STARS project - Satellite technology for advanced railway signalling

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Motivation

Applications of Global Navigation Satellite System (GNSS) in Railways are become more and more frequent. So far, the focus has mostly been on non-safety related applications, such as in passenger information systems and for freight logistics, which are typically not standardised. When moving GNSS application into the domain of safety, such as for train control systems, a much better understanding of GNSS behaviour is needed. Despite of the multiple past rail research projects, the necessary level of knowledge on the characterisation of the satellite-based positioning performance within the rail environment is missing. This is especially true for the use of GNSS in standardised applications, such as the European Railway Traffic Management System (ERTMS), where performance of GNSS receivers should be harmonised to achieve standardised, guaranteed performance and thus interoperability between on-board units of different suppliers. The ERTMS system has been developed over the last two decades to eventually replace all existing national train control and train radio systems which have significantly hampered cross border rail traffic in Europe, but also the opening of rail networks to open competition between operators.

Project objectives and expected results

The main objective of the STARS (Satellite Technology for Advanced Railway Signalling) project, funded by GSA (European GNSS Agency), is to fill the gap between ERTMS needs for safety critical applications and GNSS services, through a characterisation of the railway environment and of GNSS performances assessment in that environment. STARS consortium is comprised of the major European signalling manufacturers, space industry and research centres, committed to significantly contribute to the development of satellite-based train positioning technology for modern train control systems, such as ERTMS[1].

STARS project will 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 constituted of 3 phases (see Fig. 1): the first one leads to the elaboration of reference data and characterisation of the railway environment through a measurement campaign. Within the second one experts 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.

[1] STARS website: www.stars-rail.eu

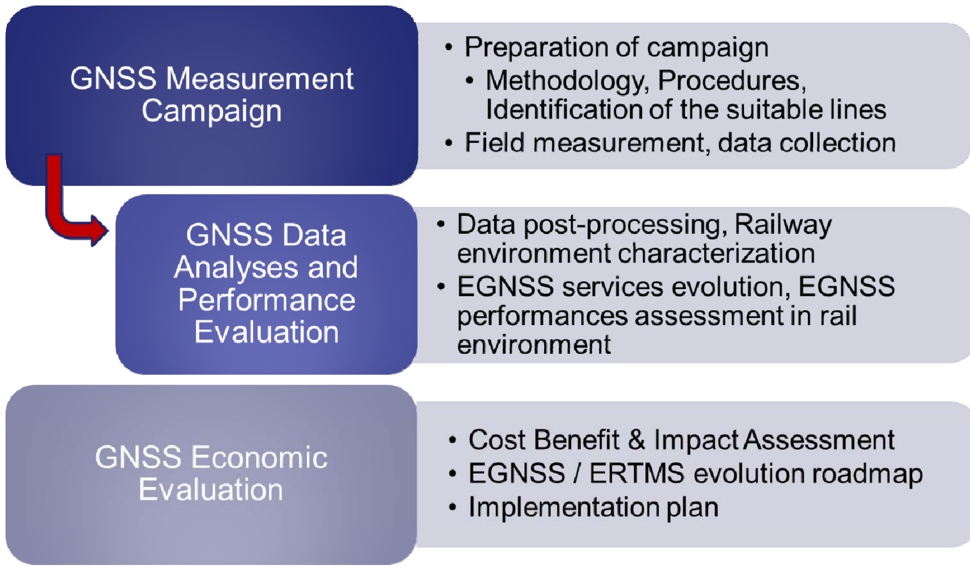

Fig. 1: STARS project study logic

STARS measurement methodology

The achievable performance of GNSS-based train localisation in regards to accuracy, availability and integrity/safety depends on multiple factors. They can be divided into two main categories. The first ones can be influenced (or at least partially influenced) by human decision making, while the second ones are moreinfluenced by the environment and thus more difficult to control. Table 1 lists a number of these influences:

Categories	**Sources of interference**
Fully or partially controllable by human decision making	RF interferences generated by train on-board equipment, Multipath due to the train type and railway infrastructure along the track, Type of train (diesel, electric), Type of railway line (Electrified/non-electrified, tilting trains, speed characteristics), Position of an antenna on the train, Type of GNSS antenna and related installations (wide-band, multipurpose, elevation gain pattern, etc.), type of GNSS receiver (multi/single constellation, frequencies, sensitivity, etc.);
Outside human influence	Objects such as tunnels, bridges, buildings or terrain limiting satellite visibility, attenuation of signals by weather, foliage etc., RF interference generated by external sources, multipath due to non-railway environment, atmosphere, ionosphere and troposphere influences, weather effects, space weather

Table 1: Sources of influence impacting GNSS-based train positioning performance

The project has discussed multiple approaches how to analyse the impact of most of the above listed influences on GNSS performance. Table 2 lists a number of these techniques, of which many are being applied within the STARS project:

Local phenomena	Technique
Multipath	Code minus Carrier (CMC) technique: The use of one frequency code phase measurement and two-frequency carrier phase measurements;
	Effect characterized via an output from GNSS receiver's Multipath mitigation algorithm;
	Effect characterized via GNSS Post-processing technique of GNSS RF samples;
	Post-processing of raw data simultaneously measured with RHCP and LHCP antennas;
	A priory estimate of multipath effects based on 3D-environment model;
	A priory estimate of multipath effects based on 360° camera;
	A priory estimate of multipath effects based on orthophoto map;
RFI	RFI effects estimates derived from Post processing of RF samples (required tool: high frequency digitizer);
	RFI effects estimates derived from Snapshots of spectra (required tool: spectral / vector signal analyzer);
	Effect characterized via an output from GNSS receiver's interference mitigation algorithm;
	Analysis of signal quality indicator(s) in raw data (C/N0, SNR, I&Q correlator outputs);
	Using geographical data to estimate potential RF interference sources in railway track areas];
GNSS Signal attenuation, sky visibility	Analysis of signal quality indicator(s) in raw data (C/N0, SNR);
	A priory estimate of effects based on 3D-environment model;
	A priory estimate of effects based on 360° camera pictures taken along the track;
	A priory estimate of effects based on track orthophoto map;

Table 2: Considered techniques for characterisation of local phenomena in rail environment

These techniques are to be further detailed, analysed and evolved within the project, based on the real data collected through the extensive STARS measurement campaigns (see the next section).

For an evaluation of the achieved train localisation performance it is also essential to establish a ground truth reference. It is a position estimate itself, but based on different technologies independent of GNSS to satisfy required localization accuracy and to avoid common cause errors. In general, for establishing a highly accurate ground truth three elements are necessary:

1. Accurate track data base
2. Absolute reference markers
3. Relative distance measurement between reference markers

Several available technologies for establishing the ground truth are being used within the different measurements sites of the project, depending on their availability. This includes:

- Eurobalises
- Magnetic Identification Balises
- RFID tags
- ETCS odometry
- Wheel tachometer
- Optical correlation sensor
- Doppler radar

Measurement campaign

To achieve results which are applicable across the diverse European railway network it was essential to select a number of representative sites for the measurements campaign. Selection of both test tracks and vehicles was therefore an essential part of the STARS project. Thanks to support from a number of railway infrastructure companies and rail operators, three test sites were finally selected.

Table 3 summarizes the criteria relevant for selection optimum test vehicles and tracks:

Criteria	Description
Diversity of rail application types	Various types of lines (secondary lines, urban tracks, high speed lines, etc.)
Environmental diversity	Mountainous tracks, Open sky sections, restricted visibility sections, tunnels, urban environment, etc.
Operated track length and diversity	Track should provide enough diversity avoid that measurements are only performed in an area which might be uniformly impacted by a single parameter.
Availability of geographical track database	One of the most important source of information for the establishment of a ground truth.
Availability of absolute reference markers along the track	Reference markers are required to provide frequent absolute position information.
Availability of a reference markers reader onboard the train	Train equipped for reading reference markers and to provide this information to STAR measurement equipment.
Diversity of traction systems	Electric traction generates significant electromagnetic interference, which might interfere with GNSS reception, which is an influence that should be measured. Significant differences exist e.g. between DC and AC power supplies.
Speed range	GNSS performance in certain environments is speed dependent. It is therefore of advantage if measurements can be performed in a range of speeds also covering very high and very low speeds.
Availability of on-board odometry information	Establishment of an accurate ground truth depends on accurate odometry information between reference points, as the absolute train position will have to be compared with the position determined by GNSS.
Feasibility of getting an approval within the STARS schedule	Complexity and required effort for the approval of test installations differ significantly from country to country. Support from railway infrastructure companies and rail operators, as well as safety authorities is essential to obtain approvals within the short timeframe of the project.
Access to the train, possibility to install/ maintain STARS equipment	Many factors have to be considered for the installation of equipemtn: available space, cost of the installation, installation time, access to the train, etc.
Frequency of test runs	To gain enough data, test runs must be scheduled frequently. It was therefore decided to use trains in regular service to perform measurements, which was however increasing the complexity to obtain the necessary approvals.
Cost	It was essential to select vehicles on which measurements can be performed during regular operations, as renting trains was not possible within the budget of the project.

Table 3: Criteria for selection of proper lines and trains, suitable for STARS measurement campaign

The final selection of the three test sites was based on obtaining the best compromise between the many factors listed above.

As of the end of 2016, the STARS measurement campaigns have started (see Fig. 2) in three countries (Czech Republic, Switzerland, Italy). The selected lines and vehicles represent the various types of rail environments in Europe (e.g. open environment, urban and mountainous areas etc.), as well as traction systems (AC/DC electric traction, diesel traction).

Collected data (raw GNSS signals as well as data from a number of receivers) are continuously being uploaded to a centralised, cloud-based repository, giving easy access to all project partners across Europe to perform the individual types of analysis.

Fig. 2: STARS measurement campaign – examples of vehicles and environments

Ambitions and expected impacts

The project aims to improve ERTMS through the application of GNSS, leading to economic benefits through reduction of trackside equipment, reduction of maintenance, increase of availability and performance. The output of the project will feed directly into the standardisation work of ERTMS, and shall become part of an upcoming release of the standard.

The STARS project is based on (but not limited to) the theoretical work produced by previous research projects such as NGTC[2] or ERSAT-EAV. Its results will be effectively utilised by ongoing and future linked R&D projects, most significantly Shift2Rail JU[3] (see Fig. 3).

[2] NGTC website: www.ngtc.eu

[3] Shift2Rail JU website: www.shift2rail.org

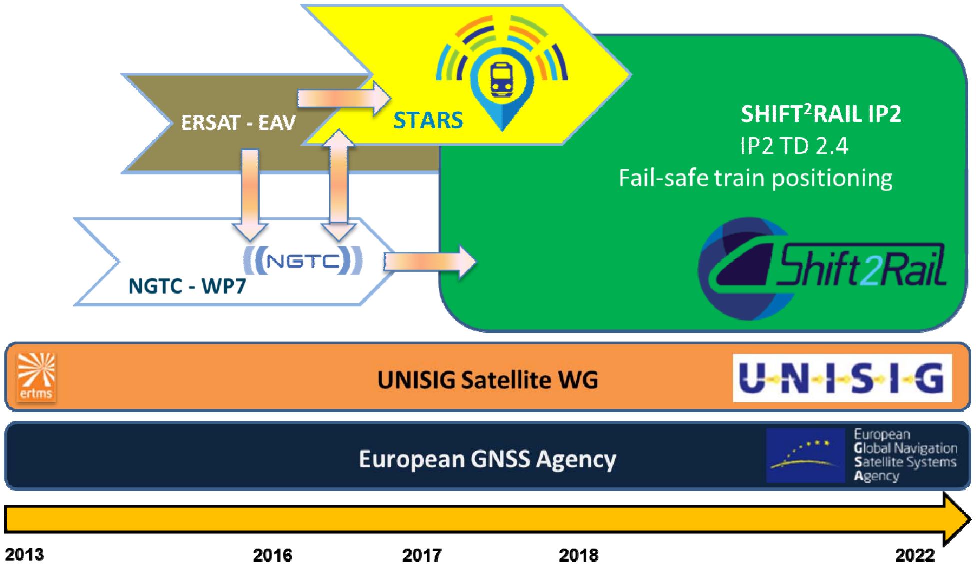

Fig. 3: Major links between STARS and other projects / initiatives

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