D4.2 PART 4 - INTERFACE SPECIFICATION TRACKSIDE-FIELD DEVICES

Executive Summary

This part of the report provides functional and non-functional requirements with interface specifications for track-to-field communication. This report is Part 4 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 [D4.2T], to understand the context and main conclusions of this part of the deliverable.

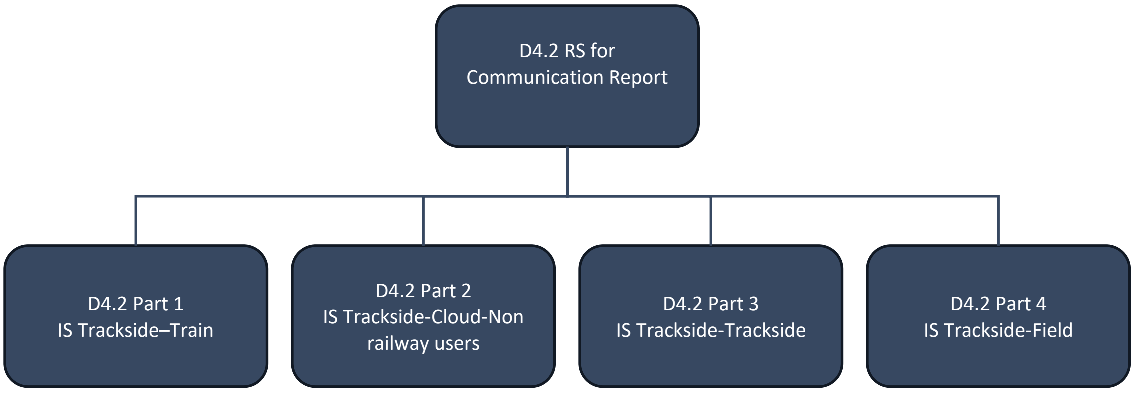

Figure 1: D4.2 Requirement specifications for Communication Report Document Structure

The interface specification is influenced by the ISO (International Standards Organisation) OSI-model (Open Systems Interconnection), describing the interface in different layers. As field devices, switches with the corresponding point machines, level crossings (LX), signals (e.g. lights, loudspeaker), axle counters and track circuits are considered.

Requirements from deliverable D2.2 [D2.2] have been used as top requirements for developing this document. Those top requirements are referenced by citation in the document. Further considerations of safety and security aspects as well as cloud communications 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 goal of this deliverable is to provide requirement specifications that could serve as a guideline 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]. In order to do so, different railway architectures that utilize e.g., wireless communications for adding new elements to existing brownfield deployments, were developed. 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 effectively included in the system.

1. Process

The requirements and system description described in this document have been derived from a set of reference use cases. To create both outputs, use cases and architecture, the steps in Figure 2 have been followed.

The mean of applying such a process is to follow a sensitive, conclusive, and clear approach with the final aim of identifying a coherent and justified set of requirements:

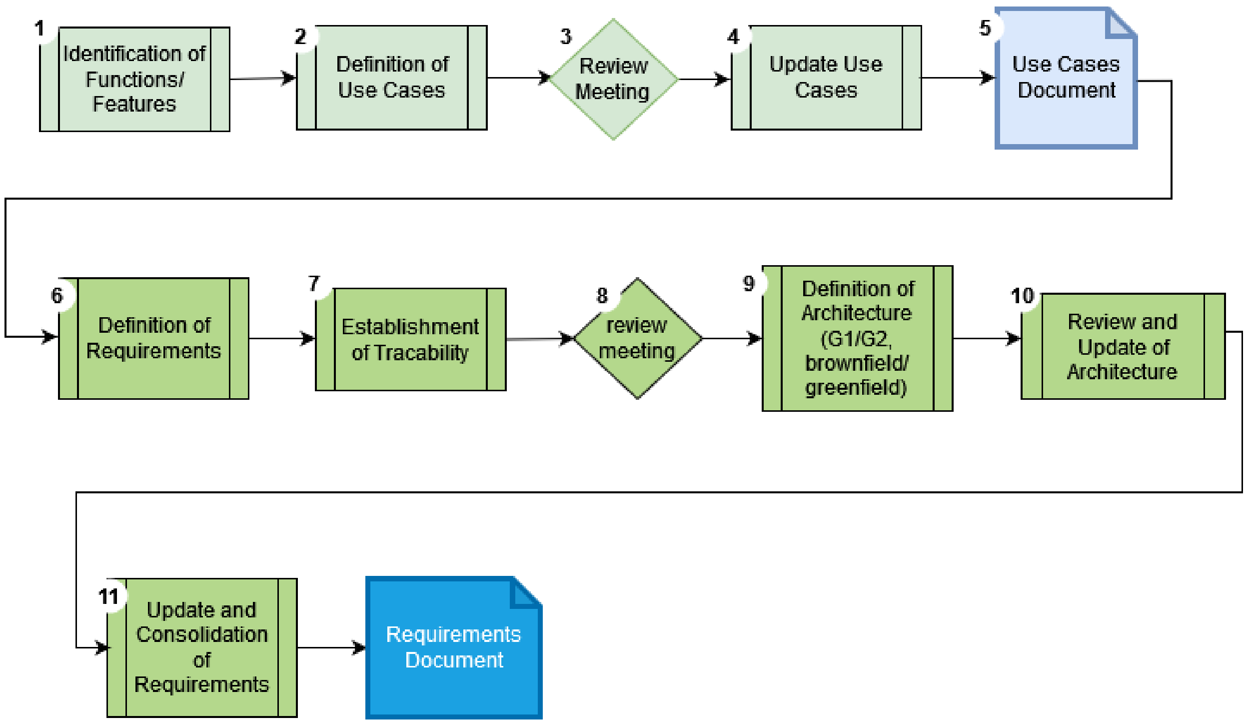

Figure 2: Process followed for this document

1. Identification of Functions/Features: In a first work field devices 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 und 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 this present document.

2. Reuse of Shit2Rail results

For the architecture of G1 and G2 lines the concept of the Smart Wayside Object Controller (SWOC) [X2R1D7.1] of S2R projects X2Rail-1 and X2Rail-4 was utilized, where it was envisioned that field elements like level crossing, switches, signals or axle counters are controlled by a SWOC.

Therefore, the concept of the SWOC has been introduced in the development of track-to-field system architecture. The results of the above mentioned S2R projects were studied and proved useful due to their comprehensive analysis of possible advantages of deploying wireless links for connection between spatially distributed trackside subsystems, along with field elements, 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.

Nevertheless, some metallic cabling naturally cannot be completely removed in the last few meters from the SWOC to some specific field elements like point-machines, signals, axle counters, track circuits, LX barrier machines, warning boards and annulment sensor which need a galvanic connection from the SWOC and, in some cases, a considerable amount of power to be transported to them from respective energy harvesting sources.
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-field architecture for G1 lines

For the general architecture of G1 lines, the document refers to the architecture presented in D2.1, Figure 28 [D2.1].

The specific architecture for *brownfield* for G1 lines considered in this document is shown Figure 3. The architecture considers the use cases where field objects like point machine, level crossing etc. communicate via an object controller (OC)/smart wayside object controller (SWOC) to the interlocking (IXL). The figure includes a radio block centre (RBC) in case of ERMTS ETCS Level 2.

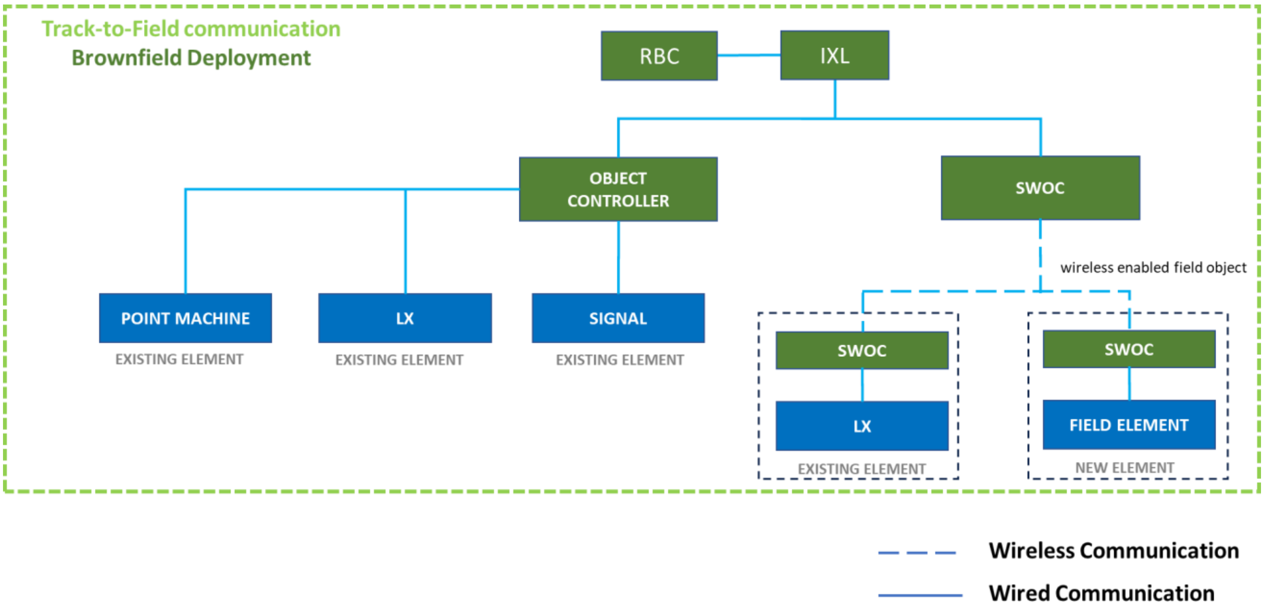

Figure 3: Envisioned architecture for track-to-field communication for G1 lines (Brownfield)

In the shown brownfield deployment, existing field devices are mostly connected to the interlocking system (IXL) via the object controller (OC) using wired connections, such as fibre optic or copper cables. It should, however, be possible to allow replacing wired connections by wireless ones, to reduce maintenance costs or re-investment in case of damaged cables. In cases where wireless communication links are used to replace wired links, or when new field devices are added to an existing brownfield installation, it is suggested to introduce SWOCs (see also [X2R1D7.2]) to the existing brownfield deployment. A SWOC is an enhanced OC that can control one or more field devices and has wireless capability. In Figure 3, a SWOC is connected to an IXL in close proximity and establishes a wireless communication link with other SWOCs, each of which controls a nearby field device, e.g., an existing level crossing or a new element that has to be added to the setup. The SWOC together with the field device is termed wireless enabled field object. Since SWOCs already have defined interfaces, the downtime can be reduced and no groundwork is necessary. If the SWOC is furthermore supplied with renewable energy supplies and has energy storage systems even more costs can be saved.

Wireless interfaces considered are:

- IXL to wirelessly enabled field objects (LX, point machine, signal, etc) via SWOC

For a *greenfield* deployment it is envisioned that

(a) all participating track and field devices, i.e., IXL, OC/SWOC, RBC, are wirelessly enabled and the communication can be done wirelessly if cost savings are possible.

(b) the wireless enabled field objects are energy self-sufficient, i.e., they can have autonomous power supply which allows for cost reduction. This use case is considered in more detail in [D4.1]

A system description of this case is shown in Figure 4. The case of a greenfield deployment in G1 lines considers an IXL that is connected wirelessly to an OC or SWOC and the OC or SWOC locally controls a field device (i.e., point machine, level crossing or signal). In case of ERMTS ETCS Level 2 an RBC is wirelessly connected to the IXL. In case where the wireless solution does not allow for any significant cost savings, the left side of in Figure 4 shows the case where still wired connections are used.

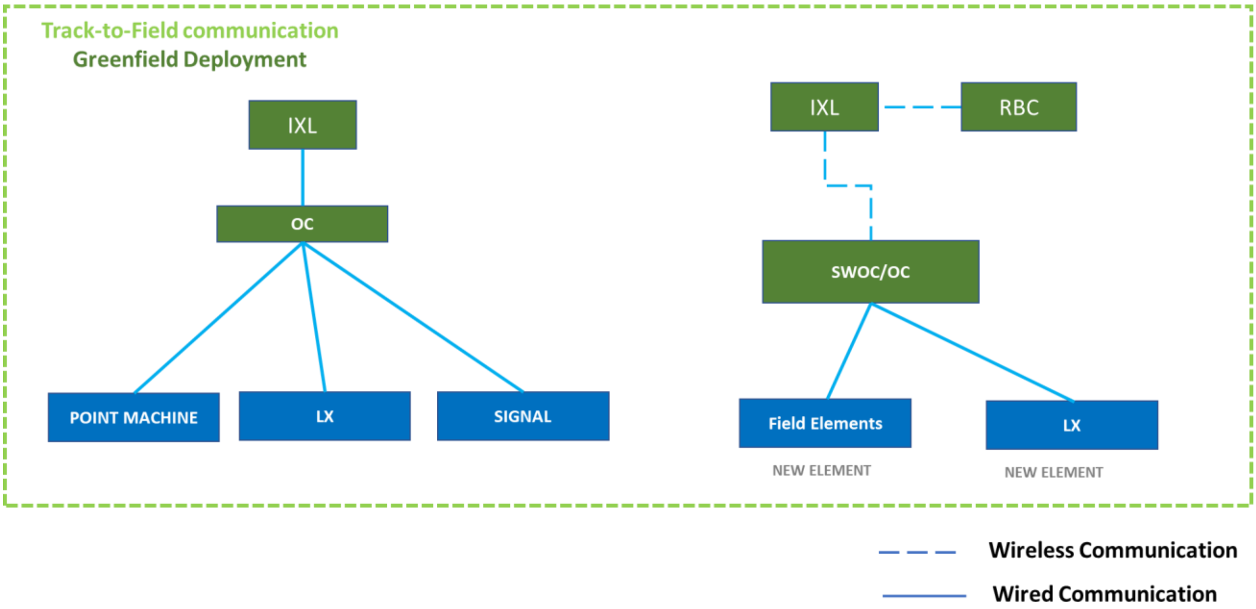

Figure 4: Envisioned architecture for track-to-field communication for G1 lines (Greenfield)

Wireless interfaces are:

- IXL to SWOC
- IXL to RBC

3.2. Track-to-field architecture for G2 lines

In case of G2 lines a high-level conceptual architecture is considered. The conceptual architecture of G2 lines can be found in [D2.1], Figure 13 and a more detailed concept can be found in [D5.2]. For G2 lines a traffic management system (TMS)/centralized traffic control (CTC) is deployed, integrating 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 G2 lines for a *brownfield* deployment considered in this deliverable is shown in Figure 5. In this architecture point machines and level crossings are considered as main field devices. Positioning of the train is done as defined in [D2.1].

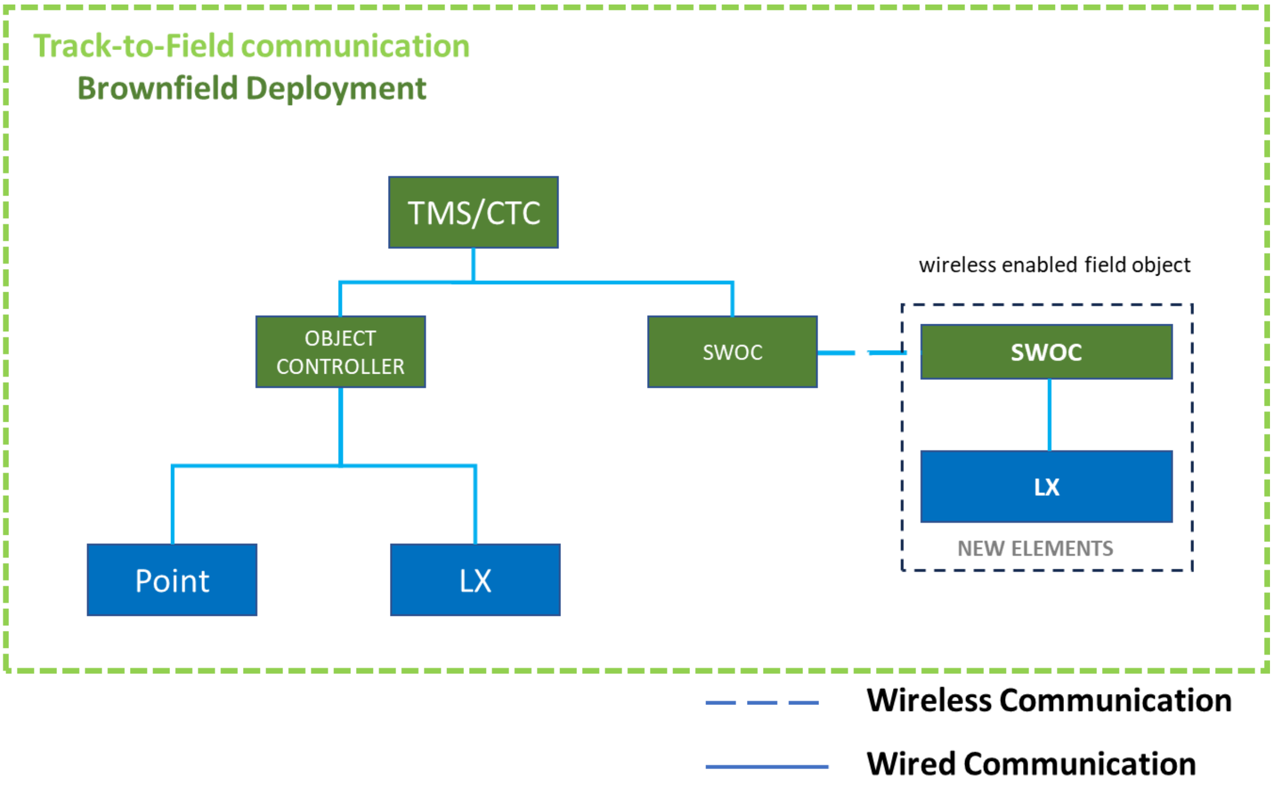

Figure 5: Envisioned architecture for track-to-field communication for G2 lines (Brownfield)

If the object controller is close to the field device, wired connections can be considered between object controller and field device. This can even be considered if the field devices are wirelessly controlled and powered by solar/battery. The presence of a trackside object controller has no impact on the applicability of the above architecture concept that normally sees the control functionality as integrated at TMS/CTC level. New field devices, primarily LXs, are envisioned by connecting a SWOC to the TMS/CTC, with the new LX having its own SWOC for local control. The connection between the SWOCs is envisioned wirelessly.

The specific architecture for G2 lines for a *greenfield* deployment considered in this deliverable is shown in Figure 6.

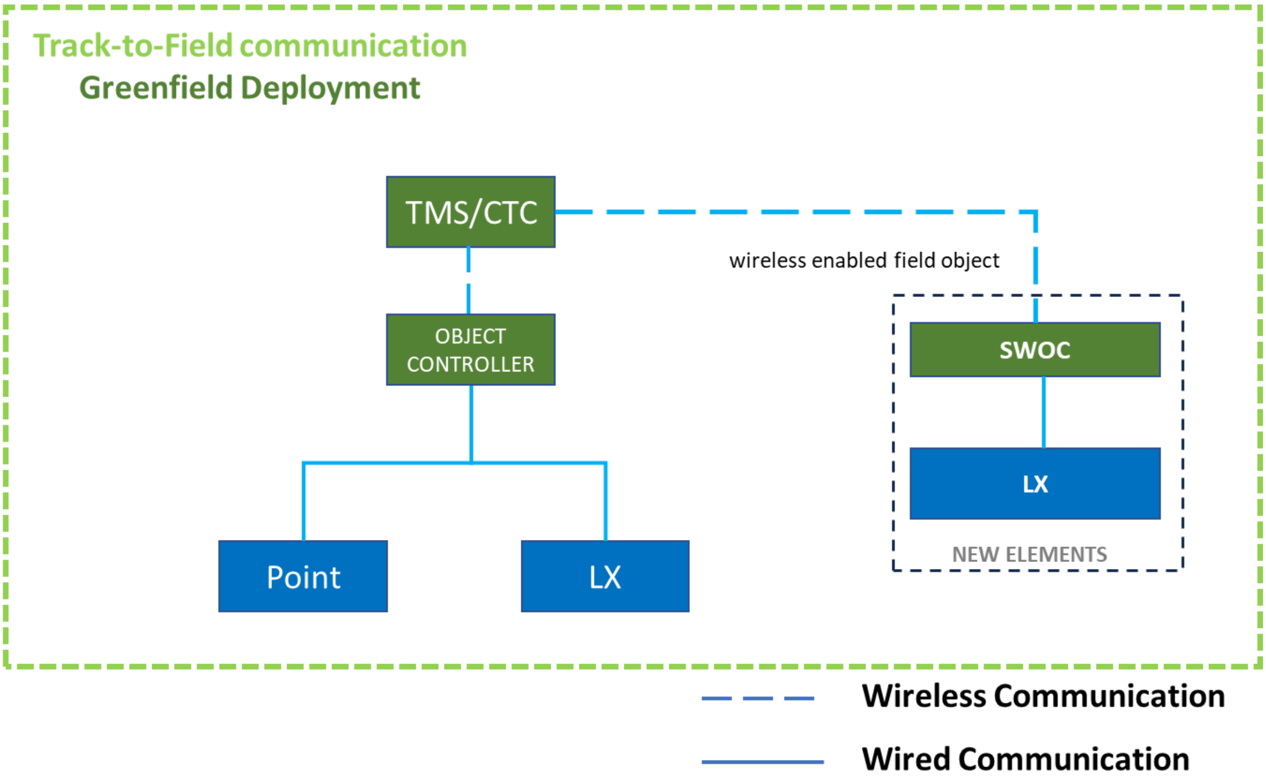

Figure 6: Envisioned architecture for track-to-field communication for G2 lines (Greenfield)

Compared to a brownfield deployment, additionally the TMS/CTC communication link to object controller might be directly wireless. Furthermore, the communication link from an OC to an LX, that is locally controlled by a SWOC, might be wireless. With this considered system description a reduced cabling is possible for greenfield deployments allowing to reduce costs.

Leveraging on the adoption of IP based standard protocols and data sharing thorough 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".

3.3. Architecture with autonomous LX

As autonomous LX we considered a LX that does not have any connection to an IXL, but has a logic locally to detect rail vehicles, secure the crossing and give clearance to the approaching rail vehicle. The case of autonomous level crossings is relevant for all use cases, such as brownfield and greenfield deployments for G1 lines.

4. 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 socio-economic objectives (SEO), was conducted.

To this end the FP6 Task 2.3 “KPI achievement monitoring” (see [D2.3]) was taken to 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.

5. Top Functional and Non-functional Requirements

In Table 1 a mix of functional and non-functional requirements for track-to-field communications is 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
NFRCM 1.1.	The wireless communication system shall be scalable, covering minimal regional line systems up to fully equipped regional lines.	Supports OPEX reduction by facilitating cost-effective expansion.	[D2.2, NFRCM1.]
NFRCM 1.2.	The communications 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, NFRCM2.]
NFRCM 3.	The wireless communication system shall be compatible with the application of the European Standard EN 50159 [EN50159].	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 14.	The wireless communication system shall support both, centralized and distributed energy systems.	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]
NFRCM 1.3	The wireless communication system hardware and software should preferably utilize commercial off-the-shelf (COTS) solutions.	Costs Reduction. Easier implementation.	[D2.2, NFRCM16]

NFRCM 1.4.	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, NFRCM17]
NFRCM 1.5.	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]
FRCM 1.1.	The SWOC of a wireless enabled field object should provide a specific module for power management.	Wayside assets operational req.	[D2.2, ORWA 2]
FRCM 1.2.	The Level Crossing/Switch/Point machine power management module shall operate in the environment class compatible with the IM needs.	Wayside assets operational req.	[D2.2]
FRCM 1.3.	The SWOC/OC should allow the configuration of different energy sources	Wayside assets operational req.	[D2.2, ORWA 4.]
FRCM 1.4.	The power management module of a SWOC should know when to switch between energy sources	Allows for higher availability	[D2.2, ORWA 4.]
FRCM 1.5.	The SWOC shall implement remote maintenance facilities throughout the wired or wireless connection.	Wayside assets operational req.	[D2.2, ORWA 5.]
FRCM 1.6.	The power management module shall allow the use of energy self-sufficient power supply alternatives.	Wayside assets operational req.	[D2., ORWA 8.]

6. PHYSICAL LAYER

The physical channel of the communication system is envisioned to be a mix between wired (fibre or copper) and wireless channel for maximum CAPEX and OPEX reduction. At scenarios where beneficial (depending on the concrete realisation of brownfield/greenfield and G1/G2 lines) wireless enabled field devices can be interconnected to track devices via a wireless communication links. This can be accomplished using different communication standards (e.g. 5G, etc.) following the national frequency regulations and the requirements listed in Table 2 and below. These tables include quality of service specifications and newly derived specifications from use cases defined in [D4.4UC]. Intermediate network devices are not specified here and may also include, e.g., repeaters and other kind of physical channels.

Concrete requirements for wireless data rates, latencies and reliability are difficult to define. In EULYNX Baseline Set 4 Release 2 [EU.Doc.100], the specified data rates for wireless communication links 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. Reviewing technical specifications of data rates required in signaling networks of different main manufacturers or vendors, data rates in the same range (4kBit/s – 10Mbit/s) were observed.

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.

Table 2: Requirements for the Physical Layer

ID	Statement	Rationale	Source
FRCM 1.7.	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 1.6	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.]
NFRCM 10.	The wireless communication system shall comply with either IEEE, 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 1.1.	The wireless communication system should support implementation of FRMCS specifications as much as possible.	Reducing both OPEX and CAPEX by fostering interoperability and supporting seamless integration with evolving railway technologies.	[D2.2., NFRCMG1.1]
SRCM 1.2.	The track-to-field 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]
NFRCM 1.7.	The physical components of the communication system shall operate reliably within a temperature range of -40°C to +85°C and under high humidity conditions up to 95%.	Ensuring physical robustness in extreme temperatures and humidity is essential for maintaining communication reliability in harsh railway environments.	

FRCM 1.8.	The transmitter shall have adjustable power settings.	Adjustable transmission power is necessary to optimize coverage areas while managing interference effectively as well as have effective cost saving communications.	[D2.2, NFRCM 15]
NFRCM 1.8.	The physical layer shall include redundant communication paths to ensure system reliability in case of primary link failure.	Redundancy at the physical layer enhances system reliability and availability, critical for safety-critical applications.	[D2.2, NFRCM 15]
SRCM 1.3.	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: New Requirements for the Physical Layer Derived from Task 4.2.2 Use Cases

ID	Statement	Rationale	Source
NFRCM 1.9	The latency of primary to secondary SWOC communication shall not influence RAMS	A degradation of RAMS would reduce safety	UC_WP4_4.2.2_001 UC_WP4_4.2.2_002 UC_WP4_4.2.2_006 - UC_WP4_4.4_004

7. LINK LAYER

The link layer shall follow the requirements listed in Table 4

Table 4: Requirements for the Link Layer

ID	Statement	Rationale	Source
FRCM 2.	The wireless communication module physical interface towards the local control system should support Ethernet as specified in the IEEE 802.3 standards.	Supporting IEEE 802.3 Ethernet standards of the physical interface ensures interoperability and cost-effective integration aligns with OPEX and CAPEX goals, fostering standardized communication, efficiency, and adaptability to evolving railway technologies.	[D2.2]
NFRCM 1.10	The communication system shall implement Quality of Service (QoS) mechanisms.	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]
SCRM 1.4.	The wireless enabled field devices should comply with a 5G NR link standard	5G NR is considered as possible successor of GSM-R	New
FRCM 1.9.	The wireless communication system shall include/support the establishment of error detection and recovery mechanisms applied at layer 2 level.	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, ORCM 9]
FRCM 1.10.	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 1.11.	The wireless communication system shall 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.	[D2.2, FRCM 1]

8. NETWORK LAYER

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

Table 5: Requirements for the Network Layer

ID	Statement	Rationale	Source
FRCM 1.12.	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 1.11.	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	Aligns with both OPEX and CAPEX considerations by ensuring compatibility, minimizing upgrade costs, and fostering long-term operational efficiency.	[D2.2, FRCM15]
NFRCM 1.12.	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.]

9. TRANSPORT LAYER

The transport layer shall follow the requirements listed in Table 6. Network ports to be shared by endpoints are agreed according to regulations and they are configurable at startup phase and/ or connection phase.

Table 6: Requirements for the Transport Layer

ID	Statement	Rationale	Source
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]

10. APPLICATION LAYER

The application layer interface shall follow the requirements listed in Table 7.

Table 7: Requirements for the Application Layer

ID	Statement	Rationale	Source
FRCM 1.13	The wireless communication system shall enable the transmission of both standardized vital communication protocols and non-vital communication protocols in signaling systems.	Supports OPEX reduction by ensuring efficient resource allocation based on specific operational needs.	[D2.2, ORCM 1]
NFRCM 4.	The wireless communication system shall not compromise the current level of safety and security.	Aligns with OPEX reduction by maintaining established safety standards and reducing the risk of potential incidents. Considering the use of MNO public and /or SAT networks, the implementation of safety and cybersecurity measures is mandatory.	[D2.2]
SRCM 2.14	They wireless comms system should support EULYNX messages for communication.	Using standardized messages allows for reduction of OPEX	[D2.2, NFRCM 13]

11. References

Table 8: 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
[D4.1]	Requirement specifications for Wayside Assets Report	M24
[D4.2CL]	D4.2 Part 2 - 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 Part 4 - Use_Cases_T4.2&T4.4	M24
[D5.2]	Specifications CCS for Group 2	
[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
[X2R1D7.1]	X2R-T7.3-D-CFS-006-06_-_D7.2_-_Railway_requirements_and_standards_application_conditions	1.0