ERTMS on SATELLITE Galileo Game Changer

Enhanced Functional ERTMS Architecture Capable of using GNSS and Public Radio TLC Technologies

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EXECUTIVE SUMMARY

This document has the objective to describe the Enhanced ERTMS Functional Architecture, suitable for the introduction of the GNSS technology and the Virtual Balise concept, defined in the ERSAT-EAV, NGTC, START, RHINOS Projects, and consolidated in the WP 2 of the ERSAT GGC Project.
This document is the result of the Task 2.1 of ERSAT GGC and constitutes the deliverable D.2.1 – "Enhanced Functional ERTMS Architecture Capable of using GNSS and Public Radio TLC Technologies".
It was generated by combining the outputs of the Technical Notes "ERSAT GGC WP2 Enhanced Functional ERTMS Architecture" and "ERSAT GGC WP2 ERTMS Operational Scenarios", which have been shared and reviewed by the partners of ERSAT GGC WP 2 during the Task 2.1".

This Functional Architecture has been submitted to the System Functional Hazard Analysis in the frame of ERSAT GGC WP 3, and the outputs of the HA have been taken into account in the current version of the document.

The focus of the ERSAT GGC WP 2 is on the modifications required in the ERTMS Standard Reference Functional Architecture to introduce both the GNSS Positioning Technology and the Public Radio TLC Communication Network.

As far as the GNSS Positioning Technology is concerned, the analysis has been carried out by identifying the properties of the required Augmentation Network without going into details in the peculiarities of the Augmentation.
When some details were strictly required, these have been provided for the Augmentation Network based on the Railway Local Area Augmentation Network, because their properties are well known both in Ansaldo-STS and RFI, due to the experience gained from other projects such as the ESA 3InSat and the GSA ERSAT-EAV.
This approach has allowed the reduction of the ERSAT GGC Project risks associated with the EGNOS Augmentation Network, whose applicability in the Railway Domain is still under evaluation by the main GNSS stakeholders.

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ACRONYM AND ABBREVIATION

	Definition
ASTS	Ansaldo STS
ADC	Analog to Digital Converter
ARAIM	Advanced RAIM
ATPL	Along Track Protection Level
BG	Balise Group
BTM	Balise Transmission Module
CCS	Control-Command Subsystem
CMD	Cold Movement Detector
CRAIM	Carrier phase RAIM
CRC	Cyclic Redundancy Check
CENELEC	Comité Européen de Normalisation Électrotechnique
D	Deliverable
DB	Data Base
DMI	Driver Machine Interface
EDOR	ERTMS Data only Radio
EoM	End of Mission
ERA	European Railway Agency
ERTMS	European Rail Traffic Management System
ERSAT GGC	ERTMS on SATELLITE Galileo Game Changer
ETCS	European Train Control System
EU	European Union
EVC	European Vital Computer
GAD/TV	GNSS Augmentation Dissemination / Trackside Verification
GBAS	Ground-Based Augmentation System
GNSS	Global Navigation Satellite System
GSM	Global System for Mobile Communications
GSM-R	GSM-Railway
FS	Full Supervision

	Definition
HA	Hazard Analysis
HMI	Human Machine Interface
HPL	Horizontal Protection Level
IMU	Inertial Measurement Unit
IP	Internet Protocol
LRBG	Last Relevant Balise Group
LS	Limited Supervision
MA	Movement Authority
MinSFE	Minimum Safe Front End
MaxSFE	Maximum Safe Front End
MLCP	Multi-Link Communication Platform
MOPS	Minimum Operational Performance Standards
MP-TCP	MultiPath TCP
NGTC	Next Generation Train Control
NP	No Power
OS	On Sight
PBG	Physical Balise Group
PVT	Position, Velocity, Time
QoS	Quality of Service
PR	Position Report
RAIM	Receiver Autonomous Integrity Monitoring
RBC	Radio Block Centre
RBS	Radio Block Section
RF	Radio Frequency
RHINOS	Railway High Integrity Navigation Overlay System
RM	Radio Message
SB	Stand-By
SBS	Space Based Services for Railway Signalling
SFE	Safe Front End
SIS	Signal in Space

	Definition
SoM	Start of Mission
SR	Staff Responsible
STARS	Satellite Technology for Advanced Railway Signalling
SV	Satellite Vehicle
TCP	Transport Control Protocol
THR	Tolerable Hazard Rate
TLC	Telecommunication
TMS	Traffic Management System
TSI	Technical Specification for Interoperability
UNISIG	Union Industry OF Signalling
VB	Virtual Balise
VBD	Virtual Balise Detection
VBG	Virtual Balise Group
VBR	Virtual Balise Reader
VBTS	Virtual Balise Transmission System
WP	Work Package

Table 1: Acronyms and Abbreviation

1. BACKGROUND

In the framework of the Project ERSAT GGC (Grant Agreement No 776039), the WP2 is related to the review and the consolidation of the Enhanced ERTMS Functional Architecture, suitable for the introduction of the GNSS technology and the Virtual Balise concept. The functional architecture is already used in the frame of 3InSat, ERSAT-EAV, NGTC, STARS, RHINOS projects, and RFI ERSAT programme. It is used to the definition and development of the Functional and Not Functional Test Specification to validate new ERTMS systems, obtained by the instantiation of the above-consolidated Enhanced ERTMS Functional Architecture.
In the context of ERSATGGC WP2, the Task 2.1 aims at the definition and the development of the enhancement functional ERTMS architecture, suitable for the introduction of the GNSS technology in the ERTMS Train Position function and of the IP-Based Public Mobile Radio Networks (Land and/or Satellite). It provides as deliverable D2.1 the current document ("Enhanced Functional ERTMS Architecture Capable of using GNSS and Public Radio TLC Technologies").

According to **Article 2, point 3** of the regulation in force COMMISSION REGULATION (EU) 2016/919 of 27 May 2016 on the technical specification for interoperability relating to the 'control-command and signalling' subsystems of the rail system in the European Union [10], the TSI (Technical Specification for Interoperability) shall apply to the following networks

(a) the trans-European conventional rail system network as defined in Annex I, point 1.1 to Directive 2008/57/EC [11];
(b) the trans-European high-speed rail system network as defined in Annex I, point 2.1 to Directive 2008/57/EC [11];
(c) other parts of the network of the rail system in the Union, following the extension of scope as described in Annex I point 4 of Directive 2008/57/EC[11];

Regional low traffic lines is a category included in above point (a), the trans-European conventional rail system network.

According to **Chapter 4** of the Technical specification for interoperability CCS [12] are characterized by the Control-Command and Signalling safety characteristics relevant to interoperability**,** as specified in Subset-091 [5].

The validity of the quantified safety requirements indicated in **SUBSET-091** [5] depends on several factors, i.e. assumptions on the characteristics of transmission systems, **mission profile**, and operational issues.

According to **Chapter 4**, point **4.2.1.13** of the **SUBSET-091** [5]**,** in order to arrive at a numerical limit for the constituent hazard rates, sensitivity analysis has been undertaken on the Mission Profile covering, for example different percentage times for operational modes. This is intended to ensure that the resulting targets are applicable to a wide range of real life applications.

According to **Chapter 10.2**, point **10.2.1.1** of the **SUBSET-091** [5]**,** the subset defines a reference Infrastructure, representing average physical and operational characteristics of the railway network, to which the interoperability Directive applies.

The conclusion is Conventional Mission Profile provided into **SUBSET-091**[5]**,** is applicable also to **Regional** rail system network.

The following main guidelines drove the High Level Functional Architecture identification reported in this document:

- Minimizing the impact on current ERTMS/ETCS specification
- Avoiding unnecessary constraints in order to let each supplier designing its own Virtual Balise Transmission system and the Virtual Balise Reader (VBR)
- Concentrating on the introduction of the Virtual Balise Concept and Public Radio TLC Communication Network, and all the impacts on the ERTMS functions, and safety analysis
- Defining the main properties of the Augmentation Network required for completing the definition of the enhanced ERTMS functional architecture, and executing the system functional hazard analysis. The detailed specification, the design, the development and the verification of the Augmentation Network are outside the scope of ERSAT-GGC.

2. INTRODUCTION

The aim of this document is to identify the High Level Functional Architecture suitable for the introduction of the Virtual Balise Concept and the use of Public Radio TLC Communication Network. This document is the outcome of the ERSAT GGC Task 2.1 activities, and constitute the deliverable D2.1 “Enhanced Functional ERTMS Architecture Capable of using GNSS and Public Radio TLC Technologies”.

Chapter 3 describes the Virtual Balise Concept, based on the experience gained in other previous R&D projects and consolidated within the ERSAT GGC Project.

Chapter 4 concentrates on the High Level Functional Architecture suitable for the introduction of the GNSS technology and the Virtual Balise concept, and Public Radio TLC Technologies.

Chapter 5 describes the ERTMS Operational Scenarios that have been identified as relevant with respect to the introduction of Virtual Balise concept.
In addition, in order to reduce the travelled distance in SR mode during the Start of Mission or the number of SoMs with Invalid/Unknown position, also the use of Cold Movement Detector (CMD) has been taken into account.

3. VIRTUAL BALISE CONCEPT

The Physical Balise is a physical equipment installed on a sleeper. During the design phase of an ERTMS trackside subsystem, the signalling designer establishes the track location where the Eurobalise must be installed, and the information that the Eurobalise must send to the on-board platform. The information sent from the Eurobalise is contained within a balise telegram. The identification of the location and of the information must be done in accordance with the national signalling rules and the ERTMS/ETCS Dimensioning and Engineering rules (Subset 040 [4]).
A telegram contains a header and an identified and coherent set of packets (Subset 036 [1]).
The information part of the balise telegram (also named balise information), i.e. the user bits, is the telegram without CRC, control bits, and synchronization bits.
The length of the telegram is either up to 341 bits (including 210 User Bits) which is also referred to as "short telegram", or (up to) 1023 bits (including 830 User Bits) which is also referred to as "long telegram".

The Virtual Balise is an abstract data type capable of storing the fixed Eurobalise user bits associated with a balise telegram.
Signalling designer, during the design phase, shall establishes the track location, where such a virtual balise would be logically installed (e.g. km 13+212), and the user-bits (i.e. the information) that the virtual balise must send to the on-board platform, in the same way to what the signalling designer does for the physical balise.
That information must be sent to the on-board platform, when the estimated GNSS-based position of the GNSS Antenna mounted on the train roof and projected to the track (Virtual Antenna reference mark) matches the location established by the signalling designer.
It is worth to remark that the introduction of the Virtual Balise concept, and the related examples, refers to an idealized description useful for the comprehension of the proposed High Level Functional Architecture.

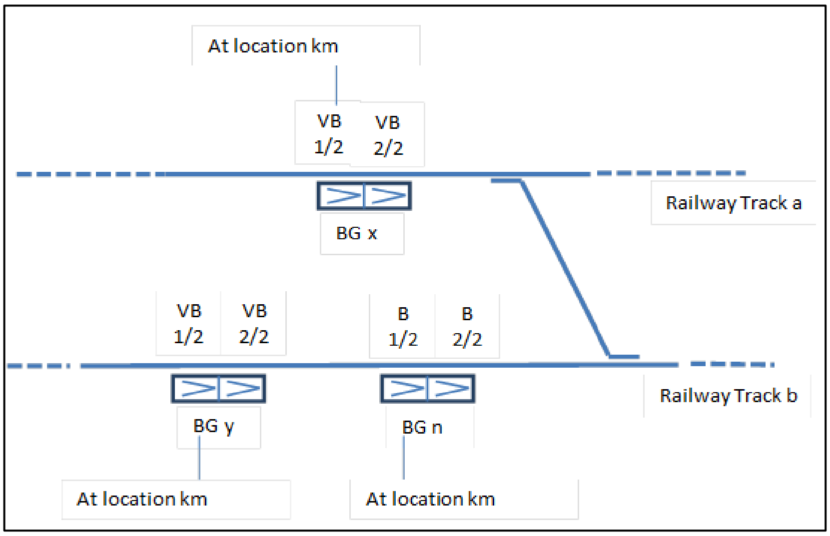

Figure 1 : Example of Schematic Plan with both Physical and Virtual balises

For example, Figure 1 represents the output of a signalling design phase, where the following balise groups have been identified using both physical balises ('B') and virtual balises ('VB') with the related described properties:

- The balise group named BG n is composed of two physical balises; the BG location reference is the balise B1/2 located at km 12+120, the second balise is located at a distance equal to 3 m from the first balise. The balises must be programmed with the user-bits identified by the signalling designer.
- The balise group named BG y is made up of two virtual balises; the BG location reference is the balise VB1/2 located at km 12+232, the second balise is located at a distance equal to 3 m from the first balise. The user-bits specified by the signalling designer must be respectively stored into the abstract data associated with the virtual balises.
- The balise group named BG x is composed of two virtual balises; the BG location reference is the balise VB1/2 located at km 12+132, the second balise is located at a distance equal to 3 m from the first balise. The user-bits specified by the signalling designer must be respectively stored into the abstract data associated with the other two virtual balises.

In accordance with this example, two physical balises will be installed on "Railway Track b" with the telegrams associated with the identified user bits. On the other hand, four virtual balises will be stored as abstract data associated with "Railway Track a" and "Railway Track b" in the track database, that will be uploaded to the on-board platform during the train mission. Each abstract data will include the corresponding User Bits and its location in the railway database will be associated with the location identified in the railway schematic plan.

Let us assume to have a train equipped with:

a) an ERTMS/ETCS compliant BTM, and related Antenna;
b) a new on-board module, named Virtual Balise Reader (VBR), with its related Antenna
c) the ERTMS/ETCS kernel.

It is worth to remark that the BTM function and the VBR function can be implemented on a unique safe platform, and that both functions can be active at the same time, independent from each other.

During the train run:

a) the BTM generates the tele-powering signal to energize any Eurobalise that it can encounter.
b) the VBR periodically computes the estimated GNSS-based position of the GNSS Antenna, mounted on the train roof and projected to the track (Virtual Antenna reference mark), and compares it with the locations associated with the virtual balises stored in the on-board track database.

After passing over a physical balise, and for each correctly decoded telegram, the BTM provides both the user bits of the decoded telegram and the reference position of the physical balise to the ERTMS/ETCS Kernel. On the other hand, when the estimated GNSS position matches the stored position on the on-board track database, VBR provides both the user bits associated with the virtual balise and the reference position of the virtual balise to the ERTMS/ETCS Kernel.

Therefore, the ERTMS/ETCS kernel logically receives the same information (i.e. user-bits and the reference location) independently from the type of medium through which this information is sent (physical or virtual balise).

The ERTMS/ETCS kernel remains responsible for implementing all the ERTMS/ETCS functions related to balises (e.g. LRBG, Linking, Expectation window, balise message consistency checks, etc.).

As far as expectation window is concerned (see SUBSET-026 [3]), the ERTMS/ETCS Kernel accepts a balise group marked as linked and included in the linking information from:

- when the max safe front end of the train has passed the first possible location of the balise group

Until

- when the min safe front end of the train has passed the last possible location of the balise group

Taking the offset between the front of the train and the balise antenna into account. (SUBSET-026, §3.4.4.4.3) [3].

The linking distance and the Balise Group location accuracy (SUBSET-026, §3.4.4.4.3.1) define the first possible location and the last possible location of the balise group.
The interval between the outer limits to accept the balise group, defines the "Expectation window" (SUBSET-026, §3.4.4.4.3.2).

The error in the detection of the position reference of the balise group in the case of the BTM is included in the fixed range for the Physical Balise, while in the case of the VBR it must be included in a variable range, whose extremes are calculated dynamically for each Virtual Balise.

In order to allow the ERTMS / ETCS kernel to compute the train confidence interval, the VBR must provide the error in detecting the position reference of the balise, as well as the user bits and the position reference of the balise.

Since the detection accuracy of a Virtual Balise is dynamic and it is not known a-priori, the resulting confidence interval consists, as well as in the Over/Under-reading amount, also in both the expected GNSS uncertainty and the "dynamic balise detection accuracy" (actual GNSS uncertainty).

The "expectations window" depends on the confidence interval currently calculated by the EVC, which includes the uncertainty of GNSS determined with respect to the last BG considered (LRBG). The accuracy of the associated position of the next virtual balise instead it refers to the accuracy value of the detection at the target level of integrity.

The value of the expected GNSS uncertainty is a predetermined value designed to support wayside engineers, and is analogous to the current Q_LOCACC parameter.
A possible solution for calculating the correct location accuracy is to take into account the following elements:

- **Expected Virtual Balise Location Accuracy**, in analogy with the Physical Balise, is still a fixed value, determined by taking into account the performance of the GNSS receiver in nominal conditions
- **Virtual Balise Detection Accuracy**, is a dynamic value, that represents the GNSS position uncertainty (protection level) associated with virtual balise detection.

The **Virtual Balise location accuracy** is determined by taking into account both the expected Virtual Balise location accuracy and Virtual Balise detection accuracy.

The confidence interval is calculated by taking into account this new value of **Virtual Balise location accuracy**, determined together with the virtual balise detection, and the odometric over/under reading amount.
The integrity associated with the estimated position and confidence interval, calculated by the VBR, is the key aspect of the Virtual Balise concept.

4. HIGH LEVEL FUNCTIONAL ARCHITECTURE FOR THE INTRODUCTION OF THE VIRTUAL BALISE CONCEPT

The NGTC and STARS projects are already discussing a possible high-level reference functional architecture that identifies the new elements to be added to the ERTMS/ETCS architecture in order to introduce the Virtual Balise Concept. In addition, X2Rail-2 WP3, taking also into account previous projects (see [13]), is specifying the Fail Safe Train positioning (including satellite technology), and in this framework the technical note "High Level Functional Architecture suitable for the introduction of the Virtual Balise Concept" [17] has been issued and disseminated among the ERTMS User Group.

The Virtual Balise Concept used in this technical note and the Enhanced Functional ERTMS Architecture defined here, take into account the functional architecture proposed by NGTC (e.g. see [19] §3.2.1.5) and is compatible with the architecture proposed in X2RAIL-2 (see [17]).

The following guidelines have been taken into account for the identification of the proposed High Level Functional Architecture, described in this document, for the introduction of the Virtual Balise concept.

A. The **VBR element**, in analogy with BTM in the current ERTMS/ETCS specification, is part of the ETCS On-board constituent. Therefore, its implementation is in charge to each supplier.
B. The Enhanced Functional ERTMS Architecture defined here shall lay the foundations for the composition of a high level **Virtual Balise Transmission System (VBTS)** document specification, suitable for completing the definition of the enhanced ERTMS functional architecture. The aim of that document (not in the scope of this project) will be to describe the interfaces of the new functional elements (e.g. Virtual Balise Reader, Augmentation Network) and its main functional and non-functional requirements. The high level VBTS specification will be performed following an analogy with the Subset 036 [1].

4.1 HIGH LEVEL FUNCTIONAL ARCHITECTURE

The ERTMS/ETCS reference functional architecture outlines the following three transmission systems:

A. Eurobalise Transmission System
B. Euroloop Transmission System
C. Radio Transmission System

The proposed High Level Functional Architecture, suitable for the introduction of the Virtual Balise Concept (see Figure 2), foresees the introduction of an additional transmission system that is named Virtual Balise Transmission System (VBTS), marked in red in Figure 2.

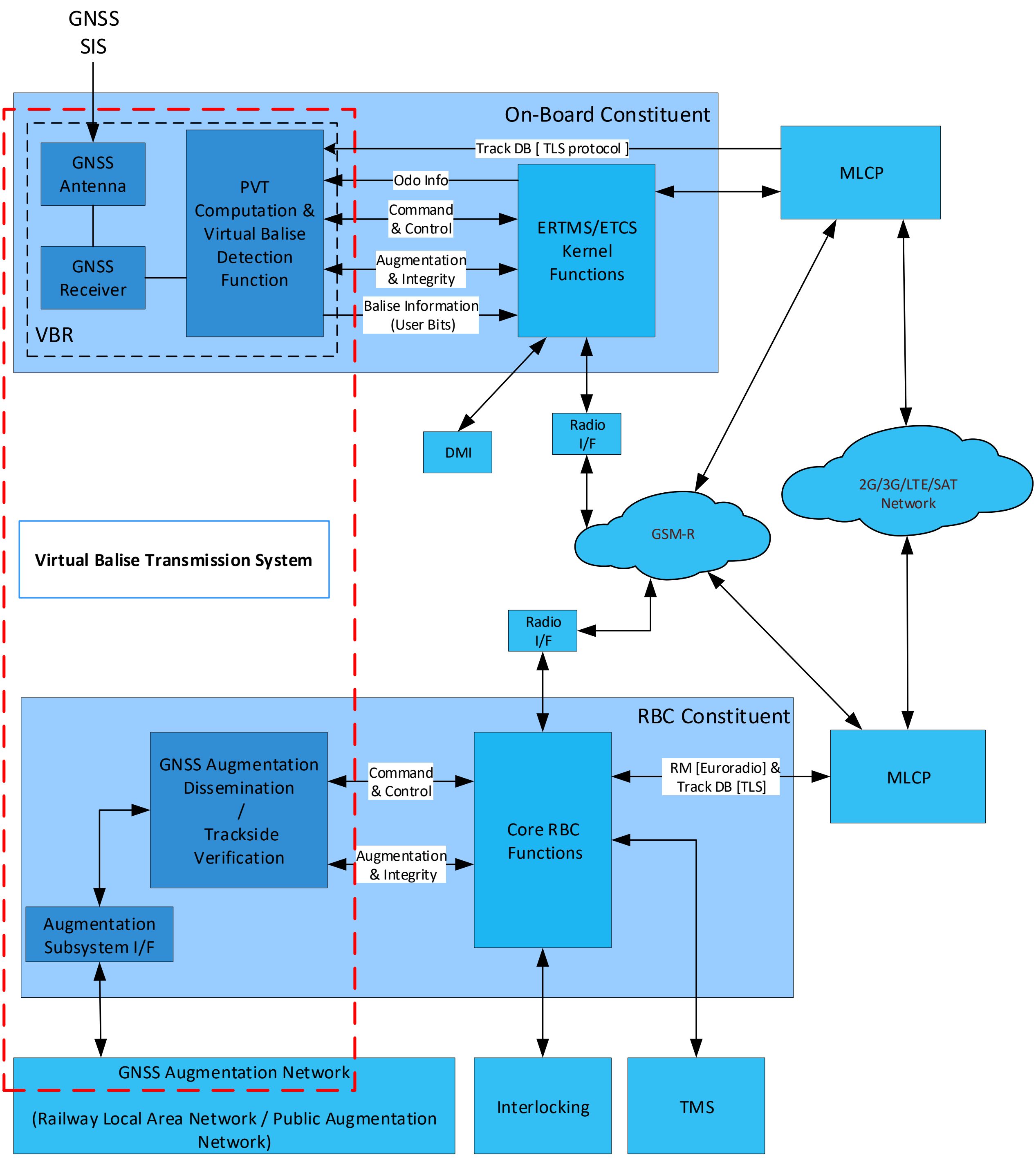

Figure 2 : High Level Functional Architecture for the introduction of the Virtual Balise concept

For the sake of simplicity, the VBTS in Figure 2 reports only those ERTMS/ETCS functions that are relevant for the implementation of the Virtual Balise concept.

It is worth to remark that all the functions and the interfaces of the ERTMS/ETCS reference architecture are still valid and applicable, e.g. those associated with the Eurobalise transmission system.
Due to a poor coverage of the Geostationary Augmentation SIS measured on railway lines, the approach foresees the distribution of the GBAS (Railway Local Augmentation Network) information to each train individually over the ETCS radio airgap through the RBC. In accordance to this approach, the proposed architecture foresee that the augmentation is sent to each on-board constituent from RBC only, via Euroradio.
The proposed architecture also allows the transmission of Navigation Data from RBC to each on-board.

4.2 VIRTUAL BALISE TRANSMISSION SYSTEM

The **Virtual Balise Transmission System (VBTS)** introduced in paragraph 4.1 is a safe spot transmission based system, as for the Eurobalise Transmission System.
The goal of this system is to convey information from the trackside infrastructure to the on-board equipment in terms of balise information (i.e. user-bits of the balise telegram).

The "**GNSS Receiver Function**" is in charge of providing both (a) the code and the carrier phase measurements and (b) diagnostic data on the acquired **GNSS SIS** to the "PVT Computation & Virtual Balise Detection Function". As aforementioned, being the augmentation information transmitted through the RBC, this functional block does not process augmentation information.

The main Functions to be performed by the **PVT Computation and Virtual Balise Detection** block are:

- The computation of the position of the train, by using the code and the carrier phase measurements, to detect virtual balises
- The detection of virtual balises by using the above computed train position and pre-known virtual balise positions stored into an on-board track description
- The provision of the following information to the ETCS on-board kernel when a balise passage occurs:
  - Time / odometer stamp of the detected virtual balise centre and the dynamically computed virtual balise detection accuracy (i.e. the on-board estimated maximum virtual balise location error computed at the detection time in accordance with the pre-established THR)
  - User-bits of the balise telegram for the detected virtual balise, stored into an on-board track description
- To guarantee:
  - the delivery of virtual balises in the correct sequence
  - Cross-talk protection (delivery of balises that are "virtually" placed on the railway track portion that the train is actually travelling)
- To ensure Immunity to environmental noise

- To execute Start-up tests
- To dynamically execute run-time tests to detect failures in the virtual balise detection function; the anomaly must be reported to the ERTMS/ETCS Kernel
- To detect User-bit Errors

In the context of the Virtual Balise Transmission System, both the ERTMS/ETCS Kernel and the module **Core RBC Functions** have the following double role:

a) the implementation of all the ERTMS/ETCS functions in accordance with Subset026 [3]
b) the implementation of the gateway function for enabling the cooperation between the (on-board) **VBR** and the (trackside) **GNSS Augmentation Dissemination / Trackside Verification (GAD/TV)** via new dedicated packets exchanged via Euroradio messages.

The aforementioned **gateway function** has been introduced in the proposed architecture in order to enable the cooperation between on-board and trackside minimizing the impact on ERTMS/ETCS specification.
In order to allow compatibility with existing Subsets, an existing ERTMS/ETCS packet (e.g. packet 44) could be used to exchange this information with no impact on existing on-board implementations.

The **GNSS Augmentation Dissemination / Trackside Verification** functional block is responsible for either:

- Disseminating the GNSS augmentation information received from the Railway Local Augmentation Network to the on-board
- Based on the position information obtained from the "Core RBC Functions" block and timely warning information received from the augmentation network, computing and disseminating alarms to the on-board, in order to apply specific reactions, when required.

The **GNSS Augmentation Network** shall be a Railway Augmentation System suitable for providing the Safe-Of-Life service compliant with safety, performance, and quality railway requirements. In general, the augmentation network is expected to provide the integrity information (i.e. exclude a given satellite because it is faulty) and the corrections (i.e. suitable to compensate the effects of atmospheric phenomena on GNSS measurements), in order to allow safe and accurate positioning. As aforementioned, the proposed architecture foresees that the trackside interoperable RBC component is responsible for disseminating the augmentation to on-board. Therefore, as the radio communication coverage between the trackside RBC and the on-board is guaranteed for allowing the train mission, the same ERTMS communication session can be used for transferring the augmentation information from the RBC to the on-board. This guarantees the dissemination of the augmentation information for the entire train's mission. Moreover, as the ERTMS communication session enables safe and secure (in terms of security) exchanges of messages between both RBC and on-board, the use of this communication session also guarantees the dissemination of augmentation information in accordance with the CENELEC EN 50159 [7].

The **Trackside Verification Function** is responsible for carrying out additional railway verification checks on:

a) The train position determined via the on-board position report
b) The on-board applied pseudo range corrections.

These additional checks will be based on, for example, coherence checks with the track occupancy, the sequence of occupancy of adjacent tracks, the knowledge of the status of the line or station, etc.
It is worth to remark that also previous projects identified the need to carry out additional checks by a trackside verification block (e.g. NGTC [19]).

Adopting the concepts of trusted and non-trusted parts, the components of the Virtual Balise Transmission System introduced in the proposed architecture can be characterized as follows:

- Trusted (safe) parts:
  - Virtual Balise Reader Functions
  - GNSS Augmentation Dissemination / Trackside Verification

- Non-trusted parts:
  - Global Navigation Satellite total System, i.e. the combined ground and airborne subsystems in its role as a source of positioning errors (failures and feared events originating from the system)
  - Airgap as the set of interfaces among SVs and on-board train GNSS Antenna. Therefore, the airgap refers to the GNSS signal in space as a source of positioning errors (feared events originating from the propagation environment)
  - On-board GNSS antenna.

4.2.1 INTERFACES

The Virtual Balise Transmission System communicates with the On-Board and RBC Constituents by means of the following interfaces.

A. Command & Control (On-Board constituent side)

This interface (not standard) is related to the management of the VBR equipment (e.g. equipment configuration, diagnostics etc.), and, in analogy with BTM-ERTMS/ETCS interface (see Subset 036 § 4.1.3.1), each designer shall use safety critical protocol that guarantees the Safety Integrity Level of 4 at system level. The connection between the VBR equipment and the on-board signalling core is bidirectional (e.g. depending on the design ERTMS/ETCS Kernel shall manage internal VBR state machines, receive VBR equipment autotest results, etc.).

B. Command & Control (RBC constituent side)

This interface (not standard) relates to the management of the "GNSS Augmentation Dissemination / Trackside Verification" module within the RBC constituent.
Each designer shall use safety critical protocol that guarantees the Safety Integrity Level of 4 at system level. The communication is bidirectional.

The information exchanged through **interface (A and B)**, includes:

a) RBC requests of Database version verification
b) Result of Database version verification (Match or Mismatch)
c) Track route discrimination information
d) Position Initialization Result (Valid or Not Valid)
e) ERTMS/ETCS Train Localization
f) RBC requests the Satellite Position Initialization (Q_STATUS)
g) Information contained in Position Report

C. Augmentation & Integrity (for both On-Board and RBC constituent sides)

This interface is involved in the dissemination of the GNSS augmentation information received from the GNSS Augmentation Network.
The GNSS Augmentation Dissemination/Trackside Verification Functional block is responsible for disseminating the augmentation to the on-board, and is needed a bidirectional communication, and here are some examples:

- When VBR detects events that affect the integrity of the estimated position (e.g. related to fault detection and monitoring techniques in PVT computation, Railways RAIM integrity checks (see PVT computation in §4.2).
- VBR information (e.g. on-board applied pseudo range corrections) could be used in the Trackside Verification Function (see GNSS Augmentation Network in §4.2).

- The position information estimated by VBR (e.g. in SoM) can be used for the selection of augmentation information applicable to the geographical area where the position of the VBR is estimated.

D. ODO Info (Odometry Information)

The ERTMS/ETCS Odometry information is transmitted from the On-Board Constituent to the Virtual Balise Transmission System for time and odometer stamping of Virtual Balises (as for the BTM, see Subset-036 [1]) as well as for crosscheck purposes.

E. Balise Information

The Virtual Balise generates and transmits to the On-Board Constituent the same information generated by the BTM Function for a Physical Balise (user bits, odometer time or space stamping). The dynamic calculation of the accuracy, based the protection level and other variables/parameters, rather than a fixed value, is the only difference between Physical Balise and Virtual Balise, and it is transmitted to the On-Board Constituent, too.

F. Track DB (on-board constituent)

The on-board Trackside information (Track DB) is downloaded by the VBR from the Trackside, through an Ethernet link (from VBR to the MLCP), using the standard Transport Layer Security protocol.

G. RM (Radio Messages) & Track DB (RBC constituent)

It is an Ethernet link from the Core RBC to the MLCP, used to exchange both the Track DB through the Transport Layer Security protocol, and the Radio Messages through the Euroradio-IP protocol.

4.3 VIRTUAL BALISE READER FUNCTION ARCHITECTURE

This paragraph introduces the Virtual Balise Reader High Level Functional Architecture as the result of the discussion among ERSAT GGC WP2.1 members.

As shown in the previous paragraphs, the Virtual Balise Reader (VBR) functional block comprises the core of the additional on-board functions needed to implement the virtual balise concept in the context of ERTMS/ETCS. It is composed of:

- GNSS Antenna
- GNSS Receiver Function
- Virtual Balise Reader Function

As described in §4.2.1, the main inputs of the Virtual Balise Reader are:

- GNSS SIS signals
- Augmentation information
- Signalling information received from the trackside module GNSS Augmentation Dissemination/Trackside Verification
- Time and odometer reference from the ERTMS/ETCS kernel.

It is worth to remark here that the above mentioned inputs represent a minimum set and that they can be supplemented with other inputs such as Navigation Data from RBC.

The Virtual Balise Reader computes both (a) unconstrained train position and related HPL and (b) constrained train position (i.e. the position already constrained on the track) with related ATPL.
The constrained train position with the corresponding ATPL is computed making use of the track description information; it is used by VBR in order to carry out the detection of virtual balises.
The VBR computes continuously (e.g. with the refresh rate of the GNSS Receiver Function) the position information based on GNSS SIS and augmentation information received and compares it with a list of absolute reference positions stored in the on-board track description to detect the virtual balise.

Once a virtual balise has been detected, the VBR delivers the balise information associated with the detected virtual balise, the time or odometer stamp of the virtual balise center and the dynamically computed estimation of the virtual balise location accuracy.

The High Level Architecture of the Virtual Balise reader element in the on-board constituent is shown in Figure 3. It is worth to remark that this architecture reuses and extends the concepts introduced in STARS and is compatible with the High Level Functional Architecture presented in X2RAIL-2 [17].

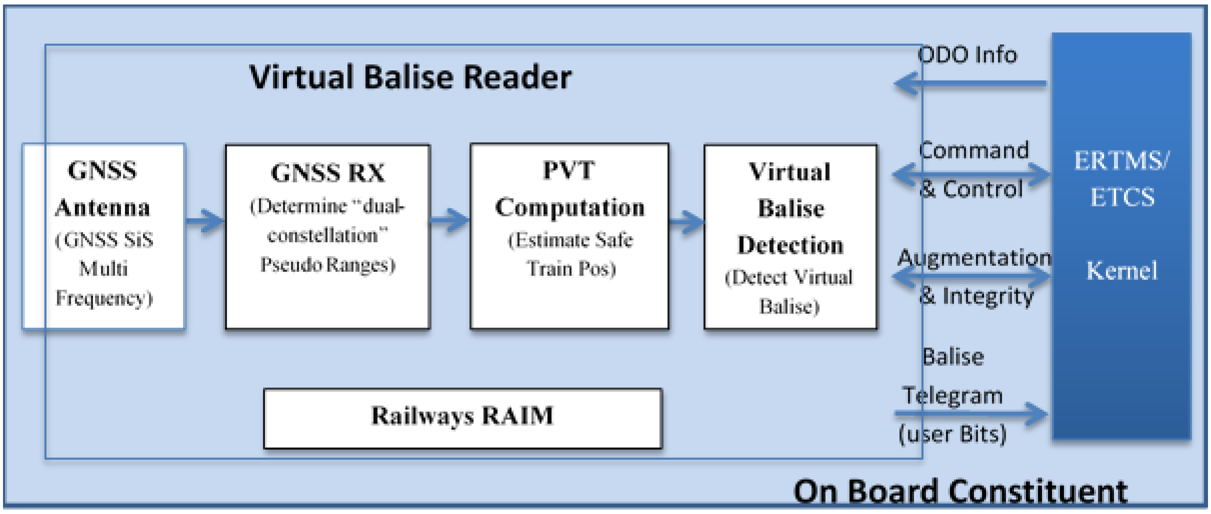

Figure 3 : High Level Virtual Balise Reader Architecture

GNSS Antenna is the radiating element that receives the GNSS SIS signals.

GNSS RX includes the RF front-end with the ADC, and it processes digital signals and forwards different measurements to the PVT computation block. Such measurements include but are not limited to pseudo range and carrier phase measurements, navigation data, and carrier-to-noise ratio. The "GNSS RX" does not receive any augmentation information nor any railway signalling information (e.g. odometry, track description).

The **PVT Computation** is responsible for the computation of the GNSS PVT algorithms specific to the railway environment. The main PVT computation functions can be summarized as follows:

- Compute, when necessary (for example in SoM), the unconstrained position information with the corresponding horizontal protection level.
- Compute the constrained position information (i.e. the position already constrained on the track) with the corresponding ATPL by making use of the track description information. This track description information can be uploaded from trackside repositories, and coherence between the on-board VBR and the trackside "GNSS Augmentation Dissemination/Trackside Verification" module is checked via specific new packets into Euroradio messages (see the gateway function introduced in paragraph 4.2).
- Provide integrity to the computed position by using augmentation information and the output of the additional monitoring techniques implemented on-board. The combined use of the augmentation information and these monitoring techniques enables this functional block to compute a protection level taking into account the various sources of error that induce position uncertainty, for examples ionosphere and troposphere propagation, multipath or electromagnetic interference threats. Implement fault detection and exclusion algorithms using both GNSS information and railway signalling information. The purpose, of these further defensive techniques, is the detection of local feared GNSS events that might lead to unbounded position errors in accordance with the assigned THR. For example, the use

of SIL4 odometry information based on the multi-sensor technology, already available on the on-board, has been demonstrated as a valid mitigation technique to any residual hazard associated with GNSS misleading information.

The **Virtual Balise Detection (VBD)** functional block carries out the following functions:

- Compare the GNSS based train position with pre-known virtual balise positions stored in the on-board track description to declare virtual balise detection
- Receive odometry data from ERTMS/ETCS kernel to properly stamp the detected virtual balise
- Provide the following information to the ETCS on-board kernel when a virtual balise is detected:
    - Time / odometer stamp of the detected virtual balise center; this information takes into account the position of the GNSS Antenna with respect to the front end of the respective engine with respect to the train orientation
    - The detection error associated with the virtual balise detection accuracy
    - Balise information (user bits) for the detected virtual balise, stored into an on-board track description
- Guarantee the delivery of virtual balises in the correct sequence
- Guarantee Cross-talk protection in accordance with the assigned THR
- Ensure Immunity to environmental noise by means of the implementation of robust detection algorithms
- Detect the corruption of User-bits
- Dynamically execute run time tests to detect failures in the virtual balise detection function and notify this anomaly to the ERTMS/ETCS Kernel

Railways RAIM block due to the peculiarities of the railway environment with respect to RF channel impairments, the Railways RAIM functional block includes the set of cascaded integrity checks to be executed on-board to cope with GNSS system and local feared events that may have impact on the GNSS position to be used for detecting the virtual balise.

The first set of these integrity checks can be executed in the GNSS receiver in the pseudo range domain at the level of the satellite signal individually. The objective of these checks is to isolate and exclude faulted or suspect code measurements and phase measurements before the next integrity checks at the level of PVT computation conduct the final check in the position domain. As the GNSS receiver is not a safe railway component, diagnostic information must also be provided to the PVT Computation block (that is a safe component) so that it can implement safe periodic run time checks.

For the remaining set of integrity checks, many studies are still in progress and different possible CRAIM or ARAIM algorithms have been proposed (e.g. [6] and [7]). In addition, one of these integrity checks is the odometry cross check that exploits the high precision of the SIL 4 odometry in a limited spatial interval.

Finally, as far as the implementation of the complete VBR functional block is concerned, it must be compliant with the CENELEC recommendations about SIL 4 platform. Therefore, at least two **independent** GNSS chains, i.e. from the GNSS Antenna to the virtual balise delivery, along with the correlated information, are required.

Considering the railway environment it is worth to remark here that Virtual Balise Reader Function shall manage also situations in which GNSS signals are temporarily not available (e.g. tunnels).
As examples of possible VBR design capable of managing this situation, there is the use of external inputs (e.g. the use of SIL4 odometry information) or additional optional internal sensors (e.g. IMU).
The WP 4 of ERSAT GGC will define the process for the Track Survey and Track Classification, that, given the GNSS based positioning services performance along the line, will allow to select which areas are suitable for the location of virtual balises.

4.4 RADIO COMMUNICATION SYSTEM

This paragraph introduces the Radio Communication System based on a Multi-bearer public network (terrestrial and satellite communication) to be used to exchange data information between RBC Constituent and On-Board Constituent.
Starting from the results obtained in the following projects:

- “Next Generation Train Control System” [NGTC] (WP6, [14],[15])
- “Space Based Services for Railway Signalling” [SBS] (WP3, WP6, WP8 and WP9, [20], [21], [22], [23])

The Radio Communication System concept IP, based on a bearer-independent telecom system, is taken into consideration from rail stakeholders and ERA as ERTMS radio communication evolution.

The Radio Communication system will use multiple public networks and intelligent routing, guaranteeing the possibility to interwork with legacy GSM-R network.
The IP-based solution will enable the use of multiple technologies instead of a single one.
Multi-Link Communication Platform (MLCP) with cognitive algorithms will guarantee a Quality of Service suitable for the railway application domain.
In order to use different telecommunication technologies to manage connections between RBC Constituent and On-Board Constituent, Multipath TCP (MP-TCP) technique will be used.
MP-TCP as an extension of TCP will add the possibility to exploit several paths, instead of a single TCP connection to the application layer.

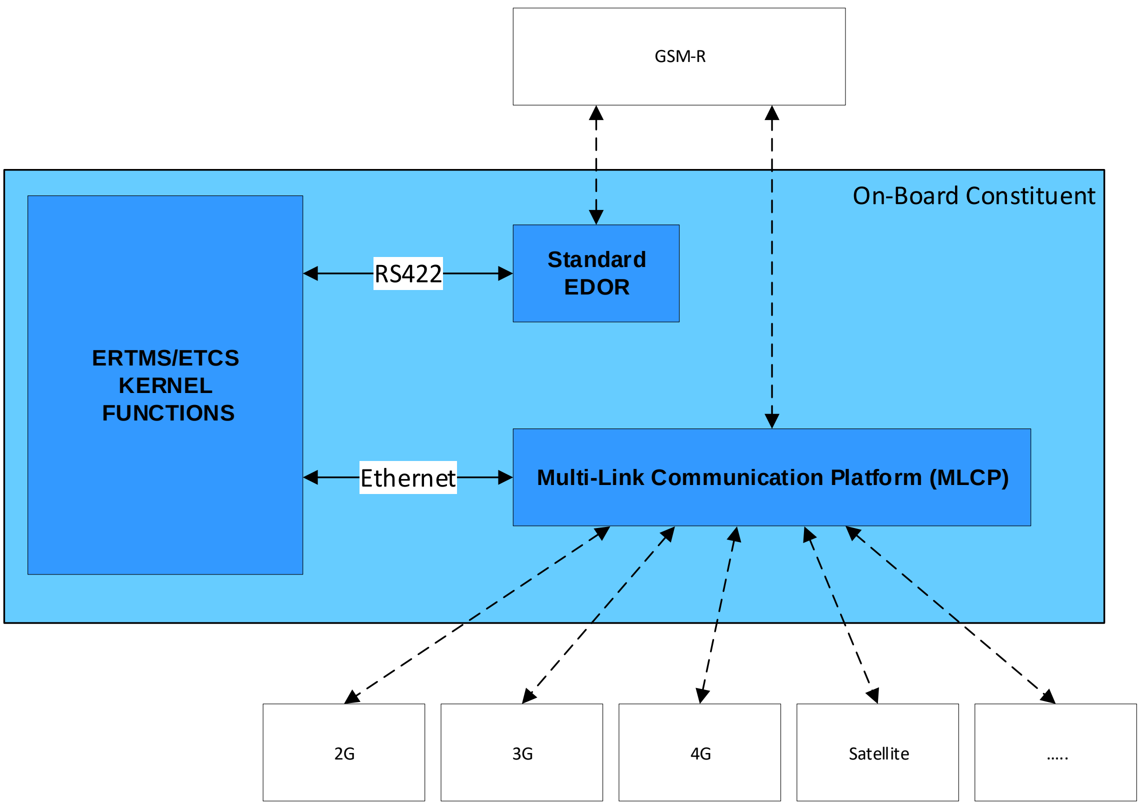

Figure 4 : Multi-Bearer IP based Communication Network System

The MLCP will follow Euroradio protocol as defined in Subset-037 and the Subset 093 to guarantee the QoS requirements.

5. ERTMS OPERATIONAL SCENARIOS

5.1 PRELIMINARY ENGINEERING RULES

During this preliminary phase of sharing the following operative scenarios, it has been considered as initial hypothesis, the use, as well as Virtual Balises, of a limited number of Physical Balises to be laid within the stations.
This choice has been necessary for:

- The initialization of the satellite tracking system (i.e. during the SoM phases) to allow it to safely discriminate the correct track on which the train is located.
- Ensure the capture and processing of telegrams that contain information related to safety.

5.2 VBR INITIALIZED

This paragraph provides the definition of the Virtual Balise Reader status INITIALIZED.
When in the following scenarios is indicated that the status of "VBR "Initialized" is considered, means that when it can operate under "Nominal" conditions, that is what and It is able to associate an unique path for its current position (nominal position and related confidence interval), and provides the Virtual Balises to the ERTMS/ETCS Kernel the Virtual Balises.

5.3 REGISTRATION AND START UP

The following procedure describes the establishment of the Communication Session between the RBC and the EVC that it starts from the safe connection set-up until the sending of the SOM Position Report (excluded).

Initial state:

a) The EVC mode is Stand-By (SB) [The desk has been open, or the driver has selected Exit from Shunting].

b) The EVC requests to the driver to enter/revalidate Driver ID.

c) The level stored is Level 2 and the RBC data are valid.

d) The EVC is able to consider train's position as valid, or invalid, or not known at all.

Events:

1. The EVC requests the set-up of a Safe Connection with the RBC.
2. The EVC sends the message Initiation of Communication Session to the RBC [Msg155] that checks that the number of connected trains is lower than the maximum number of train connections managed by RBC (configuration parameter).
3. RBC sends the RBC/RIU System Version [Msg32] to the EVC with the request to acknowledgement (M_ACK=1) and M_VERSION = 32.
4. EVC sends the ACK message [Msg146] to the message [Msg32], and starts the verification of the version compatibility between trackside and EVC.
5. RBC receives the ACK message [Msg146] and starts a wait timer to receive the message Session Established [Msg159].
6. EVC verifies the compatibility and sends the Session Established message [Msg159], including the on-board supported system versions packet [Pkt2] to RBC.

Note:
If the system versions are compatible, the EVC considers the communication session established and informs the driver.

7. RBC receives the Session Established message [Msg159], terminates the wait timer to receive the Session Established message [Msg159], and considers the communication session also established for trackside.
8. GAD/TV starts the handshake to verify GAD/TV Track DB version and VBR Track DB version (e.g. EVC track database/information).
9. RBC sends:
    - General Message [Msg24], with acknowledgment request (M_ACK=1), that includes the request to the validation of the track DB.
    - General Message [Msg24], with acknowledgment request (M_ACK=1), that include the packet Position Report Parameters [Pkt58] and the variable M_LOC=0 (now).
10. EVC sends immediately a Position Report message [Msg136] including the Data used by applications outside the ERTMS/ETCS which communicates if the track DB is received, and the version is the same, and:

- If the GAD/TV Track DB version is the same of VBR track DB version, then the procedure of start-up proceed from step 11.
- If the GAD/TV Track DB version is not the same of VBR track DB version, then the VBR performs the updating of the track DB and after only the procedure for checking and verifying the Track DB, will start again from point 8, meanwhile the SoM procedure proceed from step11 independently.

Note:
The mismatch could be possible because a different version of the GAD/TV and VBR track DBs or no track DB is uploaded on-board.

Note:
The information that the complete and correct update of the VBR Track DB has been carried out will be important later to decide if RBC will be able or not to send a movement authorization to the train, following the receipt of the [Msg132].

11. RBC starts the handshake to configure the EVC (a) when and how often the train has to ask for a movement authority and (b) when and how often the train position has to be reported:
    - RBC sends a General Message [Msg24], with acknowledgment request (M_ACK=1), that includes the packets Movement Authority Request Parameters [Pkt57] and Position Report Parameters [Pkt58]
    - EVC sends the ACK message [Msg146] to RBC
    - RBC receives the ACK message [Msg146]
12. RBC starts the handshake to provide the National Values to the EVC:
    - RBC sends a General Message [Msg24], with acknowledgment request (M_ACK=1), that includes the National Values packet [Pkt3] with variables set in accordance with the ERTMS Baseline applied and the variable D_VALIDNV set to 32767 (BL3 special value to enable the immediate use of national values)
    - EVC sends the ACK message [Msg146] to RBC
    - RBC receives such a message [Msg146]

5.3.1 ALTERNATIVE PATH

Proposal for future possible discussion

Scope of this paragraph is only to propose a possible change request about how the on-board handles and checks the Track DB. It is a starting point for further analysis about a possible alternative way to proceed, because it requires a modification of the SoM flowchart described in the UNISIG Subset-026.

The idea is to provide that the verification of the DB version be carried out before that the board considers the communication session to be active, and concurrently with the ERTMS system version check [event 3 in the previous paragraph]. In case of the Track DB version is different of the Trackside version, the EVC must stop the start-up procedure and provides to the updating of the correct Track DB version.

5.4 START OF MISSION IN LEVEL 2 WITH Q_STATUS "KNOWN"

According to [1] UNISIG, "SUBSET-026- System Requirements Specification" Version 3.6.0. §4.11, in the following scenarios, the EVC can send a SOM Position Report with Q_STATUS=1, if the train has previously switched in Standby (SB) mode, and the previous status, of stored information, was set to "Valid". This behaviour is independent for the presence or not to the CMD.

Other behaviour is possible when the train has previously switched in No Power (NP) mode, and the status of stored information becomes to "INVALID". If the train is equipped with a CMD, when it switches in SB mode, and no cold movement occurred, It is able to re-validated the stored information, that back "VALID".

5.4.1 TERMINAL RAILWAY STATION

Rationales:

a. Each platform belonging to a Terminal Railway Station is equipped with two physical BGs:
   - One BG aligned with the starting signal
   - One BG placed near and in rear (i.e. 30 meters) of the starting signal
b. The EVC and RBC have established a new communication session, as explained in § 5.3.
c. The conditions of freedom of the Route in advance of the train position (i.e. the departure route is correctly set and locked within the station) are satisfied.
d. [Assumption] The VBR has successfully completed the update of the Track DB.

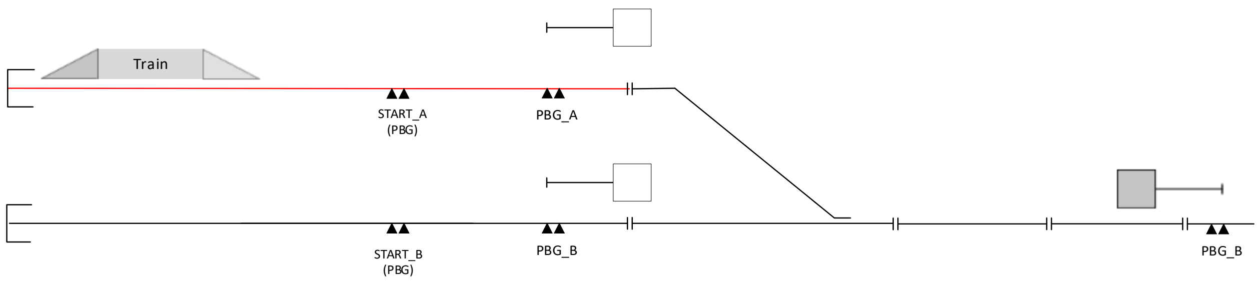

Figure 5 : Terminal Station - SoM with Q_Status "known"

Events:

1. The EVC sends the Start of Mission Position Report message [Msg157], including the information on the stored position (Q_STATUS = 1);
2. RBC receives the SOM Position Report message [Msg157] and checks that:
   - No PR variables have Unknown value
   - The LRBG of the PR is included in the RBC configuration
3. The reference BG of the PR received is located in advance of the Min Safe Front End (MinSFE) of the train.

4. RBC regards the SoM PR as valid, and the GAD/TV sends to the VBR the information to select the track in not ambiguous way (or an equivalent information which defines the platform) to the VBR, where the train is localised.
5. VBR is initialized.
6. RBC commands the visualization of the train icon on the RBC HMI Monitor.
7. EVC sends the Validated Train Data message [Msg129] to RBC, including the Position Report packet [Pkt0] and the Validated train data packet [Pkt11].
8. RBC receives the message [Msg129], checks the data, considers such data as acceptable and starts the handshake to acknowledge the Train Data:
   - RBC sends the Acknowledgement of Train Data message [Msg8] with acknowledgement request (M_ACK = 1)
   - EVC sends the ACK message [Msg146] to RBC
   - RBC receives the ACK message [Msg146]
9. The START button is enabled on DMI; the Driver waits to receive from the Dispatcher the authorization to press it.
10. Driver enters the Train running number, if it is not valid yet.
11. EVC sends a Position Report message [Msg136], including the Train running number packet [Pkt5].
12. Once authorized by the Dispatcher, the Driver presses the START button.
13. The EVC sends the MA Request message [Msg132] and waits for the authorization to move.
14. RBC sends the MA with Shifted Location Reference message [Msg33] to EVC:
   - An On-Sight (OS) or a Limited Supervision (LS) profile [Pkt80] up to the first signal in advance of the train
   - Full Supervision Movement Authority starting from the first signal in advance of the train up to the last virtual signal where the FS conditions are all fulfilled

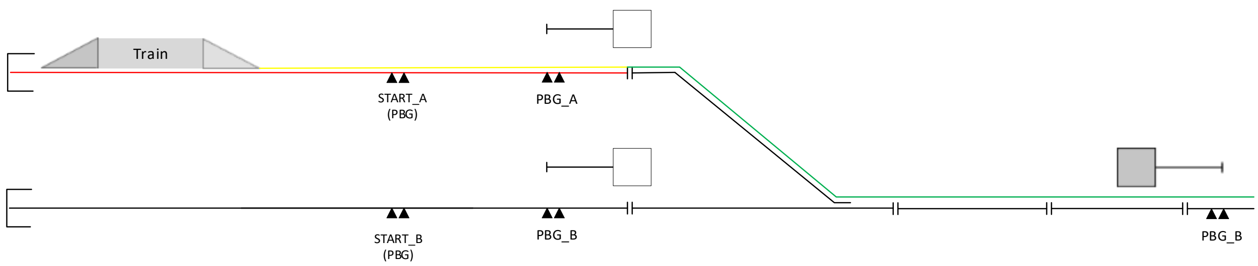

Figure 6 : Terminal Station - First Movement Authority with LS (or OS) mode profile

5.4.2 ALTERNATIVE PATHS

a) The first Radio Block section is not available

The conditions of freedom of the Radio Block Section in advance of the train position are not satisfied (i.e. it is not possible to set and/or lock the departure route within the station).
In this case, the Driver should not receive the authorization to press the START button on DMI (operational rule).

If the START button is pressed and the RBC receives the MA Request message [Msg132], the RBC shall not send any Movement Authority to the EVC, but sends a SR Authorisation with D_SR set to a minimum distance, sufficient to allow the train movement in SR mode, only after Override procedure.

Note:
According to [1] UNISIG, "SUBSET-026 - System Requirements Specification" Version 3.6.0., chapter 5.4.4, the EVC waits for an answer when the MA Request message is sent.
SR Authorisation sent by RBC is necessary in order to avoid a possible deadlock in the EVC DMI.

b) The VBR has not completed the track DB uploading

The Track DB uploading should take few seconds and it is transparent to the driver and Dispatcher.
In the case that the driver can press the START button, after that, the RBC receives the MA Request message [Msg132] and:

- Shall not send any Movement Authority to the EVC.
- Shall send a SR Authorisation with D_SR set to a distance, which allows the train movement in SR mode only with an Override procedure.
- Shall inform the Driver (with a text message) and the Dispatcher (with an alarm on the HMI Monitor) about the reason of the missed MA;

Note:
According to [1] UNISIG, "SUBSET-026 - System Requirements Specification" Version 3.6.0., chapter 5.4.4, the EVC waits for an answer when the MA Request message is sent.
SR Authorisation sent by RBC is necessary in order to avoid a possible deadlock in the EVC DMI.

5.4.3 INTERMEDIATE STATION

Rationales:

a) Each platform belonging to an Intermediate Railway Station is equipped with one physical BG aligned to each starting signal.
b) The EVC and RBC have established a new communication session, as explained in § 5.3.
c) The conditions of freedom of the Route in advance of the train position (i.e. the departure route is correctly set and locked within the station) are satisfied.
d) [Assumption] The VBR has successfully completed the update of the Track DB.

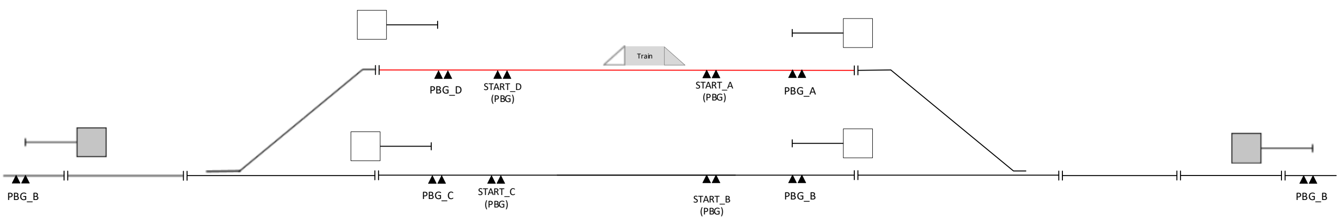

Figure 7 : Intermediate Station - SoM with Q_STATUS "Known"

Events:

1. The EVC sends the Start of Mission Position Report message [Msg157], including the information on the stored position (Q_STATUS = 1).
2. RBC receives the SOM Position Report message [Msg157] and checks that:
   - No PR variables have Unknown value.
   - The LRBG of the PR is included in the RBC configuration.
3. The reference BG of the PR received is located in rear of the Min Safe Front End (MinSFE) of the train.
4. There is no switch point that may lead to an alternative route, located between the LRBG and the MaxSFE (with respect to the train orientation).
5. RBC regards the SoM PR as valid, and the GAD/TV sends to the VBR the information to select the track in not ambiguous way, where the train is localized.
6. VBR is initialized.
7. RBC commands the visualization of the train icon on the RBC HMI Monitor.
8. EVC sends the Validated Train Data message [Msg129] to RBC, including the Position Report packet [Pkt0] and the validated train data packet [Pkt11].
9. RBC receives such a message [Msg129], checks the data, considers such data as acceptable and starts the handshake to acknowledge the Train Data:
   - RBC sends the Acknowledgement of Train Data message [Msg8] with acknowledgement request (M_ACK = 1).
   - EVC sends the ACK message [Msg146] to RBC.
   - RBC receives such a message [Msg146].
10. The START button is enabled on DMI; the driver waits to receive from the Dispatcher the authorization to press it.

11. Once authorized by the Dispatcher, the Driver presses the START button.
12. The EVC sends the MA Request message [Msg132], and waits for the authorization to move.
13. RBC sends the Movement Authority message [Msg3] to EVC:
    - An On-Sight (OS), or a Limited Supervision (LS) profile [Pkt80] up to the first signal in advance of the train.
    - Full Supervision Movement Authority starting from the first signal in advance of the train up to the last virtual signal where the FS conditions are all fulfilled.

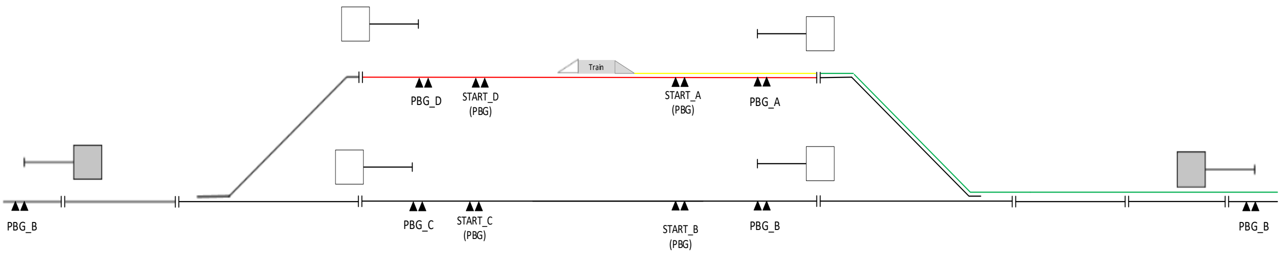

Figure 8 : Intermediate Station - First Movement Authority with LS (or OS) mode profile

5.4.4 ALTERNATIVE PATHS

a) The first Radio Block Section is not available

The same described in §5.4.2, point a).

b) The train proceeds in the opposite direction with respect to the previous Mission

The train proceeds in the opposite direction with respect to the previous Mission (i.e. when arriving on the station platform).
If the EVC reports a known position to RBC, the scenario is the same described in § 5.4.3.
If the EVC reports an unknown position to RBC, the scenario is the same described in § 5.6.6.

5.5 LINE

This scenario represents a degraded case with respect to the nominal one, where the train would not perform a SoM along the line. This would happen only due to a fault and after the previous Communication Session has been closed.
The line is equipped only with virtual balises (i.e VBG_A).

Rationales:

a) The Driver has performed an EoM along the line.
b) The previous communication session is considered as closed due a Safe Connection Failure.
c) The EVC and RBC have established a new communication session, as explained in § 5.3.
d) RBC considers the line track section as occupied by a not connected train (this information is not related to the physical occupation).
e) RBC has stored, during the previous mission, both NID_OPERATIONAL and NID_ENGINE of the train, and then RBC knows that the direction of train is the same of the previous mission.
f) [Assumption] The VBR has successfully completed the update of the Track DB.

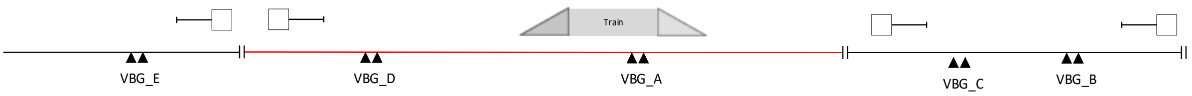

Figure 9 : Line - SoM in Level 2 with Q_STATUS "Known"

Events:

1. The EVC sends the Start of Mission Position Report message [Msg157], including the information on the stored position (Q_STATUS = 1).
2. RBC receives the SOM Position Report message [Msg157] and checks that:
   - No PR variables have Unknown value.
   - The LRBG of the PR is included in the RBC configurations.
3. The reference BG of the PR received, is located in rear the Min Safe Front End (MinSFE) of the train.
4. RBC regards the SoM PR as valid and the GAD/TV sends the information to select the track in not ambiguous way to the VBR, where the train is localised.
5. VBR is initialized.
6. RBC commands the visualization of the train icon on the RBC HMI Monitor.
7. EVC sends the Validated Train Data message [Msg129] to RBC, including the Position Report packet [Pkt0] and the Validated train data packet [Pkt11].
8. RBC receives the message [Msg129], checks the data, considers such data as acceptable and starts the handshake to acknowledge the Train Data:
   - RBC sends the Acknowledgement of Train Data message [Msg8] with acknowledgement request (M_ACK = 1)

- EVC sends the ACK message [Msg146] to RBC
- RBC receives the ACK message [Msg146]

9. The START button is enabled on DMI; the driver waits to receive from the Dispatcher the authorization to press it.
10. The driver enters the Train running number, if it is not valid yet.
11. EVC sends a Position Report message [Msg136], including the Train running number packet [Pkt5].
12. Once authorized by the Dispatcher, the Driver presses the START button.
13. The EVC sends the MA Request message [Msg132] and waits for the authorization to move.
14. RBC sends the Movement Authority message [Msg3] to EVC:
    - An On-Sight (OS) or a Limited Supervision (LS) profile [Pkt80] up to the first signal in front of the train.
    - Full Supervision Movement Authority starting from the first signal in advance of the train up to the last virtual signal where the FS conditions are all fulfilled.

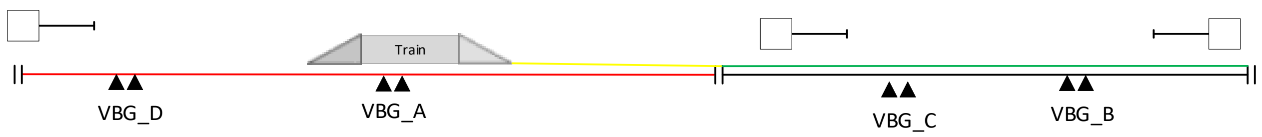

Figure 10 : Line - First Movement Authority with LS mode profile

Note:
RBC can send a MA in FS (without LS or OS profile) if the SoM procedure of the train starts within defined waiting time, which begins on the moment the safe connection is lost.

5.6 START OF MISSION IN LEVEL 2 WITH Q_STATUS "UNKNOWN"

5.6.1 TERMINAL RAILWAY STATION

a) SoM with a train position approximation

This scenario describes a situation where it is possible to associate the NID_ENGINE with the Track Section, previously occupied by Train. This association can be used to discriminate the Track where the train is located.

Rationales:

a) Each platform belonging to a Terminal Railway Station is equipped with two physical BGs:
- One BG aligned with the starting signal
- One BG placed near and in rear (i.e. 30 meters) of the starting signal

b) The EVC and RBC have established a new communication session, as explained in § 5.3.
c) RBC considers the platform occupied by a not connected train (this information is not related to the physical occupation).
d) The conditions of freedom of the Route in advance of the train position (i.e. the departure route is correctly set and locked within the station) are satisfied.
e) RBC has stored the association between Nid_engine and Track section of the train, and then RBC knowns the direction of the train.
f) [Assumption] The VBR has successfully completed the update of the Track DB.

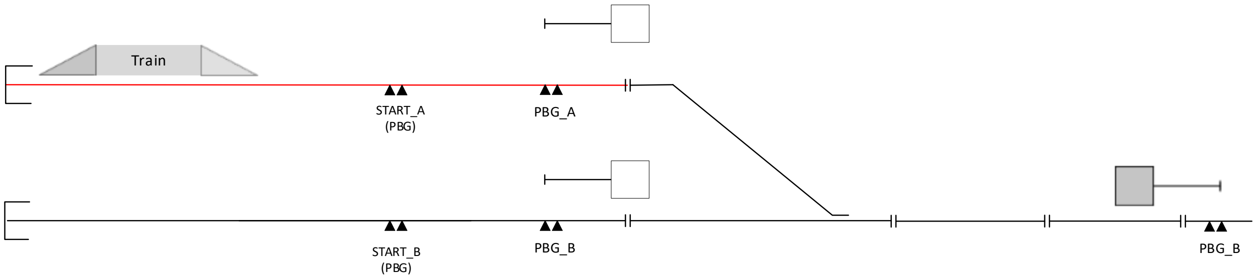

Figure 11 : Terminal Station - SoM with Q_STATUS = "UnKnown"

Events:

1. The EVC sends the Start of Mission Position Report message [Msg157], including the information Q_STATUS = 0/2.
2. RBC considers the SoM PR Invalid/unknown, and then RBC considers the train Not Localized.
3. RBC cannot visualize any train icon on the RBC HMI Monitor.
4. RBC starts the handshake to inform to EVC that the train has been accepted:

- RBC sends Train Accepted message [Msg41] to EVC with [M_ACK = 1]
- EVC sends the ACK message [Msg146] to RBC

5. EVC sends the Validated Train Data message [Msg129] to RBC, including the Position Report packet [Pkt0] and the validated train data packet [Pkt11].
6. RBC receives the message [Msg129], checks the data, considers such data as acceptable, and starts the handshake to acknowledge the Train Data:
   - RBC sends the Acknowledgement of Train Data message [Msg8] with acknowledgement request (M_ACK = 1)
   - EVC sends the ACK message [Msg146] to RBC
   - RBC receives the ACK message [Msg146]
7. The START button is enabled on DMI; the driver waits to receive from the Dispatcher the authorization to press it.
8. The driver enters the Train running number, if it is not valid yet.
9. EVC sends a Position Report message [136], including the Train running number packet [Pkt5].
10. RBC checks that:
    - A not connected train is present on the track section
    - The association between Nid_engine stored and Nid_engine received from the EVC is the same
11. RBC regards the position of the train as "APPROXIMATE".
12. GAD/TV sends the information to select the track in not ambiguous way (or an equivalent information which defines the platform) to the VBR, where the train position is "APPROXIMATE".
13. VBR is initialized.
14. Once authorized by Dispatcher, the Driver presses the START button.
15. The EVC sends the MA Request message [Msg132] and waits for the authorization to move.
16. RBC sends the SR Authorization message [Msg2] to EVC with D_SR=infinite and including the List of Balises in SR Authority packet [Pkt63] including Balise of the current RBS plus the Balise of the RBS in advance.
17. EVC starts to move in SR Mode.
18. The Train detects the first Physical BG (i.e. PBG_A in Figure 11).
19. RBC regards the EVC as localized and commands the visualization of the train icon on the RBC HMI Monitor.
20. RBC sends the Movement Authority message [Msg3] to EVC.
    - An On-Sight (OS) or a Limited Supervision (LS) profile [Pkt80] up to the first signal in front of the train
    - Full Supervision Movement Authority starting from the first signal in advance of the train up to the last virtual signal where the FS conditions are all fulfilled

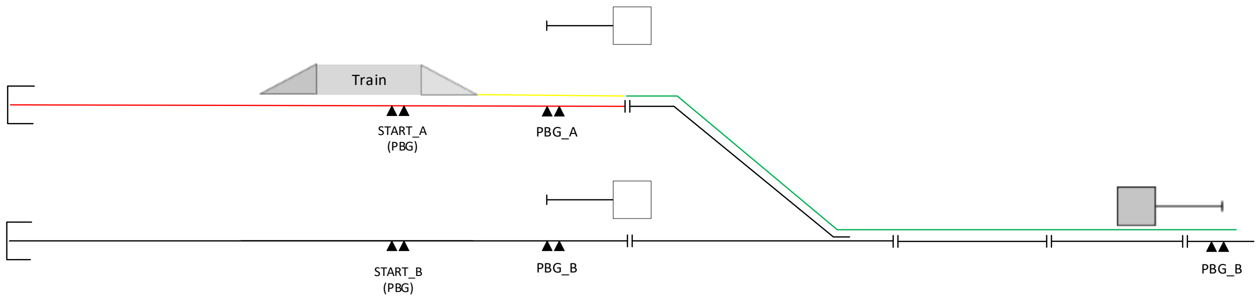

Figure 12 : Terminal Station - First Movement Authority with LS (or OS) mode profile

5.6.2 TMS-RBC CONNECTION IS AVAILABLE

Rationales:

a) Each platform belonging to a Terminal Railway Station is equipped with two physical BGs:
   - One BG aligned with the starting signal
   - One BG placed near and in rear (i.e. 30 meters) of the starting signal

e) The EVC and RBC have established a new communication session, as explained in § 5.3.

b) The conditions of freedom of the Route in advance of the train position (i.e. the departure route is correctly set and locked within the station) are satisfied.

c) RBC is not able to associate the track with train NID_ENGINE.

d) [Assumption] The VBR has successfully completed the update of the Track DB.

e) TMS-RBC connection is available.

Events:

1. The EVC sends the Start of Mission Position Report message [Msg157], including the information Q_STATUS = 0/2.
2. RBC considers the SoM PR Invalid/unknown, then, RBC considers the train Not Localized.
3. RBC cannot visualize any train icon on the RBC HMI Monitor.
4. RBC starts the handshake to inform to EVC that the train has been accepted:
   - RBC sends Train Accepted message [Msg41] to EVC with [M_ACK = 1]
   - EVC sends the ACK message [Msg146] to RBC
5. EVC sends the Validated Train Data message [Msg129] to RBC, including the Position Report packet [Pkt0] and the validated train data packet [Pkt11].
6. RBC receives the message [Msg129], checks the data, considers such data as acceptable and starts the handshake to acknowledge the Train Data:
   - RBC sends the Acknowledgement of Train Data message [Msg8] with acknowledgement request (M_ACK = 1)
   - EVC sends the ACK message [Msg146] to RBC
   - RBC receives the ACK message [Msg146]
7. The START button is enabled on DMI; the driver waits to receive from the Dispatcher the authorization to press it.
8. The driver enters the Train running number, if it is not valid yet.
9. EVC sends a Position Report message [136], including the Train running number packet [Pkt5].
10. RBC checks that:
    - A NID_OPERATIONAL received by the TMS is the same reported by the EVC
    - The track section associated to the NID_OPERATIONAL received by the TMS is considered, by the RBC, occupied by a not connected train (this information is independent from the physical occupancy of the track)
11. RBC notifies to GAD/TV the information related to the not ambiguous train position.
12. GAD/TV sends the information to select the track in not ambiguous way (or an equivalent information which defines the platform) to the VBR, according to the information received by the TMS.

13. RBC regards the position of the train as “APPROXIMATE”.
14. VBR is initialized.
15. Once authorized by the Dispatcher, the Driver presses the START button.
16. The EVC sends the MA Request message [Msg132] and waits for the authorization to move.
17. RBC sends the SR Authorization message [Msg2] to EVC with D_SR=infinite and including the List of Balises in SR Authority packet [Pkt63] including Balise of the current RBS plus the Balise of the RBS in advance.
18. EVC starts to move and detect the first BG (i.e. PBG START_A in Figure 12).
19. RBC regards the EVC as localized and commands the visualization of the train icon on the RBC HMI Monitor.
20. RBC sends the Movement Authority message [Msg3] to EVC:
    - An On-Sight (OS) or a Limited Supervision (LS) profile [Pkt80] up to the first signal in front of the train
    - Full Supervision Movement Authority starting from the first signal in advance of the train up to the last virtual signal where the FS conditions are all fulfilled

5.6.3 ALTERNATIVE PATH

a) Confirmation from the Driver of the Signal Id

In order to integrate the procedure described in §5.6.2, it is possible to introduce steps with the driver’s confirmation. The procedure, described with step from 10 to 12, involves sending a text message containing the "Signal ID" of the signal, which is assumed by RBC is placed in front of the train, which must be confirmed by the Driver after having carried out the visual check.

Note:
The procedure described above remains applicable even if the new steps are not included.

Rationales:

a) Each platform belonging to a Terminal Railway Station is equipped with two physical BGs:
    - One BG aligned with the starting signal
    - One BG placed near and in rear (i.e. 30 meters) of the starting signal

b) The EVC and RBC have established a new communication session, as explained in § 5.3.
c) The conditions of freedom of the Route in advance of the train position (i.e. the departure route is correctly set and locked within the station) are satisfied.
d) RBC is not able to associate the track with train NID_ENGINE.
e) [Assumption] The VBR has successfully completed the update of the Track DB.
f) TMS-RBC connection is available.

Events:

1. The EVC sends the Start of Mission Position Report message [Msg157], including the information Q_STATUS = 0/2.
2. RBC considers the SoM PR Invalid/unknown, then, RBC considers the train Not Localized.
3. RBC cannot visualize any train icon on the RBC HMI Monitor.
4. RBC starts the handshake to inform to EVC that the train has been accepted:
   - RBC sends Train Accepted message [Msg41] to EVC with [M_ACK = 1]
   - EVC sends the ACK message [Msg146] to RBC
5. EVC sends the Validated Train Data message [Msg129] to RBC, including the Position Report packet [Pkt0] and the validated train data packet [Pkt11].
6. RBC receives the message [Msg129], checks the data, considers such data as acceptable and starts the handshake to acknowledge the Train Data:
   - RBC sends the Acknowledgement of Train Data message [Msg8] with acknowledgement request (M_ACK = 1)
   - EVC sends the ACK message [Msg146] to RBC
   - RBC receives the ACK message [Msg146]
7. The START button is enabled on DMI; the driver waits to receive from the Dispatcher the authorization to press it.
8. The driver enters the Train running number, if it is not valid yet.
9. EVC sends a Position Report message [136], including the Train running number packet [Pkt5].
10. RBC checks that:
    - A NID_OPERATIONAL received by the TMS is the same reported by the EVC
    - The track section associated to the NID_OPERATIONAL received by the TMS is considered occupied by RBC (this information is independent from the physical occupancy of the track)
11. RBC sends a General Message [Msg24] including the Packet for sending plain text messages [Pkt72] with the following information:
    - A message with the “Signal Id” associated to the Track is sent to the VBR
    - A request of confirmation from the driver
12. The driver confirms the Text Message on the DMI.
13. EVC sends the Text Message Acknowledged by Driver message [Msg158].
14. RBC notifies to GAD/TV the information related to the not ambiguous train position.
15. GAD/TV sends the information to select the track in not ambiguous way (or an equivalent information which defines the platform) to the VBR, according to the information received by the TMS.
16. RBC regards the position of the train as “APPROXIMATE”.
17. VBR is initialized.
18. Once authorized by the Dispatcher, the Driver presses the START button.
19. The EVC sends the MA Request message [Msg132] and waits for the authorization to move.

20. RBC sends the SR Authorization message [Msg2] to EVC with D_SR=infinite and including the List of Balises in SR Authority packet [Pkt63] including Balise of the current RBS plus the Balise of the RBS in advance.
21. EVC starts to move and detect the first BG (i.e. PBG_A in Figure 12).
22. RBC regards the EVC as localized and commands the visualization of the train icon on the RBC HMI Monitor.
23. RBC sends the Movement Authority message [Msg3] to EVC:
    - An On-Sight (OS) or a Limited Supervision (LS) profile [Pkt80] up to the first signal in front of the train
    - Full Supervision Movement Authority starting from the first signal in advance of the train up to the last virtual signal where the FS conditions are all fulfilled

5.6.4 TMS-RBC CONNECTION IS NOT AVAILABLE

Rationales:

a) Each platform belonging to a Terminal Railway Station is equipped with two physical BGs:
    - One BG aligned with the starting signal
    - One BG placed near and in rear (i.e. 30 meters) of the starting signal
b) The EVC and RBC have established a new communication session, as explained in § 5.3.
c) The conditions of freedom of the Route in advance of the train position (i.e. the departure route is correctly set and locked within the station) are satisfied.
d) RBC is not able to associate the track with train NID_ENGINE.
e) [Assumption] The VBR has successfully completed the update of the Track DB.

Events:

1. The EVC sends the Start of Mission Position Report message [Msg157], including the information Q_STATUS = 0/2.
2. RBC considers the SoM PR Invalid/unknown, and then RBC considers the train Not Localized.
3. RBC cannot visualize any train icon on the RBC HMI Monitor.
4. RBC starts the handshake to inform to EVC that the train has been accepted:
    - RBC sends Train Accepted message [Msg41] to EVC with [M_ACK = 1]
    - EVC sends the ACK message [Msg146] to RBC
5. EVC sends the Validated Train Data message [Msg129] to RBC, including the Position Report packet [Pkt0] and the Validated Train Data packet [Pkt11].
6. RBC receives the message [Msg129], checks the data, considers such data as acceptable and starts the handshake to acknowledge the Train Data:
    - RBC sends the Acknowledgement of Train Data message [Msg8] with acknowledgement request (M_ACK = 1)
    - EVC sends the ACK message [Msg146] to RBC
    - RBC receives the ACK message [Msg146]

7. The START button is enabled on DMI; the driver waits to receive from the Dispatcher the authorization to press it.
8. The Driver enters the Train running number, if it is not valid yet.
9. EVC sends a Position Report message [Msg136], including the Train running number packet [Pkt5].
10. Dispatcher authorises the Driver to start the procedure of OVERRIDE.
11. Once authorized, the Driver starts the procedure of OVERRIDE.
12. EVC starts to move in SR Mode, and detect the first BG (i.e. PBG_A).
13. VBR is initialized.
14. RBC regards the EVC as localized and commands the visualization of the train icon on the RBC HMI Monitor.
15. RBC sends the Movement Authority message [Msg3] to EVC:
    - An On-Sight (OS) or a Limited Supervision (LS) profile [Pkt80] up to the first signal in front of the train
    - Full Supervision Movement Authority starting from the first signal in advance of the train up to the last virtual signal where the FS conditions are all fulfilled

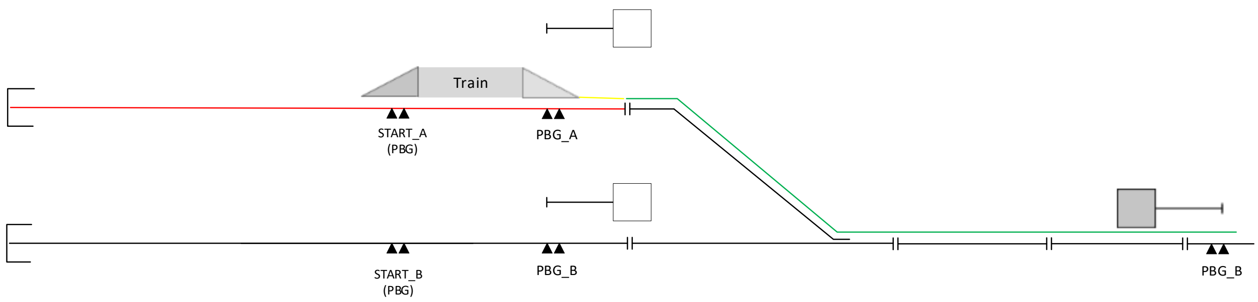

Figure 13 : Terminal Station - First Movement Authority with LS (or OS) mode profile

5.6.5 ALTERNATIVE PATH

a) Train position approximation with command from Dispatcher

Rationales:

a) Each platform belonging to a Terminal Railway Station is equipped with two physical BGs:
    - One BG aligned with the starting signal
    - One BG placed near and in rear (i.e. 30 meters) of the starting signal
b) The EVC and RBC have established a new communication session, as explained in § 5.3.
c) The conditions of freedom of the Route in advance of the train position (i.e. the departure route is correctly set and locked within the station) are satisfied.
d) RBC is not able to associate the track with train NID_ENGINE.
e) A command to the Dispatcher to set track in not ambiguous way is available.
f) [Assumption] The VBR has successfully completed the update of the Track DB.

Events:

1. The EVC sends the Start of Mission Position Report message [Msg157], including the information Q_STATUS = 0/2.
2. RBC considers the SoM PR Invalid/Unknown and then RBC considers the train Not Localized.
3. RBC cannot visualize any train icon on the RBC HMI Monitor.
4. RBC starts the handshake to inform to EVC that the train has been accepted:
   - RBC sends Train Accepted message [Msg41] to EVC with [M_ACK = 1]
   - EVC sends the ACK message [Msg146] to RBC
5. EVC sends the Validated Train Data message [Msg129] to RBC, including the Position Report packet [Pkt0] and the Validated train data packet [Pkt11].
6. RBC receives the message [Msg129], checks the data, considers such data as acceptable and starts the handshake to acknowledge the Train Data:
   - RBC sends the Acknowledgement of Train Data message [Msg8] with acknowledgement request (M_ACK = 1)
   - EVC sends the ACK message [Msg146] to RBC
   - RBC receives the ACK message [Msg146]
7. The START button is enabled on DMI; the Driver waits to receive from the Dispatcher the authorization to move.
8. The driver enters the Train running number, if it is not valid yet.
9. EVC sends a Position Report message [Msg136], including the Train running number packet [Pkt5].
10. GAD/TV sends to the VBR the information to select the track in not ambiguous way (or an equivalent information which defines the platform) where the train is localised, according to the command from the Dispatcher.
11. RBC sends a General Message [Msg24] including the Packet for sending plain text messages [Pkt72] with the following information:
    - A message with the “Signal Id” associated to the Track selected by the Dispatcher
    - Request of confirmation from the driver
12. The driver confirms the Text Message on the DMI.
13. EVC sends the Text Message Acknowledged by Driver message [Msg158].
14. RBC regards the position of the train as “APPROXIMATE”.
15. VBR is initialized.
16. Once authorized by the Dispatcher, the Driver presses the START button.
17. The EVC sends the MA Request message [Msg132] and waits for the authorization to move.
18. RBC sends the SR Authorization message [Msg2] to EVC with D_SR=infinite and including the List of Balises in SR Authority packet [Pkt63], including Balise of the current RBS plus the Balise of the RBS in advance.
19. EVC starts to move and detect the first BG (i.e. PBG_A in Figure 14).
20. RBC regards the EVC as localized and commands the visualization of the train icon on the RBC HMI Monitor.
21. RBC sends the Movement Authority message [Msg3] to EVC:

- An On-Sight (OS) or a Limited Supervision (LS) profile [Pkt80] up to the first signal in front of the train
- Full Supervision Movement Authority starting from the first signal in advance of the train up to the last virtual signal where the FS conditions are all fulfilled

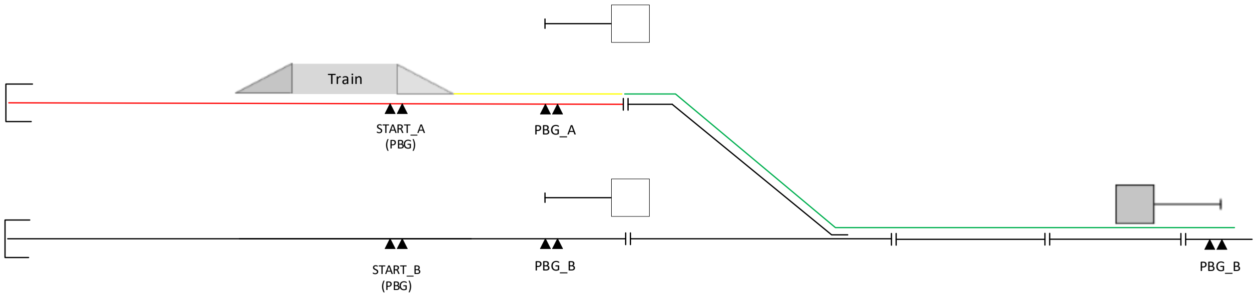

Figure 14 : Terminal Station - First Movement Authority with LS (or OS) mode profile

5.6.6 INTERMEDIATE RAILWAY STATION

Rationales:

a) Each platform belonging to an Intermediate Railway Station is equipped with one physical BG aligned to each starting signal.
b) The EVC and RBC have established a new communication session, as explained in § 5.3.
c) The conditions of freedom of the Route in advance of the train position (i.e. the departure route is correctly set and locked within the station) are satisfied.
d) [Assumption] The VBR has successfully completed the update of the Track DB.

Event:
The scenario is the same described in § 5.6.1.

5.6.7 LINE

This scenario represents a degraded case with respect to the nominal one, where the train would not perform a SoM along the line. This would happen only due to a fault and after the previous Communication Session has been closed.
The line is equipped only with virtual balises (i.e VBG_A).

Rationales:

a) The Driver has performed an EoM along the line.
b) The communication session is considered as closed due a Safe Connection Failure.
c) The EVC and RBC have established a new communication session, as explained in § 5.3.
d) RBC considers the line track section as occupied by a not connected train (this information is not related to the physical occupation).
e) [Assumption] The VBR has successfully completed the update of the Track DB.

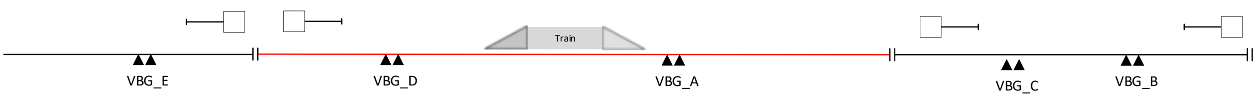

Figure 15 : Line - SoM with Q_STATUS = "UnKnown"

Events scenario are the same described in §5.6.1, with the following exception:

- EVC starts to move and detect the first VBG (i.e. VBG_A in Figure 15).

CONCLUSIONS

In the frame of the WP 2 of the ERSAT GGC Project, the Enhanced ERTMS Functional Architecture, suitable for the introduction of the GNSS technology and the Virtual Balise concept, and for the integration of the IP based Public Mobile Radio Networks has been analysed.
As a continuation of the previous research projects (ERSAT-EAV, NGTC, STARS, RHINOS, SBS, etc.), the Enhanced ERTMS Functional Architecture has been developed and consolidated; the specification of the proposed Functional Architecture has been produced in the current document.

In addition, the strategy for guaranteeing the backward compatibility with existing ERTMS systems, for minimizing the impact on the current ERTMS procedures, and for avoiding the introduction of criticality with respect to the suppliers of ERTMS Technology, has been evaluated with positive results.

In particular, the proposed Enhanced ERTMS Functional Architecture includes:

- The functional description of the required new functional blocks at the level of On-Board and RBC constituents;
- The identification and the functional description of the new interfaces;
- The main ERTMS procedures affected by the introduction of such new functionalities;
- The signalling mitigations required for coping with hazards introduced by the GNSS based Virtual Balise detection.

The Enhanced ERTMS Functional Architecture developed in the current document has been object of the Safety Analysis in the frame of WP3.1 of the ERSAT GGC Project, and will be furtherly evaluated and assessed during the WP3.2 and WP5 of ERSAT GGC.

Additionally, in the WP2.1 or ERSAT GGC the specification of Functional and Non Functional Tests applicable to the Enhanced ERTMS Functional Architecture will be developed.

These steps will lead to the certification process of the satellite assets to allow the ERTMS to operate seamlessly with Virtual Balises, and represent a fundamental contribution to the roadmap of the ERTMS for the adoption of the EGNSS satellite technology and the Public Radio TLC Technologies.

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