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A new platform for rail communications – adopting 5G for railways

White paper

5G offers a major opportunity for rail operators to transform their operations for the better. Its high speed and extreme traffic handling capacity, together with ultra-low response times, highest reliability and support for massive machine type communication (IoT), will allow rail networks to improve safety, optimize costs and make their services more attractive to passengers in many ways. Such capabilities will make the telecommunication network the cornerstone of railways' ambitions for further digitization.

With the Future Railway Mobile Communications System due to replace GSM-R and other legacy systems, rail operators can begin to plan early how they will prepare and migrate their networks to take advantage of 5G - the leading mobile technology that will serve the world far into the future.

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Executive summary: the future of railway communications will be built on 5G

The future of rail transport critically depends on taking advantage of advanced communications systems to increase safety, cut operating costs and improve the experience for rail passengers towards a digital railway.

While 4G introduced some functionality for mission-critical communications, 5G is set to go much further in meeting the demands of the Communications Service Provider (CSP) market, as well as, from day one, fully supporting the mission-critical needs of industries and enterprises, including rail operators. As well as providing efficient broadband capabilities, 5G networks will offer measures to build ultra-high reliability networks with ultra-low latency. It will also serve the need of massive Machine Type Communication (mMTC) for sensors and predictive maintenance that train operators will increasingly need in the future to improve and optimize their services. With huge performance improvements over previous generations of mobile technology, 5G delivers high speeds of up to 10 Gbps and very low latency, the time for the network to respond to requests from the mobile device. Furthermore, 5G also achieves such performance at much lower cost than other technologies.

Even more important, 5G will bring additional communications flexibility for railway operators that use dedicated networks for mission-critical services and commercial 5G network slices from CSPs for additional capacity for non-critical services.

This will bring rail operators new opportunities and applications based on mobile broadband capabilities.

Applications can be categorized into three segments:

- Critical: applications essential for train movements and safety or a legal obligation, such as emergency communications, shunting, presence, trackside maintenance, Automatic Train Operation (ATO), Automatic Train Control (ATC) and Automatic Train Protection (ATP).
- Performance: applications that help to improve the performance of the railway operation, such as train departure procedures and telemetry.
- Business: applications that support the railway business operation in general, such as wireless internet and ticketing support.

Led by ERA and UIC, the Future Railway Mobile Communications System (FRMCS) is the single global standard for railway communications. While FRMCS will be functional in nature, 3GPP technologies such as 5G will be best positioned to meet all the needs of railway operators.

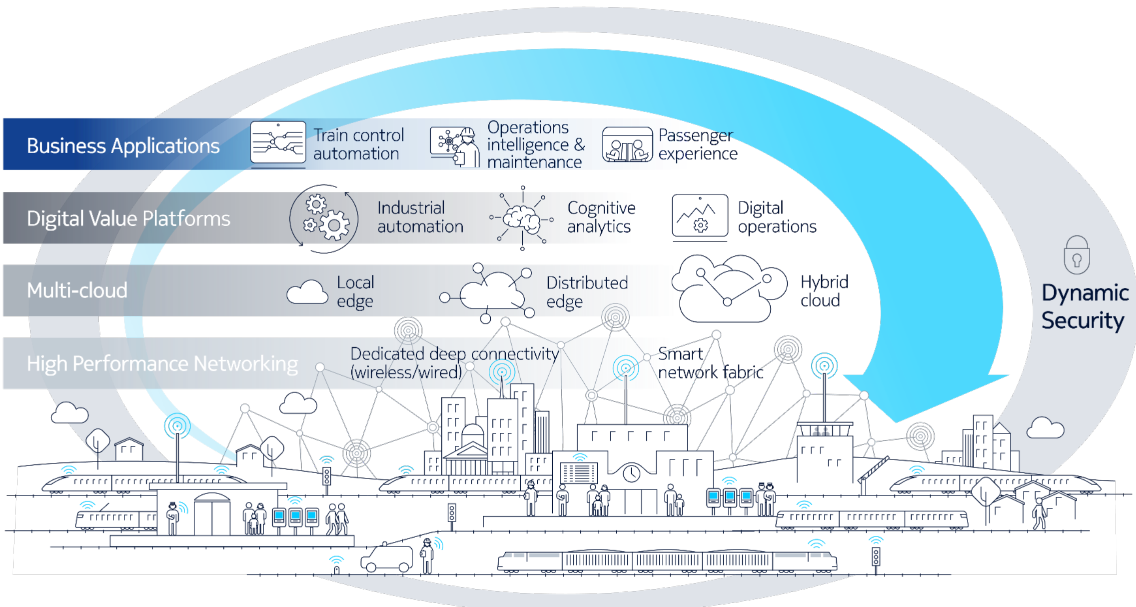
Rail operators are advised to start planning early to migrate their existing networks to the forthcoming FRMCS standard if they are to make full use of the opportunities. While it has served the rail industry well for many years, GSM is maturing, with support largely terminating by around 2030. 5G is expected to serve railways for much longer, with likely implementation in the mid-2020s to provide reliable service extending over the next few decades. However, in Europe the roadmap for ETCS extends to 2050.

This means that for several years, GSM-R and FRMCS will run in parallel during the migration period. Current GSM-R networks must be kept up to date to achieve the highest standards of quality and performance and meet the latest European Train Control System (ETCS) requirements and to free up spectrum for FRMCS. Railway organizations must upgrade trains, which is not a quick task. Additionally, overall harmonization in Europe is needed and a proper legal framework needs to be established.

Rail operators currently using GSM-R are recommended to modernize their existing GSM-R networks by introducing IP technology as in the transmission networks for FRMCS, or with ETCS over GPRS for ETCS, ensuring they are prepared for a parallel rollout of 5G for railways starting from around 2025.

As a leader in both 5G and radio communications for railways, Nokia is well equipped to provide rail operators with the expertise and advice they need to make full use of these exciting opportunities.

Figure 1. Nokia has a clear vision of the future of railway communications. The Nokia Bell Labs Future X architecture for railways provides an intelligent, dynamic communications and cloud-based platform to support all of the individual systems, processes and activities of the railway



The mobile broadband opportunity for railways

The way people live, work, play and communicate is set to be transformed by ultra-fast, reliable mobile broadband. Industries as well as consumers will benefit, and the rail industry is no exception. For rail, the benefits will be many, including enhanced safety, improved operational efficiency and innovative passenger services, helping them achieve further digitization to make the railway more competitive.

To meet its priorities, rail needs a communications technology that offers high speed, high security and high capacity to support passenger connectivity needs, as well as safety-critical operational applications such as train signaling, and safety-related applications like CCTV and on-board communications.

All this can be achieved with a single, converged and flexible network, sweeping away the complexities and inefficiencies of managing a mixture of several network technologies, including GSM-R, TETRA, DMR, Wi-Fi and even analog technologies like VHF/UHF.

FRMCS – a global standard for rail communications

The FRMCS is intended as a single global standard for railway communications. A successor to GSM-R, FRMCS conforms to European regulations while also meeting the needs and obligations of rail organizations outside Europe. As well as the mainline railways, UITP (Union Internationale des Transports Publics), the International Association of Public Transport, also supports FRMCS.

As a mobile broadband-ready technology, FRMCS will support the needs of rail in six ways:

Demand for broadband

- Automation for self-driving trains
- Increasing operational efficiency
- Improving customer experience

Optimization of networks

- Further unifying network technology towards IP
- Reduce complexity
- Increase flexibility

Long term support

- Support for ERTMS/ETCS (as examples) for the next decades
- Manage the obsolescence of GSM technology

Critical communication

- Voice, evolving to group video calls
- Train control, automated train operation
- Machine-to-Machine (M2M) and telemetry for critical elements

Performance communication

- M2M and telemetry
- Predictive maintenance
- CCTV for passenger security and train movement control, passenger Information, staff communication, lineside (fixed)

Business communication

- Wi-Fi on board

One of the main targets of FRMCS is to achieve maximum flexibility by separating the railway functions from the network and radio bearer that carries them. This makes it possible to use standard mobile radio technologies such as 4G and 5G, Wi-Fi, fixed networks or even satellites. In contrast to GSM-R, railway functionality is mainly realized on the application layer. The evolution of 3GPP technology to 5G supports multi access and application centric communications.

Although this flexibility is desirable, it is also important to harmonize network technologies across countries, for example for Europe, and avoid deploying too many different solutions. The latest thinking of the UIC and the European Railway Agency shows a clear preference towards 5G, a choice supported by many major European railway operators.

However, some railway operators see a solid business case for implementing early broadband technology for rail based on LTE. This may give them an opportunity to become familiar with 3GPP broadband technology, followed later by a smooth migration to a 5G FRMCS solution.

A compelling case for 5G

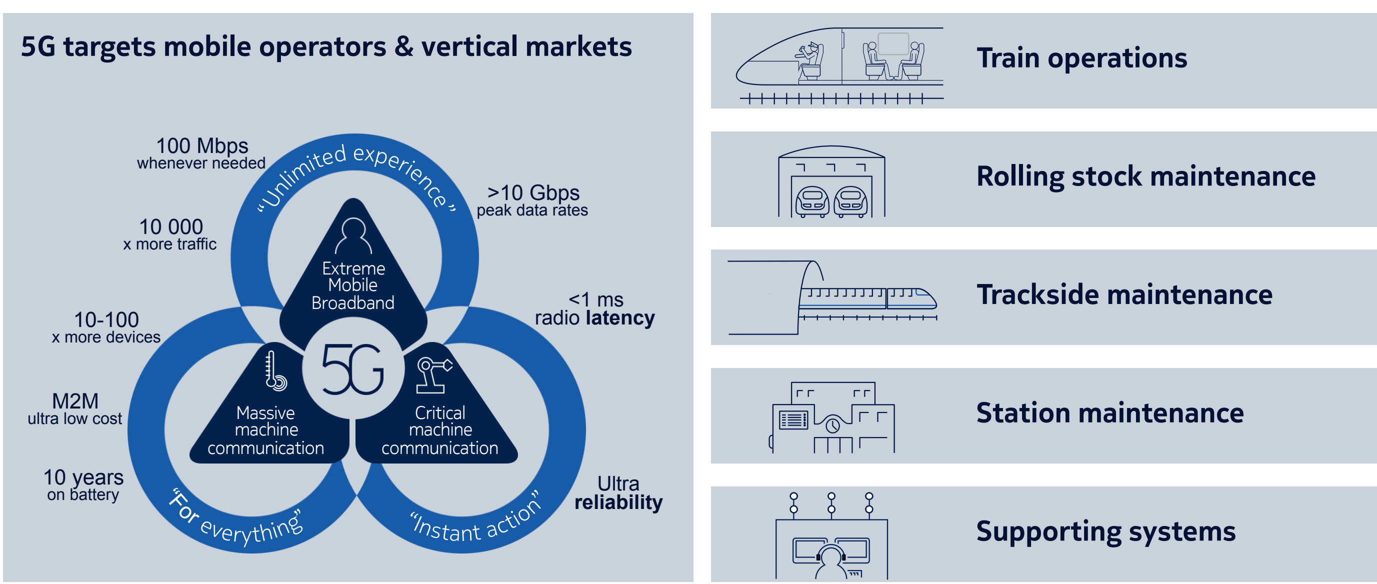
There are several reasons for choosing 5G technology as the basis for the future of rail communications. FRMCS based on 5G is expected to be introduced in Europe around 2025, by which time it is likely that the 3GPP will have ceased standardization work on 4G LTE technology. Additionally, 5G can be expected to serve railways for much longer, extending over the next 15-20 years.

Many of the future uses for railway communications will demand minimal delay between the radio and the network, known as latency, as well as the ability to work in the Cloud. Examples include automated train operation and broadband M2M communication. Although today LTE provides a high quality of service and broadband capabilities, 5G is specifically designed for these kinds of ultra-reliable, low-latency mission-critical communications, which also include video applications. This is supported by 5G flexible deployment schemes using cloud and mobile edge computing.

There is also a huge effort to use 5G technology for the forthcoming Industry 4.0 transformation, and it is expected to become the dominant technology for vertical markets. Using 5G as a common technology will also make it easier for intermodal communication concepts, for cars and other vehicles to interwork with FRMCS to communicate with trains.

> **“Deutsche Bahn expects deployed 5G and Cloud technology to be 99 percent off-the-shelf and ‘mainstream’ technology but sees the need for dedicated research and innovation to optimize 5G and Cloud technology for rail scenarios.”**
>
> Dr. Patrick Marsch, DB NetzAG -DigitalisierungBahnbetrieb/ Systemarchitektur

Figure 2. 5G offers extremely high performance in many dimensions to support all the communications needs of rail operators



5G capabilities put full automation within reach

One of the major goals of many industries, not least rail operators, is to make greater use of automation, to cut costs but also to remove human error and promote greater safety. With its high speed and capacity, 5G offers the data handling abilities that extensive automation demands.

Automation has already made great inroads in rail transport, such as people movers at airports, various metro lines across the globe and in special freight applications like mining trains. Enhancing ETCS, Automated Train Operation (ATO) is being introduced to mainline rail services. Although train control as well as rolling stock solutions are commercially available today, several challenges remain. Solutions that offer precise yet affordable location of trains, obstacle detection and a sufficient and reliable communication system are yet to be developed.

When it comes to maintaining rolling stock, the first steps towards automation are complete. However, preventive maintenance is still the most common philosophy, whereas industry generally is moving more towards condition-based maintenance, where interventions are made only when issues start to occur.

Even so, this is often too late, so a newer trend is predictive maintenance. So far, few pilot projects have proven successful in this area. This is because solutions are often too siloed - even restricted to vendors of components of rolling stock. Rail operators often face the issue that these solutions are not open, and data cannot be shared.

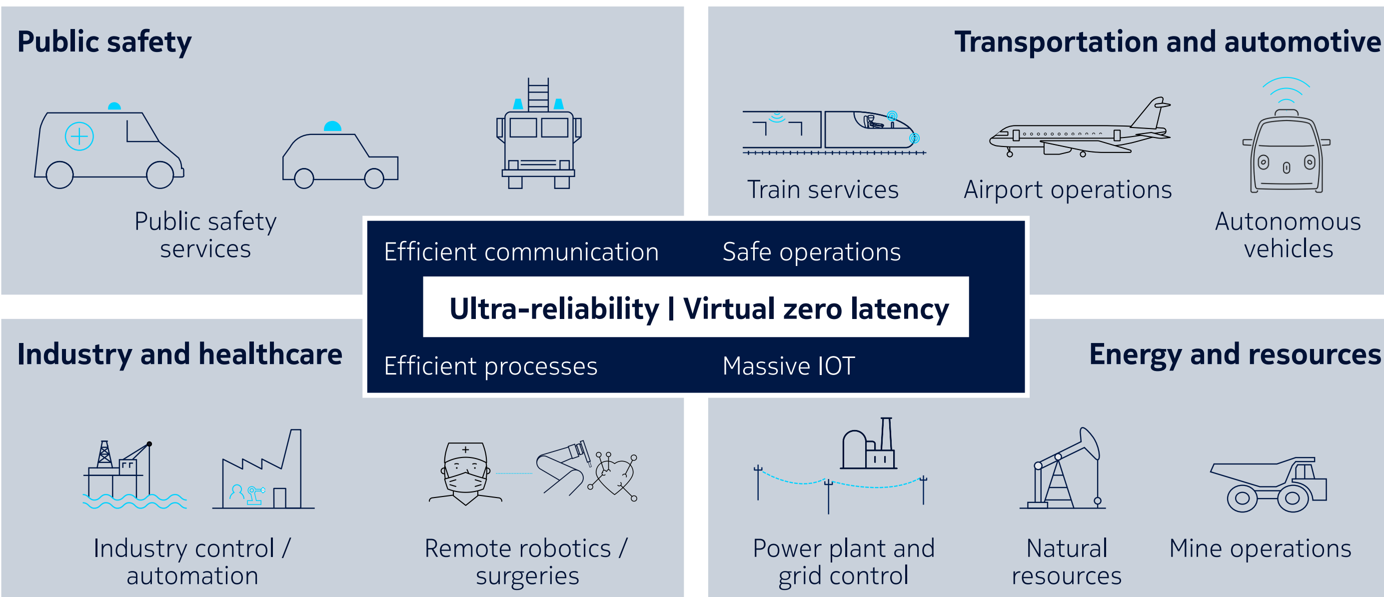
Trackside maintenance is one of the most challenging tasks to automate. However, there are some promising solutions being created by start-ups. In trackside maintenance, more than in any other case, it is important to find solutions where only minor deployments in the field are required.

Today, most automation is occurring in railway stations. Elevator and escalator maintenance is often already based on their condition. However, these solutions are siloed, as they are often provided by the elevator vendors. Another issue is that solutions are often driven by large deployments in central or major stations, but the biggest benefits can be achieved by optimizing maintenance at small, unstaffed rail stations.

What is 5G? An overview of the technology

Essentially, 5G provides radically new connectivity capabilities that are both agile and sustainable. Networks based on 5G will deliver extreme mobile broadband with unprecedented network speed and capacity, while making use of additional spectrum bands. New services and many Internet of Things (IoT) applications require ultra-low latency connectivity, coupled with ultra-reliability.

Figure 3. Introducing new radio systems and network architecture, 5G networks will be flexible and reliable, offering extreme performance in many ways, to meet a huge range of uses in many sectors



The key technologies underlying 5G

5G is a combination of several technologies, but it will not follow the static, one-size-fits-all approach of previous mobile communications generations. Instead, 5G networks will be programmable and software-driven. They will be highly scalable to meet the communication demands of consumers and enterprises.

The building blocks of 5G architecture

There are several ways to deploy 5G. The first phase of a 5G rollout can use dual connectivity, with devices connecting to both 5G and LTE networks. This is practical if the LTE network uses low band spectrum and the 5G network uses high band spectrum that offers limited coverage.

5G can be also deployed as a standalone solution without LTE.

Frequencies for all occasions

5G NR (New Radio) is a new global standard air interface for 5G networks. It is the most flexible way to benefit from all available spectrum options, currently spanning 600 MHz to 90 GHz, including licensed, shared access and unlicensed, Frequency Division Duplex (FDD) and Time Division Duplex (TDD) bands, narrowband and wideband allocations are possible, and new spectrum options are continuously introduced

- **Low bands (below 1 GHz)** are needed for wide area coverage, for ultra-high reliability and for deep indoor penetration. Extensive coverage is particularly important for Internet of Things (IoT) and critical communication.
- **Mid bands (3.5 GHz and 4.5 GHz)** will be used for 5G coverage and capacity in urban areas by reusing existing base station sites. The spectrum around 3.5 GHz is attractive for 5G because large bands of spectrum are available across the world that could support gigabit data rates.
- **High bands (mmWave spectrum above 20 GHz)** offer extreme mobile broadband capacity with data rates up to 20 Gbps.
- **Unlicensed bands** such as 5 GHz, and in the future 60 GHz, offer additional offload options for best-effort traffic and less critical applications not needing guaranteed Quality of Service (QoS).

Even higher network capacity with Massive MIMO

5G can offer increased capacity through its use of Multiple Input Multiple Output, or MIMO. This typically uses two transmit and two receive antennas to double the capacity.

Massive MIMO goes even further, using many simultaneous transmit and receive streams to create much higher network capacity. Normally, sub-6 GHz bands have smaller bandwidth, but Massive MIMO multi-stream transmission can achieve gigabit peak data rates. Massive MIMO is also an effective way to use 3-40 GHz bands to increase peak data rates through multi-stream transmission.

Research is ongoing on how these concepts support railway deployments, considering also aspects as available space on trains for complex antenna solutions.

Getting latency below one millisecond

A practical end-to-end latency in typical LTE networks is tens of milliseconds when connected and even longer when starting from idle. For many railway applications, new technologies are needed that can reduce latency by 90 percent, for example when remotely maneuvering trains as in shunting operations.5G networks will use various techniques to reduce latency substantially, such as shorter transmission frames, flexible resource allocation and edge computing to place the processing closer to the user and thus reduce the distances that data needs to travel in the backhaul network. These technologies will help 5G networks achieve one millisecond latency or even less.

The 5G core will be cloud-native

The rise of IoT and the deployment of 5G technologies will require networks to support a much wider range of services. The one-size-fits-all architecture of networks must change and is being led by the evolution to a cloud-native core network that is both programmable and highly scalable.

A cloud-native architecture, which is built from the ground up for the cloud, allows operators to support both the scale and performance demands brought by broadband evolution and the introduction of IoT/ Machine Type Communications (MTC) and 5G. New development techniques allow operators to introduce industry specific 5G services more rapidly increasing reliability.

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Evolving 5G transport technologies

With the development of the 5G radio network and the 5G core, the transport technologies that carry data traffic between them must evolve to meet their demands. A consideration for railways is the diverse locations of radios required to support new use cases, requiring flexible transport technologies to reach them.

These will include a mixture of advanced microwave, IP, Optical, Next Generation Passive Optical Network (PON), and Wireless Mesh relay technologies, all updated to transport 5G traffic securely and resiliently.

5G network slicing

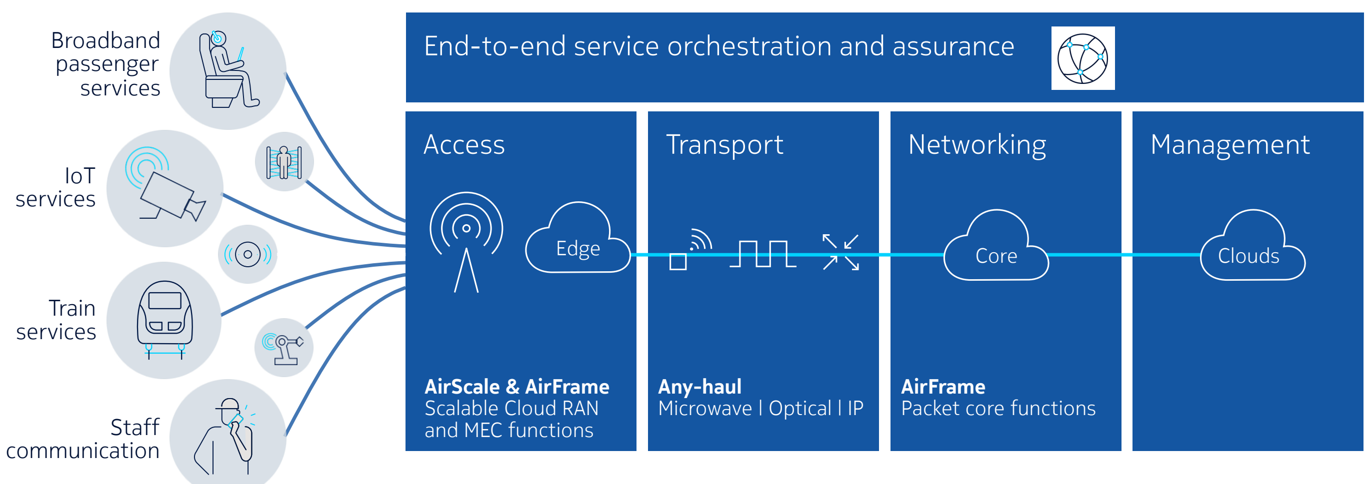
Different users will have different demands on 5G networks with sometimes very diverse and extreme requirements for latency, throughput, capacity and availability. Supporting all these different uses cost-effectively from one common infrastructure can be achieved by network slicing.

With network slicing, several different end-to-end, separate networks can be provided and operated independently for each customer, supporting, for example, smartphones, tablets and virtual reality applications.

Network slicing can provide cost-effective and flexible support for the wide range of rail applications that are likely to be implemented in the future.

Network Slicing enables separate, dedicated railway operator networks, or the use of public mobile operator slices for running non-mission-critical services.

Figure 4. 5G network slicing provides the flexibility needed for additional railway services



Uses and benefits of FMRCS and 5G

Seamless 5G connectivity, cloudified data and analytics engines will enable railway operators to partner with third parties to offer innovative applications and services.

Mission-critical applications

Mission-critical reliability is mainly required by CBTC/ETCS systems, although operational voice services also demand extreme network prioritization as they help to ensure security and provide an essential means of manually sustaining train operations should the CBTC/ETCS system fail. A CBTC/ETCS application will typically tolerate a communications loss of no more than a few seconds, while a mission-critical voice service will usually have higher tolerance of communications loss. Further Automation even increases the demand.

Predictive maintenance and operations intelligence

The maintenance and repair of rolling stock, track components, depots and stations, often across large geographies, poses challenges in planning the use of repair equipment and teams. Predictive maintenance applications, using IoT asset management and advanced data analytics promise to reduce costs, increase asset utilization, enhance safety, minimize delays and reduce revenue loss. Digital twin systems can be introduced to increase efficiency through the simulation of trains and rail infrastructure.

Video surveillance for operational security

A typical railway operation has multiple, high-quality CCTV systems generating many video streams. This requires a cost-effective and reliable high capacity communications network able to handle traffic of several Mbps per camera and thousands of video streams. Video analytics can automatically discover anomalies in people's behavior, alerting safety and security personnel so they can intervene. In fully automated mode, video is important for obstacle detection, or provide situational awareness, for example degraded train operation.

High-capacity and low latency connectivity will support applications that help improve passenger safety and security. These will include driver video for advance views of platforms and level crossings, as well as remote supervision of passengers through on-board closed CCTV.

Such CCTV systems will contain innovative features such as video analytics software to automatically detect intrusions, strange behavior or unattended baggage.

On-board CCTV services require high uplink throughput, while the platform CCTV service requires high downlink throughput. Of all types of application traffic for rail operations, CCTV traffic probably takes up the most capacity.

The digital passenger

The modern passenger expects to be connected constantly and be provided with personal, bespoke communications and services. Making sure the passenger has full broadband access in-station and on-board is only the beginning. Their smartphone and wearables, such as a watch, can provide important information such as directions, alerts and information updates.

Railway personnel can provide better services by being equipped with handheld devices that can immediately identify the passenger and provide them with key contextual information.

Enhanced passenger experience

Enhancing the passenger experience can be achieved through passenger information and multimedia entertainment applications. For instance, passenger information applications can provide route information and weather forecasts. Entertainment applications can provide video streaming.

This type of "Infotainment" traffic is typically low priority and may consume only a low to moderate amount of network capacity. It also tolerates relatively high network latency. However, passenger Internet services could eventually become the single highest consumer of network capacity.

Reducing operational costs

Lower maintenance and operational costs will be achieved through the efficient operation of rolling stock, based on real-time information and improved communication between moving trains, maintenance staff and track-side systems.

Operational costs will also be reduced by introducing new applications (for example remote diagnostics and Augmented Reality (AR) based remote maintenance) and services to simplify and automate operational processes, as well as by consolidating fragmented legacy networks with a unified 5G network capable of running multiple services.

Critical, performance and business applications

The International Union of Railways (UIC) defines three categories of application that may be enabled and supported by FRMCS:

- Critical: applications essential for train movements and safety or a legal obligation, such as emergency communications, shunting, presence, trackside maintenance, ATC, etc.
- Performance: applications that help to improve the performance of the railway operation, such as train departure, telemetry, etc.
- Business: applications that support the railway business operation in general, such as wireless internet, etc.

Source: Future Railway Mobile Communication System: User Requirements Specification https://uic.org/IMG/pdf/frmcs_user_requirements_specification_version_4.0.0.pdf

The route to FRMCS/5G for rail operators

European mainline railway operators are restricted by a legal requirement that the next-generation railway telecommunication system must be standardized. UIC, ERA (the European Union Agency for Railway), ETSI and 3GPP are defining a telecommunications system capable of replacing GSM-R from 2022 onwards, with the migration phase expected to last until 2030 at the earliest.

The first 5G trials and proofs of concept in the mobile operator market have already commenced and are seeing a fast ramp-up over the coming months. 5G-based FRMCS commercial roll out in Europe is expected from 2024/2025 onwards.

European frequency standardization and regulation is currently driven by ECC/CEPT, where different options – including the reuse of existing GSM-R spectrum – are under evaluation are expecting lower frequencies to be used for 5G in the EU. The first roll outs of 5G focus on high frequencies, but there is strong interest from all regions to deploy 5G in frequency bands below 1 GHZ.

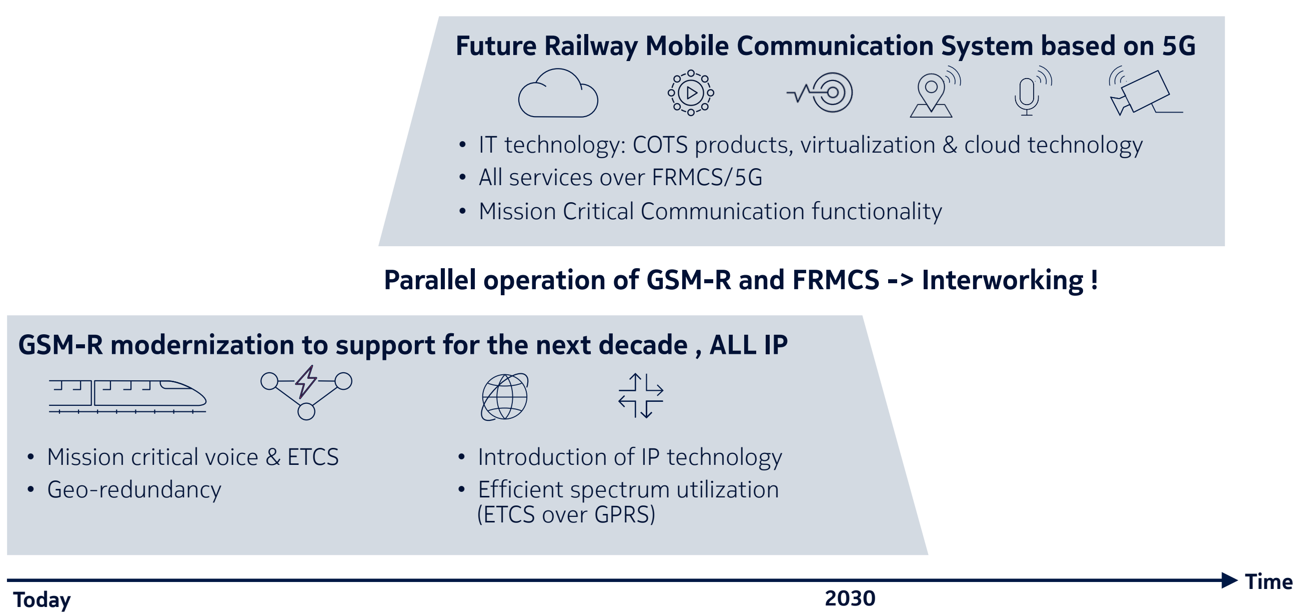
Independent of the radio technology, available spectrum remains the most important challenge facing the railway operator. Because GSM-R and FRMCS will run in parallel during migration, the efficient use of GSM-R spectrum is essential. Current GSM-R networks are not yet wholly updated to GPRS and so must be modernized to meet the latest ETCS requirements and free up spectrum for the use of FRMCS in parallel.

For existing GSM-R customers Nokia recommends modernizing existing GSM-R networks by introducing GPRS for IP services within the next two years, ensuring they are prepared for a parallel rollout of 5G for railways starting from 2025. This will also allow them to slowly convert rolling stock terminals to packet-based ETCS components in the train. Also, railway operators are advised to modernize their IP access network and start connecting GSM-R base stations via IP protocol in preparation for the FRMCS base station, which will be IP-native.

As it will be difficult to maintain basic GSM-R equipment beyond around 2030, a modernized GSM-R network will need to meet all the basic ETCS requirements by that point. This means the time slot for migrating to 5G for railways to meet ETCS would be between 2025 and about 2030 and beyond. During this period, railway operators may opt to run 5G networks for a short period to cover areas of high broadband demand, in parallel to the GSM-R network used to provide the ETCS mission-critical services.

For mainline railway operators outside Europe who currently do not run a GSM-R network and do not have to follow ERA/UIC standardization, the introduction of standard LTE for train control and rail broadband services would be technically feasible and would provide a first step to 5G for railways.

Figure 5. With the deployment of 5G starting in the mid-2020s and GSM-R reaching end of life around 2030, rail operators will need to run both technologies in parallel. Preparations for this period need to be made, principally updating existing networks including transmission and GPRS to support all-IP operation



Making a success of migration

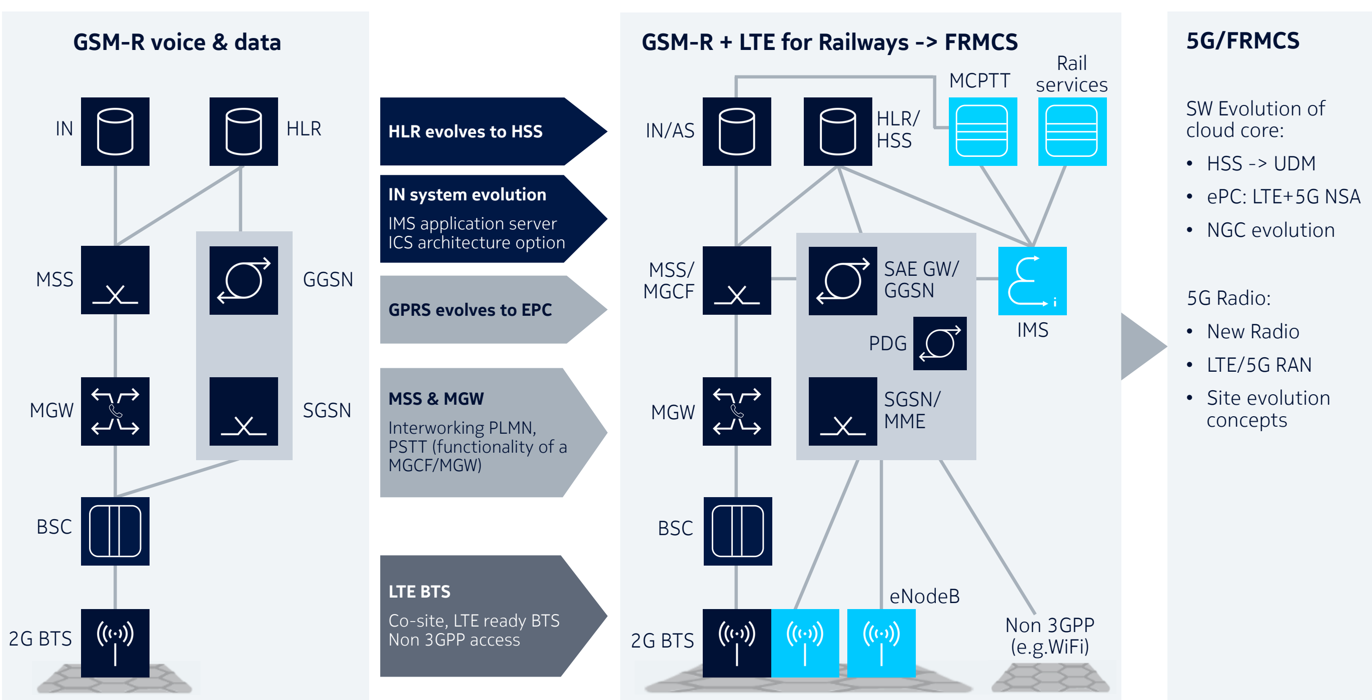
Migrating from analog legacy systems or GSM-R to FRMCS is not an overnight task. As well as updating the railway infrastructure, rolling stock must also be modernized. It is especially important that the migration of infrastructure and rolling stock are aligned to support the movement of trains across international borders, as is common in Europe.

Implementing FRMCS is also a legal requirement in Europe, requiring careful planning and allowing enough time for the migration to take place. Such issues are currently being investigated by the ERA (European Agency for Railway).

With its long experience in deploying GSM-R, Nokia is well placed to support the transition of railway infrastructure to FRMCS, helping to ensure interoperability throughout the migration period. It is vital that the introduction of FRMCS does not disrupt the running of the GSM-R network.

There are many benefits for railway operators in adopting the strategies and technologies that have underpinned the successful and smooth migration of 3GPP from 2G to 4G and 5G. For example, the latest Nokia core nodes, like Packet Core, HSS and MSS, are ready to support all access technologies through simple software updates. Distributed radio access networks with flexible deployment options support the easy transition of the radio subsystem by taking advantage of existing sites and transmission deployments.

Figure 6. From GSM-R to FRMCS – adopting a well-proven path



Nokia – leading the way to 5G

Nokia is the leading railway communications solutions provider and together with Bell Labs is developing the most innovative 5G portfolio. Its networks portfolio is field proven with the major mobile network operators worldwide and it has developed the expertise to modernize and migrate rail networks to the highest safety and efficiency standards.

Nokia is the market leader in GSM-R with 21 networks covering more than 109,000 km of GSM-R track and more than 80 mission-critical railway IP/optical networks deployed. As a principal driver of the industry's standardization work in GSM-R and the evolution to LTE/FRMCS, Nokia can support railway operators as they seek to move from their existing communications networks to ones based on IP.

As a member of UNIFE/UNITEL and with close relations to ERA, UIC, ETSI and 3GPP, Nokia is both driving the standards and ensuring that its products are fully compliant.

In addition to a full portfolio of railway solutions, Nokia also contributes its professional railway services, such as integration for predictive maintenance and station management.

It offers the highest compliancy standards in the communications industry, as well as best-in-class cyber security solutions. For any migration strategy to 5G, rail operators need to consider the evolving threat of cyber-attacks. Nokia's security portfolio helps keep networks, communications, and devices safe from cyber threats, combining a variety of security techniques to protect high-value assets and services.

With a track record of successfully supplying both GSM-R and 5G, Nokia is best prepared to handle the interworking of new 5G and existing GSM-R networks, crucial during the network migration phase.

Nokia Future X – the right track for rail 5G

The Nokia Future X 5G architecture for railways provides an intelligent, dynamic communications and cloud-based platform to support all railway systems, processes and activities. It enables better interaction between many existing systems, as well as providing a launch pad for innovative applications and services.

Future X architecture is based on dedicated, universal broadband connectivity, both wireless and wired, to connect with people, sensors, trains, video monitors and automated train control, all securely and with the highest reliability.

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Conclusion

5G is set to make a major impact on all aspects of society and industry and railway communications is no different. Railway operators have an opportunity to update their legacy networks and move to a new world of supreme safety, high operational efficiency and on-train mobile broadband.

Offering high speed, high capacity and low latency, 5G can provide enormous benefits and will help rail operators move to a new era in automated operations and customer service.

The FRMCS, based on 3GPP evolution towards 5G, has been proposed as a single global standard for railway communications.

With GSM-R expected to be supported until around 2030, rail operators need to start planning early to migrate their existing networks to the new standard if they are to take full advantage of the opportunities. One example would be the introduction of IP-based transmission for today's GSM-R networks, as a first step towards FRMCS.

Experienced in both 5G and radio communications for railways, Nokia is well placed to ensure rail operators navigate the transition and help them make their communications systems fit for the broadband future.

Abbreviations

3GPP	3rd Generation Project Partnership
5G	5th Generation mobile network
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATP	Automatic Train Protection
CBTC	Communications-Based Train Control
CCTV	Closed Circuit Television
DMR	Digital Mobile Radio
ERA	European Union Agency for Railways
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FRMCS	Future Railway Mobile Communications System
GPRS	General Packet Radio Service
GSM-R	GSM Railway
HSS	Home Subscriber Server
IP/MPLS	IP/Multiprotocol Label Switching
IoT	Internet of Things

LTE	Long Term Evolution
M2M	Machine-to-Machine
MBB	Mobile Broadband
MIMO	Multiple Input Multiple Output
MSS	Mobile Switching Center Server
mMTC	massive Machine Type Communications
NR	New Radio
PON	Passive Optical Network
QoS	Quality of Service
TDD	Time Division Duplex
TETRA	Terrestrial Trunked Radio
UHF	Ultra-High Frequency
UIC	European Union – Agency for Railway
VHF	Very High Frequency

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