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CEIT's Multi-connectivity Platform Development

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Introduction

During a typical journey, a train continuously exchanges information with the trackside infrastructure in order to meet some safety requirements. Along the last years, these requirements have been evolving to support the increasing number of trains and daily journeys. This evolution can be translated into more stringent signaling and control requirements that demand higher data reliability and data availability. Thus, more data to exchange per unit of time.

Nowadays, voice communication between trains and controllers, railway emergency calls, and Automatic Train Protection (ATP) data transfer [1] are some of the applications that most illustrate how train-trackside communications are essential for the proper functioning of a train trip. Application counterparts that aren't in the same location must exchange data and voice information, emerging the need to incorporate a communication system into the infrastructure, particularly a wireless system from which the train can establish a connection with the trackside infrastructure.

For a long time, the most popular of these communication systems has been Global System for Mobile Communications - Railways (GSM-R) [2]. The success of GSM-R, over a couple of decades, relies on its integration with the European Rail Traffic Management System (ERTMS) [3]. being GSM-R the communication system which performs the functions of the control and signaling system.

While different technologies such as cellular technologies are constantly evolving giving more and more capabilities to the final users, railway communications are stacked in GSM-R. As GSM-R is a technology based on GSM, is becoming obsolete being its end of its lifecycle 2030 [4], [5]. Beyond this point, maintaining the same level of service quality for infrastructure managers will become progressively challenging and costly. Then, the adoption of new communication technologies, systems and standards is required.

In this context, the International Union of Railways (UIC) is working on the definition of the Future Railway Mobile Communication System (FRMCS) in cooperation with the different stakeholders from the rail sector. The main targets of FRMCS are to be the successor of GSM-R and contribute to the digitalization of railway communications. For that goal, FRMCS is divided into several working groups aiming to deliver a set of specifications for the sector [6].The principal FRMCS directives alongside the wide range of scenarios, in which services are desired to be provided, are being covered by different research projects such as 5GRAIL [7], 5GMED [8], X2RAIL-5 [9], or Europe's Rail FP2 R2DATO [10] to name a few.

In this regard, this abstract aims to provide a quick overview of the state of train-trackside communication systems and to contextualize CEIT's work in this area as part of Europe's Rail FP2-R2DATO project.

FRMCS and related research projects

In this section, a brief description of FRMCS is provided together with the main highlights of previous and current related research projects: 5GRAIL, 5GMED, X2RAIL-5, R2DATO.

FRMCS

As stated in the previous section, FRMCS has been designed by UIC as the evolution of communication system for the future of the railways with two main goals: on one hand, finding a successor to GSM-R due to its obsolescence and, on the other hand, enabling and supporting the digitalization of the railways, providing services such as the transmission and reception of increasing volumes of data.

As part of the European strategy to promote the use of trains over other modes of transportation, such as short flights, FRMCS is committed to enhancing the safety and comfort of travelers by employing applications of three use categories [11]: (i) critical services to oversee and supervise train operations and ensure safety (incorporating mission-critical applications, not just those currently supported by GSM-R), (ii) performance services to enhance the efficiency of railway operations and (iii) business services enhance passenger comfort. Therefore, it is necessary to have a communication system in which applications of different levels of criticality coexist, each with an appropriate QoS.

FRMCS proposes a 5G dedicated network with an MCx server responsible for managing QoS. There are two main ways to access FRMCS services [12]: a Direct access mode, which essentially means access by a handheld device enabled to that in which the application is embedded, and the Gateway access mode, in which an application can access the FRMCS services through an On-Board/Trackside FRMCS gateway. The application communicates with the On-Board/Trackside FRMCS gateway via a local onboard/trackside transport network and the On-Board device manages the radio access and is responsible for supporting communication services for the On-board applications.

The design of these gateways, particularly the On-Board gateway, has received special attention in several research projects, as shown in the following subsections.

5GRAIL

The primary goal of 5GRAIL is to validate the first set of FRMCS specifications, referred to as FRMCS V1, through the developing and testing of prototypes within the FRMCS ecosystem [13]. The project establishes functional tests and then proceed with the development and assessment of prototypes. This includes prototypes for both trackside infrastructure and on-board systems and it is planned to use applications like ETCS, ATO, voice services, and TMCS.

5GRAIL seeks to decrease the costs associated with specific equipment and reduce the time required for installation engineering in the On-Board system. The project attempts to unify all train-trackside communications following the so-called Telecom On-Board Architecture (TOBA) [14].

This project followed a dedicated network model, mainly using a 5G standalone (5GSA) network for communications. The On-Board gateway is connected to different RAN and allows the communication of On-Board applications with their pair in the Trackside. This network follows and architecture shown in Figure 1, which is a simplification of the test scenario presented in [15].

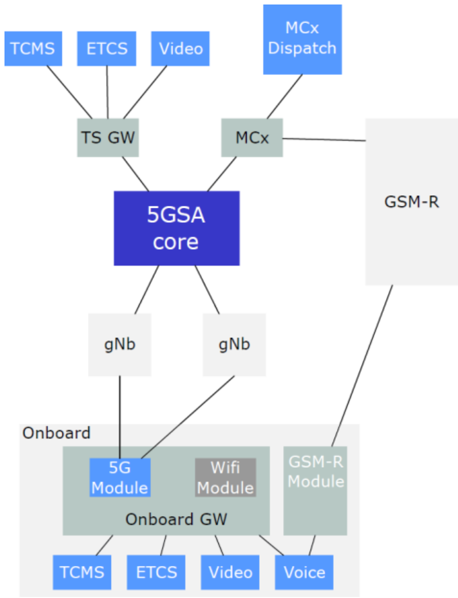

Figure 1: 5GRAIL lab test network configuration [15]

5GMED

The 5GMED project uses the line between Figueras and Perpignan, in the Mediterranean corridor, which includes a cross border between Spain and France to join different actors of the railway sectors as Mobile Network Operators (MNOs), road and rail operators, and telecom neutral hosts to develop a communication system for non-critical applications and artificial intelligent functions [16].

The 5GMED project leverages the proximity of the E-15 European route and the high-speed rail track within the selected cross-border section. In this scenario, the 5GMED Consortium attempts to showcase the potential of a proposal based on a multi-stakeholder 5G infrastructure featuring a variety of radio technologies, as shown in Figure 2 (a simplification of the 5GMED architecture presented [17]).

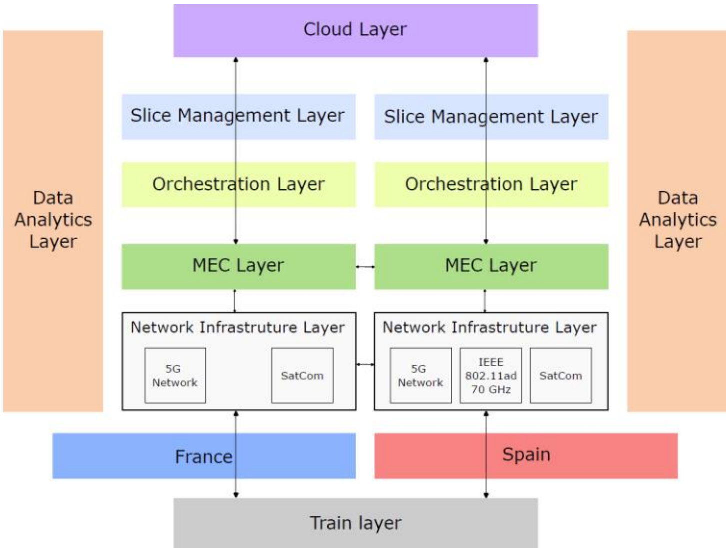

Figure 2: 5GMED Architecture [17]

This architecture shows the use, on both sides of a border, of a 5G Stand Alone (SA) network and Satellite connection. Also, when the train is in Spanish land other radio technology can be used: IEEE 802.11ad 70 GHz. In this multi-bearer approach (understand bearer as each radio interface from which the On-Board gateway can communicate the applications), different technologies, arranged by preference for each application, can be used to provide specific services considering the train's location along the rails [18].

X2RAIL-5

X2RAIL was developed inside the scope of Shift2Rail program, which was the first European rail initiative to seek focus on research and innovation [19] being its main goal to overcome the limitations of the existing communication system by adapting radio communication systems that establish the backbone for the next generation of advanced rail automation systems.

It is particularly of interest the research carried out in Work Package 3 where an Adaptable Communication System (ACS) was developed for all railways and the field test of prototypes and different demonstrators (for highspeed/ mainline, urban/suburban, and regional/freight lines). ACS is aligned with FRMCS in several aspects and aims to investigate various business models, considering both dedicated and public networks. In that line, ACS intends to be a bearer agnostic approach capable of performing the decoupling of digital applications from the communication system, to take advantage of different wireless technologies [20].

Figure 3 (which is a reproduction from [20]) describes ACS through its components. It is important to highlight two points: on the one hand, despite not being illustrated in the figure for simplicity, the same functions of the Trackside are present in the On-Board system and on the other hand, the bearers showed are examples and the system is not bound to those or even limited in number.

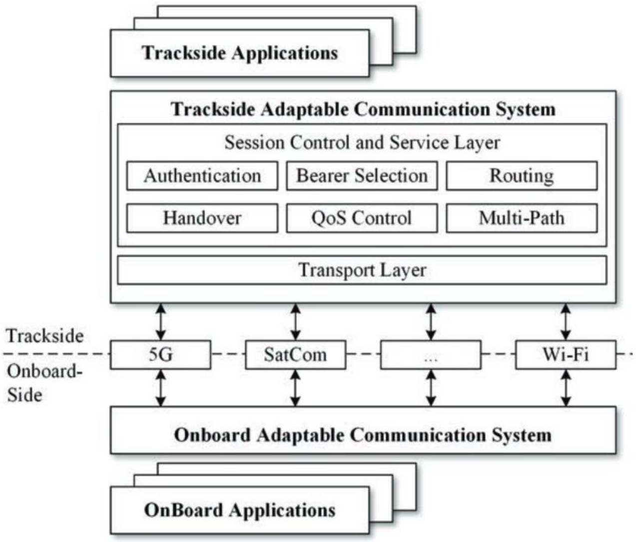

Figure 3: Adaptable Communication System Block Diagram [20]

Europe's Rail FP2-R2DATO

The vision of Europe's Rail is to create a high-capacity, flexible, multi-modal, and reliable European railway network through an integrated system approach. This will be achieved by removing interoperability barriers and offering solutions for full integration, benefiting both European citizens and cargo [21]. Europe's Rail counts with a list of flagship projects, among them the R2DATO project with the goal of using the digitalisation and automation of rail operations to develop the next generation of ATC and implement scalable automation in train operations, aiming to achieve GoA4 by 2030 [22].

CEIT’s Multi-connectivity Platform (MP)

Within the scope of Europe's Rail Flagship Project 2, CEIT is participating in the development of a prototype of the ACS/Multi-connectivity Platform for Regional Lines. This includes the architecture design, specification, prototyping, and testing of both, On-Board and Trackside gateways.

CEIT MP, unlike FRMCS, does not use only a dedicated network, instead seeks to use combinations of public and private networks with the applications being agnostic to the bearers employed. Following this multi-bearer approach, it aims to integrate features of FRMCS, such as the interface of the gateways for applications, to have information about the different applications and control their access to the system, and the capacity to serve applications with critical and non-critical uses.

Figure 4 shows a diagram of CEIT MP system concept. It can be highlighted that CEIT’s MP consists of the following:

- An On-Board MP with its Trackside MP counterpart. A single Trackside MP can handle more than one On-Board MPs.
- The connection between On-Board MP and Trackside MP shall be performed through four different bearers: IEEE 802.11ad 70 GHz, a private network (in case of having different interfaces for communication at the front and rear of the train, this technology would have two bearers), two fifth-generation public networks from different operators, and SATCOM.
- The applications considered are ATO and ETCS on the On-Board and Trackside and, WiFi for passengers On-Board which does not need to connect to the trackside pair, so the traffic should be redirected to the Internet without needing to be processed in the Trackside gateway.
- An Operation Management and Control Subsystem (OMC) from which an administrator can manage configurations, visualize performance indicators, and track and solve errors.
- The tests are foreseen at different levels from laboratory to on-site. At the first level at CEIT laboratory, tools such as SATCOM emulator are planned to be used. Then the integration with other systems in the locations is also foreseen, where real equipment for ATO and ETCS applications and for the bearers (IEEE 802.11ad 70 GHz, MNO_1 (4G/5G), MNO_2 (4G/5G) and SATCOM) is planned to be used. Finally, field tests are foreseen.

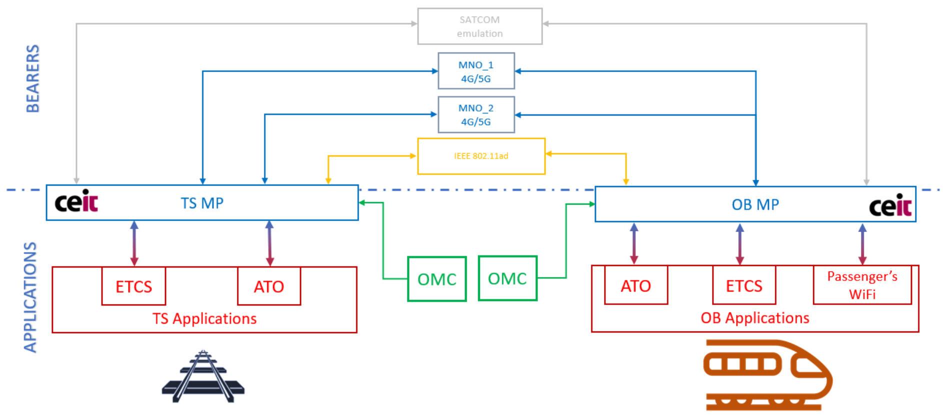

Figure 4: CEIT Multi-connectivity platform diagram

Conclusions and Future Work

In a context where the railway industry is expanding to new applications and requiring greater sensor coverage, which demands greater capacity of data transmission, a traditional communication system like GSM-R is facing the obsolescence . In consequence, research efforts have been put into the development of new systems for train-trackside communications. In particular in the design of a network where non-critical and critical applications can coexist and the development of the gateways needed to the access of the applications to the network services. Different approaches have been taken to address these issues considering, to a certain extent, the FRMCS directives.

The most noticeable difference among the approaches lies in the network models, in terms of ownership of the network. FRMCS and the system implemented in 5GRAIL are in line with using a dedicated private network under Infrastructure Manager control and ownership. This provides greater flexibility, as the design can be adapted to operational requirements. Less flexible but more economical options can be found in 5GMED, where the radio access networks of mobile network operators and SATCOM are used, and in the cases of X2RAIL's ACS and CEIT MP, which seek a system that can adapt to and use any type of network.

As part of the FP2-R2DATO Work Package 28, CEIT is developing a pair of On-Board and Trackside gateways. The central idea of the CEIT proposal is aligned with the ACS principles of bearer agnosticism, using a set of radio bearers and a set of applications for which the communication system should be transparent. After the design step, the prototyping of the CEIT MP system and performance test will be carried out.

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