Experimental Trials for the Future Railway Mobile Communication System in 5GRail Project

Sébastien Tardif
Research&Development
Kontron Transportation
Montigny-le-Bretonneux, France
sebastien.tardif@kontron.com

Nazih Salhab
Infrastructure Engineering
SNCF-Réseau
La Plaine Saint-Denis, France
orcid.org/0000-0002-0654-424X

Vassiliki Nikolopoulou
Railway System Departement
UIC (International Union of Railways)
Paris, France
nikolopoulou@uic.org

Michael Kloecker
E2E Solution Management for Railway
Nokia Solutions and Networks
Munich, Germany
Michael.Kloecker@nokia.com

Bernd Holfeld
Digital Rail Germany
DB Netz AG
Berlin, Germany
bernd.holfeld@deutschebahn.com

Farid Bazizi
Research&Development
Kontron Transportation
Montigny-le-Bretonneux, France
farid.bazizi@kontron.com

Dan Mandoc
Railway System Departement
UIC (International Union of Railways)
Paris, France
mandoc@uic.org

Marion Berbineau
COSYS
Université Gustave Eiffel, IFSTTAR
Marne-la-Vallée, France
marion.berbineau@univ-eiffel.fr

Stefanos Gogos
Technical Affairs Unit
UNIFE
Brussels, Belgium
Stefanos.GOGOS@unife.org

***Abstract*— 5GRAIL is an EU Horizon 2020 project and part of the funding call on 5G for Connected and Automated Mobility. The project aims at designing and testing the first prototypes of the Future Railways Mobile Communication System (FRMCS) which will become the worldwide standard for railway operational communications [1]. This paper aims at describing the lab environment that has been set-up for 5GRAIL, with a focus on the activities of the French partners as part of Work Package 4 and the kind of tests they have been committed to. Then, activities of Work Package 5 in scope of field tests to be performed in France will be discussed and illustrated with details on the operations led by the railway operator SNCF.**

Keywords—GSM-R, FRMCS, RMR, 5G, CAM, MCX, TOBA

I. INTRODUCTION

The current GSM-R system is more than 20-years-old success story as it achieved a lot for the railway sector: by providing reliable voice and data services, that proved to be most effective for safety and train operations, it nowadays clearly appears as an essential part of any railway operator infrastructure. Yet, knowing the foreseen needs from the considered next generation railway applications and considering that 2G-based connectivity will face obsolescence issues in a near future, it is well understood that GSM-R must give way to a new system. The successor technology, known as Future Railways Mobile Communication System (FRMCS), will not only bring the 5G technology and its interesting assets and features, but also a new architecture that will provide a welcome flexibility in the whole ecosystem.

Indeed, one important topic is the introduction of the so-called FRMCS gateways in the end-to-end communication chain [2] [3]. First idea behind this is the decoupling between railway application devices and the telecommunication network. As shown in **Figure 1**, on-board and trackside applications must communicate with on-board [4] and trackside gateways (OBGW / TSGW respectively) that take

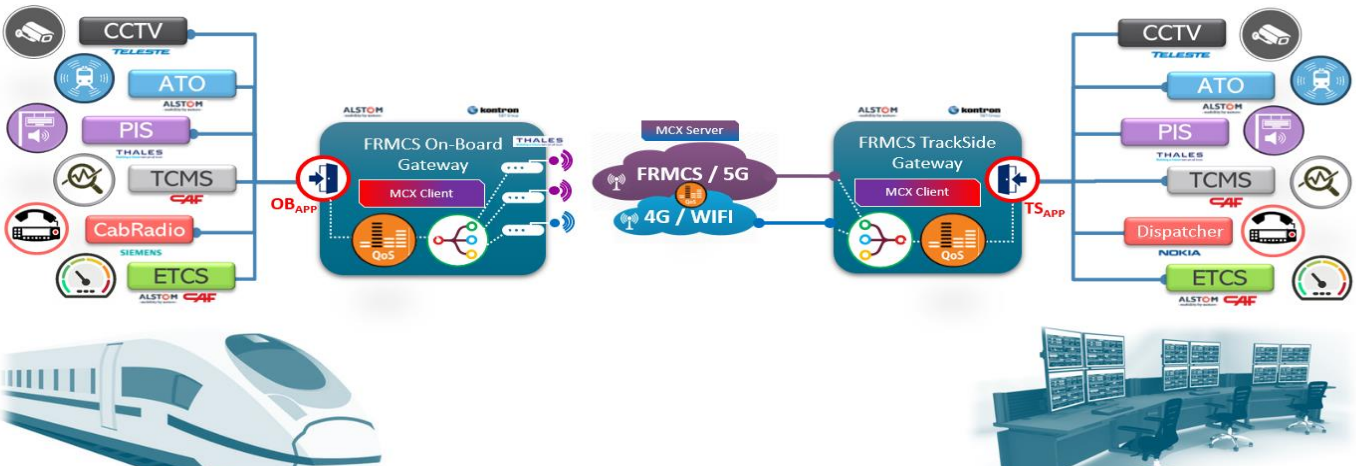

Figure 1: Integration of 5GRAIL test applications with FRMCS On-Board and Trackside Gateways

5GRAIL achieved first real experiments of Future Railway Mobile Communication System.

in charge the use of any needed telecommunication service. Communications between applications and FRMCS gateways are then achieved over standard interfaces called Onboard and Trackside application (OBapp and TSapp), ensuring this way that any newly created application can be easily inserted in the FRMCS system. A second idea is linked to the way the on-board and trackside applications will establish a communication path between them: in order to do so, an IP Multimedia System (IMS) network with a 3GPP Mission Critical Service (MCx) Application Server (AS) is added in the system, and railway applications simply have to use dedicated MCx clients in order to set-up a mission critical flow [5] [6]. Yet, the development of the MCx client software development is not necessarily part of railway application providers expertise and therefore the handling of MCx client inside FRMCS gateways is a significant and convenient option, called loose coupling mode. Other way of proceeding being MCx client merged with the application, also known as tight coupling mode.

It is then clear that the evolution from GSM-R to FRMCS is not just a simple change of mobile network generation but comes with a completely new system design with typical ways of proceeding. In order to concretely launch the race towards FRMCS, the EU-funded Horizon 2020 project 5GRAIL has been kicked-off as part of the 5G for Connected and Automated Mobility (CAM) funding call by end of 2020 [1]. Formed by a large consortium of railway operators, telecommunication industry players and universities, its main goals are to develop the very first FRMCS prototypes and ensure a verification of protocol specifications as well as their review and enrichment. So far 5GRAIL has executed the first end to end FRMCS test runs in laboratory, while field tests are expected to be performed in spring and summer 2023. This paper summarizes in the following sections the scope of work and the technical achievements of 5GRAIL work packages involved in the organization of the experiments that are conducted in France, knowing that some other experiments, only briefly detailed here, are also executed in Hungary and Germany.

II. 5GRAIL Lab Trials

A. *5GRAIL Work Packages involved in Lab Tests*

5GRAIL project is divided into several Work Packages (WP) in order to better organize the different activities among the consortium. Regarding laboratory tests, it has been decided that two Work Packages, WP3 and WP4, will be created:

WP3 has a strong focus on (but is not limited to) the integration of voice applications over FRMCS, being performed in Nokia's lab premises in Budapest, Hungary. Here, the following applications are tested:

- 5G/FRMCS-based MCPTT point-to-point and group voice communication realized by Siemens,
- 5G/FRMCS-based Railway Emergency Call (REC) realized by Siemens,
- European Train Control System (ETCS) realized by CAF,
- Train Control and Monitoring System (TCMS) realized by CAF,
- Non-critical video application and CCTV archive transfer realized by Teleste.

WP4 concentrates on railway data applications in Kontron's lab in Montigny-le-Bretonneux near Paris, France. Precisely, these data applications are tested:

- European Train Control System (ETCS) provided by Alstom,
- Automatic Train Operation (ATO) provided by Alstom,
- Passenger Information System (PIS) provided by Thales,
- Remote Vision (RV) provided by SNCF, and which aims at providing real time video from a camera installed in the front of the train engine.

ETCS, ATO and PIS applications, all OBapp and TSapp compliant, were designed and developed within WP2 whereas RV, which interacts with FRMCS Gateways as if they were IP routers, is a standard application only used in WP4 in with field tests de-risking purpose. WP2 is also responsible of providing FRMCS Gateways to WP3 and WP4, Kontron and Alstom delivering its own prototype [7]. To sum-up, the WP4 lab is the place to host all FRMCS applications and prototypes delivered by WP2, to integrate them in the whole system as shown on **Figure 2**:

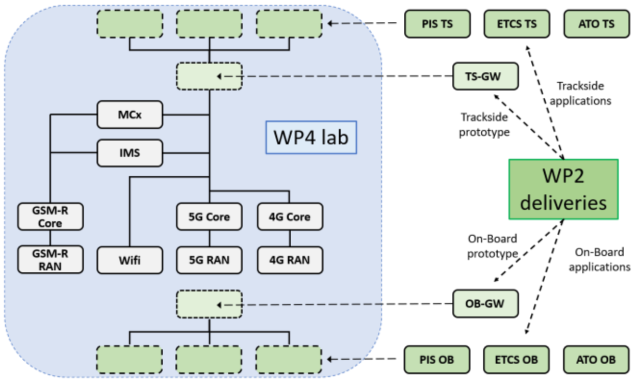

Figure 2: WP4 is the place for some WP2 FRMCS prototypes integration

These integration tests, but also more advanced ones, that will be discussed in part II.C, are given by a specific work package, WP1, lead by International Union of Railways (UIC).

B. *5GRAIL WP4 Lab set-up*

In order to fulfil its duty, WP4 had to set-up a multi-site lab thanks to the use of VPNs between the different partners:

- PIS On-board and Trackside applications were hosted in the office of Thales in Velizy and a VPN was setup with Kontron's lab in order to carry OBapp and TSapp traffic
- Alstom ATO and ETCS applications were installed directly in Kontron's office, in a dedicated rack also hosting Alstom FRMCS Gateways. VPNs were established with Alstom premises for engineer to remotely operate their devices.

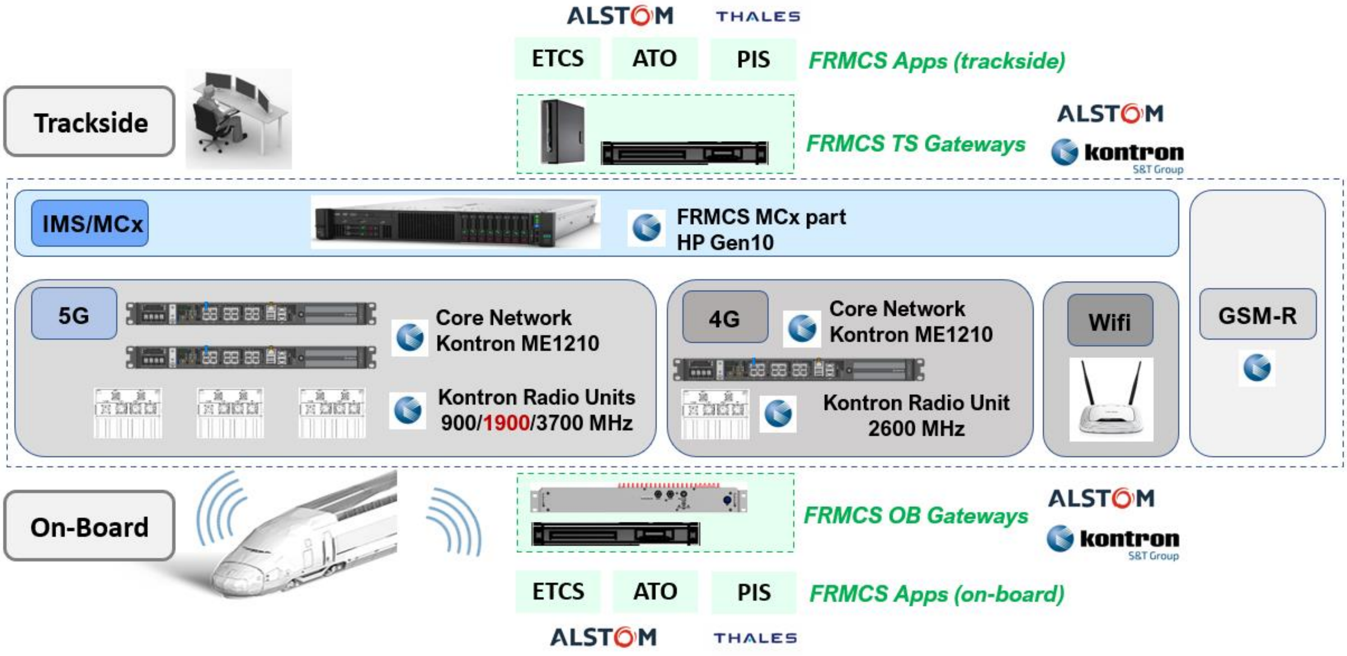

Figure 3: Schematic view of 5GRAIL WP4 lab

Kontron oversees providing telecommunication facilities needed for this FRMCS network:

- Two 5G SA networks, with especially several on-purpose designed 5G Radio Units (RU) operating in the N39 FRMCS band (1900 MHz). Other RUs in N8 and N78 were also used in the lab,
- An IMS part with a 3GPP MCx Application Server,
- A 4G network used in some test-cases related with bearer flexibility,
- A GSM-R network to interconnect with to consider some interworking scenarios.

Globally, WP4 lab looks like the schematic view shown on **Figure 3**.

C. 5GRAIL WP4 first achievements

<u>*First end to end FRMCS call*</u>

All the lab integration efforts lead to the very first FRMCS end to end call using ATO and FRMCS Gateways over 5G SA network, in March 2022. This was a major achievement quickly disseminated to the FRMCS community. Later, other FRMCS calls were performed on N39 band with ATO, PIS and ETCS applications.

<u>*QoS management and multi-path usage*</u>

Services brought by FRMCS can be linked with a specific QoS according to the needs of the connected applications. For instance, ETCS is a very critical application that demands priority over RV for instance. WP4 had no PCF function but QoS could be statically assigned using DSCP method. This enabled to check that critical flows could be protected, with a chosen 5QI, when concurrent less important flows exist.

Besides, FRMCS OB Gateways can handle multiple bearers at the same time. This enables for instance the ability to use one specific bearer with to priority, and a possible failover to another one. This kind of test was performed in WP4 with ETCS application, and a service continuity could be achieved.

<u>*Cross-border scenarios*</u>

There is a specific focus on cross-border scenarios in the 5GRAIL project as it is a well-known complex topic. Even if 5G SA roaming interfaces were not available in the products that were installed, we could consider many related tests cases. First step was to experiment the case where the train simply disconnect from a 5G network and reconnect to another one, with active Remote Vision application. That one uses a MCx client in OBGW that must manage the change of IP address when entering new 5G network: a new registration and communication re-establishment is needed.

Another way of doing can be seen on **Figure 4.**

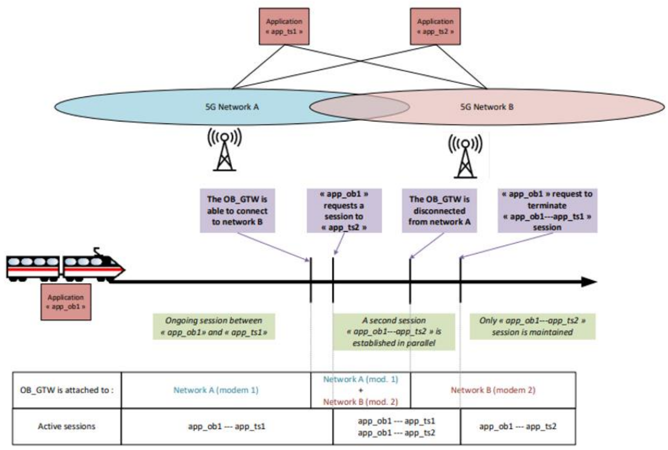

Figure 4: Cross-border test with two 5G modems in OBGW

In that case, two 5G modems are used and the FRMCS application can use any of them, according to the radio conditions.

Figure 5 : Test site in France in the scope of field tests (WP5)

<u>*Preparation activities for WP5 tests*</u>

5GRAIL includes a field test activity managed by WP5. In fact, WP5 is split into two parts: French tests with SNCF in Vigreux, near Paris, and German side, in Erzgebirge area, which uses a Deutsche Bahn dedicated test line. The objective of these first FRMCS field tests are underlined in section III. WP4 will move part of its network to support this activity and, meanwhile, is involved in a de-risking activity of what will happen on-site.
This is the reason why many tests have been done using a radio multi-path and fading emulator that helped us reproduce the speed effect and the Radio Frequency (RF) propagation conditions we can expect in the field tests (WP5).

III. 5GRAIL FIELD TRIALS

A. Motivation and Objective

The aim of the field tests is to provide realistic 5G railway field test environment to evaluate the prototype of the developed technical solutions as part of this innovative 5GRAIL project. The elaborated prototypes pre-validated in the laboratories as part of works executed in other work packages (WP2, WP3 and WP4) will be integrated into real railway environments, as well as rolling stock running on rail tracks with dedicated 5G radio coverage, which will allow evaluation of their functionalities and performances. This field test will demonstrate the usability of 5G to answer railways needs using railways applications and simulators. The testing will be performed in two test sites (France and Germany), each having different characteristics. Moreover, it will be conducted in parallel in the two sites with different scopes. Functional field tests will be executed with a focus on **voice services** in Germany and **data services** in France. Some similar end-to-end connectivity tests will be executed in both test sites to compare the results in different deployment conditions. In addition, some cross-border simulations will be executed with different and complementary scenarios in each of the two test sites. This will allow evaluating different configurations for cross border scenarios, which correspond to different choices of 5G frequencies and stages of GSM-R to 5G migration.
It is worthy to note that the works performed in the field work package (WP5) has a dependency on the laboratories' pre-validation (WP3 and WP4) and completion. Indeed, the lab validation of prototypes of WP3 and WP4 shall be finalized prior the prototypes could be used for integration in the field trial environment for test plan execution.

The supported use cases in the German field are as follows:

- 5G/FRMCS-based MCPTT voice communication covering point-to-point calls, group calls and railway emergency calls,
- 5G/FRMCS-based MC-Data communication covering ETCS, TCMS/telemetry as well as non-critical video transmissions and CCTV archive transfers,
- Cross-border simulation test with continuous service of a video application realized as transition between two 5G/FRMCS networks using two 5G cores,
- Bearer flex simulation test with transfer from one to another 5G/FRMCS bearer using the same 5G core by example of CCTV archive transfers.

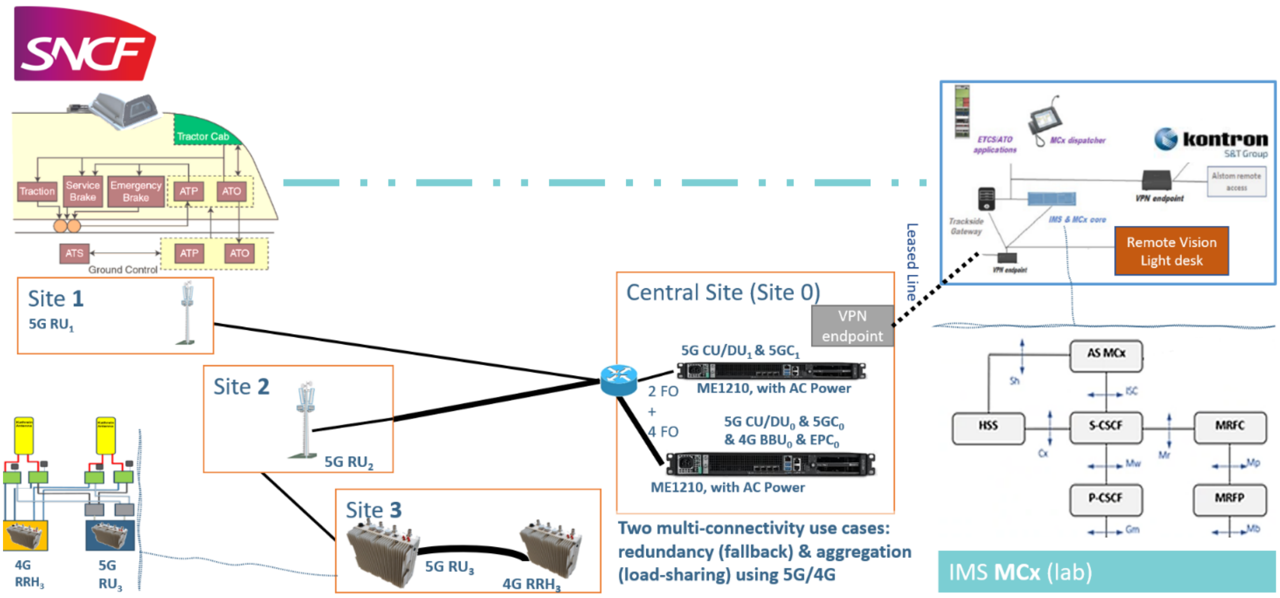

Figure 6: Field Test High-Level Architecture for the French field

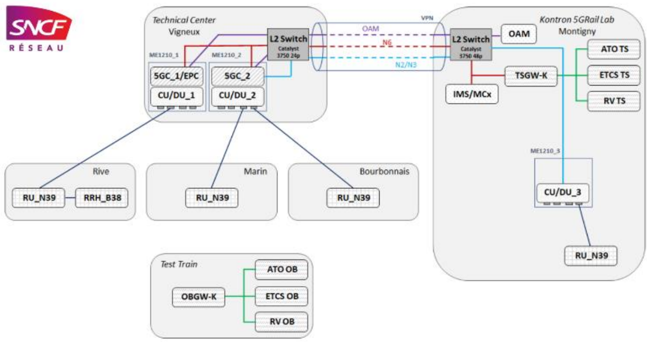

Figure 7: French Field Test Architecture with detailed signal flows

The supported use cases in the French field are as follows:

- European Train Control System (ETCS),
- Automatic Train Operation (ATO),
- Bearer flexibility 5G and 4G (links redundancy and links aggregation use cases) with ETCS,
- Train front camera real-time video (as for remote driving configuration); and
- Cross-border simulation test case using two 5G cores with Transition for the continuity of ETCS

B. Field Preparations at French Test Site

In France, (SNCF Test Site), the train runs will occur on a portion of commercial line in the suburb of Paris region. 5G RAN is to be deployed in 3 sites with possible reuse of existing GSM-R/GPRS installation.

The traffic from these three sites is concentrated in the "Command Centre" non-radio site. The train speed is up to 70 km/h. The antenna and masts shall be provided by SNCF, as depicted in **Figure 5**. The frequencies to be used are the Railway Mobile Radio (RMR) ones that is the 1900 MHz spectrum. B38 (2600 MHz) is another frequency band that will be used for the 4G RAN to test different use cases of the multi-connectivity (bearer-flexibility among 4G and 5G technologies).

C. Field Test Architecture at French Test Site

The 5G Radio Access Network (RAN) component, precisely, the radio, digital and Central Units (RU, CU/DU) in addition to the 4G Baseband Unit (BBU) and Remote Radio Head RRH will be integrated to two 5G Core as well as another 4G Core, supplied by Kontron. They will be integrated in SNCF's sites. The Central site ("Command Centre"), hosting the 5G CU/DU, 5GC and 4G-BBU, and 4G Core shall be connected to a remote laboratory at Kontron premises, where trackside materials are also installed as depicted in **Figure 6**. In **Figure 7**, we depict a further decomposition of the architecture for the French test field elaborating the different signal flows between the central command centre site (in Vigneux) and the remote laboratory (in Montigny) to have a staging platform. We can see the different railway applications (ATO, ETCS, and RV in bottom rectangle) that will be installed in the test train connected to the OBGW to access the 5G infrastructure (radio access and core network in top and left rectangles) before reaching the counterpart server on the trackside in the laboratory part (right rectangle).

IV. Conclusion

Thanks to the 5GRAIL project, a major step forward has been achieved on the way towards FRMCS realization as the related lab and field experiments could not only provide feedback on the first set of specifications for railway operational communications, known as FRMCS V1, but also created a clear momentum among all partners. For instance, industrials could design and test their prototypes, foreseeing then solutions, components, and products they will use in the future to address their customers' needs.

Besides, 5GRAIL stands as a place for a global acceleration on FRMCS as it creates exchanges opportunities for all stakeholders through conferences, advisory boards, and lab visits. We must also underline the technical ramp up that this project boosted as engineers had to develop new critical skills on various subjects like 5G Stand-Alone, IP Multimedia System (IMS) or Mission Critical (MCx). Numerous achievements have already been recorded so far; let for example mention the first end to end FRMCS call with On-board application (Obapp) and Trackside application (Tsapp) interfaces over N39 Railway mobile Radio (RMR) band, the ability to use multiple telecommunication bearers, in failover scenario or at the same time and even in order to carry in parallel the same communication, not to mention the test of interworking function between GSM-R and FRMCS for MCPTT service, which is also a quite important topic considering FRMCS and GSM-R coexistence.

Many efforts are still to be made in this exciting and challenging journey that will make FRMCS real; they should bring robustness to existing prototypes, fine tune parameters, focus on cybersecurity essential requirements and much more, but the 5GRAIL project is already proud to have contributed and paved the way toward this goal.

Acknowledgment

The work described herein has been carried out within the project "5G for future RAILway mobile communication system" (5GRAIL). This project has received funding from the European Union's Horizon 2020 research and innovation program, under grant agreement N° 951725.

References

[1] Horizon 2020 Framework Program, Grant Agreement Project: 951725 – 5GRAIL, p.138.

[2] UIC - International Union of Railways, AT-7800, FRMCS System Requirements Specification (FRMCS SRS)

[3] UIC - International Union of Railways, FU-7120, FRMCS Functional Requirement Specification (FRMCS FRS)

[4] UIC - International Union of Railways, TOBA-7510, Telecom On-board System – Functional Requirements Specification (FRS)

[5] 3GPP TR 22.889 V17.4.0, Study on Future Railway Mobile Communication System, Stage 1 (Release 16 & Release 17), on-line: https://www.3gpp.org/DynaReport/22889.htm, accessed: 2023-01-10.

[6] 3GPP TS 22.289 V17.0.0, Technical Specification Group Services and System Aspects. Mobile Communication System for Railways Stage 1 (Release 17), on-line: https://3gpp.org/DynaReport/22889.htm, accessed: 2023-01-10.

[7] 5GRAIL, Deliverable D2.1-Telecom On-Board Architecture Report" In-press: https://5grail.eu/, accessed: 2023-01-10.