Hybrid FRMCS 5G Architectures and Network Operation Models for Future Rail Operation

Executive Summary

Introduction

Less traffic, less congestion, less particulate matter – and more people and more goods on the rails: The rail sector in Europe is on the verge of a technological leap into the digital future. The sector initiative "Digitale Schiene Deutschland" is taking advantage of this opportunity and bringing future technologies into the rail system. This benefits not only passengers, but also the climate and Germany as a business location. And all this without having to construct a single new track. The foundation for this is being laid with the fundamental modernisation and digitalisation of the infrastructure through the consistent introduction of digital control and safety technology. In addition, Digitale Schiene Deutschland is working on a far-reaching digitalisation of the railway system. For this, a system architecture will detail the tasks of individual components of the railway system, and how they should work together.

On this basis, numerous digital technologies will then be tested and further developed for use in the system: for example, an AI-based traffic and incident management system will provide intelligent and automated control of trains in the future. These will then run fully automatically and at an optimal distance from each other. The latest sensor technology for environment perception coupled with high-precision train location and an automated interruption detection are further technologies that will play an important role in the digitalisation of the railway system. Overall, a significant improvement in capacity, punctuality and efficiency of the railway system will be achieved, all of which are requirements for more traffic on the railway and a strengthening of the railway as the climate friendly mode of transport of the future.

The rail system of the future will be characterised by data-intensive applications that must communicate with each other in real time. To handle the increased connectivity demands accompanied by digital rail operation, the 5G based Future Railway Mobile Communication System (FRMCS) will be introduced and replace the current GSM-R system on the long run. Due to regulatory and legal aspects, Deutsche Bahn AG (DB) envisions to operate an own FRMCS system. However, the assumed FRMCS standard enables to employ multiple interconnected networks within the FRMCS architecture. Complementing the DB-owned FRMCS system by public 5G networks offers suitable options to introduce additional redundancy and increase data capacity and is denoted in the following as hybrid architecture.

Within this collaborative project between Vodafone and Deutsche Bahn within the sector initiative Digitale Schiene Deutschland (DSD), various hybrid architectural options and features in context of FRMCS have been analysed together with their suitability for the new use cases envisioned by DSD with challenging requirements on data rate, latency and reliability. This summary of the project focusses on the derived architectural analyses, while conclusions on further aspects of the project, e.g., on cost estimation are not part of this description.

The FRMCS architecture (based on current status of FRMCS standardization) comprises of transport stratum and service stratum. The transport stratum is based on the 5G system, comprised of the radio access and the 5G Core. The service stratum is mainly utilising the Mission Critical services (MCX) framework, standardised by 3GPP. For the trackside of the FRMCS system the main service stratum functionalities are comprised by the FRMCS service server. In this work, it is assumed that the DB owned and operated network comprises of both strata, hence a 5G system and an MCX based FRMCS service server. Furthermore, the FRMCS service server is assumed not to be operated by a public operator. Hybrid FRMCS network designs refer to the ability to combine the DB operated FRMCS network with a public 5G transport stratum operated by an MNO (Mobile Network Operator). The hybrid network architecture offers redundancy in case the DB 5G network is not available. In addition, the hybrid approach offers possibilities for utilising both 5G networks in parallel to increase network capacity for non-critical rail operation applications. The key conclusions from the project, in particular regarding the developed and studied architectures, are summarized in the following.

Hybrid Architecture Studies

Different network architectures were analyzed for onboard deployments with a single radio (fallback) and with multiple radios (failsafe). For the latter case, different considerations on the utilisation of SIM cards have been studied.

Architecture 1: Single Radio Scenario for Fallback: Single Onboard Radio with IM SIM Card

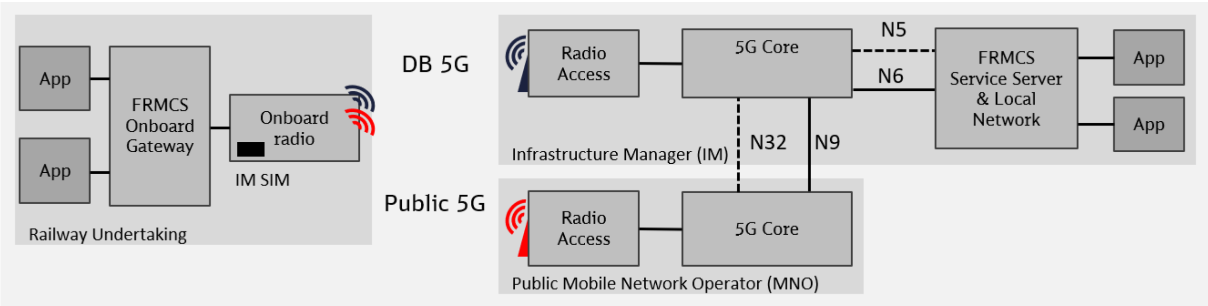

Figure 1: Architecture 1 - Fallback scenario with single onboard radio

In this configuration, there is only a single radio considered, equipped with a SIM card of the Infrastructure Manager (IM), e.g., DB Netz. The 5G network of the IM is interconnected with the 5G network of the MNO via N32 and N9 reference points, both standardized by 3GPP. N32 is handling control information, e.g., for the QoS management, while N9 refers to the user plane.

Advantages:

- Can compensate failures in the Radio Access network of the IM as well as continuous poor connectivity
- Likely to be covered by early FRMCS specification
- Usage of QoS in public network possible (potentially in combination with network slicing)

Disadvantages:

- Cannot compensate failures of the core network and the service server
- Multiple minutes service interruption without optimization in the IM network

Architecture 2A: Dual Radio Scenario for Failsafe: Two Onboard Radios, with different SIM Cards

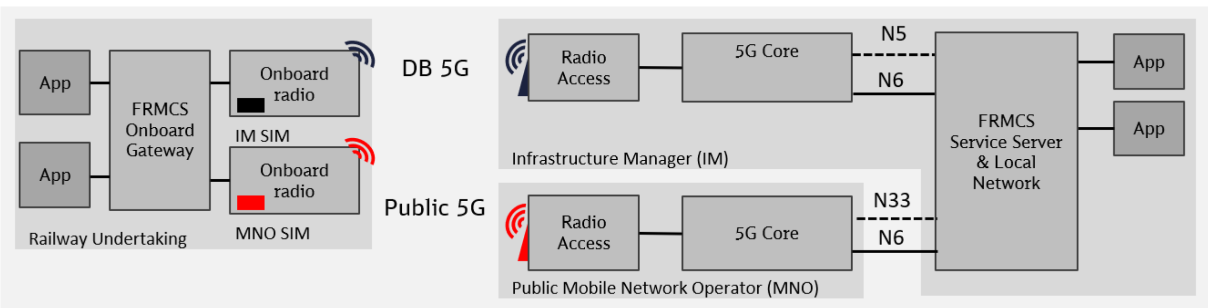

Figure 2: Architecture 2A - Failsafe scenario with two onboard radios

In this configuration there are two onboard radios, with one IM SIM card and one MNO SIM card, where both the SIM cards are in their respective home networks. In this architecture, the IM 5G network and the MNO 5G network are not interconnected, while the public 5G system is interfacing with the DB FRMCS service server via N33 reference point for the QoS management and via N6 reference point for the data traffic, both part of the 3GPP 5G standard. In order, to enable a flexible usage of both networks in parallel, advanced multipath mechanisms need to be employed. Such mechanisms should allow to choose the network for each individual session. More advanced features might enable instantaneous switching of an ongoing session from one network to the other, e.g., based on poor connectivity conditions.

Advantages:

- Can compensate failures in the IM radio access + 5G Core network and poor connectivity
- Can achieve service continuity with proper multipath mechanisms (not part of this study)
- Usage of QoS in public network possible via N33 reference point

Disadvantages:

- Higher complexity onboard and trackside, due to multiple modems and multipath mechanism
- Requires N33 specification for Mission Critical Services & support by public MNO

Architecture 2B: Dual Radio Scenario for Failsafe: Two Onboard Radios, with IM SIM Cards Each

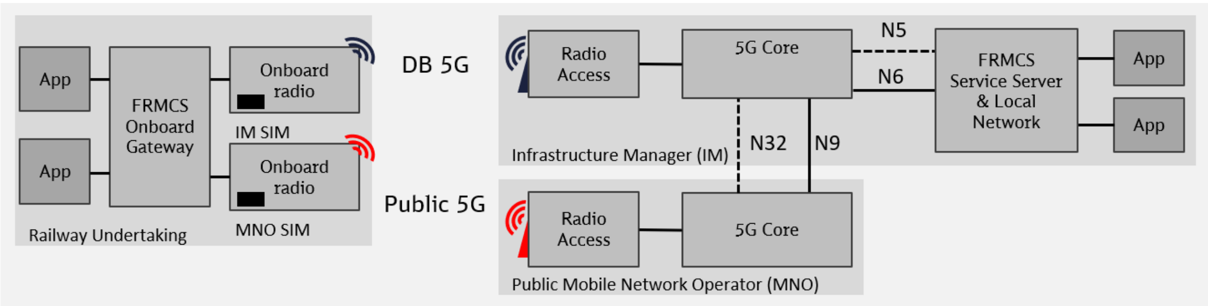

Figure 3: Architecture 2B - Failsafe sceanrio with two onboard radios

In this configuration there are two UEs, both with DB SIM cards, where one radio is directly connected to the DB 5G network, while the other radio is always roaming to the MNO network. The interconnection between IM and MNO network, is based on N32 and N9 reference points, referring to a roaming scenario as in the "Architecture 1" with a single onboard radio. However, this architecture is extended by an additional onboard radio, which need to be configured to roam into the MNO network by default. Also here, respective multipath mechanisms should be employed to maximally utilise the given architecture capabilities.

Advantages:

- Can compensate failures in the IM radio access and poor connectivity
- Can achieve service continuity with proper multipath mechanisms (not part of this study)
- Usage of QoS in public network possible (potentially in combination with network slicing)
- All specifications available

Dis-advantages:

- Higher complexity onboard and trackside, due to multiple modems and multipath mechanism
- Cannot compensate failures of the core network and the service server

- Special configuration in the second onboard radio or SIM card for realizing permanent roaming

Conclusions

The joint project identified potential hybrid architectural solutions and assessed its applicability in the railway context. The fallback architecture has been identified as a suitable possibility to increase the reliability of FRMCS compared to a DB-owned network only. Such design can already be applied for first rollouts of FRMCS, as it might be supported in the early versions of the FRMCS specification. Moreover, the failsafe approach has the potential to further increase network reliability, while in addition handle more demanding data rate requirements by introducing parallel connections. However, the architecture requires higher complexity at the onboard side and might not be supported already by the first versions of FRMCS. Note that the first failsafe scenario is ultimately recommended, e.g., as it comes with higher reliability. However, specification of N33 for Mission Critical Services needs to be concluded in 3GPP. For full flexible parallel usage of both networks, suitable multipath solutions should be studied for both failsafe architectures in the future.