Travelling Virtual Balise for ETCS

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Abstract

The railway industry has taken a great effort and is currently focused on exploitation of global navigation satellite system (GNSS) for the European train control system (ETCS). It has been assessed that replacement of track balises, used for safe train location determination, with virtual balises (VBs) detected by means of GNSS will significantly reduce the track-side infrastructure and operational costs. However, this innovated ETCS can be put into operations only in the case when detection of VBs by means of GNSS will achieve the same safety integrity level (SIL 4) and availability as it is required for physical balise groups (BGs).

This paper describes a novel travelling virtual balise (TVB) concept, which was proposed to meet the demanding ETCS safety requirements for GNSS using the existing European Geostationary Navigation Overlay Service (EGNOS) safety-of-life (SoL) service. The TVB concept profits from the basic feature of GNSS – i.e. the ability of abundant train position determination in GNSS service volume, which cannot be realized by current track balise groups (BGs) with a spacing of hundreds of metres or more. The frequent GNSS train positions are utilized for (1) fast diagnostics of on-board location determination system (LDS), (2) introduction of reactive fail-safety into LDS and (3) derivation and justification of the ETCS safety requirements for EGNOS.

The TVB concept brings one significant advantage to ETCS in contrast to the static VBs – i.e. the safety requirement for LDS doesn't depend longer on the distance between successive VBs. It means that the existing spacing between physical BGs (up to 2.5 km) can be also preserved in case of TVBs. It can significantly improve the availability of LDS. Further it was found that a less demanding tolerable hazard rate (THR) requirement for GNSS of about 1e-7/1 h or more still enables to meet the ETCS THR requirement for VB determination, i.e. THRVB of 0.67e-9/1 h. Thus the ETCS TVB concept opens the door for efficient use of the EGNOS SoL service, originally developed for aviation.

Keywords: EGNOS, ETCS, Galileo, GPS, high-safety integrity, LDS, railway signalling, reactive fail-safety, safety-related systems, SIL 4.

1 Motivation

Safe train position, velocity and time (PVT) belong among basic quantities which are required for railway signalling. Nowadays all these quantities can be effectively provided by Global Navigation Satellite System (GNSS). The very idea of the exploitation of the Global Positioning System (GPS) satellites for signalling and train control is not new. The first experiments and field tests focused on train position determination using GPS and differential GPS (DGPS) were mainly performed in the United States and Europe more than 25 years ago. At that time the USA started work on the Positive Train Control (PTC) system, which is based on GPS, and Europe chosen the European Train Control System, where track balises and on-board Balise Transmission Module (BTM) are used for safe train position determination. Both PTC and ETCS have been successfully implemented on thousands of kilometres of tracks.

Besides Europe, ETCS has also become successful in Asia – mainly in China, Turkey, Taiwan and South Korea. However, additional installations of ETCS with ʺclassicalʺ track balises on heavy haul and other lines may not be in some countries efficient (Australia, Russia, China, etc.) - mainly due to high investment and maintenance cost of ETCS balises. The European Commission was aware of this potential ETCS limitation and therefore gradually initiated several R&D projects oriented on use of GNSS for signalling and ETCS in the 1990s.

There are two important dates regarding use of GNSS for ETCS. Firstly, on May 8th, 1998 a mixed train position determination solution by means of ETCS track balises and virtual GPS balises was described by Sterner [1]. And on the 2nd March 2011, the European Geostationary Navigation Overlay Service (EGNOS) based on GPS with its Safety-of-Life (SoL) Service was officially declared available for safety operations in aviation. EGNOS belongs to the family of wide-area Satellite Based Augmentation Systems (SBAS), similarly as e.g. US WAAS (RTCA DO-229 [2]), Japanese MSAT/QZSS, and Russian SDCM. In spite of fact that SBAS with was originally developed and certified for safety operations in aviation, it also represents a strategic infrastructure for safety-related systems in land transport, including rail (Pullen et al [3], Neri et al [4]). It should be also mentioned that the European railway community had also a lot of expectations from nascent Galileo and its SoL service in the first decade of new century. But finally the standalone Galileo SoL service was cancelled and it was decided to include Galileo into the multi-constellation and multi-frequency EGNOS V3 which should be operational around 2022.

Safe exploitation of aeronautical GNSS SoL service in railway signalling primarily means that the SoL service must be employed according to CENELEC standards (EN 50126 [8], EN 50128 [9], EN 50129 [10]). Excepting this the GNSS SoL service must be also utilised effectively according to a realistic and generally acceptable strategy. The strategy says that GNSS should only replace the train location determination function, which is currently performed by means of track ETCS balise groups (BGs) and on-board BTM, a balise reader. Other ETCS subsystems, such as safe odometry (SIL 4), should remain untouched.

And finally, there is a strong will in Europe to preferably employ the current well working single-constellation EGNOS V2 (based on GPS) for ETCS and not to wait until 2022 for EGNOS V3. It is often said, that "what is sufficient for airplanes from viewpoint of safety, it must be also applicable for trains". Later on Galileo or other constellations (GLONASS, BeiDou) could be used for availability of safety integrity improvement. In order to be able to think upon the EGNOS V2 exploitation for ETCS, there is necessary to make evidence first that EGNOS V2 is able to meet safety requirements for virtual balise detection. Due to this reason the Travelling Virtual Balise (TVB) concept was proposed. It is demonstrated in this paper that the existing EGNOS SoL service, originally developed for safety operations in aviation, is able using the TVB concept to meet the ETCS THR requirements for VB detection.

Differences in train position determination by means of physical balise groups and virtual balises are outlined in Section 2. Section 3 briefly describes the allocation of ETCS Tolerable Hazard Rate requirement to the virtual balise and thus also for the entire LDS based on GNSS. Basic fail-safe principles applicable in railway safety-related systems compliant with SIL 3 and SIL 4 and their relation to the mono/multi-constellation LDS solutions are described in Section 4. Finally, the applicability of existing EGNOS V2 for the ETCS LDS with the reactive fail-safety architecture is justified by means of a so-called Travelling Virtual Balise (TVB) and rapid LDS diagnosis in Section 5. The rapid and independent GNSS diagnosis undoubtedly represents the key to the LDS solution.

2 Physical and virtual balises for train position reporting

In order to demonstrate the positive impact of the GNSS diagnosis on the ETCS safety integrity, a train position determination function within the ETCS using classical track balise groups and virtual balises is outlined first.

The classical ETCS track BG, also called Information Point (IP), which shall be compliant with SIL 4 and λ_{IP} of 1e-9/1 hour (SUBSET-088 [6]), determines together with the on-board BTM the absolute position of train. The ETCS odometry (SIL 4) provides the instant speed of train and the relative distance from the Last Relevant Balise Group (LRBG) including its Confidence Interval (CI). The train position, velocity and other data are reported via GSM-R to the track-side Radio Block Centre (RBC). One of the important odometry functions is called linking of balises via relative distance measurement. It is in fact an independent diagnosis of balises and on-board unit (ONB) because it enables detection of a deleted (missing) balise, incorrectly inserted balise or ONB fault.

In case of the virtual balise concept the absolute position of train is determined using the LDS based on GNSS. The instant position of the train is compared with the position of virtual balises whose coordinates are stored in the on-board European Vital Computer (EVC) and in RBC. If the actual GNSS train position together with the relevant Confidence Interval (CI) match with a virtual balise stored in the database, then the VB is considered as the Last Relevant Virtual Balise (LRVB) – see Fig. 1. The odometry together with the track
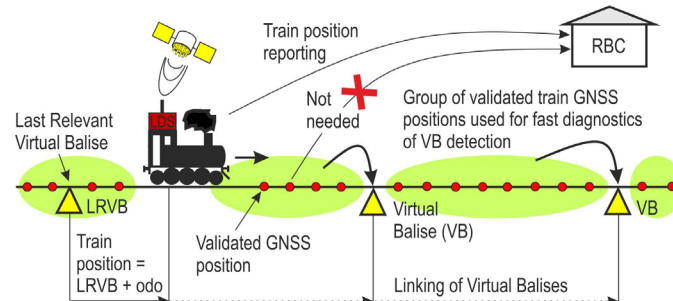
Figure 1:   Exploitation of EGNOS SoL service within ETCS VB concept.

database perform two following functions: 1) diagnosis of the consecutive virtual balises using linking with its direct positive impact on the desirable reduction of the safety integrity requirement for the GNSS LDS – i.e. GNSS THR increasing, and also 2) provision of the relative train position from the LRVB for ordinary train position reporting to the RBC. The relative train position is also provided when a VB is missed due to temporal GNSS Signal-In-Space (SIS) service outages or SIS shadowing in a harsh railway environment. The above described virtual balise concept copies in fact the ETCS train position determination function using track balise groups.

Now it should be said how ETCS can profit from GNSS. Let's compare for this purpose the diagnosis of train position determination in case of ETCS with track balises and diagnosis in the ETCS VB concept.

The ETCS ONB is able to perform fault diagnosis of physical balise groups (BGs) and also its own diagnosis only in locations of BGs. It is possible thanks to BG linking because position of next BG with respect to the LRBG position is known to the ONB and the correct BG detection can be validated using a so-called Expectation Window (ExW). The ExW includes all potential uncertainties due to odometry and BG position errors. As it is depicted in Fig. 1, GNSS LDS is able to perform its fault diagnosis also in the vicinity of virtual balises or on the whole track section between virtual balises, depending on SIS visibility. It is important for LDS initialization (system start-up) in Staff Responsible (SR) mode or during entry into an ETCS area from an unfitted area. At this moment it is considered that position of train on parallel tracks can be determined using existing track elements such as track circuits, axle counters or balises. But in the future the safe parallel track discrimination function will be also performed by GNSS (Neri et al [5]).

Abundant GNSS train positions outside of the VB vicinity are not in fact needed under normal operation (after LDS initialization) for train position reporting to RBC because it is provided by means of the relative distance measurement from the Last Relevant Virtual Balise (LRVB). However it is evident that these abundant GNSS positions together with the odometry data can be effectively used for the GNSS diagnosis and it can finally lead to reduction of safety requirements for the LDS based on GNSS.

3 Safety requirements for virtual balise and LDS

The ETCS Tolerable Hazard Rate (THR) requirements for virtual balise and GNSS LDS were derived by means of the ETCS Core THR allocation in SUBSET-088 [6] and SUBSET-091 [7]. The target ETCS Core THR of 2e-9/ 1 hour/ train is equally allocated to ETCS ONB (1e-9/ 1 hour) and all ETCS track-side equipment. Then THR related to Balise Transmission hazard THR_{BTX} of 0.67e-9/ 1 hour was determined. THR_{BTX} was further sub-allocated to different track IP failure modes, such as balise deletion ($THR_{BTX\ Deletion} < 3.3e\text{-}10/$ 1 hour), balise insertion ($THR_{BTX\ Insertion} < 3.3e\text{-}10/$ 1 hour), and balise corruption ($THR_{BTX\ Corruption} < 1e\text{-}11/$ 1 hour). Since GNSS position is determined on board of train, then only two following failure modes for virtual balise were analyzed: virtual balise deletion, and virtual balise insertion (Filip and Rispoli [11], Filip [13]). These two VB failure modes can be described as:

- *Virtual Balise Deletion* - means an event, when a VB (i.e. virtual IP) was not detected by means of on-board GNSS LDS. It can happen due to: 1) excessive latent LDS error (wrong position), or 2) absence of train position in the GNSS LDS output. In both cases no VB is detected within the Expectation Window (ExW) provided by the odometry.

- *Virtual Balise Insertion* - means an event when a wrong virtual balise is determined due to wrong GNSS LDS position.

Since both VB failure modes are caused by a wrong GNSS LDS position (i.e. incorrect or no position), and diagnosis for both failure modes is provided by rapid and independent diagnosis in GNSS service volume, then the total THR_{BTX} of 0.67e-9/ 1 hour was taken as THR for VB, i.e. $THR_{VB} = 0.67e\text{-}9/$ 1 hour. THR_{VB} determines in fact tolerable hazard rate for the entire GNSS based LDS, i.e. $THR_{GNSS\ LDS}$, consisting of GNSS, odometry, etc. Tolerable hazard rate for single GNSS, i.e. THR_{GNSS} (THR_{SBAS}), will be then derived for a given LDS architecture and for the most demanding LDS operational mode within ETCS. If we omit Temporally Speed Restriction (TSR) mode, then the most demanding operational mode from viewpoint of safety for baseline ETCS is start of mission. It is because linking (diagnosis) of BGs cannot be used during this mode. Therefore start of mission will be used for derivation of THR_{GNSS} - provided that safe parallel track discrimination can be solved using classical means, by two-tier GNSS augmentation (Neri et al [5]), or by EGNOS V3 after 2022.

4 Single versus multi-constellation EGNOS for LDS

Railway safety-related systems to be compliant with SIL 3 or SIL 4 must ensure that they will remain safe in the event of any kind of single random HW fault. This principle is known as fail-safety and can be achieved by means of the following techniques: inherent fail-safety, composite fail-safety or reactive fail-safety (EN 50129 [10] and Lovric et al [14]). It is evident that implementation of these techniques not only determines which level of LDS safety will be achieved, but also how efficiently GNSS will be used within the LDS.
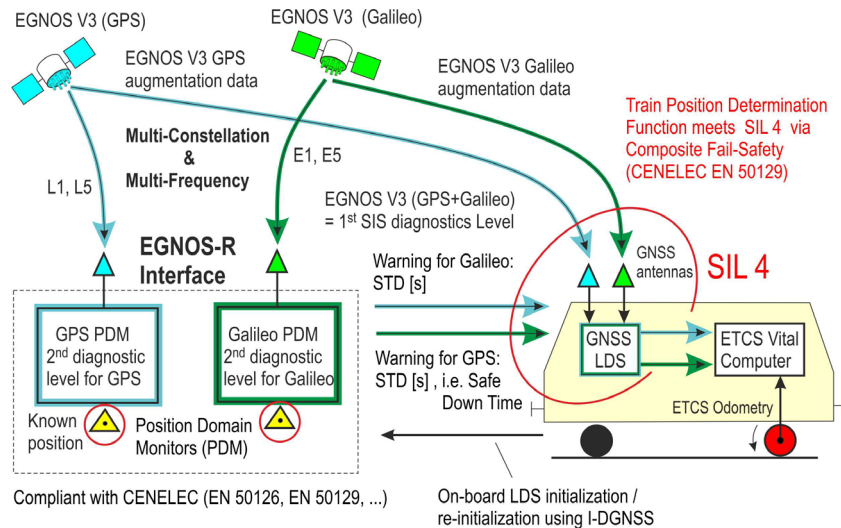
Figure 2: LDS based on dual-constellation EGNOS V3
and composite fail-safety.

The inherent fail-safety technique allows a safety-related function to be performed by a single channel, provided that all the credible failure modes of the channel are not hazardous. It would be very difficult or impossible to make such evidence in case of complex SBAS and therefore inherent fail-safety is not further considered for the SBAS (EGNOS) based LDS.

The composite fail-safety technique allows a safety-related function to be performed by at least two independent channels. Hazardous fault in one channel shall be detected and negated sufficiently quickly to meet the required THR. The fault is detected by the comparison of the output values of these two or more channels, or also by means of an additional independent diagnosis. This technique has been already employed in case of the dual-constellation EGNOS-R interface - see Fig. 2 (Filip and Rispoli [12], Filip [13]). The EGNOS-R was mainly proposed with the intention to meet THR of 1e-8/ 1 hour (SIL 4) for Signal-In-Space and simplify the required safety case and certification according to railway CENELEC safety standards. It was found that introduction of EGNOS-R also enables to reduce the EGNOS Confidence Interval (CI) magnitude in the position domain.

Finally, the reactive fail-safety technique allows a safety-related function to be performed by a single channel, provided its safe operation is assured by fast detection and negation of any dangerous fault. The existing single-constellation EGNOS V2 itself can be considered as a system with reactive fail-safety, because the safety function is performed by the GPS and its correctness is checked by the EGNOS infrastructure – see Fig. 3 (a). Nevertheless, the standalone EGNOS V2 is not yet able to meet the ETCS SIL 4 requirement for train position determination. It is because the position determination function
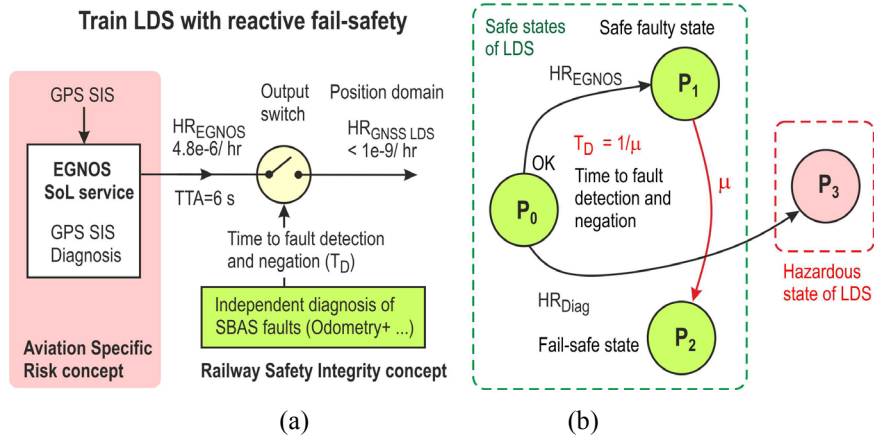
Figure 3: LDS based on single-constellation EGNOS V2 with reactive fail-safety: (a) High-level architecture, (b) Markov model.

must also meet the required integrity level in case of local effects, such as multipath, EMI, spoofing, etc. against which SBAS does not protect. That's why the SBAS fault diagnosis must be completed with an additional independent fault diagnosis realised e.g. using the safe ETCS odometry (SIL 4), 3-dimensional track database (SIL 4) and other relevant techniques.

Markov model of the LDS based on single-constellation EGNOS and reactive fail-safety is depicted in Fig. 3 (b). The following four system states are defined for the model:

- P_0 - Fully functional LDS state: both SBAS and independent SBAS diagnosis work well according to the specifications;
- P_1 - Safe faulty LDS state: SBAS is faulty and rapid diagnosis is functional;
- P_2 - Fail-safe state of the LDS: SBAS fault was detected and negated;
- P_3 - Hazardous LDS state: Independent diagnosis of SBAS is faulty. Note: Although SBAS is functioning properly according to the specifications, the LDS is in a dangerous state.

The corresponding time-dependent LDS state probability $P_1(t)$ can be derived from the model as follows

$$P_1(t) = -\frac{HR_{SBAS}[e^{-(HR_{SBAS} + HR_{Diag})\cdot t} - e^{-\mu \cdot t}]}{HR_{SBAS} + HR_{Diag} - \mu} \tag{1}$$

where HR_{SBAS} − Hazard Rate of SBAS per 1 hour, HR_{Diag} - Hazard Rate of SBAS independent diagnosis, μ - rate of diagnosis and fault negation. $P_1(t)$ is the safe faulty state probability in case of SBAS fault. Since $(HR_{SBAS} + HR_{Diag})$ is much smaller than μ, then eqn (1) can be simplified as follows

$$P_1(t) \approx -\frac{HR_{SBAS} \cdot [1-0]}{-\mu} = HR_{SBAS} \cdot T_D \tag{2}$$

where T_D is time to fault detection and negation, which is also sometimes called Safe Down Time (SDT) – see (EN 50129 [10]). It is evident from eqn (2) that $P_1(t)$ depends on T_D (i.e. on $1/\mu$) and is no longer dependent on the time t. The corresponding LDS Hazard Rate during 1 hour long mission can be expressed as $HR_{GNSS\ LDS} = HR_{SBAS} \times T_D \times 1\ hour^{-1}$. This relation will be further used for derivation of the ETCS THR requirement for SBAS/ EGNOS in Section 5.

The conclusion: while composite fail-safety was mainly used for EGNOS safety integrity improvement to meet ETCS safety requirements for the LDS, then reactive fail-safety implemented in the LDS is on the contrary indented for reduction of ETCS safety requirements for EGNOS. The reactive LDS solution exploiting the existing aviation EGNOS V2 SoL service is described below.

5   From static to travelling virtual balise

The baseline ETCS requires both track balises and ONB for safe train position determination. On the other hand GNSS estimates the position on board of train. Let us assume that λ_{ONB} is the rate of occurrence of ONB being unable to detect a correctly working ETCS Information Point (IP). If linking of IPs is active, then the duration of ONB failure corresponds to the time interval T_L between two successive IPs marked as linked. Further if the average speed of train is v and the linking distance D_L, then the probability of ONB failure causing the IP deletion is

$$P_{f,\ ONB} = \lambda_{ONB} \times T_L = \lambda_{ONB} \times (D_L/v) \tag{3}$$

There is no safety requirement in respect of not being able to detect an information point when IP linking is active – see (SUBSET-088 [6]). As lately as two expected consecutive IPs announced by linking are not detected by ONB in the expectation window, measured from the LRBG, the on-board vital computer shall consider the linking command of the second IP as a command to apply the service brake. Then the hazardous failure rate of ONB corresponding to the deletion of any IP met during 1 hour long mission is

$$HR_{ONB} = \lambda_{ONB} \times (2 \times T_L) \times 1\ h^{-1} \tag{4}$$

It should be mentioned here that balise insertion due to a wrong train position could have much more serious consequences – it could e.g. happen when system is initiated. In order to check the ONB functionality even before the detection of a regular and properly working BG by the ONB, an additional hypothetical "testing" BG can be placed on the track ahead of the regular BG in the direction of movement from the LRBG – see Fig. 4. A much shorter ONB failure duration T_D is achieved in this case. Equation (3) can be then modified as

$$P_{f,\ ONB} = \lambda_{ONB} \times T_D \tag{5}$$

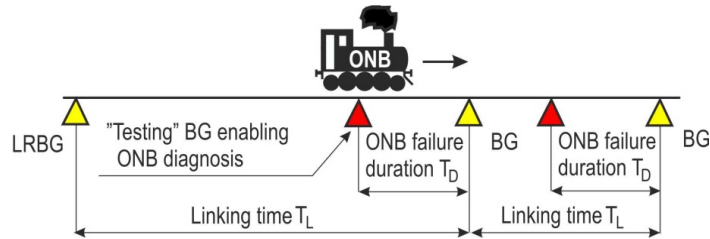and the corresponding ONB hazardous failure rate per mission (1 hour) is

Figure 4: Diagnosis of ETCS on-board unit using "testing" balise group.

$$HR_{ONB} = \lambda_{ONB} \times T_D \times 1\ hour^{-1} \qquad (6)$$

Hazardous ONB failure rate related to IP deletion according to eqn (4) can be thus reduced with respect to HR in eqn (6) significantly. However it is evident that installation of the additional physical "testing" BGs on a track would be very inefficient. Nevertheless, this reactive fail-safety principle can be easily implemented in case of the GNSS LDS. The "testing" BG is simply replaced by a so-called Travelling Virtual Balise (TVB), as it is depicted in Fig. 5.

The TVB is equivalent to LRBG or LRVB from viewpoint of safety integrity because it is a validated GNSS train position using the independent diagnosis. The TVB arises from the LRVB as the validated subsequent GNSS train position generated just after the LRVB is detected, and further *travels* to the next virtual balise location in a given direction of movement. The TVB can also originate on a track section between two VBs during LDS initialization.

The detection function of the presence of an Information Point (IP) by ETCS on-board unit is a critical function and this function is the most critical when IPs are employed in such scenarios where linking is not used. It is e.g. during ONB initialization in SR mode or during entry into an ETCS area from an unfitted area when wrong IP can be inserted or IP can be deleted (missed). The ETCS THR requirement for GNSS must be derived using these scenarios considering that VB insertion could cause a more dangerous situation than VB deletion.
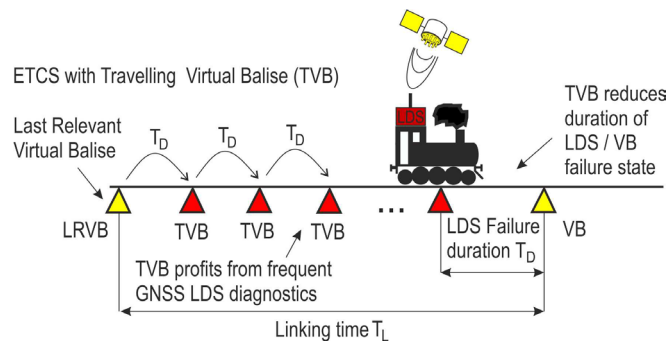

Figure 5: Travelling Virtual Balise introduced for justification
of ETCS LDS architecture with reactive-fail safety.

It is evident that the *travelling* VB can be utilized for the LDS diagnosis related to next VB deletion or insertion in the same manner as the hypothetical *static* "testing" BG is used for the ONB diagnosis in Fig. 4. The ETCS THR requirement for GNSS, i.e. THR_{GNSS}, can be determined for the LDS start-up from the THR requirement for VB deletion or insertion per mission, i.e. $THR_{GNSS\,VB}$ of 0.67e-9 hour^{-1} (see Section 3 and 4), as follows

$$0.67\text{e-9 hour}^{-1} = THR_{GNSS} * T_D * \text{hour}^{-1} \qquad (7)$$

where T_D is the duration of GNSS hazardous failure defined as the time interval between the two consecutive linked TVBs or linked TVB and next VB. Let's assume e.g. HR_{GNSS} of 1e-7/ hour which corresponds to the SBAS Integrity Risk requirement for the aviation Non Precision Approach (NPA or En-route). Then according to eqn (7) the acceptable hazard duration T_D due to VB deletion/ insertion is

$$T_D = 0.67\text{e-9/ 1e-7} * 1 \text{ hour} = 6.7\text{e-3 hour} = 24.12 \text{ s}$$

It should be noted that the allowed Horizontal Alert Limit (HAL) is quite large in this case, i.e. 0.3 nmi (556 m). HR of on-board GNSS receiver subsystem is neglected in this estimation.

The Signal-In-Space (SIS) Integrity Risk (IR) of 2e-7/150 s for Precision Approach (PA) including LPV-200 operations is required in the vertical direction. Excepting this the SIS IR of 1e-9/150 s in the horizontal/ lateral (one dimensional) direction shall be also met for the aviation PA operations. It seems that the integrity (i.e. guarantee) of accuracy in the horizontal plane or in the track direction would be sufficient for signalling in case of the reactive LDS architecture. Nevertheless, three dimensional (3D) track map appears as an effective means for the independent diagnosis of SBAS, and therefore the IR of 2e-7/150 was conservatively selected for signalling. The SBAS SIS Hazard Rate approximately corresponds to 4.8e-6/ 1 hour. Then the allowed duration of SBAS failure can be estimated as

$$T_D = 0.67\text{e-9/ 4.8e-6} * 1 \text{ hour} = 1.36\text{e-4 hour} = 0.50 \text{ s}$$

The HAL of 40 m and VAL (Vertical AL) of 35 m is required for LPV-200 operations, where the pilot's decision height is 200 feet (60 m) above the runway. The actual WAAS/ EGNOS accuracies (95%) in horizontal/lateral and vertical directions are typically better than 1.1 m and 1.5 m, respectively. The real SBAS performance in terms of SIS integrity is better than it is required by aviation. Let's consider the real EGNOS IR for of 6e-8/ 150 s for LPV I operations. Then the corresponding EGNOS SIS Hazard Rate is 1.44e-6/ 1 hour and the acceptable duration of failure T_D of 1.44 s can be estimated according to eqn (7). If SBAS receiver with an output rate of 10 Hz will be used, then all the above calculated values of T_D are realistic – however under the condition that all SBAS failure modes will be properly detected and negated.

In spite of fact that the TVB is not a priory defined by means of its geographic coordinates, it can efficiently substitute a number of static VBs with known positions and small spacing between them, which might be introduced for reduction safety requirements for GNSS, but might be also hardly detectable.

6   Conclusion

The Travelling Virtual Balise (TVB) was introduced into the ETCS virtual balise concept with the intention to justify exploitation of the existing aviation EGNOS V2 SoL service for the train LDS to be compliant with SIL 4 at a system level. The TVB concept fully supports the harmonization of the aviation and railway safety requirements for efficient use of the single EGNOS V2 SoL service for both aviation *safety-critical systems* and railway *safety-related systems*. Further the TVB ensures the continuity in the ETCS balise concept evolution oriented from the baseline ETCS platform with physical track balises to more efficient virtual ones stored in the ONB and track-side RBC.

The term TVB has been proposed to reflect the analogy between the ETCS static "testing" track balise group and "testing" virtual balise intended for rapid fault diagnosis of the entire ETCS LDS. The adjective *travelling* means that geographic coordinates of the TVB are not a priori known. The TVB propagates on the track section between two subsequent virtual balises (VBs), which can have the same spacing as the track BGs. The abundant GNSS train positions together with the odometry data and combined with other diagnostic methods, e.g. pseudorange validation using a 3D track database, are used for fast TVB validation for the required safety integrity.

The TVB is a validated train GNSS position that meets the THR requirement for VB deletion or insertion, i.e. THR_{VB} of 0.67e-9/ 1 hour. The diagnosis of both LDS ONB and GNSS Signal-In-Space mainly relies on TVB/VB linking. The TVB concept is fully consistent with reactive fail-safety where the main channel itself, i.e. GNSS, may not meet safety requirements, but the diagnostic channel must detect all possible dangerous failures so quickly that the overall safety target is met. The TVB brings the additional benefits:

- TVB enables to preserve or even enlarge the virtual balise spacing with the respect to the maximum allowed ETCS BG spacing (2500 m) without any impact on the entire LDS safety;
- Temporal TVB unavailability doesn't influence safety of train position determination because the safe ETCS odometry (SIL 4) is used for train position reporting in respect to the LRVB when it is required;
- Additional GNSS constellations such as Galileo, GLONASS or BeiDou can be used for LDS availability of integrity improvement;
- TVB efficiently substitutes a number static VBs with small VB spacing;
- Introduction of the TVB doesn't influence the ETCS safety concept and the backward compatibility with the baseline ETCS is preserved.

Acknowledgement

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