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The importance of 5G networks for railway transport development

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Abstract

Digitisation of transport is a tool for achieving the European Union's political goals included in the Digital Single Market Strategy for Europe. For rail transport, digital innovation is required to increase its competitiveness. One of the tools of the digital transformation of railways is 5G networks, the fifth generation of wireless communication systems. The purpose of this article is to present the benefits of implementing 5G network for railway operators. Focus was placed on its innovative features, such as ultra-fast access to Internet services, very high connection reliability, and extremely low data transmission delays. Examples of new services for railway operators based on the capabilities of 5G networks were presented. This article describes the unique functions of the 5G network in which resources can be flexibly allocated depending on current traffic needs thanks to the network slicing function, e.g., for services of key importance to rail traffic and commercial services for other market segments. Roadmap proposals for transforming the current rail communication network infrastructure towards the target FRMCS system are presented. The analysis was based on source materials from Nokia Corporation, available literature, EU documents and regulations, as well as institutional studies of the railway sector.

Introduction

The dynamic development of railway transport services increasingly depends on the effective use of advanced communication systems by operators to increase the safety of transport, decrease operational costs, and improve the general satisfaction of railway passengers. The issue requires digital transformation processes that integrate modern technologies into existing physical systems, those that form innovative business models and processes, as well as those that create so-called smart products and services (Leyen, 2020). Due to progress in the use of new technologies, starting with the Internet through the Internet of Things (IoT), cloud computing, big data analytics, etc., digitisation permits the implementation of Industry 4.0 and "Industrial Internet of Things" (IIoT) concepts (European Parliament, 2019). The development of technology related to mobile devices and common Internet access also play an important role, and will be a relevant factor in the development of society's needs in the coming decades. It will also serve as the basis for creating new services to improve mobility, thus increasing the added value due to the use of transport (Załoga & Wojan, 2017).

In its strategic programmes, the European Union has used digitisation as a fundamental pillar of economic and social growth, as reflected in its Europe 2020 strategy, which has been realised since 2010. So far, the framework for the development of smart transportation systems (2010) and new programmes for expanding the digital markets known as "A Digital Single Market Strategy for Europe" (2015) and

"Competitive Digital Single Market – Towards a European Gigabit Society" (2016) have been established. A new EU Directive 2018/1972 was established by the European Electronic Communications Code. Digitisation has also become one of the six priorities for the new European Commission outlined in the "Political guidelines for the next European Commission 2019–2024" programme. It announces the development of a new Digital Service Act and joint standards for the EU's 5G networks (Leyen, 2020).

Rail transport is an important area of digitisation policies. In 2016, a group of international rail organisations (UIC, CER) and associations (CIT, EIM) developed the Roadmap for Digital Railways (CER, 2016), and a year later, a joint railway digitisation declaration was signed with wider participation (ERTA, UIP, UITP, UNIFE). The following were used as the most fundamental pillars of railway digitisation (Mahboob & Zio, 2018):

1) railway communication,
2) improving customer satisfaction,
3) increasing system capacity,
4) open data processing platforms.

Railway projects face challenges related to the so-called Digital Railway Revolution, problems with Big Data, predictive network maintenance, artificial intelligence, stand-alone rail vehicles, and hyperloop technology. Future rail capabilities and connectivity needs have been captured and grouped into four umbrella use-cases: connected devices, operations, passengers, and intervention (NetworkRail, 2020).

One of the tools for the digital transformation of rail is the 5G network, or the fifth generation of wireless communication systems. This technology contributes to the construction of a smart communication infrastructure dedicated to transport, i.e. those that collect, use, and share data in real-time over the entire range of various devices such as: sensors, detectors, or autonomous drones (Mahboob & Zio, 2018). Intelligent infrastructure is the result of equipping physical infrastructure with smart capabilities (Guizani & Anan, 2014). In EU terminology (European Commission, 2019), 5G networks refer to "a set of all relevant network infrastructure elements in the field of mobile and wireless communications technology, used for the needs of value added communications and services, with advanced operational parameters, such as very high data transfer speed and bandwidth, low latency connectivity, extremely high reliability or the ability to support a large number of connected devices". Such infrastructure requires specific protection. The EU has made it a priority task to develop European systems of cybersecurity certification for products, services, and processes in the scope of Information Communication Technology used as part of 5G networks.

The national 5G network construction strategies adopted so far by nine European countries support the use of this innovative technology for transport. The 5G Strategy of Poland (Ministerstwo Cyfryzacji, 2018) stipulates the coverage of major transport routes with 5G networks by 2025.

This article presents selected functions and possibilities for implementing 5G networks and their benefits for railway operators. This issue has not yet been widely reported in the literature on the subject. The problem analysis was based on the European Union development programmes, as well as materials and available studies from Nokia Corporation (Nokia, 2018; 2019a;2019b).

The objectives of implementing 5G in rail transport

Although currently widely used 2/3/4G technologies have introduced numerous new functions in critical rail communication networks, 5G systems will meet the most advanced requirements of communication service providers in the future. The main advantages of 5G include: ultra-fast access to Internet services, very high connection reliability, low signal transmission delay, and support for a large number of users with various quality requirements for the services provided. The capabilities of this latest-generation mobile network will meet the needs of mass communication between devices (mMTC – *massive Machine-Type Communication*) and sensors used to predict events in railway infrastructure, which operators will need more of in the future to improve and optimise the services they offer.

The predicted increase in data transmission speed via 5G networks is expected to achieve a throughput of 1 to 10 Gb/s while guaranteeing very low data transmission delays. The added value of 5G technology is also a significant increase in the performance of telecommunications traffic (network slicing), while ensuring lower costs compared with older cellular technologies. The main performance features of 5G networks for basic telecommunications services are shown in Figure 1.

As noted above, 5G networks will ensure new possibilities for the flexible management of network resources, which will be available for railway operators to use for tasks such as extracting network

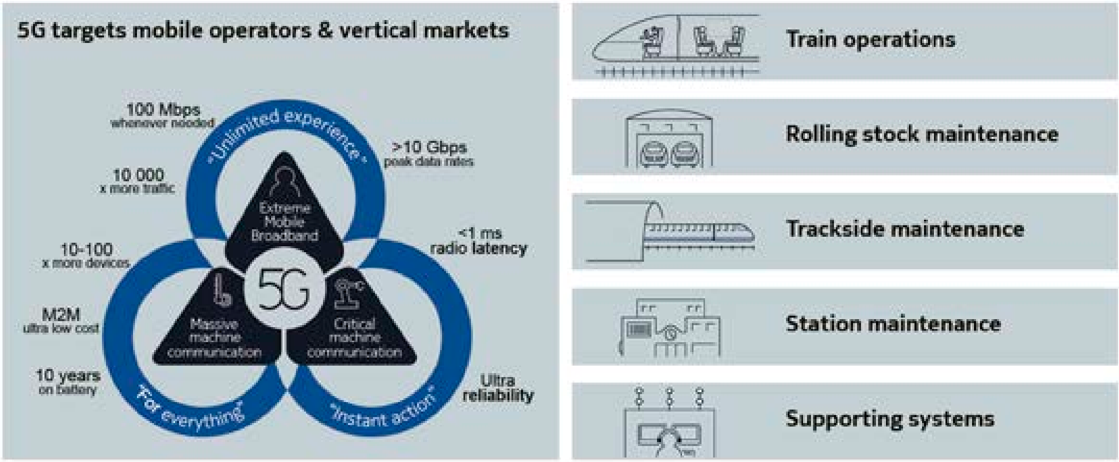

Figure 1. The main parameters of 5G network services built for railway operators (Nokia, 2019a)

resources for rail-critical services. Furthermore, the network will be able to offer commercial packages with an offer for other types of services or market segments. This should provide opportunities for railway operators to generate income from the provision of services and applications based on mobile ultra-wideband Internet.

The classification of 5G network services for rail communication network operators is comprised of three basic segments:

1. Critical services: applications necessary for train control and safety or legal obligations, such as emergency traffic, manoeuvring rolling stock, monitoring the presence of rail vehicles, trackside maintenance, *Automatic Train Operation*, or ATO; *Automatic Train Control*, or ATC; or *Automatic Train Protection*, or ATP.
2. Performance services: services that improve the efficiency and effectiveness of rail transport, through avenues such as telemetry or IoT systems.
3. Business services: services that generally support railway activities, such as wireless ultra-broadband Internet, e-tickets, travel services, etc.

Led by ERA and UIC, the *Future Railway Mobile Communications System* (FRMCS) is the only global rail communication standard, and technologies such as 5G are best prepared to meet the requirements of railway operators defined therein. It is crucial that rail operators start planning the migration of their

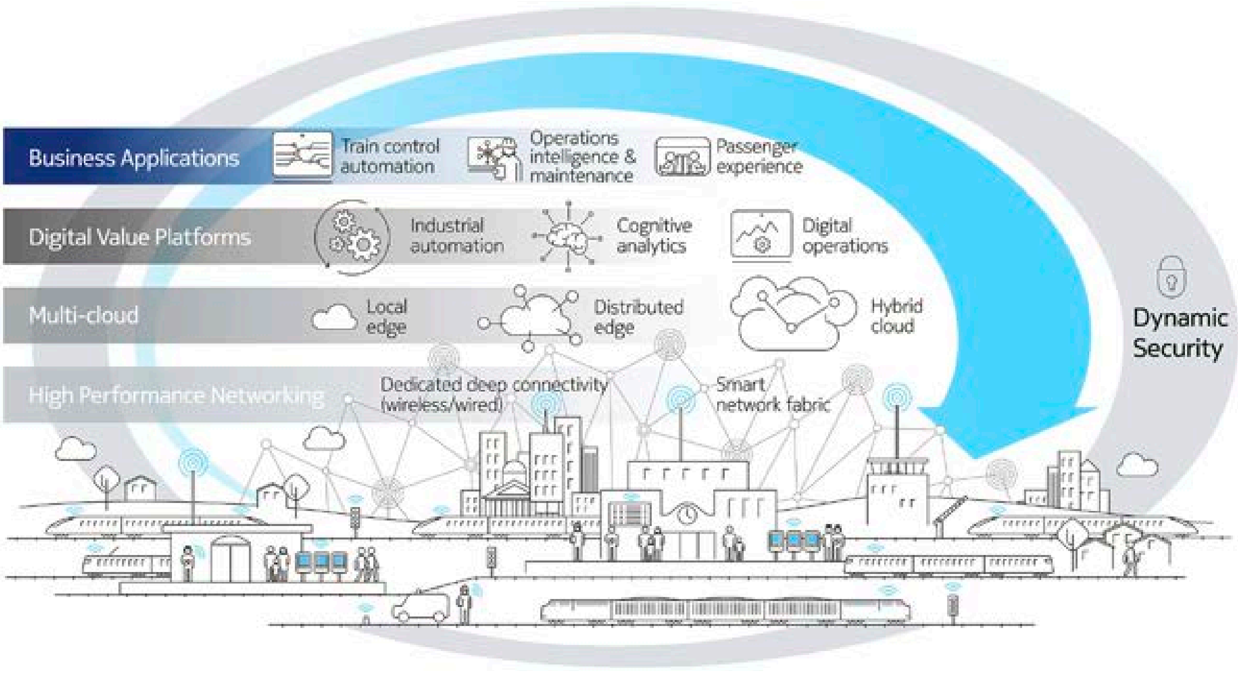

Figure 2. Diagram of the target architecture of the Nokia Future X rail network (Nokia, 2019a)

existing networks based on the FRMCS standard sufficiently in advance, if they are to fully use the business and technological opportunities created by them. A road map has been defined for this issue in Europe; it will extend until 2050, which means that GSM-R and FRMCS systems will operate in parallel for several years during the network transformation period.

The current GSM-R network used by rail operators must be modernised to offer top-quality service standard and meet the latest requirements of the European Train Control System (ETCS), as well as to free up the occupied frequency band for FRMCS. Railway organisations should accelerate the complex process of modernising both their telecommunications networks and rolling stock. Proper and effective harmonisation of this transformation process in Europe and the creation of an appropriate legal framework is needed for its smooth operation in the near future.

Nokia and its research and development centre, Bell Labs Future X, developed a special telecommunications network architecture for railways that provides smart and dynamic communication on a cloud platform that supports all individual rail systems and processes, as shown in Figure 2.

For railway operators, the main benefits of implementing the abovementioned 5G network include:
- increasing the level of safety (including operational applications of key importance for safety, such as train signalling, CCTV, and on-board communication);
- enhancing the efficiency and operational efficiency of railway operators;
- increasing the innovation of passenger services, supporting the digitisation of services, and improving the level of competitiveness of rail carriers.

All the above-mentioned advantages can be achieved with one coherent and flexible 5G network, which removes the complexity and inefficiency of multi-layer network management based on technologies such as GSM-R, TETRA, DMR, VHF/UHF, or Wi-Fi.

FRMCS as a global rail communication standard

As previously mentioned, the FRMCS system is to serve as a single global standard for rail communication in the future. As a successor to GSM-R, FRMCS complies with European standards, while meeting the needs and requirements of rail organisations outside Europe. In addition to the main rail carriers, the UITP (*Union Internationale des Transports Publics*) also supports the introduction of networks compliant with the FRMCS standard. As a mobile technology tailored to broadband communications, FRMCS will support the needs of rail operators in six basic aspects:

1. Providing access to broadband Internet
   - Automation of self-directing rails;
   - Increasing operational efficiency;
   - Improving the quality of customer service.
2. Optimisation of network resources
   - Further harmonisation of network technologies towards IP;
   - Reducing network complexity;
   - Increasing network flexibility.
3. Long-term support for telecommunications infrastructure
   - Support for ERTMS/ETCS systems for the upcoming decades;
   - Management of outdated GSM technology.
4. Critical communication services
   - A voice that evolves to group video calls;
   - Train control, such as automated train operation;
   - Machine-to-Machine (M2M) and telemetry for critical elements.
5. Communication to increase business efficiency
   - M2M and telemetry;
   - Predictive maintenance of railway infrastructure;
   - CCTV services for passenger protection and train traffic control, passenger information, and personnel communication.
6. Business communication
   - Wi-Fi on board trains.

One of the main goals of FRMCS is to achieve maximum flexibility by separating railway functions implemented in the network and via radio links. This enables the use of standard mobile radio technologies such as 4G and 5G, Wi-Fi, landline networks, and even satellites. Unlike GSM-R, this functionality is mainly implemented in the service and application layers. The evolution of technology to a 5G network supports multi-access communication and is oriented towards individual services and their specific requirements.

There are also railway operators on the market who are more inclined to implement broadband technology based on LTE/4G systems in rail transport. Such an approach could give them an opportunity to become acquainted with the specific provisions for broadband Internet services, followed by the creation of a more effective plan for the smooth migration to the target 5G FRMCS solution in the future.

Application and advantages of FMRCS and 5G networks

The use of opportunities given by 5G, cloud data processing, and advanced artificial intelligence analytical algorithms will allow railway operators to build partnerships with third companies to offer innovative applications and services, among which we can distinguish categories such as (Nokia, 2019b):

1. Critical services

   Reliability is critically important in CBTC/ETCS systems, although the implementation of operational voice services also requires a high level of priority in the network. This ensures safety and the necessary means for manual upkeep of railway traffic in case emergencies occur with other systems. CBTC/ETCS services usually tolerate a loss of communication for no more than a few seconds, and a critical voice service will have a higher tolerance for temporary loss of communication.

2. Predictive analysis of network maintenance and its effective management

   The maintenance and repair of rolling stock, track elements, depots, and stations, often over a large area, is a challenge when planning the effective use of repair equipment and assembly units. The maintenance infrastructure and its repair based on predictive planning uses IoT sensor resources and advanced data analysis to optimise costs, increase the use of network resources, enhance security, and minimise delays. The use of digital systems for simulating train movement and loads on rail infrastructure should improve the efficiency of existing rail transport processes.

3. Video surveillance for increased operational security

   Rail communication network operators currently use CCTV systems, which generate thousands of data streams with video services. These require an economic and reliable communication network with high bandwidth that can handle several Mbps traffic per camera and manage thousands of video calls simultaneously. The use of analytical algorithms for video services can automatically detect anomalies in the behaviour of people, warning security and safety personnel so that they can intervene with appropriate actions. The video service is gaining importance in the course of automating transport processes, for example in detecting obstacles on tracks.

   Modern CCTV systems include innovative features such as video analysis software for intrusion detection, suspicious behaviour, or unattended luggage. Of all types of services, movement of the application for CCTV railway systems requires the highest signal transmission speed, as well as the largest information carrier capacity for data collection.

4. "Digital passenger"

   The modern passenger expects to be continually connected to the Internet and receive a range of services in line with his or her needs. Providing the passenger with full broadband access at the station and onboard the train is a basic functionality offered by rail operators. Railway staff can also provide better services when they are equipped with handheld devices that can immediately identify a passenger and provide key contextual information.

5. Passenger satisfaction

   Improved passenger satisfaction can be achieved by providing them with appropriate information and a high quality of multimedia entertainment applications. For example, information apps dedicated to passengers can provide current route data, interesting locations passed, or the current weather forecast at their destination.

   This type of traffic, known as "infotainment," is usually low-priority and can only consume low-to-moderate amounts of network resources. It also tolerates relatively long delays in the network. However, the passenger Internet service may eventually become a service that consumes the most network resources due to the growing popularity of video services among customers. For this change, railway operators should prepare their strategy to develop the network and its ability to handle traffic generated by passengers.

6. Reduction of operating costs

   Maintenance and operating costs can be lowered through the operation of more efficient rolling stock using real-time information and better communication between moving trains, maintenance staff, and track-side systems. Operating costs can also be reduced by introducing new applications – for example, remote diagnostics, remote maintenance based on augmented reality (AR), services that simplify and automate processes, as well as consolidation of fragmented older networks using a unified 5G network.

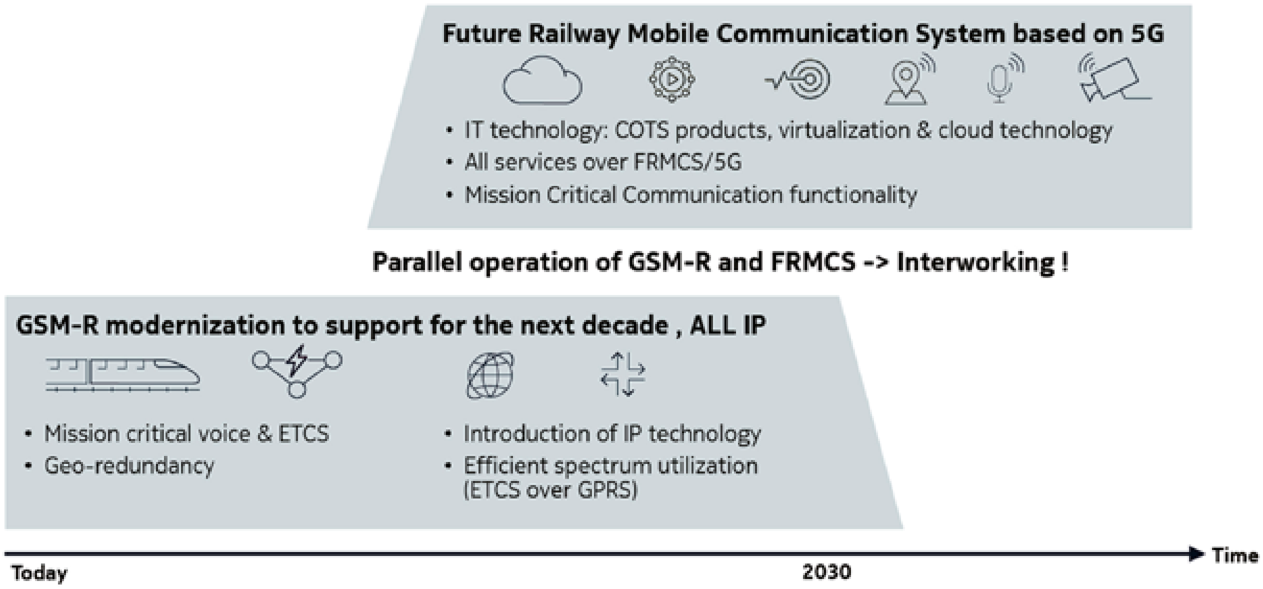

Figure 3. Example of a road map for the modernisation of railway communication networks (Nokia, 2019a)

The evolution of FRMCS and 5G systems for railway operators

2019 saw the launch of the first commercial 5G network, whose services are now offered by mobile operators in the most innovative markets, such as the USA, South Korea, or Japan. An FRMCS system based on 5G technology should be available in Europe around 2024/2025. The European normalisation of frequency bands managed by ECC and CEPT assumes the reuse of existing frequency spectrum for GSM-R. The first 5G implementations focused on higher frequencies than those currently used in GSM-R, but operators and infrastructure providers are interested in the implementation of 5G in frequency bands below 1 GHz, which should improve the economic profitability of building this system.

Independent of radio technology, the available frequency spectrum remains one of the major challenges for rail operators. Because GSM-R and FRMCS will operate in parallel during the network migration period, more efficient use of the current GSM-R band is required. GSM-R network operators should modernise their systems by introducing a GPRS system for IP services in the coming years, ensuring that they are prepared for the parallel implementation of railway-dedicated 5G services by 2025. This will also allow the gradual replacement of terminals in rolling stock with newer ETCS systems (Nokia, 2018).

The years 2025–2030 mark a period for the final migration of the railway communication infrastructure to the 5G network. At this time, railway operators should launch the 5G network in areas that report a high demand for the use of broadband services and offer parallel GSM-R network services of major importance for ETCS. For major rail operators outside Europe that currently do not use GSM-R, the introduction of the LTE standard for train control and provision of broadband Internet services would be technically feasible and would be the first step in building a 5G network for rail in the future. An example of the potential road map for railway operators encompassing the abovementioned technologies is presented in Figure 3.

Conclusions

The 5G network will exert a growing influence on many aspects of society and industries in the future, and rail communication systems and services will also be impacted. Railway operators have the opportunity to modernise existing networks and move to a new ecosystem offering the highest security, a high operational efficiency, and access to mobile broadband Internet on trains.

The use of 5G technology is also planned in the upcoming transformation as part of the so-called Industry 4.0. The use of the 5G standard as a common technology will play a major role in intermodal transport, in which the means of transportation will be able to cooperate with FRMCS as part of an effective homogeneous communication network.

By offering high-speed data transmission, enormous capacity, and low signal transmission delays, the 5G network will provide significant benefits to railway operators and help them enter a new era of automated operations with improved customer service. The FRMCS system, based on the evolution towards 5G, has been proposed as a common global standard for rail communication. Because the GSM-R system is to be operated only until 2030, it is recommended that railway operators begin work on transforming their telecommunication infrastructure now. Such a proactive approach will allow railway entities to fully exploit the possibilities of their new communication system, and also introduce profound changes in their existing business models and operational processes.

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