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EGNOS service evaluation in railway environment for safety-critical operations

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Abstract

GNSS is expected to help the railway system to be modernized. However, such localization applications requires a high level of accuracy and safety that deserve to use the best potential of satellite-based technologies. The augmentation systems, as the satellite-based augmentation system EGNOS (European Geostationary Navigation Overlay Service), helps to increase the nominal performance. One of the tasks of the EU STARS project deals with the study of the usability of EGNOS in railway environments. EGNOS has indeed been developed driven by the requirements of civil aviation safety procedures in conditions for signal reception that differ from the railway ones.
In this paper, after introducing the needs and the basic principles of these systems, we describe the limitations caused by the specificities of railways and some solutions perspectives proposed by the project.

Keywords: GNSS, Satellite Navigation, Transport safety, Rail.

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1. Introduction

1.1. GNSS introduction in the rail sector

EGNSS (European Global Navigation Satellite System) is the core of European projects since the beginning of the 2000s, in the context of the ERTMS (European Rail Traffic Management System) deployment also.

Historically, in Europe, each country developed its own railway infrastructure, equipment and operational rules. The consequences are heterogeneity of electrification, rolling stock, maintenance and exploitation rules, signalling… Europe has defined the ERTMS to harmonize this. ETCS (European Train Control System) is the ERTMS sub-system dedicated to control and protect trains. Migration is progressive and performed by stages from level 0 to 3. The goal is first to let coexist current external systems and new balises and to progressively move some of the trackside equipment to transpose intelligence on-board.

GNSS is considered in the highest level of ETCS or its declination to regional lines, namely ETCS L3 and ETCS Regional. In level 3, no line side signals will be required for delivering movement authorities. A train shall be able to locate itself (Neri & al. (2015)). All information will be exchanged between the ETCS on-board system and the RBC trackside system (Radio Block Center) through mobile network. Trains will communicate their location and integrity (safety information guaranteeing that the train did not lose any wagon and that train true position is not outside train position confidence interval with a certain probability determined by the confidence level related to SIL4). This level shall also improve line capacity by making possible to manage circulations with moving blocks. In this context, GNSS is investigated to be the basis for the embedded train locator.
The use of GNSS in order to provide a low cost solution for signalling and in particular in the highest level of ETCS (level 3) and the ERTMS Regional is an issue since the beginning of the 2000's as introduced by Raymond &al. (2015). With several projects, the European Commission, through the successive Framework Programs funded researches in order to explore and promote the use of satellites for such solutions. First main projects were APOLO (Filip et al. (2001)), GADEROS (Urech et al. (2002)) and LOCOPROL (Mertens and Franckart (2003)) but one can mention tens of others in the past decade until the recent GaLoROI (Manz et al. (2014)) or 3inSat (Rispoli et al. (2014)) projects. All these projects, if they did not lead to operational commercialized products, surely helped GNSS to be introduced in railway mentalities as developed by Marais et al. (2017). Most of these projects included the intention to use EGNOS.

The global ambition of railway innovation is to contribute to a more competitive and resource-efficient European Transport system. The targets are: *(i)* to improve services and customer quality, *(ii)* increase capacity, *(iii)* increase reliability, *(iv)* reduce lifecycle costs, enhance interoperability and, *(v)* simplify business processes for all four rail market segments, *i.e.*, high-speed and intercity passenger rail, regional passenger rail, urban/suburban passenger rail and rail freight. In this context, the development of innovative on-board train location shall reduce wayside infrastructure costs and increase lines capacity.

The introduction of GNSS in the rail domain is now recognized as a powerful tool for ERTMS deployment, old system renewal. A study performed by Bocconi University for the ERSAT EAV projects shows that GNSS-based ERTMS proves to be especially convenient because of relevant savings in operating expenses: -67% each year compared to the traditional ERTMS [Galileo Services, 2016]. Moreover, the cost/benefit ratio will be maximized if satcoms are integrated in the global system.
First application is through the Virtual Balise Concept in ERTMS L2 or 3 but next steps to be prepared are also Moving block operation and automatic train operation.
The NGTC project, that gathered together the main industries involved in ETCS and CBTC, consolidated the use of GNSS in the Virtual Balise concept and has developed and validated Generic Moving Block principles applicable to different railway types.

The Memorandum of Understanding signed between the EC decision makers and rail stakeholders, identified GNSS as capable to play a major role in the development of ERTMS and that Galileo could help to make rail transport more efficient and reliable. Indeed, the development of an absolute and safe train positioning system allows the reduction of the use of traditional train detection systems based on a multi-sensor concept, where GNSS is the preferred technology.

Cost reduction will help **saving low traffic lines**, where the maintenance and operation costs generate economic risks leading to the closing of the line. Reduction of these lines will reduce the transport service for citizens and shift the traffic on the road with growing energy consumption. Moreover, the deployment of ERTMS on local lines with obsolete equipment will **increase their safety**.

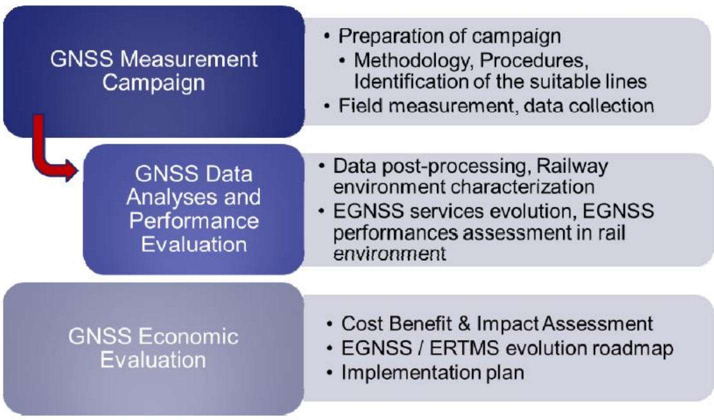
1.2. The STARS objectives

The multiple past rail research projects have helped a better understanding of the benefit of GNSS-based solutions in rail and have helped railway stakeholders to take charge of this innovative concept. Some of the projects have dealt with the localisation unit itself, some others on global concepts but the necessary level of knowledge on the characterisation of the satellite-based positioning performance within the rail environment is missing. In order to fill the gap between ERTMS needs for safety critical applications and GNSS services, GSA (European GNSS Agency) funds the STARS (Satellite Technology for Advanced Railway Signalling) project. The project aims to characterise the railway environment effects on GNSS performances.
Indeed, for the development of a fail-safe positioning system based primarily on GNSS, the deep knowledge of GNSS performance is a pre-requisite so that we will be able to determine the expected performance, their impact on safety, and if necessary the technologies to be associated to reach required performance.

STARS project aims to meet the specified high-level objectives by delivering the following results:

- The universal approach for predicting the achievable GNSS performance in a railway environment, especially focused on safety critical applications;
- The analyses of the necessary evolution of ERTMS to include GNSS services;
- The quantification of the economic benefits for introduction of GNSS-based virtual balise concept in railways through reduction of cost;

The study logic is composed of 3 phases (see Fig. 1): the first one targets the measurement campaign devoted to the characterisation of the railway environment through a measurement campaign. The second step consists in data processing in order to assess the GNSS performances achievable in this environment as well as the possible evolutions of European GNSS services and ERTMS/ETCS functions. The third phase includes analyses of the economic benefits from the application of GNSS in modern rail signalling and possible implementation roadmap.



• Fig. 1 STARS project study logic by Stamm and Gurnik (2017)

The purpose of this paper is to focus on the EGNSS performances assessment part in rail environment and to present the results of the tasks devoted to:

- State of the art of the EGNOS use in previous rail applications in order to highlight the identified limitations caused by the rail specificities,
- Recommendations for future use or evolutions of the systems.

2. Introduction to GNSS Based augmentation systems

2.1. General principles

Development of GNSS augmentation systems characteristics has been driven by the requirements of civil aviation safety procedures. Indeed, the augmentation systems are primarily intended to support precision approach operations before the landing phase. For such operations, the user requires to be warned in real-time (less than 6 seconds) in case the positioning error exceeds the requirements or in case of a failure.
Thus, the main idea of GNSS augmentation system is to compensate part of the positioning errors, often called "common mode errors", as experienced by a GNSS user on the ground (typically a GNSS receiver) similarly to a GNSS antenna/receiver belonging to an augmentation system. Local Area Augmentation systems such as GBAS (Ground Based Augmentation System) assumes that two receivers situated in close vicinity will face some close errors caused by ionospheric propagation, satellite position or clock errors, etc. Wide Area Augmentation systems such as EGNOS decorrelates the different errors (clocks, ephemeris and Ionosphere) and transmits each of them to the user receiver that will recombine these different errors values according to its geographical position.
The first function of GNSS augmentation systems, whatever they are, is to transmit the different correction to the user for him/her to compensate a part of the positioning error and benefit of a better accuracy. A second service is integrity monitoring.
The transmission can be performed by terrestrial or satellite links and will offer respectively local or wide area services. We will focus on satellite-based ones in the following.

2.2. Accuracy increase

Accuracy is the degree of conformance of the estimated position with the true position. Accuracy is a statistical measure of performance and indicates trueness and precision in terms of deviation between a measured and a true value with respect to a confidence level.
As every augmentation system, the system relies on a network of monitoring stations (with very well known positions). Each station receives GNSS signals that are processed in order to estimate the pseudo-range corrections by comparison with the known monitoring station position. Once the pseudo-range corrections have been computed, they are transmitted in the form of "differential corrections" by means of either a terrestrial radio link or a GEO satellite.

2.3. Integrity monitoring

The second function of an augmentation system is to offer guarantees to the user about the position confidence level. The system shall detect system and propagation failures (as a satellite failure or message error, or ionospheric event or even an internal error) and alert the user in a dedicated time (TTA – Time To Alert).
Thus, position integrity is a measure of trust that can be placed in the correctness of the information supplied by a navigation system and it includes the ability of the system to provide timely warnings to users when a satellite or the entire system should not be used for navigation. This definition can be clarified thanks to four main parameters: Alert Limit (AL), Integrity Risk, Time to Alert (TTA) and Protection Level (PL).

- Alert Limit represents the largest position error allowable for safe operation.
- Integrity Risk is the probability of providing a signal leading to a position that is out of tolerance without warning the user in a given period of time. It defines the maximum probability with which a fault free receiver is allowed to provide position failures not detected by the integrity monitoring system.
- Time to Alert (TTA) is the maximum allowable elapsed time from the onset of a positioning failure until the equipment announces the alert.
- The PL is a statistical error bound computed so as to guarantee that the probability of the absolute position error exceeding the alert limit is smaller than or equal to the target integrity risk.

For terrestrial transport, the HPL (Horizontal PL) is of main interest and bounds the horizontal position error with a confidence level derived from the integrity risk requirement. As the true HPE (Horizontal Position Error) is never known, except in test or evaluation conditions with reference measurements, HPL is the indicator of accuracy and is compared to HAL, defined by the application requirements. As summarized in figure 1, the system is declared available when HPL<HAL and unavailable when HPL>HAL. If HPL is correctly estimated, HPE should always be smaller than HPL as presented in the two first cases of figure 2. Then, we can consider that the integrity monitoring process correctly protect the system from being unsafe. First case is the nominal case where the integrity monitoring process correctly works and the position information can be used with confidence. In the second case, the system is declared unavailable, i.e. it cannot guarantee the safety of the position. The train shall be located by another system or stopped (for safety procedure). The third and fourth cases represent situations where HPL do not bound correctly HPE. In the third case, as the true error remains below the requirements (HPE<HAL), it is not critical for safety (no detection but no safety impact – Misleading information). However, due to non-detected failures HPE can sometimes exceed HAL as illustrated in the fourth case. Staying below the requirements (HPL<HAL) the alert will not be activated. However, in case HPE exceeds HAL, a risk on integrity occurs. The occurrence of the two last event has to be strongly minimized.

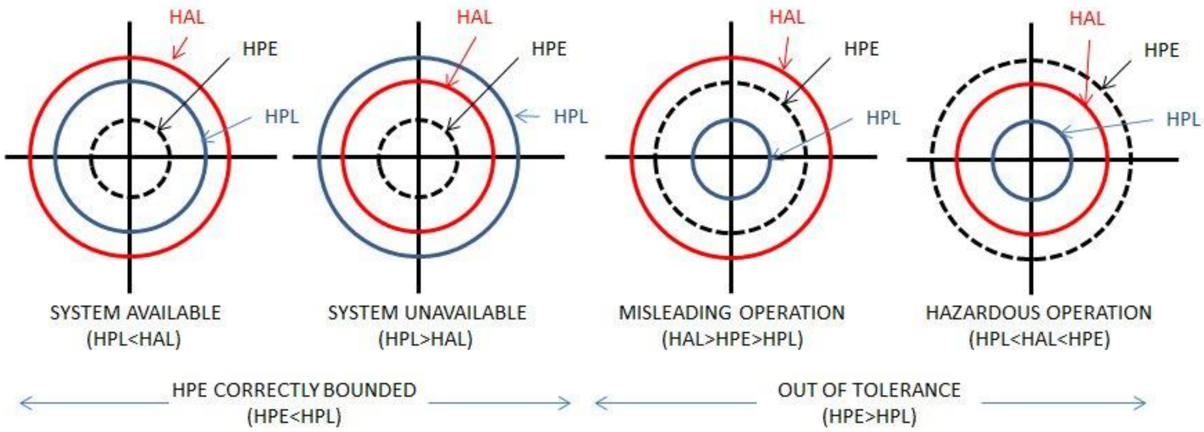


Fig. 2 Possible situations obtained with GNSS integrity monitoring

2.4. Satellite-based Augmentation Systems (SBAS)

SBAS (Satellite-Based Augmentation System), originally implemented by the U.S.A FAA as Wide Area Augmentation System (WAAS) (as opposed to LAAS-Local Area Augmentation Systems). In SBAS, geostationary (GEO) satellites broadcast additional signals and correction messages.
Presently, in Europe, EGNOS (Version 2) is the SBAS solution developed and currently augments L1 (1575.42 MHz) Coarse/Acquisition (C/A) GPS civilian signal function. Version 3 will feature new capabilities, including dual frequency and dual-constellation with both GPS and Galileo, apart from the user segment, EGNOS is composed of two segments: the ground segment and the space segment.

The system decorrelates the different errors budgets (clocks, ephemeris and ionosphere). It furthermore estimates the residual errors, i.e. an overbound of residual errors expected after having applied corrections broadcasted by EGNOS. The errors are characterised by two parameters:

- User Differential Range Error (UDRE).

The UDRE estimates the residual range error after the application of SV clock and ephemeris error correction for a given GNSS satellite.

- Grid Ionospheric Vertical Error (GIVE).

GIVE estimates the vertical residual error at predefined Ionospheric Grid points after application of the ionospheric corrections for a given geographical grid point.
These parameters will be of main importance to bound the user positioning error in the safety-critical applications.

For the integrity in the range domain, the range error is partially bounded by a threshold based on the UDRE and GIVE parameters. For each pseudo range, Knowing that the local phenomena such as interference and multipath have a bounded value for an airplane, EGNOS computes an residual error (UDRE and GIVE) so that it bounds a 5.33σ the real (unknown) error ($\varepsilon \leq 5.33\sigma$ where ε is total true error (range error or ionospheric error and σ is the computed SBAS Range error estimate standard deviation). This will almost certainly NOT be true in railway applications where the local environment is much more challenging.

Moreover, EGNOS also monitors and detects GNSS anomalies if necessary and is required to alert the user of any dysfunction within a time $t < TTA$ (Time To Alert) of 6 seconds.

3. SBAS limitations in the rail environment

3.1. EGNOS suitability to rail specifications

EGNOS is capable of providing ranging and correction data for accuracy enhancement but also integrity data, i.e. data to estimate the residual errors that can be expected by the users after having applied the corrections. As seen before these last data are the User Differential Range Error (UDRE) and the Grid Ionospheric Vertical Error (GIVE), commonly called 'sigmas'. These two parameters can be used to determine an aggregate error, i.e. a bounded estimation of the horizontal and vertical position error that serves to compute the Protection Level (PL).
EGNOS is obviously used in most of the projects, as the service is open and free. However, the EGNOS Precision Approach (PA) and Non-precision Approach (NPA) navigation modes for civil aviation were designed according to specific aeronautical requirements (Filip 2010).
As described by Filip et al. (2010), PA mode is very demanding in terms of SBAS data availability for example: PAs require that all satellites use SBAS corrections. NPA accepts that ionospheric corrections could be unavailable sometimes. NPA can also be used with longer degradation for fast corrections. This can cause larger error in HPE and HPL computation but one can propose to detect and manage it with diagnostics and multi sensor-based solutions. Thus, Filip et al. (2010) notices that "this navigation mode seems more acceptable for railway safety-related applications than the PA mode". However, the conclusions says "The determination of the EGNOS dependability attributes in terms of failure modes, failure rates (on 1 hour basis), reliability and availability is needed for design, validation and certification of the land GNSS based safety-related systems".

3.2. EGNOS availability

Due to the geostationnarity of the EGNOS satellites, its availability is not optimal along railway lines.
The tests performed in the LOCOPROL project, considering over 3000km of rail route in Italy, showed an overall measured availability of 66% for accuracy enhancement in Bortolotto and Choquette (2003). LOCOPROL also simulates EGNOS availability on other tracks along the CFTA railway mountainous line between Nice and Digne in the south of France (Marais et al. (2006)). Because of the very quick changes of the environment around the antenna, EGNOS state of reception can vary very quickly also. Simulation results showed that 60% of the reception durations were shorter than 10 seconds and 40% shorter than 5 seconds that do not allow the receiver to benefit from integrity data. Nevertheless, some long areas of reception are observed. The longest one has a duration of 275 seconds, which allows the receiver to benefit of some corrections for accuracy gain.

In the RUNE project, the EGNOS-based solutions along the line between Torino and Chivasso (and return) showed availability of around 45% of time.

Ali et al. (2012) give another example. Even if the application is related to road in this article, reception conditions can be very close from railway ones. The paper shows that EGNOS was received 84% of the time along the highway against around 10% in the urban context.
An alternative of the use of the EGNOS signal is the broadcast of the EGNOS information via terrestrial transmitters or via internet as proposed by the EDAS service. The availability of this alternative link is then to be verified.
Moreover, let us mention that the availability of the SBAS may be required only in concrete locations (e.g. at place and surrounding where the virtual balise is placed) and not along the entire railway line. The global availability of the SBAS can then be reduced along the line and the requirements be concentrated locally.

3.3. Classical pseudo-range error models versus real models

Today, only the aviation domain has defined specific service requirements for EGNOS use, as well as certification and individual authorization procedures. EGNOS 'sigmas' estimate the residual error boundaries after common mode error corrections but without local error estimation.
With EGNOS, σ_{UDRE} & σ_{GIVE} are the bases for HPL/VPL computation, under the assumption that pseudo-range errors follow normal centered laws and are independent. As illustrated in figure 3 with the observation of the pseudo-range error distribution of one satellite in time, one can notice that this assumption is not always verified,

in particular in case of NLOS (Non Line of Sight) reception, i.e. when the direct signal between the transmitting satellite and the receiver is not free of obstacle..

When based on ground-based infrastructure, residuals are estimated by the Ranging Integrity Monitoring Stations (RIMS), grounds stations that do not take either into account local errors, which cannot be ignored in land transport applications.
Indeed, HPL computed by EGNOS assumes that the local errors are bounded by the values defined in MOPS. These values have been established for airplane and are not at all representative of local environment of railway users. Such formulas that bound local error of railway applications indeed need to be established.

This work will be performed in the last part of the STARS H2020 European project (2016-2018).

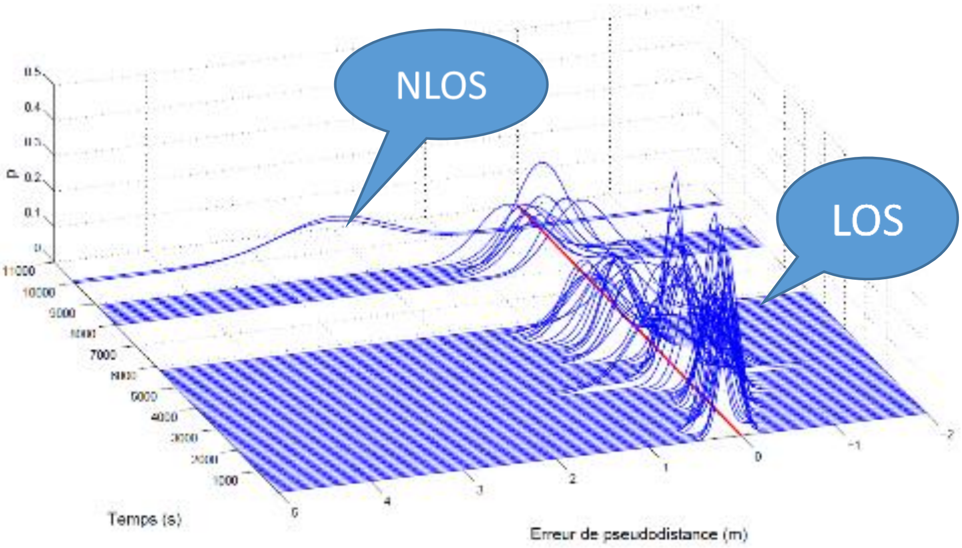


Fig 3. Pseudo-range error distribution versus time for LOS and NLOS received satellites (Viandier 2011)

3.4. PL computation on the basis of LOS models

The receiver can statistically estimate the variance σ_i^2 on the residual pseudo-range errors (the initial pseudo-range errors being corrected with EGNOS data) function of σ_{UDRE}^2 and σ_{GIVE}^2. The variance related to the position errors according to the horizontal and vertical components ($\sigma_{Hposition}^2$and $\sigma_{Vposition}^2$) is deduced from σ_i^2 as indicated in equation 1. The terms of the equation are obtained from a least square residual algorithm in which it is admitted that the position error is a linear combination of the pseudo-range errors.

$$\sigma^2_{Xposition} = \sum_{i=1}^{N} S^2_{X,i} . \sigma_i^2 \qquad (1)$$

with X the horizontal or vertical component, N number of pseudo-ranges used in the position estimation, $S^2_{X,i}$ is a parameter quantifying the geometrical impact of the satellites on the position, calculated on the basis of the same method than the dilution of precision GDOP.

Finally, the error distribution of the position follows a normal distribution $N(0, \sigma_{Xposition})$ as it depends on the pseudo-range error combination that also follow a normal distribution. By inverting the cumulative density function of this distribution at the specified risk integrity probability (i.e. $cdf^{-1}(N)$ at the value of a specified missed probability P_{MD}), PL can be obtained. For example, $HPL = 6. \sigma_{Hposition}$ for an integrity risk of $0.5.10^{-9}$ for the horizontal component, and $VPL = 5.33. \sigma_{Vposition}$ for an integrity risk of $0.5.10^{-7}$ on the vertical component.

Based on classical SBAS-based HPL computation, the RUNE project experimented HPL in the order of 10m along a railway line

In road domain, a HPL correctly bounding the errors (HPL<8m) has been measured by (Ali 2012) along highways but in the urban context, the authors illustrate that the receiver worked in safe operation mode only for 15% of the time.
In the 3inSat project, based on EGNOS and the local augmentation system deployed presented above, PL also vary between 5 and 20m approximately, function of the augmentation system availability as presented by [10]. Recent results obtained on the Sardinia line show PL values around 14m.

However, one can notice that in the past projects, except in the 3inSat project and as far as we have seen, computed PL have not been compared to real PE in order to demonstrate the suitability of its computation in a railway environment. In 3inSat (2016), the Augmented PVT performance has been assessed with respect to a Ground Truth developed by using an RTK Receiver installed on board and the RTK Networks available in the area of the demonstration and has shown that the Phase 2 LDS System:

- does not provide a solution less than 2% of the epochs:
- is potentially intrusive (Protection Level > Application Threshold) less than 20% of the epochs
- is in MI/HMI less than 2% of the epochs.

3.5. EGNOS Time to Alert

Finally, let's mention the fact, that the EGNOS TTA is 6s, and can be sometimes problematic in the railway domain because some railway systems may require faster safe reaction than 6s.

4. Solutions and recommendations from the STARS project

After the first steps of work of the STARS consortium, and the publication of deliverables 5.1 and 5.3, the following recommendations can be written:

- As previous projects experienced before, the reception of GEO satellites signals from ground users is sometimes difficult. Nevertheless, the use of GEO satellites to distribute EGNOS corrections is not mandatory and other distribution channels can be envisaged. For example, the use of the existing EDAS or the creation of an additional "railway dedicated" interface could be considered in order to directly distribute EGNOS corrections toward ERTMS/ETCS system. Such direct distribution of EGNOS corrections to ERTMS/ETCS system could also bring an advantage because present EGNOS SIS can easily be jammed on ground and legacy EGNOS SIS does not provide support for authentication. Therefore, the usage of EGNOS system in the area close to jammer equipment can be made impossible but the distribution of EGNOS corrections directly through ERTMS/ETCS transmission means could circumvent the above limitations by providing the necessary security protection for the distribution channel.
- The future evolutions of EGNOS including dual frequency and multi constellation will offer additional resistance to signal blockage, for example in urban canyon, by taking advantage of the increased number of satellites.
- The bounding formulas for residual errors (sigma) used in aviation domain are not representative of railway environment and new formulas will need to be defined. One of the main goal of the STARS project is then to measure GNSS services real performances in a variety of user environments in order to propose the formulas that will correctly bound the user local effects and/or to identify ways to detect when local environment effects are over the acceptable limit.
- The user position equation will have to be standardized for the railway domain so that EGNOS system, knowing the equations implemented in user receivers will be able to guarantee the integrity of the user position computed using these standard equations.
- A 2D "protection level" will need to be defined along with its associated equation. The distinction of "Along track" and "Cross track" protection levels could be interesting.
- The certification process is an important point that has to be addressed early enough by Europe, so that additional constraints on safety dossier presentation and content as well as additional constraints on design can be tackled at an early stage of the program to not endanger it.

5. Conclusions

EGNOS use in railway environments faces difficulties such as visibility or technical constraints but as shown in the past projects, when EGNOS is received and can be used, it shows its benefit on accuracy and integrity.

Several issues for EGNOS have been identified:

- EGNOS visibility in constrained environment is not guaranteed. This is one of the reasons of ground-based augmentation solutions developed as a complementary system in Sardinia.
- EGNOS integrity monitoring concept has been developed for aeronautics and relies on the definition of phases of flight or modes. Such phases do not exist in railways.
- EGNOS integrity monitoring concept relies on the comparison of Protection Levels with Alert Limits. Alert Limits bounds tolerable errors around the estimated position that are not defined in railways specifications.
- Propagation conditions in a railway environment differ from the open-sky environment encountered by a plane. Thus EGNOS error models (computed for open sky environment) have to be compared to real error model in order to evaluate their suitability to the application context. Moreover, it will be interesting to evaluate the consistency of PL values regarding the true errors in order to quantify the capacity of EGNOS to properly bound the rail positioning errors.

As a consequence of the above discussion:

- User positioning equation needs to be specified
- User integrity equation needs to be specified.
- User local environment needs to be characterized.
- Certification process need to be addressed

And in order to request EGNOS performances that are measurable, it is highly desirable that performances required from EGNOS by ERTMS/ETCS are defined at the output of a user receiver presenting what is considered as the Minimum performances needed for railway applications.

Acknowledgements

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6. References

3inSat (2016). Final Report of the ESA Artes IAP 3inSat project,

Ali, K., Pini, M., & Dovis, F. (2012). Measured performance of the application of EGNOS in the road traffic sector. GPS solutions, 16(2), 135-145.

Bortolotto, M., Choquette, F. (2003). EGNOS trials on Italian high-speed tilting trains. In proceedings of the GNSS 2003 conference, Graz, Austria.

EGNOS Safety of Life (SoL) Service Definition Document (2016). Revision 3.1.

Filip, A., Bažant, L., & Mocek, H. (2010). The experimental evaluation of the EGNOS safety-of-life services for railway signalling. WIT Transactions on The Built Environment, 114.

Filip, A., Bažant, L., Mocek, H., Taufer, J., & Maixner, V. (2001). Architecture of GNSS aided signalling: Analysis and experiments. In Proceedings of Word Congress on Railway Research (WCRR).

Manz, H., Schnieder, E., Becker, U., Seedorff, C., & Baudis, A. (2014, April). Approach to Certification of Satellite Based Localisation Unit in Railways. In Transport Research Arena (TRA) 5th Conference: Transport Solutions from Research to Deployment.

Marais, J., Beugin, J., 2017. STARS D5.1. State of the art of EGNSS projects for the rail application, STARS project public deliverable.

Marais, J., Beugin, J., & Berbineau, M. (2017). A Survey of GNSS-Based Research and Developments for the European Railway Signaling. IEEE Transactions on Intelligent Transportation Systems.

Marais, J., Flancquart, A., & Lefebvre, S. (2006). Satellite availability in a railway mountainous environment: Can we use satellite positioning for safety applications? In World Congress on Railway Research (WCRR), Montréal.

Mertens, P., & Franckart, J. P. (2003). Low-cost signalling on Low density lines. Railway Gazette International.

Neri, A., Rispoli, F., & Salvatori, P. (2015). An analytical assessment of a GNSS-based train integrity solution in typical ERTMS level 3 scenarios. In Proceedings of ENC 2015.

Neri, A., Filip, A., Rispoli, F., & Vegni, A. M. (2012). An analytical evaluation for hazardous failure rate in a satellite-based train positioning system with reference to the ERTMS train control systems. In 25th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2012) (pp. 2770-2784). The Institute of Navigation.

Raymond, G., Marais, J., Berbineau, M. (2004) Innovations Bring Satellite Control within Reach, Railway Gazette International, Déc. 2004, p835-837.

Rispoli, F., Neri, A., & Senesi, F. (2014). Innovative train control systems based on ERTMS and satellite-public TLC networks. Computers in Railways XIV: Railway Engineering Design and Optimization, 135, 51.

Stamm, B., Gurnik, P., 2017. STARS project - Satellite technology for advanced railway signaling, European Navigation Conference 2017, May 9-12, SwissTech Convention Center, Lausanne.

Urech, A., Pérez Diestro, J., & Gonzalez, O. (2002, July). GADEROS, a GAlileo Demonstrator for Railway Operation System. In Data Systems in Aerospace (Vol. 509, p. 46).

Viandier, N., (2011), Modélisation et Utilisation des erreurs de pseudo-distances GNSS en environnement transport pour l'amélioration des performances de localisation, PhD Ecole Centrale de Lille.