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Table of contents

Executive Summary	4
List of abbreviations, acronyms and definitions.....	5
List of figures.....	7
1. Introduction	9
2. Methodology	13
3. Status of Play	17
4. Key cost drivers affecting G2 lines competitiveness	27
5. G2 Lines Requirements.....	29
6. G2 Line solution	31
7. Preliminary elements to define a Migration Plan	41
8. GOVSATCOM and Federated Data Space: Standardization & Interoperability.....	44
9. G2 Demonstrators	47
10. Conclusions.....	50
11. References	51
12. Annexes.....	52
Annex 1. GOVSATCOM	52
Annex 2: Federated Data Space	54
Annex 3: G2 Operational and Functional Requirements and System Architecture – WP2 and System Pillar interactions	57
<i>Operational Requirements (from WP2)</i>	58
<i>Functional Requirements (from WP2)</i>	61
<i>Non-Functional Requirements (from WP2)</i>	63
Annex 4: Cost Analysis.....	65

Executive Summary

Group 2 Regional Lines (G2 Lines) are lines or network of lines that are not functionally/operationally connected with the mainline network (ER JU Multi Annual Work Programme and Article 1.3 (c) of the EU Interoperability Directive [8]). Group 2 regional rail is operated by passenger and/or freight services that do not enter mainline infrastructure.

G2 Lines approach is completely different from the one considered in Group 1 Regional lines (G1 Lines). While G1 lines are required to ensure interoperability within the European network, G2 lines being free from such requirement allow for a radical new approach which will be described in the document and can be summarized by the following key concepts:

1. Decouple the railway application from the telecommunication technologies.
2. Keep free the system architecture as much as possible avoiding constraining future developments.
3. Data sharing as the mean to ensure standardization and competition.

In this report, we will analyse how the above concepts match European initiatives on Satellite communications and Federated Data Spaces.

Moreover, G2 lines, apart few exceptions, are characterized by very low traffic and consequently can accommodate solutions based on not expensive technologies thanks to the less demanding operations.

List of abbreviations, acronyms and definitions

Abbreviation / Acronym	Definition
AD	Automatic Driving
ADM	Automatic Driving Module
APM	Automatic processing module
ATAF	Automatic track ahead free
ATO	Automatic Train Operation
ATO OB EG	ATO On Board EnGaged
ATO-TS	ATO trackside
ATP	Automatic Train Protection
BG	Balise Group
CAPEX	Capital Expenditure
CCS	Control-Command and Signalling
DC	Direct Current
DMI	Driver Machine Interface
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
ETCS L2/L3	European Train Control System Level 2/Level 3
ETCS SR	ETCS Staff Responsible mode
FA	Flagship Area
FP	Flagship Project
FRMCS	Future Radio Mobile Communication System
G1 line	Group 1 Line - Regional line connected to main network
G2 line	Group 2 Line - functionally/operationally not connected to main network
GNSS	Global Navigation Satellite System
GOA	Grade of Automation
GPRS	General Packet Radio Service
GSM-R	Global System for Mobile Communications - Railway
JP	Journey Profile
IM	Infrastructure Manager
IP	Internet Protocol
LTE	Long-Term Evolution (broadband communication standard)
LX	Level Crossing
MA	Movement Authority
OB	On Board

OPEX	Operational Expenditures
OS MA	On Sight Movement Authority
PER	Perception
PIS	Passenger Information System
RBC	Radio Block Center
SEO	Socio Economic Objective
TCO	Total Cost of Ownership
TMS	Traffic Management System
ICT	Information and Communication Technology
TRL	Technology Readiness Level
TSI	Technical Specifications for Interoperability
TSR	Temporary Speed Restriction

List of figures

Figure 1: Regional lines key cost drivers	27
Figure 2: G2 Lines solution.....	32
Figure 3: G2 Lines Internet Protocol Based System Architecture	34
Figure 4: G2 Lines System Architecture	36
Figure 5: G2 Internal interfaces	37
Figure 6: Satellite communication demonstrator	47
Figure 7: Satellite positioning demonstrator	48
Figure 8: Integrated interlocking and RBC functions	49
Figure 9: Unit cost of GSM-R and NG	65
Figure 10: Total Costs for a G2 Line equipped with GSM-R or NG	66
Figure 11: G2 Lines telecom solution based on satellite communication	66

List of tables

Table 1: PTC and ERTMS deployment time and cost (Year 2021) **Error! Bookmark not defined.**

1. Introduction

The need

Regional railway lines play a vital role in Europe's rail transport system. They are essential not only for local passengers and freight services but also as feeders to the main rail network. These lines significantly support the European Union's cohesion policy. However, their primary challenge is cost inefficiency, which has led to the closure of many regional lines and continues to threaten others.

In light of climate change and the European Union's Sustainable and Smart Mobility Strategy, it is crucial to enhance the appeal of these lines. Revitalizing or renewing them is necessary to make them cost-effective, socially and environmentally sustainable, and aligned with current customer needs. This requires a substantial reduction in operating and infrastructure costs and better integration with multimodal services such as car-sharing, on-demand buses, cycling, bike-sharing, and walking.

To achieve this, customer services must be tailored to meet customer needs, ensuring high service quality and operational reliability for regional lines

The Regional Railway Need

Regional lines need to be revitalised to make them economically, socially and environmentally sustainable and meet current customer needs.

- Reduce CAPEX & OPEX costs by 40%
- Improve punctuality & reduce travel time
- Flexibility: on-demand service & intermodality

GROUP 2 REGIONAL LINES KEY ISSUES

Regional railway lines in Europe are at risk of being dismantled due to several factors:

1. **Financial Constraints:** Maintaining and upgrading regional rail lines can be costly. Often, these lines do not generate enough revenue to cover their operational and maintenance costs, leading to financial strain on operators and governments.
2. **Competition from Other Transport Modes:** The availability of rural road network reducing the demand for regional rail services.
3. **Infrastructure Prioritization:** Investments often prioritize high-speed rail and major intercity connections over regional lines. This can lead to the neglect and eventual closure of less profitable regional routes.

4. **Urbanization and Demographic Changes:** As populations shift towards urban centers, the demand for regional rail services in rural areas decreases, making these lines less viable.

Group 2 lines being characterized mostly by low density traffic are affected by above factors more than the Group 1 lines, therefore it is imperative to explore innovative solutions to minimize dramatically their Total Cost of Ownership (TCO).

Despite these challenges, there are efforts to preserve and even revive Group 2 regional lines.

GROUP 2 LINES GOALS AND KPIs

One of the major challenges for infrastructure managers and railway operators is to enhance capacity and performance while reducing both capital expenditure (CAPEX) and operational expenditure (OPEX) on low traffic density lines. This applies to both regional passenger and freight lines. The intense and growing competition from trucks, cars, buses, and other transport modes puts significant pressure on railway operators. This competition limits the ability to invest in costly infrastructure projects, such as new or refurbished lines, and instead necessitates improvements in capacity and efficiency, focusing on performance and energy savings.

To address this, it is essential to accelerate modernization by integrating existing technologies to create solutions that increase capacity and reduce maintenance costs. This can be achieved through a single integrated system connected to operation control centers capable of managing intermodality. While transitioning from traditional signaling to future railway operations is slow and challenging within complex main networks, this evolution can be faster and easier on Group 2 lines.

We claim that today's available technologies allow for the design of solutions for low-density lines that are much more cost efficient and more advanced than the modern systems currently installed on main / interoperable lines. A system utilizing public radio communication and satellites, intelligent on-board systems, cloud-based control rooms, and minimal wayside equipment can

reduce CAPEX and OPEX by at least 40%. This approach ensures higher system availability through reduced critical wayside elements, increased punctuality, precise forecasting, on-demand services, energy savings, and seamless integration with other transport modes, thanks to the availability of precise real-time data.

In line with what is highlighted above, the Control-Command and Signalling (CCS) for G2 lines should focus mainly on the Total Cost of Ownership: this is in line with the socio-economic objectives (SEO) of FP6 Future.

Please find below an excerpt from the Future – FP6 Grant Agreement Table 3 (Socio-Economic Objectives) listing applicable SEOs for what concerns the CCS:

SEO1: Overall reduction of the Total Cost of Ownership (CAPEX and OPEX) of the CCS system, while maintaining or increasing the present safety level. Expected decrease targeting 25%.

SEO2: Reduced the CAPEX of radio network and allowing for higher savings due to the utilization of public radio network in low density lines Expected decrease by targeting 15%.

SEO3: Increased system availability due to reduced trackside asset failure and more reliable CCS (average delay minutes per assets and signaling failures). Expected increase by targeting 10%.

SEO8: Reduced OPEX costs/km (reduction expected due to trackside assets decrease) for trackside railway assets. Expected decreased targeting 30%.

2. Methodology

G2 LINES REQUIREMENTS

Extensive work was performed in FP6 to define G2 lines requirements (please see Annex 3 for a comprehensive list of requirements with their rationale coming from the collaborative work within FP6 WP2).

This requirement analysis was performed in two ways: internally in FP6 receiving feedback from the various partners which include representatives from the major European Railway national operators and externally getting feedback from national initiatives in Europe and receiving feedback worldwide.

National initiatives in Europe like DRAISY (France - SNCF) and Optimised Train Track Operations - OTTO (UK – Network Rail) have been studied confirming the need of cost-effective solutions for regional lines based on public radio, satellite positioning and wireless solutions minimizing trackside elements.

Several dedicated freight line projects are in development worldwide where the utilization of satellites for positioning and communication combined with virtual block (no track circuits or axle counters for train detection) is critical to ensure an acceptable Total Cost of Ownership.

A REVERSE APPROACH

As mentioned in the introduction, G2 lines offer the possibility to adopt a significantly different approach compared to traditional methods. Given the simpler characteristics of these lines and the need to minimize costs, a reverse methodology was chosen: instead of collecting many specific secondary requirements from the various G2 lines with the risk to develop a too complex solution, a pragmatic and reverse approach was adopted. This approach involves creating a solution that, taking into account only the major common and critical requirements (see Annex 3), is based on

the less expensive technologies, assuming it will adequately meet the key requirements of G2 lines defined by infrastructure managers, ideally supported by railway undertaking in charge of servicing the line.

The idea behind is that one of the costs drivers of CCS systems is the tendency of developing tailored solutions for each application (especially trackside). Considering that G2 lines cannot afford the cost of individual specific developments and adaptations we claim that a standardized solution is the only feasible approach.

Such an approach cannot be applied easily in the mainline and G1 network because of the many constraints due to the need to manage integration with several existing systems and national safety & operational framework. Instead G2 lines being separated from the rest of the network allow for total replacement of obsolescent existing systems without constraints.

An interesting parallel can be made with underground metro systems where the same new CTBC systems can be installed in cities of different countries without the need for specific adaptation (apart from the need for local homologation).

In conclusion such reverse approach has been applied resulting in the following key concepts which should be common for all G2 lines:

Telecommunication Agnosticism

The ICT industry has evolved faster than the railway industry. Considering this, it makes sense to separate pure railway applications (such as interlockings and ATP on-board systems) from telecommunication technology. The core idea behind the G2 lines methodology is that telecommunication technology will continue to advance rapidly, ensuring that the performance and quality available as a commodity will more than meet any G2 line requirements. Therefore, the proposed architecture for G2 lines is "telecom agnostic," meaning it is independent of the specific telecommunication technology used by different system elements. The only acceptable

constraint is that any telecom technology used for G2 lines should support IP “Internet Protocols” ***Minimal Architecture Specification***

One of the key ideas of G2 lines approach is the following: do not specify what does not need to be specified. Overspecification results in constraints that reduce innovation and competition.

For example, there is no architecture defined for the G2 lines on-board system to be installed in the train. Simply because it is not necessary: any on board system able to localize safely and precisely its position, able to make the train braking respecting movement authorities and temporary speed restrictions, is suitable for G2 lines. All that by guaranteeing the CENELEC compliance demonstrating required safety requirements.

It does not matter whether such on-board system is made by one single module or several modules. In the railway sector the idea to specify interchangeable modules being supplied by different vendors was very successful and almost universally accepted as able to bring cost reduction and competition. Unfortunately, the opposite has been recorded in many cases – this idea resulted in extra costs, less competition, less innovation and delays in adopting new technologies.

It is worth noting that the writer does not underestimate the complexity of the railway European network. Railways are considered the most complex transport mode due to several factors:

1. ***Coexistence of very old technologies and modern technologies results in diverse national rules.*** Railway is the only transport mode with systems in operation older than one century!
2. ***Coordination and Scheduling.*** Unlike road and maritime transport, where vehicles can move relatively independently, trains must adhere to strict schedules and coordination. This is crucial to avoid collisions of schedules and ensure efficient use of tracks, especially on busy routes.
3. ***Coexistence of different modes of operation.*** Mainline and hump yard operations are so different to require completely different systems.
4. ***Safety regulation.*** Rail transport is subject to the most stringent safety regulations.

Notwithstanding European railway network complexity, digitalization is now making available new solutions which open new scenarios. If this is true for the European railway network, then such an opportunity is even applicable in an easier and faster way on the G2 lines which are inherently simpler and less constrained by interoperability issues.

Data sharing and standardization

The specification of standard architectures, as already mentioned, has been the key concept to ensure standardization and interoperability in Europe.

We do think that, in the digitalization era, it is time to move from a system architecture centric approach to a Data-Driven and Digital Services centric paradigm.

In line with this concept, we will explore how the Federated Data Space European initiative (please also refer to the activities in WP31 of Europe's Rail Joint Undertaking Flagship Project 1) can contribute to implementing a successful G2 line solution ensuring efficiency, standardization and openness to future evolutions.

3. Status of Play

EUROPEAN NATIONAL ATP SYSTEMS (CLASS B SYSTEMS)

INTRODUCTION

Before the advent of ERTMS, each European country developed its own Automatic Train Protection (ATP) systems to ensure railway safety. These systems, now referred to as Class B systems, are still in use across many national networks. While they differ in design and functionality, their core purpose is to prevent train collisions and overspeed incidents by enforcing signal compliance and speed restrictions.

With the introduction of ERTMS/ETCS (European Train Control System), a standardized system aimed at interoperability across Europe, Class B systems are being gradually phased out or integrated via Specific Transmission Modules (STMs) that allow ETCS-equipped trains to operate on legacy infrastructure.

KEY CHARACTERISTICS OF CLASS B SYSTEMS

- **Nationally Developed:** Each system was developed independently, leading to a lack of interoperability.
- **Trackside and Onboard Components:** Most systems rely on trackside signals and onboard equipment to monitor train speed and signal adherence.
- **Limited Scalability:** Many systems are not easily adaptable to high-speed or cross-border operations.
- **Safety-Oriented:** Despite their limitations, Class B systems have significantly contributed to railway safety in their respective countries.

EXAMPLES OF CLASS B SYSTEMS BY COUNTRY

COUNTRY	SYSTEM(s)
Germany	PZB (INDUSI), LZB

COUNTRY	SYSTEM(s)
France	KVB, TVM 300/430, Crocodile
Italy	RS4 Codici, SCMT, SSC
Spain	ASFA, LZB
UK	AWS, TPWS
Belgium	TBL 1, TBL 2, TBL1+, Crocodile
Austria	PZB, LZB
Sweden/Norway	ATC-2
Finland	ATP-VR/RHK
Czech Republic	LS
Hungary	EVM
Denmark	ZUB 123
Poland	SHP, EAP
Netherlands	ATB-EG, ATB-NG

Note: Even when countries use the same system name (e.g., PZB), versions may differ and are not necessarily interoperable

TRANSITION TO ERTMS

The European Union Agency for Railways (ERA) mandates the gradual replacement of Class B systems with ERTMS to ensure interoperability, reduce costs, and enhance safety. However, due to the high cost and complexity of infrastructure upgrades, many countries continue to operate Class B systems in parallel with ERTMS.

To bridge the gap, ETCS Level STM (Specific Transmission Module) allows ETCS-equipped trains to interpret signals from Class B systems. This hybrid approach ensures continuity of operations during the transition period.

COMPARISON: CLASS B vs. ERTMS

FEATURE	CLASS B SYSTEMS	ERTMS/ETCS
Interoperability	Limited (national only)	High (pan-European)
Technology	Electromechanical/electronic	Digital, radio-based (GSM-R)
Speed Support	Varies, often limited	Supports high-speed rail (>300 km/h)
Safety Level	High, but varies by system	Uniform high safety standards
Deployment	Legacy systems, still widely used	Gradually expanding across Europe

OBSOLESCENCE AND COST CHALLENGES

- **Aging Infrastructure:** Many Class B systems were developed in the mid-to-late 20th century and are based on outdated technologies, such as analog electronics or electromechanical relays.
- **Cost of Spare Parts and Expertise:** As manufacturers discontinue support, sourcing spare parts becomes increasingly difficult and expensive. Additionally, fewer technicians are trained to maintain these legacy systems.
- **Technological Limitations:** Class B systems often lack the flexibility to support modern operational needs such as high-speed rail, real-time diagnostics, or advanced automation.

Please also refer to next Chapter 4 which analyses cost drivers affecting traditional signalling systems (like the Class B ones) based on trackside detection systems and signals.

In conclusion, Class B systems cannot represent a solution for G2 lines since they are obsolete and expensive. As a matter of fact, these old systems not only are gradually dismantled in Europe, but they are also not considered in the worldwide market where there is a clear trend toward wireless solutions.

LESSONS LEARNT FROM THE EUROPEAN AND USA STANDARDS

European Rail Traffic Management System (ERTMS) and Positive Train Control (PTC) are respectively the standards adopted in USA and Europe. These two standards have been also successfully installed and are being installed in several countries worldwide.

Analysing the deployment and technical characteristics of PTC and the ERTMS is crucial for identifying the optimal solution for G2 low-density lines.

ERTMS

The European Rail Traffic Management System (ERTMS) was initiated in the 1990s to address the fragmentation of national train protection systems across Europe. Each country had developed its own ATP (Automatic Train Protection), creating barriers to cross-border rail operations. The European Union, through the European Union Agency for Railways (ERA), launched ERTMS to:

- Ensure interoperability across national networks.
- Enhance safety and efficiency of rail traffic.
- Reduce long-term operational and maintenance costs.

ERTMS comprises two main components: the European Train Control System (ETCS) and GSM-R radio communication. ETCS enforces train movement authorities and speed restrictions through trackside and onboard equipment, including Eurobalises. ERTMS is designed to replace national Automatic Train Protection (ATP) systems and facilitate cross-border operations. While ERTMS offers high safety and performance, especially on high-speed lines, its deployment involves significant infrastructure upgrades and integration with legacy systems. Recent developments aim

to reduce reliance on trackside equipment by incorporating satellite positioning and transitioning to newer communication standards like FRMCS (see [5]).

ERTMS is being deployed across Europe, with varying degrees of progress (see [7] and [11]). High-speed lines have seen successful implementations, while legacy Class B systems are still in use in many regions. ETCS-equipped trains often rely on STM (Specific Transmission Modules) to operate on older infrastructure. Despite its benefits, ERTMS deployment has been slowed by technical complexity and high costs (see [2], [4], [10]).

PTC

Positive Train Control (PTC) is an advanced safety system designed to automatically prevent train accidents caused by human error. It monitors and controls train movements to avoid:

- Train-to-train collisions
- Derailments due to excessive speed
- Unauthorized entry into work zones
- Movement through misaligned switches

PTC integrates GPS, wireless radio, onboard computers, and centralized control systems to track train positions and enforce safety protocols in real time.

PTC was mandated by the U.S. Congress through the Rail Safety Improvement Act of 2008 (RSIA) following a tragic accident in Chatsworth, California, where a commuter train collided with a freight train, resulting in 25 fatalities and over 100 injuries. The accident was attributed to human error - specifically, a failure to comply with signal indications.

The RSIA required Class I railroads and passenger rail operators to implement PTC on lines carrying passengers or hazardous materials. The deadline was initially set for 2015 but was later extended to December 2020 due to the complexity and scale of deployment.

By the end of 2020, PTC was fully implemented across:

- ~95,000 km of track
- ~23,000 locomotives

PTC systems vary by operator but generally follow a common architecture that overlays existing signaling systems. It is particularly effective in **dark territories**—areas without traditional signals—where it provides a cost-effective safety solution.

PTC has significantly improved rail safety in the U.S., reducing the risk of accidents due to human error. Its successful deployment — fast and cost-effective — demonstrates the potential of modular, scalable safety technologies (see [1], [3]).

While not designed for interoperability across national borders, PTC serves as a model for **cost-efficient safety systems**, especially for **freight-dominated or low-density networks**.

Both ERTMS and PTC have enhanced safety and performance where implemented. **However, there is potential for a more cost-effective and modern solution tailored to the specific needs of low-density lines.**

To illustrate this, consider high-speed lines as an extreme example. ETCS Level 2 has been highly successful for high-speed lines in Europe and China (with its derivative, CTCS Level 3 and shortly KTCS in South Korea). The high availability of dedicated and redundant GSM-R radio networks is essential for these lines, where the cost is justified by the high performance.

In contrast, for low-density lines with fewer trains and lower availability requirements, using public networks is sensible. Similarly, while Commercial-Off-The-Shelf (COTS) hardware and software (for non-safety-related elements) should be a goal for low-cost solutions on low-density lines, such solutions cannot provide the necessary reliability for high-speed lines.

CBTC SYSTEMS

Communication Based Train Control systems are modern railway signalling systems that use continuous, high-capacity, bidirectional wireless communication between trains and trackside equipment to manage train operations. Unlike traditional fixed-block systems, CBTC allows for moving block operation, enabling trains to run closer together safely and efficiently.

Key Features of CBTC are:

Wireless Communication: uses radio signals (Wi-Fi, LTE, or proprietary systems) to transmit real-time data between trains and control centers. Enables continuous train tracking and dynamic updates.

Moving Block Technology: replaces fixed blocks with virtual blocks that move with the train. Increases line capacity by reducing the headway (distance/time between trains).

Automatic Train Operation (ATO): CBTC systems often support ATO, enabling driverless or semi-automatic train operations. Levels of automation range from manual driving with supervision to fully unattended train operation (UTO).

Real-Time Monitoring: Provides precise train location, speed, and status to the control center. Enhances safety, punctuality, and energy efficiency.

The typical CBTC system architecture includes:

Onboard Equipment. Train-borne computers, odometers, and communication units.

Wayside Equipment. Zone controllers, interlockings, and radio access points.

Control Center. Centralized system for traffic management, diagnostics, and supervision.

Key benefits of CBTC are:

Higher Capacity. Trains can run closer together, increasing throughput.

Improved Safety. Continuous monitoring and automatic braking reduce human error.

Operational Flexibility. Supports dynamic scheduling and real-time adjustments.

Lower Operating Costs. Enables driverless operation and reduces energy consumption.

Better Passenger Service. More frequent and reliable service with reduced delays.

CBTC was originally developed for urban metro and light rail systems, where: trains run at high frequency, stations are closely spaced and automation and short headways are critical.

However, CBTC is not limited to metro systems, although that's where it is most commonly used today. It is increasingly being considered—and in some cases implemented—for mainline railways, especially in dense commuter corridors or urban-regional rail networks where high capacity, automation, and real-time control are beneficial.

CBTC systems unfortunately are not suitable for G2 Lines for several reasons.

The first one is that it is over-engineering for the G2 line use case being designed for high-frequency, high-capacity urban rail systems. It offers features like: Automatic Train Operation (ATO) and short headways (90–120 seconds) which are unnecessary for rural or remote lines.

The second is high capital and maintenance costs since CBTC requires: continuous radio coverage (Wi-Fi, LTE, or proprietary systems), trackside equipment like zone controllers and access points. The cost per train-kilometer or per passenger is disproportionately high.

Finally, a third issue is due to infrastructure and terrain challenges: remote lines often traverse mountainous or forested areas with poor connectivity, are characterized by high number of level crossings (while CBTC is mainly applied in segregated lines). Installing and maintaining CBTC in such environments is technically challenging and expensive.

In conclusion, CBTC systems are too expensive and sophisticated for G2 lines¹.

RAILWAY SIGNALING AND TRAIN CONTROL TREND TOWARD WIRELESS SOLUTIONS

The signalling and train control sector is clearly moving towards minimizing wayside equipment, utilizing wireless communication, integrating on-board intelligence, and establishing large national operation control centers. Taking into account these trends, we are looking for a modern signalling and train control system based on four key pillars:

1. **On-board:** Precise positioning using GNSS + sensors; Track database uploaded via wireless communication; Radio-based Automatic Train Protection (ATP) in a moving/virtual block environment
2. **Wayside:** Point machines and level crossings remotely controlled via radio by the dispatching center
3. **Control Room:** a dispatching center able to integrate, as a minimum, interlocking and radio-block function. Optionally also able to manage a) real time optimisation (non-safety related) of routing and scheduling of trains and b) Remote control of rolling stock
4. **Communication:** IP-based data radio protocols, applicable to various types of data radio networks

To our knowledge, no railway lines worldwide are equipped with such a minimalist solution. For instance, the European Railway Traffic Management System (ERTMS) currently requires the installation of Eurobalise transponders (even if it is worth mentioning that the evolution of ERTMS

¹ Obviously, a manufacturer of CBTC system can consider simplifying and modifying its proprietary CBTC system to develop a wireless modern solution for G2 lines by: eliminating features like ATO and precision stopping (needed for screen doors); adding management of level crossings; adapting the system to low cost communication solution. However doing so such manufacturer will have to develop a complete new system which is what is proposed in this report.

foresees satellite positioning to reduce the installation of transponders), whereas G2 lines requires to eliminates the need for any transponders along the track, offering clear lifetime cost reduction benefits.

It is worth clarifying that G2 lines due to their limited traffic do not need a moving/virtual block in order to increase performances (more capacity, less headway etc.)... the moving/virtual block solution is a natural consequence of the minimization of wayside elements (removal of trackside train detection) which is needed to reduce costs.

4. Key cost drivers affecting G2 lines competitiveness

A deep analysis of the cost drivers of existing CCS solutions available for regional railways is summarized in Figure 1.

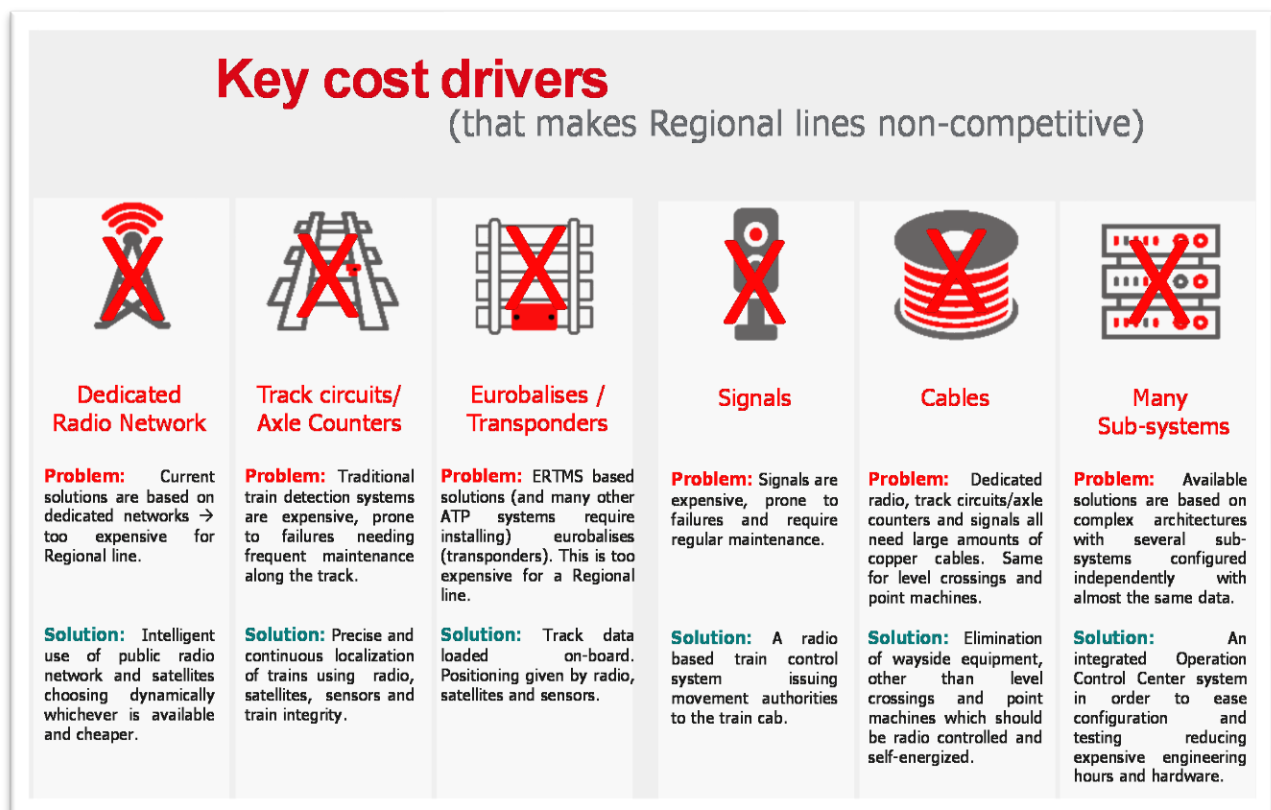


Figure 1: Regional lines key cost drivers

Thanks to this analysis, we defined the following key principles to design an efficient solution for G2 regional lines:

- **Reduction of Wayside Installations:** By focusing on onboard-centric solutions, we aim to significantly reduce installation, maintenance, and upgrade costs. This involves determining precise locations through communication systems (satellite, radio) and sensors in collaboration with wayside systems.

- **Adoption of Moving/Virtual Block Techniques:** This approach allows for greater capacity and the elimination of traditional signals.
- **Onboard Track Databases:** Utilizing geographical data in onboard track databases, such as PTC and CBTC, further reduces the complexity and cost of wayside installations, maintenance, and upgrades.
- **Transition to Public Networks:** We are moving away from expensive, soon-to-be obsolete dedicated radio network solutions in favor of public networks.
- **Simplification of Operation Control Centers:** Rationalizing and simplifying these systems will enhance efficiency and reduce costs.

It is worth noting that the above principles are general and applicable to any regional line world-wide. Interactions with other EU Rail Flagship Projects influenced this work in a positive way raising the attention on the additional specific needs of European regional railways.

Input received by WP31 of Flagship Project 1 – Motion led to the preparation of a use case for the application of Federated Data Space in the domain of CCS for Group 2 lines. In a following dedicated chapter, the potential utilization of Federated Data Space will be explained.

A very important Conference was organized by the Joint Undertaking organization in Madrid on September 13th, 2023: Space for Innovation in Rail. In that context, the European Commission gave a significant boost to the collaboration between Innovation Pillar and EUSPA. In the following pages we will explain how GOVSATCOM can be crucial to deploy an efficient and safe solution for G2 lines.

Therefore, the additional following principles:

- **Federated Data Space:** moving from a centralized data management to a distributed one.
- **GOVSATCOM:** provide a standard access to a reliable and safe satellite communication to the G2 lines.

5. G2 Lines Requirements

G2 lines main requirement is to reduce as much as possible the cost of the solution: the goal is to re-open closed lines and to save lines that are loss-making and thus about the service to be suspended. For more information please also refer to Annex 3.

Such cost reduction requirements can be specified as follows for G2 lines in line with the goals and KPI's stated in the Grant Agreement:

WAYSIDE CCS NON-FUNCTIONAL REQUIREMENTS G2 LINES

ID	Description	Rationale
WSCCSNFG2_1.	G2 Lines shall bring reduction of OPEX costs per kilometre of wayside assets of at least 30% with respect to current figures for an equivalent scope, including energy saving.	Reduction of TCO.
WSCCSNFG2_2.	G2 Lines shall bring reduction of CAPEX costs for signalling and traffic management of at least 25% with respect to current figures for an equivalent scope.	Reduction of TCO.
WSCCSNFG2_3.	The CCS implemented on a G2 line should improve the availability of the line by at least 10%.	Reduction of TCO.

ON-BOARD CCS NON-FUNCTIONAL REQUIREMENTS G2 LINES

ID	Description	Rationale
NFROB 1.	G2 Lines shall improve reliability of positioning of at least 15% with respect to current figures for an equivalent scope.	Reduction of TCO.
NFROB 2.	G2 Lines shall bring reduction of CAPEX costs positioning of at least 15% with respect to current figures for an equivalent scope.	Reduction of TCO.
NFROB 3.	G2 Lines shall bring reduction of OPEX costs positioning of at least 15% with respect to current figures for an equivalent scope.	Reduction of TCO.

Please refer to the FP6-Future Grant Agreement 101101962 sections 1.1.1.3 and 2.3.2.1 for more details on above goals and KPI's.

The need of reducing radically costs is also applicable for the communication technology. Consequently, for G2 lines the focus is only in transmitting vital data to ensure safety and minimal operations for running the trains. In other words, it is not foreseen to provide any service to passengers (like wi-fi connections, streaming services etc.).

FP6 goal is to standardize the solution to achieve above minimum requirement.

Obviously, a regional G2 line able to access to a coverage with higher performances may decide to offer additional services which will be managed by dedicated systems external to the critical and vital CCS applications.

In general, the data to be transmitted to and from the G2 lines data centres require a very little throughput in the order of Kbytes.

The acceptable latency for these G2 lines may vary a lot depending on several factors, however current communications technologies by far exceed the needs of a typical G2 line which can easily cope with few seconds of latency. It is worth underlining again that while a mainline railway service requires redundancy of a dedicated telecom network to ensure a high level of availability, in the case of G2 lines it is acceptable to operate a train in degraded mode to cope with a temporary lack of communication.

Finally, the fast evolution of telecommunication technology which foresees the integration of terrestrial and satellites networks in a transparent manner will by far cover the G2 lines requirements.

6. G2 Line solution

G2 LINES (MINIMAL) ARCHITECTURE

G2 Lines are characterized by three key elements (with respect to G1 lines):

1. No need of interoperability with the European network which implies no need to comply with TSI CCS [9].
2. The need to reduce costs as much as possible which implies to consider as mandatory only requirements to ensure safety and basic operations.
3. G2 lines are low density lines with no requirements for high performances.

No need for interoperability should not be confused with no need for standardization. G2 lines solution should allow for interchangeability of products among the different G2 lines thanks to an open standard.



Figure 2: G2 Lines solution

The proposed approach aims at ensuring standard interfaces and standard data protocols (preferably supporting the use of COTS). Intentionally, we avoid defining a detailed architecture of each key component: our approach is to define the minimal data to be exchanged among the components and leave to the industry the freedom to develop further innovative solutions without being constrained by pre-defined architectures. For example, we do not specify the architecture of the train on-board systems, instead we define the interfaces/protocols allowing the train to receive and send the data needed to ensure a safe and performant movement. In other words, in our approach trains equipped with different ATP systems can run in the same line as long as they are able to communicate with the standard protocols and until they are able to safely respect the movement authorities sent by the control room. This compatibility among differently equipped trains and different control rooms will allow competition and innovation.

Consequently, for G2 lines, intentionally, there is no architecture defined for the on-board system or any other element of the system.

A dedicated radio network typically represents around 20% to 30% of the overall CAPEX cost of new signalling systems, not to mention the OPEX costs for its maintenance. Telecommunication technology evolves faster than railway technology: therefore, it is critical to keep the train radio communication module separated from the Railway applications (i.e., the ATP and ATO).

AN INTERNET-PROTOCOL BASED APPROACH

Historically, railway infrastructures have played a strategic role not only in civil activities but also in military operations. Consequently, telecommunications have always been considered extremely critical in this context, necessitating high RAMS (Reliability, Availability, Maintainability, and Safety) performance.

This necessity explains why railways generally require dedicated telecommunications infrastructures to ensure complete control and provide the high level of service needed. In Europe, dedicated telecom networks are not only associated with railway operations but also have specialized solutions designed and implemented, such as GSM-R and its successor, FRMCS.

It's worth noting that other sectors, like banking, have adopted a different approach to customer services. Nowadays, secure money transfers can be performed using mobile phones, tablets, or laptops, regardless of whether they are connected wirelessly or not; an internet protocol connection is all that is needed.

It is understandable that the requirements of a high-speed train traveling at 300 km/h cannot be compared to those of a person performing a bank transfer. While a person can wait minutes to repeat an aborted operation, a high-speed train cannot afford such delays.

Though as a matter of fact, G2 line trains have significantly different communication requirements compared to high-speed or mainline trains. A G2 line train can wait seconds or even a few minutes

to receive an updated movement authority. Considering this, the proposed solution for G2 lines is internet-protocol-based and thus "telecommunication agnostic": each element does not need direct contact with any other element since all necessary information is available in remotely distributed data centers.

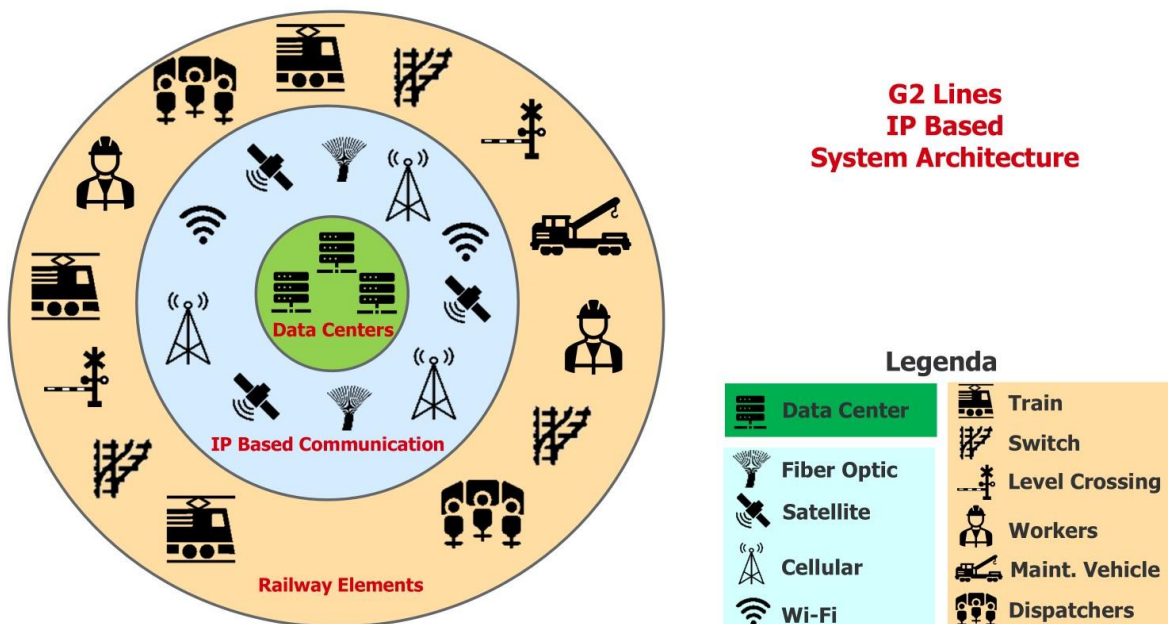


Figure 3: G2 Lines Internet Protocol Based System Architecture

G2 Lines architecture foresees one or more **Data Centres** responsible to perform two main functions:

1. Safely store and share real-time data (train position, switch status, etc.) and configuration data (track map, timetable, etc.).
2. Host safety critical centralized applications/functions (interlocking, radio block, temporary speed restrictions management, etc.)

These Data Centres must be developed specifically for railways applications. Safety critical certification requires specific servers (e.g. CENELEC SIL4 certified) to be part of such data centres.

One of the advantages of this approach is that a data centre can serve more G2 Lines with obvious reductions in the cost of HW and maintenance personnel. It should be noted that G2 Lines are often managed by small organizations unable to manage the complexity of the technology and located in remote areas where technicians are not locally available (long time to intervene on a failure).

It is foreseen the application of Federated Databases in collaboration with Flagship Project 1 WorkPackage 31. The Federated Databases will allow sharing data in a distributed way and among different owners of the data.

This architecture can also be seen as a sort of client-server structure where the servers are in the **data centres** and the clients access the servers through an internet-protocol connection.

The physical link between servers and clients can be any communication technology supporting internet protocols.

INTERFACES AND PROTOCOL STANDARDIZATION

As already mentioned, one of the key elements of the G2 line proposed solution is to intentionally avoid specifying the architecture at the level of the so-called railway elements (see Figure 3). To make this concept clearer Figure 4 gives another representation of G2 lines architecture focusing for sake of simplicity on the key railway elements: Dispatching Center, On-board unit and Wayside elements (level crossings and switches) and excluding workers and maintenance vehicles.

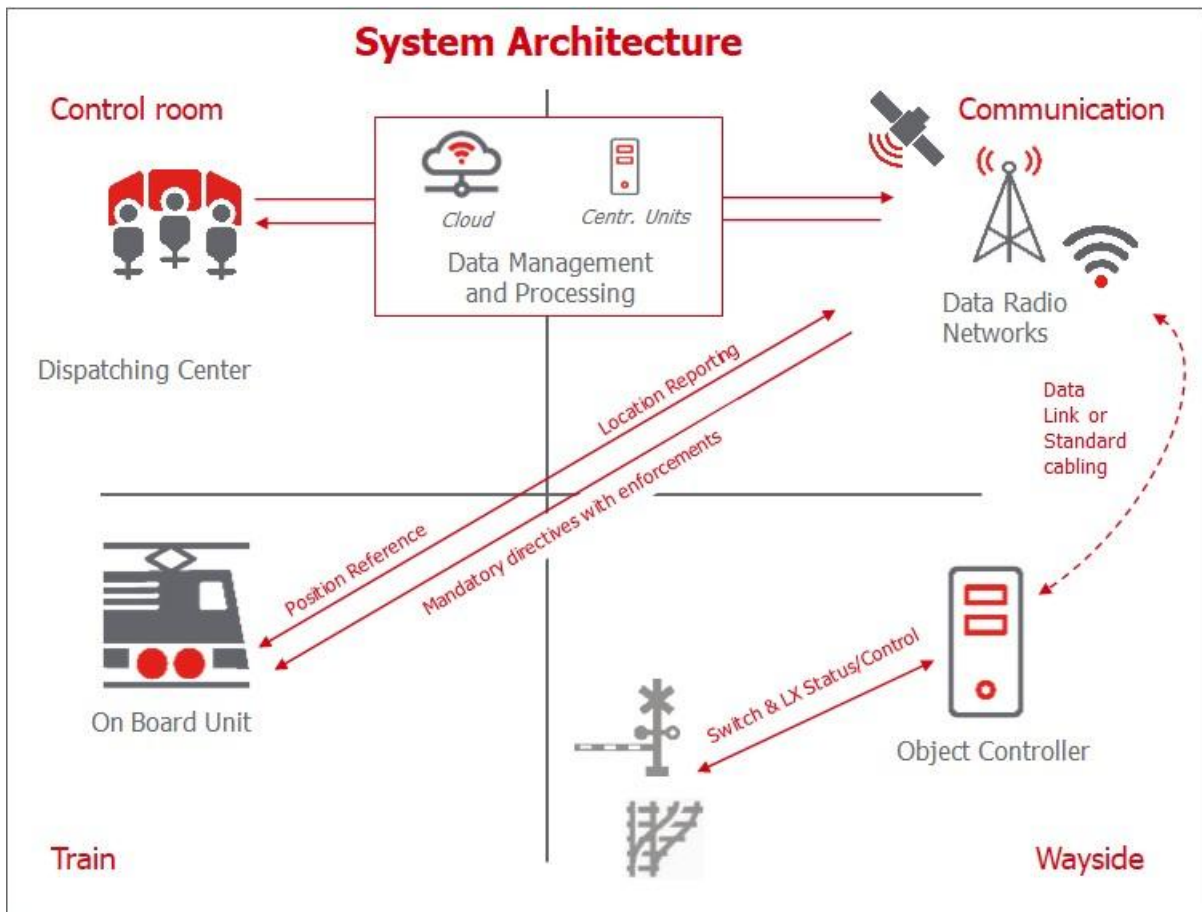


Figure 4: G2 Lines System Architecture

The key idea is that there is no need to specify the architecture of the on-board unit: it does not matter whether it is composed by 1 or 2 or 10 modules. What matters is that the Train is equipped with an on-board system able to exchange information with the data management and processing center with a **standard** protocol. The same applies to the wayside objects and the dispatching centers.

It is worth considering for a better understanding and for the sake of completeness which are the main interfaces implemented though the G2 Lines architecture:

- Internal Interfaces (see Figure 5Error! Reference source not found.);

- External Interfaces (to be defined). With “external to G2 Lines” users/systems through standardised protocol (e.g. for intermodality). The definition of this interfaces will be part of next waves of FA project.

Communication data network (Internet Protocol standard messaging on radio)				
Data Management: Cloud (highest security, availability, encryption)				
Interfacing Building blocks		Physical layer	Protocol	High-level exchanged information
Control Room - CCS	Train On-board	- Radio	Internet Protocol standard messaging	- Position reference - Location reporting - Mandatory directives - Enforcements - Setup & service (trip data, digital map upload) - Setup & Service (configuration) - Setup & Service (diagnostic/status)
Control Room - CCS	Wayside - Object Controller	- Radio (- Wired network*)	Internet Protocol standard messaging	- Command and control registering - Command and control safe confirmation - Setup & service (configuration) - Setup & Service (diagnostic/status)
Wayside - Object Controller	Wayside - track equipment	- Radio (- Wired network*)	Internet Protocol standard messaging	- Command and control execution - Setup & Service (configuration) - Setup & Service (diagnostic/status)
Train On-board	Wayside (track equip/ OC)	- Radio	Internet Protocol standard messaging	- Service (diagnostic/status)

*if strictly imposed by pre-existing infrastructures

Figure 5: G2 Internal interfaces

In conclusion, standardizing the minimum set of interfaces and protocols with the minimum necessary data it is possible to achieve two critical goals:

1. Leave maximum freedom to suppliers to implement their on-board/wayside/ dispatching/data center. Such freedom allows to evolve their product architecture following the technological progress. E.g. it is not needed to specify how the train detect its position, what is required is to be able to detect it: no matters if today with a combination of sensors from a proprietary solution by a railway manufacturer or tomorrow with a COTS localization device supplied by telecoms manufacturers.
2. Ensure interchangeability among different manufacturer thanks to standard interfaces and protocols.

SOLUTIONS PILLARS

The proposed solution is based on several pillars which are described shortly below:

Solution Pillar 1: Decoupling the railway application from the telecommunication technology.

It's important to note that telecommunication technology advances more rapidly than railway technology. Therefore, it's crucial to keep the train radio communication module separate from railway applications (such as ATP and ATO). Consequently, it is strategic to use Internet Protocol standards-based messaging and routing, which allows for:

- a. Transparent access to cellular, Wi-Fi, and satellite communications (and future technologies) with automatic selection of the most available and cost-effective option.
- b. Access to the latest encryption and authentication algorithms.
- c. Wide availability of commercial off-the-shelf (COTS) solutions.

Solution Pillar 2: Decoupling positioning from the railway application.

Positioning technology is advancing rapidly. Currently, it is possible to achieve centimeter-level precision using satellites combined with sensors. In the near future, 6G and 7G will further enhance precision localization, making it more affordable and easier to implement by integrating cellular and satellite technologies.

These technologies will evolve faster than railway technology, so the positioning module should be kept separate from railway applications (such as ATP and ATO). This approach will allow regional lines to update positioning technology with commercial off-the-shelf (COTS) hardware and software without needing to modify the railway on-board applications.

Solution Pillar 3: Communication based train control (CBTC).

One of the highest costs for low-density lines is associated with track circuits (or axle counters) and lateral (optical) signals. Even Eurobalises are too expensive.

Modern train control solutions are radio-based, such as various CBTC systems for automatic metros, ERTMS L2/L3 for railways, and Positive Train Control. These systems enable wireless communication between operation control rooms, trains, and wayside elements, eliminating the need for signals, track circuits, and costly copper cables.

Radio and satellite technologies provide precise train positioning to the onboard unit, which can then reference an onboard track database, removing the need for Eurobalises or other transponders along the track. Since key information is transmitted via radio to the onboard unit, lateral signals become redundant. For safety reasons, to eliminate track circuits (or axle counters), the system requires the onboard unit to determine train length and integrity. In a "closed" system like a G2 low-density line with well-defined rolling stock, cost-effective solutions for train integrity and length are available.

Solution Pillar 4: Wireless and Self-energized wayside.

Level crossings and switches are essential components of regional railways that cannot be eliminated due to cost and capacity management reasons. However, technological advancements now allow for the upgrade of these elements to make them:

- a. Operated by renewable energy, reducing environmental impact, and eliminating the need for expensive power cables.
- b. Controlled by radio, removing the need for cables.

By combining batteries, solar panels, and radio communication, these structural elements can be modernized to become an integral part of the overall solution.

Solution Pillar 5: Integrated railway critical application in data centers.

Existing system architectures are typically composed of multiple layers to efficiently manage railway traffic. While this complexity is necessary for main lines and large railway stations, it becomes too costly for simpler, low-density lines. For instance, the ERTMS standard separates Interlocking, Radio Block Center, and Traffic Management System, with each system requiring extensive engineering hours for data configuration and testing.

As a result, G2 low-density lines require a fast, easily configurable, and low-cost integrated system. A single hardware unit can manage all necessary functions, which helps to:

- a. Simplify configuration and testing, reducing expensive engineering hours and software maintenance.
- b. Lower hardware costs and related maintenance.

It's important to note that simplification and lower costs do not equate to downgraded functionality. Modern technologies enable this integrated system to optimize train journeys, increase punctuality, reduce travel time, and support on-demand passenger services.

Additionally, cloud-based services provided by data centres can reduce the costs of managing and maintaining servers, applications, and databases, allowing for web-based access for remote operators, such as maintenance staff on the track side.

7. Preliminary elements to define a Migration Plan

At this early stage it is difficult to define a migration plan for G2 lines. However, the urgent need for an efficient solution requires pragmatic approaches to allow for fast implementation. Below are described two requirements to help an easier implementation of this solution on G2 lines.

On-board system able to run in different modes of operation

The G2 line solution should allow multiple modes of operations. To be more specific the on-board system should be able to cope with different train control modes.

This is not a new concept: in the ERTMS standard a train equipped with an ETCS L2 on-board system is able to run also in a line equipped with ETCS L1 wayside. Similarly, a PTC on-board system (we refer to the Wabtec product which is the PTC solution adopted by most of North American railways) can run both in areas equipped with signaling as well as in the so-called dark territories (areas not equipped with signaling). The recent evolutions of ETCS and PTC also foresee the ability to run in a virtual block environment.

Therefore, it is considered crucial for the G2 line on-board system to be able to run either in fixed block or virtual block/moving block modes of operation.

Such capability is needed to allow the G2 lines to be equipped gradually or, in other words, in phases where required.

However it must be noted that the most effective approach would be to implement the target solution on the G2 line and switch it on in one shot. Such approach will limit the cost and complexity of the solution and will make this requirement of multiple modes of operation not needed.

Shared Data centers

It is difficult to define universal characteristics among the different G2 lines. As a matter of fact, they are defined by the fact that they are not required to be interoperable. Apart from this characteristic which also represents their definition the G2 line can:

1. *Operate only passenger, only freight or both services*
2. *Be very short or long*
3. *Be geographically positioned in rural, remote or in urban areas*

However, it is evident that most of them are characterized by being managed by relatively small organizations and by limited budget availability.

Consequently, it is obvious that for G2 lines a solution which minimizes the costs associated to the need for local expertise and management of complex systems will be welcome.

Shared data centers hosting servers able to manage services for a cluster of G2 lines will reduce both the CAPEX and the OPEX cost of the critical applications. The result is that local G2 lines managers will have only to bear the individual cost to maintain the equipment which must be operated locally: wireless crossings, wireless switches, and on-board systems together with web-based applications on tablets and/or desktops to dispatch the trains. All the critical applications should run in servers in these shared data centers. The sharing will reduce the individual cost and will free the local operator by the need to have dedicated experts locally.

Clearly this approach is not only important to reduce costs, but it is also extremely important, especially for G2 lines positioned in remote areas. It helps explaining that only an unlikely shutdown of all the servers represents a critical situation which affects all operations, while the failure of a single switch machine or level crossing or a tablet/desktop has a limited impact: it reduces the overall system performance but normally does not lead to a complete stopping of the services.

Such common data center will provide G2 lines with a level of availability similar or superior to the one of the systems deployed on mainline at a fraction of the cost.

In conclusion we propose that creating clusters of G2 lines managers sharing common data centers (together with a technical solution that allows for a smooth transition from existing signaling to a virtual block) is critical to support the adoption of the proposed G2 lines solution and pave the way for a fast migration.

8. GOVSATCOM and Federated Data Space: Standardization & Interoperability

As already mentioned, the interactions with EU Rail Flagship Project 1 – Motion and the initiatives of the European Commission to support satellite technologies implementation in the European railway domain have heavily and positively influenced the innovation on G2 lines.

In line with Flagship Project 6 Grant Agreement even if G2 lines are not required to respect Technical Specifications for Interoperability (TSIs) however it is strongly advised that the solution should be standardized.

GOVSATCOM

G2 Line solution is telecommunication agnostic therefore it does not matter which telecommunication means is used by the railway elements (please refer to Figure 3: G2 Lines Internet Protocol Based System Architecture) to be connected with the data centers.

However, it is considered strategic to be able to offer a **standardized** service at European level ensuring reliability and cybersecurity together with independence from private operators. Since the G2 lines offers public service to the European citizens it is justified to aim at helping them with a European institutional support.

GOVSATCOM is potentially the best solution to cover this need.

Flagship Project 6 is willing to advocate for Regional lines the availability of GOVSATCOM services for G2 lines to support a standard, low cost, full coverage and secure way of communication for all these rural and remote lines. Please find in Annex 1 more information about GOVSATCOM.

FEDERATED DATA SPACE

Federated Data Space data ecosystem matches perfectly with the CCS solution for G2 lines since it provides the most evolved way to share data (please refer to Annex 2 for an introduction about Federated Data Space).

The most interesting characteristic of Federated Data Space is that data holders can set rules to define how the data can be exchanged.

In the CCS G2 line context this allows, for example, the infrastructure manager to establish under which rules a train can run in his line. And such rules can be adaptable to the train and infrastructure characteristics: a train able to report precisely and safely its position, length and train integrity will be authorized to run under virtual/moving block operations if the infrastructure allows it. Clearly, different sets of rules will allow managing different types of operations from fixed block to moving block, from passenger to freight.

Needless to mention that Federated Data Space also represents the best mean to manage intermodality, allowing for sophisticated interactions among different modes of transport. An example may help illustrating how: we can imagine a bus service operator bringing passengers to a railway station exchanging information about the final destination of the passenger, the expected time of arrival of the buses and departure time of the train (which can be made flexible under certain conditions to serve better the maximum number of passengers).

IMPLICATION ON INTEROPERABILITY

It is worth underlining that G2 lines can be also seen as a simplified testing field to apply new solutions that can potentially be deployed also in the interoperable network in a second phase.

GOVSATCOM services and Federated Data Space could make easier managing interoperability in the next future.

In the last four decades the need for interoperability in the European network has been managed by the development of a dedicated system: the ERTMS. In the future we should be prepared to move forward: interoperability could be managed by sharing the status of the railway elements and the operational rules in a railway Federated Data Space. This evolution will increase competition, accelerate innovation, and will reduce the complexity of the railway system.

9. G2 Demonstrators

Three demonstrators are planned on G2 lines within the FP6 Project. The first one will focus on demonstrating the quality of commercial satellite communication (please refer to Solution Pillar 1), the second will demonstrate the accuracy of satellite positioning (please refer to Solution Pillar 2) and finally the third will demonstrate integrated interlocking and radio block functions in one application (please refer to Solution Pillar 5).

Please find below a graphical description of the three demonstrators.

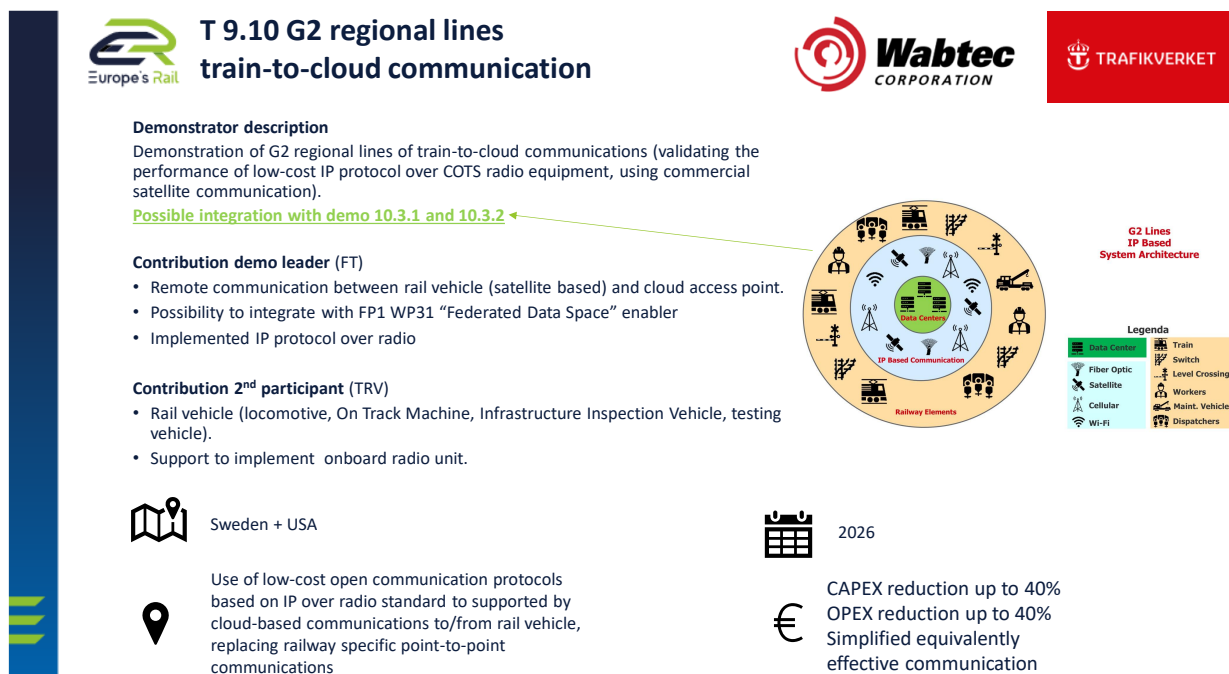


Figure 6: Satellite communication demonstrator



T 10.3.1 Cost-effective fail-safe highly accurate train positioning on G2 lines

Demonstrator description

Demonstrators for Cost-effective fail-safe highly accurate train positioning on G2 lines (COTS based technologies for non-interoperable regional lines).

Possible integration with demo 9.10 and 10.3.2

Contribution demo leader (FT)

- Preparatory work for operational conditions.
- Demo concept documentation.
- Demo testing documentation.
- Railways industry satellite receiver.
- Partial On-board train protection system (not connected to train braking system).

Contribution 2nd participant (TRV)

- Support to preparatory work for operational conditions.
- Support to preparation of demo documentation.
- Selection of demo site; stretch of s line for tests.
- COTS satellite receiver.
- Rail vehicle (locomotive, On Track Machine, Infrastructure Inspection Vehicle, testing vehicle).
- Permission to perform the tests from the NSA.
- Path allocation



Sweden + USA



Use COTS satellite receiver for absolute positioning, validated against reference measurements provided by railways industrial satellite receiver



2026



Reduction of CAPEX and OPEX costs positioning of at least 15% with respect to current figures for an equivalent scope.

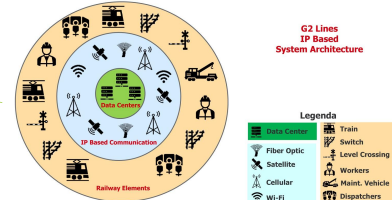


Figure 7: Satellite positioning demonstrator



T 10.3.2 fail-safe interlocking+RBC on G2 lines

Demonstrator description

Demonstrators for Cost-effective fail-safe highly accurate train positioning on G2 lines (COTS based technologies for non-interoperable regional lines).

Possible integration with demo 9.10 and 10.3.1

Contribution demo leader (FT)

- Preparatory work for operational conditions.
- Demo concept documentation.
- Demo testing documentation.
- Integrated IxL/RBC system.
- Railways industry satellite receiver.
- On-board train protection system (not connected to train braking system).
- Site survey to collect input federated data for digital map

Contribution 2nd participant (TRV)

- Support to preparatory work for operational conditions.
- Support to preparation of demo documentation.
- Selection of demo site; stretch of line for tests.
- COTS satellite receiver



Sweden + USA



Use COTS satellite receiver for absolute positioning, validated against reference measurements provided by railways industrial satellite receiver



2026



Reduction of CAPEX costs positioning of at least 15% with respect to current figures for an equivalent scope.

Reduction of OPEX costs positioning of at least 15% with respect to current figures for an equivalent scope

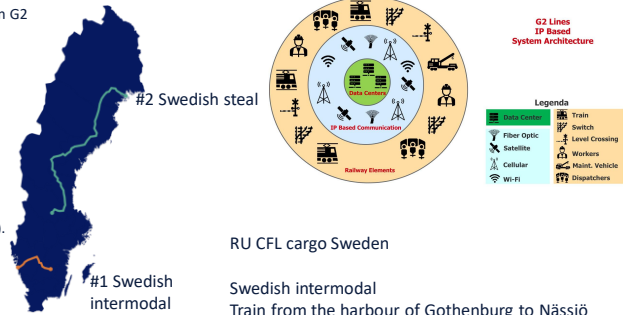


Figure 8: Integrated interlocking and RBC functions

10. Conclusions

Today's available technologies are suitably mature for creating new solutions for G2 low density railway lines based on radio public networks, cloud computing, Federated Data Space, satellites, and COTS products to reduce dramatically the CAPEX and OPEX costs.

The significant minimisation of wayside equipment achievable with the solution proposed is expected to result in at least 30% saving on CAPEX and 40% on OPEX. Moreover, the system availability will also be increased by the reduction of critical wayside components as the signalling system availability is affected adversely by the failure of wayside elements such as signals, track circuits and axle counters. It is also not rare for Railway operations to be interrupted through vandalism or theft (typically of copper cables).

Finally, this modern solution via precise information of train position, speed, etc. opens the door to the introduction of several advanced services for both passengers and freight lines such as precise forecasting, flexible / on demand service and intermodality.

The proposed innovative approach is a game changer for the regional G2 lines preserving them from the risk of closure. The key beneficiaries are the public transport authorities and railway undertakings in charge of operating passenger low density lines and freight delivering cargo in remote areas. By its nature, the proposed approach brings huge benefits by a smooth transition from pre-existing/old signaling system, to the new train control technology. That includes the possibility to act as an overlay ATP during the time required for a complete migration to fully digitalised system.

Finally, this solution may also have in future a positive impact on the whole European network where technologies tested in a simplified environment like the one of the G2 lines could be applied with more maturity and confidence in mainline and high-speed railway line applications.

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12.ANNEXES

ANNEX 1. GOVSATCOM

5. GOVSATCOM: Comprehensive Overview

The **Governmental Satellite Communications (GOVSATCOM)** initiative is a key component of the European Union's space strategy, aimed at providing secure, resilient, and cost-effective satellite communication services to support security and safety-critical missions. This initiative is designed to meet the needs of EU and national public authorities, including national security actors, EU agencies, and institutions.

6. Objectives and Importance

GOVSATCOM is essential for ensuring the long-term availability of reliable satellite communications for governmental operations. The initiative addresses the evolving political and security landscape, where threats range from natural disasters and pandemics to cyber-attacks and traditional conflicts. By providing robust communication capabilities, GOVSATCOM enhances the EU's ability to respond to these threats effectively.

7. Key Features

1. **Secure and Resilient Communications:** GOVSATCOM ensures that communication channels are secure, resilient against jamming and interference, and protected from interception and intrusion. This is crucial for missions that involve sensitive information and require guaranteed access to communication networks.
2. **Cost-Efficiency:** By pooling the capacity of governmental and commercial satellite communication providers, GOVSATCOM offers cost-effective solutions. This shared capacity model allows for efficient use of resources while maintaining high security standards.
3. **User-Centric Approach:** The program is designed with a strong focus on user needs. It aims to meet the specific requirements of security-critical missions, ensuring that the services provided are aligned with the operational demands of its users.
4. **Support for EU Policies:** GOVSATCOM supports various EU policies, including the EU Maritime Strategy and the EU Arctic Policy. It contributes to the EU's global strategy for foreign and security policy by enhancing the EU's capacity to protect its citizens and interests.

8. Applications and Use Cases

GOVSATCOM is utilized in several critical areas:

- **Crisis Management:** This includes civilian and military missions, natural and man-made disasters, humanitarian crises, and maritime emergencies. Secure satellite communications are vital for coordinating responses and ensuring effective management of these situations.
- **Surveillance:** GOVSATCOM supports border and maritime surveillance, as well as monitoring illegal trafficking. These capabilities are essential for maintaining security and managing threats at the EU's borders.
- **Key Infrastructure Protection:** The initiative provides communication services for critical infrastructure, including transport and EU space infrastructures like Galileo and EGNOS. This ensures that these vital systems remain operational and secure.

9. Implementation and Governance

The implementation of GOVSATCOM began in 2021 under the new EU Space Programme Regulation. The European Union Agency for the Space Programme (EUSPA) is responsible for the preparatory activities, including establishing and managing the network of future GOVSATCOM users. This network, developed under the ENTRUSTED Horizon Europe project, includes 25 organizations from Member States and EU agencies.

EUSPA is also tasked with defining the security baseline for the program, ensuring that it meets the stringent security requirements of its users. Additionally, the agency is developing the architecture for the program's secure ground infrastructure, known as the GOVSATCOM Hubs.

10. Benefits and Future Prospects

GOVSATCOM offers numerous benefits, including enhanced security, cost-efficiency, and support for critical EU policies. By providing reliable and secure communication services, it strengthens the EU's ability to manage security threats and protect its citizens. The initiative also promotes European non-dependence in terms of technologies, assets, operations, and services, contributing to the EU's strategic autonomy.

As the program continues to develop, it is expected to play a crucial role in the EU's security and defense landscape, supporting a wide range of missions and operations across various sectors.

References

- [1] [GOVSATCOM | EU Agency for the Space Programme](#)
- [2] [GOVSATCOM | Satellite Communications - European Commission](#)

ANNEX 2: FEDERATED DATA SPACE

Introduction

A **Federated Data Space** is a type of data ecosystem where multiple, autonomous data sources are interconnected and can be accessed in a unified manner. Here are some key points to understand about Federated Data Spaces:

1. **Autonomy and Distribution:** The individual data sources (or databases) remain autonomous, meaning they operate independently but are part of a larger, interconnected system.
2. **Shared Policies and Rules:** These data spaces are governed by shared policies and rules that ensure secure, transparent, and trusted data access. Data holders control who can access their data, for what purpose, and under what conditions.
3. **Integration and Interoperability:** Federated Data Spaces integrate data from various sources based on need, allowing for seamless data exchange and interoperability across different systems.
4. **User-Friendly Access:** Users can access data in a secure and easy manner, often through a single query interface, despite the data being distributed across multiple locations.

This concept is particularly relevant in today's data-driven world, as it supports efficient data sharing and collaboration while maintaining data sovereignty and security.

Federated Data Spaces offer several key benefits.

They improve data accessibility by allowing users to query and retrieve data from multiple sources through a single interface, eliminating the need to centralize data physically. This approach enhances data governance and security, as data remains in its original repositories, enabling better enforcement of access controls and security policies tailored to each data source. Additionally, federated data spaces reduce costs associated with data movement and storage, as there's no need to duplicate data in a central location.

Moreover, they facilitate the seamless integration of new data sources, allowing organizations to grow and incorporate new data without disrupting existing workflows. This flexibility and scalability enable real-time data sharing and collaboration, making federated data spaces a

powerful solution for organizations aiming to leverage their data assets effectively while maintaining control and security.

European Commission and Federated Data Space

The European Commission has been actively promoting the development of **Common European Data Spaces** as part of its broader data strategy. This initiative aims to create a single market for data, enabling data to flow freely across the EU and across various sectors.

The key objectives of these data spaces include:

1. **Enhanced Data Sharing:** Facilitating the pooling and sharing of data in a secure and trustworthy environment. This is intended to benefit European businesses, public administrations, and citizens by making more data available for access and reuse.
2. **Data-Driven Innovation:** Supporting the development of new data-driven products and services. By providing a reliable framework for data sharing, the initiative aims to unleash the potential of data-driven innovation across the EU.
3. **Interoperability and Governance:** Establishing common data infrastructures and governance frameworks to ensure interoperability and secure data transactions. This includes developing reference architecture, building blocks, and interoperability specifications.
4. **Sector-Specific Data Spaces:** Creating data spaces in strategic fields such as health, agriculture, manufacturing, energy, mobility, finance, public administration, and more. These sector-specific data spaces will gradually be interconnected to form a cohesive single market for data.

The European Commission also supports the development of these data spaces through initiatives like the **Data Spaces Support Centre**, which provides guidance on best practices and common requirements.

This initiative is a significant step towards harnessing the value of data for the benefit of the European economy and society, fostering innovation while ensuring data sovereignty and security.

European Railway sector and Federated Data Space

The European railway sector is actively developing a **Federated Data Space** through initiatives like the **European Rail Data Space (RDS)**. This initiative aims to create a secure, interoperable data ecosystem for the entire rail community in Europe.

One of the key projects under this initiative is the **FP1-MOTIONAL project**, which focuses on delivering a viable Rail Data Space. This project supports data sharing and communication among rail operators, infrastructure managers, and suppliers, aligning with the broader European Mobility Data Space. The RDS is designed to enhance the competitiveness and sustainability of the rail industry by providing opportunities to create new services and products through shared data assets.

The RDS also aims to integrate rail transportation into a comprehensive mobility system, utilizing open-source architectures and complying with the GAIA-X Trust Framework. This approach ensures that the rail sector can contribute to and benefit from the European Data Strategy, promoting data sovereignty, a level playing field, and decentralized infrastructure.

These efforts are part of a broader push towards digitalization in the rail sector, making it more interoperable, resilient, and adaptable to future demands.

- [1] [Data spaces: Introducing the concept and relevance in today's world](#)
- [2] [When open data meets data spaces | data.europa.eu](#)
- [3] [When open data meets data spaces | data.europa.eu](#)
- [4] [Common European Data Spaces - Shaping Europe's digital future](#)
- [5] [European Rail Data Space - International Data Spaces](#)
- [6] [Europe's Rail Project Results Published in November 2023](#)

ANNEX 3: G2 OPERATIONAL AND FUNCTIONAL REQUIREMENTS AND SYSTEM ARCHITECTURE – WP2 AND SYSTEM PILLAR INTERACTIONS

INTRODUCTION

This annex contains references to the collaborative work performed on G2 lines with WP2. Requirements and Architecture developed and described in D2.1 and D2.2 issued by WP2 for G2 lines are here briefly reported for the reader convenience.

At the beginning of FP6 project several interactions with the System Pillar took place to define priorities and areas of collaboration. It was decided that the System Pillar would have given priority to G1 lines in this phase of FA6 since G1 lines are subject to TSI and careful analysis of any deviation requires verification and support from the System Pillar. On the other hand, given G2 lines are not interoperable, and therefore not subject to the TSI, the interaction with System Pillar in this phase of the project was considered less critical no further analysis regarding alignment and permissible deviations from European TSIs is considered necessary, apart from a comparative assessment of the available alternatives, including ERTMS. During several meetings (e.g. Maturity Check Points) the System Pillar was informed about the progress made on G2 lines activities from FP6. It is worth underlining that since G2 lines solution/s will be required to be standardized the interaction with the System Pillar is foreseen to become critical in next phase of the project.

Operational Requirements (from WP2)

WAYSIDE CCS OPERATIONAL REQUIREMENTS G2 LINES

ID	Description	Rationale
ORWSG2 1.	The Wayside CCS for G2 Lines shall ensure compliance with applicable safety regulations (e.g., CENELEC EN 50126/8/9).	Wayside CCS needs to be approved and standardized.
ORWSG2 2.	CCS for G2 Lines shall contribute to the overall reduction of CAPEX and OPEX of the CCS system, while maintaining the safety level identified by the IM for the specific line.	This is to fulfil FP6 Socio-Economic Objectives (SEO): SEO1, SEO3, SEO4, SEO5 and SEO8. G2 CCS must significantly reduce trackside field element needs and costs (train detection, signals, etc.), thereby lowering CAPEX and OPEX.
ORWSG2 3.	Onboard Train Integrity and Train Length information shall contribute to the overall reduction of CAPEX and OPEX of the CCS system, while maintaining the target safety level defined by IM.	This is to fulfil FP6 Socio-Economic Objectives (SEO): SEO1, SEO3, SEO4, SEO5 and SEO8. Train Integrity and Length contributes to the reduction of trackside train detection system implementation, thereby lowering CAPEX and OPEX.

ID	Description	Rationale
ORWSG2 4.	Trains which are not reporting confirmed integrity must still be authorised to run on the line.	It is based on the moving block or Fixed Virtual Block principles. This trains will have operational impact in the expected performance.
ORWSG2 5.	The Wayside CCS for G2 Lines should be based on integrated IxL-RBC architecture.	Simplify and reduce the engineering cost for configuration and safety validation.
ORWSG2 6.	The Wayside CCS for G2 Lines shall be compliant with applicable EU cybersecurity directives.	Wayside CCS needs to be approved and standardized

ON-BOARD CCS OPERATIONAL REQUIREMENTS G2 LINES

ID	Description	Rationale
OROBG2 1.	The On Board CCS for G2 Lines shall facilitate the safe, efficient and effective operation/use of railway infrastructure and rolling stock.	Cost efficiency
OROBG2 2.	The On-Board system must be able to determine train integrity.	Needed since the G2 lines require to minimize as much as possible traditional wayside train detection systems
OROBG2 3.	The On-Board system must be able to calculate the train length.	Needed since the G2 lines require to minimize as much as possible traditional wayside train detection systems

ID	Description	Rationale
OROBG2 4.	The On-Board CCS for G2 Lines shall base the train positioning on onboard digital map and GNSS satellite-based technologies.	Needed since the G2 lines require to minimize as much as possible traditional wayside train detection systems
OROBG2 5.	The On-Board CCS for G2 Lines shall be telecom agnostic using mobile public/private radio communication and satellites for communications.	Needed to avoid the huge CAPEX and OPEX cost of a dedicated radio network
OROBG2 6.	The On-Board CCS for G2 Lines shall use IP-based data radio protocols for communications.	Needed to be able to follow the evolution of telecommunication technology

WAYSIDE ASSETS OPERATIONAL REQUIREMENTS G2 LINES

ID	Description	Rationale
ORWAG2 1	The Wayside Assets for G2 Lines should avoid using train detection wayside equipment.	Cost efficiency
ORWAG2 2	The Wayside Assets for G2 Lines should avoid using train positioning wayside equipment	Cost efficiency
ORWAG2 3	The Wayside Assets for G2 Lines shall be limited to the minimum required for safe management such as level crossing and point machines.	Cost efficiency
ORWAG2 4	The Wayside Assets for G2 Lines shall be based on reliable power supply with battery or solar backup for remote areas	Cost efficiency and environmental impact

Functional Requirements (from WP2)

WAYSIDE CCS FUNCTIONAL REQUIREMENTS G2 LINES

ID	Description	Rationale
FRWSG2 1	The Wayside CCS for G2 Lines shall detect the presence and absence of trains in the defined sections using the digital onboard map and satellite-based position information	Cost efficiency
FRWSG2 2	The Wayside CCS for G2 Lines shall enable safe setting and locking of routes based on train movements.	Basic safety requirement
FRWSG2 3	The Wayside CCS for G2 Lines shall prevent conflicting movements through interlocking logic.	Basic safety requirement
FRWSG2 4	The Wayside CCS for G2 Lines shall support manual and automatic route setting modes	Flexibility and efficiency
FRWSG2 5	The Wayside CCS for G2 Lines shall operate points remotely or locally	In normal operations points shall be operated remotely. However, in some degraded modes local operations may be required.
FRWSG2 6	The Wayside CCS for G2 Lines shall detect and report point position (normal/reverse) and failures	Basic safety requirement
FRWSG2 7	The Wayside CCS for G2 Lines shall lock points during train movements to ensure safety	Basic safety requirement
FRWSG2 8	The Wayside CCS for G2 Lines shall monitor track section occupancy and release	Basic safety requirement
FRWSG2 9	The Wayside CCS for G2 Lines shall detect train separation and/or integrity issues	Basic safety requirement

FRWSG2 10	The Wayside CCS for G2 Lines shall interface with CCS onboard systems	Basic requirement for train control
FRWSG2 11	The Wayside CCS for G2 Lines shall ensure safe state in case of power loss, communication failure, or component malfunction	Management of degraded modes
FRWSG2 12	The Wayside CCS for G2 Lines shall include redundant power and communication paths for critical systems	Basic reliability requirement

ON BOARD CCS FUNCTIONAL REQUIREMENTS G2 LINES

ID	Description	Rationale
FROBG2 1.	The On-Board CCS for G2 Lines shall determine train position using digital onboard map and GNSS satellite-based positioning.	Cost efficiency
FROBG2 2.	The On-board CCS for G2 Lines shall also be able to communicate via public radio networks	Cost efficiency
FROBG2 3.	The On-Board CCS for G2 Lines shall provide position data to driver interface and wayside systems	Basic safety requirement
FROBG2 4.	The On-Board CCS for G2 Lines shall monitor actual train speed against permitted speed profiles	Basic safety requirement
FROBG2 5.	The On-Board CCS for G2 Lines shall interface with the train's braking system for automatic brake application	Basic safety requirement
FROBG2 6.	The On-Board CCS for G2 Lines shall enable emergency brake override by the driver	Basic safety requirement
FROBG2 7.	The On-Board CCS for G2 Lines shall detect train integrity	Cost efficiency (no wayside train detection systems in the track)

Non-Functional Requirements (from WP2)

WAYSIDE CCS NON-FUNCTIONAL REQUIREMENTS G2 LINES

ID	Description	Rationale
WSCCSNFG2_4.	G2 Lines shall bring reduction of OPEX costs per kilometre of wayside assets of at least 30% with respect to current figures for an equivalent scope, including energy saving.	Reduction of TCO.
WSCCSNFG2_5.	G2 Lines shall bring reduction of CAPEX costs for signalling and traffic management of at least 25% with respect to current figures for an equivalent scope.	Reduction of TCO.
WSCCSNFG2_6.	The CCS implemented on a G2 line should improve the availability of the line by at least 10%.	Reduction of TCO.

ON-BOARD CCS NON-FUNCTIONAL REQUIREMENTS G2 LINES

ID	Description	Rationale
NFROB 4.	G2 Lines shall improve reliability of positioning of at least 15% with respect to current figures for an equivalent scope.	Reduction of TCO.
NFROB 5.	G2 Lines shall bring reduction of CAPEX costs positioning of at least 15% with respect to current figures for an equivalent scope.	Reduction of TCO.
NFROB 6.	G2 Lines shall bring reduction of OPEX costs positioning of at least 15% with respect to current figures for an equivalent scope.	Reduction of TCO.

WAYSIDE ASSETS NON-FUNCTIONAL REQUIREMENTS

ID	Description	Rationale
NFRCMG2_1	CAPEX of wayside assets for G2 Lines shall reduce at least 40% with respect to current figures for main lines.	Reduction of TCO.
NFRCMG2_2	OPEX of wayside assets for G2 Lines shall reduce at least 40% with respect to current figures for main lines.	Reduction of TCO.

ANNEX 4: COST ANALYSIS

INTRODUCTION

This annex contains a preliminary cost analysis of the expected savings that can be obtained by implementing the proposed G2 solution.

Please also refer to WP2 public report Deliverable 2.3 – “First Release of KPI Achievement”.

TELECOMMUNICATIONS COSTS

As explained in various chapters of this deliverable, a key element to reduce the TCO for G2 lines is a telecommunication agnostic approach allowing for the utilization of public radio/satellite networks based on IP protocols.

In 2016 Systra published a very interesting study on migration from GSM-R to new generation radio communication systems (NG).

Please find below the link to download the study:

<https://www.era.europa.eu/content/study-migration-railway-radio-communication-system-gsm-r-other-solutions>.

This study contains several statistical data about the CAPEX and OPEX costs of GSM-R and the expected ones for NGs which we will use in this analysis. According to the study the following figures can be considered:

Wayside	CAPEX	OPEX
	Cost per KM	Cost per KM/year
GSM-R	60.000 €	3.300 €
NG	30.000 €	3.300 €
Onboard	CAPEX	OPEX
	Cost per unit	Cost per unit/year
CAB Radio	18.000 €	1.000 €

Figure 9: Unit cost of GSM-R and NG

It is important to understand that above figures are averages coming from statistical data therefore they are closer to reality for an average line and are optimistic for small regional G2 lines. It is obvious that the cost per km and the cost per traction unit will be higher for shorter lines and for smaller fleets.

Please also note the following two assumptions from the Systra study:

1. The cost per km of NG is considered half of the GSM-R assuming to reuse the infrastructure of already installed GSM-R. If NG is expected to be installed from scratch, then its cost would be equivalent to the GSM-R one.
2. Systra assumed that the new CAB radio for NG will cost approximately as the average cost of GSM-R CAB Radio (this is why the above table do not distinguish between GSM-R and NG CAB Radio).

G2 Line of 100Km and 10 trains		
	Total CAPEX	Total OPEX per year
GSM-R	6.000.000 €	330.000 €
NG	3.000.000 €	330.000 €
CAB Radio	180.000 €	10.000 €

Figure 10: Total Costs for a G2 Line equipped with GSM-R or NG

As Figure 10 shows the CAPEX cost with the existing (GSM-R) or future NG (FRMCS) solutions will be over 3M€ if an existing infrastructure is available or over 6M€ in case of a greenfield installation. OPEX costs exceed 330K€.

As explained in Chapter 6 for G2 lines there is no need to look for interoperability therefore it is possible and necessary to achieve a zero CAPEX cost for the wayside telecom network either using public cellular networks (if the railway line has a coverage) or satellite communication which ensures global coverage.

G2 Solution for a Line of 100Km and 10 trains		
	Total CAPEX	Total OPEX per year
Satellite network	- €	- €
VSAT CAB Radio	60.000 €	84.000 €

Figure 11: G2 Lines telecom solution based on satellite communication

A COTS VSAT CAB Radio have a cost of approximately 6K€² and based on experience coming from several international projects the cost of using the satellite communication per train per month is

² An example of COTS Satellite radio is the BGAN Explorer 325 which uses the INMARSAT satellite service.

in the range of 700€. It is worth noting that the costs of satellite communication is becoming year by year less expensive.

Finally, we would like reminding that the telecommunication sector is evolving quicker than railways and that 5G will be soon replaced by 6G and later by 7G. 7G will integrate terrestrial antennas with satellites in a transparent way for the user and ensuring coverage and performance everywhere. This is why the G2 lines solution is based on a telecommunication agnostic approach decoupling the railway application from telecommunication technology.

In conclusion, comparing Figure 10 and Figure 11 costs it is clear the huge saving of the proposed approach which exceeds by far the target sets at the beginning of FP6 project.

WAYSIDE ELEMENTS COSTS

It is common knowledge that wayside equipment and related cables are one of the key cost drivers of CCS. This is confirmed by several initiatives in place to reduce the cost of ERTMS by eliminating lateral signals (with ETCS L2); reducing the number of balises (by developing safe on-board centric positioning); using virtual block to reduce the need of track circuits and axle counters (hybrid ERTMS). The proposed solution for G2 lines pushes the above initiatives to their limits by eliminating:

- wayside transponders for positioning.
- Lineside light signals.
- Trackside Train Detection systems like track circuits and axle counters, with all related expensive cables.

Such results are obtained by implementing pure virtual/moving block systems which aim is not improving capacity and performance (an indirect advantage which can be questionable for low density lines) but keeping at minimum the CAPEX and OPEX costs.

Therefore, the saving achieved on the CAPEX and OPEX cost related to train detection and positioning is 100% since there is no need any more for these expensive elements.

The only wayside elements that are kept in the G2 lines are switches and level crossings, but these do not belong to the CCS: they need to be controlled by the CCS.

Of course, it is possible to optimize the number of switches and to reduce the number of level crossing in various ways. However, this type of optimization is not in the scope of this work.

DATA CENTERS CONTROLLING SEVERAL G2 LINES AND ITS IMPACT ON OPERATIONAL AND SAFETY APPROVAL COSTS

G2 Lines are typically operated by small organizations therefore it is extremely useful to reduce operational activities to be performed by their staff. Please see Chapter 6 and Chapter 7 which explain the importance of common Data Centers controlling several G2 Lines.

In this Annex we would like to focus on another strategic reason which makes clear why common Data Centers are critical to make G2 lines cost effective.

It is well known that certifications and authorisation of CCS systems are a complex, expensive and time-consuming tasks. As a matter of fact, certifications and authorisations can put at risk the business case of the G2 line proposed solution.

Similarly, to imagine the definition of different operational rules for each individual G2 line is another barrier to making a feasible business case.

For the above reasons the idea of G2 lines is to develop a standard solution to be applied as is (with no individual requirements or adaptation) by every G2 line.

In practice the approach would be the following:

1. A common generic product safety certification.
2. One set of operational rules (identical for all G2 lines).
3. One authorisation process at National/regional level valid for all G2 lines in the country/region.

This will require G2 lines operators of a given country to set-up a consortium which would share the Data Center controlling the application of several lines. All applications should share the same certification, authorisation and operational rules. Ideally items 1. and 2. would be common for all European G2 lines while 3. will have to be performed at National level.