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► **To cite this version:**

B Holfeld, R Fritzsche, T Karabinos, G Boistault, M Berbineau, et al.. The 5G-RACOM Project: 5G for Resilient and Green Rail COMMunications. Transport Research Arena, Apr 2024, Dublin, Ireland. hal-04706750

HAL Id: hal-04706750

<https://hal.science/hal-04706750v1>

Submitted on 23 Sep 2024

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The 5G-RACOM Project: 5G for Resilient and Green Rail COMMunications

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Abstract. The German-French innovation project 5G-RACOM is investigating solutions for the efficient, reliable and sustainable use of the Future Railway Mobile Communication System (FRMCS) and the associated frequency spectrum. FRMCS is foreseen to be the successor to GSM-R and will ensure high-performance and real-time wireless communication between trains and infrastructure based on 5G technologies. FRMCS will deliver the basis for the digitalization and automation of railway operations and is, hence, fundamental to increase rail network capacity. 5G-RACOM has three objectives for a spectrum-efficient, a resilient and a robust FRMCS system design: (1) radio channel modeling studies at 900 MHz and 1900 MHz in different railroad operational scenarios including high-speed lines, tunnels, rural areas, (2) evaluation of the coexistence of GSM-R and FRMCS at 900 MHz and prototype development for technology migration, and (3) solutions for hybrid FRMCS networks in which the private FRMCS network is complemented by public mobile networks, e.g., as a fallback layer or capacity enhancement.

Keywords: FRMCS, 5G, Railway mobile radio, Mission-critical services, Hybrid railway networks, Multipath, Radio channel modeling.

1 Introduction

The advancing digitalization of rail operations comes with highly demanding connectivity requirements. As the current 2G based railway mobile communication

system GSM-R is not meeting those demands and will become obsolete in the 2030s, the 5G based Future Railway Mobile Communication System (FRMCS) is under development at European level [1], [2], [3]. FRMCS standardization is driven forward at UIC (International Union of Railways) and ETSI (European Telecommunications Standardizations Institute) within the Technical Committee for Railway Telecommunications (TC RT). Two railway mobile radio (RMR) frequency spectrum bands (at 900 MHz and 1900 MHz) have been allocated for FRMCS deployment in Europe [4] while parts of the radio spectrum are already in use with GSM-R (at 900 MHz). Additional spectrum, e.g., from public mobile network operators (PMNOs) is considered. The FRMCS architecture is based on two main paradigms: (1) Modularity enables separation of the application and the communication system as well as separation of services and pure transport. (2) Relying on standardized components and off-the-shelf technologies. Services are based on the mission critical services framework (MCx), standardized in 3GPP, while the transport is based on 5G with flexibility to integrate other access technologies as well as additional networks.

To make further progress, French and German railway infrastructure managers, telecommunication vendors, research institutes and academia joined forces in the 5G-RACOM project [5], under the “Franco-German Ecosystem for Private 5G Networks” initiative, to drive innovations towards a powerful private 5G network for railways. This project aims at investigating, developing and demonstrating key technologies to achieve a green, resilient, and future-proof FRMCS system by two paths: 1) exploiting the available RMR frequency spectrum most efficiently and 2) extending FRMCS towards additional public frequency spectrum via a hybrid network architecture.

2 Radio channel modeling and co-existence of FRMCS and GSM-R radios in the 900 MHz band

Radio channel models will be developed based on trials on tracks along four different types of environments: high speed, intercity, regional and urban lines. These environments vary in terms of vegetation, profile of the terrain, presence or absence of buildings, and trains’ speed. These differences have a major influence on radio propagation in the RMR bands. Three complementary MIMO radio channel sounders are considered [6], [7], [8]. The measured data will be used to develop 3D stochastic MIMO channel models and Ray Tracing (RT) technique, which is recognized as a good solution to complement stochastic models and emulate spatially-consistent MIMO radio channel properties (e.g., the map-based approach in the 3GPP TR 138 901 model). Channel sounding systems are able to extract the complex impulse response of the channel on a given frequency band in order to extract crucial information such as slow and fast fading distributions, Doppler spectrum, non-stationarity information in the channel, delays, position of the scatters, etc. At the time of writing of the paper, the measurement campaigns are in preparation and preliminary results obtained will be given in the final presentation.

Current GSM-R networks are deployed using FDD mode in a 900 MHz harmonized frequency band of 2 x 4 MHz (876-880 MHz uplink (UL) / 921-925 MHz downlink

(DL) – R-GSM 900). While this spectral range is, in Europe, entirely devoted to the needs of GSM-R, some European countries have been authorized to take benefit of a spectral complement. This is particularly the case in Germany, Liechtenstein and Switzerland where the 873-876 MHz (UL) and 918-921 MHz (DL) frequency bands may also be used for railways needs (ER-GSM Band). In 2020, CEPT concluded the harmonization of the 900 MHz frequency range, allocating 2 x 5.6 MHz, (874.4-880 MHz UL / 919.4-925 MHz DL), operated in FDD mode, for both the current and future railway needs. This band is now allocated by 3GPP as 5G NR band n100, also called “RMR 900”. This decision implies that the coexistence issue between current GSM-R systems and the future FRMCS standard should be addressed. To enable this coexistence, a simple approach could be proposed.

Considering the 2 x 5.6 MHz FDD part devoted to railways in the 900 MHz band, a GSM-R re-farming could be envisaged to release at least a bandwidth of 2 x 3 MHz, in UL and DL parts, on which a reduced 5G system could operate. As illustrated in Fig. 2, a narrowband 5G system [9] is introduced adjacent to the GSM-R carriers that have been re-farmed. This collocated approach using a 5G NR system of approx. 3 MHz system bandwidth is currently under study in 3GPP.

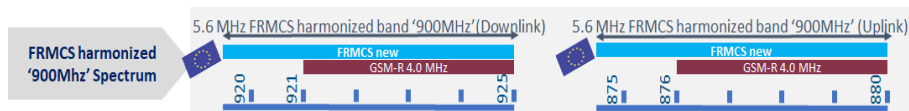


Fig. 1. Harmonized FRMCS 900 MHz spectrum.

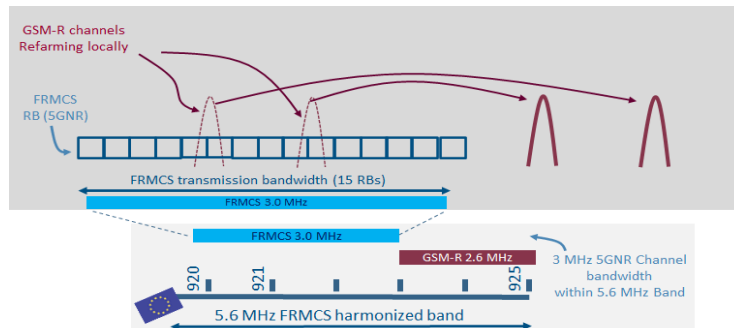


Fig. 2. FRMCS and GSM-R 900 MHz coexistence using “collocation” approach.

Another innovative approach could consist of deploying a 2 x 5 MHz 5G NR system overlapping the current 2 x 4 MHz GSM-R system. This approach is designed to operate in coexistence with the existing GSM-R system by minimizing inter-system interference. This is achieved through advanced scheduling techniques in the base station to protect GSM-R carriers while remaining fully compatible with standard FRMCS handsets and cab radios using 5G NR (meaning no change on mobile devices required, standard RMR 900 UE used). In both approaches, the 5G resources will be limited. The “whitespace” coexistence scheme consists of locating the current GSM-R technology and the 5G NR technology onto the same frequency band. The main goal is

to allow a smooth introduction of the 5G NR RMR 900 inside the GSM-R band without impacting GSM-R performance. The aim is to not allocate additional spectrum nor introducing complex filtering solution to solve RF coexistence problems that would strongly impact the legacy GSM-R system. The proposed method ensures that in a given spectrum (on which GSM-R is already deployed) 5G NR deployment is possible with a maximized capacity not reachable by other methods. The concept consists in reusing the inter GSM-R carriers frequency spaces as follows: Into the 900 MHz harmonized band two railway systems, the current GSM-R 4 MHz standard and the future FRMCS standard based on 5G NR 5 MHz (25 RBs) OFDM technology, for both UL and DL. 5G NR resource blocks (RBs) coinciding with GSM-R carriers are blanked in order to prevent GSM-R carriers from being disturbed by adjacent interferers. The resulting “whitespace” approach is depicted in Fig. 3. Note that in both coexistence approaches, a coordination scheme between radio and computing schedulers in the context of 5G FRMCS is needed to satisfy application QoS requirements (in terms of throughput, processing time, packet loss, etc.).

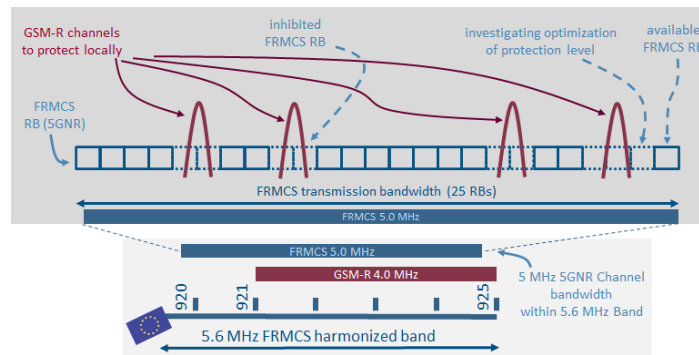


Fig. 3. FRMCS and GSM-R 900 MHz coexistence using “whitespace” approach.

3 Hybrid FRMCS networks

To increase resilience and availability in railway communications, but also to provide capacity enhancement and improve overall coverage, 5G-RACOM is working on extending the FRMCS network with access to the resources of public 5G mobile networks in a hybrid FRMCS network architecture. The hybrid architecture concept is illustrated in Fig. 4. It is based on the use of selected multipath (MP) technology that will enable railway infrastructure managers to use multiple independent transmission paths to implement individual policies for all railway applications incl. video streaming and group communications. The overall solution as implemented by the 5G-RACOM project shall provide support for the following high-level use cases: 1) application specific path selection, 2) resilience via fallback, 3) resilience via path selection, 4) resilience via duplication, 5) capacity complement and 6) coverage complement.

For the typical FRMCS approach a connection between an application inside the train and its counterpart at the trackside is established with a single network and a single

onboard radio. The onboard gateway offers that multiple railway applications located inside the train can access the FRMCS network. The service server (i.e., MCx server) at the trackside is managing services offered towards the railway applications utilizing MCPTT, MCData or MCVideo capabilities. 5G-RACOM will interconnect the service server at the trackside also with the public 5G mobile network to provide another connectivity option. At the train side, additional onboard 5G radio(s) will be integrated within the onboard system architecture and connected with the onboard gateway. To utilize both networks flexibly, seamlessly and in a parallel fashion, the MP function needs to be implemented on both the onboard side and the trackside of the FRMCS system and will anchor/aggregate all the traffic. These MP functions would then provide steering, switching and splitting capabilities necessary for using multiple independent transmission paths by railway applications within the hybrid FRMCS network in a transparent manner, see Table 1.

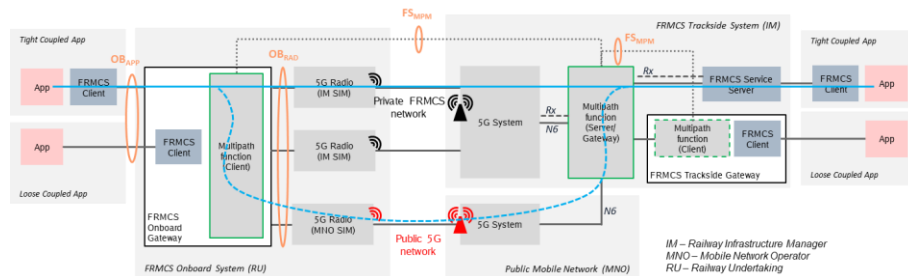


Fig. 4. High-level view of a hybrid FRMCS architecture incl. multipath functions.

Steering	=	FRMCS	or	Public 5G	=	Best network selection
Switching	=	FRMCS	from/to	Public 5G	=	Seamless handover
Splitting	=	FRMCS	and	Public 5G	=	Network aggregation

Table 1. Steering, switching and splitting capabilities in multipath functions.

MP functions should consider, among others, the availability of the network, the instantaneous quality of the networks as well as the QoS requirements of the specific railway application. Based on such information, MP functions can apply policies as defined by the railway infrastructure manager. Scenarios such as poor radio conditions of the FRMCS network can be compensated by adaptive re-routing of the traffic, whose QoS cannot be supported. In cases of a complete unavailability of the FRMCS network, the complete traffic could be handled by the public 5G network. High volume applications such as video streaming can be offloaded to the public 5G network in case of insufficient capacity of the FRMCS network. For supporting QoS of railway applications also within the public network, a dedicated network slice is envisaged in the public 5G network for which specific service level agreements can be provided by the mobile network operator. The N6 interface in 3GPP 5G networks will be used for the data transfer from/to public 5G network while no signalling interface will be used between the networks in the project. Different candidate multipath technologies and protocols such as MP-TCP, MP-QUIC, SCTP, load balancing based solution and SD-WAN are under investigation in the project, while the most suitable solution will be

selected for conceptualization, implementation and elaboration within a real-world hybrid FRMCS test network. This test network will be realized in the Ore Mountains in Germany, combining a private 5G FRMCS test network from Deutsche Bahn and a public 5G mobile network under joint operation of Vodafone and Technische Universität Chemnitz, that can implement 5G-RACOM's test configurations.

4 Conclusions

Exploiting the frequency spectrum allocated for FRMCS through an efficient and robust system design is essential for the existing mission-critical railway applications to migrate from GSM-R to FRMCS and a key step for future railway operations to be introduced and deployed. 5G-RACOM contributes to this by providing solutions for radio channel modeling, for GSM-R and FRMCS coexistence in the 900 MHz band and for design and realization of hybrid FRMCS system architectures, incl. selection of multipath protocols for optimized routing.

Acknowledgement

This work is funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) and the French Ministère de l'Économie, des Finances et de la Souveraineté industrielle et numérique (MEFSIN) in the innovation project program "Private 5G Networks for the Industry".

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