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

Developed by EIM and CER, with input provided by UIC, UNIFE/UNITEL and members of the European Rail industry.

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Content

1 Executive summary

The EU has formulated ambitious environmental plans by announcing a new European Green Deal aimed at accelerating emissions reduction. The goal is to make Europe climate-neutral 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. Advanced 5G communication services for rail significantly contribute to achieving these ambitions.

In this SDA, two 5G lighthouses are described: The Gigabit Train, which offers a modern travel environment by supporting digital customer experience (reliable and high-performance connectivity for passengers), and Digital Rail Operations (communication services necessary for train movement and rail operation enhancement), which improves capacity and regularity of railways in order to “shift to rail”. The SDA provides guidance for deployment planning and CEF2 funding of 5G mobile infrastructure and services along railway lines in order to implement Gigabit Train and Digital Rail Operations applications.

The SDA also considers new cooperation models since 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.

Innovation, interoperability and digitalisation will have a positive multiplier effect on the wider (railway) industry. Innovation should be fostered to contribute to making the Single European Railway Area (SERA) more competitive. 5G including FRMCS will enable the digital deliverables such as Automatic Train Operation (ATO) and European Rail Traffic Management System (ERTMS) to be deployed.

EIM and CER members (Railway Infrastructure Managers and Railway Undertakings) consider 5G to be essential for supplying services on railway corridors and advocate providing adequate EU funding for the deployment of 5G under the Connecting Europe Facility (Transport and Digital).

In order to enable current and future rail traffic, a high level of service needs to be ensured on high-speed, main, mass transit and freight lines. This can be achieved by networks that utilise dedicated spectrum. Guided by the EC mandate, ECC and CEPT work on providing two times 5.6 MHz in the 900 MHz band and 10 MHz in the 1900 MHz band. Availability of these bands will enable both mission critical and (some) performance applications as well as the migration of GSM-R to FRMCS. Increased usage of FRMCS is expected to be caused by the introduction of applications such as remote video control and Automatic Train Operation (ATO). Mission critical applications require adequate quality of service: if ETCS experiences a connectivity outage, trains will stop, whilst a reliable railway emergency call is paramount to railway safety.

Passenger connectivity will be provided by mobile network operators (MNOs) through public 5G services. Support of the rail-specific use cases, e.g. a thousand passengers per train with connectivity needs in the Gigabit/s range, requires innovation and continuous improvement of 5G. Cooperation and sharing models between MNOs and railways (IMs and RUs) need to be developed in order to overcome the low economic viability. It is important to leverage sharing of passive infrastructure (such as sites, towers, power supply installations and fibre transmission systems) to increase cost efficiency and potentially allow the use of rail-owned infrastructure.

Sharing active network elements (e.g. 5G slicing) is not per se excluded. Depending on national policy, public services might be used e.g. for regional lines, performance applications or as a backup. However, the use of public networks for rail operation services is subject to national regulatory, liability and legal constraints.

The feasibility of 5G active network sharing is challenging and has to be proven. Critical aspects such as interoperability, QoS, service level agreements, regulations, legal issues and liability requirements must be scrutinised

2 EU policy on railways

2.1 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. In the course of this year (2020), the Commission will adopt a 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, which the Commission will propose by 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.

2.2 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.

- However, in many EU 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.
- 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

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[1] https://www.cer.be/publications/latest-publications/cer-policy-agenda-2019-2024

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 next-generation Shift2Rail, but also other interoperability initiatives, should be fostered to contribute to making the Single European Railway Area (SERA) more competitive. 5G 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 the Shift2Rail EU Joint Undertaking, 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 third-country 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 in the rail sector will allow the EU to keep up the pace of innovation in the field of connectivity technologies while setting the standards to minimise the risk of cyber-attacks.
- The SDA 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.

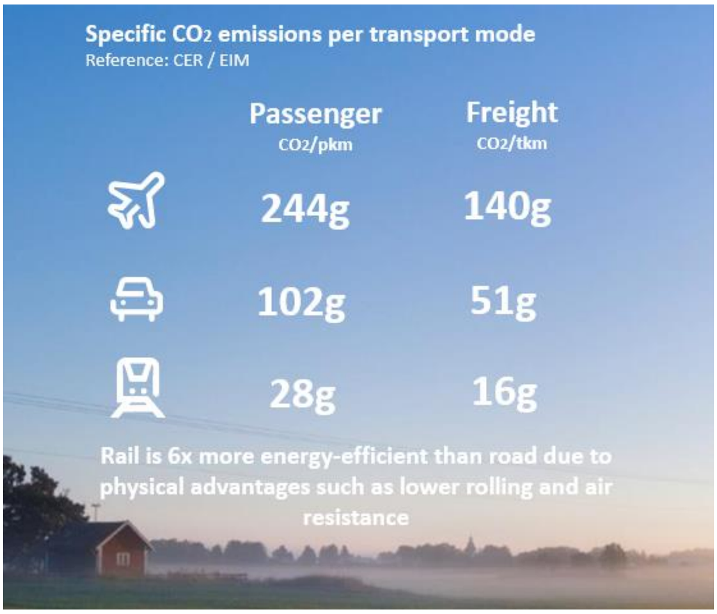
Ensuring EU defence and military mobility is a task that was assigned to rail, and to the IMs in particular, only relatively recently. Military mobility and cyber security are at the forefront of the political discussion. The wider rail sector, including its rail infrastructure managers, will contribute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

3 Railway vision and goals for mobile communications

3.1 Current challenges and opportunities for rail

Within the context of the European Green Deal, EIM and CER 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, the goal being to double the number of travellers compared with previous years.



Specific CO_2 emissions per transport mode
Reference: CER / EIM

	Passenger CO_2/pkm	Freight CO_2/tkm
✈	244g	140g
🚗	102g	51g
🚆	28g	16g

Rail is 6x more energy-efficient than road due to physical advantages such as lower rolling and air resistance

Figure 1 CO_2 emissions by transport mode

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 300 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. In fact, 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.

Rail Operations

Supporting Digital Rail Operations by introducing higher levels of ETCS and the Future Railway Mobile Communication System (FRMCS) will allow headways between trains to be significantly shortened, with a massive impact on capacity. 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. Higher levels of automation (ATO and ERTMS) ensure an increase in track utilisation and cost optimisation.

5G benefits

Advanced 5G communication services for rail significantly contribute to achieving these ambitions. However, 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, 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 Gigabit Train and Digital Rail Operations applications.

3.2 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 is similar to 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 at least 1 Gbit/s per train carrying 1,000 passengers, without accounting for future applications and usage rates per passenger.

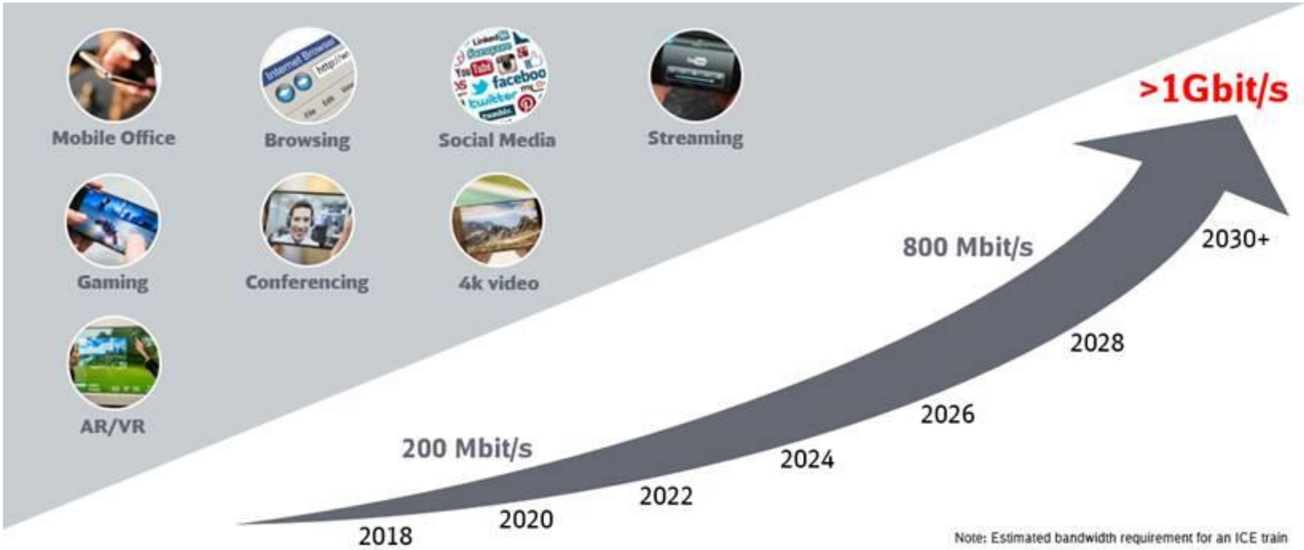


Figure 2 Gigabit Train: overview of applications and throughput requirements of trains carrying 1,000 passengers

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 is currently the best option to aggregate enough mobile capacity along railway lines to respond to the connectivity demand. Therefore, this SDA analyses mobile networks, requirements and solutions for the Gigabit Train assuming MNOs continue to provide trackside coverage. Complementary to this model, Digital Rail Operations also relies on privately-owned special-purpose networks with dedicated spectrum to meet quality and regulatory requirements.

3.3 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.

The EU legal framework for railways – the Control Command and Signalling Technical Specification for Interoperability (CCS TSI) – specifies 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 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 between 2025 and 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 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 will incorporate FRMCS as the successor to GSM-R and support new railway functionalities such as ATO and the Train Control Management System (TCMS). The work on user, functional and system requirements, specifications and standards 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 update the TSI in 2022 by incorporating FRMCS version 1.0.

5G is the target technology for FRMCS. It is expected to provide a low-latency and spectrally efficient foundation which will be mainly for critical applications, but will also include some performance applications.

For critical applications in particular, dedicated, harmonised 900 MHz and 1900 MHz frequency bands are expected to be available for railway-operated FRMCS/5G 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 Sections 6 and 7.

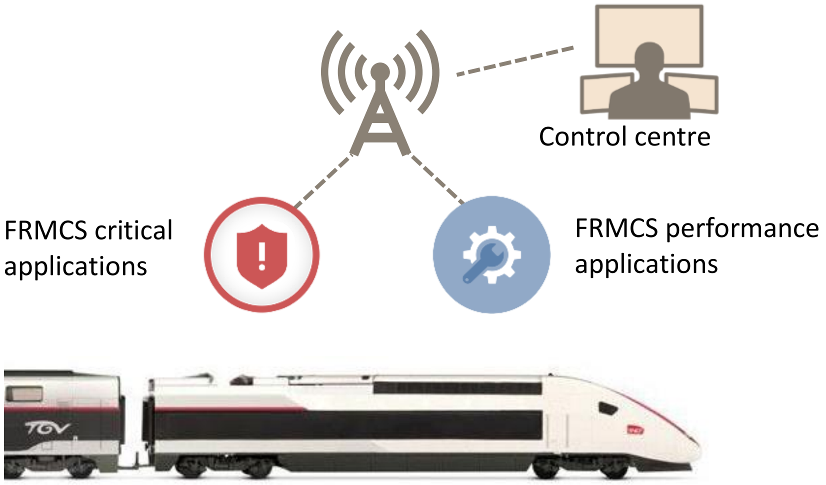


Figure 3 5G for FRMCS critical and performance applications

Beyond the immediate needs of rail operations, 5G will also serve as a stepping stone to further innovation in the rail sector such as predictive maintenance and reducing deployment costs. 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 antennas, massive MIMO and coordinated multi-point services optimised towards rail scenarios and aimed at minimising deployment costs. For E2E Quality of Service management to handle the diversity of rail applications, methods will be needed for cost-efficient infrastructure sharing (slicing) among MNOs and railway infrastructure managers (within the boundaries of national regulatory constraints).

3.4 Objective of the Strategic Deployment Agenda

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 50–100 Mbit/s. This does not fulfil long-term needs in the ranges of the 1–2 Gbit/s 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, mMIMO, network slicing 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.
- 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 and technical solutions need to be considered. 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 2021 and 2027. It is the basis for innovation and enhanced services for rail operations and rail passengers, public/private cooperation, investments and partnerships, and 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 generic technical constituents and innovations needed to meet railway service requirements
3. Provide an understanding of market situations, regulations, standardisation bodies, cooperation (models), sharing of assets (such as trackside infrastructure), and stakeholders
4. Provide a vision on deployment scenarios along corridors and designated areas, taking into account the EU funding criteria
5. Provide an indication of the costs of deployment along corridors and designated area
6. Provide guidance on planning and timelines for deployment

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

4 Service requirements

4.1 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 no different from what they will be using 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, streaming, gaming, onboard media portals, concierge services, etc.
- ***Connectivity for staff*: drivers, controllers, 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 3.3).

High-performing, continuous mobile networks 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.

4.2 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 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 (staff and infrastructure):
Examples include Railway Emergency Calls, passenger surveillance, CCTV and telemetry applications.

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 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. Driverless train operation will require 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.

5 Building blocks needed to meet service requirements

5.1 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 5.2.

Figure 4 provides an overview of innovations required for Digital Rail Operations and the Gigabit Train.

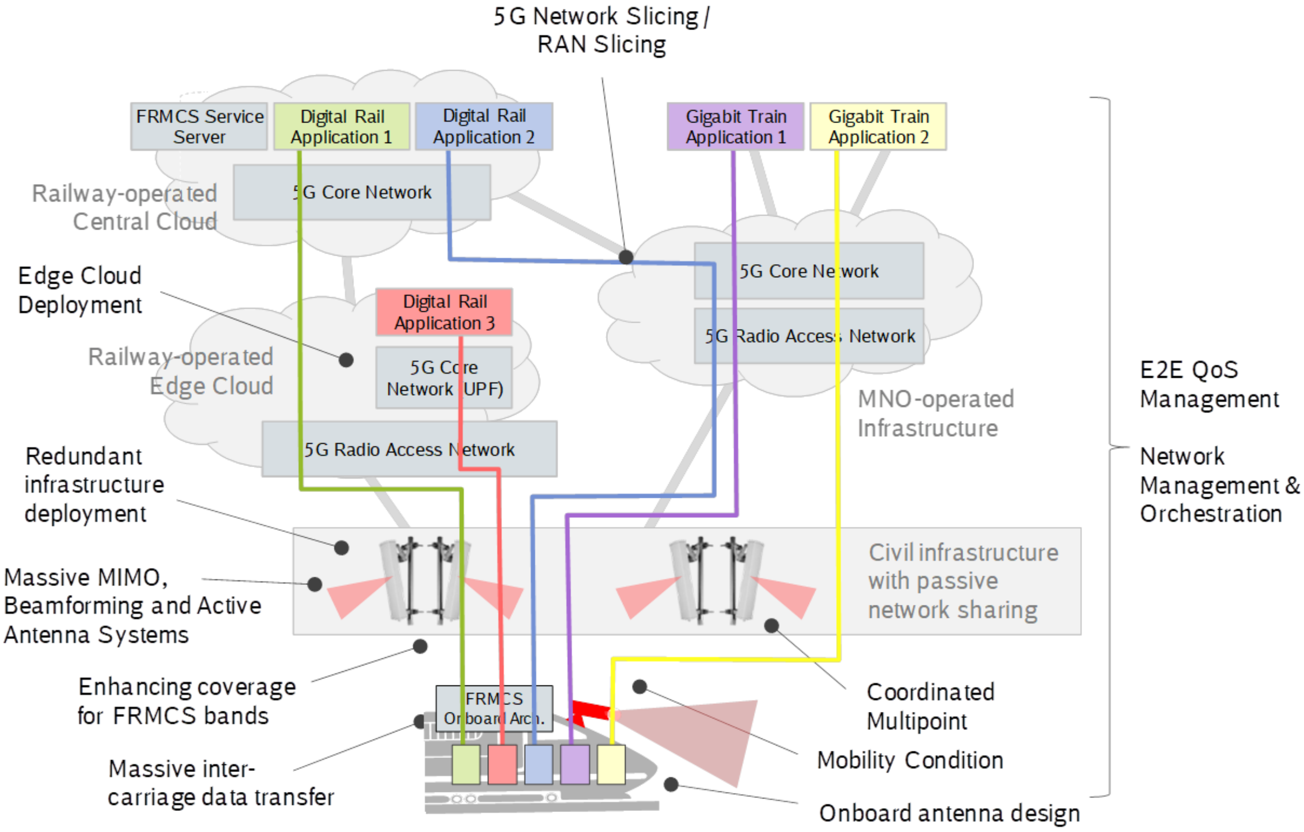


Figure 4 Overview of a subset of required innovations for the Gigabit Train and Digital Rail Operations

5.2 Innovations common to the Gigabit Train and Digital Rail Operations

5.2.1 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.

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.

5.2.2 Massive inter-coach data transfer

Massive inter-coach data transfer is a topic which could be addressed during deployment. It extends the gigabit throughput throughout the train and allows gigabit in-train coverage between coaches if cabling between coaches cannot provide a sufficient bitrate.

5.2.3 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).

5.2.4 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. This is achievable in 5G networks due to the availability of advanced virtualisation and orchestration capabilities, including virtual networking functions (VNF) and software defined networking (SDN) architectures.

Network slicing is an important feature of 5G networks and provides connectivity services tailored to designated customer requirements. Vertical industries such as railways (slice customers) agree on a set of common slice attributes which define the service. Slicing is beneficial for MNOs and its customers since it may enhance the efficiency, productivity and time to market of vertical markets and will give operators the opportunity to address the business-to-business segment more effectively.

A slice is characterised by one or more of the following attributes and functions:

- Functionality (priority, security, mobility)
- Subscriber management
- Throughput
- Reliability
- Availability (service levels)
- QoS attributes (latency, priority)
- Slice management and orchestration
- Application programming interfaces (APIs)

Slicing can be applied to both Gigabit Train and Digital Rail Operation applications and needs to be investigated further. Regulatory and liability aspects should be scrutinised, and a proof of concept is recommended.

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.

5.2.5 Onboard antenna design

Current (single-pole) antenna elements for mobile communications are mostly positioned at the centre of the roof of a train. There are several ideas for improvement that are worthwhile to investigate. For example, one option would be to place four antennas on both sides of the train roof, tilting them 45° compared with traditional mounting arrangements. Another idea is to replicate antennas with a certain spacing in the direction of travel, again to exploit further diversity and hence increase the robustness of radio links.

5.2.6 Coordinated multi-point

Coordinated multi-point (CoMP) refers to techniques where multiple base stations coordinate their transmission or even jointly transmit to or jointly receive signals from one or multiple devices.

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.

5.3 Gigabit Train

5.3.1 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.
- Indirect connectivity:
  Railway undertakings provide internet access to their passengers via Wi-Fi. Voice is provided via Voice over Wi-Fi, repeater technology for CS calls or with the help of frequency transparent windows.

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).

5.3.2 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 in the vicinity of the track from getting poor service as a train passes by.

5.3.3 4G/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). Early deployments will be adopting either non-standalone option 3 or standalone option 2 as the standardisation of these two options has already been completed. Since most passengers will still be using LTE handsets for passenger connectivity and penetration of 5G SA capable devices will be slow, the NSA option is preferred for early deployments.

5.3.4 mmWave

Millimetre wave at high frequencies such as 26 GHz may in the future become useful for enhancing passenger connectivity in railway stations. Recent modelling of mmWave applications in high-speed rail environments showed multiple Gbit/s throughput within a <1 km cell radius at perfect line of sight. However, the 5G railway corridors chosen will not have perfect line of sight available throughout. This is why this technology is not ideal for track coverage but can still be a solution for train depots, maintenance facilities and railway stations.

5.4 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 already being elaborated in detail at UIC, ETSI and 3GPP in the context of the standardisation of the Future Railway Mobile Communication System (FRMCS). Key innovations that are being investigated here and are subject to standardisation include, among others:

- Expansion and usage of the mission critical (MC) 3GPP framework for rail operations
- Co-existence of GSM-R and 5G in the same spectrum or with complementary spectrum and capability of application layer equipment to use the different transport layers in parallel
- A new telecom onboard architecture with standardised interfaces that allows onboard applications to utilise the latest advances in cellular technology while the applications remain agnostic to the exact transport technology used

In addition to these aspects, which are expected to be concluded with the ERA CCS TSI in 2022, there are, however, many degrees of freedom in how exactly to deploy, implement and configurate a 5G-based FRMCS system that require dedicated innovation.

5.4.1 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 preemption, etc. As for previous innovations, it is deemed necessary to perform detailed investigations and conduct pilots to determine which form of QoS management and which configuration thereof is best suited to rail operations.

5.4.2 Redundant infrastructure deployment

Beside more stringent data rate and latency requirements, applications for future rail operations are often also characterised by increased reliability needs (for instance up to 99.999% reliability).

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.

5.4.3 Enhancing coverage for FRMCS bands

Deploying FRMCS in parallel with a GSM-R infrastructure poses several challenges. In some countries, the 1900 MHz band will enable a smooth migration from GSM-R to FRMCS. This migration will require installing 5G equipment on existing GSM-R towers and onboard systems with 5G radio on rolling stock. Moving to higher frequencies requires a densification of the network grid with shorter inter-site distances. In order to leverage infrastructure investments, it appears evident that passive infrastructure elements such as sites, IP transport infrastructure and electric power to feed the active network equipment should be shared between the two lighthouse projects.

5.4.4 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.

5.4.5 Network management and orchestration

Virtualisation of PNFs (physical network functions) is common in 4G networks and will also be essential in a 5G network. To manage these virtual elements, which are also referred to as virtual network functions (VNFs), ETSI has defined an architectural framework called MANO – management and orchestration (of VNFs).

The 5G railway network will consist of virtual network functions whose control requires MANO. Apart from this, with MANO, service onboarding will be easy and fast. The way network management and orchestration is implemented within the actual network is an implementation design aspect that offers opportunities for innovation and railway-specific tailoring.

5.4.6 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.

5.4.7 Bearer flexibility and related onboard and trackside architecture

While the FRMCS system will be based on 5G technology, it is purposely designed to provide "bearer flexibility", meaning that it can also use other 3GPP transport technologies such as 4G, or non-3GPP transport technologies such as satellite connectivity or Wi-Fi, in a way that is fully transparent to the applications such as ETCS, voice, ATO, etc. A key element for achieving this is the FRMCS Mobile Gateway, which ensures that multiple onboard applications can make use of different transport domains through a single or through multiple onboard radio modules.

Beyond standardisation, it is expected that innovation will be required on how the onboard system is designed, for instance on physical installation, connectivity to train bus systems and how to provide maximum reliability and resilience in cases where individual network components (either onboard or trackside) fail.

6 Regulatory aspects

The provision of mobile services along railway tracks is not necessarily attractive 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 of both the Digital Rail Operations (e.g. ETCS and ATO) and Gigabit Train types. IMs and MNOs would have to work closely together to define a shared infrastructure (masts, fibre optics, equipment rooms).

2. **Standardising QoE metrics for rail**

   It would be appropriate to define a standard QoE framework for regulatory purposes at EU level, with target values being subsequently specified by national regulators. A transparent monitoring process needs to be agreed upon and implemented to follow up on progress and maintain service levels.

3. **Prioritisation of B2B SIM cards**

   RUs provide internet access via Wi-Fi using modems with standard 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.

4. **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.

5. **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.

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

   Passive infrastructure sharing (e.g. sharing of sites, antenna masts, equipment cabinets) among IMs and MNOs may be possible but requires legal provisions in case mobile services are terminated unintentionally (e.g. due to bankruptcy). Ownership of the shared infrastructure must then be transferred to the IM.

7. **Active infrastructure sharing**
   Active infrastructure sharing (e.g. based on E2E network slicing or RAN slicing) for critical services can be explored further, taking into account the regulatory framework and constraints.

7 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 and the MNO customer 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.

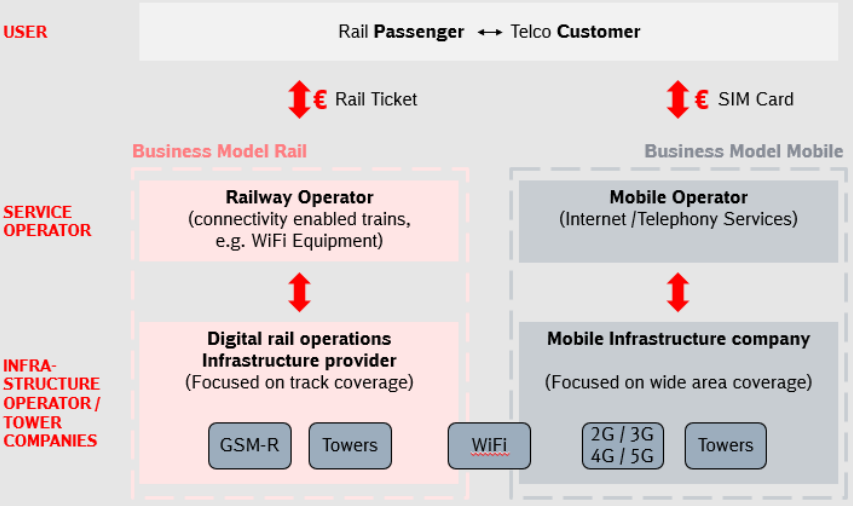


Figure 5 Gigabit Train (direct and indirect coverage)

Both need to be fuelled by the same public mobile network architecture, as it will be the only infrastructure available that is able to cope with connectivity needs of this order of magnitude.

Demand-driven mobile network delivery for rail requires **building a rail-dedicated, special-purpose passive and active network** that involves higher costs than current mobile network designs aiming for area coverage. Typically, 70–80% of costs stem from the passive infrastructure, i.e. **many towers spaced at short intervals**. Therefore, it is a valid question to ask how this investment can be afforded. One lever is cost reduction by network sharing. National regulation allows FRMCS passive mobile infrastructure to be shared with future 5G (MNO public) infrastructure under strict safety and security conditions. Potentially, 5G infrastructure along railway lines could also become the basic passive infrastructure for MNOs.

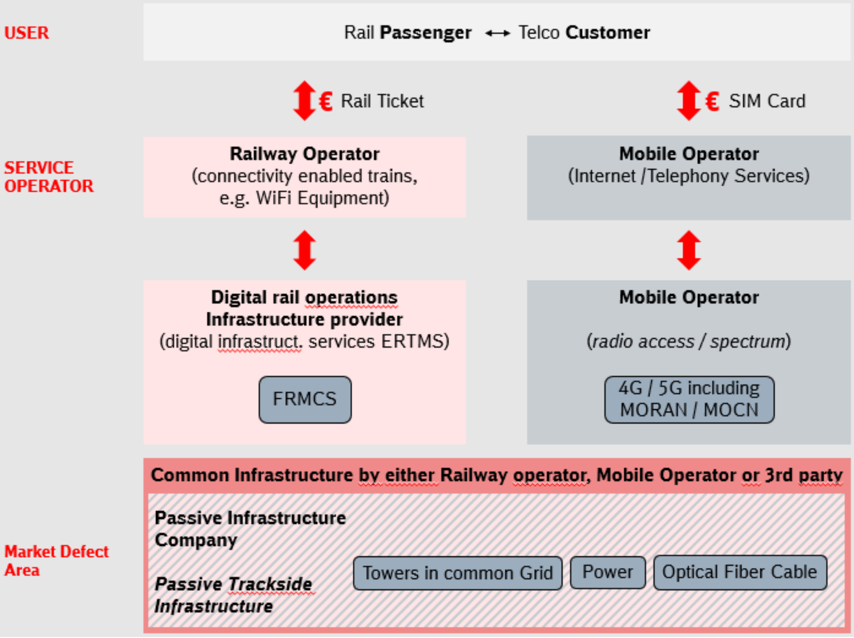


Figure 6 Sharing infrastructure (Gigabit Train and Digital Rail Operations)

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. Tighter regulation and intense network sharing may improve financial feasibility on more high-frequency rail corridors, but these levers do not appear to be sufficient. **Additional funding of passive infrastructure for both FRMCS and public mobile networks seems an appropriate option**; depending on the national situation and requirements for secure rail-specific mobile networks, public or private tower companies may play a key role in future changes to business and cooperation models.

For a 5G-based FRMCS system, the situation is similar to that shown in Figure 7. 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).

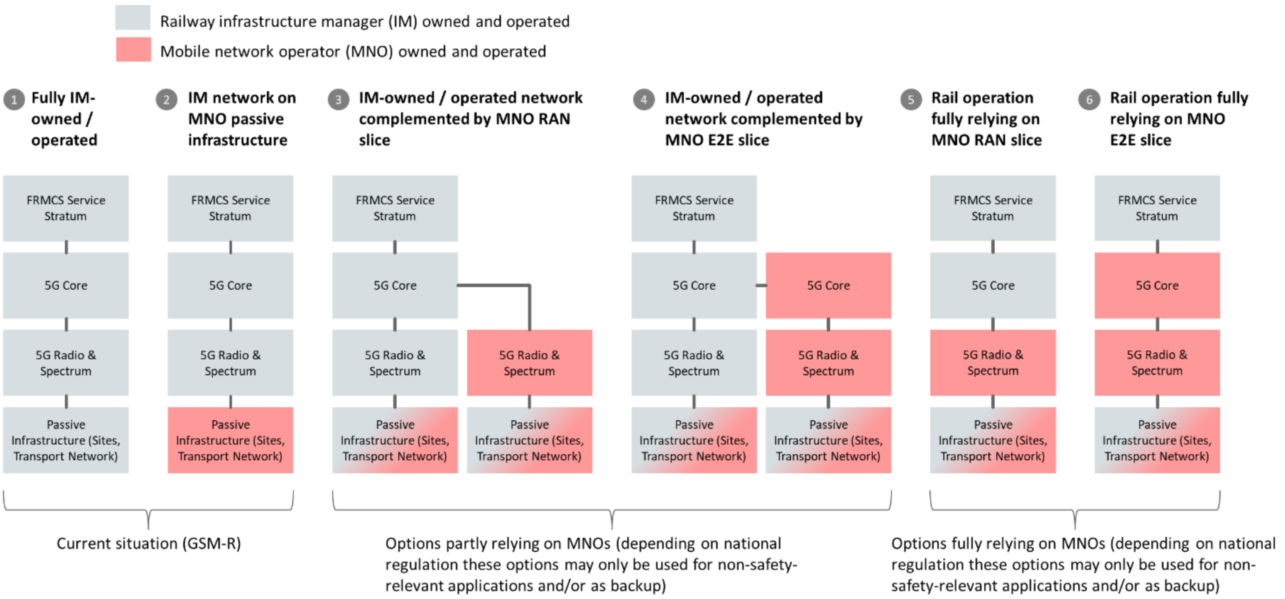


Figure 7. Principal deployment options (broken down by IM-owned/operated and MNO-owned/operated technologies) for Digital Rail Operations.

While the passive infrastructure parts (boxes at the bottom of Figure 7) can be shared with Gigabit Train deployments, the rest of the layers, such as 5G radio and 5G core, will always be provided by the MNO delivering connectivity for Gigabit Train.

On the left side of Figure 7, **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 RAN slice 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 E2E 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 E2E slice provided by a mobile network operator. Such a RAN or E2E slice must include all FRMCS applications required by infrastructure managers (IMs) while ensuring all ERTMS interoperability requirements.

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

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

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 time to exploit connectivity	• Legal obligation of Member States to roll out 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	• Availability • Reliability • Resilience • Quality of service
Main constraints	• Low economic viability when it comes to funding the dedicated trackside infrastructure along railway lines • Proper sharing models for 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 "functional authority" of the railway infrastructure manager (for safety-related applications and connectivity) • Need for E2E homologation of safety-related applications and associated connectivity
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 communication services (e.g. group communication, role management, service authorisation, recording, etc.) that go beyond pure IP connectivity • Typically long life cycles of railway operation applications and onboard equipment
Key ecosystem characteristics	• Choice of onboard equipment/technology may be left to each railway undertaking	• Choice of onboard equipment/technology largely determined by national infrastructure managers and national vehicle funding policies

A high level of service must be ensured on significant parts of the railway infrastructure (current and future) by a mobile network infrastructure that will utilise dedicated spectrum in the 900 MHz and 1900 MHz bands as mandated by EC and CEPT.

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

8 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.

8.1 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 and MNOs
- Cross-border operation (for example along TEN-T corridors)
- Operation which supports the most important service requirements of Digital Rail Operations and the Gigabit Train
- Operation in designated areas (e.g. rural, low-density lines)
- Realistic timelines for deployment, compliant with the planning of the CEF2 funding framework

8.2 Gigabit Train

8.2.1 Deployment scenarios

Examples of Gigabit Train corridor deployment are shown in Figure 9. The suggested architecture is a combination of shared passive architecture (potentially shared with a network for Digital Rail Operations) and shared active architecture.

8.2.2 Timeline for Gigabit Train deployment

Two phases of deployment are envisaged.

Phase 1: Gigabit basic functionality

1. The ideal timeline for starting projects for the Gigabit Train would be 2021 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 NSA (non-standalone) 5G deployment architecture should be broadly available by 2021.
2. A prerequisite for deploying NSA 5G is the availability of LTE technology as an anchor technology in the same area; if LTE is not available in the area in question, no 5G NSA enhancements can be achieved. In the long-term, SA 5G networks will be independent from the LTE anchor band.

Phase 2 - Gigabit extended functionality

1. 5G could also be applicable in depots and railway stations, even using additional, not yet allocated frequency bands such as 26/28 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 (1–2 GHz), 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 Gbit/s.

8.3 Digital Rail Operations

8.3.1 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 planned to be addressed in the context of the Horizon 2020 ICT-053 call, where parties representing railway infrastructure managers, railway suppliers and associated stakeholders are involved. In the early CEF2 phase (2021–2023), it will be important to complement possible ICT-053 activities with corridor deployments, which will reflect further progress achieved in FRMCS and 5G standardisation.

The second step is to conduct trials with proven products and services in a cross-border railway environment (2023–2027). These trials additionally provide insight and guidelines for coverage, frequency plans, performance metrics, GSM-R/FRMCS coexistence criteria and migration scenarios. This will allow for early FRMCS deployments, as foreseen by some Member States.

Early deployments could include:

1. European IPv6 backbone: An IPv6 backbone is regarded as a building block for cross-border deployments and is used to interconnect FRMCS networks at European level. This will be an evolution of the existing GSM-R European Interconnection Network (ENIR).

2. Train location information service: Positioning technologies are deployed as a comprehensive service (e.g. GNSS-based localisation in conjunction with 5G positioning, train describer systems and landmark detection, etc.) to support cross-border applications and services.

8.3.2 Timeline for the deployment of Digital Rail Operations

It is recommended to split the CEF2 timeline into two deployment phases. The boundary between phase 1 and phase 2 is the release of the ERA TSI (expected for 2022). As the TSI marks the point where the standardisation of the first FRMCS version will be delivered, the two deployment phases will be very different in nature:

- In the first phase (2021–2023), the focus will be on developing and evaluating FRMCS/5G prototypes (possibly also supported by ICT-053) and supporting the ongoing FRMCS/5G standardisation.
- In this phase, basic 5G corridor deployments could also be 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 (2023–2027) will comprise larger cross-border FRMCS/5G deployments, possibly extending the basic 5G corridor deployments and based on standardised and selected technology, with an emphasis on deployment optimisation, cross-border interoperability and various aspects that go beyond standardisation, such as the many innovations listed in Section 5 above.

- It is essential that in parallel to phases 1 and 2, ETCS roll-out along the same corridors is pursued along with preparing the infrastructure for ATO and other applications.

The timeline is illustrated in Figure 8:

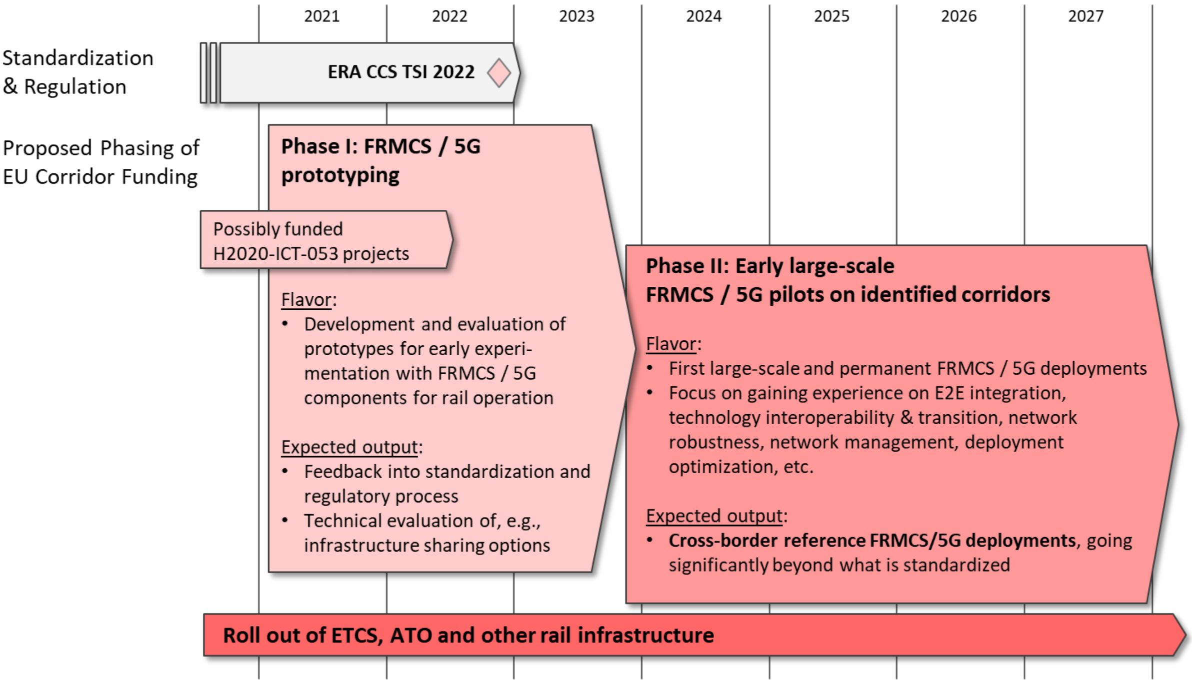


Figure 8 Deployment timeline (Digital Rail Operations)

Note that the early FRMCS adopters plan to start commercial operation in 2025, hence it is crucial to adopt the ambitious timeline shown here.

8.4 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 (cross-border)**
   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 fibre optics).

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).

8.5 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.

8.5.1 Deployment scenario for cost estimation

The cost estimate is based upon mobile service provisioning along an imaginative 200 km corridor. Costs are broken down into the following categories:

1. Infrastructure (Radio Access Network)
2. Trains, coaches and locomotives (onboard Wi-Fi and FRMCS gateways)
3. FRMCS core network

Infrastructure (Radio Access Network)

Characteristics:

1. Cross-border operation for the Gigabit Train (up to 1 Gbit/s) and Digital Rail Operations along a 200 km line (100 km on each side of the border)
2. Homogeneous infrastructure environment (no tunnels or other challenging infrastructure elements such as bridges or extraordinary terrain conditions)
3. Non-standalone deployment architecture based on 4G and 5G NR with an inter-site distance (ISD) of 2–3 km. Existing mobile network sites are not (re)used
4. Use of a total of 240 MHz of available spectrum in the 3.5 GHz band and use of 5G NR
5. Use of three 4G carriers with a total of 145 MHz of available spectrum in the 700, 900 and 1,800 MHz bands (other sub 2 GHz spectrum can be used depending on availability in each individual country)
6. Use of 1900 MHz (10 MHz) for Digital Rail Operations (FRMCS) as a private network and sharing of passive infrastructure. The 900 MHz GSM-R network is assumed to be re-used as is, at least during the migration phase

Train equipment (onboard Wi-Fi and FRMCS gateways)

Characteristics:

1. 10 locomotives with eight coaches each are in service on the corridor
2. Each train is equipped with a Wi-Fi system:
   - One "*parent coach*" and a second "redundant parent coach"
   - Six "*child coaches*" with double access points
3. All coaches are equipped with radio transparent windows
4. Each locomotive is equipped with an FRMCS onboard gateway

FRMCS core network

The FRMCS core network infrastructure consists of:

1. A 5G Core (transport stratum)

2. A 5G/FRMCS service stratum (trackside cloud environment for hosting the FRMCS server and railway applications)
3. An IPv6 Backbone
4. A train location information service

8.5.2 Cost drivers and cost estimation constraints

At this stage (with FRMCS standardisation in progress), it is not possible to provide adequate cost estimates for Train equipment and FRMCS core network.

Additional cost drivers for FRMCS are:

1. FRMCS server providing central authentication and MCX functionality
2. Additional voice communication services
3. Stringent coverage requirements and KPIs
4. Stringent requirements for reliability and availability (e.g. geo-redundancy)
5. Verification, validation and certification
6. Stringent maintenance, longer lifecycles and demanding service levels

8.5.3 Cost estimate

The cumulative costs of the scenario involving a RAN infrastructure and a core network, train equipment and licences are shown in Table 2.

Table 2 Cumulative cost estimate

Cost item/subsystem	**Costs (investment) in EUR million**
Infrastructure (shared passive infrastructure (RAN) with 2 MNOs + 1 FRMCS provider)	31.5
Train equipment (10 locomotives with eight coaches each)	TBD
FRMCS core network	TBD
Licence (FRMCS spectrum)	TBD
Total	31.5

Cost estimates for the FRMCS core network and train equipment cannot be provided at this stage. However, since costs of the radio network account for the largest share of total costs, adequate cost indications can be given anyway.

Normalised costs per infrastructure element are shown in Table 3.

Table 3 Normalised cost estimates (Note: cost per km will drop when systems are used on longer railway corridors)

Cost item	**Cost (investment) in EUR million**
Cost per km (infrastructure)	0.2
Cost per site	0.4
Cost per train (Gigabit Train + FRMCS)	TBD

OPEX costs are estimated at 20% of total investment costs.

8.5.4 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.

8.5.5 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

8.6 Examples of corridors for deployment

Figure 9 provides an overview of potential (cross-border) corridors for deployment. Countries that have expressed initial interest are Austria, Belgium, Finland, Germany, the Netherlands, Portugal and Sweden.

Note that cross-border corridors are shown in red. National railway lines are shown in blue.

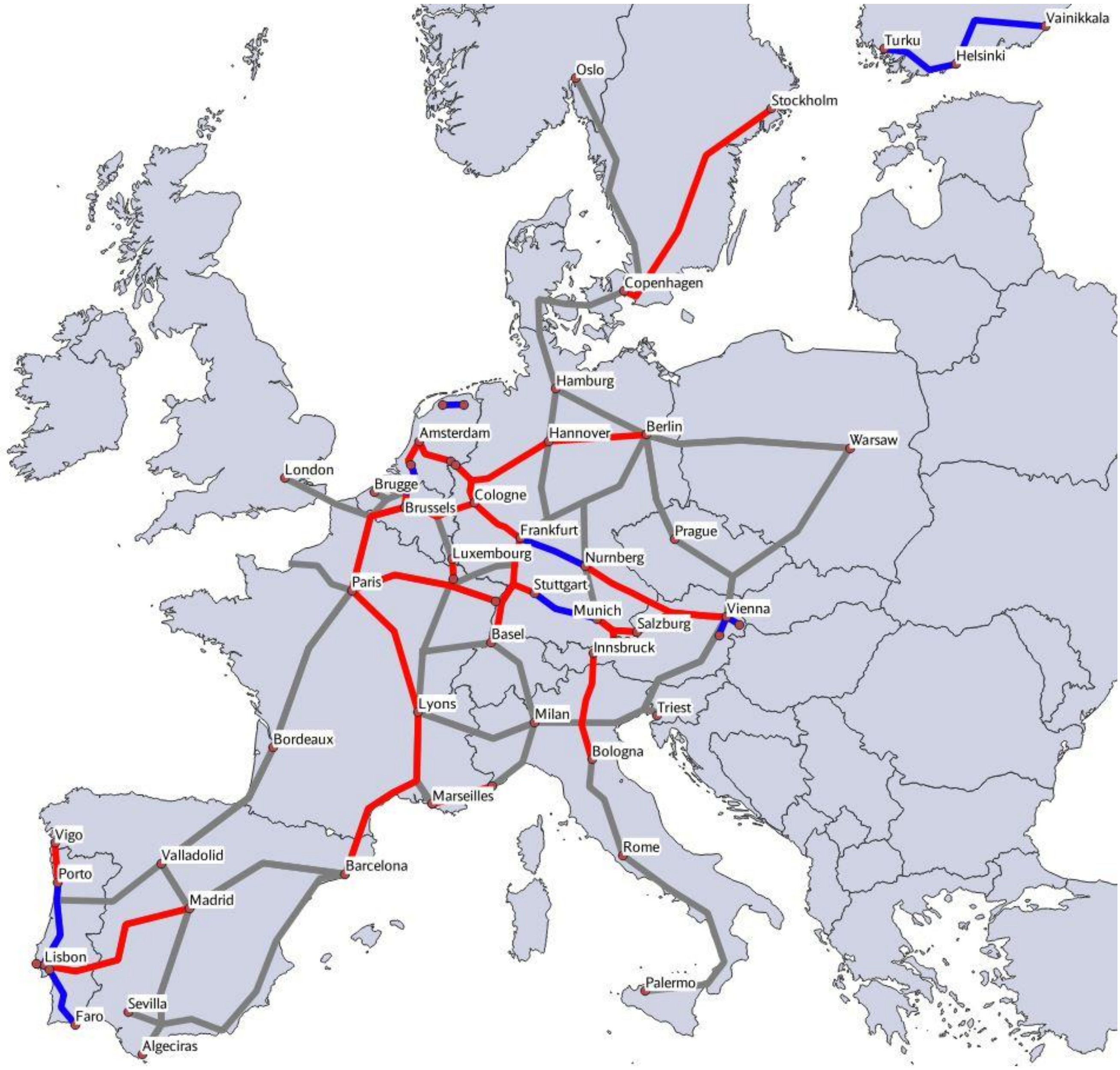


Figure 9 Potential railway corridors for 5G deployment in Europe

Details of railway lines per country (first indication):

Austria

Kufstein – Innsbruck
Salzburg – Vienna
Vienna – Parndorf
Vienna – Neunkirchen
Vienna – Gänserndorf

Belgium

Amsterdam – Brussels
Paris – Brussels – Frankfurt

Finland

Turku – Helsinki
Helsinki – Vainikkalances

France

Frankfurt – Paris
Munich – Stuttgart – Strasbourg/Paris
Paris – Brussels – Frankfurt
Marseille – Ventimiglia
Paris – Lyon – Barcelona
Paris – Brussels – Amsterdam
Metz – Luxembourg

Germany

Frankfurt – Brussels – Paris
Frankfurt – Paris
Frankfurt – Amsterdam
Frankfurt – Nuremberg – Vienna
Frankfurt – Basle
Munich – Vienna
Munich – Bologna
Munich – Stuttgart – Strasbourg/Paris

Portugal

Lisbon – Madrid
Lisbon – Porto - Vigo
Lisbon – Pinhal Novo-Faro
Lisbon – Sintra

The Netherlands

Amsterdam – Brussels
Rotterdam (Kijfhoek) – Roosendaal – Belgian border (Antwerp)
Betuweroute (Zevenaar – Emmerich), freight line
Amsterdam – Frankfurt
Amsterdam – Berlin
Leeuwarden – Groningen (rural line)
Hanzelijn (Lelystad – Zwolle)

Sweden

Stockholm – Copenhagen