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GNSS Augmentation for ERTMS/ETCS

System Requirement Specification

EUG Solution for Enhanced Onboard Localisation Change Request (CR1368) – GNSS Augmentation for ERTMS/ETCS

Ref: 20E085
Version: 0g
Date: 06/10/2023

Modification history

Version	Date	Modification / Description	Editor
0a	01/05/2020	Initial version (incomplete draft)	C. Wullems (ESA)
0a	21/05/2020	Initial version (incomplete draft) – update	C. Wullems (ESA)
0a	26/05/2020	Update after internal review (C. Lopez de Echazarreta, ESA)	
0a	05/06/2020	Update after internal review (C. Neville, EUSPA)	
0a	15/06/2020	Update after internal review (E. Lacarra, R. González, N. Blanco, ESSP)	
0b	01/07/2020	Major update considering a new TTA mechanism and possibility to resume SBAS message streams	C. Wullems (ESA)
0c	08/07/2020	Initial draft release	C. Wullems (ESA)
0d	14/04/2022	Major update and revision to implement comments from JWG review (EUG, Shift2Rail X2Rail5-WP5: Alstom, Hitachi Rail STS, AŽD, CAF, NSL)	C. Wullems (ESA)
0e	29/04/2022	Update after internal review (C. Lopez de Echazarreta, F. Salgueiro, ESA)	
0e	03/05/2022	Update after review by X2Rail5-WP5 (L. Freda Albanese, F. Poli, Hitachi Rail STS)	
0e	04/05/2022	Update after internal review (C. Neville, EUSPA)	
0e	09/05/2022	Update after review by X2Rail5-WP5 (V. Karel, AŽD)	
0e	14/05/2022	Update after review by X2Rail5-WP5 (A. Lucidi, L. Cuvelier, Alstom)	
0e	25/05/2022	Update after internal review (G. Fernandez, ESSP)	
0f	31/05/2022	Draft release for EURAIL System Pillar	C. Wullems (ESA)
0g	30/05/2023	Update after workshop 29/09/2022 <ul style="list-style-type: none"> • updated reference architecture in figure 2-1 addressing action items related to simplification of trackside functions; • updated basic functions in section 2.1, GA functions in section 2.2, and operational states of GA-OB and GA-TS in section 2.3 and 2.4 for alignment with simplified reference architecture; and • updated section 2.2 and 3 addressing action items related to protocol changes 	C. Wullems (ESA)

		(e.g., removal of versioning), updated sequence diagrams, descriptions of protocol.	
0g	15/06/2023	<p>Document update:</p> <ul style="list-style-type: none"> • Updated section 2.2 to address simplification of navigation data handling (encapsulation of GNSS navigation data), improvement of GNSS navigation data selection parameters; • Updated section 2.2, replacing packet and message numbers with names, aligned with ICD, to avoid impact of renumbering changes; • Update of Annex A, simplification and reorganisation of content, improving readability; • Update of Annex B, aligning figures and content with simplified reference architecture, addition of section on hypothetical EGNOS SIS performances (replacing table previously in Annex A); and • Editorial updates improving readability, correction of typographical errors. 	C. Wullems (ESA)
0g	10/08/2023	Update after internal review (E. Lacarra, G. Fernandez, ESSP)	
0g	27/09/2023	Minor updates (correction of typographical errors, removal of paragraph that referenced removed versioning mechanism)	C. Wullems (ESA)
0g	06/10/2023	Minor updates after JWG workshop 02/10/2023. Draft release for input to ERJU work packages on GNSS Augmentation for Rail based on EGNOS.	C. Wullems (ESA)

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1 Introduction

1.1 Scope and Purpose

- 1.1.1.1 The GNSS Augmentation (GA) dissemination framework for ERTMS/ETCS aims to support the use of GA Systems such as EGNOS (the European Geostationary Navigation Overlay Service) to enable the use of GNSS in on-board train localisation in a technology-neutral manner.
- 1.1.1.2 GA Systems use ground monitoring stations at known positions to receive and process navigation signals from core GNSS constellations with the objective of protecting users from feared events (e.g., satellite failures), estimating common errors (e.g., satellite orbit / clock errors, ionospheric errors that are also applicable to users) and providing differential corrections and integrity information (statistical bound on the correction residual errors and ionospheric errors) to users to improve accuracy and increase confidence in the positioning solution.
- 1.1.1.3 GA can play an important role in supporting safe positioning concepts for on-board localisation with benefits including the following:
- GA is very effective in detecting system faults as it has access to ground truth. Techniques such as RAIM for the detection of satellites faults is intrinsically weaker, as receiver autonomous techniques require the navigation solution to be overdetermined, and therefore require at least 5 satellites (more for fault detection and exclusion) and requirements for strong geometry. GA can protect the user against system faults even with only 4 satellites.
 - The use of GA allows GNSS satellites to be utilised more efficiently, as a failed satellite does not need to be detected by the GNSS receiver. In the case of a failed satellite, the receiver performance is not impacted other than by the loss of a ranging source.
 - The use of regional augmentation systems such as EGNOS provides an opportunity to leverage existing investments made for aviation with regional-level service coverage.
- 1.1.1.4 The concept of the GA dissemination framework for ERTMS/ETCS was defined by a Joint Working Group comprised of the EEIG ERTMS Users Group, ESA, EUSPA, and Shift2Rail X2Rail5-WP5.
- 1.1.1.5 The **scope** of this document is to define the system functional requirements for an interoperable GA dissemination framework for ERTMS/ETCS, enabling the use of GNSS augmentation in a technology-neutral manner.
- 1.1.1.6 The **purpose** of this document is to define the system requirements that must be fulfilled to provide interoperable GA. This document defines the following:
- GA functional architecture and interfaces (defined to the level required to support interoperability and safety analyses);
 - GA-related functions; and
 - GA operational states.

1.1.1.7 The annexes of this document provide additional support information:

- Train positioning in ERTMS/ETCS using GNSS and augmentation, including general principles of GNSS augmentation for ERTMS/ETCS;
- EGNOS-based GA for ERTMS/ETCS; and
- Open points to be addressed.

1.1.1.8 This document is part of a package of documents on the GS for ERTMS/ETCS in support of Change Request (CR1368). The package is comprised of the following documents:

- GNSS Augmentation for ERTMS/ETCS – System Requirement Specification [EUG-20E085] (this document)
- GNSS Augmentation for ERTMS/ETCS – Interface Control Document for GA-OB / GA-TS (Airgap) [EUG-20E087]
- GNSS Augmentation for ERTMS/ETCS – System Functional Hazard Analysis [EUG-20E086]

1.2 References

1.2.1.1 The following documents are references in this document:

PERSPECTIVE	ERA, "Report on ERTMS Longer Term Perspective," 18/12/2015.
[SS040]	UNISIG, "ERTMS/ETCS – Dimensioning and Engineering Rules – SUBSET-040 Issue 3.4.0." 2015
[SS041]	UNISIG, "ERTMS/ETCS – Performance Requirements for Interoperability – SUBSET-041 Issue 3.2.0." 2015.
[SS091]	UNISIG, "ERTMS/ETCS – Safety Requirements for the Technical Interoperability of ETCS in Levels 1 & 2 – SUBSET-091 Issue 3.6.0." 2016.
[EUG-20E087]	EUG, "GNSS Augmentation for ERTMS/ETCS – Interface Control Document for GA-OB / GA-TS (Airgap). Version 0g." 2023.
[EUG-20E086]	EUG, "GNSS Augmentation for ERTMS/ETCS – System Functional Hazard Analysis. Version 0g." 2023.
[EN50159]	CENELEC, "Railway applications – Communication, signalling and processing systems – Safety-related communication in transmission systems – EN 50159." CENELEC, Brussels, Belgium, 2010.
[DO-229]	RTCA, "DO-229F – Minimum Operational Performance Standards for Global Positioning System/Satellite Based Augmentation System Airborne Equipment." RTCA Inc., Washington D.C., USA, 2020.

[ED-259]	EUROCAE, “ED-259A (v0.17) – Minimum Operational Performance Standard for Galileo / Global Positioning System / Satellite-based Augmentation System Airborne Equipment.” Saint-Denis, France, 2023.
[IS-GPS-200]	GPS Directorate, “Interface Specification – NAVSTAR GPS Space Segment / Navigation User Segment User Interfaces – IS-GPS-200. Rev. N.” 2022.
[IS-GPS-705]	GPS Directorate, “Interface Specification – NAVSTAR GPS Space Segment / User Segment L5 Interfaces – IS-GPS-705. Rev. J.” 2022.
[GPS-SPS-PS]	United States Department of Defense, “Global Positioning System Standard Positioning Service Performance Standard – 5 th Edition” 2020.
[GAL-OS-SIS-ICD]	European Commission, “European GNSS (Galileo) Open Service – Signal-in-Space Interface Control Document. Issue 2.0.” 2021.
[GAL-OS-SDD]	European Commission, “European GNSS (Galileo) Open Service – Service Definition Document. Issue 2.1.” 2021.

1.3 Terms and Abbreviations

1.3.1.1 The following terms and abbreviations are used in this document:

ATO	Automatic Train Operations
ATP	Automatic Train Protection
BGD	Broadcast Group Delay
CCS	Control-Command and Signalling
CED	Clock and Ephemeris Data
CPF	Central Processing Facility
CRC	Cyclic Redundancy Check
DFC	Dual Frequency Correction
DFMC	Dual Frequency Multiple Constellation
DFRE	Dual Frequency Range Error (dual frequency UDRE)
DFRECI	Dual Frequency Range Error Change Indicator
DFREI	Dual Frequency Range Error Indicator
EEIG	European Economic Interest Group
EGNOS	European Geostationary Navigation Overlay Service (SBAS developed by the European Union)
ENT	EGNOS Network Time
ERA	European Union Agency for Railways (formerly European Railway Agency)
ERJU	Europe's Rail Joint Undertaking
ERTMS	European Rail Traffic Management System
ESA	European Space Agency
ESSP	European Satellite Services Provider
ETCS	European Train Control System
EUG	EEIG ERTMS Users Group
EUSPA	European Union Agency for the Space Programme (formerly European GNSS Agency)
FA	Operational state: Failure
FRMCS	Future Railway Mobile Communication System

GA	GNSS Augmentation
GAC	GNSS Augmentation Channel
GADF	GNSS Augmentation Dissemination Function
GAM	GNSS Augmentation Message
GA-OB	GNSS Augmentation On-board
GAS	GNSS Augmentation System
GA-TS	GNSS Augmentation Trackside
GEO	Geostationary Earth Orbit
GIVE	Grid Ionospheric Vertical Error
GN	Operational state: GA Message Stream Not Available
GNSS	Global Navigation Satellite System
GO	Operational state: GA Message Stream Operational
GPS	Global Positioning System
GR	Operational state: GA Message Stream Ready
ICD	Interface Control Document
IGSO	Inclined GeoSynchronous Orbits
IOD	Issue of Data
IODC	Issue of Data Clock
IODE	Issue of Data Ephemeris
IODF	Issue of Data Fast Corrections
IODG	Issue of Data used for matching MT39/40 pair in DFMC service
IODI	Issue of Data Ionospheric
IODN	Issue of Data Navigation Data (Galileo E1 I/NAV and E5a F/NAV)
IODM	Issue of Data Mask
IODP	Issue of Data PRN Mask
IODS	Issue of Data Service
KF	Kalman Filter
LPV	Localizer Performance with Vertical Guidance
MCC	Mission Control Centre
MOPS	Minimum Operation Performance Standard

MT	Message Type
NLES	Navigation Land Earth Station
NLOS	Non-Line-Of-Sight
NP	Operational state: No Power
NPA	Non-Precision Approach
OBAD	Old But Active Data
OBU	On-Board Unit
OP	Operational
OS	Open Service
PRN	Pseudo-Random Noise
RAIM	Receiver Autonomous Integrity Monitoring
RAM	Reliability, Availability and Maintainability
RBC	Radio Block Centre
RFI	Radio Frequency Interference
RIMS	Range and Integrity Monitoring Stations
RSS	Root-Sum-Square
RTCA	Radio Technical Commission for Aeronautics
SARPs	Standards and Recommended Practices
SB	Operational state: Standby
SBAS	Satellite Based Augmentation System
SDD	Service Definition Document
SFSC	Single Frequency Single Constellation
SIS	Signal in Space
SNT	SBAS Network Time
SoL	Safety of Life
SQM	Signal Quality Monitoring
SV	Satellite Vehicle
TBC	To Be Confirmed
TBD	To Be Defined
TEC	Total Electron Content

THR	Tolerable Hazard Rate
TSI	Technical Specification for Interoperability
TTA	Time To Alert
UDRE	User Differential Range Error
UDREI	User Differential Range Error Indicator
UIRE	User Ionospheric Range Error
UTC	Universal Time Coordinate
VLF	Vehicle Localisation Function
VLS	Vehicle Localisation Sensor
VPL	Vertical Protection Level
WLS	Weighted Least Squares
xAL	Horizontal or Vertical Alert Limit
xPL	Horizontal or Vertical Protection Level

2 GNSS Augmentation (GA) for ERTMS/ETCS

2.1 Overview

2.1.1.1 The GNSS augmentation dissemination framework for ERTMS/ETCS has been designed as an agnostic framework supporting GNSS augmentation systems that are based on compatible principles, i.e., provision of a pseudorange domain integrity service meeting minimum signal-in-space performance requirements. This ensures a future-proof approach that can support services as they evolve and provide different interfaces, additional capabilities, and additional commitments.

2.1.1.2 An overview of the proposed approach and general principles for GNSS augmentation in ERTMS/ETCS are described in Annex A. Specificities of the hypothetical use of the European Satellite Based Augmentation System (SBAS), EGNOS – European Geostationary Navigation Overlay Service, is provided in Annex B, with an illustrative example of EGNOS services and performances.

2.1.1.3 The following sections describe the GA dissemination framework, including:

- The reference functional architecture;
- Basic functions of GA for ERTMS/ETCS;
- Requirements for functions of the GA dissemination framework;
- The operational states, state transitions and active functions for each operational state of on-board and trackside GA elements; and
- Configuration management.

2.1.2 GA Reference Functional Architecture

2.1.2.1 Figure 2-1 illustrates the high-level reference functional architecture of GNSS Augmentation for ERTMS/ETCS, which is comprised of the GNSS Augmentation On-board (GA-OB) and GNSS Augmentation Trackside (GA-TS):

- a) The GA-OB includes GNSS receiver(s), one type of several Vehicle Localisation Sensors (VLSs) used by the Vehicle Localisation Function (VLF), and GNSS Augmentation Processing within the VLF.
- b) The GA-TS includes the GNSS Augmentation Dissemination Function (GADF) and the trackside interfaces to the GNSS Augmentation System (GAS) and GNSS.

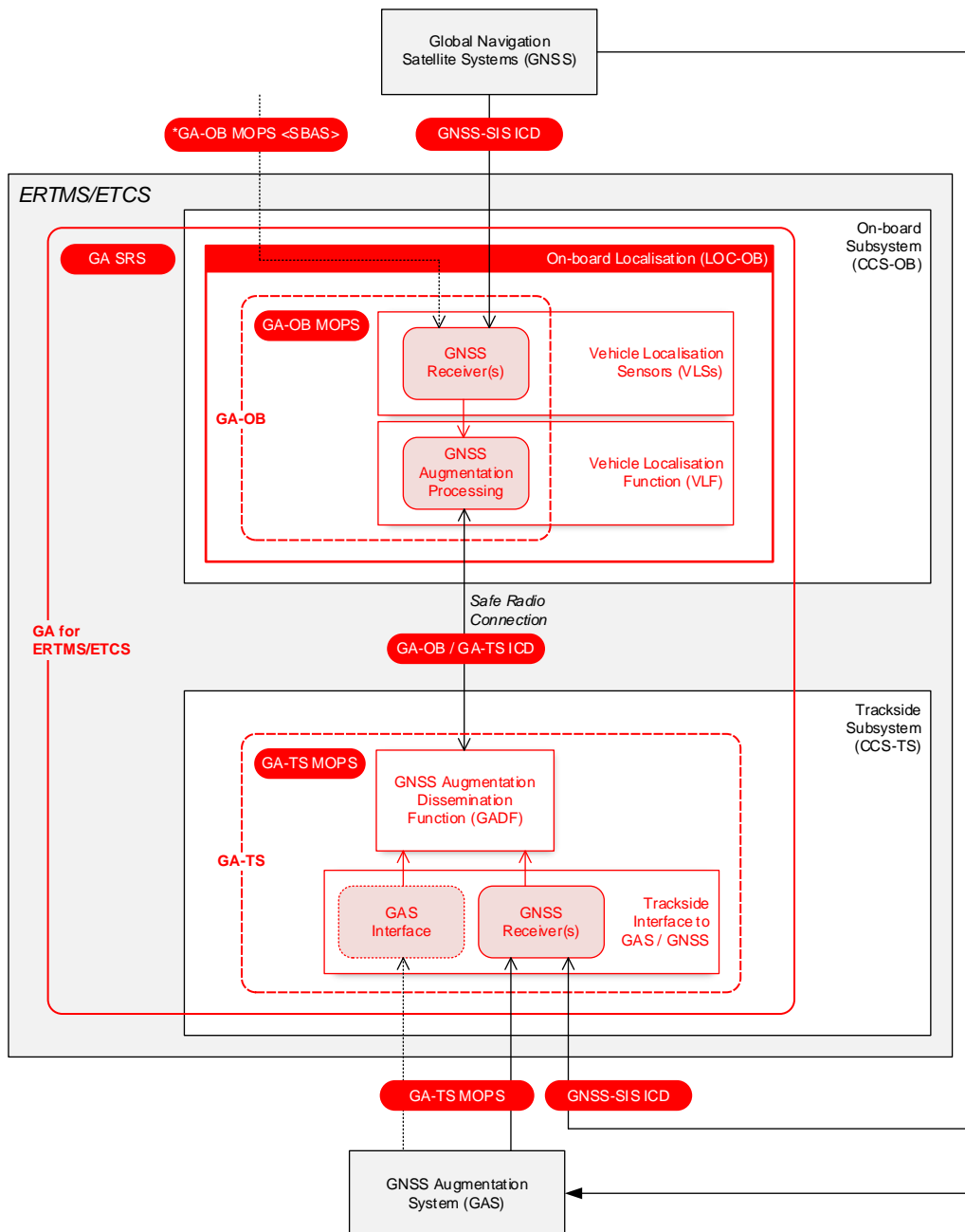


Figure 2-1. GNSS Augmentation Reference Functional Architecture for ERTMS/ETCS

2.1.2.2 The Vehicle Localisation Function (VLF) utilises GNSS augmentation to improve position accuracy and derive a statistical bounding (at the required level of confidence) on position errors through the application of corrections and residual pseudorange error models. The on-board GNSS receiver(s) and GNSS augmentation processing shall conform to the specific Minimum Operational Performance Standards (MOPS) of one or more of the GNSS augmentation services that are supported by the trackside. It is assumed the trackside would support a mandatory set of EGNOS-based services linked with a future baseline (ETCS version) for Europe. Markets outside of Europe are not constrained by the CCS TSI.

2.1.2.3 The GA-OB MOPS would define assumptions on the GNSS receiver configuration space (carrier smoothing filter, correlator type and spacing, GNSS signal bandwidth, group delay, etc.), and would address requirements on GNSS signal and message processing, GAS

message processing and computation of pseudorange error bounds for the specific GNSS augmentation service.

- 2.1.2.4 In addition to reception of GNSS augmentation information via the trackside, the GA-OB may support direct reception of SBAS messages via the SBAS GEO SIS; however, principles for use of this interface are not currently defined in this version of the SRS¹. It should be noted that information from EGNOS received by the VLF via the GS-TS and via the SBAS GEO SIS cannot be mixed in a single GNSS processing channel.
- 2.1.2.5 The GA-TS is responsible for the interface to the GNSS Augmentation System (GAS). The GNSS Augmentation Dissemination Function (GADF) is responsible for the dissemination of GA messages containing correction and integrity information to the GA-OB. The GADF timestamps and encapsulates GA messages in GAM packets, leaving the in-built message protections (e.g., CRC) intact. While the GADF performs some message processing (e.g., in support of maintaining active data sets), by encapsulating GA messages, the complexity of the function is greatly reduced, and assumptions related to inbuilt defences against message-level hazards that are assumed by the GNSS augmentation service and its respective integrity commitments are maintained. The GADF can also provide GNSS navigation data to the GA-OB to support faster start-up time, especially in difficult start-up environments (e.g., where there is significant obscuration of GNSS satellites).
- 2.1.2.6 The GA-TS also is responsible for obtaining navigation data from the Global Navigation Satellite System (GNSS), where subframes / pages / messages containing navigation data are encapsulated and provided to the GA-OB. This includes GNSS navigation data for constellations supported by the GAS (e.g., for EGNOS: GPS LNAV and Galileo F/NAV).
- 2.1.2.7 The ICD for GA-OB / GA-TS [EUG-20E087] defines interoperability-relevant messages, packets and variables exchanged between the GA-OB and GA-TS.
- 2.1.2.8 The Safe Radio Connection between the GA-OB and GA-TS is intentionally left undefined; for example, it could potentially be the EURORADIO channel between the on-board and trackside or a dedicated GNSS augmentation channel between the GA-OB and GA-TS provided by the FRMCS.

2.1.3 GA Functions

- 2.1.3.1 GNSS Augmentation for ERTMS/ETCS is comprised of the functions listed in Table 2-1. The table additionally indicates the documents where requirements are defined each of the functions.

¹ The majority of stakeholders (suppliers and users involved in the CR1368 JWG) have not identified a need for this interface, rather citing that it significantly increases complexity. A task within X2Rail5 has been defined to provide justification for this interface and to inform a decision to keep or remove the interface – Refer to Open Items in Annex C.

Table 2-1. Functions of GNSS Augmentation for ERTMS/ETCS

Macro Function / Sub Function		GA Dissemination Framework Requirements (SRS)	On-board GA-Specific Requirements (GA-OB MOPS)	Trackside GA-Specific Requirements (GA-TS MOPS)	GNSS-Specific Signal-in-Space ICD (GNSS-SIS-ICD)	Messages, packets and variables exchanged over airgap for GA (GA-OB / GA-TS ICD)
F1	Vehicle Localisation Sensors (VLSs) <GNSS Receiver>					
F1.1	Process GNSS signal		X		X	
F2	Vehicle Localisation Function (VLF) <GNSS Augmentation Processing>					
F2.1	Process GNSS navigation data (received from GNSS receiver and GA-TS)	X	X		X	X
F2.2	Process GA messages (received from GA-TS)	X	X			X
F2.3	GNSS pseudorange determination and use		X			
F2.4	Compute and apply GNSS pseudorange error models (GA-provided integrity)		X			
F2.5	Supervise GA message content timeout	X	X			
F2.6	Supervise and manage TTA	X	X			
F2.7	Manage GA session	X				X
F3	Trackside Interface to SBAS / GNSS <GNSS Receiver>					
F3.1	Process SBAS signal			X		
F3.2	Process GNSS signal			X	X	
F4	Trackside Interface to GAS <TBD> (future placeholder)					
F5	GNSS Augmentation Dissemination Function (GADF)					
F5.1	Select GACs	X		X		
F5.2	Process GA messages for selected GACs (received from trackside interface to SBAS / GAS)	X		X		
F5.3	Provide GA message stream(s)	X				
F5.4	Provide GA active data for selected GACs	X				
F5.5	Provide GA active alerts for selected GACs	X				
F5.6	Process GNSS navigation data (received from trackside interface to GNSS)	X		X	X	
F5.7	Provide GNSS navigation data sets	X			X	
F5.8	Manage GA session	X				X

Note: Functionality related to reception of SBAS messages by the on-board GNSS receiver(s) from the SBAS GEO SIS is not addressed in this document. If it is decided to keep this interface, it will be addressed in a future release of the document.

2.2 GA Session Management

2.2.1 Initiating a GA Session

2.2.1.1 The GA-OB can request a GNSS augmentation (GA) session when:

- a) GNSS Augmentation is supported by the system version; and
- b) A communication session between the GA-OB and GA-TS has been established.

2.2.1.2 A GA session shall be established according to the following steps:

- a) The GA-OB shall send an *Initiate GA Session* message to the GA-TS.
- b) The GA-TS shall respond with a *GA Session Established* message, indicating GA session has been established.
 - If the GA-TS is unable to establish the GA session, it shall respond with a *GA Session Error* message (with M_GAERR=0, *Unable to establish GA session*)
- c) Upon reception of the *GA Session Established* message, the GA-OB shall acknowledge establishment of the GA session to the trackside.

2.2.1.3 Once a GA session is established, the GA-OB can request allocation of a GA message stream (stream of GNSS augmentation messages from the GA-TS) or resumption of a previously suspended GA message stream (refer to Section 2.2.2).

2.2.1.4 To request allocation of a GA message stream, the GA-OB shall send an *Allocate GA Message Stream* message with the GA message stream identifier (NID_GAMS) and the GA services supported by the GA-OB. Valid GA message stream identifiers are:

- NID_GAMS = 0, Primary GA message stream (shall be supported by the GA-OB)
- NID_GAMS = 1, Secondary GA message stream (may optionally be supported by the GA-OB)

2.2.1.5 The GA-TS shall respond as follows:

- a) If the GA-TS can provide a GA message stream with a service compatible with GA services supported by the GA-OB, it shall respond with a *GA Message Stream Allocated / Resumed* message including of the following information:
 - GA message stream identifier (NID_GAMS)
 - GA service identifier (NID_GAS)
 - GA channel identifier (NID_GAC)
 - GA service national values (configuration values that are specific to the GNSS augmentation service).
- b) The GA-TS requires the *GA Message Stream Allocated / Resumed* message to be acknowledged by the GA-OB before starting to send GA Messages associated with the allocated GA message stream.
- c) If a GA message stream has already been allocated, the GA-TS shall allocate a GA message stream for a different GA channel from the same service provider or from a different service provider for a service compatible with GA services supported by the GA-OB.
- d) If the GA-TS cannot provide a GA message stream compatible with supported GA services, it shall respond with a *GA Session Error* message (with M_GAERR=0, *Unable to establish GA session*).

2.2.1.6 The National Values for the GA service include the following:

- GA Maximum System TTA (T_NVGAMAXSYSTTA)
- GA Maximum TTA (T_NVGAMAXTTA)
- GA Broadcast Update Rate (T_NVGAMBUR)

2.2.1.7 A *GA Message* contains the following information:

- GA message stream identifier (NID_GAMS)
- One or more GNSS Augmentation Message (GAM) packets including:
 - GNSS augmentation message type (Q_GAMT), indicating whether encapsulated message is a nominal message or an alert message. Q_GAMT is also used to indicate “do not use GA message stream”;
 - GA reference time qualifier (Q_GAT);
 - Timestamp of the end of GNSS augmentation message reception by the GA-TS (T_GAM) in reference time indicated by Q_GAT; and
 - GA message (M_GAM), encapsulating the GNSS augmentation message.

2.2.1.8 The GA-TS shall continue sending *GA Messages* associated with the allocated GA message stream(s) to the GA-OB until terminated by:

- A request from the GA-OB to suspend a GA message stream;
- Termination of the GA session by the GA-OB or the GA-TS; or
- Termination of the underlying communication session between the GA-OB and GA-TS.

2.2.1.9 The GA-OB can suspend a GA message stream by sending a *Suspend GA Message Stream* message with the relevant GA message stream identifier (NID_GAMS) to the GA-TS. The GA-TS shall respond with a *GA Message Stream Suspended* message, confirming suspension of the message stream.

2.2.1.10 The GA-OB can terminate a GA session (and any active GA message streams) by sending a *Terminate GA Session* message to the GA-TS. The GA-TS shall respond with a *GA Session Terminated* message.

2.2.1.11 If the GA-TS terminates a GA session, it shall send a *GA Session Terminated* message, requiring the message to be acknowledged by the GA-OB.

2.2.1.12 An example of establishing and terminating a GA session is illustrated by the sequence diagram in Figure 2-2.

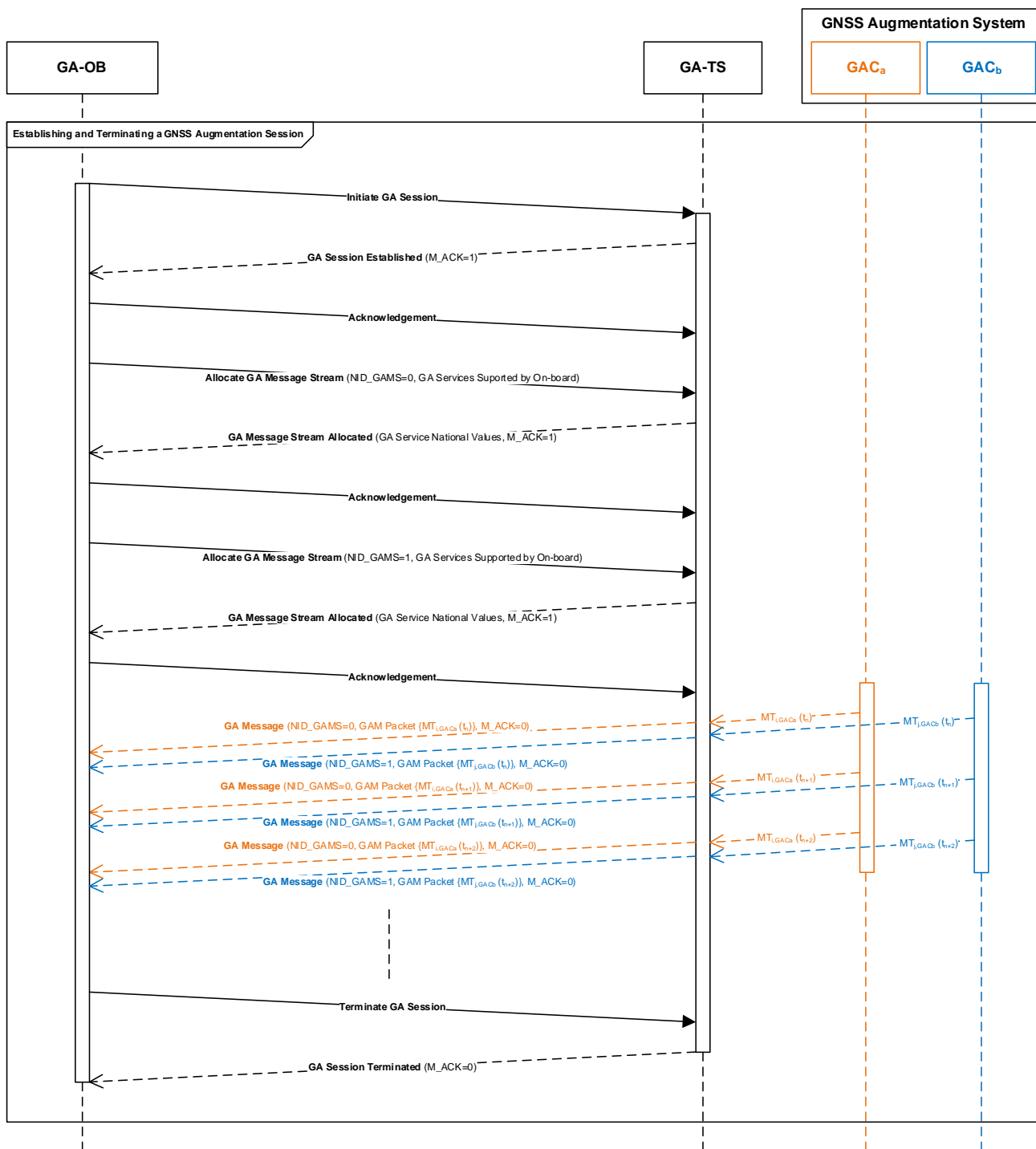


Figure 2-2. Establishing and terminating a GA Session

2.2.2 Resuming a GA Message Stream

2.2.2.1 The *resume GA message stream* function is provided to minimise impact from temporary disruption to the communication session between the GA-OB and GA-TS, including announced radio holes, which may result in an intervention if timer T_GATIMEOUT expires (i.e., all GA integrity data for the GA message stream becomes unavailable). The *resume GA message stream* function allows the GA-OB to restore integrity data that have not timed out (particularly relevant for integrity data with long update intervals and timeouts) by ensuring any active alerts (i.e., alerts that have not timed out) are processed by the GA-OB before the GA message stream is resumed.

2.2.2.2 Under nominal conditions, the GA data timeout mechanism provides resilience against message loss and ensures through the application of degradation parameters, that for any valid combination of active data, residuals are bounded at the specified level of confidence. In the case of non-nominal conditions, where the GNSS augmentation system has erroneously broadcast integrity data not bounding the residuals at the required level of confidence, an alert sequence is transmitted by the GNSS augmentation system.

2.2.2.3 To restore integrity data that have not timed out, it is necessary to ensure transmission of alerts (GA messages with Q_GAMT=1) or “do not use for safety applications” (GA messages with Q_GAMT=2) have not been missed during the period from the last GA message received by the GA-OB to the time of resumption of the GA message stream.

- If the timestamp (T_GAM) of the last GA message received in the GA message stream to be resumed is known, then the GA-TS shall provide the on-board with all active alerts received from the timestamp of the last GA message to the time the GA message stream is resumed.
- If the timestamp of the last GA message received from the GA message stream to be resumed is not available / unknown, the GA-OB shall not restore integrity data and shall resume processing GA messages from the state where all integrity data have timed out.

Justification: In the case of SBAS, UDREI and DFREI data has a timeout of 12 seconds; the impact of timing-out this data in the event of disruption of the GA message stream on availability and continuity is minimal due to the high update rate of the information once the GA message stream is resumed. In the case of the SBAS L1 service, GIVEI data has a maximum update rate of 300 seconds and a timeout of 600 seconds; therefore, timing-out this data has a significant impact on availability and continuity. The risk of not timing out this data is that during an outage, an alert may have been missed by the GA-OB (e.g., in the case of a coverage hole in a tunnel). As this data is still active (i.e., has not timed out) when the communications link is restored, the missed alerts may result in hazardous misleading information (i.e., errors that are not bounded at the required level of confidence).

2.2.2.4 Assuming the GA-OB already has an active GA session (otherwise a new GA session needs to be established), it shall send a *Resume GA Message Stream* message to the GA-TS

requesting the message stream (identified by NID_GAMS) to be resumed. The *Resume GA Message Stream* message contains the following information:

- GA message stream identifier (NID_GAMS)
- GA reference time for T_GAM (Q_GAT)
- Timestamp from last GA message received from the GA message stream (T_GAM)

2.2.2.5 The GA-TS shall respond as follows:

- a) If the GA-TS can resume the GA message stream, it shall respond to the GA-OB with a *GA Message Stream Allocated / Resumed* message, requiring acknowledgement, with the following information:
 - GA message stream identifier (NID_GAMS)
 - GA service identifier (NID_GAS)
 - GA channel identifier (NID_GAC)
 - GA service national values
- b) Upon acknowledgement of the *GA Message Stream Allocated / Resumed* message, the GA-TS shall send a *GA Message* to the GA-OB, requiring acknowledgement, containing all active alerts covering the period from the last GA message received to the time of resumption of the GA message stream. This message shall be acknowledged by the GA-OB prior to the GA-TS resuming the GA message stream.
- c) If there were no alerts during this period, the GA-TS resumes sending *GA Messages* associated with the GA message stream without acknowledgement.
- d) If the GA-TS cannot resume the message stream:
 - The GA-TS shall respond with a *GA Session Error* message (with M_GAERR=2, unable to resume primary GA message stream; or M_GAERR=3, unable to resume secondary GA message stream).
 - The on-board equipment shall cease using and discard any ranging data associated with the GA message stream and all GA message types obtained from the GA message stream.

2.2.2.6 An example of resuming a GA session is illustrated by the sequence diagram in Figure 2-3.

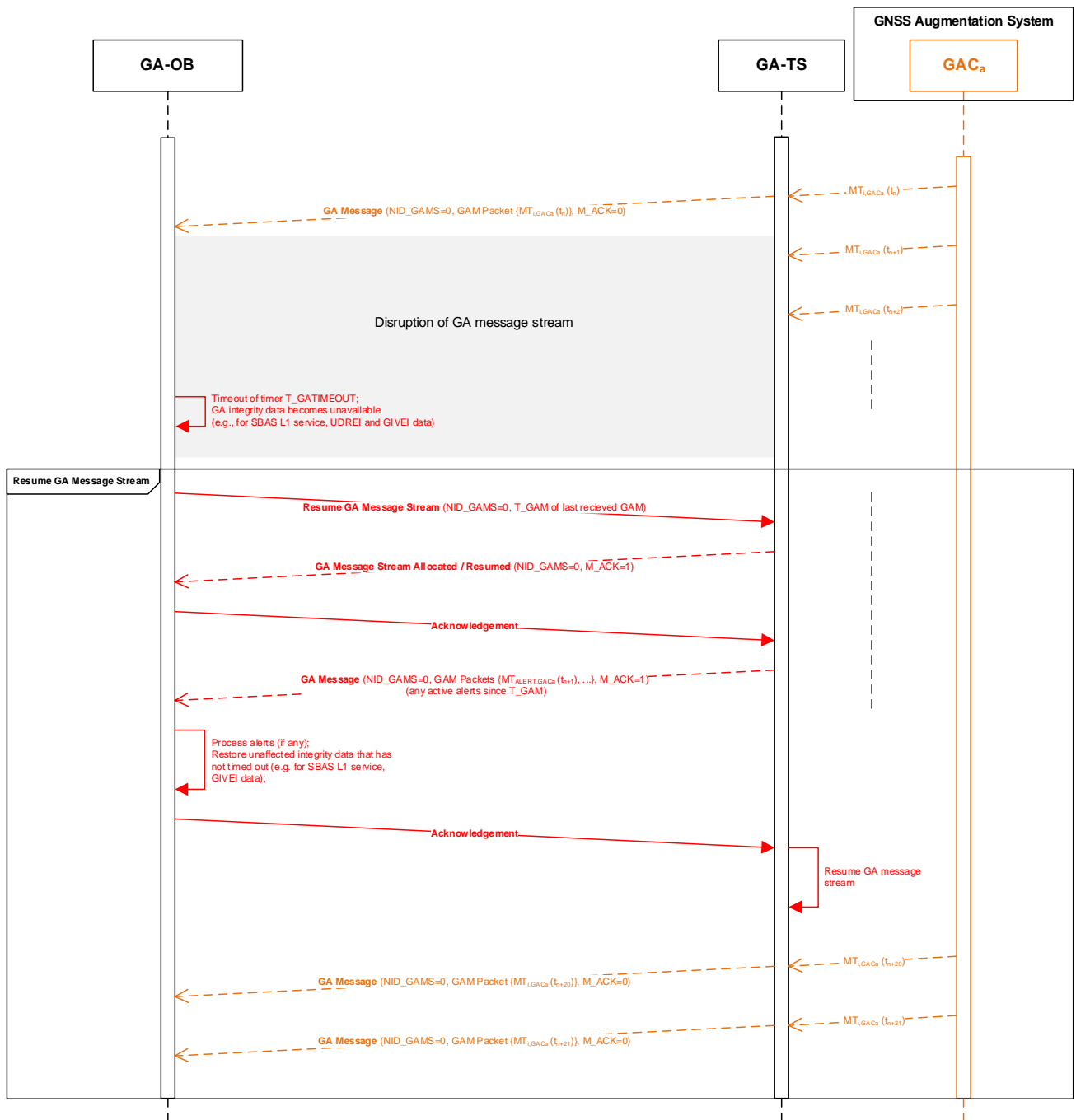


Figure 2-3. Resume GA message stream

2.2.3 Management of Radio Holes

2.2.3.1 If radio contact is lost, the GA session is terminated by the trackside. Once radio contact is restored (i.e., a new communication session between the GA-OB and GA-TS has been established), the GA-OB shall establish a new GA session. The GA-OB can attempt to resume the GA message stream(s) by sending a *Resume GA Message Stream* message to the GA-TS for each stream to be resumed.

2.2.3.2 If a GA message stream cannot be resumed, the GA-OB can request allocation of GA message stream(s) by sending an *Allocate GA Message Stream* message to the GA-TS for

each stream to be allocated. To minimise the time GNSS integrity is unavailable, the GA-OB can request GA active data from the GA-TS (refer to Section 2.2.4).

2.2.4 Provision of GA Active Data Sets to the GA-OB

2.2.4.1 Once a GA session is established and a GA message stream allocated, the GA-OB can make a request to the GA-TS for GA active data, which comprises of a set of GA messages containing the most recent active data (i.e., data most recently received by trackside that has not yet timed out). This reduces the amount of time the GA-OB needs to wait before a valid combination of active data is available allowing the GNSS channel to enter a state of availability with integrity.

2.2.4.2 GA active data shall be provided to the GA-OB according to the following steps:

- a) A GA session must have already been established and a GA message stream allocated, with the GA-OB processing GA messages from the GA message stream.
- b) The GA-OB shall send a *GA Active Data Request* message to the GA-TS with the GA message stream identifier (NID_GAMS).
- c) The GA-TS shall respond as follows:
 - If GA active data is available to the GA-TS, it shall respond with the first of n *GA Active Data Set* messages. The GA-TS requires each *GA Active Data Set* message to be acknowledged by the GA-OB (see below).
 - If GA active data is not available to the GA-TS, it shall respond with an empty *GA Active Data Set* message not requiring acknowledgement by the GA-OB.

2.2.4.3 The GA-TS shall ensure that the maximum message length is not exceeded, splitting the set of packets that comprise the active data over multiple *GA Active Data Set* messages.

- Maximum ETCS message length of 500 bytes (maximum length per message to allow for the dimensioning of radio input buffers) is defined in [SS040, 4.2.2.1].

2.2.4.4 Each message shall be acknowledged by the GA-OB, indicating to the GA-TS to send the next message until all n messages have been sent to and acknowledged by the GA-OB.

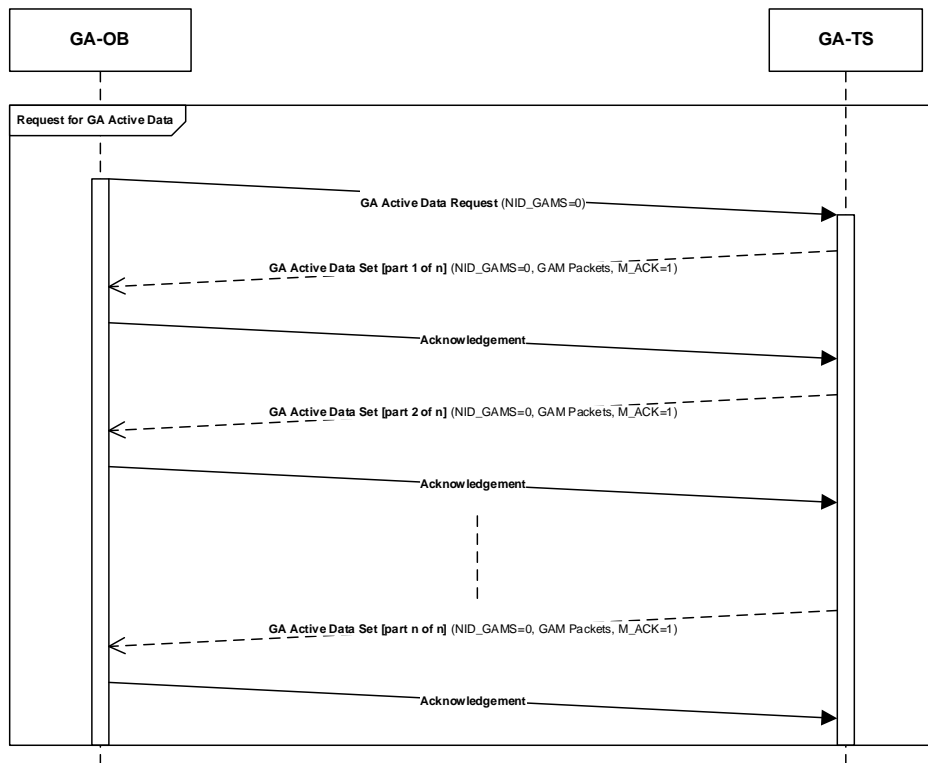


Figure 2-4. Requesting GA Active Data

- 2.2.4.5 If the GA-TS does not receive an acknowledgement message within T_GAADSRTIMEOUT seconds for one of the *GA Active Data Set* messages, the GA-TS shall retransmit the unacknowledged message. Once the number of unsuccessful retransmissions reaches N_GAADSMAXRETRIES, the GA-TS shall abort providing *GA Active Data Set* messages.
- 2.2.4.6 The GA-OB shall discard any GA messages provided in *GA Active Data Set* messages if the timestamp of the GA message is older than the timestamp of the same GA message type received from the GA message stream.

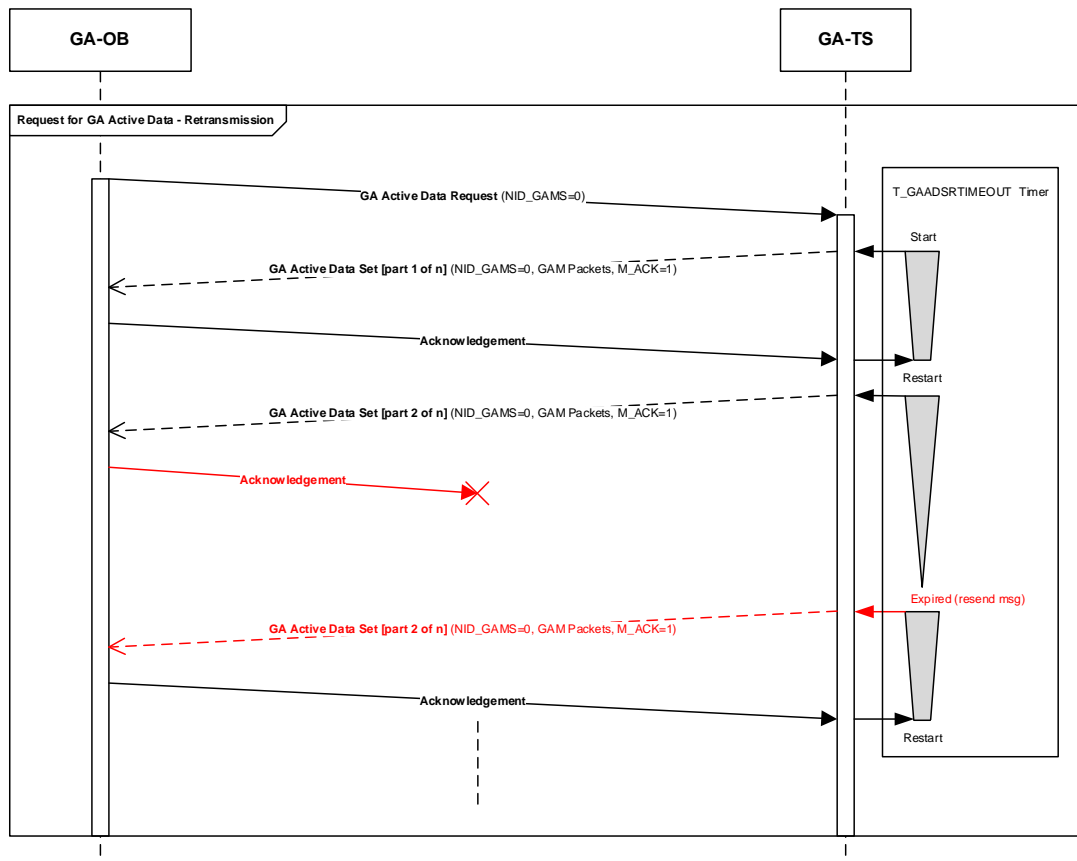


Figure 2-5. Requesting GA Active Data – Retransmission mechanism

2.2.5 Provision of GNSS Navigation Data Sets to the GA-OB

2.2.5.1 Once a GA session is established, the GA-OB can make a request to the GA-TS for GNSS navigation data. This reduces the time at start-up for the demodulation of GNSS navigation data, especially in difficult start-up environments (e.g., where there is significant obscuration of GNSS satellites).

2.2.5.2 GNSS navigation data shall be provided to the GA-OB according to the following steps:

- a) An GA session must have already been established.
- b) The GA-OB shall send a *GNSS Navigation Data Request* message to the GA-TS indicating the requested navigation datasets. For each dataset to be requested the following information is required:
 - Navigation data set type to be requested (Q_GNDT), which includes GPS LNAV, Galileo F/NAV, Galileo I/NAV and GPS CNAV (additional types may be supported in the future)
 - Selection of subframes / page / word / message types for the specified data set type (Q_GPSLNAVSF / Q_GALFNAVPT / Q_GALINAVWT / Q_GPSCNAVMT)
 - GNSS navigation data set selection (Q_GNDSS), where options include:
 - i. Current data set (latest broadcast)

- ii. Matched data set (matched to current augmentation IOD)
 - iii. Matched data set and any different data sets up to the current data set
 - iv. Last 3 different data sets
 - v. Last 4 different data sets
- Selection of satellite vehicles (SVs) in view (as determined by GA-TS) or selection by SV mask (Q_GSVS)
 - If selection of satellites by SV mask is selected by Q_GSVS, the SV mask (M_GSVMASK) identifies the satellites for which the navigation data is required. The SV mask slot numbers are assigned to satellites in the order of a satellite's identifier within a given constellation (e.g., for GPS, PRN numbers; for Galileo, SV identifiers).
- c) The GA-TS shall respond as follows:
- If the requested GNSS navigation data is available to the GA-TS, it shall respond with the first of n *GNSS Navigation Data Set* messages. The GA-TS requires each *GNSS Navigation Data Set* message to be acknowledged by the GA-OB (see below).
 - If only a partial set of the requested GNSS navigation is available to the GA-TS, the partial set shall be provided.
 - If the requested GNSS navigation data is not available to the GA-TS, it shall respond with an empty *GNSS Navigation Data Set* message not requiring acknowledgement by the GA-OB.
- 2.2.5.3 The GADF shall ensure that the maximum message length is not exceeded, splitting the set of packets that comprise the GNSS navigation data over multiple *GNSS Navigation Data Set* messages.
- Maximum ETCS message length of 500 bytes (maximum length per message to allow for the dimensioning of radio input buffers) is defined in [SS040, 4.2.2.1].
- 2.2.5.4 Each message shall be acknowledged by the GA-OB, indicating to the GA-TS to send the next message until all n messages have been sent to and acknowledged by the GA-OB.

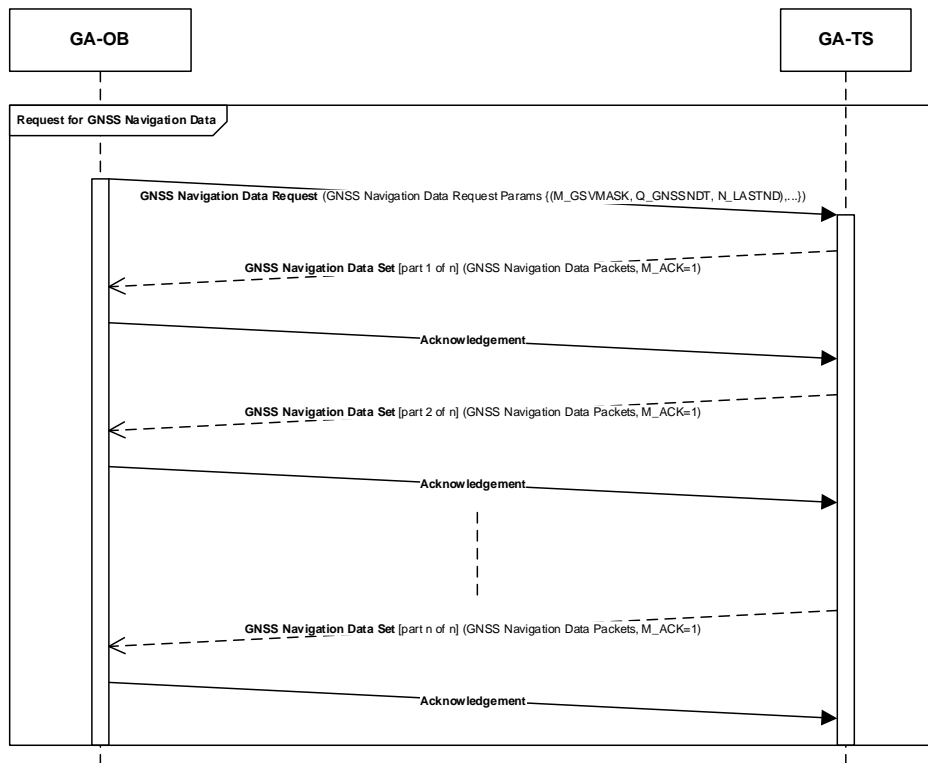


Figure 2-6. Requesting GNSS navigation data

2.2.5.5 If the GA-TS does not receive an acknowledgement message within T_GNSSNDSRTIMEOUT seconds for one of the *GNSS Navigation Data Set* messages, the GA-TS shall retransmit the unacknowledged message. Once the number of unsuccessful retransmissions reaches N_GNSSNDSMAXRETRIES, the GA-TS shall abort providing *GNSS Navigation Data Set* messages.

2.3 Management of Alerts

2.3.1.1 Under nominal conditions, the GA-TS shall send unacknowledged (M_ACK=0) *GA messages* to the GA-OB. The timeout mechanism and application of degradation parameters of messages received from the GAS ensure that integrity is guaranteed under nominal conditions for any valid combination of active data with resilience against message loss.

2.3.1.2 There are several non-nominal conditions where the GA-TS shall require acknowledgement by the GA-OB:

- a) Reception of an alert from the GAS
 - The GA-TS shall send a *GA Message* encapsulating the alert message to the GA-OB with GA message type Q_GAMT = 1 (GA alert message), requiring acknowledgement.
- b) Reception of a message from the GAS indicating service not to be used for safety applications.

- The GA-TS shall send a *GA Message* encapsulating the “Do Not Use” message to the GA-OB with GA message type Q_GAMT = 2 (DNU GA message stream), requiring acknowledgement, indicating that the GA-OB shall no longer use the GA message stream.
- In the case of SBAS, this is reception of MT0 (Do Not Use for Safety Applications); MT0/0 could be received if SBAS ground system determined that there was a problem in the signals or data already transmitted. This message applies to a particular PRN signal, not the satellite itself as there could be more than one signal broadcast by an SBAS satellite; or during testing MT0/2 (Legacy) and MT0/3X (DFMC) may also be broadcast by an SBAS satellite, where the contents of MT2 or MT3X are broadcasted in each MT0.

c) GA-TS/GAS communications link failure

- In the case of a communications link failure between the GA-TS and GAS, the GA-TS shall send a *GA Message* with GA message type Q_GAMT = 2 (DNU GA message stream) to the GA-OB, requiring acknowledgement, indicating that the GA-OB shall no longer use the GA message stream.
- In the case of SBAS (link between GA-TS and SBAS via SIS), a communications link failure is indicated when no valid SBAS message has been received for 4 consecutive seconds.

d) Other GA-TS error conditions / failures

- The GA-TS shall send a *GA Message* with GA message type Q_GAMT = 2 (DNU GA message stream) to the GA-OB, requiring acknowledgement, indicating that the GA-OB shall no longer use the GA message stream.

2.3.1.3 When the GA-TS sends a *GA Message* with GA message type Q_GAMT = 1 (GA alert message) to the GA-OB:

- a) The GA-TS shall suspend the relevant GA message stream until the *GA Message* is acknowledged by GA-OB (i.e., acknowledgement received by trackside).
- b) If the message is not acknowledged within T_GAMRTIMEOUT seconds, the GA-TS shall re-send the *GA Message* until acknowledged or the communication session between the GA-OB and GA-TS is terminated (e.g., due to timeout of the communication session).
- c) Once acknowledged, the GA-TS shall:
 - Ensure any additional alert messages (different alert sequences) received during suspension of the message stream are sent to the GA-OB in a *GA Message* requiring acknowledgement.
 - Resume the suspended GA message stream.

2.3.1.4 When the GA-TS sends a *GA Message* with GA message type Q_GAMT = 2 (DNU GA message stream) to the GA-OB:

- a) The GA-TS shall suspend the relevant GA message stream.
- b) If the message is not acknowledged within T_GAMRTIMEOUT seconds, the GA-TS shall re-send the *GA Message* until acknowledged or the communication session between the GA-OB and GA-TS is terminated (e.g., due to timeout of the communication session).

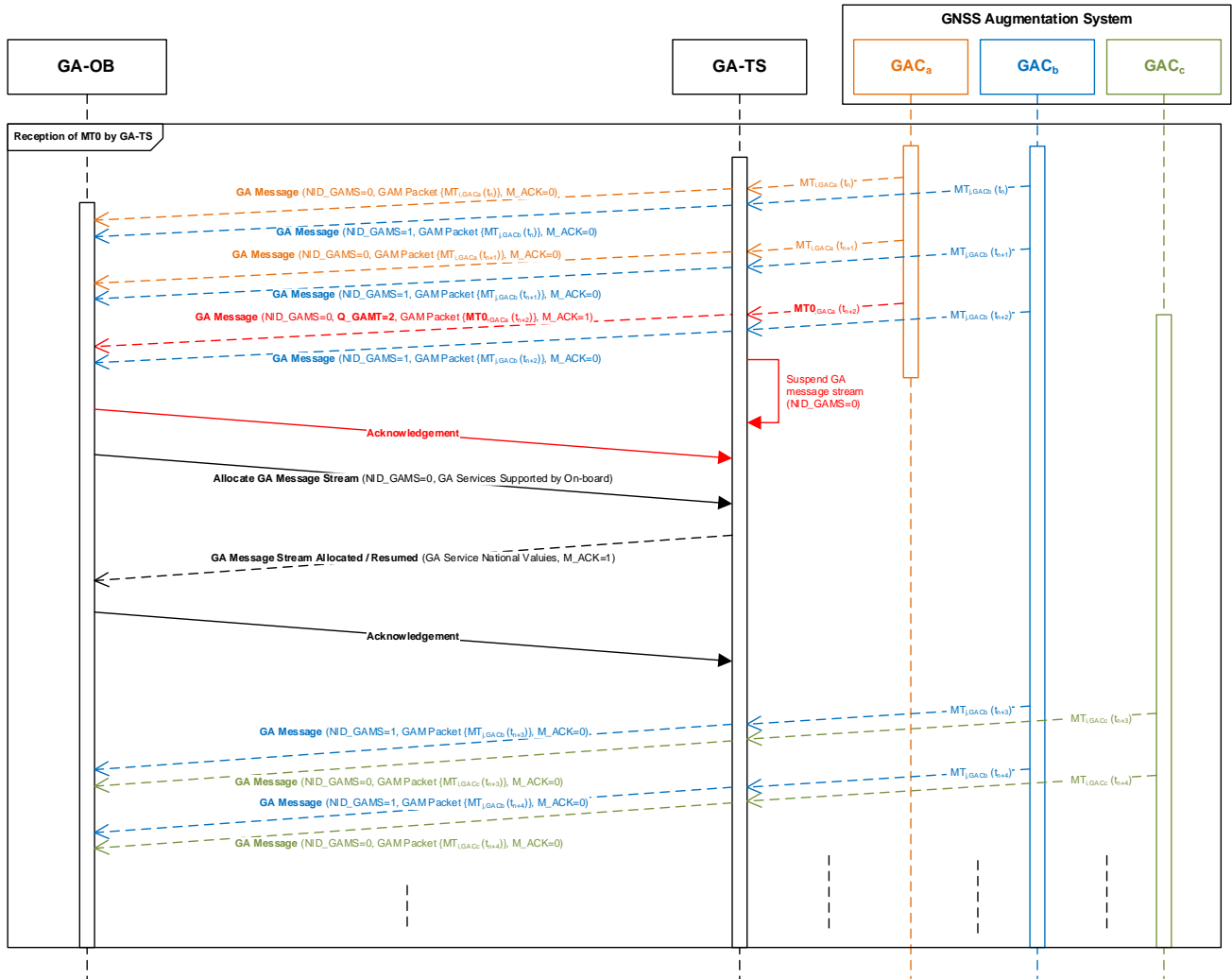


Figure 2-7. Reception of a SBAS MT0 by GA-TS

2.3.2 Reception of a GA Message Indicating DNU GA Message Stream by GA-OB

2.3.2.1 If a GA Message with GA message type Q_GAMT = 2 (DNU GA message stream) is received by the GA-OB:

- a) The GA-OB shall acknowledge receipt of the message
- b) The GA-OB shall cease using and discard any ranging data and GA data obtained from the GA message stream identified by the GA message
- c) In the case of SBAS,
 - For the SBAS L1 Service, the GA-OB shall cease using and discard any ranging data and all message types 1-7, 9-10, 18, and 24-28 obtained from the GA message stream identified by the GA message.
 - For the SBAS DFMC Service, the GA-OB shall cease using and discard any ranging data and all message types 31, 34, 35, 36, 32, 39, 40, 37, and 42 obtained from the SBAS message stream identified by the GA message.

2.3.2.2 For a GA-OB capable of multi-channel GA processing (i.e., implementing two channels, each processing a different GA message stream in parallel):

- Assuming one GA message source is still healthy, the GA-OB shall ensure the healthy source is selected. If the channel processing the unhealthy source is currently selected, the GA-OB shall switch to the channel processing the healthy GA message stream. A GA message source is defined as healthy when it is broadcasting valid messages and no “do not use” indication has been received (i.e., for SBAS reception of MT0).
- The GA-OB shall request allocation of a new GA message stream to the GA-TS by sending an *Allocate GA Message Stream* message. If a new message stream can be allocated (i.e., another healthy GA message source is available to the GA-TS), the GA-OB shall start processing the new GA message stream after having discarded any GNSS ranging data and GA data as detailed above.

2.3.2.3 For GA-OB with single-channel GA processing (i.e., implementing a single processing channel):

- The GA-OB shall request allocation of a new GA message stream to the GA-TS by sending an *Allocate GA Message Stream* message. If a new message stream can be allocated (i.e., another healthy GA message source is available to the GA-TS), the GA-OB shall start processing the new GA message stream after having discarded any GNSS ranging data and GA data as detailed above.
- To minimise the time the GNSS integrity is unavailable due to the processing of GA messages from an initial state, the GA-OB can make a request to the GA-TS for GA active data (refer to Section 2.2.4) to reduce the time required for the GNSS channel to enter a state of availability with integrity.

2.4 Supervision and Management of Time To Alert (GA-OB)

2.4.1.1 Under nominal conditions, the GNSS Augmentation System (GAS) shall guarantee integrity for any valid combination of active data. Resilience against message loss is provided through timeouts for message content and the application of degradation parameters.

2.4.1.2 In the case of an alert condition, integrity is ensured with a reactive fail-safe design, where the TTA is the time elapsed from the onset of the alert condition to its detection and negation in the GA-OB. An alert condition occurs when the GAS has erroneously broadcast integrity data not bounding the residuals (i.e., orbit and clock correction and ionosphere residual errors) at the required confidence level.

2.4.1.3 Figure 2-8 provides a concrete example of the timing relationships of the TTA in terms of non-train and train events for GNSS augmentation based on SBAS.

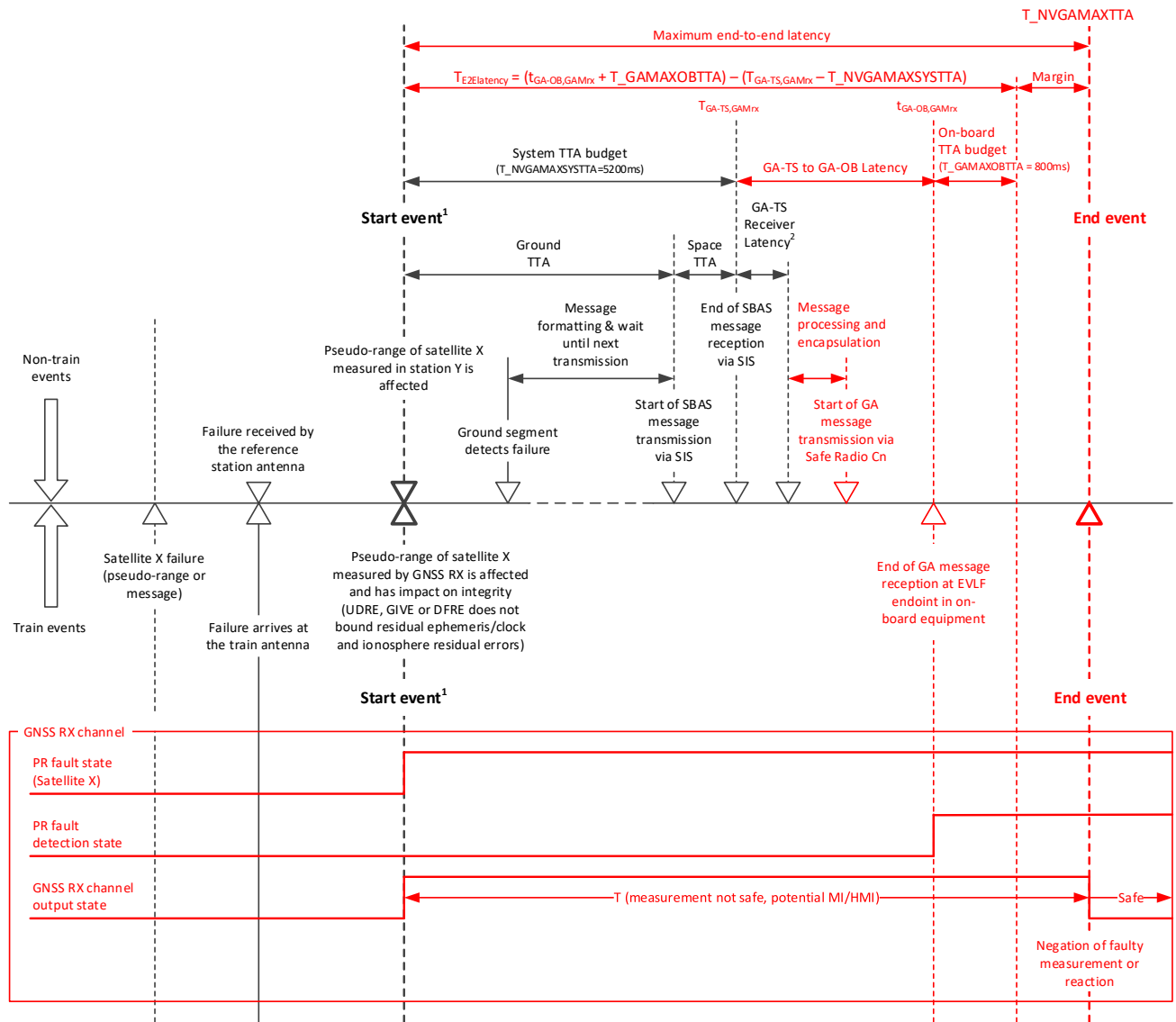


Figure 2-8. TTA example for SBAS (for reception of SBAS SIS at GA-TS and dissemination to GA-OB via Communication Session between the GA-OB and GA-TS)

Note 1.— Both events are considered as simultaneous. This is not strictly the case because of difference of performance between specific receivers. There is a slight difference due to receiver processing between the time the pseudo-range measurement is affected, and the erroneous data are displayed. For practical reasons, this is not reflected in this diagram.

Note 2.— The GA-TS receiver latency is related to the output of SBAS messages from the GNSS/SBAS receiver in the GA-TS.

2.4.1.4 A detailed breakdown of the allocations in the SBAS example illustrated in Figure 2-8 is provided in the table below:

Budget	Allocation	Remarks
Ground TTA budget	3900 ms	5200 – Space TTA = 3900 ms
Space TTA budget	1300 ms	1300 = uplink time (150 ms) + SBAS message length (1000 ms) + downlink time (150 ms)
SBAS System TTA budget	$T_NVGMAXSYSTTA = 5200$ ms	System TTA requirement for SBAS supporting precision approach from SARP [7] (when last bit of an SBAS message arrives at the antenna port of GA-TS GNSS receiver)
GA-TS to GA-OB latency	$t_{GA-OB,GAMrx} - T_{GA-TS,GAMrx}$	Latency between the end of reception of SBAS message by the GA-TS GNSS receiver (when last bit of an SBAS message arrives at antenna port) and the end of reception of GA

		message at GA-OB endpoint in the on-board equipment. This includes latency introduced by message processing on the GA-TS and transmission via communication session established between GA-OB and GA-TS. It is assumed that the uncertainty of GA-TS and GA-OB timestamps < 1ms.
On-board TTA budget	$T_GAMAXOBTTA = 800 \text{ ms}$	Budget for processing latency from end of reception of GA message at GA-OB endpoint in the on-board equipment to raising an alert (negation of fault).
End-to-End Latency	$T_{E2Elatency}$	$(t_{GA-OB,GAMrx} + T_GAMAXOBTTA) - (T_{GA-TS,GAMrx} - T_NVGAMAXSYSTTA)$

Note: The GA-OB endpoint refers to the VLF within the on-board equipment. For example, the GA communication channel could include forwarding on an internal bus of the on-board equipment to the GA-OB endpoint.

2.4.1.5 It is assumed that the GA system TTA budget ($T_NVGAMAXSYSTTA$) is guaranteed by the GAS to its interface in the GA-TS (e.g., in the case of SBAS, the SBAS/GNSS receiver in the GA-TS). Considering additional latencies introduced by dissemination of GA messages to the GA-OB via the communication session established between the GA-OB and GA-TS, additional mechanisms are required for supervising GA message latency to ensure it is below the configured end-to-end TTA threshold ($T_NVGAMAXTTA$). In the case the threshold is exceeded, the GNSS channel transitions to a safe state (e.g., the GNSS channel status indicates that integrity is unavailable).

2.4.1.6 The GA Maximum TTA ($T_NVGAMAXTTA$) has been defined as a national value that is specific to the GNSS augmentation system, allowing for optimisation / tuning of performances. The dimensioning of this value shall take into consideration the following:

- GA Maximum System TTA (e.g., $T_NVGAMAXSYSTTA = 5200 \text{ ms}$ in the case of EGNOS L1 and DFMC SoL Services);
- Latency of GA-TS processing (including processing and encapsulation of GA messages; e.g., in the case of EGNOS L1 and DFMC services, this includes allocation for the GA-TS GNSS receiver);
- GA-TS to GA-OB transfer delay over safe radio connection;
- The GA broadcast update rate for supervision of continuity of transmission (e.g., $T_NVGAMBUR = 1000 \text{ ms}$ in the case of EGNOS L1 and DFMC SoL Services);
- On-board equipment maximum TTA (fixed value $T_GAMAXOBTTA = 800 \text{ ms}$); and
- Margin to cope with variations in safe radio connection performance.

Note: this value is part of the national values and is configured by the infrastructure manager taking into consideration the performance and dimensioning of the safe radio connection. This variable is used by the GA-OB to determine $T_GATIMEOUT$ for supervision of the GA message stream and to ensure correct assumptions are made within the EVLF regarding time to detect and negate faulty measurements caused by GNSS errors or anomalies detected by the GAS.

Tuning of this parameter is a trade-off between impacts on train positioning performance (i.e., degradation from larger values) and impacts on availability from smaller values. For

example, a larger value may result in an increased train confidence interval and reduced accuracy as a result of coasting from last validated train position for longer periods compared to smaller values that may result in more frequent transitions to an unavailability state when threshold is exceeded due to conditions of the safe radio connection.

- 2.4.1.7 For each GA message stream in the GA session, the GA-OB shall supervise when no valid GA message has been received for T_GATIMEOUT seconds (refer to Figure 2-9). If Timer T_GATIMEOUT expires, the GA-OB shall ensure all GA integrity data for the GA message stream become unavailable. The resume GA message stream function is used to restore integrity data that would not have timed out (especially for integrity data with long update intervals and timeouts) by ensuring any missed alerts are processed by the GA-OB – refer to Section 2.2.2).
- 2.4.1.8 If T_GATIMEOUT supervision is unavailable the GA-OB shall ensure all GA integrity data for affected GA message streams become unavailable (e.g., due to unavailability of the GNSS Augmentation Time (GAT) reference on the GA-OB as indicated by Q_GAT in the GAM packet, unavailability of the GAT reference on the GA-TS for timestamping).

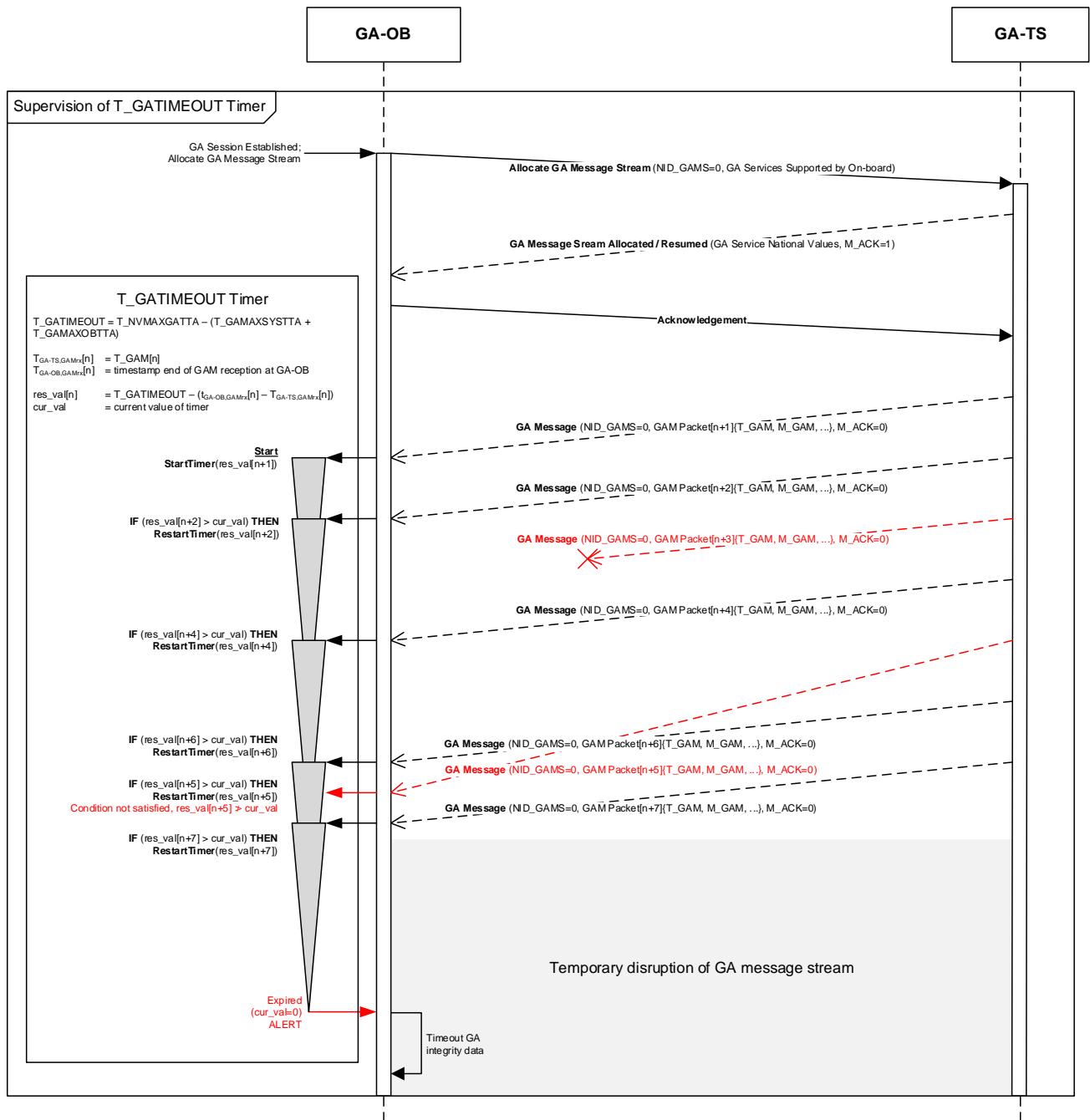


Figure 2-9. Supervision of Timer T_GATIMEOUT (latency between GA-TS and GA-OB)

2.4.1.9 The supervision of Timer T_GATIMEOUT assumes continuity of signal (i.e., the rate of GA messages broadcast within a GA message stream of at least one message every T_NVGAMBUR milliseconds). The GA-TS shall ensure continuity of signal by providing a GA message for each GAC at least every T_NVGAMBUR milliseconds:

- If a message is not available from the GAS, the GA-TS shall provide a GAM Packet encapsulating an empty / null message.
- In the case of SBAS, T_NVGAMBUR = 1000 ms; continuity of signal is guaranteed for the SBAS L1 and L5 signal. The SBAS null message (MT63) is used as a filler message if no other message is available for broadcast for the one-second time slot.

2.4.1.10 The management of alerts for the GA-OB is based on the use of a positive acknowledgement paradigm over the Safe Radio Connection between the GA-TS and GA-OB.

2.4.1.11 When an alert condition occurs, the GAS alerts the user (GA-OB) of the alert condition. The GA-TS forwards the alert to the GA-OB encapsulated in a GA message that requires acknowledgement. The GA message stream is suspended until the alert is acknowledged by the GA-OB.

2.4.1.12 Figure 2-10 and Figure 2-11 illustrate management of alerts for the GA-OB considering GAS based on SBAS as an example. In Figure 2-10, suspension and resumption of GA message stream occurs before timeout of timer T_GATIMEOUT. Figure 2-11 illustrates the case of reception of an alert with disruption of the Safe Radio Connection.

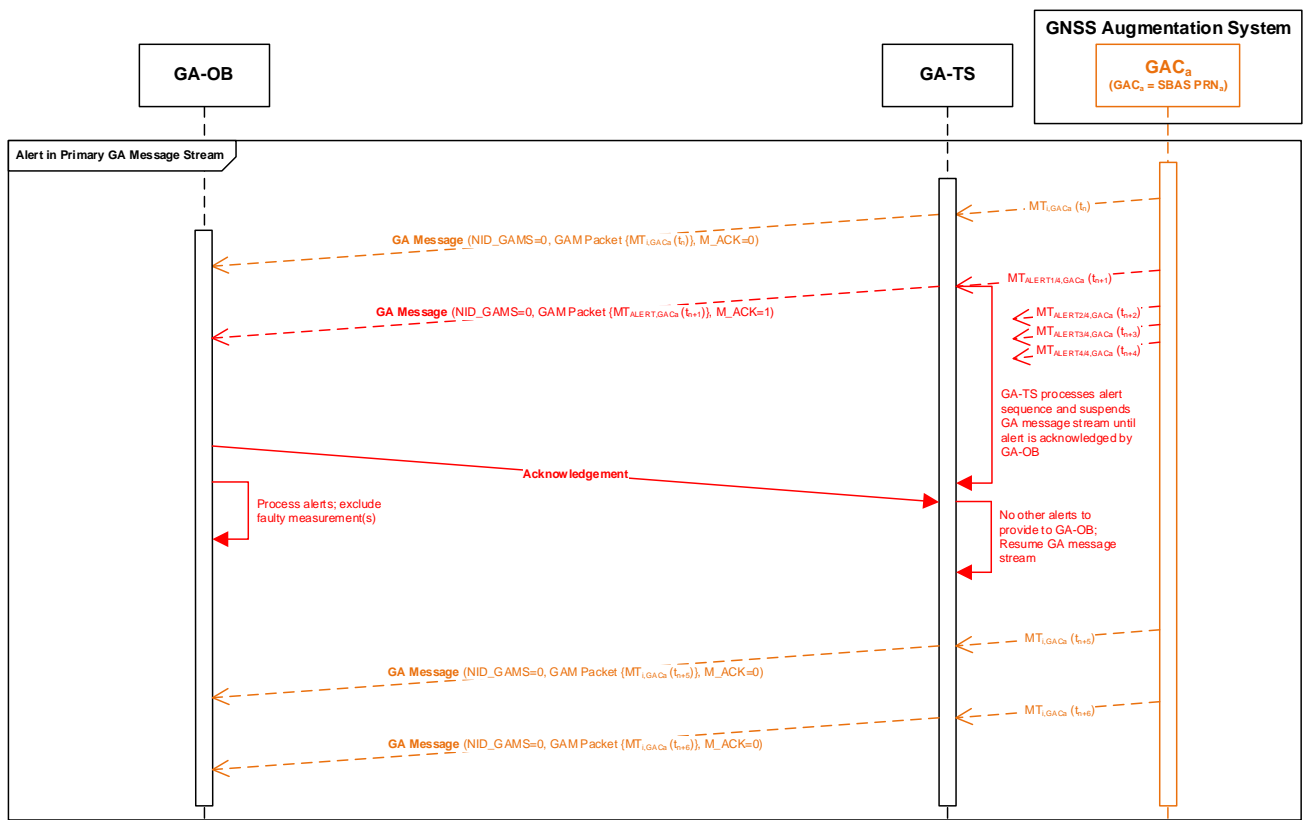


Figure 2-10. Reception of an alert (SBAS example)

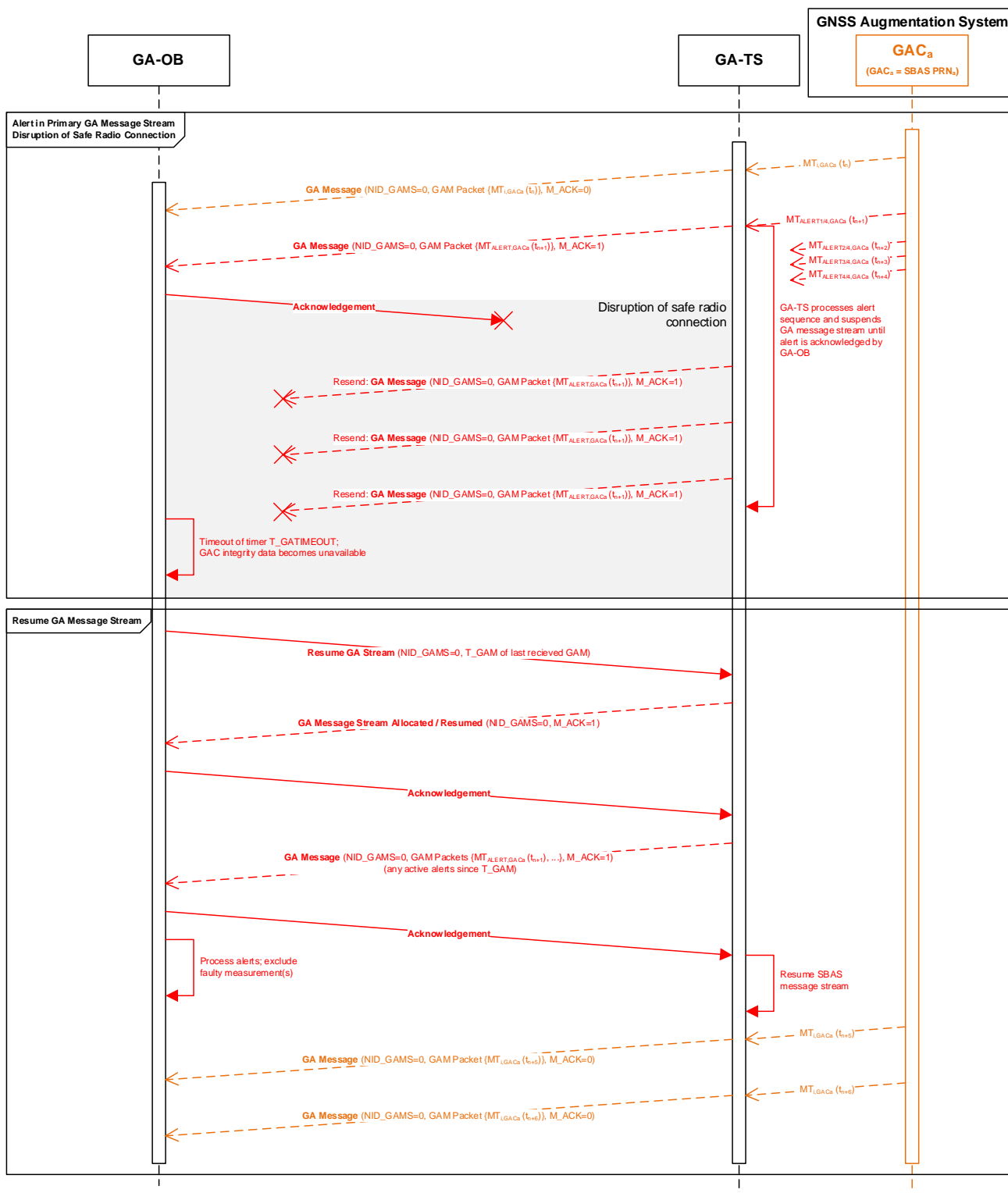


Figure 2-11. Reception of an alert with disruption of safe radio connection (SBAS example)

2.5 Supervision of GA Message Content Timeout (GA-OB)

2.5.1.1 The GA-OB shall only use broadcast GA data within the current valid time interval. Timeout supervision shall be performed such that GA message content is valid when:

$$t_{\text{GA-OB,now}} - T_{\text{GA-TS,GAMrx}} \leq \text{timeout}(\text{GA message content})$$

where: $t_{\text{GA-OB,now}}$ is the current time of the GA-OB in milliseconds, $T_{\text{GA-TS,GAMrx}}$ is the time of the end of reception of the GA message by the GA-TS in milliseconds, and $\text{timeout}(\text{GA message content})$ is the timeout interval for GA message content in milliseconds.

Note: $T_{\text{GA-TS,GAMrx}}$ is provided by the variable T_GAM in *GAM Packets* sent by the GA-TS to the GA-OB. The reference time of T_GAM is indicated by the qualifier Q_GAT in the *GAM Packet*.

- 2.5.1.2 The GA-OB shall ensure that $t_{\text{GA-OB,now}}$ and $T_{\text{GA-TS,GAMrx}}$ have the same reference time (e.g., in the case of SBAS, both times shall be in SBAS Network Time).
- 2.5.1.3 Wrap around (rollover) of the timestamp $T_{\text{GA-TS,GAMrx}}$ can occur during a GA session and shall have no impact on system behaviour (i.e., the GA-OB correcting for rollover if needed).
- 2.5.1.4 If GA message content timeout supervision is unavailable (e.g., due to unavailability of the GNSS augmentation time reference on the GA-OB as indicated by Q_GAT in the *GAM Packet*, unavailability of the GNSS augmentation time reference on the GA-TS for timestamping, etc.), GA message content (i.e., the message from GAS encapsulated in the *GAM Packet*) shall be discarded by the GA-OB.
- 2.5.1.5 Refer to the relevant GA-OB-MOPS for definition of timeouts for GA message content.

2.6 GNSS Signal Processing (GA-OB)

- 2.6.1.1 The GNSS signal processing function of the VLS<GNSS Receiver> includes:
- GNSS pre-correlation signal processing;
 - Acquisition and tracking of GNSS signals; and
 - GNSS navigation data demodulation, FEC decoding and frame synchronisation.
- 2.6.1.2 GNSS signal processing requirements for the GA-OB are provided in the GA-OB MOPS for the specific GA railway SoL service and relevant GNSS-SIS-ICDs.

2.7 GNSS Navigation Data Processing (GA-OB)

- 2.7.1.1 The GNSS navigation data processing function of the VLF is responsible for processing navigation data bits received from the on-board GNSS receiver(s) and the GA-TS. GNSS navigation data processing includes:
- Performing CRC / parity checks on GNSS navigation data;
 - Decoding of navigation message parameters; and
 - Message consistency checks (e.g., consistency of IODs (IODC/IODE), reference times. etc., as described in the GA-OB MOPS).

2.7.1.2 GNSS navigation data processing requirements for the GA-OB are provided in the GA-OB MOPS for the specific GA railway SoL service and relevant GNSS-SIS-ICDs.

2.8 GA Message Processing (GA-OB)

2.8.1.1 GA message processing function of the VLF is responsible for:

- Timestamping GA messages received from the GA-TS;
- Performing CRC checks on GA message content; and
- Processing of GA message content (encapsulated messages) according to GA-OB MOPS.

2.8.1.2 The GA-OB shall support processing of at least one GA message stream and may optionally support processing of two GA message streams (a primary and secondary stream). A GA session can support up to two GA message streams.

2.8.1.3 Justification for support of two GA message streams:

- Considering GNSS augmentation based on SBAS: processing of two PRNs is specified in the aviation MOPS and is linked to unavailability of the GEO itself as well as the unavailability of the Navigation Land Earth Stations (NLES). NLES switching may lead to a GEO SIS outage. Having a parallel processing of at least two SBAS GEOs avoids a service outage if the on-board receiver has two channels capable of processing SBAS message streams from two PRNs with fast switching between channels in case of an unexpected service outage. Note: it is not mandatory for the on-board to support processing of two message streams.

2.8.1.4 GA message processing requirements for the GA-OB are provided in the GA-OB MOPS for the specific GA railway SoL service.

2.8.2 Timestamping of GA Messages Received from GA-TS

2.8.2.1 The GA-OB shall timestamp the end of reception of GNSS Augmentation Messages (GAMs) received from GA-TS.

- Timestamp $t_{\text{GA-OB,GAMrx}}$ shall be within 1ms of end of reception of GA message at the GA-OB endpoint in the on-board equipment.
- The GA-OB shall ensure that $t_{\text{GA-OB,GAMrx}}$ has the same reference time as $T_{\text{GA-TS,GAMrx}}$, which is provided by the variable T_GAM in the *GAM Packets* sent by the GA-TS to the GA-OB. The reference time of T_GAM is indicated by the qualifier Q_GAT in the *GAM Packet*.
- The GA-OB endpoint refers to the function within the on-board equipment. For example, the GA communication channel could include reception of GA messages by another function within the on-board and forwarding on the internal bus to the GA-OB, the endpoint.

2.9 Pseudorange Determination and Use (GA-OB)

2.9.1.1 Pseudorange determination and use function of the VLF is responsible for:

- Carrier smoothing on pseudorange measurements;
- Measurement quality monitoring (i.e., detection of cycle slips and other measurement faults);
- Pseudorange determination (i.e., determination of corrected pseudoranges considering application of GA corrections and tropospheric correction to carrier-smoothed pseudoranges);
- Satellite selection criteria (i.e., conditions for use as defined in GA-OB MOPS including the validity of correction and integrity data, satellite elevation mask, etc.).

2.9.1.2 Requirements on pseudorange determination and use for the GA-OB are provided in the GA-OB MOPS for the specific GA railway SoL service.

2.10 Computation and Application of Pseudorange Error Models (GA-OB)

2.10.1.1 The compute and apply pseudorange error models function of the VLF is responsible for:

- Computing and applying the model for differential correction residual error; and
- Computing and applying the model for residual ionospheric error.

2.10.1.2 In addition to the above, the following pseudorange error models also need to be taken into account in the VLF:

- *Tropospheric correction residual errors* (after application of tropospheric correction), the assumed model is the DO-229 / ED-259A tropospheric model (validation of tropospheric model for railway is an open item noted in Annex C).
- *Receiver errors*, including receiver noise, thermal noise, interference, inter-channel biases, extrapolation, time since smoothing filter initialisation, and processing errors for smoothed pseudoranges.
- *Multipath and antenna group delay variation* for smoothed measurements (also considering the transient phase of the smoothing filter).
- *Ionospheric divergence* for single frequency users caused by the difference between the implemented smoothing filter and the reference smoothing filter given an ionospheric code-carrier divergence. For example, considering SBAS L1:
 - For single frequency L1 measurements that are smoothed by the reference filter (defined in GA-OB MOPS) with the filter weighting function α being a constant (i.e., having a time constant of 100s), applying SBAS L1 ionospheric corrections, $\sigma_{\text{divg}} = 0\text{m}$.
 - Single frequency L1 measurements that are smoothed by the reference filter with the filter weighting function α being variant during the first 100s, applying SBAS L1 ionospheric corrections, σ_{divg} will need to account for the residual ionospheric error caused by the difference between the implemented filter

(time variant) and the reference filter (time constant) during the transient phase of the filter (i.e., before filter reaches steady-state) assuming a code-carrier divergence rate of 0.012 m/s. After steady-state is reached, $\sigma_{\text{divg}} = 0\text{m}$.

2.10.1.3 Requirements on computation and application of pseudorange error models for the GA-OB are provided in the GA-OB MOPS for the specific GA railway SoL service.

2.11 Trackside Interface to GAS and GNSS (GA-TS)

2.11.1.1 The trackside interface to the GAS and GNSS provides the interface between the GAS, GNSS and the GADF. The interface to a generic GAS is not defined; however, the interface to SBAS via the SBAS SIS has been included in support of EGNOS (refer to Figure B-1 in Annex B).

2.11.2 SBAS Signal Processing (GA-TS)

2.11.2.1 The SBAS signal processing function of the Trackside Interface to SBAS<GNSS Receiver> includes:

- SBAS pre-correlation signal processing;
- Acquisition and tracking of SBAS signals; and
- SBAS data demodulation, FEC decoding and frame synchronisation.

2.11.2.2 SBAS signal processing requirements for the GA-TS are provided in the GA-TS MOPS<SBAS> for the specific GA railway SoL.

2.11.3 GNSS Signal Processing (GA-TS)

2.11.3.1 The GNSS signal processing function of the Trackside Interface to GNSS<GNSS Receiver> includes:

- GNSS pre-correlation signal processing;
- Acquisition and tracking of GNSS signals; and
- GNSS navigation data demodulation, FEC decoding and frame synchronisation.

2.11.3.2 GNSS signal processing requirements for the GA-TS are provided in the GA-TS MOPS for the specific GA railway SoL service and relevant GNSS-SIS-ICDs.

2.12 Selection of GACs (GA-TS)

2.12.1.1 The GA-TS shall select GNSS Augmentation Channels (GACs) for compatible services from authorised GNSS Augmentation System (GAS) providers. These are service providers for

which use of the railway SoL service has been approved by the GA service provider and authorised by relevant safety authorities.

2.12.1.2 Other criteria for selection of GACs is addressed in the relevant GA-TS MOPS (e.g., in the case of an EGNOS railway SoL service provided via the GEO SIS, selection of GEO signals broadcasting valid messages, passing CRC, with no reception of MT0, etc.).

2.13 Processing of GA Messages for Selected GACs (GA-TS)

2.13.1.1 The GA message processing function of the GADF is responsible for processing GA messages received from the trackside interface to the GAS for the selected GACs. This includes:

- Timestamping reception of messages from the GAS;
- Performing CRC checks on GA messages;
- Encapsulation of GA messages in GAM packets;
- Processing of GA messages on the trackside to support the GADF functions (i.e., provision of GA active data, GA active alerts, etc.).

2.13.1.2 Message processing requirements for the GA-TS are provided in the GA-TS MOPS for the specific GA railway SoL service.

2.13.2 Timestamping Reception of Messages from GAS

2.13.2.1 The GA-TS shall timestamp the end of reception of GNSS Augmentation Messages (GAMs) received from the GNSS Augmentation System (GAS).

- The timestamp (T_GAM) shall have a resolution of 1ms and is a 32-bit value containing the timestamp (time of week with a maximum value of 604799999 ms) in the reference time indicated by the qualifier Q_GAT (e.g., in the case of EGNOS, Q_GAT = SBAS Network Time).
- The GA-TS shall not change the time reference frame of the GA corrections.
- The timestamp (T_GAM) shall be within 1ms of the end of reception of GA message by GA-TS.
- Wrap around (rollover) of the timestamp can occur during a GA session and shall have no impact on system behaviour.

2.13.2.2 Figure 2-12 illustrates the timestamping of GA messages by the GA-TS.

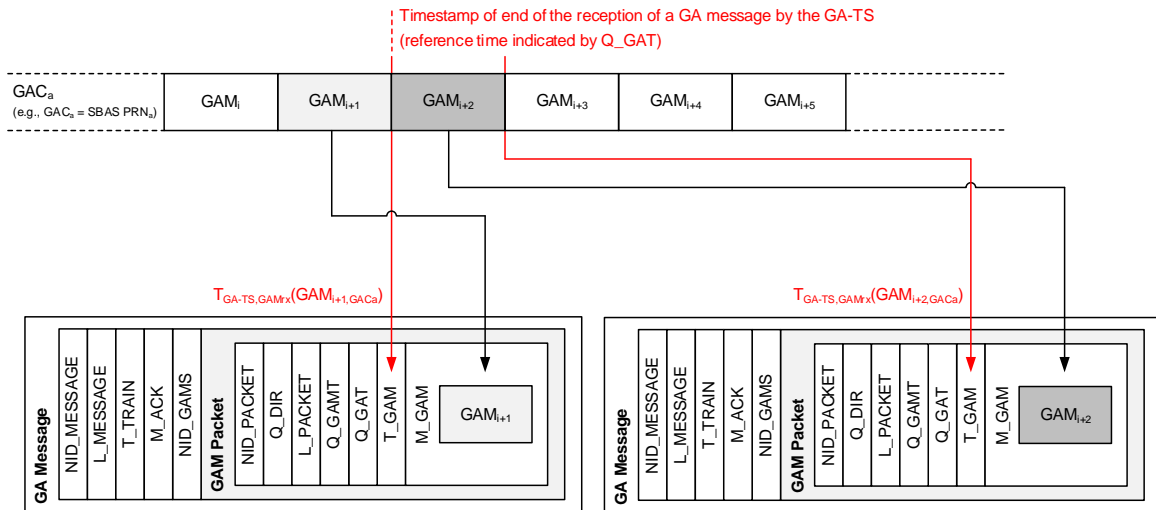


Figure 2-12. Timestamping of GA Messages by GA-TS

2.13.2.3 Justification for approach:

- When using GA corrections, the GA-OB's solution for time will be with respect to the GA Network Time. In the case of SBAS, this is the SBAS Network Time (SNT).
- This approach supports timestamping with different reference times (indicated by Q_GAT). While UTC can be used, flexibility in supporting GA message timestamping using the reference time of the GNSS Augmentation System was considered due to the increased complexity of providing UTC time offset parameters in the context of safety-related applications.
- For example, in the case of EGNOS, the GA-TS timestamping mechanism cannot rely on the UTC timing information provided in SBAS MT12 / MT42 as the EGNOS safety case only considers the use of EGNOS as a navigation system and does not provide any analysis of safety of life applications that may rely on the timing service. The provision of a real-time EGNOS Network Time (ENT) offset to UTC is secondary function of EGNOS and is not relevant to the navigation service (i.e., not considered as critical for the primary mission). For this reason, timestamping in the case of EGNOS shall be in SNT (SBAS Network Time).

2.13.3 Encapsulation of Messages Received from GAS in GAM Packets

2.13.3.1 The GA-TS shall encapsulate messages received from the GNSS Augmentation System (GAS) in *GAM Packets*, with a timestamp of the end of reception of the message from the GAS (T_GAM) and the reference time of the timestamp (Q_GAT).

2.14 Provision of GA Message Stream(s) (GA-TS)

2.14.1.1 The GA message stream provision function of the GADF is responsible for:

- Allocation of GA message streams; and
- Suspension and resumption of GA message streams.

2.14.1.2 Refer to Section 2.2 for requirements on provision of GA message streams.

2.15 Provision of GA Active Data for Selected GACs (GA-TS)

2.15.1.1 The GA-TS shall maintain a set of GA active data (data most recently received that has not timed out) for selected GACs of a supported GA service to enable transmission of active data sets to the GA-OB when requested.

2.15.1.2 Refer to Section 2.2.4 for requirements on provision of GA active data sets to the GA-OB.

2.16 Provision of GA Active Alerts for Selected GACs (GA-TS)

2.16.1.1 The GA-TS shall maintain GA active alerts for selected GACs of a supported GA service to enable resuming of a GA message stream, which allows the GA-OB to restore integrity data that have not timed out by ensuring active alerts (i.e., alerts that have not timed out) are processed by the GA-OB before the GA message stream is resumed.

2.16.1.2 Refer to Section 2.3 for requirements on the management of alerts.

2.17 GNSS Navigation Data Processing (GA-TS)

2.17.1.1 The GNSS navigation data processing function of the GADF is responsible for processing navigation data bits received from the trackside interface to GNSS (trackside GNSS receiver(s)). GNSS navigation data processing includes:

- Performing CRC / parity checks on GNSS navigation data;
- Decoding of navigation message parameters; and
- Message consistency checks (e.g., consistency of IODs (IODC/IODE), reference times. etc., as described in the GA-TS MOPS).

2.17.1.2 GNSS navigation data processing requirements for the GA-TS are provided in the GA-TS MOPS for the specific GA railway SoL service and relevant GNSS-SIS-ICDs.

2.18 Provision of GNSS Navigation Data Sets (GA-TS)

2.18.1.1 The GA-TS shall maintain sets of GNSS navigation data for each visible satellite of the core constellations (GPS and Galileo) to enable transmission of navigation data sets to the GA-OB when requested.

2.18.1.2 For GPS LNAV, the GA-TS shall:

- Maintain the last three different sets of LNAV clock / ephemeris parameters, where different data sets are identified by a bitwise comparison with the data of the older sets retained by the GA-TS. This ensures the issue of data (IOD) in the GA corrections matches the IOD associated with one of the last different navigation datasets; and
- Ensure consistency of the dataset with matching IODC/IODE, where IODE matches 8 LSBs of the IODC.

2.18.1.3 For Galileo F/NAV, the GA-TS shall:

- Maintain the last four different sets of F/NAV clock / ephemeris parameters, where different data sets are identified by a bitwise comparison with the data of the older sets retained by the GA-TS. This ensures the issue of data (IOD) in the GA corrections matches the IOD associated with one of the last different navigation datasets; and
- Ensure consistency of the dataset where page types 1, 2, 3, and 4 have a matching IODnav.

2.18.1.4 The GA-TS may optionally maintain sets of GNSS navigation data for visible satellites from other constellations (e.g., BEIDOU, GLONASS, etc.) as needed to support specific GA services or degraded modes of operation of the GA-OB.

2.18.1.5 Refer to Section 2.2.5 for requirements on the provision of GNSS navigation data sets to the GA-OB.

2.19 Safe Radio Connection Message Consistency

2.19.1.1 Note: The Safe Radio Connection between the GA-OB and GA-TS is currently undefined (to be defined in a future release of this specification). GA application messages are defined in the GA ICD [EUG-20E087]).

2.19.1.2 The GA-OB shall discard a message transmitted by the GA-TS if it is not consistent.

2.19.1.3 The GA-TS shall discard a message transmitted by the GA-OB if it is not consistent.

2.19.1.4 A radio message is consistent when the following checks have been passed:

- Protocol level checks have passed (e.g., verification of CRC, verification of cryptographic authenticity / integrity, etc.);
- Message timestamp checks have passed (i.e., with respect to T_TRAIN); and
- Messages are complete and variables in messages do not have invalid values (refer to GA ICD [EUG-20E087]).

2.19.1.5 Messages shall be timestamped by the GA-TS with a value corresponding to the time of transmission.

2.19.1.6 Message sequence supervision shall be performed using the message timestamp (T_TRAIN). If the timestamp of the last received message is less than or equal to the former one, it shall be discarded. There shall always be a timestamp increment between consecutive messages.

2.20 GA Dissemination Framework Version Management

2.20.1.1 The GA dissemination framework version shall be embedded into the ETCS system version and follow ETCS rules.

2.21 GA-OB Operational States

2.21.1.1 Operational states of the GNSS Augmentation On-board (GA-OB) are described in this section.

2.21.1.2 The GA-OB shall support at least one GA message stream and may optionally support two GA message streams (a primary and secondary stream). A GA session can support up to two GA message streams, where operational states GN, GR and GO are related to each GA message stream of the session.

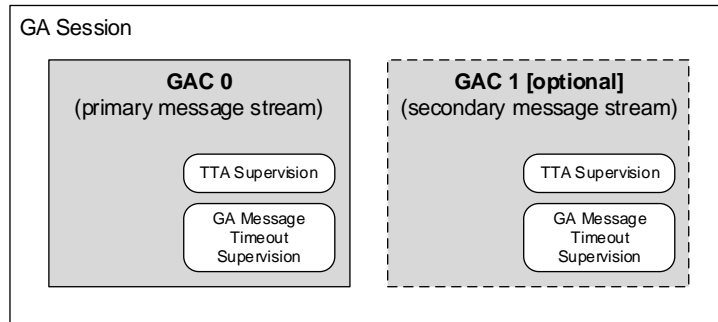


Figure 2-13. GA Session and GA Message Streams

2.21.2 No Power (NP)

2.21.2.1 The GA-OB is in NP state when LOC-OB is switched off.

2.21.3 Standby (SB)

2.21.3.1 This is the default state entered when the LOC-OB is switched on.

2.21.3.2 In this state, the GA-OB can establish a communication session with the GA-TS and request a GA session.

2.21.4 GA Message Stream Not Available (GN) [Primary, Secondary]

2.21.4.1 In this state, the GA message stream is not available. The GA-OB has an active GA session, and the GA message stream has not been allocated.

2.21.4.2 The GA-OB can request the following from the GA-TS:

- GNSS navigation data
- Allocation of a GA message stream
- Termination of the GA session

2.21.5 GA Message Stream Ready (GR) [Primary, Secondary]

2.21.5.1 In this state, the GA message stream is ready for operation. The GA-OB has an active GA session, and the GA message stream has been allocated but the GA message stream is

suspended. TTA supervision is active, and supervision of GA message content timeout is active.

2.21.5.2 If transition to this state was caused by timeout of timer T_GATIMEOUT (TTA supervision), all GA integrity data for this GAC are unavailable.

2.21.5.3 The GA-OB can request the following from the GA-TS:

- GA active data set for the allocated GA message stream
- GNSS navigation data
- Resumption of the GA message stream
- Termination of the GA session

2.21.6 GA Message Stream Operational (GO) [Primary, Secondary]

2.21.6.1 In this state, the GA message stream is operational. The GA-OB has an active GA session and GA message stream has been allocated. The GA message stream is receiving GA messages, TTA supervision is active, and supervision of GA message content timeout is active.

2.21.6.2 If transition to this state was caused by resumption of the GA message stream, GA integrity data may be restored if conditions allow (i.e., GA integrity data have not timed out and any missed alerts have been processed).

2.21.6.3 The GA-OB can request the following from the GA-TS:

- GA active data set for the allocated GA message stream
- GNSS navigation data
- Suspension of the GA message stream
- Termination of the GA session

2.21.7 GA-OB failure (FA)

2.21.7.1 The GA-OB enters the FA state for detected faults / error conditions that prevents GA functions from being performed.

2.21.8 Transition Between States

2.21.8.1 This section defines the transitions between GA-OB states and the transition conditions.

2.21.8.2 Note the following conventions are used for the transition table:

- “>n” indicates that condition [n] must be fulfilled to trigger transition from the state identified in the column to the state identified by the arrow “>”
- Each transition from a given state is given a priority order indicated by “-px-”, where x is the priority order. The priority is provided to avoid a conflict between different

transitions when they occur at the same time (i.e., in the same clock cycle). P1 has a higher priority than P2.

- Some transitions are given the same priority when it has been determined that these transitions cannot occur at the same time and can never lead to a conflicting situation.

Table 2-2. GA-OB transition table

NP	<10 -p1-	<10 -p1-	<10 -p1-	<10 -p1-	<10 -p1-
1> -p1-	SB	<8,9 -p3-	<8,9 -p3-	<8,9 -p3-	
	2> -p3-	GN	<7 -p4-		
			GR	<6 -p5-	
		3> -p4-	4> -p5-	GO	
	5> -p2-	5> -p2-	5> -p2-	5> -p2-	FA

Table 2-3. Transition conditions table

Condition ID	Transition conditions
[1]	LOC-OB is powered on
[2]	GA session established (i.e., GA-OB initiates GA session; GA-TS confirms establishment of GA session; GA-OB acknowledges establishment of the session to the GA-TS)
[3]	GA message stream allocated (i.e., GA-OB sends request for allocation of GA message stream to GA-TS with the GA services supported by the GA-OB; GA-TS confirms allocation of GA message stream with details of GA service, channel identifier and service national values; GA-TS starts sending GA messages)
[4]	GA-OB acknowledges alert GA message AND timer T_GATIMEOUT has not timed out; OR GA message stream resumed (i.e., GA-OB sends resume GA message stream request to GA-TS with timestamp of last GA message received from the GA message stream; GA-TS sends any missed alert messages since last GA message; GA-OB acknowledges any missed alert messages and the GA-TS resumes sending GA messages).
[5]	GA-OB detects a fault / error condition that prevents GA functions from being performed

[6]	Timeout of timer T_GATIMEOUT; OR Reception of an alert GA message (i.e., <i>GAM Packet</i> with Q_GAMT = 1); OR Reception of a DNU message stream indication (i.e., <i>GAM Packet</i> with Q_GAMT = 2); OR Reception of <i>GA Message Stream Suspended</i> message from GA-TS (i.e., acknowledgement from GA-TS of request to suspend GA message stream by GA-OB).
[7]	GA message stream cannot be resumed
[8]	Termination of GA session by the GA-OB (i.e., reception of a <i>GA Session Terminated</i> message from GA-TS in response to the GA-OB sending a <i>Terminate GA Session</i> message to the GA-TS)
[9]	Termination of GA session by the GA-TS (i.e., if the GA-TS detects fault / error condition that impacts the GA session, session expires, etc.)
[10]	LOC-OB is powered off

2.21.9 GA-OB Active Functions Table

2.21.9.1 Note: the active functions table only addresses interoperability-relevant functions of the LOC-OB for GNSS augmentation.

2.21.9.2 The following conventions are used for the active functions table:

- X = functions shall be active
- Empty case = function shall be inactive

GA-OB Functions		Related Requirement	NP	SB	GN	GR	GO	FA
F1	Vehicle Localisation Sensors (VLSs) <GNSS Receiver>							
F1.1	Process GNSS signal	SRS §2.6		X	X	X	X	
F.1.1.1	<i>GNSS pre-correlation signal processing</i>	<i>GA-OB MOPS</i>		X	X	X	X	
F.1.1.2	<i>Acquisition and tracking of GNSS signals</i>	<i>GA-OB MOPS</i>		X	X	X	X	
F.1.1.3	<i>GNSS navigation data demodulation, FEC decoding and frame synchronisation</i>	<i>GNSS-SIS-ICD²</i>		X	X	X	X	
F2	Vehicle Localisation Function (VLF) <GNSS Augmentation Processing>							
F2.1	Process GNSS navigation data (received from GNSS receiver and GA-TS)	SRS §2.7, 2.2.5			X	X	X	
F2.1.1	<i>GNSS navigation data CRC / parity checks</i>	<i>GNSS-SIS-ICD</i>			X	X	X	
F2.1.2	<i>Decoding navigation message parameters</i>	<i>GNSS-SIS-ICD</i>			X	X	X	

² Examples of GNSS signal-in-space ICDs: GPS: [IS-GPS-200] and [IS-GPS-705]; Galileo: [GAL-OS-SIS-ICD]

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GA-OB Functions	Related Requirement	NP	SB	GN	GR	GO	FA
F2.1.3 <i>Message consistency checks</i>	GA-OB MOPS			X	X	X	
F2.2 Processing of GA Messages received from GA-TS (including alert messages and GA messages with DNU GA message stream indication)	SRS §2.8, 2.3				X	X	
F2.2.1 <i>Timestamp GA messages received from GA-TS</i>	SRS §2.8.2				X	X	
F2.2.2 <i>GA message content CRC checks</i>	GA-OB MOPS				X	X	
F2.2.3 <i>Process GA message content (i.e., encapsulated GNSS augmentation message content)</i>	GA-OB MOPS				X	X	
F2.3 GNSS pseudorange determination and use	SRS §2.9		X	X	X	X	
F2.3.1 <i>Carrier smoothing on pseudorange measurements</i>	GA-OB MOPS		X	X	X	X	
F2.3.2 <i>Measurement quality monitoring</i>	GA-OB MOPS		X	X	X	X	
F2.3.3 <i>Pseudorange determination</i>	GA-OB MOPS		X	X	X	X	
F2.3.4 <i>GNSS satellite selection (use criteria)</i>	GA-OB MOPS		X	X	X	X	
F2.4 Compute and apply pseudorange error models (GA-provided integrity)	SRS §2.10				X	X	
F2.4.1 <i>Compute and apply model for differential correction residual error</i>	GA-OB MOPS				X	X	
F2.4.2 <i>Compute and apply model for residual ionospheric error</i>	GA-OB MOPS				X	X	
F2.5 Supervise GA message content timeout	SRS §2.5; GA-OB MOPS				X	X	
F2.6 Supervise and manage TTA	SRS §2.4				X	X	
F2.7 Manage GA Session	SRS §2.2		X	X	X	X	

2.22 GA-TS Operational States

2.22.1.1 Operational states of the GNSS Augmentation Trackside (GA-TS) are described in this section.

2.22.2 No Power (NP)

2.22.2.1 The GA-TS is in NP state when switched off.

2.22.3 Standby (SB)

2.22.3.1 This is the default state entered when the GA-TS is switched on.

2.22.3.2 In this state, the GA-TS is not receiving GA messages from the GNSS Augmentation System or receiving GNSS navigation data. The GA-TS cannot accept requests for a GA session from GA-OBs.

2.22.4 Operational (OP)

2.22.4.1 In this state, the GA-TS is receiving valid GA messages from the GNSS Augmentation System (GAS) and receiving GNSS navigation data for all visible satellites of the core constellations (GPS and Galileo). The GA-TS is timestamping the reception of GA messages, maintaining active data and active alerts for each GNSS Augmentation Channel (GAC), and is maintaining GNSS navigation data sets.

2.22.4.2 The GA-TS can accept the following requests from GA-OBs:

- Establishment of a GA session
- Allocation of a GA message stream
- Request for GA active data
- Request for GNSS navigation data
- Resumption of a GA message stream
- Suspension of a GA message stream
- Termination of a GA session

2.22.5 GA-TS Failure (FA)

2.22.5.1 The GA-TS enters FA state for detected faults / error conditions that prevent GA-TS functions from being performed.

2.22.6 Transition Between States

2.22.6.1 This section defines the transitions between GA-TS states and the transition conditions.

2.22.6.2 Note the following conventions are used for the transition table:

- “>n” indicates that condition [n] must be fulfilled to trigger transition from the state identified in the column to the state identified by the arrow “>”
- Each transition from a given state is given a priority order indicated by “-px-”, where x is the priority order. The priority is provided to avoid a conflict between different transitions when they occur at the same time (i.e., in the same clock cycle). P1 has a higher priority than P2.
- Some transitions are given the same priority when it has been determined that these transitions cannot occur at the same time and can never lead to a conflicting situation.

Table 2-4. GA-TS transition table

NP	<5 -p1-	<5 -p1-	<5 -p1-
1> -p1-	SB	<4 -p3-	
	2> -p3-	OP	
	3> -p2-	3> -p2-	FA

Table 2-5. Transition conditions table

Condition ID	Transition conditions
[1]	GA-TS is powered on
[2]	<p>Connection with authorised GNSS Augmentation System (GAS) is established (i.e., GAS providing railway SoL service approved for use by the GA service provider and authorised by relevant railway safety authorities);</p> <p>AND</p> <p>At least one of the GNSS Augmentation Channels (GACs) of the GAS is broadcasting valid messages (i.e., in the case of SBAS, messages passing CRC with no reception of MT0).</p> <p><i>In the case of EGNOS L1 and DFMC services, the GA-TS acquires SBAS L1 and L5 signals using a GNSS/SBAS receiver enabling the demodulation of SBAS messages for multiple PRNs (GACs). Future versions of EGNOS may support connection via a terrestrial link.</i></p>
[3]	GA-TS detects a fault / error condition that prevents GA-TS functions from being performed
[4]	GNSS Augmentation System becomes unavailable (i.e., no GACs available that are broadcasting valid messages – e.g., due to interference in L1 / L5 frequencies near trackside GNSS/SBAS receiver in the case of SBAS)
[5]	GA-TS is powered off

2.22.7 GA-TS Active Functions Table

2.22.7.1 The following conventions are used for the active functions table:

- X = functions shall be active
- Empty case = function shall be inactive

GA-TS Functions	Related Requirement	NP	SB	OP	FA
F3 Trackside Interface to SBAS / GNSS <GNSS Receiver>					
F3.1 Process SBAS signal	SRS §2.11.2		X	X	
<i>F3.1.1 SBAS pre-correlation signal processing</i>	<i>GA-TS MOPS</i>		X	X	
<i>F3.1.2 Acquisition and tracking of SBAS signals</i>	<i>GA-TS MOPS</i>		X	X	
<i>F3.1.3 SBAS data demodulation, FEC decoding and frame synchronisation</i>	<i>GA-TS MOPS</i>		X	X	
F3.2 Process GNSS signal	SRS §2.11.3		X	X	
<i>F3.1.1 GNSS pre-correlation signal processing</i>	<i>GA-TS MOPS; GNSS-SIS-ICD</i>		X	X	
<i>F3.1.2 Acquisition and tracking of GNSS signals</i>	<i>GA-TS MOPS; GNSS-SIS-ICD</i>		X	X	
<i>F3.1.3 GNSS navigation data demodulation and FEC decoding</i>	<i>GNSS-SIS-ICD</i>		X	X	
F4 Trackside Interface to GAS <TBD> (future)					
F5 GNSS Augmentation Dissemination Function (GADF)					
F5.1 Select GACs	SRS §2.12; GA-TS MOPS		X	X	
F5.2 Processing of GA messages for selected GACs	SRS §2.13			X	
<i>F5.2.1 Timestamping reception of messages from GAS</i>	<i>SRS §2.13.2</i>			X	
<i>F5.2.2 Performing CRC checks on GA messages</i>	<i>GA-TS MOPS</i>			X	
<i>F5.2.3 Encapsulation of GA messages in GAM Packets</i>	<i>SRS §2.13.3; GA-TS MOPS</i>			X	
<i>F5.2.4 Process GA messages</i>	<i>GA-TS MOPS</i>			X	
F5.3 Provide GA message stream(s)	SRS §2.2.1			X	

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GA-TS Functions	Related Requirement	NP	SB	OP	FA
<i>F5.3.1 Allocate GA message stream</i>	<i>SRS §2.2.1</i>			X	
<i>F5.3.2 Suspend GA message stream</i>	<i>SRS §2.2.1</i>			X	
<i>F5.3.3 Resume GA message stream</i>	<i>SRS §2.2.2</i>			X	
F5.4 Provide GA active data for selected GACs	SRS §2.15, 2.2.4; GA-TS MOPS			X	
F5.5 Provide GA active alerts for selected GACs	SRS §2.16, 2.3; GA-TS MOPS			X	
F5.6 Process GNSS navigation data (received from trackside interface to GNSS)	SRS §2.17			X	
<i>F5.6.1 GNSS navigation data CRC / parity checks</i>	<i>GNSS-SIS-ICD</i>			X	
<i>F5.6.2 Decoding navigation message parameters</i>	<i>GNSS-SIS-ICD</i>			X	
<i>F5.6.3 Message consistency checks</i>	<i>GA-TS MOPS</i>			X	
F5.7 Provide GNSS navigation data sets	SRS §2.18, 2.2.5; GNSS-SIS-ICD			X	
F5.8 Manage GA Session	SRS §2.2			X	

3 GA-TS Configuration Management

3.1.1.1 The following table provides a preliminary list of configuration items related to the GA-TS.

Table 3-1. Configuration items

Ref	Configuration Items	Description
1	T_NVGAMAXSYSTTA	GA service maximum system TTA
2	T_NVGAMAXTTA	GA service maximum TTA
3	T_NVGAMBUR	GA service broadcast update rate
4	Configuration parameters for GA service selection	Parameters relating to prioritisation of GA services compatible with GA-OB to be selected for allocation to GA message streams
5	Configuration parameters for GAC selection	Parameters relating to selection of GACs for a given GA service

Annex A Train Positioning in ERTMS/ETCS using GNSS and Augmentation

A.1 Overview

- A.1.1.1 GNSS is considered one of several elements in an on-board localisation architecture (LOC-OB), where GNSS receiver(s) and other sensors potentially including inertial, rotational, radar-based, and optical sensors are used in a multi-sensor architecture to meet application-level performance requirements.
- A.1.1.2 GNSS augmentation provides an important contribution to achieving application-level performance requirements in terms of accuracy improvement and integrity for monitored GNSS signals.
- A.1.1.3 The Railway SoL Service concept is expected to be quasi-independent of the user concept of operations, with a limited set of assumptions, allowing for use of GNSS augmentation in a technology-neutral manner, also facilitating a simplification of service provision requirements and operations. It would provide on-board equipment manufacturers with the flexibility to integrate GNSS augmentation into their solutions without a high-level of prescription on the design of the localisation equipment, hybridisation approach, etc.
- A.1.1.4 A GNSS augmentation system providing a Railway SoL Service is assumed to provide commitments on pseudorange domain performances excluding impact from the local environment. The on-board equipment perimeter would be responsible for protecting user from local feared events (including intentional events such as spoofing and jamming); bounding of residual errors due to receiver and the local environment; and for computation of an along-track train position, train velocity and acceleration and their respective confidence intervals.
- A.1.1.5 Figure A-1 provides an illustrative example of train positioning with GNSS + SBAS, highlighting integrity requirements at application level and integrity performances for the GNSS + SBAS element that contribute to a supplier-specific solution for meeting application-level performances.

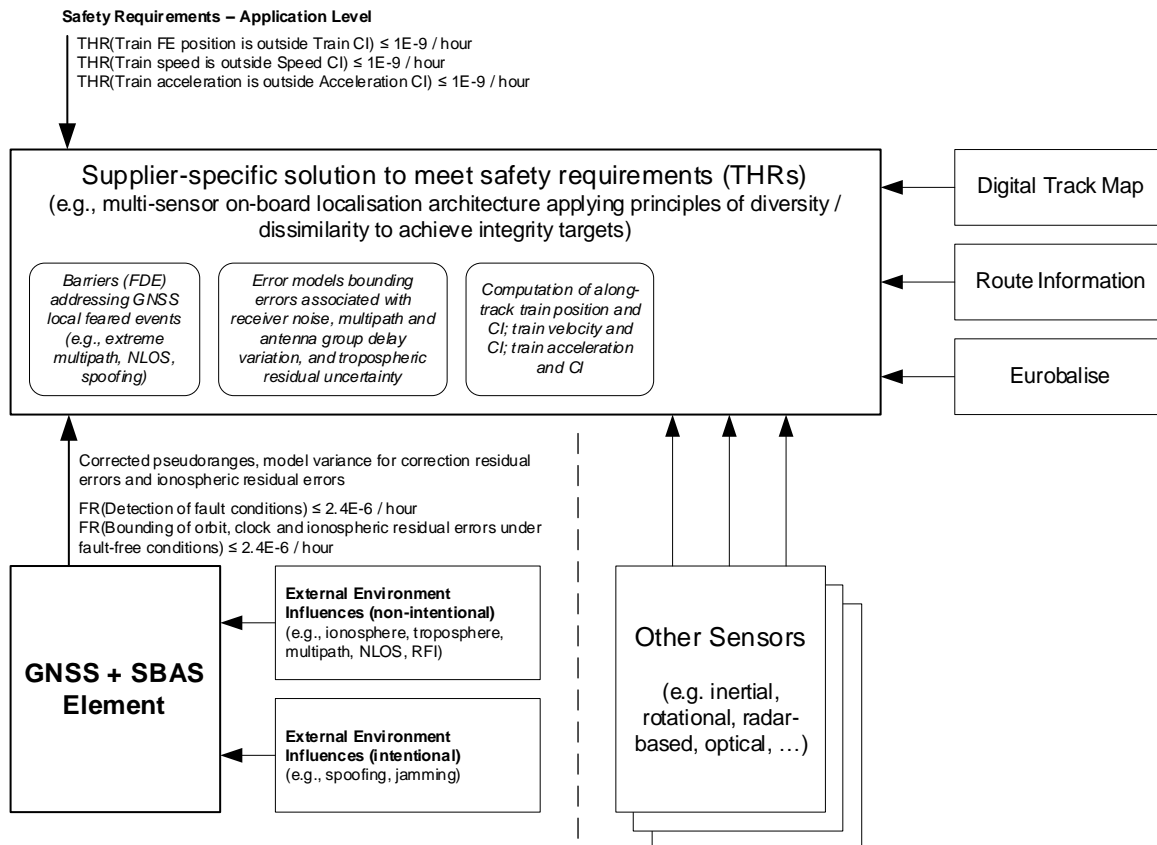


Figure A-1. Example of train positioning with GNSS + SBAS

- A.1.1.6 The GNSS augmentation framework for ERTMS/ETCS described in this document has been designed to be agnostic to GNSS augmentation systems that are based on compatible GNSS augmentation principles, i.e., provision of a pseudorange domain integrity service meeting minimum signal-in-space performance requirements for GNSS receivers that conform to a set of essential requirements, ensuring *technical interoperability* of on-board equipment.
- A.1.1.7 Technical interoperability of on-board equipment means GNSS equipment from different suppliers can safely operate with a given GNSS Augmentation System (GAS) assuming the GNSS equipment conforms to essential requirements on the GNSS receiver (i.e., range of critical receiver parameters), limiting complexity and ensuring assumptions are met by the ground monitoring subsystem of the GAS. These requirements would be common to the Minimum Operational Performance Specifications (MOPS') of compatible GAS', where the MOPS of a specific GAS would address the specificities of message processing, application of corrections, and computation of bounds for pseudorange residual errors, in addition to these requirements.
- A.1.1.8 Technical interoperability also enables the use of on-board equipment with different compatible GNSS Augmentation Systems. In aviation, SBAS and GBAS were designed with commonality for critical receiver parameters, enabling the use of a single set of navigational equipment on aircraft for both SBAS and GBAS approaches from different suppliers / service providers. A similar approach is foreseen for railway, enabling a single set of on-board equipment to operate with EGNOS and other GNSS augmentation solutions for markets

outside the EGNOS service area. In this way, the on-board equipment can support different GNSS augmentation services through implementations of GA-specific software modules that address the specificities of the GAS, including MOPS-compliant message processing, application of corrections, computation of pseudorange error bounds, etc., whilst maintaining hardware that is compatible with different GAS'.

A.2 Use of GNSS Augmentation Services and Prescriptions on the GNSS Receiver

A.2.1.1 Use of a compliant GNSS Augmentation System requires conformance to a minimum set of essential requirements that must be fulfilled for commitments on pseudorange domain integrity to be valid. A *Minimum Operational Performance Standard for GNSS Augmentation On-board Equipment (GA-OB MOPS)* is needed for each type of GNSS augmentation, addressing essential requirements including:

- GNSS Signal processing
- Critical parameters of the user receiver configuration space
- Augmentation message processing
- Computation of pseudorange error bounds (i.e., variance of correction residuals and slant range ionospheric error)

A.2.1.2 It is expected that a demonstration of conformance of the on-board GNSS receiver(s) to a given GA-OB MOPS will be required, in addition to evidence of safe integration of the receiver within the on-board localisation architecture, for the on-board equipment to be authorised for the GA service.

A.2.1.3 Constraining the receiver implementation through prescription of critical parameters of the user receiver configuration space is necessary to enable technical interoperability between receivers from different manufacturers and to limit the complexity of the GNSS augmentation ground monitoring subsystem. These critical parameters directly influence how each point in the threat space for each fault mode translate to an error in the differentially corrected smoothed pseudorange.

A.2.1.4 The design of GNSS augmentation ground monitors considers the error that would be induced in the corrected smoothed pseudorange given the full range of critical parameters that comprise the user receiver configuration space for each fault mode to be protected by the GNSS augmentation system.

A.2.1.5 For example, the current SARPs identifies the signal deformation threats (EWF anomalies) and defines the SQM function that allows them to be mitigated for both SBAS and GBAS. As noted in the SARPs [SARPS, Attachment D-43, Section 8]:

The signal effects that might cause a GBAS or SBAS to output MI can be categorised into three different effects on the correlation function as follows:

- a) *Dead zones: If the correlation function loses its peak, the receiver's discriminator function will include a flat spot or dead zone. If the reference receiver and aircraft receiver settle in different portions of this dead zone, MI can result.*

- b) False peaks: If the reference receiver and aircraft receiver lock to different peaks, MI could exist.
- c) Distortions: If the correlation peak is misshapen, an aircraft that uses a correlator spacing other than the one used by the reference receivers may experience MI.

A.2.1.6 The SARPs defines three threat models and the SQM function to detect these anomalies through characterisation of the correlation peak. The critical user receiver parameters for the signal distortion threat are:

- *Smoothing filter type*. The fault condition will appear as a step in raw code measurement both for user and ground receivers. The step is filtered by the smoothing filter in the ground and user receivers, impacting detection threshold and whether the increasing pseudorange error exceeds limit for protection before detection threshold is reached.
- *Correlator type* (Early-Late (E-L) or Double Delta (DD))
- *Correlator spacing*
- *GNSS signal bandwidth* (from reception at antenna through RF, IF, and A/D conversion)
- *Group delay* (from reception at antenna through RF, IF, and A/D conversion)

A.2.1.7 The user receiver must conform with the prescribed critical parameters for the ground monitor to protect users against the defined threat models.

A.3 Use of Pseudorange and Bounding of Residual Errors with GNSS Augmentation

A.3.1.1 A generic Railway SoL Service (pseudorange domain integrity service) would be expected to provide commitments on bounding of correction residuals and ionospheric delay.

A.3.1.2 Assuming the user performs PVT computations with a snapshot weighted least squares (WLS) algorithm, integrity is guaranteed when the pseudorange error is bounded for all measurements. The residual errors for pseudorange measurements for fault-free satellites are modelled by root-sum-squaring the error components (under the assumption of zero-mean normal distributions).

A.3.1.3 Equation A-1 illustrates the error components provided by a generic Railway SoL Service, with mappings to examples for the following GNSS augmentation services:

- *SBAS L1*;
- *SBAS DFMC*; and
- *GBAS L1*, GBAS Approach Service Type C (GAST C) with L1 signals only (integrity performances are equivalent to SBAS SoL service for precision approach, with integrity risk = 2×10^{-7} in any approach (150s) and a TTA = 6s). Note that DFMC (L1/L5) is currently not supported but is foreseen in the future GAST F (CAT-II/III). An adaptation of GBAS may be suitable for export markets outside the EGNOS coverage area or coverage area of an SBAS providing a Railway SoL Service. The GBAS example is intended for illustrative purposes only.

$$\sigma_i = \sqrt{\sigma_{i,CRE}^2 + \sigma_{i,iono}^2}$$

Where:

$\sigma_{i,CRE}^2$ is the variance of the correction residual error for satellite i :

- For SBAS L1, $\sigma_{i,CRE}^2$ is the model variance for the residual error when SBAS L1 corrections (long term, fast and range rate) are applied, and the degradation model is used ($\sigma_{i,flt}^2$).
- For SBAS DFMC, $\sigma_{i,CRE}^2$ is the model variance for the residual error after application of SBAS dual-frequency corrections ($\sigma_{i,DFC}^2$).
- For GBAS L1, $\sigma_{i,CRE}^2$ is the variance of the total post correction fault-free noise term provided by the ground function (σ_{i,pr_gnd}^2).

$\Sigma_{i,iono}^2$ is the variance of the residual ionospheric error for satellite i :

- For SBAS L1, $\sigma_{i,iono}^2$ is the model variance for the slant range ionospheric error when applying SBAS L1 ionospheric corrections ($\sigma_{i,UIRE}^2$).
- For SBAS DFMC, $\sigma_{i,iono}^2$ is the model variance describing the residual ionospheric error (including ionospheric higher-order effects, ray bending and excess TEC) when applying the ionosphere-free dual-frequency L1/L5 combination.
- For GBAS L1, $\sigma_{i,iono}^2$ is the variance for the residual ionospheric delay due to spatial decorrelation uncertainty.

A.3.1.4 If Kalman filters are used (instead of PVT computations with snapshot WLS algorithm), the residual error bounds broadcast by the GAS may not be suitable for use if the effect of the biases and the time-correlation of the remaining error distribution after corrections are not accounted for properly.

A.3.1.5 Additional information from the GAS (e.g., upper bound of error correlation time and bias values) can improve support for Kalman filtering. In the case of EGNOS, commitments on the upper bound of error correlation time and bias values for orbit, clock, and ionospheric errors are not currently provided. Such features may be investigated for a future Railway SoL service but are not foreseen in the short term.

A.3.1.6 Protection levels computed from the Kalman filter-estimated covariance may not bound position errors at the required level of confidence as assumptions on errors being uncorrelated (i.e., errors related to ephemeris/clock and ionosphere are correlated in time) and error distributions being zero-mean Gaussian are not valid. **It is the responsibility of the manufacturer perimeter to address such issues and ensure the safety of the Vehicle Localisation Function.**

A.3.1.7 While the computation of protection levels is outside the scope of the Railway SoL Service (i.e., service is not expected to provide commitments on position domain performances as is implied by track-constrained position domain error bounds), it is expected that guidance could be provided for the computation of protection levels (e.g., reference algorithms for WLS

and Kalman Filtering approaches) as an informative annex of the Railway SoL Service MOPS for a specific GAS.

A.3.1.8 Note that the computation of along-track protection levels depends on the definition of a safety-related interoperable digital track map, and additionally requires pseudorange error models to be defined for error components including:

- *Tropospheric correction residual errors*, the assumed model is the DO-229 / ED-259A tropospheric model (validation of tropospheric model for railway is an open item noted in Annex C).
- *Receiver errors*, including receiver noise, thermal noise, interference, inter-channel biases, extrapolation, time since smoothing filter initialisation, and processing errors for smoothed pseudoranges.
- *Multipath and antenna group delay variation*.
- *Ionospheric divergence* for single frequency users caused by the difference between the implemented smoothing filter and the reference smoothing filter given an ionospheric code-carrier divergence. For example, in SBAS L1 residual ionospheric errors caused by the difference between the implemented smoothing filter and the reference smoothing filter given an ionospheric code-carrier divergence during the transient phase (i.e., before filter reaches steady-state) for L1 single frequency measurements smoothed with the time variant reference smoothing filter, applying SBAS L1 ionospheric corrections. Not applicable for SBAS DFMC (i.e., using ionosphere free dual-frequency measurements) or GBAS, as it requires (nearly) matched smoothing filters in ground and on-board to limit sensitivity to ionospheric divergence (SBAS L1 can implement smoothing filters with a longer weighting function time constant as it removes divergence on ground using GPS L2 measurements).

A.4 Considerations on Responsibility and Critical User Receiver Parameters

A.4.1.1 It is understood some of the MOPS-compliant critical user receiver parameters such as the smoothing filter type may be impacted by local effects of the railway environment (e.g., carrier phase discontinuities) and as such, may result in poor performance.

A.4.1.2 For cases such as this, where a deviation from the requirements may be necessary, it is proposed for a future iteration of this specification that guidance is provided on how to deviate from prescribed critical user receiver parameters in a controlled manner to ensure integrity requirements are met.

A.4.1.3 The guidance could be included in an informative annex and would address:

- Definition of minimum constraints.
- Information on the effects / impact (if can be determined) of not implementing the prescribed parameters.
- Guidance on how to deviate in a controlled manner. For example, in the case of the smoothing filter, guidance on how to justify that integrity assumptions are not violated

considering differences of the implemented smoothing filter with respect to the response of the reference smoothing filter, addressing:

- a) The transient function of the error during convergence time of the filter (i.e., elapsed time since smoothing filter re-initialisation until in the steady state).
- b) Inflation of residual error variances in the case of a smoothing filter with a weighting function time constant < 100 seconds (i.e., in the steady state).
- c) For single frequency users, residual ionospheric error caused by the difference between the implemented filter and the reference filter caused by ionospheric divergence during the transient phase.

Annex B EGNOS-based GNSS Augmentation in ERTMS/ETCS

B.1 The European Geostationary Navigation Overlay Service (EGNOS)

- B.1.1.1 EGNOS, the European Satellite Based Augmentation System (SBAS), is a system designed to augment Global Navigation Satellite Systems (GNSS) by providing users with ephemeris, clock and ionospheric error corrections, and integrity information broadcasted via geostationary satellites. Currently EGNOS augments GPS L1 signals only; however, the next generation of EGNOS will provide a Dual Frequency Multi Constellation (DFMC) service augmenting GPS and Galileo L1/E1 and L5/E5a signals, in addition to the GPS L1 service.
- B.1.1.2 The EGNOS ground segment is comprised of a network of monitoring stations (RIMS) that are used to collect measurements, which are elaborated by the Central Processing Facility (CPF). The CPF computes ephemeris corrections, clock corrections, and a model for ionospheric errors, valid for the defined service area, improving positioning accuracy for users within this area.
- B.1.1.3 The CPF estimates residual error variances (assuming application of corrections broadcast by the system) – the User Differential Range Error (UDRE) and Grid Ionospheric Vertical Error (GIVE) for single frequency users, and the Dual Frequency Range Error (DFRE) for dual frequency users. These residual error variances are used in the determination of a protection level, a statistical bounding of the position error that meets the integrity requirement for a given operation (e.g., for the LPV-200 service level that supports approach operations based on SBAS with a minimum decision height of 200 feet, integrity requirement is $1-2 \times 10^{-7}$ in any approach). The CPF can detect when errors exceed certain thresholds or anomalies in the GPS, Galileo or SBAS systems themselves. In these cases, the user must be alerted within the Time to Alert (TTA).

B.2 Hypothetical EGNOS Signal-in-space Performances

- B.2.1.1 Note that EGNOS Signal-in-space (SIS) performances for future Railway SoL Services have not yet been defined; **the description of services and performances in this section is hypothetical and intended for illustrative purposes only.**
- B.2.1.2 Table B-1 provides an example of hypothetical SIS performances for four service levels, supporting a stepwise approach for the introduction of the EGNOS Railway SoL service in ERTMS/ETCS, progressively targeting operations and railway area performance profiles requiring more stringent performances.
- The service levels would be mapped to operations (e.g., ATP, ATO, etc.) and localisation requirements for various railway area performance profiles (e.g., mainline, dense traffic line, train traffic node, precise positioning area, safe precise operation < 30 km/h, etc.), enabling a stepwise introduction of the EGNOS Railway SoL Service in ERTMS/ETCS.
 - Assuming SIS performance requirements vis-à-vis operation and railway area performance profile are included in the CCS-TSI (i.e., performance requirements for interoperability), trackside designers can design trackside according to supported

performance profiles (e.g., trackside design can accommodate larger maximum confidence interval with appropriately dimensioned overlaps, and Eurobalises can be used in specific cases where performances fall short of application requirements and more stringent performances are needed). With this approach, trackside compatibility parameters would define minimum supported performance profile.

B.2.1.3 Table B-1 additionally provides a hypothetical mapping of service levels to future EGNOS Railway SoL services. SL1 and SL2 performances, in a first step, are based on bottom-up analysis (achievable performances based on SBAS aviation SoL L1 and DFMC services); SL3A and SL3B progressively introduce additional functionality through possible evolutions of the EGNOS design to meet improved performances / safety, supporting a stepwise improvement to operations. The mapping of application-level performances to service levels and service levels to EGNOS Railway SoL services would likely need to be validated using implementations / demonstrators of reference on-board architectures.

B.2.1.4 The hypothetical EGNOS Railway SoL Services listed in Table B-1 are briefly described below:

- *EGNOS L1 Railway SoL Service* – based on pseudorange integrity performances of EGNOS SoL L1 service with reception of EGNOS messages via the SIS at the trackside.
- *EGNOS DFMC Railway SoL Service* – based on pseudorange integrity performances of EGNOS SoL DFMC service with reception of EGNOS messages via the SIS at the trackside.
- *EGNOS DFMC+ Railway SoL Service* – Medium-term evolution of EGNOS SoL DFMC service, potentially including provision of additional information to better support Kalman filtering disseminated via an alternative channel. Reception of EGNOS messages via the SIS at the trackside.
- *EGNOS Next Railway SoL Service* – Long-term evolution of EGNOS for railway, potentially including additional commitments in the pseudorange domain and pseudorange-rate domain, enhanced support for Kalman filtering, and a dedicated terrestrial dissemination channel for railway with a message structure optimised for railway.

Table B-1. Hypothetical EGNOS Railway SoL Service Signal-in-Space Performances

Hypothetical commitments on SIS performances		Hypothetical Service Levels			
		SL1	SL2	SL3A	SL3B
Integrity	Detection of fault conditions (Note 1 and 12)	1-2.4E-6 /h	1-2.4E-6 /h	1-2.4E-6 /h	1-2.4E-6 /h
	Bounding of pseudorange error residuals (orbit, clock and ionospheric delay) under fault-free conditions (Note 2 and 3)	1-2.4E-6 /h	1-2.4E-6 /h	1-2.4E-6 /h	1-2.4E-6 /h
	Bounding of pseudorange-rate error residuals (orbit, clock and ionospheric delay) under fault-free conditions (Note 2 and 3)				1-2.4E-6 /h
	Time-to-alert (SBAS to GA-TS) (Note 4)	5.2s	5.2s	5.2s	≤ 5.2s
Accuracy	Pseudorange accuracy (95%) (Note 5)		TBC (pr_acc_1)	TBC (pr_acc_1)	TBC (pr_acc_2)
	Pseudorange-rate accuracy (95%) (Note 6)				TBC
Continuity	Pseudorange continuity risk (Note 7)				TBC
	Pseudorange-rate continuity risk (Note 8)				TBC
Availability	Pseudorange availability (Note 9)			TBC	TBC
	Pseudorange-rate availability (Note 10)				TBC
Enhanced Support for Kalman filtering	Provision of bias values (Note 11)			TBC	TBC
	Pseudorange residual error time correlation bound (Note 11)			TBC	TBC
	Pseudorange-rate residual error time correlation bound (Note 11)			TBC	TBC
Hypothetical mapping of Service Levels to potential future EGNOS Railway SoL Services					
EGNOS L1 Railway SoL Service		X			
EGNOS DFMC Railway SoL Service		X	X		
EGNOS DFMC+ Railway SoL Service		X	X	X	
EGNOS Next Railway SoL Service		X	X	X	X

Note 1.— A fault condition is the presence in the System of any feared events or any events beyond the defined fault-free conditions.

Note 2.— Fault-free conditions refer to no extreme ionosphere / scintillation conditions; included in fault-free conditions is frequently observed events such as ground station nominal multipath / interference / cycle slips, interruptions in the ground segment, processing facility switches, etc.

Note 3.— Tropospheric error is not actively monitored by the GNSS augmentation system and is therefore not included in SIS commitments. Tropospheric refraction is a local phenomenon, where water vapour associated with precipitation, thunderstorms and bad weather is a significant contributor to tropospheric delay. The proposed tropospheric correction and residual tropospheric error model is the model defined in [DO-229] and [ED-259A], which is a blind model that has been validated using historical data for use in the aviation SoL service.

Conditions for use of tropospheric model for railway are TBC (i.e., imposition of masking angle < 10 degrees of elevation to reduce mapping function anomalies from the blind model; inflation of residual error bounding in extreme weather conditions).

Validation of the tropospheric model for railway is an open item noted in Annex C.

Note 4.— The EGNOS to GA-TS time to alert (TTA) is defined as the maximum duration accepted between the occurrence of an alert condition and the reception of this alert by the GA-TS (i.e., when the last bit of a SBAS message indicating “Don't Use” arrives at the antenna port of the GA-TS GNSS receiver). The duration includes the time to detect the alert condition; however, this duration excludes the user receiver allocation (0.8 seconds).

An alert condition occurs when the GNSS augmentation system has erroneously broadcast integrity data not bounding the correction residuals or vertical ionospheric error at the specified confidence level for any valid combination of active data.

The railway SoL service would provide commitments on TTA to the GA-TS boundary only; this is not the end-to-end TTA, which is the duration between the occurrence of an alert condition and the time the alert is received at the endpoint (the VLF within the on-board equipment, which may include forwarding of GA messages on an internal bus).

SBAS messages are received and disseminated over a track to train radio channel for which message latency is supervised. The maximum end-to-end TTA is a variable defining a threshold that if exceeded, transitions the positioning function to a safe state. This variable is dimensioned taking into consideration:

- EGNOS to GA-TS TTA (5200 ms in the case of SL1, SL2 and SL3A, where SBAS messages are received via SIS);
- Latency of GA-TS processing (including allocation for the GA-TS GNSS receiver, processing and encapsulation of GA messages by GA-TS);
- GA-TS to GA-OB transfer delay over safe radio connection;
- Broadcast update rate (1 Hz in the case of SL1, SL2 and SL3A, where SBAS messages are received via SIS);
- On-board equipment (including on-board GNSS receiver) maximum TTA (800 ms allocation); and
- Margin to cope with variations in safe radio connection performance.

Note 5.— Pseudorange accuracy excludes receiver noise and local effects (e.g., multipath, NLOS, RFI). Definition and performance computation methodology is TBC.

- *pr_acc_1*: Commitments on pseudorange accuracy are not currently provided by EGNOS. TBC if commitments on pseudorange accuracy can be provided in the short / medium terms.
- *pr_acc_2*: new commitments on pseudorange accuracy.

Note 6.— Pseudorange-rate accuracy excludes receiver noise and local effects (e.g., multipath, NLOS, RFI). Definition and performance computation methodology is TBC.

Note 7.— Continuity of service refers to a System's capability to perform its function without unscheduled interruptions during the intended operation; it is the probability that the service is available, and the System meets its integrity performance over a period of time given that it is available at the beginning of the period of time.

Pseudorange continuity risk refers to the probability that continuity is not provided and is potentially linked to:

- a) Minimum set of constraints at GNSS SIS constellation level and EGNOS RAM level (including switchover between redundant elements); and
- b) Probability that variance of correction residuals and variance of vertical ionosphere error (for single frequency users) does not exceed defined thresholds over a given period of time (e.g., for L1 service: $P(\sigma_{\text{fit}} > \sigma_{\text{fit_max}})$ or $P(\sigma_{\text{UIRE}} > \sigma_{\text{UIRE_max}}) < x / \text{time period}$; and for DFMC services: $P(\sigma_{\text{DFC}} > \sigma_{\text{DFC_max}}) < x / \text{time period}$).

Definition and performance computation methodology is TBC.

Note 8.— Pseudorange-rate continuity risk definition and performance computation methodology is TBC.

Note 9.— Availability for the aviation SoL service is based on meeting accuracy and integrity requirements in the position domain (i.e., when $x_{\text{PL}} < x_{\text{AL}}$). The railway SoL service concept does not provide commitments on position domain performances, which are highly dependent on the user receiver and assumptions of the user environment.

Pseudorange availability requirements are therefore potentially linked to the availability of variances of correction residuals and vertical ionospheric error below a given threshold for the service volume (e.g., for L1 service: $\sigma_{\text{fit}} < \sigma_{\text{fit_max}}$ and $\sigma_{\text{UIRE}} < \sigma_{\text{UIRE_max}}$; and for DFMC services: $\sigma_{\text{DFC}} < \sigma_{\text{DFC_max}}$), also considering planned and unplanned events (i.e., related to GNSS SIS constellation availability and EGNOS RAM-related availability).

Definition and performance computation methodology is TBC.

Note 10.–Pseudorange-rate availability definition and performance computation methodology is TBC.

Note 11.–In snapshot Weighted Least Square, integrity is guaranteed if pseudorange error is bounded for all measurements; however, if Kalman filters are used, the protection level is computed from the estimated covariance with the assumption that measurement error distribution is uncorrelated and zero-mean Gaussian. This assumption is not valid as errors (i.e., orbit, clock, and ionospheric errors) are correlated in time and are not Gaussian.

Methods for handling temporal correlation on measurement errors and errors from biases of previous epochs within the KF are TBC; however, an upper bound on error correlation time and bias values (to address non-Gaussian error distributions) are likely to be needed for orbit, clock, and ionospheric errors, to support Kalman filtering. It should also be noted that the requirement for carrier smoothing of pseudoranges also implies measurements will have a time correlated noise, which needs to be taken into account in the KF.

In the case of SL3A hypothetically supported by “EGNOS DFMC+ Railway SoL Service”, it is TBC if time correlation on residual errors can be characterised and a bound on residual error time correlation as well as bias values could be provided to user via an alternative channel (i.e., with minimal impact on system design for EGNOS DFMC service).

Note 12.–Integrity requirements for the Railway SoL Service, in a first step, are based on bottom-up analysis (i.e., achievable performances based on EGNOS aviation SoL L1 and DFMC services).

Precision approach services are associated with the most stringent level of integrity performance currently provided by EGNOS. The EGNOS SoL service for Precision Approach (i.e., LPV200 – supporting precision approach operations down to LPV minima as low as 200 ft), meets an integrity risk = 2×10^{-7} in any approach (150s) with a TTA = 6s (includes 800 ms receiver allocation).

Note that while non-precision approach (NPA) meets a higher level of integrity in the position domain (integrity risk = 10^{-7} / hour, TTA = 10s, with an alert limit of 556m), NPA integrity is not committed by EGNOS in the pseudorange domain as all the barriers are designed against the Precision Approach services (i.e., for NPA service, the case of position domain impact analysis needs to be explicitly addressed).

In EGNOS for Precision Approach services, a conservative assumption is made that under fault-free conditions a violation of integrity in the pseudorange domain would result in a violation of integrity in the position domain with a probability of 1; therefore,

- an integrity risk allocation of 10^{-7} / 150s is allocated to bounding of residual errors in the pseudorange domain under fault-free conditions (i.e., no extreme ionosphere / scintillation conditions; includes ground station nominal multipath, interference, cycle slips, etc.); and
- another allocation of 10^{-7} / 150s is made for detection of fault conditions (i.e., presence in the system of any feared events or any events beyond the defined fault-free conditions).

For railway applications, the integrity risk is translated to a one-hour exposure time. The justification for this exposure period is related to safety analyses and the apportionment to constituents in the European Train Control System (ETCS), which is undertaken against a definition of the role of that constituent and its related hazards in a representative one-hour journey.

There are 24×150 second periods in one hour, resulting in an integrity requirement of 2.4×10^{-6} / hour for bounding of residual errors in the pseudorange domain under fault-free conditions, and 2.4×10^{-6} / hour for detection of fault conditions.

B.3 Overview of Functional Reference Architecture with EGNOS-based GNSS Augmentation in ERTMS/ETCS

B.3.1.1 Figure B-1 provides a high-level reference architecture of GNSS Augmentation based on EGNOS for ERTMS/ETCS, illustrating the interface of the GA-TS to EGNOS via the EGNOS signal-in-space (SIS).

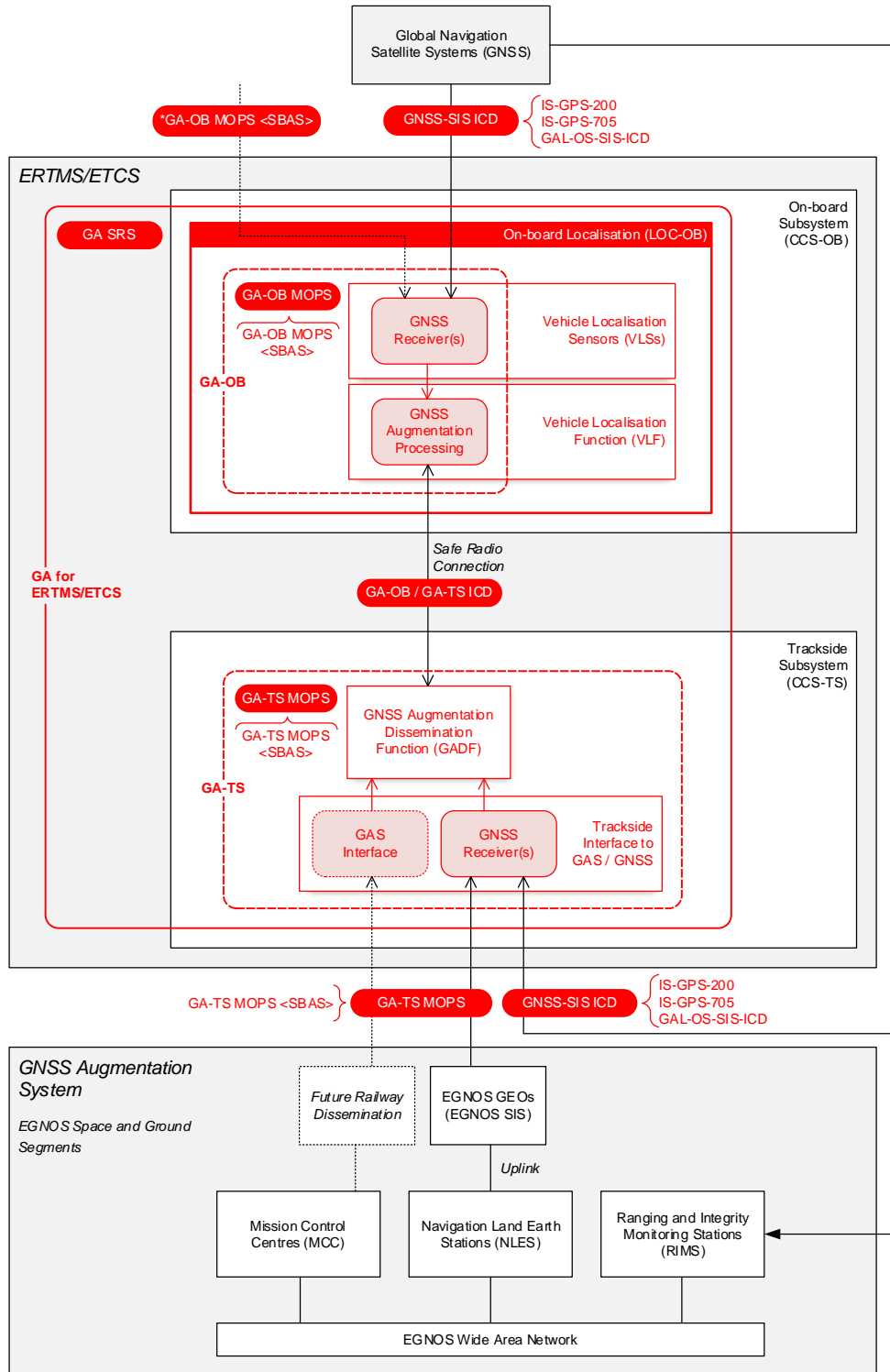


Figure B-1. GNSS Augmentation Functional Reference Architecture with EGNOS-based GA

B.3.1.2 The functional reference architecture includes the possibility for reception of SBAS messages directly by the LOC-OB from the SBAS GEO SIS. Note that this interface is SBAS-specific and is to be developed further in the next iteration of this document³. This mode of operation is expected to have a low availability due to obscuration of signals, especially in the railway environment. For this reason, on-board reception of EGNOS augmentation information via the GA-TS is considered as the primary means to ensure a high availability of augmentation information to the on-board.

Note: it is conceivable that an EGNOS railway-specific dissemination channel(s) via terrestrial or other means (e.g., including possible future concepts including SBAS E5b / signals from IGSOs (inclined geosynchronous orbits)) could be considered in the future.

B.4 EGNOS-Specific GA-OB Functions

B.4.1.1 This section provides some EGNOS-specific considerations related to the GA-OB functions.

B.4.2 SBAS Network Time (SNT)

B.4.2.1 $T_{GA-TS,GAMrx}$ is the timestamp (time of week) of the end of GA message reception by the GA-TS, provided by the variable T_GAM in *GAM Packets* included in *GA Messages* sent by the GA-TS to the GA-OB. The time reference of T_GAM is indicated by the qualifier Q_GAT in the *GAM Packets*.

B.4.2.2 For EGNOS, $Q_GAT = 0$, SBAS Network Time. The GA-OB time $t_{GA-OB,now}$ shall be in the same time reference (i.e., SBAS Network Time).

B.4.2.3 The SBAS Network Time (SNT) is the time reference maintained by SBAS for the purpose of defining corrections. The leading edge of the first symbol that depends on the first bit of the current message is broadcast from the SBAS satellite synchronous with a one-second epoch of SNT.

B.4.2.4 For SBAS L1, data blocks maintain synchronism with GPS data blocks to within the overall SBAS L1 performance requirements (i.e., SNT shall be within 50 nanoseconds of GPS system time). When using corrections, the user's solution for time will be with respect to SNT, and not with respect to GPS System Time.

B.4.2.5 For SBAS DFMC, SNT can be aligned with different GNSS constellations. The time reference for SNT is provided via the *Time Reference Identifier* in MT37 (i.e., time ref ID = 0 for GPS LNAV; time ref ID = 2 for Galileo). The GA-OB shall use the latest decoded MT37 to interpret reference times broadcast in MT32, MT40 and MT47. When using corrections, the user's solution for time will be with respect to SNT.

B.4.2.6 Changes to time reference for SNT is considered a rare event. The SBAS service provider is required to ensure that interpreting any reference time using an old but active MT37 with a different time reference ID from the current one is safe [ED-259A, DMS:236].

³ This interface is reserved for supporting reception of the SBAS GEO SIS by the GA-OB. In a future release of the SRS, principles for use of this interface will be defined. It should be noted that information from EGNOS received by the GA-OB via the GA-TS and via the SBAS GEO SIS cannot be mixed in a single GNSS processing channel.

B.4.3 Time of Applicability

B.4.3.1 Time of Applicability of information in the SBAS signal-in-space is the start of the epoch of the SNT second that is coincident with the start of transmission at the SBAS broadcasting satellite of the first bit of the 1-second message block.

B.4.4 Message Timeout Periods

B.4.4.1 The beginning of the timeout interval for message content timeout supervision is the end of the reception of a message by the SBAS/GNSS receiver in the GA-TS. This timestamp is provided in GA messages (T_GAM) to allow the GA-OB to supervise message content timeouts with respect to its current time $t_{GA-OB,now}$.

B.4.4.2 The following tables provide SBAS message content broadcast intervals and timeout for the proposed Railway SoL Service, which is assumed to be based on SBAS precision approach operations – refer to Annex A).

Table B-1. Message content broadcast intervals and timeout (SBAS L1)

Data	Associated Message Types	Maximum Update Interval (seconds)	Railway SoL Service Timeout (seconds)*
Don't Use for Safety Applications	0	6	N/A
PRN Mask	1	120	600
UDREI	2 to 6, 24	6	12
Fast Corrections	2 to 5, 24	(see Table B-2)	(see Table B-2)
Long Term Corrections	24, 25	120	240
Fast Correction Degredation	7	120	240
Degredation Parameters	10	120	240
Ionospheric Grid Mask	18	300**	1200
Ionospheric Corrections	26	300	600
Service Level	27	300 (if used)	86400
Clock-Ephemeris Covariance Matrix	28	120	240

*Note: Railway SoL Service (L1 Legacy) timeout values are equivalent to those defined for LNAV/VNAV, LP and LPV approach [DO-229].

**When PRN mask is changed, it should be repeated several times before the new masks are used to ensure all users receive the new mask before it is applied (i.e., minimising impact on continuity).

Table B-2. Fast corrections degradation factor and user timeout interval evaluation (SBAS L1)

Fast Corrections Degredation Factor Indicator (ai)	Fast Corrections Degredation Factor (ai) (m/s ²)	Railway SoL Service Timeout Interval for Fast Corrections (seconds)*	Maximum Fast Correction Update Interval (seconds)
0	0.00000	120	60
1	0.00005	120	60
2	0.00009	102	51
3	0.00012	90	45
4	0.00015	90	45
5	0.00020	78	39
6	0.00030	66	33
7	0.00045	54	27
8	0.00060	42	21
9	0.00090	30	15
10	0.00150	30	15

11	0.00210	18	9
12	0.00270	18	9
13	0.00330	18	9
14	0.00460	12	6
15	0.00580	12	6

*Note: Railway SoL Service (SBAS L1) timeout intervals for fast corrections are equivalent to those defined for LNAV/VNAV, LP and LPV approach [DO-229].

Table B-3. Message content broadcast intervals and timeout (SBAS DFMC)

Contents	Associated Message Types	Maximum Update Intervals (seconds)	Railway SoL Service Timeout (seconds)*
Do Not Use for Safety Applications	0	6	N/A
Satellite mask	31	120	600
Integrity information (DFREI and DFRECI)	34	6	12
	35		
	36		
	32		
	40		
Satellite Clock-Ephemeris error corrections and covariance matrix	32	$0.5 \times (I_{VALID})_{MT32}$ (defined in MT 37)	$(I_{VALID})_{MT32}$ (defined in MT 37)
Ephemeris and Clock covariance matrix of SBAS broadcasting satellites	39	$0.5 \times (I_{VALID})_{MT39/40}$ (defined in MT 37)	$(I_{VALID})_{MT39/40}$ (defined in MT 37)
	40		
OBAD parameters and DFREI scale table	37	120	600
Time Reference Identifier	37	120	600
SBAS provider ID	47	120	600

*Note: Railway SoL Service (SBAS DFMC) timeout values are equivalent to those defined for LNAV/VNAV, LP and LPV approach [ED-259A].

B.5 EGNOS-Specific GA-TS Functions

B.5.1.1 This section provides some EGNOS-specific considerations related to the GA-TS functions.

B.5.2 Selection of GACs

B.5.2.1 The GA-TS shall select at least two SBAS L1 PRNs (GNSS augmentation channels, GACs) that are broadcasting valid messages, passing CRC, and with no reception of MT0, from an authorised SBAS service provider (i.e., EGNOS assuming declaration of a Railway SoL service and authorisation for its use).

B.5.2.2 The GA-TS shall select at least two SBAS L5 DFMC PRNs (GACs) that are broadcasting valid messages, passing CRC, and with no reception of MT0, from an authorised SBAS service provider (i.e., EGNOS assuming declaration of a Railway SoL service and authorisation for its use).

B.5.3 Provision of GA Active Data for Selected GACs

B.5.3.1 The GA-TS shall maintain an active GA data set for selected GACs by temporarily storing the last received SBAS messages for SBAS message types, ensuring stored messages provide a consistent data set in terms of Issue of Data (IOD) (see Figure B-1).

- B.5.3.2 The GA-TS shall maintain GA active data sets for multiple IODs, providing the GA-OB with the most recent complete active data set (i.e., with IOD consistency) when requested.
- B.5.3.3 SBAS messages are temporarily stored until a new SBAS message is received for the same IOD or for the duration of the validity of the message content (i.e., until message content times out).
- B.5.3.4 Note: Upon transmission of new clock and ephemeris data from GNSS satellites, the SBAS will continue to broadcast corrections and covariance matrix with respect to the old clock and ephemeris data for a period of time enabling all SBAS users to acquire the new GNSS data.
- B.5.3.5 Message types with a short timeout and high update rate are not included in the active data set, as it is assumed that these messages can be received by the GA-OB via the GA message stream.
- B.5.3.6 Figure B-1 and Figure B-2 illustrate the relationships between message types that are broadcast on SBAS L1 and SBAS L5 respectively, including IOD-related dependencies.

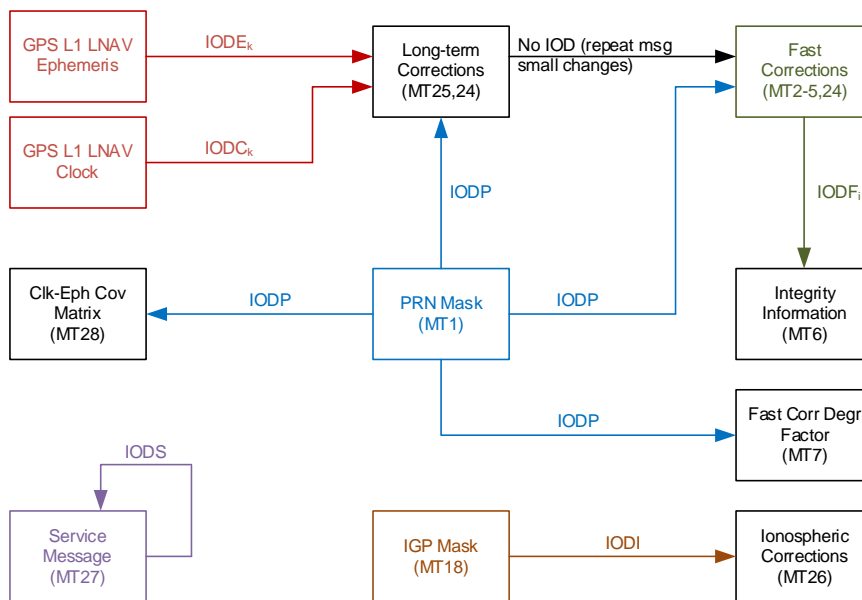


Figure B-1. Relationships between SBAS message types (SBAS L1)

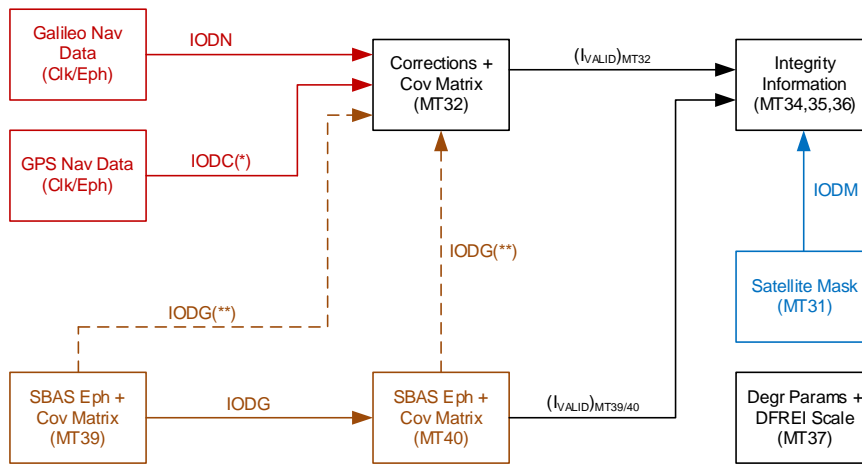


Figure B-2. Relationships between SBAS message types (SBAS DFMC)

- (*) Once the IODC/IODE consistency is checked, the IODC is used to identify the applicable set of clock and ephemeris data when applying SBAS L5 corrections.
- (**) IODG links between MT39/40 and MT32 are used when the MT32 is broadcast for an SBAS satellite.

Annex C Open Points to be Addressed in Future Iterations of the Specification

C.1.1.1 The following table provides a list of open points related to the SRS to be addressed in future iterations of the specification. Many of these open points are to be addressed in work packages defined by ERJU/ERA/EUSPA/ESA/EUG addressing GNSS Augmentation for Rail based on EGNOS.

Table C-1. Open points list

Ref	Description	Solution / Workstream	Status / Notes
1	Validation of tropospheric model for railway	[ERJU WBS on GNSS Augmentation for Rail based on EGNOS]	<p>Open.</p> <p>Validation of DO-229 / ED-259A tropospheric model for use in railway.</p> <p>Key points from preliminary investigation:</p> <ul style="list-style-type: none"> No need to validate in railway environment, model is a blind model independent of any local phenomena. Historical data is sufficient for validation. Variability comes from water vapour and pressure, with water vapour being the significant contributor (i.e., associated with precipitation, bad weather, thunderstorms). Mapping function anomalies from blind model are concentrated below 10 degrees of elevation; usage conditions of model requiring application of masking < 10 degrees would significantly reduce anomalies. Repetition of extreme events is rare, few data points. The model requires further consolidation to assess its validity under bad weather conditions.
2	GA-TS specification for EGNOS	[ERJU WBS on GNSS Augmentation for Rail based on EGNOS]	<p>Open.</p> <p>Specification to be developed once details of Railway SoL service and its commitments are confirmed by EUSPA.</p> <p>Specification includes aspects such as:</p> <ul style="list-style-type: none"> GAC selection (selection of GACs for authorised services / service providers). Barriers / diagnostic capabilities to address possible cybersecurity threats related to open SBAS transmission channel. Allocation of processing to the trackside: additional elaboration on the trackside could be considered to reduce the amount of data to be transferred to the on-board subsystem without impacting its ability to apply models for degradation of data (e.g., quantity of information related to ionospheric corrections to be transferred to the on-board subsystem can be reduced for SBAS Legacy service, by only providing the vertical delays and errors (GIVEs) for relevant Ionospheric Grid Points (IGPs).
3	Development of guidance on how to deviate from prescribed critical user receiver parameters in a controlled manner to	[ERJU WBS on GNSS Augmentation for Rail based on EGNOS]	<p>Open.</p> <p>Guidance addressing critical user receiver parameters such as:</p> <ul style="list-style-type: none"> Carrier smoothing filter (length, non-stationary state)

	ensure integrity requirements are met (refer to Annex A)		<ul style="list-style-type: none"> Correlator type, spacing, GNSS signal bandwidth, group delay
4	Development of guidance on the computation of protection levels (along-track and horizontal)	[ERJU WBS on GNSS Augmentation for Rail based on EGNOS]	<p>Open.</p> <p>Potentially to address reference algorithms for snapshot Weighted Least Squares and from Kalman Filter estimated covariance</p>
5	Update of EGNOS railway receiver guidelines (MOPS) for GA-OB and GA-TS	[ERJU WBS on GNSS Augmentation for Rail based on EGNOS]	<p>Open.</p> <p>Preliminary MOPS assumptions for GNSS trackside receiver equipment and on-board receiver equipment</p>
6	GA and GAS versioning		<p>Closed.</p> <p>As per feedback from workshop 29/09/2022, the GA / GAS versioning mechanism has been removed; it is assumed that GA version would be associated with an ETCS system version.</p> <p>Issue raised in review: GA and GAS versioning paradigms are opposite of ETCS versioning paradigm, where on-board receives system version from trackside.</p> <p>In GA SRS, on-board sends supported GA versions to trackside, trackside responds with version to be used by on-board. Similarly in the case of on-board requesting allocation of a GA message stream, GA services and versions supported by on-board are provided to trackside; trackside allocates a message stream based on the supported on-board versions.</p> <p>Motivation for different paradigm is that trackside would be expected to support different versions of augmentation.</p> <p>Note that this paradigm is also used by ATO over ERTMS (SUBSET-125/126) (handshake request, with on-board sending ATO versions supported to trackside)</p>
7	Degraded modes	[ERJU WBS on GNSS Augmentation for Rail based on EGNOS]	<p>Open.</p> <p>Issue raised in review: behaviour when the trackside cannot provide GNSS augmentation service to the on-board. What is the impact on VLF / how to handle (e.g., through definition of degraded modes / special modes)?</p>
8	GATF processing time	[ERJU WBS on GNSS Augmentation for Rail based on EGNOS]	<p>Open.</p> <p>Issue raised in review: requirement for maximum GATF processing time has not been allocated as it had been considered that it may be GAS-specific. The latency is to be considered in the end-to-end TTA (T_NVGMAXTTA) but an upper bound may need to be considered.</p>
9	Requirement for at least 2 available SBAS GEO signals for selection of GAC		<p>Closed.</p> <p>This requirement refers to the trackside only. The trackside needs to track at least 2 available SBAS GEO signals to minimise impact of a switch from one GAC (GEO) to another, also enabling the trackside to maintain active data (data most recently received that has not timed out) to support provision of active data sets to on-board in case the on-board does not support multiple message streams or not.</p> <p>Issue raised in review: in Annex B, for EGNOS-specific GATF, selection of GACs based on at least 2 available SBAS L1 and L5 GEO signals broadcasting valid messages, passing CRC and no MT0. Is it necessary to require at least 2 available SBAS GEOs? Relates to support for 2 message streams.</p>

10	Support for more than 2 GA message streams	[ERJU WBS on GNSS Augmentation for Rail based on EGNOS]	<p>Open.</p> <p>2 channels are supported, but not mandatory. The GA-OB shall support processing of at least one GA message stream and may optionally support processing of two GA message streams (a primary and secondary stream). A GA session can support up to two GA message streams (2.2.11.1).</p> <p>Although this is an optional capability, complexity of the on-board should be limited as far as possible (i.e., more complexity handled in the trackside).</p> <p>Further analysis is proposed to determine whether multiple streams should be supported, and if so whether more than 2 streams are required.</p> <p>The analyses should address the costs / benefits of supporting multiple streams and address the following cases:</p> <ol style="list-style-type: none"> 1) Switch considering multi-lane GNSS receiver (i.e., processing two streams, where receiver switches to lane processing other GEO); 2) Switch with active data from trackside for single-lane GNSS receiver (i.e., processing one stream; receiver ceases using and discards any ranging data and all message types associated with current GEO and request active data set for other GEO); and 3) Switch for single-lane GNSS receiver (i.e., processing one stream; baseline case where receiver ceases using and discards any ranging data and all message types associated with current GEO and receives SBAS messages from other GEO at 1Hz. <p>In addition, analysis may also identify options to address this complexity within EGNOS in future versions of EGNOS (long-term) considering use of a dedicated railway terrestrial dissemination capability.</p> <p>Issue raised in review: although stakeholders indicated that 2 channels should not be mandatory, it needs to be confirmed whether support should be provided for more than two parallel message streams. Currently 2 streams are supported, but not required. For example, there are cases where more than 2 would be needed to avoid discontinuity when transitioning between two service areas, where 2 streams are allocated for each service.</p>
11	Support for reception of SBAS SIS directly by VLF	Under investigation	<p>Open.</p> <p>VLF has an interface supporting direct reception of SBAS messages via the SBAS GEO SIS; however, principles for use of this interface are not currently defined in this version of the SRS.</p> <p>It was agreed at the EUG/EUSPA/ESA/X2Rail5 Joint Working Group workshop held on the 02/10/2023 that the interface be left open for further assessment. It was deemed valuable for regional line solutions (with reference to the ERJU FUTURE project, in which a demonstrator considering direct reception of EGNOS messages at the GA-OB via the EGNOS SIS is planned).</p>
12	Validation of SRS	[ERJU WBS on GNSS Augmentation for Rail based on EGNOS]	<p>Open.</p> <p>Simulations / test campaigns to validate approach described in the SRS, including:</p>

			<ul style="list-style-type: none"> • Testing impact of dissemination from trackside to on-board over FRMCS (5G, SATCOM?) in terms of latency, bandwidth requirements, etc. for a comprehensive set of scenarios (e.g., single stream / multiple streams, handovers, radio holes, radio disruptions, etc.); • Assessing degradation factors associated to corrections and alert (TTA) dissemination delay or loss of messages (accounting for use of FRMCS); • Testing impact on availability of GNSS measurements with integrity in LOC-OB; and • Assessing impact of longer TTA (e.g., on coasting / TTA compensation schemes in terms of impact on CI and accuracy). <p>And to support tuning of parameters (thresholds) related to TTA supervision.</p>
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