalties, and fosters long-term operational efficiency cost-effectively.	[D2.2, NFRCM 17]
SRCM 2.5	The wireless communication system shall be able to support CENELEC RAMS levels.	Contributing to both OPEX and CAPEX reduction. This approach minimizes the risk of disruptions, ensures continuous operation, and optimizes resource utilization, resulting in a cost-effective and resilient communication infrastructure.	[D2.2, ORCM3]
NFRCM 2.7	The wireless comms system should allow the use of energy self-sufficient power supply alternatives.	CO2 reduction.	[D2.2, ORWA 8.]

8. PHYSICAL LAYER

The transmission system architecture shall include a physical layer providing an interface to the transmission medium, closely associated with the virtual and physical connection between devices.

At the physical layer level, it is relevant to differentiate between the physical layer supported in the interfaces between the Communication system and the CCS nodes (using the communication network), and the main physical channel used by the communication system.

It is in the scope of the present document to enable the migration of wired based communication networks to wireless ones. Wireless technologies have proven to be able to satisfy automation information exchange in other verticals.

For railway communications, a mix between public and private infrastructure managers (IM) owned wireless technologies is expected. Depending on the deployment and the considered requirements the use of cellular systems like LTE/5G or other common-off the shelf (COTS) wireless systems (e.g., derivations of 802.11) that can fulfil the specified requirements as a main transmission physical channel should be used.

Accordingly, the trackside CCS nodes (RBC, IXL, OC/SWOC) should be interconnected via a wireless communication channel where possible.

Several solutions that might be able to cover the specified requirements exist, for example 3GPP 5G NR (Rel. 17 and later). Technologies deployed in the ISM frequency band bring benefits, for example the reduction in the cost of licencing spectrum. Depending on the point of view and the safety, the use of the ISM bands might not be recommended as it is an “open spectrum” that could be susceptible to interference. Nowadays, technologies based on this band have developed robust channel access and channel transmission mechanisms to take the interference from other technologies into account.

Wireless technologies that are able to fulfil the required specification, taking special account of the QoS handling, can be used as either a primary or secondary transport network.

The physical channel of the communication system is envisioned to be a mix of wired (fibre or copper) and wireless channels for an optimal CAPEX and OPEX reduction. Furthermore, convergence of the communication systems is needed to also guarantee the maximum level of reliability.

Intermediate network devices are not specified here and may also include e.g., base stations, repeaters, core nodes and other kind of physical channels.

Nevertheless, the physical layer of the interface between the communication system and the CCS nodes shall be an electrical or optical local connection following the ethernet physical channel specification.

The track devices may be interconnected to other devices via a wireless communication channel where applicable. This can be accomplished via different communication standards following the corresponding national frequency regulations and the requirements listed in Table 2**,**

Table 3 and Table 4 below. These tables include quality of service specifications and newly derived specifications from the Use Cases in Task 4.2.2.

Table 2: Top level requirements for the Physical Layer

ID	Statement	Rationale	Source
NFRCM 2.8	The wireless communication system shall guarantee the defined latency, jitter, quality of service, message reception timeout and availability requirements.	Contributing to OPEX reduction by ensuring reliable communication.	[D2.2, FRCM 11.]
FRCM 2.2	The communication system physical layer shall be based on wireless communication link.	Aligns with both OPEX and CAPEX considerations as it can potentially reduce infrastructure costs, streamline deployment, and contribute to long-term operational efficiency, resulting in cost-effective and scalable communication system.	[D2.2, NFRCM 8.]
NFRCM 10.	The wireless communication system shall comply with either IEEE, or 3GPP, ITU, ISO terrestrial and non-terrestrial radio standards.	Aligning with OPEX and CAPEX reduction by promoting a standardized and cost-effective approach to wireless communication technology.	[D2.2]
SRCM 2.6	The wireless communication system should support implementation of FRMCS specifications as much as possible to ensure future TSI compatibility, especially regarding application interfaces towards gateways (e.g., OBApp).	Reducing both OPEX and CAPEX by fostering interoperability and supporting seamless integration with evolving railway technologies.	[D2.2, NFRCMG1 1.]

Table 3: Additional requirements for the Physical Layer

ID	Description	Rationale	Source
SRCM 2.7	The wireless communication system for G1 lines should support low performance wireless data rates and latencies specified in EULYNX	EULYNX specifies standards for RBC communication	D2.2 [FRCM 11.]
SRCM	The wireless communication	EULYNX specifies standards for	D2.2 [FRCM

2.8	system for G2 lines may support low performance wireless data rates and latencies specified in EULYNX	RBC communication	11.]
SRCM 2.9	The wireless communication system of RBC to RBC for G1 lines should support the transmission of messages defined in UNISIG Subset-039 and UNISIG Subset-098	Subset-039 and Subset-098 define requirements for RBC to RBC communication	D 2.2 [NFRCM 12]
FRCM 2.3	The wireless communication system data rates should be configurable.	Compatibility with commonly used signalling systems.	D2.2 [FRCM 11.]
FRCM 2.4	The track-to-track wireless communication system for G1 and G2 lines should be able to use different bearer's technologies based on the location of the equipment.	Remote regional lines might need to rely on the support of public or private mobile network operators as well as satellite connections	D2.2 [ORCM 6]
SRCM 2.10	The track-to-track wireless communication that transports vital information should use country specific licensed spectrum	Wireless communication systems that are based on ISM frequency bands are susceptible to interference	D2.2 [NFRCM 26]
FRCM 2.5	The physical layer shall support multiple modulations with adaptive coding rates to optimize data throughput based on signal quality.	Adaptive modulation and coding enhance spectral efficiency and maintain communication quality under varying conditions.	[D2.2, NFRCM 26]
FRCM 2.6	The transmitter should have adjustable power settings.	Adjustable transmission power is necessary to optimize coverage areas while managing interference effectively as well as have effective cost saving communication.	

Table 4: Requirements specifically derived from Task 4.2.2 Use Cases

ID	Statement	Rationale	Source
NFRCM 2.9	The wireless communication links should comply to the cybersecurity standards.	Authentication is necessary for security relevant message communication	UC_WP4_4.2.2_003, UC_WP4_4.2.2_004, UC_WP4_4.2.2_005

9. LINK LAYER

The transmission system architecture shall include a link layer in charge of transferring data between nodes on the network segments across the physical layer.

The data link layer provides the functional and procedural means to transfer data between network entities and may also provide the means to detect and possibly correct errors that can occur in the physical layer.

Accordingly, a communication network suitable for communicating backbone trackside CCS nodes shall support at least the following protocols in the interface with the CCS node:

- The interface to the wireless communication module shall support Ethernet as specified in IEEE 802.3. IEEE Standard for Ethernet.

The link layer shall follow the requirements listed in Table 5.

Table 5: Requirements for the Link Layer

ID	Statement	Rationale	Source
FRCM 2	The wireless communication system module physical interface towards the control system shall support ethernet as specified in the IEEE 802.3 standards.	IEEE 802.3 Ethernet standards of the physical interface ensure interoperability and cost-effective integration aligns with OPEX and CAPEX goals, fostering standardized communication, efficiency, and adaptability to evolving railway technologies.	[D2.2]
FRCM 2.7	The communication system shall implement Quality of Service (QoS)	Aligning with OPEX and CAPEX considerations, the system optimizes efficiency, reduces latency, and ensures resource efficiency through tailored priority management for diverse traffic classes, fostering a cost-effective and responsive communication infrastructure.	[D2.2, FRCM 13]
FRCM 2.8	The wireless communication system shall include/support the establishment of error detection and recovery mechanisms applied at layer 2 level.	By detecting and correcting errors, and retransmitting corrupted packets, the communication system minimizes data loss, ensuring reliable and accurate communication between nodes.	[D2.2, ORCM 9]
FRCM 2.9	The wireless communication system should support dynamic adjustment of data Link layer parameters (e.g., frame size, retry limits) based on network conditions to optimize performance.	Dynamic adjustment of parameters allows the system to adapt to varying network conditions, optimizing performance and maintaining efficient communication.	[D2.2, ORCM 7]
FRCM 2.10	The wireless communication system should support both unicast and multicast communication modes to enable efficient data distribution to individual and multiple devices.	Supporting unicast and multicast modes facilitates efficient handling of different communication needs, from point-to-point to group communication, improving network flexibility. It is valuable for maintenance and diagnostics.	[D2.2, FRCM 1]

10. NETWORK LAYER

The transmission system architecture shall include a network layer in charge of providing the means of transferring variable-length network packets from a source to a destination host via one or more networks.

The network layer responds to service requests from the transport layer and issues service requests to the data link layer. The network layer protocol provides the next main services to the transport layer: Packetizing, routing, and forwarding.

Accordingly, a Communication Network suitable for communicating backbone trackside CCS nodes shall support at least the following network layer protocols in the interface with the CCS node:

– The interface shall support IPv4 as specified in IETF/RFC791 Internet Protocol.

– The interface should support IPv6 as specified in IETF/RFC2460 Internet Protocol, Version 6 (IPv6) Specification.

IPv4 and IPv6 include mechanisms for classifying, managing and prioritizing network traffic and providing quality of service (QoS) on IP networks, as the DiffServ architecture specified in RFC 2474 and RFC 2475.

Assignation of priority field values depends on what network equipment is being used and is out of scope of this document.

The network layer shall follow the requirements listed in Table 6:

Table 6: Requirements for the Network Layer

ID	Statement	Rationale	Source
FRCM 2.11	The wireless communication system shall support the establishment of priority policies through QoS mechanisms.	Aligns with both OPEX and CAPEX considerations by enhancing operational efficiency, reducing the risk of service disruptions, and promotes cost-effective resource utilization by tailoring communication parameters to the specific requirements of each application.	[D2.2, FRCM 12]
NFRCM 2.10	The wireless communication system should incorporate an adequate network management policy, allowing for features such as VLAN or a similar concept for network partitioning and traffic segregation.	This will allow a better network management like usual private networks used by IM and aligns with both OPEX and CAPEX considerations by enhancing security, promoting efficient resource utilization, and minimizing potential operational disruptions cost-effectively.	[D2.2, FRCM 18]
NWRCM2.1	The network layer shall support the IPv4 protocol, defined in IETF/RFC791, as its means for packet sending. Support of IPv6 for future applications is recommendable and by IETF RFC 2460 standard	IPv4 and IPv6 are widely used for packet transmission.	[D2.2, FRCM 15]

11. TRANSPORT LAYER

Transmission system architecture shall include a transport layer responsible for ensuring that the data packets arrive accurately and reliably between sender and receiver. The transport layer is an end-to-end layer, because that layer provides a point-to-point connection between the sender host and the receiver host, to deliver the services reliably.

The transport layer protocol provides the next main services to the transport layer: Connection oriented communication or connectionless communication services, reliability, flow control, and multiplexing.

Ports to be shared by endpoints are agreed according to regulations and they are configurable at startup phase and/ or connection phase.

The transport layer shall follow the requirements listed in Table 7.

Table 7: Requirements for the Transport Layer

ID	Statement	Rationale	Source
SRCM 2.11	The communication system for G1 lines should implement an interoperable safety layer for all UDP-TCP /IP connections and	Implementing an interoperable Safety Layer for all UDP-TCP/IP connections in the communication system aligns with both OPEX and CAPEX considerations by ensuring standardized safety protocols, reducing integration costs, and fostering long-term operational efficiency in a cost-effective manner.	[D2.2, NFRCM 12.]
SRCM 2.12	The communication system for G1 lines for RBC-to-RBC communication should be compatible with UNISIG Subset-098.	Ensuring standardized safety protocols allows reducing integration costs, and fosters long-term operational efficiency in a cost-effective manner.	[D2.2, NFRCM 12.]
FRCM 3	The communication system shall be designed for supporting TCP/UDP protocols in the transport layer.	Aligning with OPEX and CAPEX, supporting TCP/UDP protocols enhances operational flexibility, reduces disruptions, and ensures cost-effective communication through widely used, standardized protocols.	[D2.2]

12. SAFETY AND ADAPTATION LAYERS

Not being included the safety and adaptation layers (Safety system upper layers) in the transmission system architecture, specification of these layers is out of the scope of this document.

Regarding the information interchanged in the scope of these layers, the communication system specified in this document is only committed to supply the communication resources for the establishment of a point-to-point link between the safety nodes. The communication system shall transmit transparently messages from these upper layers in the protocol stack.

According to ***EN 50159*** standard *Railway applications - Communication, signalling and processing systems - Part 2: Safety related communication in open transmission systems*, safety related systems composed with equipment interconnected for communication purposes, through an open transmission system, shall have to necessarily implement an architecture including a Safety module in charge of a communication safety layer.

The Safety Functional Module provides the functions of the safety related transmission system.

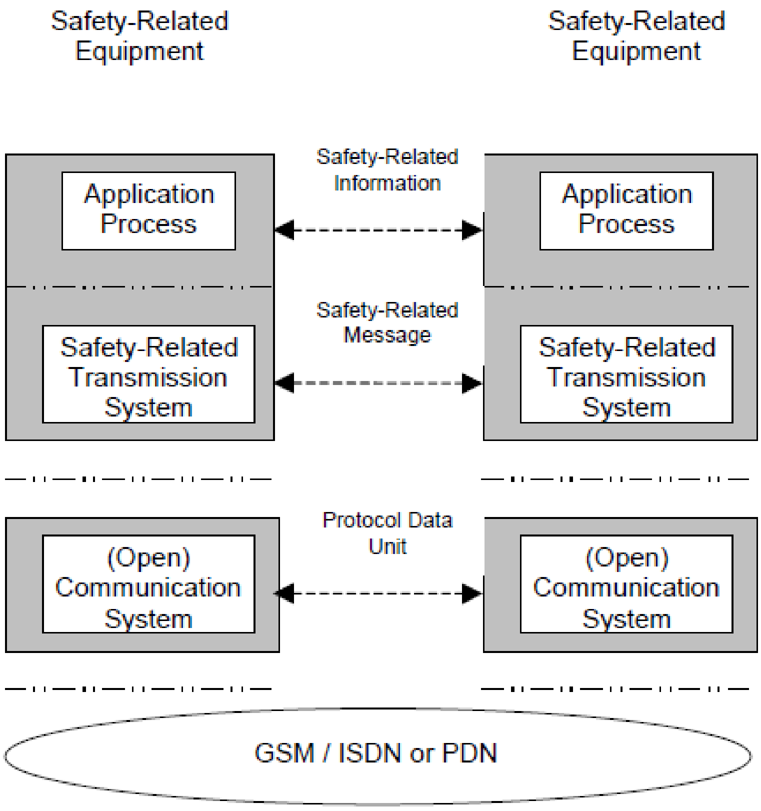

Figure 10: Structure of the EN 50159 communication system

The safety layer is a communication layer established directly point-to-point between the safety nodes. Information belonging to this layer is encapsulated inside the layers of the open communication system and transmitted transparently through the communication system.

Safety layer specification, including functional safety module and safety communication protocol, shall depend on each vendor.

Additionally, vendors usually defined an intermediate layer between safety and communication layers, needed to provide the adaptation level between the protocols of the different layers. Similarly, as safety layers, the adaptation layers shall depend on each vendor and shall be implemented differently depending on each application type and manufacturer.

13. APPLICATION LAYER

The link application shall follow the requirements listed in Table 8.

Table 8: Requirements for the Application Layer

ID	Statement	Rationale	Source
FRCM 2.12	The wireless communication system shall enable the transmission of both standardized vital communication protocols and non-vital communication protocols in signaling systems.	Aligns with both OPEX and CAPEX considerations by fostering flexibility, reducing integration costs, and accommodating diverse communication requirements in a cost-effective manner.	[D2.2, NFRCM 13.]
FRCM 2.13	All telegrams on higher layers should use TCP/UDP protocol defined in IETF/ RFC9293, IETF/RFC7323	The telegrams exchange format needs to be harmonized for exchange of messages.	[D2.2] [FRCM 3]
FRCM 2.14	They wireless comms system should support EULYNX messages for communication.	Using standardized messages allows for reduction of OPEX	[D2.2, NFRCM 13]

14. References

DOC-ID	Title	Version
[CCSTSI]	CCS TSI Appendix A – Mandatory specifications (ETCS B4 R1, RMR: GSM-R B1 MR1 + FRMCS B0, ATO B1 R1)	4.0.0
[D2.1]	Regional_Line_Architecture_02_00	M14
[D2.2]	Regional lines operational and functional requirements_02_00	M14
[D2.3]	First release of KPI achievement	M14
[D4.2CL]	Interface Specification Track-Cloud non railway user	M24
[D4.2T]	Deliverable D4.2 - Requirement specifications for communication report (top document)	M24
[D4.4UC]	D4.4_Use_Cases_T4.2&T4.4	M24
[D5.2]	Specifications CCS for Group 2	M24
[EN50159]	EN 50159:2010+A1:2020 Railway applications. Communication, signalling and processing systems. Safety-related communication in transmission systems	
[EU.Doc.100]	Specification of Point of Service-Signaling	EULYNX Baseline Set 4
[X2R1.D7.1]	X2R-WP07-D-TTS-001-02_-_D7.1_-_Analysis_of_existing_lines_and_economic_models	DB-001-02-R2
[X2R1.D7.2]	X2R-T7.3-D-CFS-006-06_-_D7.2 Railway requirements and Standards application conditions	Rev. 1.0