SATLOC – GNSS based train protection for low traffic lines

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The SATLOC project, an EFP7 funded research project supported by the GSA (European GNSS Agency), aims to meet the rising demand for a cost-efficient train control system for low traffic density lines. The system utilises GNSS (Global Navigation Satellite System) based train localization, cab-signalling, as well as data radio communication inspired by ETCS level 3. The long-term goal of SATLOC is to promote the usage of GNSS as safe method for train navigation in the railway domain with a focus on low traffic lines. Due to the characteristics of those lines the project facilitates the use of commercial mobile carriers and packet-oriented communication instead of GSM-R. However in order to keep the system architecture open and flexible, the necessary ETCS-modes and Euroradio telegrams remain predominantly untouched. This paper presents the preliminary results of test-drives on the Romanian line between Braşov and Zărneşti.

1 Features of SATLOC

Using satellite-based navigation systems for safe train location on regional lines and low traffic lines is the long-term goal of SATLOC. Approximately 40 % of the European railway network may be categorised as such, while the worldwide rate is even higher. Hence, the demand for a low cost train control system based on GNSS location is significant. Furthermore, SATLOC aims to specify standards for such systems from the railway operators' perspective. Using GNSS as a main localization technology, it is possible to avoid cost-intensive, cable-bound, track-side signalling systems, as well as sensors for the determination of track occupancy. In order to properly replace this equipment and its features, autonomous train self-localization and permanent communication between track and train is required. For data transmission ETCS levels 2 and 3 specify the GSM-R based Euroradio. As such, railway infrastructures have to install and maintain expensive GSM-R equipment. Since SATLOC has a strong ETCS background, but focuses on low traffic lines, to ETCS comparable but from ETCS adopted operational procedures and adapted technical solutions, which are feasible for those lines, have to be used. Therefore the used communication system has to meet an appropriate level of service and availability. Consequently, SATLOC utilises public mobile networks and packet oriented data transmission.

Within SATLOC, GNSS-based train location is enhanced with low-cost position sensors and adapted algorithms, which allow a train's location to be determined even if GNSS is not available for a certain timespan. SATLOC aims at a high level of safety with a THR (Tolerable Hazard Rate) comparable to ETCS (THR 10^{-7}/h). A special algorithm is being developed and tested which enables the TCC (Traffic Control Center) and the OBU (On Board Unit) to mutually supervise the state of the OBU. This "control loop" monitors the safe state of the train based on adapted time restrictions in accordance with operational requirements. If the TCC recognises unacceptable train speeds it sends an emergency stop. This system design allows for the use of low cost system components with lower safety integrity levels (SIL), which in turn lead to reduced system expenses.

2 System architecture

As mentioned above the SATLOC system is based on autonomous train self-localization using GNSS, an odometer and low cost RFID tags as balises after the switches to determine the track-selective location of a train, which is reported to the TCC. The communication between TCC and OBUs is realised via the combination of mobile carriers and packet-switched data transport, while the actual message format is taken from the ETCS specification. The basic elements of SATLOC and their principal functionality are depicted in figure 1. A digital route map is used within the TCC and the OBU and is an important reference document for the determination of the trains' GNSS location.

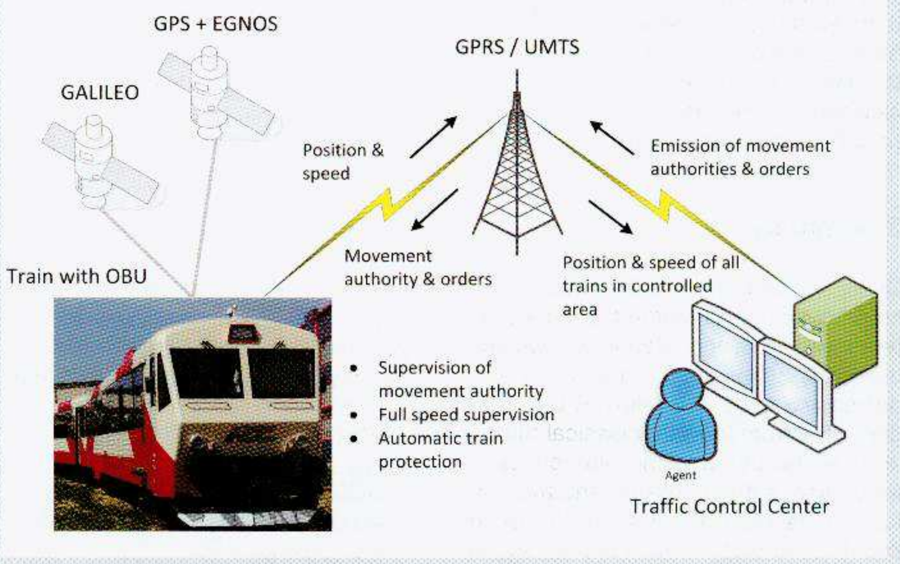

Figure 1: SATLOC – Overview

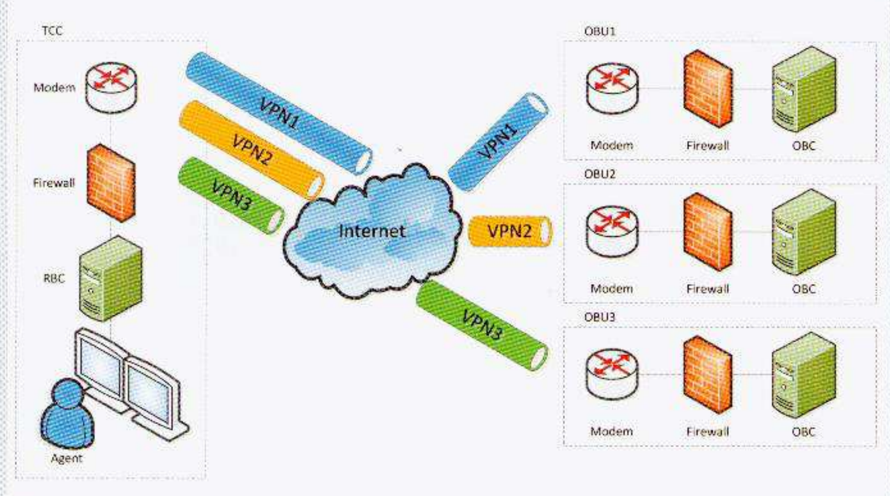

Figure 2: Architecture of the communication system

2.1 Characteristics of the test track

The Romanian single track regional line between Braşov and Zărneşti, which branches in Bartolomeu from the CFR-line Braşov – Sibiu, is used to test the SATLOC equipment. It is operated by the privately owned RCCF-TRANS and has two intermediate crossing stations, one at Cristian and the other at Râşnov. The line is equipped with mechanical interlockings and electromechanical block checks controlled by an ATP system (Indusi) for train protection. According to the actual time table, 15 train drives are scheduled per day and per direction. These trains serve 9 stops along the route in a one-hour interval. The terrain is generally rather flat and there are more or less no high buildings or trees along the line. Thus satellite visibility (GPS as well as EGNOS satellite PRN 126) is good, making this line ideal for GNSS applications. The communication network is provided by Vodafone Romania with a 2G and 3G service along the whole line. During the SATLOC project spring switches are installed at the intermediate crossing stations.

2.2 Communication system

Within ETCS (level 2 and 3) the track – train communication is realised via Euroradio with GSM-R and a circuit-switched communication architecture. All lines and all trains using ETCS level 2 have to be equipped with GSM-R. Due to economic restrictions of regional lines the operational and technical features of SATLOC have to be adapted in a suitable manner. In consequence SATLOC uses public mobile carriers and a packet-switched communication architecture.

2.3 On board equipment

The Siemens system Trainguard STC [2], [3] has been used as a basis for the OBU. It consists of an On Board Computer (OBC), a Driver Machine Interface (DMI) for cab signalling, location sensors, a cellular modem and an interface to the train's emergency brake. The functionality of all of these components is analogous to the appropriate elements of ETCS. The OBC is responsible for (1) the track-selective train self-localization using GNSS, EGNOS, an odometer and the already mentioned balises, (2) the communication with the TCC, and (3) the supervision of the movement authorities and the actual train movement. To meet the requirements of SATLOC, the adaptations to Trainguard STC mainly focus on the communication system, since previously it had been implemented as a proprietary system.

2.4 Train Control Center

The Invensys (now Siemens Invensys) ETCS Radio Block Center (RBC) is the basis for the SATLOC TCC. The RBC has been adapted to meet the SATLOC specific needs. The train dispatcher is capable of observing all train movements and can send movement authorities to the trains, which are supervised by the TCC. Shunting authorities and shunting areas may be defined, too.

3 ETCS communication with packet oriented connection

The intermediate results of the UNISIG working group dealing with the use of GPRS for ETCS [1] were used as a basis for the specification of the communication protocol. Since mobile broadband technologies like GPRS, HSPA and LTE are packet-switched an IP-based network protocol is suitable for the data communication link track.

3.1 Design

Cellular modems which have a dual SIM option have been installed at the TCC and on each train. Up to now only one mobile carrier (one SIM card) has been used, but in order to improve the availability of the data communication two independent carriers via separate SIM cards can be used. In accordance with the recommendations in [1] TCP/IP is used due to its connection oriented and packet-based features. The data link is considered as an open network according to the definitions of EN 50159. To improve the security of the communication a virtual private network (VPN) is established between each train and the TCC. The VPN encrypts the data transfer between the train and the TCC. As the technology used for the radio interface is not specified, the train – track communication can be improved by the usage of future mobile broadband technologies, especially in the domain of encryption and security.

3.2 Layers of communication

The architecture of the ETCS communication system is organised in separate hierarchical layers according to the recommendations of the OSI 7-Layer Modell. Figure 5 shows the aforementioned ETCS layers. Due to the switch from the circuit-switched communication model of Euroradio to the packet-switched TCP/IP, it was necessary to replace the ETCS transport layer with a combination of an appropriate wrapper layer and TCP/IP [1]. The wrapper layer is the interface between the TCP/IP protocol and the original ETCS layers. Its task is to encapsulate TCP/IP mechanisms in such a way that the unchanged use of the ETCS safety and application layer is ensured. Using this approach, the content and the structure of the ETCS messages, the ETCS authentication, with its generated session keys, as well as the use of CBC-MAC remains completely untouched.

The required changes in the TCC and the OBC are accordingly: As described in [1] an additional methodology for packet-switched communication has been added to the RBC of Invensys. As the previous OBC [3] was not conform with ETCS specifications concerning the message exchange, a so called ETCS translator is incorporated to act as an interface between the ETCS application layer and the original OBC application. This ETCS translator adapts the different data structures and minor differences in the sequences between ETCS and [3] in both directions. Using this architecture, the different layers can communicate with each other and in consequence enable communication between OBU and TCC.

3.3 Connection and disconnection of the communication link

According to the ETCS specifications the communication link is established when the driver enters the train data. Connecting means initializing the socket communication and establishing the logical link between OBU and TCC. The address of the TCC (IP-address or logical name) is specified within the configuration file of the OBU. The disconnection takes place after the train has deregistered from the TCC. The steps for setting up a connection and disconnecting are depicted in Figure 4.

3.4 Interruption of the communication link

Any communication link, whether by radio or cable, and independent of who is responsible for it, may be interrupted at any time. The probability of radio communication interruption is higher when relying on mobile carriers. Consequently appropriate service and quality levels for the concerned components have to be defined, which in turn have to meet the needs of low traffic lines. As mentioned in chapter 3.1, the availability of the communication link can be improved by using independent mobile carriers. Nevertheless all operational and technical sequences must be able to deal with the scenario of an interrupted communication link. The following example illustrates this. A train, which has a valid movement authority, must be able to execute its movement even if the communication link is interrupted. The valid movement authority also has to be maintained after the link is re-established. Once the OBU detects the loss of the link it is responsible for re-establishing the connection to the TCC.

Since SATLOC uses packet-oriented communication over TCP/IP, continuous supervision of the activity of the links is required. Possible variations for this supervision are mentioned in [1]: using the TCP-options "Keep Alive" or the specification of a "User Timeout". [1] also lists an appropriate implementation within the

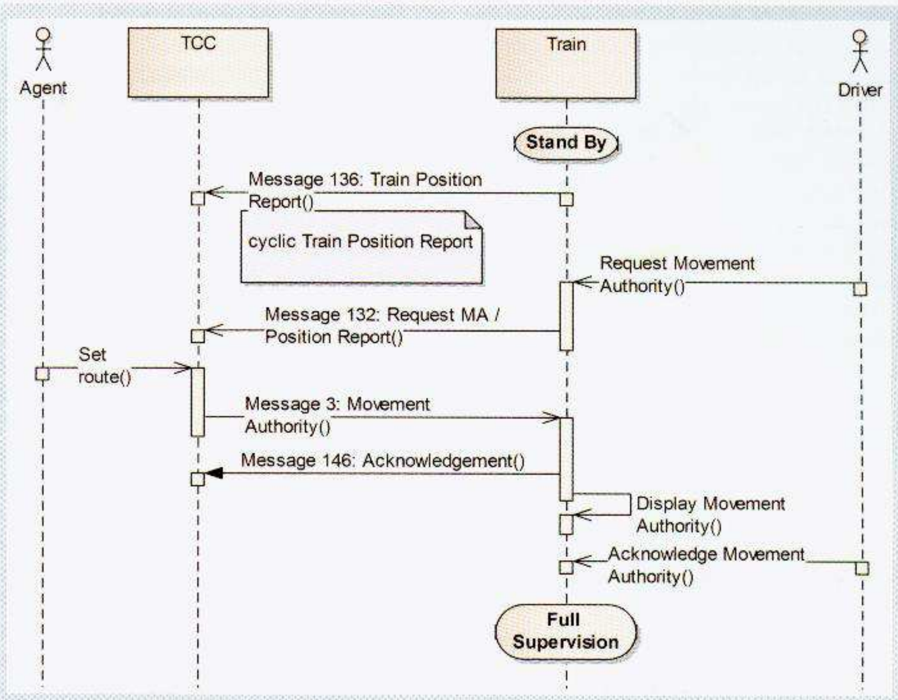

Figure 3: Sequence for requesting of a movement authority by the train driver

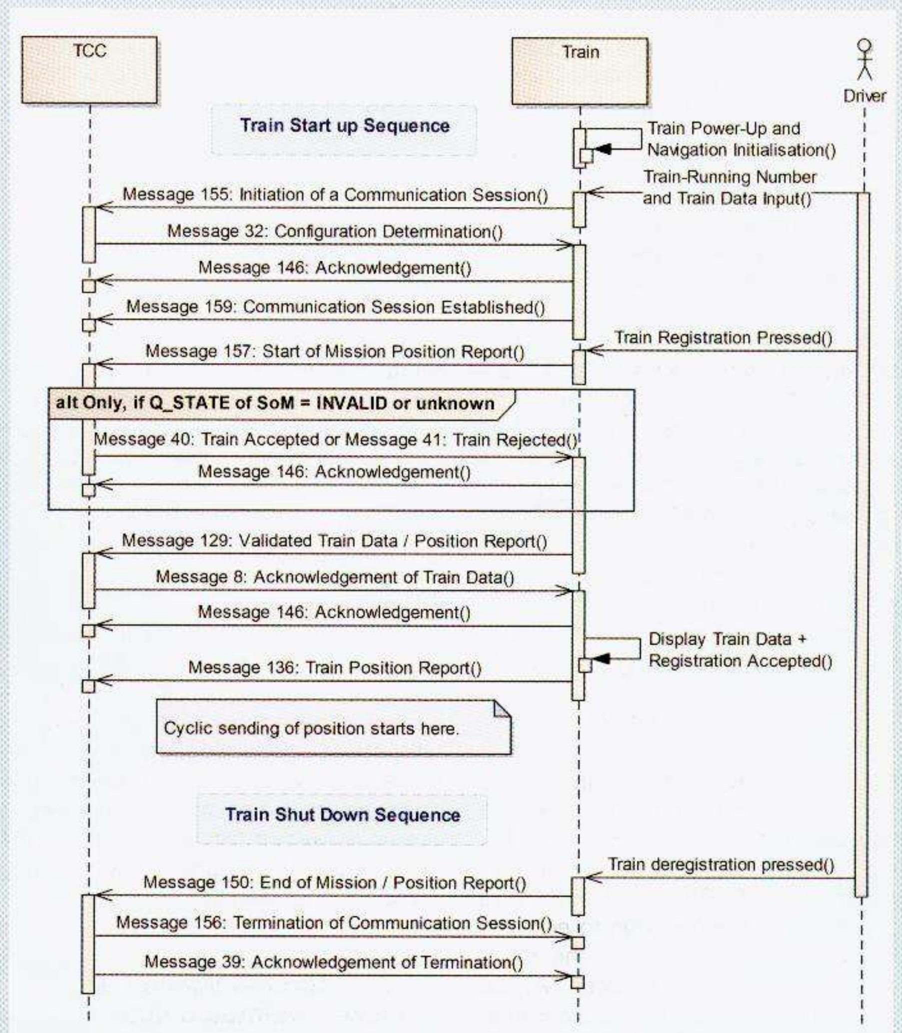

Figure 4: Sequence of registration and deregistration of a train

wrapper layer as a further option. The two former possibilities have the advantages of being configuration parameters of the TCP stack. Unfortunately, they are operating system dependent. A standardised sequence within the wrapper layer would allow enhanced operations, such as the supervision of jitter and delay, in addition to the basic feature of supervising the consistency of the link.

The supervision of the communication link within SATLOC is based on two features: (1) The TCC sends a cyclic control message to each train. (2) The trains send their position messages to the TCC every n seconds. Detecting lost telegrams is a straight forward operation. If the link is interrupted the safety and the transport layer are disconnected and re-established. Hence, according to the SRS of ETCS the application layer remains unchanged.

4 Operational sequences

As SATLOC is designated for low traffic lines and regional lines with simplified operational procedures, only a subset of ETCS modes (Stand By, Staff Responsible, Full Supervision, Shunting, Trip, Post Trip and System Failure) and a subset of ETCS messages are implemented. This subset enables movement and shunting authorisations to be issued and monitored, to handle relevant operational procedures, such as train crossing and shunting. Shunting mode has been implemented slightly different to ETCS because in SATLOC train movements are reported to the TCC even in shunting mode. Therefore the OBU and the TCC may supervise the train movements and the dispatcher can see the train movements. The motivation for this difference to ETCS is that those lines typically lack interlockings with automatic track-clear detection. In this case, it seems to be an important operational advantage to have this additional feature, which might be added to future revision of ETCS.

Figure 3 depicts the sequence of a train drivers request for a movement authority and the concerned messages between OBU and TCC.

Table 1 gives a brief overview of the differences between ETCS and SATLOC.

5 Test experiences

In the second half of 2013 several test drives took place during regular operation. The first results showed good GNSS reception, reliable train location and good repeatable accuracy using GNSS in combination with the additional sensors mentioned herein. The speed and position of the train were also monitored during these test drives. Further test drives will take place in the first half of 2014 to optimise sensors and the use of EGNOS.

During these drives, permanent communication links between the trains and the TCC were established. Noticeable interruptions of the communication did not occur. Due to the periodic position messages from the trains, the train dispatcher could follow any train movement in detail. The delay of the messages due to the delay of radio communication was less than 200 ms. Compared to the defined latency of ETCS which specifies a maximum delay of 500 ms for the transmission of a 30 Byte data telegram (99 %) this value of 200 ms shows a very reliable communication.

The test also proved that the different parts of the system (OBU, TCC) could communicate via packet-switched ETCS messages. This could be observed by the issuance and execution

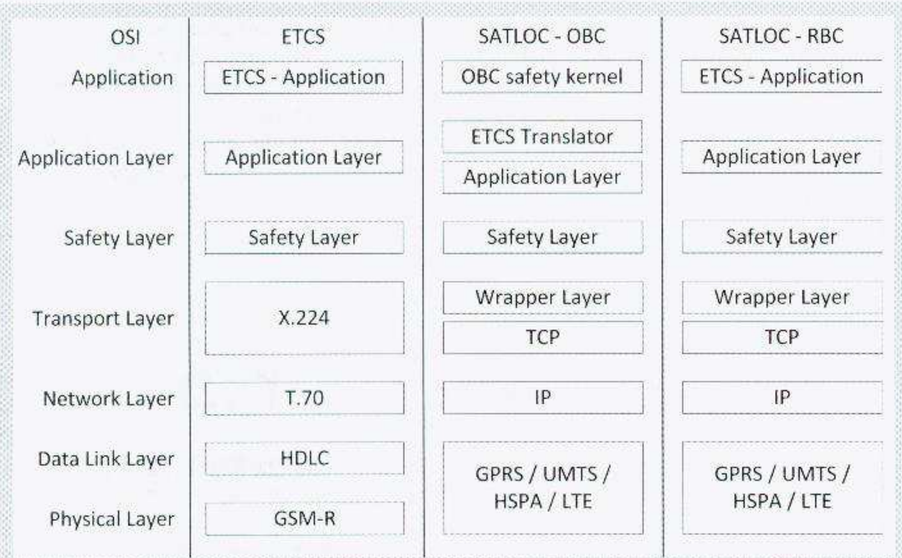

Figure 5: Comparison of the communication layers between ETCS and SATLOC on the basis of [1]

	ETCS	SATLOC
Registration / Deregistration	The train starts with unknown position until the first balise has been passed	The train knows its position immediately after the system start
Emission of movement authorities	Variable end of movement authorities based on a balise and a distance after the balise	End of movement is based on the balise and the distance too, but it is at a predefined position within the route map
Emergency stop	Similar sequence for ETCS and SATLOC	
Speed supervision	Continuous; ETCS-braking curves; Service brake and Emergency brake as required	Continuous and punctual; Simplified braking curves; Emergency brake and / or warning to the driver
Shunting mode	Shunting area may be supervised by the OBU if balises are stated by the RBC; Interlocking with safety features for track surveillance	Supervision of the shunting area by the OBU; train dispatcher can see the movement of the train during shunting; no interlocking

Table 1: Differences of ETCS and SATLOC

of movement authorities in full supervision mode. Up to now, it has been possible to perform the most relevant operational procedures using the SATLOC system.

6 Outlook

The next steps of the SATLOC project will deal with the enhanced analysis and optimisation of the GNSS location, including the integration of EGNOS data and the optimisation of certain procedural details of the operating modes. At the projects' end, the expected results will be that the utilisation of GNSS based localization including EGNOS data will be a good foundation for a low-cost train control system designed for low traffic lines.

LITERATURE

[1] UNISIG: Protocol Stack main Alternative 1 ETCS over GPRS (v3). UNISIG, 2012
[2] http://m.siemens.at/at/innovationen/innovation-stories/satloc.htm
[3] Stadlmann, B.; Kaiser, F.; Mairhofer, S.: Rechnergestütztes Zugleitsystem für die Pinzgauer Lokalbahn, Signal+Draht 05/2012, p. 28 ff.

ZUSAMMENFASSUNG

SATLOC – GNSS gestützte Zugsicherung für Strecken mit niedriger Verkehrsdichte

Im Rahmen des EFP7 beschäftigt sich das Forschungsprojekt SATLOC unter der Leitung der UIC mit der Fragestellung, wie ein kosteneffizientes Zugsicherungssystem für Bahnen mit geringem Verkehrsaufkommen realisiert werden kann. Das System setzt auf eine Zugausrüstung bestehend aus GNSS (Global Navigation Satellite System) gestützter Fahrzeugortung, Führerstandssignalisierung sowie an ETCS Level 3 angelehnte Datenkommunikation mit einem angepassten ETCS Radio Block Center (RBC) und paketorientierter Datenübertragung. Dieser Artikel beschreibt die gewählte Systemarchitektur sowie erste Erkenntnisse des noch laufenden Projektes entlang der Teststrecke zwischen Braşov und Zărneşti in Rumänien.

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