STRATEGIC DEPLOYMENT AGENDA
"5G CONNECTIVITY AND SPECTRUM FOR RAIL"

Update of the SDA of April 20th, 2020, developed by EIM, CER and UIC, with input provided by UNIFE/UNITEL and members of the European Rail industry.

Brussels, 20 September 2024

Content

1 EU policy on railways

1.1 Accelerating the shift to sustainable and smart mobility

President von der Leyen's Commission has formulated ambitious environmental plans by announcing a new *European Green Deal* aimed at accelerating emissions reduction: the goal is to cut emissions by at least 50% by 2030 and to make Europe the first climate-neutral continent by 2050. In parallel, the Commission plans to implement new policies to make the EU single market a better fit for the digital age, becoming technologically sovereign and recognising the transformative potential of 5G in the field of mobility.

Transport accounts for a quarter of the EU's greenhouse gas emissions and is still growing. To achieve climate neutrality, a 90% reduction in transport emissions is needed by 2050. Road, rail, aviation and waterborne transport will all have to contribute to the reduction. The Commission has adopted a long term strategy for sustainable and smart mobility that will address this challenge and tackle all emission sources. According to a CER/EIM study[1], rail is significantly more energy-efficient than road due to physical advantages such as lower rolling and air resistance.

Green multimodal transport needs a strong boost. Multimodality will increase the efficiency of the transport system. As a matter of priority, to make multimodal transport greener, a substantial part of the 75% of inland freight carried today by road should shift to rail and inland waterways. This will require measures to improve management and to increase the capacity of railways and inland waterways, as suggested by the Commission in 2021. The Commission will also consider presenting a revision of the Combined Transport Directive to turn it into an effective tool for supporting multimodal freight operations involving rail and waterborne transport, including short-sea shipping.

Automated and connected multimodal mobility will play an increasing role, together with smart traffic management systems enabled by digitalisation. The EU transport system and infrastructure will be made fit to support new sustainable mobility services for passengers and freight that have the potential to reduce congestion and pollution, especially in urban areas. The Commission will help develop smart systems for traffic management and Mobility as a Service solutions, through its funding instruments, such as the Connecting Europe Facility.

1.2 Benefits of 5G deployment and rail

Economic cohesion and social aspects: regional, national and cross-border rail connectivity is an enabler of economic prosperity. Developing new 5G-based customer solutions will further facilitate seamless rail connectivity between cities, regions and countries.

Increased mobility: Mobility is a key enabler of jobs, economic growth and social cohesion. As mobility is increasingly becoming multi-modal, rail can make a major contribution to creating a more interconnected European transport network.

- In many European countries, rail networks are already heavily used. (Example: In the Netherlands, Belgium and Denmark, network utilisation rates are some 70% higher than the EU average). Rail congestion reflects the extent of infrastructure capacity constraints both for passenger and freight services. It is therefore of vital importance to find sustainable ways of increasing transport capacities along national and international railway lines by way of digitalisation without having to build new tracks.

[1] CER Policy Agenda 2019-2024

- Without implementing advanced digital critical communication technologies, along with lifting interoperability barriers, it will not be possible to further boost cross-border passenger and freight services. Given that half of the total EU rail freight volumes are already cross border, digital services and node infrastructures for freight transport need to be enhanced and taken to the next level.
- Multimodal solutions are also of paramount importance for passengers and freight. 5G will enable higher customer satisfaction by providing digital solutions and connectivity across different infrastructure hubs, such as stations for high-speed trains and stations for local transport.

Sustainability and decarbonisation of transport: this is crucial in allowing the EU to reach its Paris climate goals.

- 5G deployment will be instrumental to the new Commission's strategy for a European sustainable and smart transport system in line with the new green political priorities. Better connectivity will support measures to accelerate the target of "a modal shift of 30% of road freight by 2030, and more than 50% by 2050".
- Improved passenger connectivity provided by 5G mobile services will enhance the attractiveness of rail as a means of transport.
- Rail infrastructure is the backbone of a well-performing rail system. Once the TEN-T under the Single European Railway Area (SERA) will be completed and passengers and freight will be able to move seamlessly across EU countries, rail will be able to deploy its full potential in terms of decarbonisation.

Innovation, interoperability and digitalisation will have a positive multiplier effect on the wider (railway) industry. Innovation, promoted, for example by EU Rail, but also other interoperability initiatives, should be fostered to contribute to making the Single European Railway Area (SERA) more competitive. FRMCS will enable the digital deliverables (such as Automatic Train Operation (ATO) and European Rail Traffic Management System (ERTMS)) to be deployed.

- The 5G deployment strategy supports and complements the work of the European Union Agency for Railways (ERA) to achieve full cross border interoperability within the Fourth Railway Package with regard to both rail operations and the implementation of trackside and onboard technology, such as ERTMS. ERTMS will be critical to improving traffic management, punctuality and safety aspects.
- 5G will also enable deployment of new innovative digital technologies currently under development in EU Rail, such as ATO, whose deployment will increase rail infrastructure capacity. ATO and ERTMS will ultimately make rail more energy saving and efficient, hence greener and more competitive vis-à-vis other modes of transport.
- The combination of ERTMS, ATO and 5G, along with interoperable solutions developed under the aegis of ERA, will be key enablers to reducing transport emissions and will contribute to making rail a more competitive transport mode while improving customer experience.

Geopolitics is an important priority for the railways and for the transport sector in general.

- Connecting the TEN-T network with non-European networks by 5G will impact Gigabit Train and Digital Rail Operations in terms of funding, operations, performance, standards and rules. A consistent strategy for deploying 5G – which is an EU priority - in the rail sector will allow the EU to keep up the pace of innovation in the field of connectivity technologies and improve the rail system by digitalisation while setting the standards to minimise the risk of cyber-attacks.
- The SDA for Rail can be the basis for triggering further reflections on the opportunities and threats of 5G connectivity in the rail sector and on initiatives to mitigate the risks involved.

Ensuring EU defence and military mobility is a task that was assigned to rail, and to the IMs in particular. Military mobility and cyber security are at the forefront of the political discussion. The wider rail sector, including its rail infrastructure managers, will contribute to tackling this new challenge by enabling seamless mobility for both civilian and military purposes. 5G communications will be instrumental to achieving this goal.

2 Railway vision and goals for mobile communications

2.1 Current challenges and opportunities for rail

Within the context of the European Green Deal, EIM, CER and UIC members expect the new EU objectives and forthcoming policies to offer significant opportunities to promote rail as the mode of transport for both passengers and freight.

High-end connectivity, digitalisation, automation and interoperability of rail traffic are key performance requirements for achieving these ambitious goals. In many EU countries, governments have a strong focus on supporting rail in extending the rail network and running more trains to accommodate passenger growth. Therefore, rail operations must be optimized, particularly focusing on aspects such as punctuality and capacity. Enhancing the reliability and efficiency of rail services is essential to accommodate the growing number of passengers and freight. Additionally, significant emphasis is being placed on improving passenger comfort and connectivity, ensuring a more enjoyable and convenient experience for travelers.

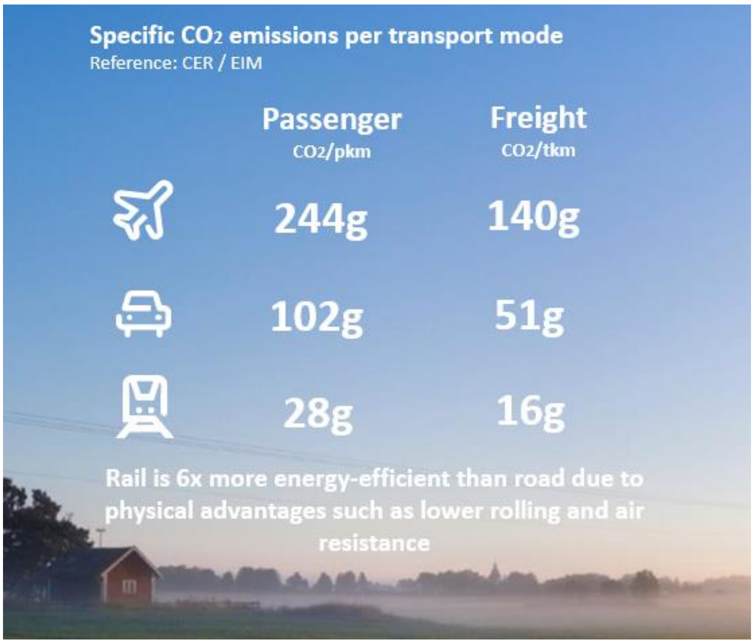

Figure 1 CO_2 emissions by transport mode

In order to ensure a successful journey, it is important to take into account the variety of stakeholders in the ecosystem so that they can join forces. Regarding the railway sector, Infrastructure Managers, Railway Undertakings for Passengers and Freight supported by their European associations and the Passengers count as the main stakeholders. Regarding the mobile telecommunication industry, Mobile Network Operators (MNOs), Infrastructure Companies (TowerCos) and Equipment suppliers are also actors of the value chain.

Passenger connectivity

For passengers, reliable and high-performance connectivity is becoming a basic need that plays an important part in their choice of transport. This makes connectivity a clear socio-economic driver. Enabling business travellers to use the train as a mobile office and providing entertainment to private customers enhances the attractiveness of rail journeys. Modern high-speed trains such as the ICE and the TGV can be compared to small and digitally active villages of up to 1,000 people, travelling through the countryside at speeds of up to 320 km/h.

While connectivity, digitalisation and interoperability offer great opportunities, European railway undertakings and rail infrastructure managers currently face the challenge to meet the massively increasing connectivity requirements for rail operations and at the same time find ways to ensure connectivity for passengers. In fact, public mobile network coverage is still patchy along the major rail corridors and is far from providing uninterrupted coverage, with 4G systems in place along all major railway lines. Mobile network operators have so far considered providing connectivity on railway lines as a weak business case, one key reason being the huge investments needed for a dedicated network infrastructure - investments that would not be prompted by market forces alone.

Digital Rail Operations

The Future Railway Mobile Communication System (FRMCS) is the radio solution which will be integrated into the rail system. It supports Digital Rail Operations by enabling higher levels of ETCS and ATO GoA-2 to -4, ultimately allowing headways between trains to be significantly shortened, with a massive impact on capacity, voice services such as the Railway Emergency Call. FRMCS will also enable TCMS, a plethora of Train Performance applications, which will smoothen the traffic. The digital railroad operational requirements, which are decisive for the installation of FRMCS, are significantly stricter in terms of availability and reliability than those for passenger connectivity. A major contribution to achieving the European Commission's ambition to decarbonise Europe can be made by shifting passenger and freight traffic to rail. Digital transformation is envisaged for vertical markets such as rail to improve operational efficiency and performance.

5G Benefits

Advanced 5G communication services for rail significantly contribute to achieving these ambitions. However, when it comes to the Gigabit train, the economic viability of the 5G market to uphold the required bandwidth and coverage levels along railway lines, stations and tunnels, is rather low (as is the case today with 4G). Hence, new cooperation models are needed.

In the SDA for Rail, two major lighthouses are described: The **Gigabit Train** and **Digital Rail Operations**. The SDA provides guidance for deployment planning and (CEF2) funding of 5G mobile infrastructure and services along railway lines in order to implement Digital Rail Operations applications and the Gigabit Train.

2.2 What is the Gigabit Train?

The goal of the Gigabit Train idea is to ensure that connectivity for passengers travelling on a high-speed train across borders provides a similar experience as connectivity at home or at work.

The increasing number of rail passengers and their usage of digital applications generate a higher demand for mobile connectivity on board trains. Forecasts until 2030 predict a demand of up to 3-5 Gbps per train carrying 1,000 passengers, without accounting for future applications and usage rates per passenger.

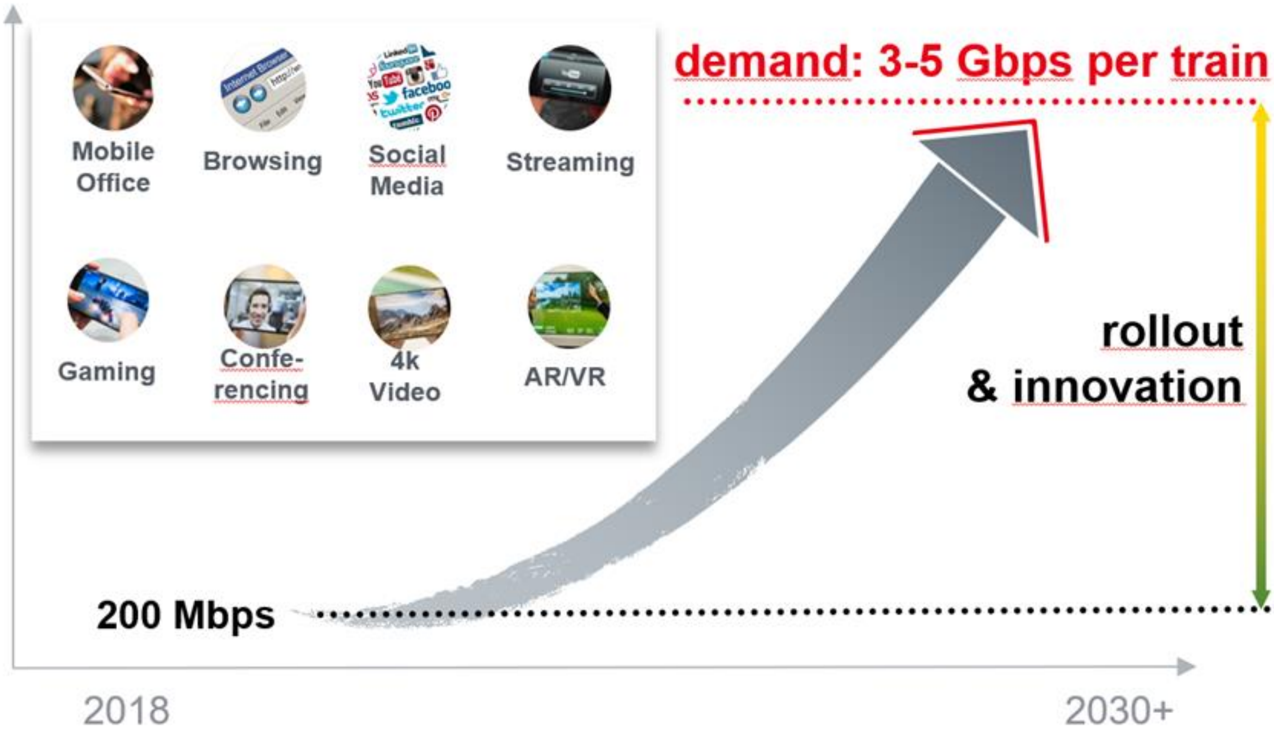

Figure 2 Gigabit Train: overview of applications and throughput requirements of trains carrying 1,000 passengers

Gigabit connectivity requires innovations in two respects: trackside mobile coverage and onboard connectivity equipment.

In the last few years, trackside mobile coverage has been provided by public mobile network operators (MNOs) with licensed spectrum. MNO spectrum can be used to provide enough mobile capacity along railway lines to respond to the connectivity demand. Therefore, the SDA for Rail analyses mobile networks, requirements and solutions for the Gigabit Train assuming MNOs continue to provide trackside coverage.

2.3 What is Digital Rail Operations?

Digital Rail Operations encompasses all mobile application and communication services necessary for train movement and industrial applications including those services required for improving and enhancing rail traffic, performance and safety.

The EU legal framework for railways – the Control Command and Signalling Technical Specification for Interoperability (CCS TSI) – specified GSM-R as the radio system to be used for train-to-track operational voice communication and ETCS data communication. GSM-R is widely used across Europe (deployed along more than 130.000 km of track), and other parts of the world, but vendors of the supply industry have indicated that obsolescence of GSM-R technology will become a risk in the longer term, advising clients to prepare for replacement until 2035.

Other reasons for considering a successor to GSM-R include the expected increase in communication demands due to a growth in passenger and freight transport, further implementation of ETCS, ATO and the expected digitalisation and automation of rail.

The railway community is working on standardising the Future Railway Mobile Communication System (FRMCS). FRMCS is one of the game changers identified in the ERA's ERTMS Longer Term Perspective document.

The CCS TSI 2023 introduces FRMCS as the successor to GSM-R and supports new railway functionalities such as ATO GoA2.

The work on functional, system and interfaces requirements specifications as well as harmonised spectrum solutions is currently underway and is being carried out by UIC, ERA, EUG, ETSI, CEPT/ECC and 3GPP. The objective is to further update the TSI by incorporating FRMCS version 2 and 3, agreed by ERA, EU-Rail JU, DG Move and UIC finally resulting in FRMCS 1st Edition which will be available in mid-2027.

FRMCS will be based on next-generation 3GPP technology, in particular 5G stand alone, mission critical. It is expected to provide a low-latency and spectrally efficient foundation mainly for critical applications, but it will also include various performance applications.

For critical applications in particular, dedicated, harmonised 900 MHz and 1900 MHz frequency bands, in addition to GSM-R bands, have been allocated conform the ECC (20) 02 decision. This spectrum shall be available for railway-operated FRMCS deployments. Services may be complemented by the use of public mobile networks, subject to legal and regulatory constraints in Member States, as explained in more detail in paragraphs 5 and 6.

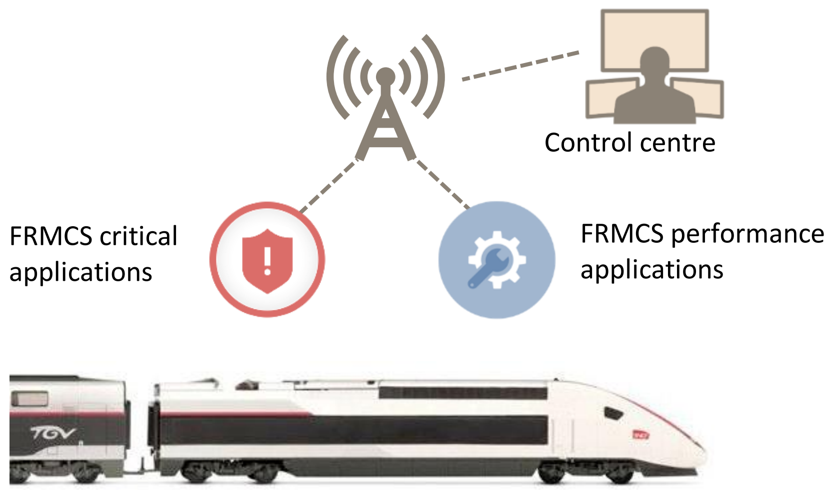

Figure 3 5G for FRMCS critical and performance applications

Beyond the immediate needs of rail operations, 5G will also serve as a stepping stone to further innovation in the rail sector. An advanced service-based 5G architecture will help to tailor cellular technology best to railway needs and enable an efficient, secure, and future-proof cloud deployment. In practice, the list of innovations is quite long: Advanced multi-radio antenna systems and multi-cell coordination schemes (such as coordinated multi-point services) aim to optimise rail scenarios and minimise deployment costs. For managing the end-to-end Quality of Service of the diversity of rail applications, methods will be needed for cost-efficient infrastructure sharing among MNOs, Tower Companies and railway infrastructure managers (within the boundaries of national regulatory constraints).

2.4 Objective of the Strategic Deployment Agenda for Rail

The Gigabit Train and Digital Rail Operations offer a variety of challenges:

- Some countries have issued coverage regulations for operators with respect to population and geographical coverage as well as waterway and railway coverage, with peak rates in the order of 50–200 Mbps. This does not fulfil long-term needs in the ranges of the 3–5 Gbps peak rates required for the Gigabit Train.

- It seems advisable to aggregate spectrum in subGHz bands and expand the usable spectrum beyond 2.6 GHz to fulfil long-term gigabit coverage. This may be achieved by using 5G for accessing additional spectrum resources, such as 3.5 GHz spectrum and millimetre-wave bands.
- Cooperation models need to be found to secure technology innovation and funding. To build trackside mobile infrastructure, it is essential to share passive infrastructures (e.g. sites, towers, fibre optic cables, power supply, equipment shelters) on a large scale in order to meet cost objectives. New technologies available with 5G (e.g. network sharing, beam forming, MIMO, network slicing, bearer flexibility and carrier aggregation) will be key.
- Railway undertakings have the task to ensure technological innovation for the onboard equipment, delivering in-train connectivity for passengers. Trackside public MNO connectivity needs to be aggregated at the train antennas and distributed inside coaches according to the layout of each individual train. In the next few years, the in-train radio design will evolve with the advent of Wi-Fi 6, frequency-transparent windows and 5G equipment.
- Technological innovations in mobile communications are necessary to realise data rates of 3-5 Gbps. A trackside infrastructure that enables the use of different frequency ranges such as 3.5 GHz as well as mmWave can provide these data rates. An efficient design and sharing of passive and active infrastructure, both existing and to be deployed, as well as the involvement of all players along the value chain, may be key to realise a technologically and economically viable trackside infrastructure for the Gigabit train and FRMCS.
- For radio network coverage quality to be objectively assessed, clear KPIs in the areas of QoE – Quality of Experience (perceived service by passengers) – and QoS – Quality of Service (measured throughput, latency, and service continuity inside and outside the train) – need to be defined, collected, and monitored on a regular basis. Expectations must be actively managed by publishing QoE levels for passengers.
- Railway-specific use cases need to be firmly embedded in research and development, so that specific technical solutions, such as a radio corridor that enables up to 3-5 Gbps using different frequency ranges such as 3.5 GHz, 6 GHz and mmWave with minimal energy consumption, are researched and developed. Other examples include travelling across borders (roaming) and travelling through tunnels.

This Strategic Deployment Agenda (SDA) reflects the vision of the rail sector on 5G. It builds a common understanding on deployment and cooperation options for 5G along rail corridors and designated areas between 2024 and 2030. It is the basis for innovation and enhanced services for rail operations and rail passengers, public/private cooperation, investments and partnerships.

It seeks to meet the following objectives:

1. Identify railway services and their key requirements, attributes and associated network performance levels as well as quality of service
2. Identify the technical constituents and innovations needed to meet railway service requirements.
3. Provide an understanding of market situations, regulations, standardisation bodies, cooperation (models) including sharing of assets (such as trackside infrastructure) and synergies from utilising the know-how of multiple stakeholders.
4. Provide a vision on deployment scenarios along corridors and designated areas, taking into account the EU funding criteria.
5. Provide guidance on planning and timelines for deployment.

The next sections focus on service requirements for Gigabit Train and Digital Rail Operations, outlining the associated use cases, required technical innovations, regulatory aspects, cooperation models and deployment scenarios.

3 Service requirements

3.1 Gigabit Train

We have already mentioned that the CER's and EIM's vision involves providing a modern rail system able to fully meet passenger expectations for a modern, fully connected travel environment that is similar to the user experience at home and in the office. However, users on a train are literally all confined in one place, which can be considered as a small village travelling through the countryside at speeds of up to 300km/h.

Requirements for connectivity in the Gigabit Train can be broken down into the following three categories:

- ***Connectivity for passengers:*** Connectivity to the internet either directly or via an onboard moving aggregation hot spot. Typical services for this category include voice calls, browsing, social media, mobile office, video conferencing, cloud apps/sync, streaming, gaming, onboard media portals, concierge services, etc.
- ***Connectivity for staff*****: conductors and onboard security staff:** Typical services in this category include voice calls, browsing, mobile office, video conferencing, A/R, simultaneous audio translation, etc.
- ***Connectivity for equipment and systems*****:** CCTV/video, passenger infotainment, display units, sensors and other applications considered non-critical to train operations.

Note that connectivity for railway staff and systems on trains in part also falls into the domain of Digital Rail Operations (see Section 2.3).

High-performing mobile networks with no interruptions are a key enabler for all the above-mentioned services. The right metrics need to be in place to assess the current situation of trackside mobile networks, set clear targets and track improvements towards these targets.

3.2 Digital Rail Operations

Digital Rail Operations encompasses all mobile applications and communication services necessary for running trains as well as those required for improving and enhancing rail. These applications are broken down into two categories: critical communication applications and train performance communication applications. A detailed overview of these types of applications can be found in the FRMCS User Requirements Specification (URS).

The most important applications can be subdivided into the following categories:

(Critical) voice and data services:

VOICE
Voice communications for train drivers and dispatchers are necessary for rail operation. This type of communication is currently used by the vast majority of trains in Europe. Communication services include point to point calls, group calls and railway emergency calls. The last one is vital for railway operations, being the last resource to avoid a train accident when all the other systems have failed.

ETCS
ETCS is a radio-based train protection system. Track-to-train communication is required to give the trackside RBC (radio block centre) the train position and speed, based on which the trains will receive a movement authority.

ATO (GoA2 to GoA4)
ATO (Automatic Train Operation) will operate based upon ETCS signalling. It will enable automated and highly optimised train control in terms of train acceleration and deceleration, for instance to optimise train timetables, train departure procedures and energy efficiency. ATO ensures signalling of segment profiles (containing track layout data incl. information on gradients, etc.) and journey profiles from ground to train.

ATO GoA4 may require an uplink capacity of 6-7 Mbps per train with very low latency (<10 ms). ATO may also include critical video communications.

Critical video

Critical video transmission (including the transmission of critical lidar and radar sensor data) is expected to become necessary for higher levels of railway automation (e.g., for GoA3 and GoA4) and RTO – Remote Train Operations. Driverless train operation will require train-to/from-trackside video and sensor communication for hazard detection in normal operation and remote access to video and sensor data from trains for degraded mode operation (including specific incidence cases) in order to be able to perform remote train control and manage railway operations appropriately.

These applications need a high quality of service, and need to be interoperable, to ensure a competitive railways system in Europe.

Other applications

Track side phones, level crossing cameras, TCMS (Train Control & Management System) are examples of other communication categories. These will considerably smoothen train operations and maintenance activities, and reduce costs.

4 Innovation needed to meet service requirements

4.1 Introduction

This section describes several innovative topics and features required to meet railway service requirements for the Gigabit Train and Digital Rail Operations. It does not focus on innovations required for developing standards (these are covered by specific pilots and demonstrators), but rather deals with innovations regarding deployment, configuration and network management. Moreover, services for passengers and services for rail operations differ in terms of requirements and performance levels, but are normally confined to the same geographical area. Therefore, certain innovations are common to both the Gigabit Train and Digital Rail Operations as described in Section 4.2.

4.2 Innovations common to the Gigabit Train and Digital Rail Operations

4.2.1 Sharing of passive infrastructure

One promising option to meet the demands of Digital Rail Operations, is to deploy the FRMCS radio access network (RAN) in close proximity to the track, forming a corridor, re-using and enhancing the existing infrastructure of GSM-R. The passive infrastructure required for this could also be leveraged for the realization of Gigabit Train, in a coexistence scenario. The key to an efficient rollout of this corridor infrastructure could e.g. be based on deploying small, cost-effective (and permit free) mast installations, creating substantial synergies in passive infrastructure deployment.

FRMCS introduction, especially within the allocated 1900 MHz RMR spectrum will result in a significant expansion of rail radio infrastructure until 2035. The number of FRMCS masts to be built requires an efficient and sustainable network design for the rollout. Furthermore, rail radio is critical infrastructure (mission critical network) and a fundamental part of the rail production system – thus, technical planning according to rail operational requirements is mandatory. Given these prerequisites the masts need to fulfil criteria regarding the construction design: e.g. be low in height, permit-free, built close to the track and highly standardizable / automatable for the rollout. A trackside corridor fulfilling these requirements, with masts possibly useable for both FRMCS and public mobile services, is key for a fast, efficient, and cost-effective deployment. Technological innovations realizing these standardized masts and designing a matching fronthaul solution and power connection are required.

4.2.2 RAN sharing

Sharing of the radio access network can be a cost-effective strategy to deploy and expand mobile radio networks. It can also be more energy efficient and add resilience.

Optimising efficiency is facilitated by sharing active infrastructure through innovative approaches, such as MORAN (Multi-Operator Radio Access Network) and MOCN (Multi-Operator Core Network). These sharing models can be used to serve the Gigabit Train only and operate a separate FRMCS RAN or implement a shared RAN for FRMCS and Gigabit Train. These services can enable efficient deployment of FRMCS and the Gigabit Train by reducing redundancy in core network infrastructure, leading to cost savings and improved operational efficiency.

4.2.3 Massive MIMO (mMIMO) and Beamforming

Massive multiple-input multiple-output (massive MIMO, mMIMO) refers to the usage of multiple radiator elements in an antenna on both sides of a wireless link, which allows spatial diversity and multi-user multiplexing to be exploited by focusing the signal transmission or reception in a certain angular direction; this is often referred to as beamforming. MIMO and massive MIMO have the potential to enhance wireless communication in the railway domain. SU-MIMO (Single User MIMO) can increase peak user throughput and system capacity for one user (train with onboard antenna) while MU-MIMO (Multi-User MIMO) can improve the throughput for many users (individual passengers in the train).

Dedicated investigations and in particular pilot deployments are expected to be performed to optimise massive MIMO towards rail scenarios (within the boundaries of the 3GPP standard) and to determine optimal configuration sets and subsequent deployment strategies. Massive MIMO has a major impact on passive infrastructure requirements (mast support). This is a subject which must be investigated further.

4.2.4 Mobility condition

In general, the performance of physical layer mechanisms is closely linked to user mobility, which refers to the onboard side of the railway system. Mobility in combination with multipath propagation results in fluctuations of the radio channel (commonly referred to as "fading"), with multiple effects to be distinguished.

The negative effects of discontinuous radio conditions can be addressed by techniques such as link adaptation (e.g. by adapting modulation and coding schemes and/or transmit powers) with respect to the expected channel state. Mobility conditions for railways should be investigated and tested. Means should be explored for improving those conditions (i.e. network configuration measures and engineering rules should be derived).

4.2.5 5G network slicing

5G network slicing allows multiple logical networks to be created on top of a common shared physical infrastructure. Customised connectivity can be provided for each network slice, with all slices running on the same shared infrastructure.

Slicing could be applied for Gigabit Train and may be applied for Digital Rail Operation applications.

It should be noted that one may in general differentiate between E2E network slicing (i.e. where a mobile network operator provides a logical E2E network slice to another tenant such as a railway infrastructure manager) and RAN slicing (e.g. where an MNO provides only a logical slice of its radio access network to be used by another tenant). In the latter case, the other tenant would operate its own core network.

4.2.6 Onboard antenna design

Design and deployment of antenna elements for mobile communications on trains must be carefully considered since they must support RMR, MNO and GSM-R frequencies.

4.2.7 Connectivity in Tunnels

Mobile coverage in tunnels has always been a complicated and expensive challenge for the railways. Leaky cable infrastructure as used today have several disadvantages, such as high attenuation no support for MIMO, problematic to support TTD operation and high costs. Omnidirectional antennas at 1.8 GHz/3.5 GHz may be a better solution. As an example, omnidirectional tunnel radio heads could be installed at alternating intervals along both sides of a tunnel tube.

4.3 Gigabit Train innovations

4.3.1 Direct and indirect connectivity

Gigabit connectivity requires innovations in two respects: trackside coverage and onboard connectivity equipment. Providing cellular trackside coverage will be a challenge for MNOs. However, transferring the trackside signal into the train is another challenge to be considered.

Two models for connectivity inside a train are typically used:

- Direct connectivity:
  Passengers use their business contract with an MNO and connect via the SIM cards in their devices. To enable this model, the MNO's licensed spectrum must be made available inside the train (direct connectivity will be massively improved by frequency transparent windows).
- Indirect connectivity:
  Railway undertakings provide internet access to their passengers via Wi-Fi. Voice is provided via Voice over Wi-Fi or repeater technology for CS calls.

For carrier frequencies up to 6 GHz, direct as well as indirect connections are possible. When using mmWaves, a rooftop antenna via an in-train distribution system is necessary to connect the passenger. Both models of in-train connectivity compete for the same trackside signal and need to be further investigated. Topics to be looked into include carrier/spectrum aggregation, modem aggregation, parent coach aggregation, mmWave pico cells and frequency transparent windows. Current windows often severely degrade the radio signal due to metal coatings to keep out UV radiation (to prevent uncontrolled heating).

4.3.2 Onboard Wi-Fi

For sufficient throughput to be offered to every user on a Gigabit Train via Wi-Fi, multiple networks need to be aggregated as the spectrum typically available from a single network provider cannot fulfil the user requirements on its own. For onboard Wi-Fi systems, a plausible solution is therefore to use capacity available from several cellular networks covering the track and to offer this passenger connectivity both via a roof-top antenna to the onboard Wi-Fi network and directly to the passengers subscribed to the respective mobile networks. Network slicing allows network operators to guarantee throughput for passenger connectivity while protecting their customers from getting poor service. mmWave trackside networks could offer an alternative for providing the required capacity.

4.3.3 Onboard 4G/5G services

Onboard small/pico cells could be alternatively deployed to provide mobile coverage inside the train. In this case an appropriate high-bandwidth backhaul technology, i.e. mmWave, would have to be deployed along the tracks. A PoC with onboard 4G/5G Pico cells and mmWave backhaul is planned in 2024 in Project 5GMED.

4.3.4 Coordinated multi-point

Coordinated multi-point (CoMP) refers to techniques where multiple base stations coordinate their transmission or even simultaneously transmit the same data to a user, enhancing signal strength and reliability. CoMP helps in managing and reducing inter-cell interference, which is a significant challenge in densely populated network areas.

Railway scenarios are particularly suitable for CoMP as the number of cells requiring coordination among each other can be significantly limited. An investigation into how CoMP (to be introduced in 5G) can best be configured to support rail scenarios is recommended.

4.3.5 Cloud-RAN

5G Cloud-RAN is a significant evolution of traditional RAN architectures, offering enhanced capabilities. The virtualized nature of Cloud-RAN makes it easier to scale the network according to demand and offers better support for high-speed, low-latency 5G services. 5G Cloud-RAN enables features such as supercell that combines several cells along the track to reduce the number of handovers and thus increases performance. A high-speed train with 1000 passengers on board for example, generates many near-simultaneous handovers, reducing performance and reliability of the mobile network. A 5G-Cloud-RAN enabling supercell can mitigate this situation.

4.3.6 5G deployment options

There are five different 5G deployment options, with SA (standalone) options consisting of only one generation of radio access technology and NSA (non-standalone) options consisting of two generations of radio access technologies (4G and 5G).

For early Gigabit train deployments, since many passengers will still be using LTE handsets for passenger connectivity and penetration of 5G SA capable devices will be slow, a combined NSA + SA solution is to be seen as a transitory solution which will pave the way to a 5G SA solution and beyond.

As highlighted by the EU Whitepaper “How to master Europe´s digital infrastructure needs” an increased focus on “future-proof” 5G SA deployments ensuring high reliability and low latency is also needed.

4.3.7 mmWave

Millimeter waves with frequency bands ranging from 24.25 GHz to 71.0 GHz (5G FR2) are a possible solution to meet the demand of 3-5 Gbps in high-speed trains and at hotspots such as railway stations, maintenance facilities, and train depots. Throughput of several Gbps can be achieved with a cell radius <1 km and perfect line-of-sight. The mmWave high-speed train (HST) application scenario is part of 5G Release 17. More application scenarios for mmWave-HST such as tunnel operations will follow in 5G Release 18. The economic viability needs to be assessed.

4.4 Digital Rail Operations

Before delving into the innovations needed for connectivity for Digital Rail Operations, it should be noted that the basis for this connectivity is elaborated in detail at UIC, ETSI and 3GPP in the context of the standardisation of FRMCS. Key innovations that are being investigated here and are subject to standardisation include, among others:

- Usage of the mission critical (MCX) 3GPP framework for rail operations, with some adaptation for railway specific needs
- High power radio modules
- Co-existence of GSM-R and FRMCS in the same spectrum (900 MHz) and/or within complementary spectrum (1900 MHz) and capability of application layer equipment to use the different transport layers in parallel.

- New telecom onboard equipment and architecture, with standardised interfaces, that allows onboard applications to utilise the latest advances in wireless technology while the applications remain agnostic to the communication layer while being cybersecurity proof.
- Separation of the User Plane and the Communication plane, to ensure future proofness.

In addition to these aspects, there are, various degrees of freedom in how exactly to deploy, implement and configurate a 3GPP 5G MCX-based FRMCS system. This requires dedicated innovation.

4.4.1 E2E QoS Management

While the previous innovations referred to mechanisms aimed at improving the physical layer of the wireless links from train to trackside (i.e. the "bit pipe"), there is also substantial room for innovation on the communication layers above, in particular considering the diversity of the needs of communication use cases for future rail operations.

In this respect, 5G offers a novel quality-of-service (QoS) management framework and in general a wide range of options on different protocol layers to perform service prioritization, etc. As for previous innovations, it is deemed necessary to conduct pilots to validate which form of QoS management and which configuration thereof is best suited to rail operations.

4.4.2 Redundancy functionality

Beside more stringent data rate and latency requirements, applications for future rail operations are often also characterised by increased reliability needs.

With 5G addressing critical communication use cases, mechanisms for achieving higher redundancy are included in the standardisation under the URLLC (ultra-reliable low latency) concepts.

4.4.3 Enhancing coverage for FRMCS bands

Deploying FRMCS in conjunction with a GSM-R infrastructure poses several challenges. This migration will require installing 5G equipment on existing GSM-R towers and onboard systems with 5G radio on rolling stock. Moving to 5G will require a densification of the network grid with shorter inter-site distances for both 900- and 1900 MHz frequency bands.

In order to leverage infrastructure investments, it appears that passive infrastructure elements such as sites, IP transport infrastructure and electric power to feed the active network equipment could be shared between Digital train operations and Gigabit train.

4.4.4 Edge cloud deployment (multi-access edge computing, MEC)

MEC or multi-access edge computing takes cloud computing to the edge of the cellular network. There are several rail operation applications that require a reduced end-to-end latency. Examples include the fusion of sensor data from the train and the trackside for increasing the accuracy of incident detection, or ATO/ETCS in the context of reduced headways and short safety distances between consecutive trains. Running rail operation applications in centralised cloud environments comes with several advantages, e.g. regarding resource utilisation and scalability.

4.4.5 Enhancing location information with 5G

For several train operation applications, accurate information about the actual train location is essential. Furthermore, some connectivity services also require location information about trains and users, for instance for location-based voice connectivity (used to be able to connect to other users in proximity of a dangerous situation). For that purpose, a variety of positioning technologies are under consideration (e.g. GNSS-based localisation in conjunction with landmark detection, etc.), which may be complemented with information from the cellular network.

4.4.6 FRMCS Multipath (Bearer flexibility) and related onboard and trackside architecture

While the FRMCS system will be based on 5G technology, it is also designed to provide "bearer flexibility” (FRMCS Multipath), meaning that it can also use other 3GPP transport services, and possibly non-3GPP technologies (e.g. satellite communications or WiFi), in a way that is fully transparent to the applications. A key element for achieving this is to ensure that multiple onboard applications can make use of data paths via different transport domains (e.g. data paths via MNOs and FRMCS networks) through multiple onboard radio modules. With FRMCS Multipath use cases such as coverage extension for train performance applications or fall back for ETCS in case of outage are served.

Beyond standardisation, it is expected that innovation will be required on how the On-Board FRMCS is designed, and how to provide maximum flexibility, reliability and resilience in cases where individual network components (either onboard or trackside) fail.

5 Regulatory aspects

The provision of mobile services along railway tracks is not necessarily attractive for mobile network operators from a business perspective. Regulation may help to improve this situation and overcome the weak economic viability. This section explores some ideas for regulation:

1. **Mandatory communication infrastructure when new tracks are built**

   Regulators may stipulate that any new track infrastructure built be equipped with passive mobile network infrastructure appropriate for providing mobile services for Digital Rail Operations (e.g. Voice (including REC), ETCS and ATO) and maybe also for e.g. Gigabit Train types. IMs and MNOs would have to work closely together in such case to define a shared infrastructure (masts, fibre optics, equipment rooms) and co-existence principles (radio, maintenance, etc.).

2. **Prioritisation of B2B SIM cards**

   RUs provide internet access via Wi-Fi using modems with standard (E-)SIM cards, each being allocated as much bandwidth from the radio infrastructure as any individual customer device. However, if it was not for the SIM card limitations, each modem would be capable of providing bandwidth for dozens of passengers. Specific rules for prioritising capacity allocation for such SIM cards may be discussed by regulators.

3. **National rail infrastructure and licences**

   Member States typically grant railway infrastructure managers licences for using mobile infrastructure for train operations. Demanding licence criteria need to be met regarding health and safety, fitness for purpose and safe and compliant rail transport including adequate governance. Such a licence may imply accountability, that is legal responsibility for the safety of passengers and staff. Accountability could impose restrictions on infrastructure ownership, outsourcing and purchase of services.

4. **Applicable rules and legal obligations**

   Functional and system requirements for critical mobile communications are stipulated by ERA by means of the CCS TSI. Meeting the requirements for interoperability has legal implications.

5. **Possible impact of sharing services and infrastructure**

   Passive infrastructure sharing (e.g. sharing of sites, antenna masts, equipment cabinets) among railway IMs, MNOs and possibly Tower Companies may be considered but requires legal provisions in case mobile services are terminated unintentionally (e.g. due to bankruptcy). Irrespective of the collaboration model, the responsibility to ensure that the shared infrastructure must suffice the requirements of Digital Railway Operations must remain to the railway IM.

6. **Active infrastructure sharing**

   Active infrastructure sharing (e.g. based on E2E network slicing or RAN sharing) for critical services can be explored further, taking into account the regulatory framework and constraints. In this sense, deployment models of 5G Gigabit RAN networks led by the figure of a “Neutral Host” could be of consideration.

7. **Corridor permit to reduce administrative burden**
   Agile permitting processes would enable quicker and more efficient deployments. To promote this goal the idea of a corridor permit could be introduced. In this specific configuration, a corridor’s rollout design (including for the towers and for the collective environmental impact of the infrastructure to be deployed) has been determined in advance, therefore required permits should not be needed on a site

by site basis but rather for the full corridor. Indeed, the rollout should rather be approved based on one permit alone to speed up deployment and keep the administrative burden to the minimum.

6 Cooperation models

From a Gigabit Train connectivity point of view, we basically have two types of customers in trains: the rail passenger using onboard Wi-Fi systems (that will use MNOs as a backhaul transmission links) and the MNO passengers using direct services from MNO coverage along the track. These two types of customers are served by two different service providers, the RU and the MNO.

Both need to be powered by the same public mobile network architecture.

Rail requires the construction of **a rail-specific, dedicated passive and active network** which is more costly than current area-coverage mobile network. Typically, 70–80% of the costs is for the passive infrastructure, i.e. **many closely spaced towers**.

It is therefore reasonable to ask how this investment can be afforded.

One lever of cost reduction could be through network sharing. National regulation may allow FRMCS passive mobile infrastructure to be shared with future 5G (MNO public) infrastructure under strict safety, maintainability and security conditions. Potentially, 5G infrastructure along railway lines could also become the passive infrastructure for MNOs under quality of service and maintainability conditions.

In summary, current business models of both rail and mobile operators do not ensure sufficient funding of mobile networks for rail purposes to enable implementation of the Gigabit Train on a large scale. Regulation

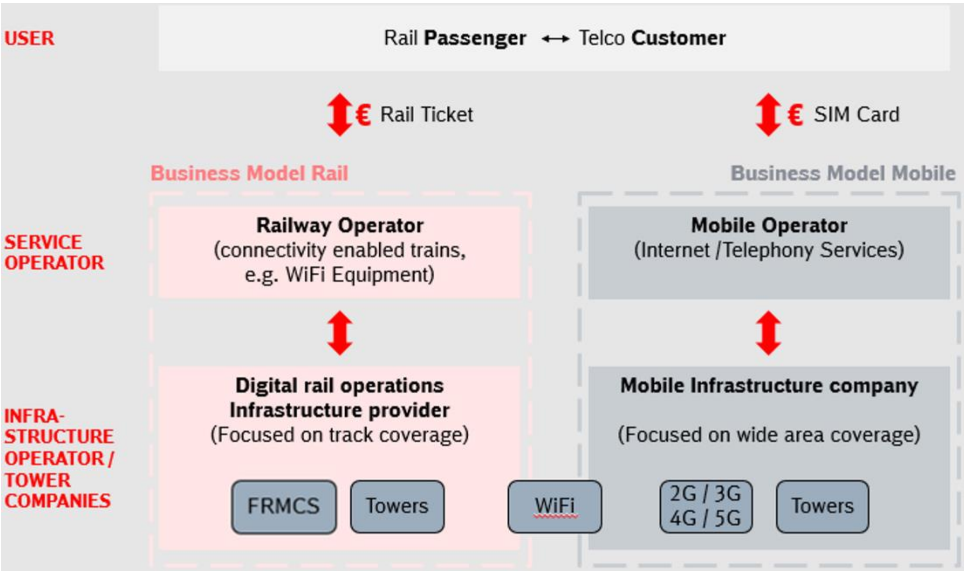

Figure 4 Sharing infrastructure (Gigabit Train and Digital Rail Operations)

and network sharing may improve financial feasibility on more high-frequency rail corridors; but these levers do not appear to be sufficient.

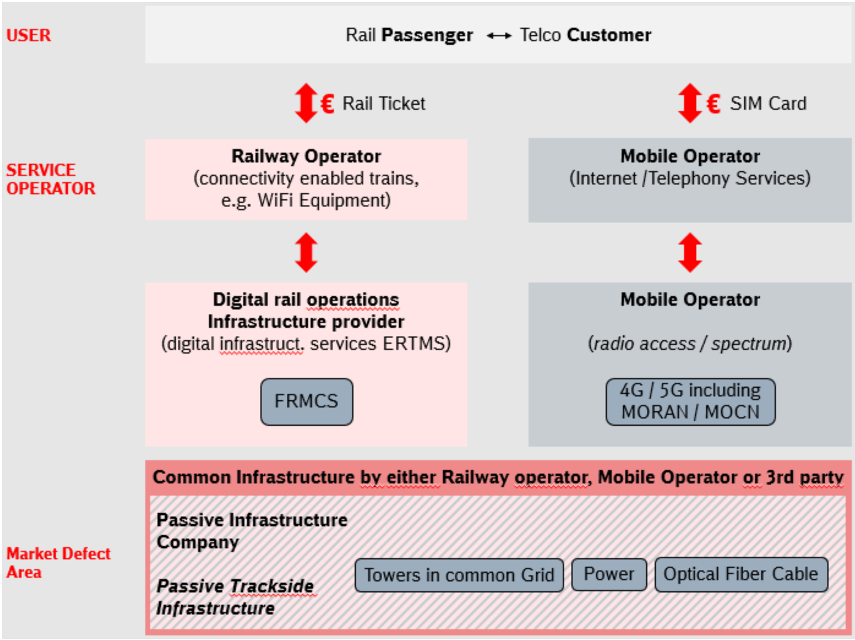

Figure 5 Gigabit Train (direct and indirect coverage)

Additional funding of CAPEX and OPEX of passive infrastructure for both FRMCS and public mobile networks could be an appropriate option; depending on the national situation and requirements for secure rail-specific mobile networks.

For a 5G-based FRMCS system, the situation is similar to that shown in Figure 6. This figure depicts principal deployment options, focusing on possible infrastructure sharing options. The list is not complete but is used to illustrate the wide range of sharing options available (which may be limited depending on national regulatory constraints). Possible options for sharing passive infrastructure and RAN are described in par. 4.2.1 and 4.2.2.

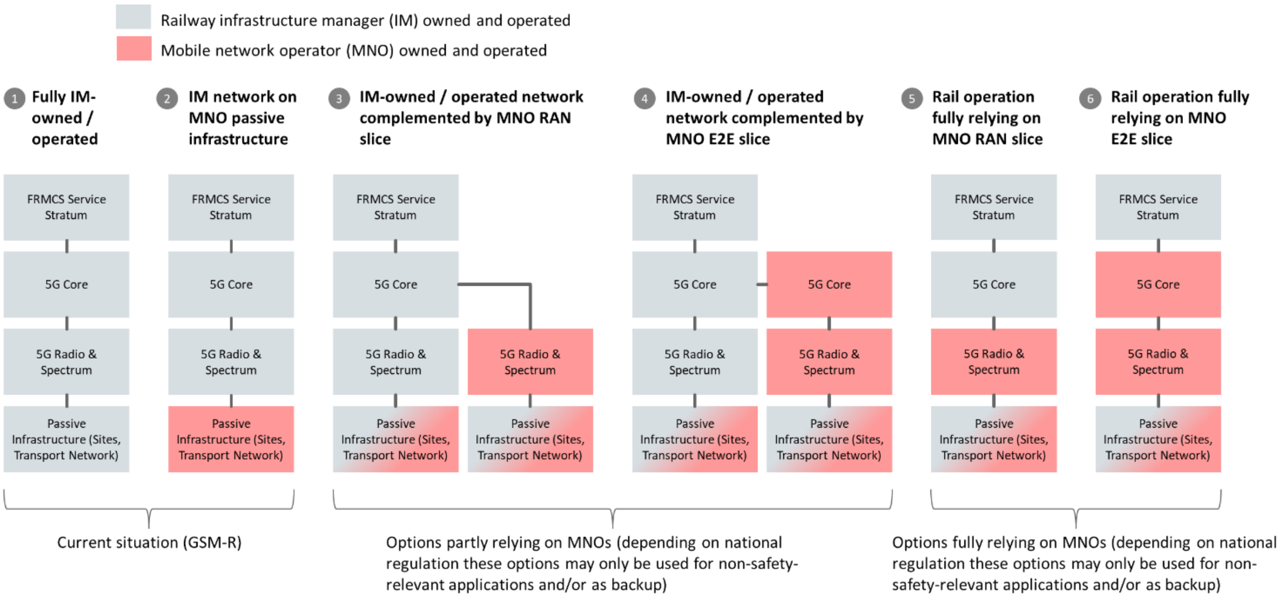

Figure 6. Principal deployment options (broken down by IM-owned/operated and MNO-owned/operated technologies) for Digital Rail Operations.[2]

On the left side of Figure 6, **option 1** depicts a setup where a railway infrastructure manager owns and operates a full FRMCS and 5G system from the passive infrastructure up to the functions in the FRMCS service stratum. This reflects the typical situation for today's GSM-R deployments across Europe.

As a first setup towards infrastructure sharing, **option 2** shows the case where a railway infrastructure manager owns and operates the active 5G equipment and the FRMCS services but uses (part of) the passive infrastructure (e.g. sites, antenna masts, optical network) of a mobile network operator.

In **option 3**, a railway infrastructure manager uses a shared RAN offered by a mobile network operator for a subset of applications and/or as a fallback option in case its own infrastructure fails. This approach is independent of the ownership of the passive infrastructure.

In **option 4**, the railway infrastructure manager uses a 5G end-to-end slice from a mobile network operator, again for a subset of applications and/or as a fallback, while likely still operating the FRMCS service stratum itself.

In **options 5 and 6**, a railway infrastructure manager relies (at least in a given geographic area) on a RAN slice or end-to-end slice provided by a mobile network operator. Such a RAN or end-to-end slice must include all FRMCS applications required by infrastructure managers (IMs) while ensuring all ERTMS interoperability requirements.

Practical FRMCS deployments may include a mixture of the above options. For example, infrastructure managers may use their own network to cover main lines (i.e. option 1 or 2 above) while using public networks for some secondary-line applications (e.g. option 3 or 4 above), where national regulatory and legal constraints allow.

The Gigabit Train and Digital Rail Operations have different characteristics that need to be taken into account when exploring sharing options and synergies between the two.

[2] It is possible that the MNO or even the railway IM network infrastructure is owned by a TowerCo.

Table 1 Characteristics of the Gigabit Train and Digital Rail Operations

	Gigabit Train	Digital Rail Operations
Main drivers	• Need to make trains more attractive for passengers by providing better connectivity than for air and car travel • Passengers having more productive time to exploit connectivity (travel time is useful).	• Legal obligation of Member States to roll out FRMCS and ETCS • Essential element for day-to-day railway operations • Need to substantially increase rail capacity due to stringent carbon emission targets in Member States • Pressure to automate rail operations and digitalisation due to demographic challenges and need for improved cost efficiency
Main KPIs	• Average throughput • Streaming performance • Stability of connectivity • Uninterrupted voice communication Note: Assessment required for difference between mass transit and high speed line requirements	• Performance • Availability • Reliability • Resilience • Quality of service • Safety • Security
Main constraints	• Low economic viability when it comes to funding the dedicated trackside infrastructure along railway lines • Proper sharing models for active/passive infrastructure • Proper cooperation models between involved parties to make for a viable business model	Potential strong legal and regulatory constraints in most countries, e.g. • Need for E2E homologation of safety-related applications and associated connectivity • Implementation costs • Certification and authorization
Key technical characteristics	• Fast changing landscape resulting in a tightly knit network grid able to provide sufficient capacity to achieve the required performance for a 1,000 passenger train • Involving multiple MNOs	• Need for specific communication services (e.g. voice group communication, role management, service authorisation, quality of service, etc.) that go beyond pure IP connectivity • Typically long life cycles of onboard equipment (10 – 15 years at minimum)
Key ecosystem characteristics	• Choice of onboard equipment/technology may be left to each railway undertaking	• Choice of onboard equipment/technology options based on CCS TSI, with some flexibility for national infrastructure managers and train operating companies

It should be noted that the usage of public networks for rail operation services is subject to national regulatory, liability and legal constraints.

7 Tentative deployment scenarios

This section describes tentative deployment scenarios for the Gigabit Train and Digital Rail Operations or a combination of both. It defines the criteria which a certain scenario (or scenarios) must meet and identifies generic building blocks to be used in the context of that specific deployment scenario. Several separate deployment scenarios for the Gigabit Train and Digital Rail Operations are proposed. Ideas for possible common deployment scenarios are also described. The list of deployment scenarios is not complete, and it is recognised that not all deployment criteria could or should be fulfilled by any individual scenario. The section is concluded with a list of railway lines and corridors where trials and deployments are envisaged.

7.1 Principles and criteria for deployment of the Gigabit Train and Digital Rail Operations

The criteria and prerequisites for deployments are:

- The extent to which the objectives of future rail communication requirements are fulfilled in terms of:
  - The Railway Vision
  - Fulfilment of service requirements
  - Innovations required
- The possibility to develop and establish the regulatory environment required for deployment
- The possibility to develop an adequate cooperation model between stakeholders
- Participation of multiple consortia across Europe, based on mutual interests of countries, railway infrastructure and train operators, regulatory bodies, the supply industry, MNOs and TowerCos
- Cross-border operation (for example along TEN-T corridors)
- Specify and test fit-for-purpose FRMCS
- Synergetic FRMCS / Gigabit train deployments
- Operation which supports the most important service requirements of Digital Rail Operations and Gigabit train in designated areas (e.g. rural, low-density lines)
- Realistic timelines for deployment, compliant with the planning of CEF2 or for other funding frameworks

7.2 Gigabit Train

7.2.1 Deployment scenarios

Examples of Gigabit Train corridor deployment are shown in par. 7.4. The suggested architecture is a combination of shared passive architecture (potentially shared with a network for Digital Rail Operations) and shared active architecture.

7.2.2 Timeline for Gigabit Train deployment

Two phases of deployment are envisaged.

Phase 1: Gigabit basic functionality

The ideal timeline for starting projects for the Gigabit Train would be 2024 as deployment of the 5G technology started at the end of 2019. Onboard modems, on-train and trackside antennas, 5G radio units, baseband and other telecommunication infrastructure for 5G deployment architecture should be broadly available by 2021. However, many European countries are yet to attribute all 5G frequency bands to operators, slowing down progress in deployment both nationally and on international routes.

Phase 2: Gigabit extended functionality

5G could also be applicable in depots, maintenance facilities, and railway stations, even using additional, not yet allocated frequency bands such as 26 GHz or even higher. Stationary use cases would fit the smaller cell sizes that can be achieved with these types of frequencies. Note that very large chunks of spectrum bandwidth will be made available in these frequency ranges, which will pave the way for even higher peak data rates typically required for service requirements such as CCTV offload or CDN storage refresh in the order of magnitude of tens of Gbps.

7.3 Digital Rail Operations

7.3.1 FRMCS European trials and first deployment

FRMCS will, by definition, support Digital Rail Operations. To ensure successful deployment, FRMCS trials need to be performed on corridors or in designated areas.

A first step is to develop and evaluate prototypes for an FRMCS end-to-end system delivering essential communication services (critical and performance) for railway applications (ETCS, ATO, voice, data and video). This first step is being addressed in the context of the Horizon 2020 ICT-053 call, via the project 5Grail, started in November 2020, and ended in December 2023, This project has built and tested the first FRMCS prototypes. In the early CEF2 phase (2021–2023), studies for 5G corridor deployments have been funded.

FRMCS introduction is developed in three steps – see Figure 7.

Step 1 is the delivery of FRMCS v1 specification and inclusion in the TSI. This step is achieved in September 2023.

Step 2, which is ongoing, is the build of FRMCS v2 specifications and the set-up of the EU Rail JU FRMCS European Trial for verification and validation also known under the working name MORANE 2.

Step 3 is executing MORANE 2 as part of EU Rail, after which FRMCS v3 specifications will be delivered. FRMCS v3 will be included as part of CCS TSI in June 2027.

Due to standards and equipment availability timelines, a number of tests campaigns will need to be funded to introduce FRMCS elements.

FRMCS v3 will be the basis of the FRMCS 1st Edition system, that will be available for Railways to start national pilots or projects.

7.3.2 Timeline for the deployment of Digital Rail Operations

The introduction of FRMCS is subdivided in three main phases:

- In the first phase (2018–2023), the focus has been on specifying, developing and evaluating FRMCS/5G prototypes (supported by ICT-053/5G Rail). The specification process was performed at 3GPP, UIC, ETSI and CEPT level. This phase was closed with the introduction of FRMCS in the CCS TSI 2023 and the finalisation of 5Grail.
  In this phase, basic 5G corridor deployments may also being realised (e.g. for serving the needs of the Gigabit Train), which are then already prepared to later support FRMCS (e.g. through passive or active network sharing).
- The second phase (2024–2027) covers the launch and execution of the EU Rail Destination 2 project to deliver the MORANE 2 trial. The emphasis is on deployment optimisation, cross-border interoperability and various aspects that go beyond standardisation, such as the innovations listed in Section 4.

- As of 2024, the third step is about delivering the FRMCS V3 specifications that will define the FRMCS 1st Edition, which will be incorporated in the CCS TSI. Initial FRMCS products are planned to reach the market from 2027 onwards.
- It is essential that in parallel to phases 1 and 2, ETCS roll-out along the same corridors is pursued alongside preparing the infrastructure for ATO and other applications.

The timeline is illustrated in Figure 7:

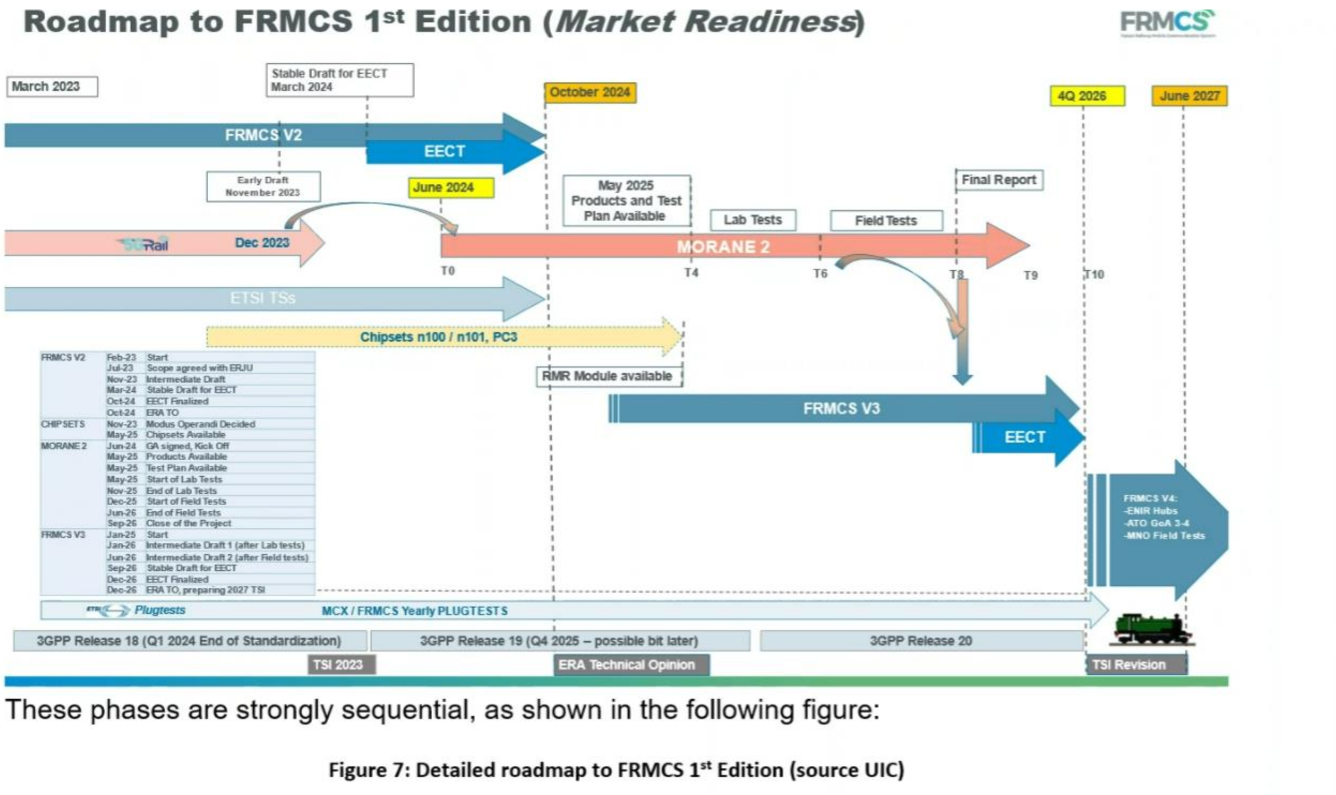

Figure 7 FRMCS Introduction Plan

Note that the early FRMCS adopters plan to start commercial operation early after the update of the CCS TSI, hence it is crucial to adopt the ambitious timeline shown here.

7.4 Tentative common deployment scenarios

Common deployment scenarios for the Gigabit Train and Digital Rail Operations are for example:

1. **Gigabit Train and Digital Rail Operations on corridors**
   Mobile communication services for Digital Rail Operations (critical applications only) are provided by using an FRMCS network with (harmonised) dedicated spectrum. Gigabit Train services are provided by MNOs, with additional connectivity for Digital Rail Operations functionality being provided by an MNO slice “Digital Rail Operations” (E2E or RAN slice) for performance applications and as a backup service for critical Digital Rail Operations applications. A high level of passive and partially active infrastructure sharing is foreseen between MNOs and infrastructure managers (i.e. FRMCS operators) (e.g. sharing masts, sites and optical fibre).
2. **Gigabit Train and Digital Rail Operations deployment in low density areas**
   Gigabit Train services are provided by MNOs and connectivity for Digital Rail Operations functionality by an MNO slice “Digital Rail Operations” (E2E or RAN slice). This slice is used for Digital Rail Operations applications alongside GSM-R. The slice provides services for mission critical services and a backup for

ETCS/GSM-R communications (with potential reduction in service reliability). After the migration phase (i.e. once GSM-R is phased out), critical communications (such as ETCS) could be provided using dedicated spectrum, or service provisioning with the MNO slice could be prolonged.
A high level of sharing is foreseen between MNOs and infrastructure managers (i.e. FRMCS operators) (e.g. sharing masts, sites and fibre optics).

7.5 Costs of deployment

This section provides a cost estimate of one of the more promising deployment scenarios. The cost analysis focuses on investment and operating costs and cost drivers and identifies potential cost reductions to be achieved through sharing and synergy between Digital Rail Operations, the 5G MNO deployment strategy and the Gigabit Train.

7.5.1 Cost reduction through sharing

Significant cost reduction is achieved by RAN infrastructure sharing. If the RAN of a single mobile operator is taken as a reference, sharing with a second operator significantly cuts costs. Starting from that, sharing with a second operator (i.e. two MNOs and one FRMCS service provider) yields additional cost optimisation.

7.5.2 Other potential cost savings

There are many additional cost saving opportunities:

1. Outsourcing of baseband units (BBUs) to "baseband hotels".
2. Upgrade and re-use of existing sites.
3. Sharing of active equipment (e.g. RAN slicing or E2E slicing).
4. Increase of the inter-site distance (ISD), adding more spectrum to compensate for a decrease in throughput.
5. The deployment of compact and therefore permit-free towers (where possible) alongside the corridors could contribute to reduce the infrastructure costs (in comparison to macro standard towers), ensuring much leaner construction works as well.
6. Enable access to existing fibre and energy grids for the 5G Gigabit and design and execute synergetic upgrades of fibre and energy grids to cover the needs of both railway and public 5G networks.

7.6 Examples of corridors for deployment

Countries that have expressed initial interest in CEF projects for (cross-border) corridors for deployment and studies are Austria, Belgium, Finland, France, Germany, Luxembourg, the Netherlands, Portugal, Spain, and Sweden.

On several national and international corridors, projects, or studies on 5G deployment for both FRMCS and public networks have already begun. Prominent examples include the cross-border corridors *5G on Track* and *5G MELUSINA*, both of which were funded under the *Connecting Europe Facility*, a European co-funding programme with a total budget of several hundred million euros:

- 5G on Track Karlsruhe-Mulhouse studied the international corridor between Karlsruhe and Mulhouse, investing in the development of new site models for mutualisation between railway infrastructure managers and public mobile network operators in cooperation with tower companies. Specifically, a full 3,6GHz deployment for a Gigabit Train objective was investigated with the objective to make the shared use of infrastructures technically possible for rail radio and public mobile radio. An innovative, standardized, and modular pole architecture was identified that is 4-6 m away from the track, covering the requirements of both FRMCS and MNOs and needing significant fewer ground to be built on. Further, it is important to note that for the investigated solution the existing infrastructure was considered (so-called “brownfield approach”), resulting in a rather large number of poles necessary to supply the route with the targeted coverage. The study provided valuable insights and proved that the industry can provide innovative, technical solutions for complex infrastructures. However, due to the complexity of a possible implementation with regard to the parties involved and solutions to be found also concerning funds, especially in a cross-border environment, a gradual deployment, first on a national level, would be an additional approach.

- 5G MELUSINA targets one of the most used railway corridors in France outside of the Greater Paris region between Metz and Luxembourg City – An international commuter line with regional traffic (<160 km/h) transporting tens of thousands of passengers every day. Apart from increased passenger services, high availability of railway communications enabling ATO would allow at least one additional hourly train per direction in rush hour, allowing to take off the ever-growing pressure from the parallel road highway linking the Lorraine region to Luxembourg.
- [Awaiting Grant Approval as of August 2024] 5GiRa is a CEF2 Digital (study) project for the corridor Arnhem – Emmerich (it is part of the TEN-T corridor Amsterdam – Frankfurt). The project explores the possibility of a hybrid FRMCS network (RMR 1900 MHz + public MNO), Gigabit train deployment and advanced sharing concepts for passive radio infrastructure (e.g. shared RAN (MOCN), Neutral hosts, MVNO or public subscriptions). RMR and MNO Data paths are used in combination with FRMCS Multipath. The setup may be used for validation and verification of FRMCS in the context of the EU Rail Destination 2 call.
- The German Gigabit Innovation Track (GINT) project is analysing the feasibility of a 5G-based gigabit corridor, specifically dedicated for the tracks (so-called “greenfield approach"), i.e. rail radio and passenger supply. Therefore, technical solution concepts, special features of the legal and regulatory framework and applicable business models are being investigated, in which, for example, radio masts can be used jointly for FRMCS connections and 5G connectivity for passengers in a competition-neutral manner.
  In addition, proposals for a future operating and cooperation model for gigabit connectivity for passengers in the train through extensive shared infrastructure utilisation ("neutral host") will be developed. These cooperation models should leverage as much as possible on the strengths of the different players (Railway IM, TowerCos, MNOs). In addition to technical analyses and laboratory tests, a 5G radio corridor in Mecklenburg-Vorpommern with around ten mobile radio sites along a 10 km test track is also planned to test the 5G gigabit corridor and gain insights with respect to planned deployments on operating lines.
- The 5G HSL Eurolink project will prepare the deployment of 5G on the HSL Paris – Brussels, which is part of the TEN-T network that connects all great European cities together. This high-speed line is the third-busiest line in France and the first busiest in Belgium.
  2 main axes will be studied:
    1. FRMCS deployment by Infrastructure Managers (IM) along the track and by Railway Undertakings (RU) on-board the train;
    2. 5G coverage along the line by MNO, with on-board facilities inside the train by Railway Undertakings.

  The first axis will ensure service continuity at the cross-border area. The next step migration to ETCS level 2 will ask to transform the network. Developing FRMCS is becoming mandatory to improve the data connectivity for trains.
  The second axis is of prime importance to provide a higher connectivity for all passenger on this line especially for the WIFI on board.

- The Brno-Bratislava study focuses on a comprehensive technical analysis in the defined area of the railway corridor between Brno (Czech Republic) and Bratislava (Slovak Republic) with the aim of implementing 5G/FRMCS systems. The OEM corridor connects two strategic cities, Brno and Bratislava, which are located close to the national border with Austria. This strategic geographical location provides a link between national and international transport routes. The OEM corridor is part of the trans-European rail corridors, which facilitates smooth crossing between countries. Specific objectives include the implementation of 5G and FRMCS communication systems considering the existing communication environment and the requirements of the transport path. The study must design the location of BTS to be usable for both systems and to meet the conditions for continuous radio coverage by FRMCS. Emphasis shall be placed on the use of existing railway infrastructure and, where appropriate, also public operators' infrastructure. The economic aspect shall include an assessment of the benefits of the proposed solution and the costs of servicing and maintaining the infrastructure for both railway administrations (SŽ and ŽSR). The study shall be based on the requirement for uninterrupted existing GSM-R operation on the corridor during 5G/FRMCS installations.
- [Awaiting Grant Approval as of August 2024] 5G4RAILSCAND is a CEF2 Digital (study and works) project for the Scandinavian – Mediterranean Corridor (TEN-T) section Oslo – Copenhagen. The project comprises of an FRMCS border crossing study and the construction of the passive telecom infrastructure preparing for the deployment of FRMCS in 2029. The main objective of the project is to prepare the railway infrastructure, in the Scan-Med corridor section Copenhagen-Gothenburg-Oslo). The project builds on a cross-border collaboration between Trafikverket (SE), Bane NOR (NO), Øresundsbro konsortiet (DK) and Banedanmark (DK). The project includes a study work package in which the planning for how to make FRMCS work cross border and for streamlining the planning of the next phase which would be implementation of active FRMCS components as soon as the standard for this has been adopted.