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George Barbu, Juliette Marais

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George Barbu[a*], Juliette Marais[b]

[a]*Union Internationale des Chemins de Fer, Paris, France*
[b] *Univ Lille Nord de France, F-59000 Lille, IFSTTAR, LEOST, F59650, Villeneuve d'Ascq, France*

Abstract

"Successful introduction of the satellite navigation technology in the railway safety needs accreditation of a new mode of thinking, innovation, convincing demonstration of concept and lifting of technical and mentality barriers."
This article shows a the state of the art of the SATLOC project aiming at reporting on the baseline of the project according to the objectives, in line with the terms of the FP7, item Galileo.2011.1.4-1 "Use of EGNOS and GALILEO for safety-of-life applications for all transport modes". The article summarizes the notable realizations of the project team, the advanced start of tests, preceded by the concept validation in the laboratory and on the pilot line Brasov-Zarnesti in Romania.

Keywords: Railway; GNSS; EGNOS.

Résumé

« Une introduction réussie de la technologie de navigation par satellite dans la sécurité ferroviaire nécessite une accréditation d'une nouvelle façon de penser, de l'innovation, une démonstration convaincante, de lever les barrières techniques et changer les mentalités. »
Cet article montre l'état d'avancement du projet SATLOC, et ses objectifs en lien avec les termes du FP7, item Galileo.2011.1.4-1 "Use of EGNOS and GALILEO for safety-of-life applications for all transport modes".
L'article résume les réalisations notables de l'équipe projet, l'avancée des tests sur la ligne pilote Brasov-Zarnesti en Roumanie ainsi que la validation de concepts en laboratoire qui les a précédés.

Mots-clé: Application ferroviaire ; GNSS ; EGNOS.

* Corresponding author information Tel.: +33-144-492-107; fax: +33-144-492-059.
E-mail address: barbu@uic.org.

1. SATLOC and its background

Since the beginning of the years 2000 a number of EC projects (APOLO, GADEROS and LOCOPROL) have tested the GNSS technology on-board of trains and have positively concluded on the capability of GNSS to satisfy the requirements of the railway applications.

The SATLOC (*Satellite based operation and management of local low traffic lines*) project comes within the scope of this long-term work. Its objective is to develop and demonstrate an innovative concept of applying the GNSS to railway safety and advanced operation on low traffic lines aiming at:

- Stimulate adoption of EGNOS in new innovative rail operation with important market impact and with important effects on socio-economic, mobility and environment;
- Prepare markets for Galileo introduction since EGNOS is the precursor of GALILEO and enablers will be created including the awareness and preparation of the railway to immediately apply the new system;
- Stimulate EU GNSS industry competitiveness in domains which are reputed (railway safety, railway integrated operations) for using mostly traditional ground-based technologies and conservative for global approach.

The overall objective provides life demonstration – to create impact and proof of evidence - validated and certified under the EU ruling and applied on the line Brasov – Zarnesti of the RCCF-TRANS (Romania).

State of the art of GNSS-based railway projects

The GPS related positioning safety integrity obtained with commercial receivers is already applicable. In the 2000's the LOCOPROL project has proposed special algorithms to use 1D intersection with rail track and to evaluate the integrity of positioning when taking into account the probabilistic incertitude of GPS constellation (Marais, 2003). It showed that the SIL 4 integrity for positioning was achievable when the accuracy requirement is in ranges of 150m along the track. Unfortunately LOCOPROL did not apply the SoL (*Safety-Of-Life*) integrity.
Industrial solutions have been tested in simulation conditions amongst which ALSTOM in the conception of LOCOPROL, BOMBARDIER that developed advanced use of track digital data, THALES with fusion of GNSS, 2D and 3D accelerometer and of on-board mechanical odometry, or ANSALDO, in the project RUNE (Albanese, 2004), that proposed the use of GNSS speed measurement in fusion with the train odometry to enhance the train odometry accuracy.

In relation with EGNOS performance in the railway environment, practical tests have been carried out in the projects GADEROS (Garcia Prieto, 2004) and GRAIL (Urech, 2006). The tests have been performed in the periods when EGNOS was only experimentally broadcasting (years 2006 – 2008). The results can be conclusive but the absence of a live demonstration using the SoL in real train operations condition was still missing.

More recently, the project GRAIL (Urech, 2008) has concluded that GNSS positioning and integrity performance (EGNOS as precursor and, notable Galileo) can be compatible with the ETCS odometry when using the GNSS receiver as a sensor, at the same level of confidence as the mechanical odometer and the Doppler radar. The GRAIL-2 will demonstrate the use of GNSS in this context (speed sensor complement to Doppler radar).

The rail sector in Europe has not yet adopted GNSS in safety-related applications. The barriers preventing the application of GNSS to rail safety have been identified within the UIC Galileo expert group (UIC, 2005):

- Missing the proof of evidence with practical and demonstrable means that sufficient safety integrity levels (SIL) can be obtained as global safety target in real train operations when GNSS is the primary source for location and speed information.
- Missing the proof of evidence that engineering and supply of flexible and scalable architectures for the on-board with train locators based on GNSS are available with affordable costs on a range of application categories such as LTL operations.

- Missing the proof of evidence that the conception of strategy for the validation of rail application with introduction of GNSS is applicable based on the multimodal validation of SIS-SoL (as per GALCERT programme) and the joint use of aviation and rail standards

The SATLOC project has been built as an answer to these identified barriers.

2. Objectives of the project

The different objectives of the project are described here above.

The elaboration and demonstration of innovative conception of GNSS use in the low traffic lines signalling and train control (primary railway safety).

The innovative conception of safely integrated signalling, train control and traffic management of the low traffic lines is based on GNSS (starting with EGNOS SoL integrity). The low traffic lines are the "E" lines according to the UIC classification, characterized by closed exploitation without –or with very limited- incidence on the main lines. The lines are low traffic density and have large headways of 20-30 minutes between trains. Freight trains are operated only occasionally and submitted to particular operational rules. The innovation consists in a new rail operation concept to realise full safety enforcement of movement authority through trains' speed and train control supervision (train's speed supervision equivalent to the ETCS functionality). The high achievable operation safety target, of 10^{-9} train hazards/h – the same as the ETCS safety target - will apply the close-loop real time interaction - reciprocal check of safe states between trains' on board computer and the Radio Block Centre (RBC-TCC). This is enabled by the continuous train position and velocity determination with GNSS (EGNOS and in the future, GALILEO) and its process on-board and in the RBC to double-supervise the train safe state in a close-loop train regulation system. The large headways and the relative low speed of operating trains (maximum 120 km/h) enable the real-time safety cross-check on-board and in the RBC with smart utilisation of the radio transmission capacity, on a marginal cost. The innovation enables the direct use of EGNOS (GALILEO) positioning accuracy and integrity risk. This makes possible the cost-efficient integration of GNSS with SoL (EGNOS and in the future, GALILEO) into the safety layers of the integrated operation, signalling, train control and train movement management. The EGNOS integrity will be applied to satisfy the required level of safety integrity and availability of the railway service.

Enlargement of the GNSS application field to railway safety, with potential of application until ~ 35 - 40% of the rail network in Europe and much higher in the world.

The innovative conception to use the on-board computer functions and radio-control centre functions in synergy and inter-connection to realise the full speed supervision train control on high safety level is actually revolutionary to demonstrate and conquest the GNSS access to rail safety. The project develops and applies innovative tools of "exportation" concept from the real-scale live demonstrator to other railway lines, based on optimised modularity and simulation of other local application conditions of GNSS and use of integrators to optimise cost, supply, commissioning and migration

Alignment of railway solutions for safety to the standards of EGNOS and GALILEO initially set to aviation.

The available GNSS integrity risk of $2{,}5*10^{-7}$ (EGNOS integrity risk @ Alert Limit and Time to Alarm) will be directly applied within the safety chain of the railway operation. The SATLOC innovative conception demonstrates the capability of the ETCS conception to integrate the new technology on functionality equivalent to ETCS L2 without track-side signals and common migration to the future L3. The bases are the On-board and RBC-TCC platforms and full ETCS "language" and specifications (subset 026). SATLOC will reach the similar functionalities on a low cost base, cheaper than the current on-board and track-side ETCS applications. SATLOC LCC (Life Cycle Cost) targets will be analysed against the economic effects and business cases of relevant applications.

Creation and inclusion of fully innovative services of integrated rail traffic control and management, real-time information for passengers, increase of transport reliability and quality which are only enabled by the continuous trains' movement supervision with GNSS.

The innovative services address the optimisation of the traffic control and management integrated with the safe operation and fully real-time information from ONE central point for the whole operated line(s).

Other innovative conceptions are created and demonstrated:

- The innovative conception of the track-side train direction and safe crossing in the stations applies pre-routed sets of switches in crossing stations (spring and trail-able switches) to avoid complicated and costly interlocking. The innovation will also address the configuration of the RBC to realise the safe movement authority elaboration in connection with the closed-loop trains' movement control applied on all trains in the controlled area. This function is an advanced approach to the future ETCS level 3.
- The innovative tools for assessment, proof and validation of safety and the optimal use of GNSS and radio in locally determined conditions.
- The innovative conception to reach a full migration towards the ERTMS/ETCS conception when integrating the ERTMS Regional UIC specifications already applied in Sweden.

The project cooperates with the relevant drivers of the innovation in the field of GNSS and with the railway integrating and supply industry. The consortium includes the UIC and the railways, SIEMENS, INVENSYS-RAIL, ANSALDO STS, TELESPAZIO SPA, IFSTTAR, TU-Braunschweig, FH-WELS, SPIRENT PLC, and AFER-Romania (the railway safety authority of Romania). RCCF-TRANS Romania is the train operator and infrastructure manager who applies SATLOC on the pilot line. UIC assures the technical and managerial coordination of the project.

3. Operational and functional requirements

SATLOC enables the satisfaction of public service requirements of low traffic density lines, in terms of:

- normal service, with an agreed timetable
- safety target, approved by the safety authority, the same as the previous railway service, e.g. the use of the ALARP methodology to define the operational system safety target
- regularity, quality, information
- cost constraints, eventually derived from a business case evaluation of the line operation

The following operating requirements have been specified:

- Movement authority (MA) SATLOC Page 4
- Train control (TC)
- Train separation (TS)
- Full speed supervision
- Train integrity – train completeness monitoring (TCM) ; (yet applied only for demonstration purpose)
- Prevention of over-speed (POS) (is restricted to prevention on maximum line speed and on permanent speed restrictions)
- Shunting (SH)
- Control of movements (CMV)
- Supervision of system's borders (SSB)
- Control and supervision of level crossings (CLC) (NAP)
- Protection of emergency personnel working on or directly adjacent to the track (PWP) (NAP)
- stop to train(s) – emergency stop command to the trains of a specific controlled area (ES)

Requirements have been specified to the following operations envisaging safety:

- Protection against train-to-train collisions (PATC)
- Prevention of over-speed (POS)
- Control of movements (CMV)
- Control and supervision of points (C) – simplified interlocking applied for low traffic density lines

4. Allocation of the operational safety target

Currently the pilot line (and even a majority of the low traffic density lines) is secured either with the telephone block or with the old (~120 years old) SIEMENS (Frietsche) electric bloc (fig. 1).

The SATLOC project consortium has decided to use the ALARP approach to allocate the safety target for the train operation on demonstration line. This should mean that the new system (SATLOC) shall realize the same or higher safety target as the current employed system. This procedure is in accordance with European laws and regulations {European Commission 2009 #265}. Although the current safety function based on the mechanical interlocking and S&H bloc are not quantitatively qualified, the study of the safety case of the operations based on such equipment concludes on a THR of ~ $4*10^{-6}$ /h. This results from the involvement of human responsibility with double check (two agents).

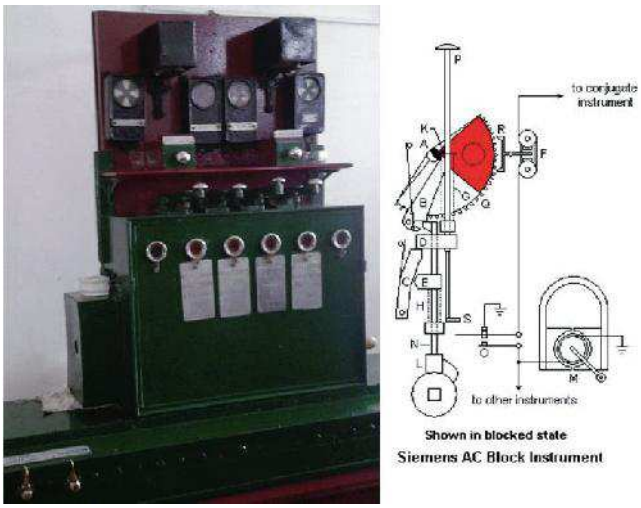

Fig. 1. S&H mechanical interlocking and block on the line Brasov-Zarnesti

If applying the ALARP, it should have been resulted that the safety target of SATLOC was inferior to the ETCS THR. Therefore, the SATLOC consortium has decided to adopt directly the safety target of the ETCS train operation. In the scope of consistency with the migration to the ETCS and moreover by force of using the general ETCS specification of RAMS and mainly Subset 026, it has been decided that the THR in the train operation on SATLOC lines will be the same as for the ETCS, i.e. 10^{-9}/h for one train.

This decision, in agreement with the safety authorities, was applicable in the context of advanced innovation, where the train and the track-side (On-board and RBC-TCC) are checking reciprocally, in close loop and in real time the accomplishment of the safety critical function of the system. This function (as also the ETCS function) is the enforcement of the Movement Authority, i.e. the safe stop of the train prior to the limits of the danger point.

The integrity risk of GNSS/EGNOS positioning function is $2,5*10^{-7}$ for each fix in open sky condition of visibility with a normal accuracy better than 3 m (typical 1 m with EGNOS augmentation). The functional algorithms of figure 2 have been implemented in the RBC – TCC taken into account the quasi-continuity of position and speed determination by GNSS.

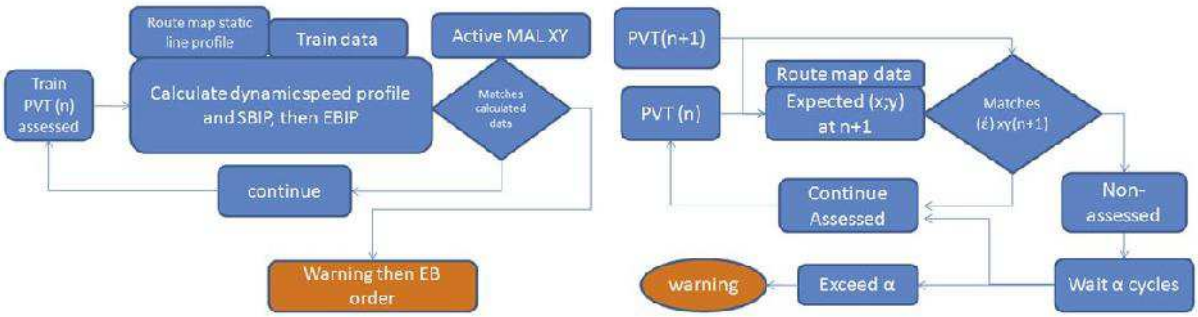

Fig. 2. The Movement Authority survey and the train tracking modules in the TCC

The train tracking module is open and running for each train registered into the controlled area. The modules verify positioning accuracy achieved by GNSS and the on-board odometry for each train, using the route map as a sensor. If repeated anomalies are detected, the module emits a warning to the driver and can also trigger an automatic emergency brake. The movement authority survey module uses, for each train, the MA data, the route map data, which includes the line static profile, and the train data. The route map is a high integrity track-axis survey in absolute coordinates (Y, X, Z) with a minimum resolution of 5 m and verifiable (through alternative topometric methods) accuracy of 50 cm. The information of the static line profile is attached to each portion of the track. When reading the route map, both the train and the TCC shall determine the speed profile of the trains and also the "intervention points" for triggering the "attention" (warning) and, if the driver does not respect the speed reduction, the trigger of the "emergency brake". As a consequence, the train OB system and the TCC survey in real time if the train actually executes the speed control. If the train fails, then the TCC module shall warn the driver and automatically trigger the emergency brake.
The reciprocal check and the interaction between the train and the TCC enable to accept lower safety integrity on each component. The interaction ensures the overall safety target that is a THR less than $2*10^{-9}$ /h for a train.

5. Technical design and implementation

The SATLOC technical design has followed the standard procedures where the hardware and software architectures have been optimised from the points of view of:

- Achievement of the operational and functional requirements;
- Balance of the overall cost constraints, mainly determined by the integrity imposed to the software functions and the hardware safety architecture;
- Selection of equipment to achieve the RAM objectives

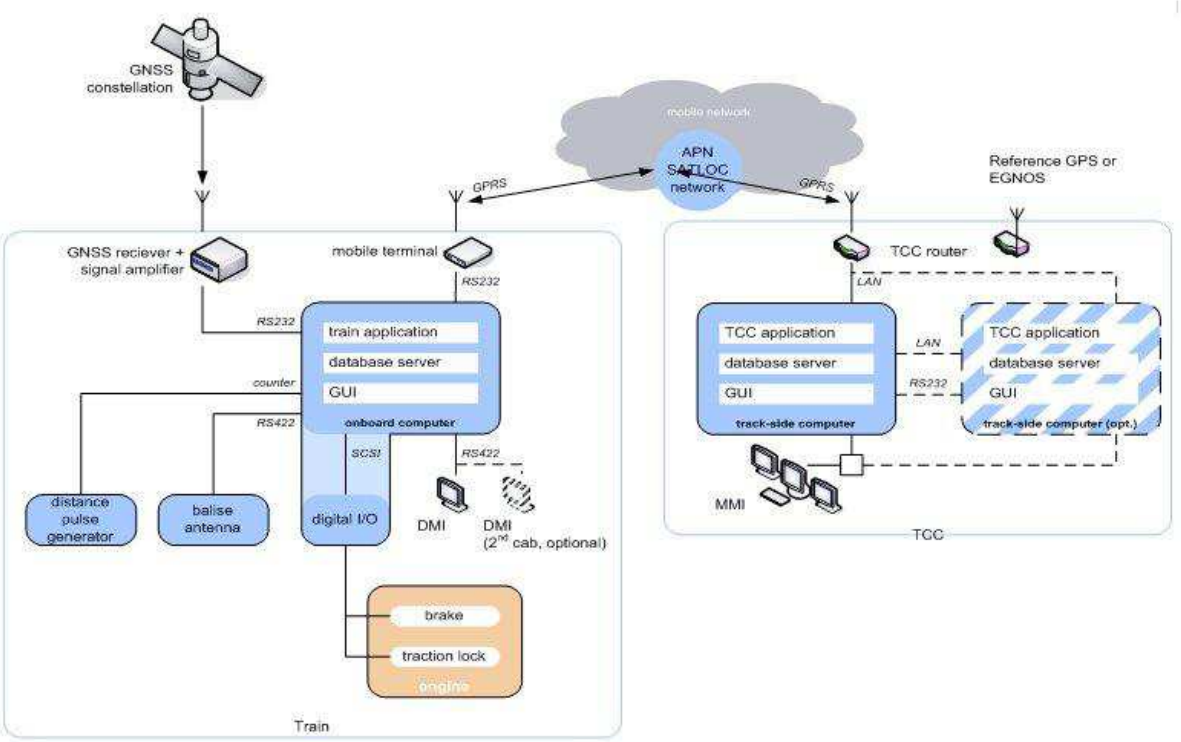

Fig. 3. SATLOC reference architecture

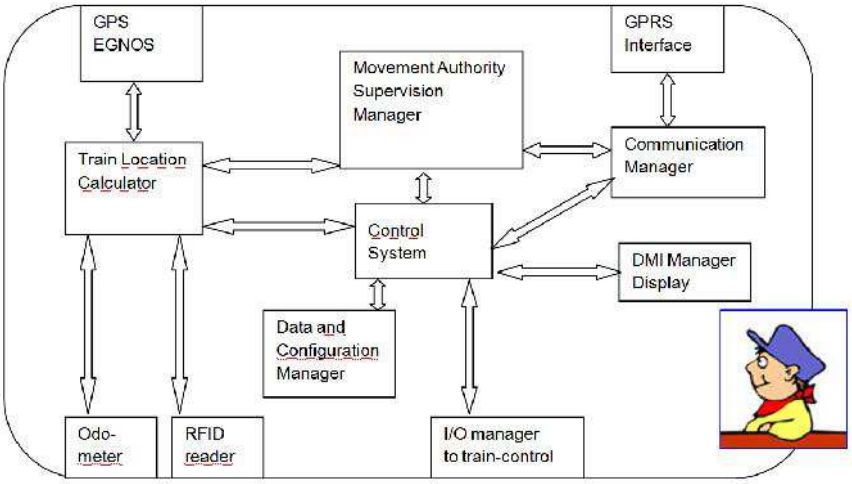

Fig. 4. Onboard Unit software architecture

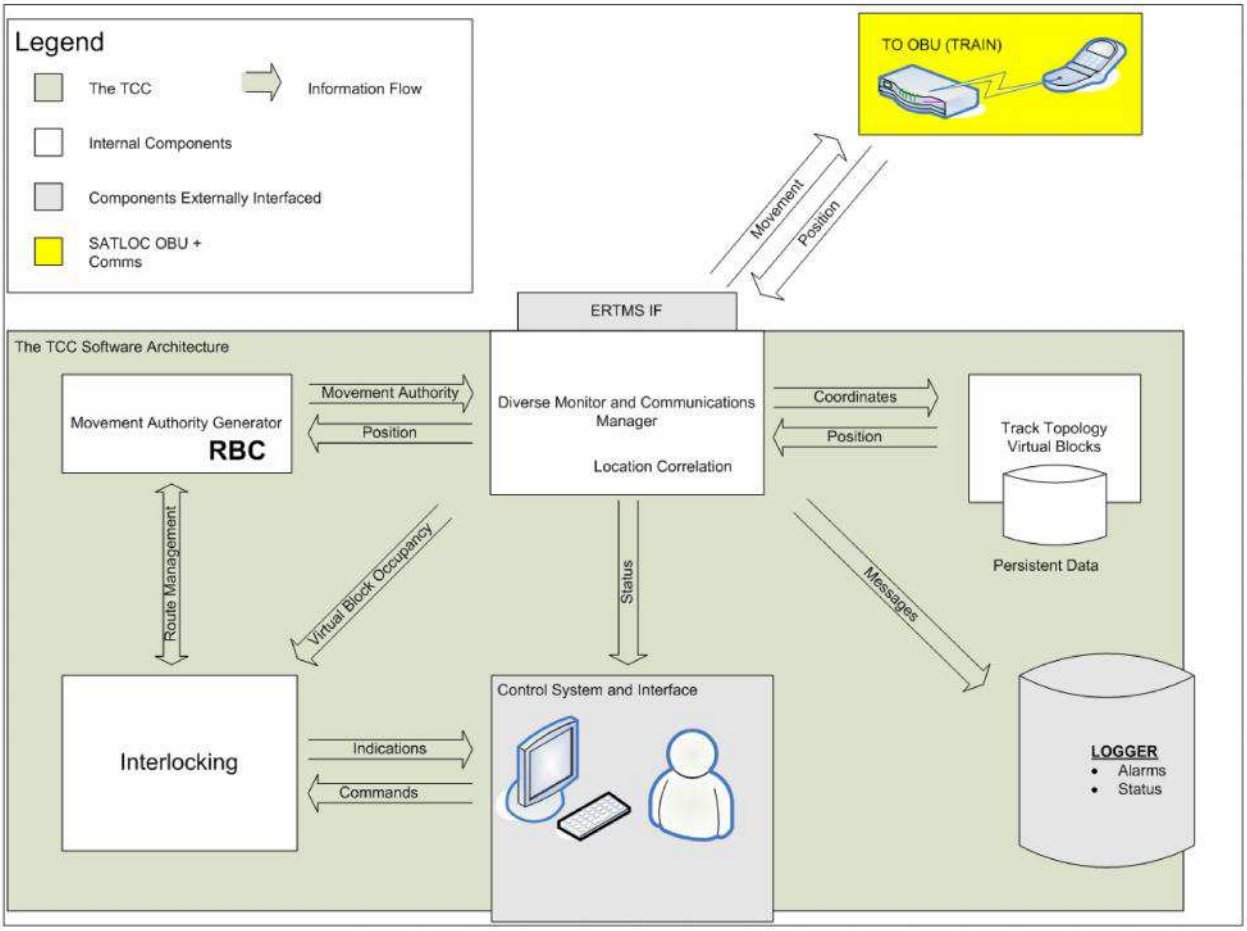

Fig. 5. RBC-TCC software architecture

The software have a modular structure as shown in figures 4 and 5. The SATLOC specific software module (Route Map) is applied identically in the TCC and onboard. The other specific modules (tracking and MA supervision) are running in the background of the interlocking and MA manager modules.

6. Train – TCC radio link. Migration towards independence from the radio bearer

Currently the TCS uses the GSM-R (rail dedicated communication system derived from the standard GSM). The GSM solution for the ETCS radio bearer has been selected in the 1992's. At that time the GSM was the most progressive digital mobile radio standard. 20 years after, the migration towards independence from the radio bearer is envisaged. SATLOC marks also in this aspect the innovative solutions.
Tests are on-going to establish if any potential end-to-end delay does not exceed the real time constraints of the operational application. As an overall observation, the data transmission by tunnelled VPN and the application of EURORADIO (where each train will have a distinct encoding key) is superior from safety, security and availability to the GSM application. It is expected (and will be proven during the exploitation phase) that also the LCC of this solution is inferior to the GSM-R.
The tests already performed (when the on-board in laboratory of the Wels OOH has been connected via VPN with the TCC in the laboratory of INVENSYS U.K.) have shown no data latency and no unavailability challenges.
The use of IP standards, already available in any performing telecommunication system makes possible the "intelligent" adaptation of the application to large class of radio bearer (including the satellite telecommunication).

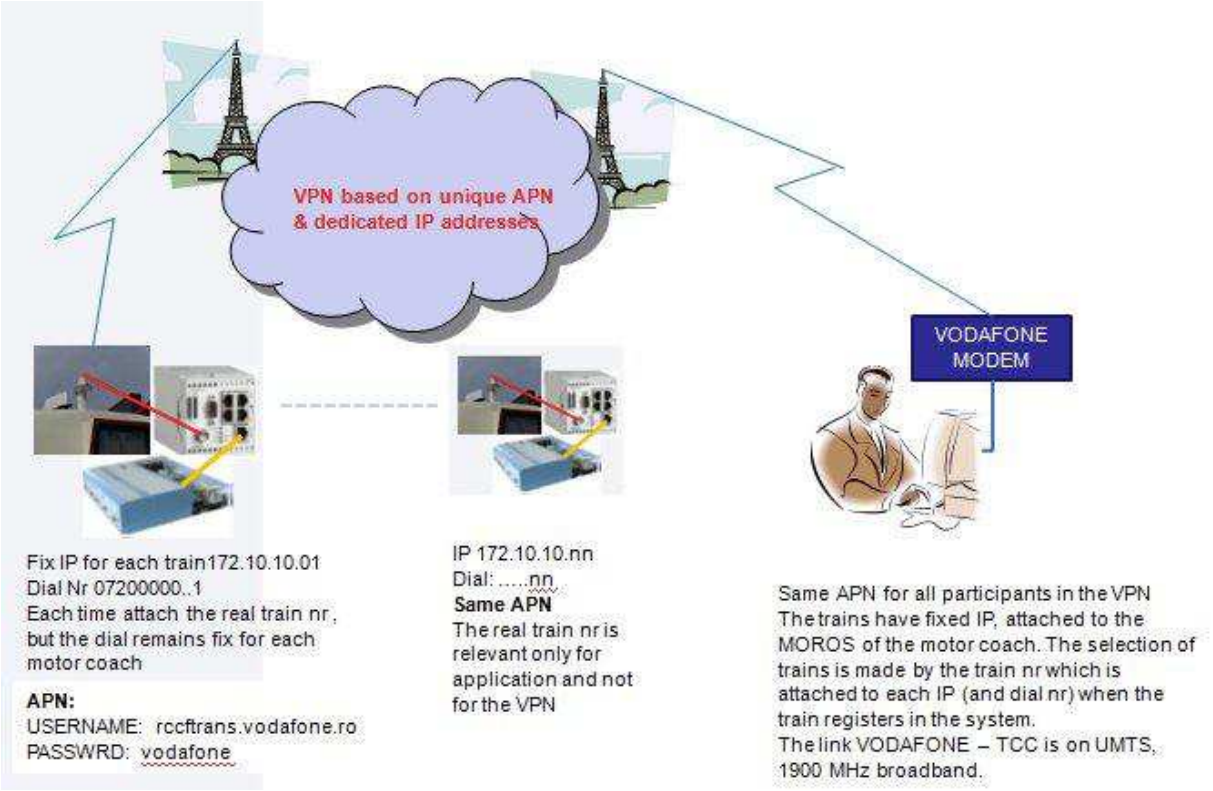

Fig. 6. VPN under UMTS bearer applied in front of the EURORADIO.

7. Laboratory and on site implementation and tests

The specification of laboratory tests is focused on demonstration of mock-up system functionality (including the key equipment and the application software):

- On board functions e.g. registration & deregistration of trains, receive and enforcement of MA where the "run" is simulated by reading the Route Map file with the "instant" speed of the train, functional display systems on the DMI and the TCC, other similar.

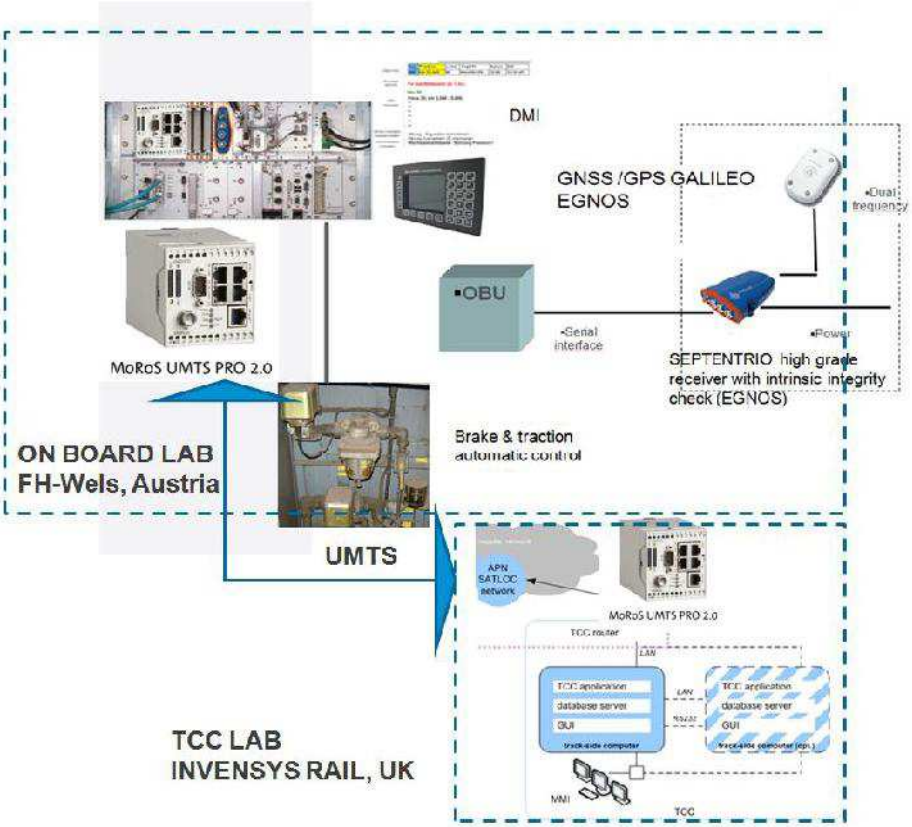

Fig. 7. Laboratory test arrangements

The laboratory tests did not target the demonstration of any "safety case" since the operational context is not available into the laboratory arrangement.

The successful accomplishment of laboratory tests has concluded on the following:

- The software components, although not perfect yet are suitable to be loaded on trains and Real TCC in Zarnesti > for tests with running trains
- The suggestions made by AFER Romanian Rail Safety Authority have been approved: they consist of implementing on the TCC display a ranked "detail" selection to support with more information the traffic management including some degraded modes.

Fig. 8. SATLOC train during the real scale tests

The real scale tests have started with the first cabled trains. During the first tests the TCC remains in the laboratory of the University of Wels and is connected with the train via an IP-VPN tunnelled channel provided by VODAFONE. The first tests made during the 25 – 28 June have shown the on-board functionality.

The TCC shift to the central control station in Zarnesti already enables to connect the trains and the TCC via the novel developed conception of safe data transmission independent of the radio carrier, based on VPN techniques supported by the public operators who cover the mobile communication on the line.
The detailed test scenarios are on-going. They are based on the consortium resolution adopted during the conclusions of the laboratory tests:

- To focus the field tests on the SATLOC system functionality and the proof of evidence that the GNSS train location is compliant with the train control and demonstrate that the close-loop interaction of the train and TCC enables the achievement a very high safety target in operational conditions.
- To demonstrate the viability of data transmission for the train control via the VPN tunneled and exclusive channel
- To create a test bed for proving the real achievable GNSS accuracy in the pilot line environment. The RFID balises which are installed in line shall serve as marks to synchronized evaluation of the fixes.

8. Conclusions and perspectives

Based on 15 years of experience and theoretical research of the UIC and of the SATLOC partners, the project started in January 2011 produces now good results.
This paper has described the project in the continuity of the past European projects. A few months before the end of the project, SATLOC has shown the feasibility of the system on a real railway line.
It is now expected that the functional, operational and technical tests will produce an important database to actually evaluate the achievement of the objectives and that SATLOC may produce a turnover in the overall mentality in favor of using the absolute positioning of trains with GNSS for primary safety, in the train control. Essential will be the use of the Route Map (with a tentative of standardization) and the concept of virtual balises. It could be also understood that the migration of ETCS and SATLOC will reach soon a meet-point where the absolute positioning of trains, the use of route maps sent via the MA's and the concept of virtual balises for interoperability will join the two systems.

Acknowledgements

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References

Albanese, A., Marradi, L., Campa, L., Orsola, B. (2004). The RUNE project: Navigation performance of GNSS-based railway user navigation equipment, *Proceedings of NAVITEC* 2004

Garcia Prieto, M.J., Gonzales Romero, O., Gutierrez Dominguez, R., Urech, A. (2004). Gaderos project field trials underway: a project is underway to apply global satellite navigation to safety-critical systems such as ERTMS and ETCS, *International Railway Journal*.

Marais,J., Berbineau, M., Frimat, O., Franckart, J.-P. (2003). A new satellite-based fail-safe train control and command for low density railway lines, *Technological Innovation for Land Transportation (TILT 2003)*, Lille, Déc. 2003.

UIC GPOE (2005). *GALILEO APPLICATIONS FOR RAIL Roadmap for implementation*, technical report (05 / 2005)

Urech, A., Garcia Prieto, M.J., Roberts, W. (2006). GRAIL, GNSS Introduction in the rail sector, *Proceedings of ENC* 2006, Manchester, UK.

Urech, A. (2008). *GRAIL Final Activity Report*, Dec. 2008, 46p. Public report available on http://www.grail-project.com/