FRMCS

Future Railway Mobile Communication System

UIC RAIL SYSTEM DEPARTMENT

FRMCS and 5G for rail: challenges, achievements and opportunities

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FRMCS AND 5G FOR RAIL
Challenges, achievements and opportunities

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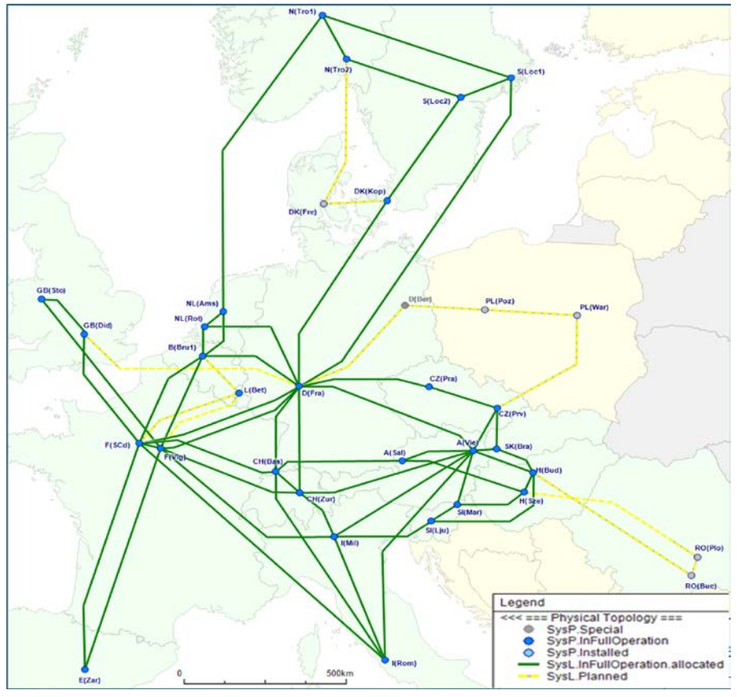
Over the last 20 years, the ground-to-train communication system has become a core part of railway operations, in particular thanks to increasingly widespread use of GSM-R, which has enabled significant harmonisation and improvement of previously heterogeneous services under legacy analogue systems. This communication system is about to undergo a far-reaching change, one designed as an evolution of the present system but which may come to prove a veritable revolution supporting numerous aspects of digitalisation in the rail sector.



GSM-R: A SUCCESS STORY

The European strategy beginning in 1997 to introduce **ERTMS** (European Railway Traffic Management System) as the standard railway control-command system was the starting-point in defining and implementing a large-scale harmonised, standardised ground-to-train communication system, **GSM-R**.

Though GSM-R was initially designed to support the **ETCS** (European Train Control System) signalling system, it was gradually adopted by the vast majority of rail operators for a wide range of other uses as well, since it offered a set of extremely secure operational communications functions which were entirely suited to their needs; as such, it has become an integral part of the railway landscape. Over a 20-year period (quite short for an industry with lengthy investment cycles), GSM-R has proven a highly effective enabler of convergence, efficiency and interoperability in Europe and elsewhere, with nearly **150,000 km** of lines equipped in Europe and **250,000 km** in the rest of the world. Development has been particularly spectacular in China, which has become the world’s biggest market in this sector of the transport industry.

From its inception, the specifications for GSM-R have been developed by **UIC** (International Union of Railways), working on behalf of the rail sector in projects such as **EIRENE** (European Integrated Railway Radio Enhanced Network) and **MORANE** (Mobile Radio for Railway Networks in Europe). This work rapidly produced two key documents named after their respective projects: **EIRENE FRS** (Functional Requirements Specification) and **MORANE SRS** (System Requirements Specification), which together define all the building blocks of a communication system which is tailored to railways’ needs. Today, these technical specifications are a vital basis for defining the ground-to-train radio system within the **CCS TSI** (Control-Command System Technical Specification for Interoperability) being overseen by **ERA** (European Railway Agency) on behalf of the European Commission.

The use of this type of system is regulated at European level in order to ensure it is both safe and interoperable between networks.

Since one of GSM-R’s key assets is its interoperability, and more broadly its user transparency for all the trains using its multiple functions (irrespective of geographical origin or route, whether purely domestic or using several national networks), in order to ensure a genuinely seamless operating concept it became necessary to create dedicated **interconnecting hubs** to transparently manage ground-to-train communications during border crossings, during which all communications, including the signalling support, are transferred from one national operator to another. These interconnection servers are located in Germany, with a back-up in Switzerland, and enable trains to transit between 17 interconnected European countries by transferring operational communications from one national network to another. They are operated under UIC’s responsibility on behalf of all the GSM-R operators concerned.

Lastly, GSM-R was designed from the outset to meet rigorous quality of service standards, given that its job is to transmit critical communications such as ETCS signalling commands or sophisticated communication functions, the best known of which is doubtless the emergency call function. With the benefit of hindsight, it is clear that the latter has proven vital in ensuring the safety of trains in service. Quite simply, **GSM-R networks are the most reliable mobile networks currently in existence**, so much so that there are numerous examples of them being the last to still be working during serious incidents after other mobile networks had lost coverage.

For all these reasons, GSM-R is acknowledged as a vital cornerstone of safe and reliable railway operations. It is probably one of the best - if not the best - examples of mass-scale rapid take-up of a system by virtually all sector stakeholders, whether European or from further afield, which achieves its stated aims of being fine-tuned to operators’ actual needs and totally interoperable while also offering exceptional quality of service.

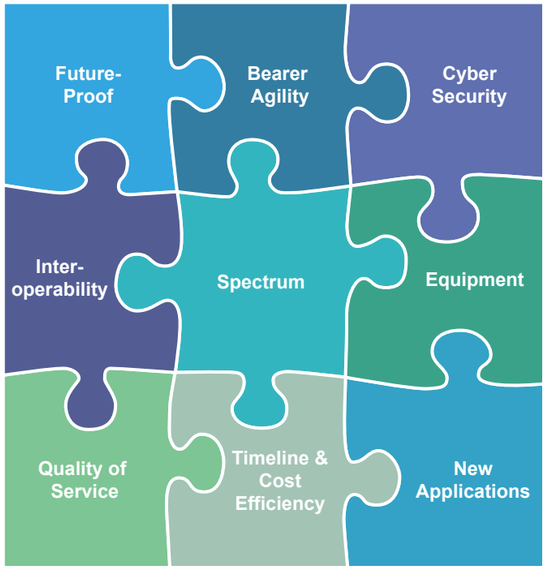
THE NEED FOR CHANGE, AND THE HUGE OPPORTUNITIES THIS OFFERS

"Its goal is clear: to usher in 5G for rail networks."

The telecoms industry's life cycles are by nature much shorter than the rail industry's, with particular strides having been made over the last 50 years such as transparent interconnection between all the world's fixed networks, the advent of mobile phones, fibre-optic terabit transfer capacities, the emergence of powerful data networks which have now become vital to business of all types, or indeed the advent of the internet. Concerning mobile phones in particular, we have quickly progressed from 2G to 3G, 4G and now 5G networks, the latter of which is starting to be rolled out in various parts of the world.

The flip-side of such impressive technological progress is, of course, that the technology rapidly becomes obsolete. And 2G, the basis for GSM-R, is no exception, despite significant and continued efforts by the telecommunications suppliers who developed GSM-R to maintain systems which are now rather out of sync with their times and general industry trends. As such, it is fairly clear to all that GSM-R networks will start to be life-expired by 2030, making their maintenance ever more costly and complex.

Aware of this inevitable reality, the UIC groups in charge of GSM-R worked hand in hand with railway operators and decided to begin looking into GSM-R's replacement as early as 2015. By 2018, they had already laid down the broad outlines of a structured programme for this replacement, the generic name of which is **Future Railway Mobile Communication System** (FRMCS). The acronym may seem a tongue-twister but it is now familiar to many, and its goal is clear: to **usher in 5G for rail networks**.



However, though the original rationale behind the programme was the regrettable yet inevitable obsolescence of GSM-R, the UIC groups realised straight away that a next-generation telecommunications network for the railways would in fact serve as the starting point for the modernisation of rolling stock and the digitalisation cycle of the entire sector - not before time given the head start many other industries already had.

One simple example is automated train operation and, in future, fully self-driving trains, which cannot exist without a high-performance, secure telecommunications network.

Equally, sophisticated train monitoring systems will not be possible without a high-quality mobile network. Not to mention the remote operation/ information applications or the inevitable use of video support which will be a necessary part of modern rolling stock.

It is therefore with this twin ambition - the need to replace an obsolete technology despite its entirely satisfactory performance on one hand, and the goal of creating the enablers of digital railway operations on the other - that the FRMCS programme was defined.

It will admittedly be no small order to replace an entirely satisfactory system with a global footprint whilst also seeking to supply the crucial core elements which are needed to ensure the on-board railway applications of the future: the necessary radio spectrum, appropriate specification and standardisation plans to ensure a longer shelf-life than for GSM-R, a new architecture, new needs, new applications, new equipment, etc.

But UIC has rapidly managed to assemble a roll-call of global railway talent in this field and being onboard the key supply industry players to see through this highly ambitious programme.

THE FRMCS PROGRAMME AT UIC: ORGANISATION AND STRATEGY

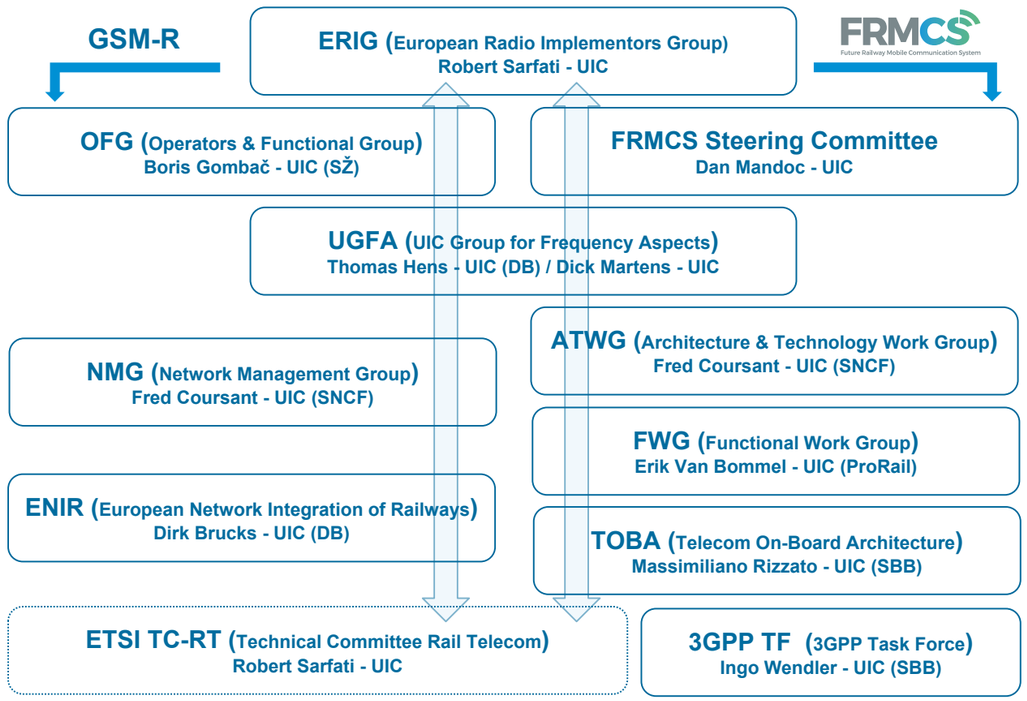
"Seeing the first roll-outs in Europe possible from 2025."

Starting in 2018, UIC created a set of dedicated FRMCS working groups working under the supervision of **ERIG** (European Radio Implementers Group, which brings together the telecoms network managers) and alongside the groups responsible for maintaining and enhancing the GSM-R specifications and managing inter-railway interoperability in Europe:

- the Functional Work Group (**FWG**), in charge of functional aspects,
- the Architecture & Technology Work Group (**ATWG**), in charge of system-related aspects,
- the UIC Group for Frequency Affairs (**UGFA**), for all work relating to the radio spectrum,
- the Telecom On-Board Architecture group (**TOBA**), tasked with defining new systems for on-board telecommunication,
- the 3GPP Task Force (**3GPP TF**), whose job was to ensure that 3GPP standardisation took account of the underlying mechanisms necessary to FRMCS,
- the FRMCS Steering Committee, which coordinated all the above and was attended by other rail sector stakeholders, in particular **ERA** (European Railway Agency).

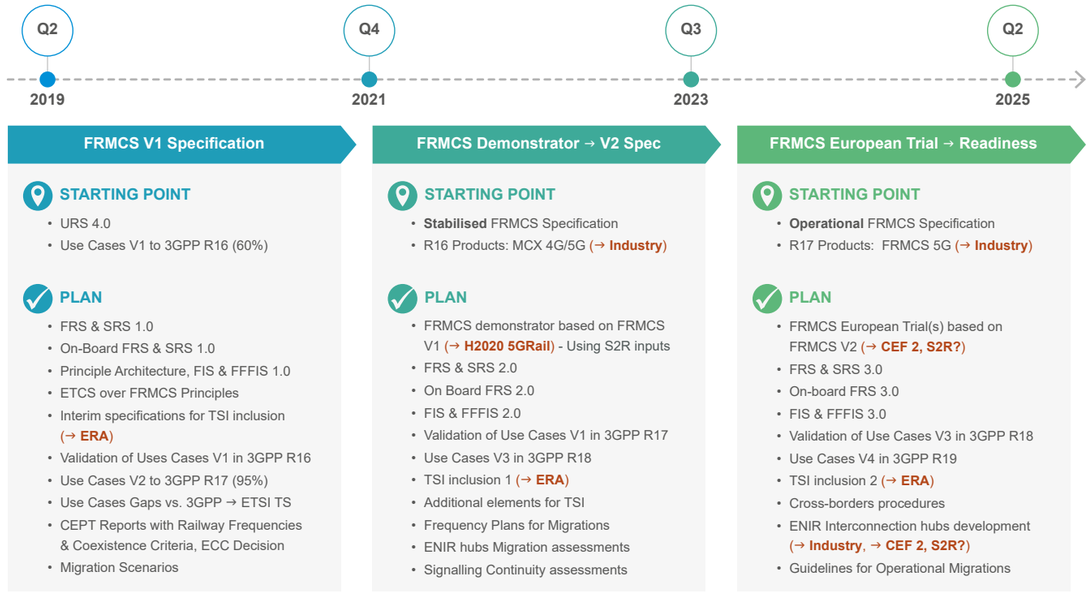
Naturally, the spectacularly successful collaboration with **ETSI**, via the specialist **TC-RT** (Technical Committee - Railway Telecommunications) was immediately renewed, having proven its worth time and again in the history of GSM-R.

The UIC GSM-R & FRMCS Programs Organisation



Closely correlated with this way of working was a three-point strategy plan, which was developed for all FRMCS work with the goal of seeing the **first roll-outs in Europe possible from 2025**:

Strategic Plan for FRMCS Introduction



- pillar one is specification and standardisation ("**FRMCS V1 Specification**"), including traffic management support, since FRMCS has necessarily to feed into the CCS TSI (Control-Command System Technical Specification for Interoperability) being overseen by ERA. This needs to happen as soon as the TSI revision begins (planned for 2022 by the European Commission) and will involve the publication of numerous technical documents and ad hoc specifications,
- pillar two is much more industry-focused ("**FRMCS Demonstrator => V2 Specification**") and involves developing initial prototypes for real-life trials in the FRMCS ecosystem and feedback from this experience to input into all the specifications developed, to take place via the H2020 5G Rail project,
- pillar three will see the finalisation of the initial scope of the FRMCS solutions to be deployed as of 2025 ("**FRMCS European Trial => Market Readiness**"); financing solutions are already being examined.

Note that this plan was drawn up in 2018 but remains entirely valid until the end of 2020, each phase and stage thereof having been fully implemented to schedule despite the pandemic and related consequences we are still enduring.

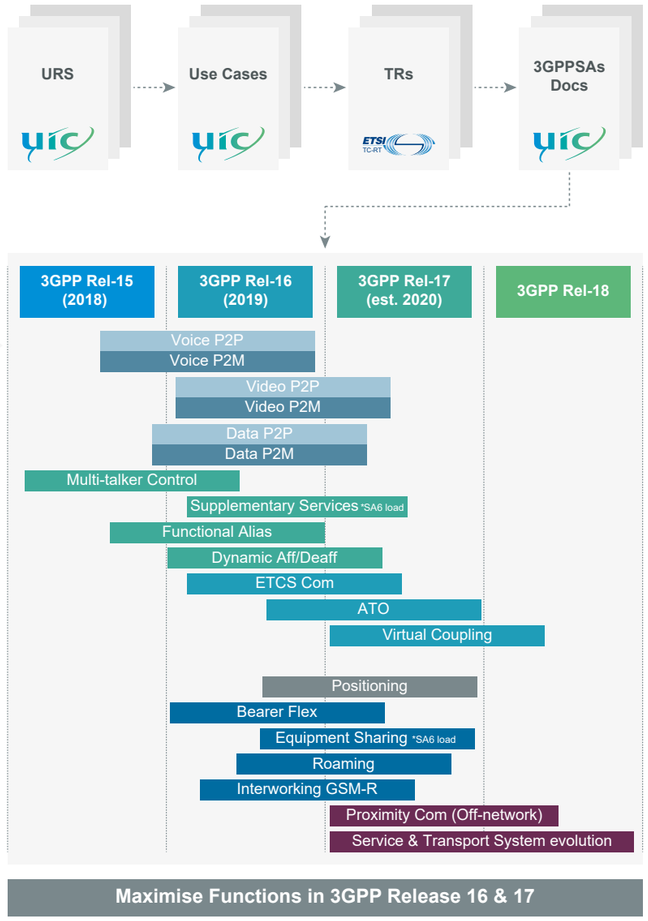
A FIRST MAJOR VICTORY: RECOGNITION OF FRMCS BY 3GPP

"This genuine recognition was the fruit of three years of patient hard work."

One of the core aims of FRMCS from the outset was to standardise the underlying "telecom building blocks" at global level via the world's most influential standards-setting body for the mobile telecommunication industry, **3GPP** (3rd Generation Partnership Project). The advantages of this would be to give the new critical communications system global reach and a longer shelf-life in a context where the development of mobile standards is gathering pace, due to its being integrated de facto into future standards and industrial developments within the telecoms world. This would automatically protect rail operators' future investments in the new system, since new radio standards would be easier to develop or indeed optimise, there would be greater competition between suppliers, and it would offer even stronger interoperability as well as protection against the dreaded "vendor lock-in" and proprietary systems which are still a problem for the sector in a number of technical fields.

To do this, a tightly-structured standardisation process was needed, since 3GPP is the global locus for all standards requests not only from telecoms operators and suppliers, but also from representatives of various vertical markets who are already familiar with this specific environment. Starting from the railways' needs as expressed in a master document, the **FRMCS URS** (User Requirements Specification), the experts in the FRMCS FWG and ATWG defined the **Use Cases** requiring telecoms standardisation mechanisms (the "telecoms building blocks" mentioned earlier), categorising and organising them in collaboration with the ETSI TC-RT to feed into the UIC 3GPP Task Force which was in charge of developing and making standardisation requests to 3GPP on behalf of the railways, such that these could be included in future versions defining **5G**, better known by the names **3GPP Release 16**, **3GPP Release 17**, **3GPP Release 18**, etc.

FRMCS 3GPP STANDARDISATION MECHANISM



Beyond the process itself, however, defending railway interests within 3GPP was no easy task, since the big telecoms players largely lack understanding or appreciation of our business. That said, little by little our persistence and technical expertise paid off, and with active support from some of the GSM-R suppliers, UIC's requests were gradually taken on board - so much so that some of our requests for standards (such as for functional addresses) were eventually adopted by other, higher-profile sectors such as the automotive industry (for the self-driving cars of the future). Thus, both 3GPP as an organisation and those working within it gradually carved out a space for rail and its specific needs.

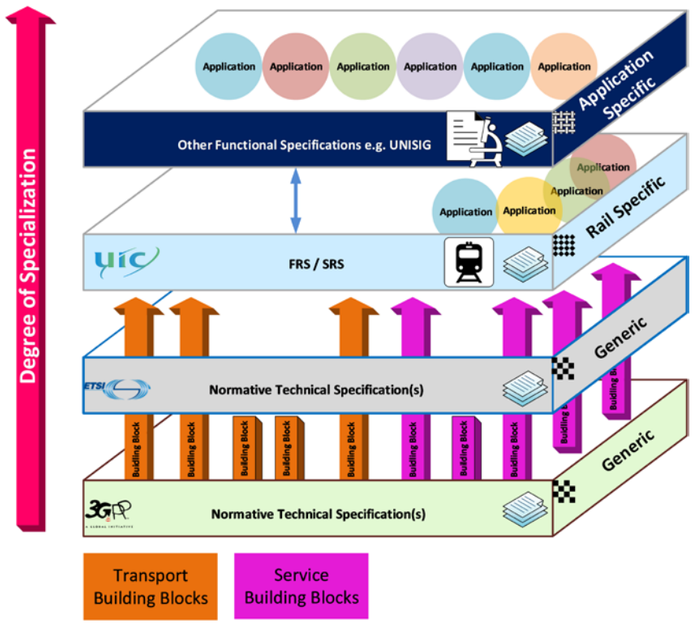
This genuine recognition was the fruit of three years of patient hard work and constant engagement with 3GPP in its offices and bodies across the globe! And the job is not over: while the essential goal was to ensure the inclusion of mechanisms for the first version of FRMCS ("FRMCS 1st Edition") which would be the baseline for the initial roll-out, our intention is of course to continue the standardisation process to gradually incorporate all future functions which may help modernise railway operations. For example, the "Off-Net" mechanism may prove necessary in some use cases, and should thus be included in Release 18 by 3GPP.

Alongside this, and closely aligned with the standardisation work, the FRMCS groups at UIC have undertaken to produce a full set of specifications for the 5G FRMCS system, in particular:

- **FRMCS FRS** (Functional Requirements Specifications) for both infrastructure and on-board equipment,
- **FRMCS SRS** (System Requirements Specifications), also for both infrastructure and on-board,
- dedicated specifications for on-board communication equipment: **TOBA FIS** (Telecom On-Board Architecture Functional Interfaces Specification) and **TOBA FFFIS** (Telecom On-Board Architecture Form Fit Functional Interfaces Specification),
- the description of how it will be interoperable with the ETCS signalling system: "**ETCS over FRMCS Principle Architecture**".

Furthermore, those standardisation components which cannot be dealt with at 3GPP level (typically the interoperability mechanisms between 2G GSM-R and 5G FRMCS, which will be useful for hybrid networks in future) will be handled by the ETSI TC-RT.

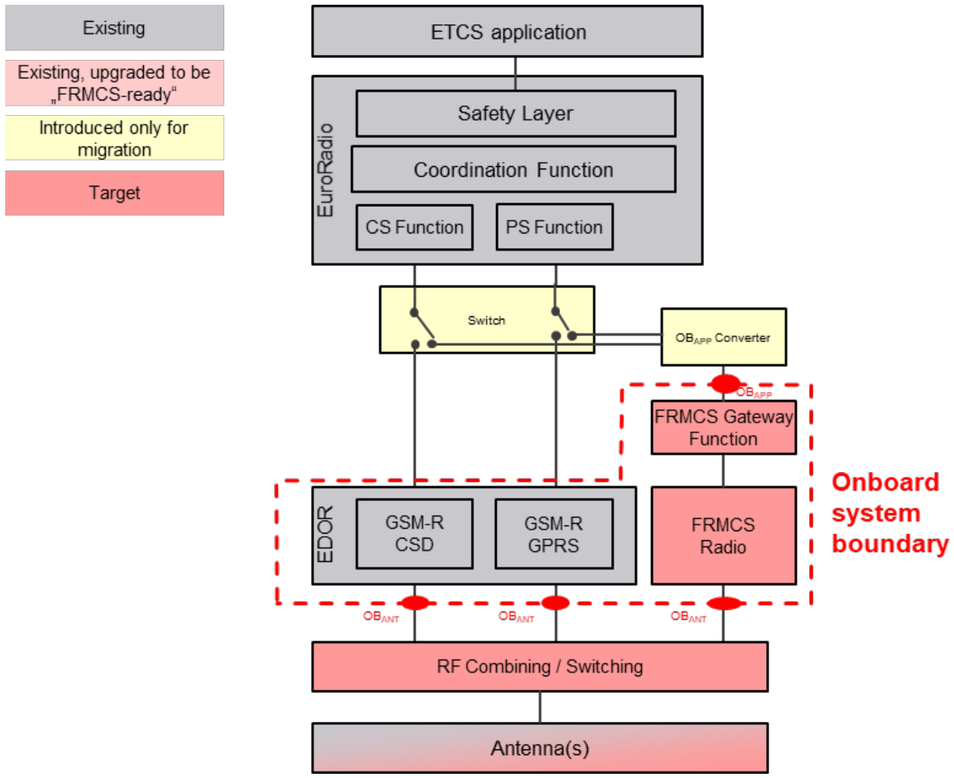
Together, all these documents will form the technical basis for the first version of FRMCS, and will be used to develop the technical appendices to the future CCS TSI 2022.



A NEW ON-BOARD ARCHITECTURE FOR TELECOMMUNICATIONS

In mid-2019, the UIC FRMCS TOBA group defined a number of architecture scenarios for on-board telecommunications and agreed that, via the ERA Control Group, what is now known as "**TOBA option 3**" for the ETCS interface would be proposed to the sector. This offers a simple yet disruptive communications vision, i.e. a single harmonised system of ground-to-train communications (codenamed "**TOBA Box**") which marks a move away from the current system where a number of different physical communications interfaces coexist within the locomotive, e.g. for voice-activated GSM-R applications and ETCS signalling.

The TOBA Box will act as a kind of **"hub" for the digital railway** within the train, taking charge of all incoming and outgoing telecommunications and supplying sufficient bandwidth and quality of service for all future on-board applications, with frequency hopping and cybersecurity functions amongst other important features. In particular, since the communications interface remains the same, once installed this architecture will allow the impacts on software and hardware to be reduced, as well as maintenance and upgrades to on-board systems. In early 2020, TOBA Option 3 was officially chosen by the sector as the baseline for the future ERTMS on-board architecture.

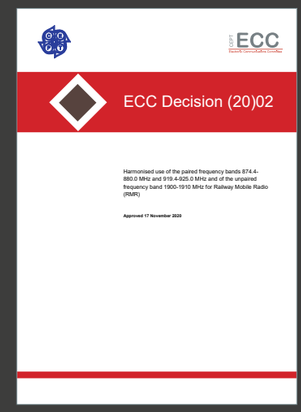


FRMCS FREQUENCIES IN EUROPE: A DECISION WITH FAR-REACHING CONSEQUENCES

In Europe, the question of dedicated railway frequencies enabling the introduction of 5G FRMCS was raised as early as 2017. Unfortunately, the action initially taken showed a general misunderstanding of the sector's needs on the part of those managing the spectrum, with a real risk that FRMCS would end up with the bare minimum, i.e. just that share of the spectrum that is currently used for GSM-R (4 MHz within the 900 MHz band).

The European Commission having tasked the CEPT-ECC (European Conference of Postal and Telecommunications Administrations - Electronic Communications Committee) to examine, inter alia, the situation in railway telecommunications, starting in 2018 the UIC UGFA adopted a proactive strategy, supported by many of the railway companies and telecoms suppliers affected, in order to define and stand up for the sector's needs in the context of FRMCS implementation. Here again, huge efforts were needed in terms of technical studies, position papers and regular participation in the many specialist CEPT working groups in which constant presence and engagement were needed (the main ones being FM, FM56, PT1 and SE7). In all these groups, we encountered strong opposition from the "big fish" in this specific field, i.e. public telecommunications operators and their suppliers, who had little regard for the needs of railway operators, even considering that railways had no need for dedicated frequencies and could simply use the available public networks (with the quality of service we are all familiar with). When it comes to frequency allocation, it is true that vested interests are never far from the surface - we just need to think of the massive turnover telecoms operators generate from these frequencies once they have purchased them from the government.

This technical-political battle (the term is not used lightly) lasted almost three years, the critical phase concluding on 17 November 2020 with the **ECC's decision on the harmonisation in Europe of dedicated frequencies for railway use in the 900 MHz (5.6 MHz) and 1900 MHz (10 MHz) bands**, coupled with **conditions of use and radio coexistence which are beneficial to our operators** since they allow levels of transmission and protection against interference which will both significantly reduce the cost of investment in terms of 5G infrastructure. The decision is due to be ratified by member states in spring 2021.



This is a major victory for our industry, almost beyond anything we dared hope for given where we started from in early 2018. It will also form the bedrock for the future development of FRMCS applications.

Lastly, it is important to stress that this victory marks genuine recognition of the rail sector as an industry on a par with others, since the 5.6 and 10 MHz - quite apart from the technical aspects and the services they will enable - are a virtual source of value worth billions of euros. Indirectly, therefore, it represents a huge saving for railway companies on the costs they would usually pay their mobile telecommunications suppliers.

THE 5G RAIL PROJECT: FRMCS GOES LIVE FOR THE FIRST TIME

Another vital part of the FRMCS programme is of course the industrialisation phase, since the FRMCS ecosystem relies on new telecommunications equipment including the specifications and standardised telecoms building blocks defined by the UIC working groups, the 3GPP and the ETSI, in particular a new on-board telecommunication system known as the TOBA Box.

5GRail

To embark upon this phase, UIC took advantage of a call for candidates issued by **DG Connect** (the European Commission Directorate-General for Digital Technology) as part of the ICT (Information and Communication Technology) workstream within the overarching Horizon 2020 programme to form a consortium called **5G Rail**, which brings together railway operators (DB, SNCF, SBB, OBB and IP) and telecoms industry players (Nokia, Kontron, Alstom, Thales, Siemens, CAF, Teleste, as well as UNIFE as the representative body for the European railway supply industry as a whole). DG Connect selected the consortium's candidacy in October 2020.

The consortium is working on **prototyping the entire FRMCS ecosystem**, starting with **simulation** and even **field test** phases in France and Germany. This work is completely aligned with the second pillar of the FRMCS strategic plan defined by UIC, namely the "FRMCS demonstrator" which will enable the following:

- development and fine-tuning of the first TOBA Box prototypes;
- development and fine-tuning of the first FRMCS-compliant 5G network equipment;
- interfacing of various solutions from the future FRMCS ecosystem: ETCS calculator based on the ETCS-FRMCS interoperability specifications and thus on the prototypes for future FRMCS-compatible signalling equipment, ATO (Automatic Train Operation) simulator, TCMS (Train Control and Monitoring Systems) on-board communication systems and on-board video applications;
- lab simulations to check the correct operation of all induced mechanisms and perform initial quality of service measurements;
- real-world tests on lines in France and Germany using trains fitted with the various prototypes;
- feedback from operational experience on all FRMCS version 1 specifications in order to amend or supplement it, if necessary, before arriving at "FRMCS 1st Edition", a finalised specification for the first deployable version of FRMCS.

A "5G Rail Advisory Board" has been set up in order to involve as many rail sector stakeholders as possible. The first members to join the committee were Network Rail, RFI, ADIF, Infrabel, Trafikverket, SZ, Rail Baltica, Shift2Rail, ERA, UNISIG, ETSI TC-RT, with many others set to request membership soon.

The 5G Rail project began in November 2020 and will conclude in April 2023, for a total investment cost of €14 million of which 70% is funded by the Horizon 2020 programme. In this project, UIC is acting as leader of the industrial consortium and as a source of technical authority.

NEXT STEPS

Though much has already been achieved, there remains much to be done before FRMCS solutions are ready for roll-out by the railways as of 2025, most obviously:

- FRMCS must be incorporated into the CCS TSI 2022 so as to be governed by the legal framework of European regulations and thus protect railway operators' investment plans;
- the 5G Rail project must go ahead, i.e. the first prototypes must be built and tested;
- technical studies for migration scenarios are needed to smooth the transition from operations under GSM-R to FRMCS;
- work on specifications must continue in order to develop future versions of FRMCS and carry out the associated standardisation work, in which context the new versions need to include support for new services;
- the European GSM-R interconnecting hubs must be upgraded to FRMCS in order to ensure full interoperability for cross-border trains;
- the final industrial project, "FRMCS European Trial" is a prerequisite before FRMCS solutions can be placed on the market, and must be seen as a kind of pre-roll-out, in all probability on selected international corridors and supported by European funding.

THE FRMCS BUSINESS MODEL AND STRATEGIC CHALLENGES

"In the final judgement: does FRMCS represent evolution or revolution?"

In the near term, FRMCS is intended to gradually replace GSM-R on some **250,000 km of lines** worldwide that currently operate with that system, which will involve fitting it to around **200,000 locomotives**.

Europe represents half of these totals. The investment involved for the sector is immense, with the new 5G networks and on-board equipment estimated to cost around **50 billion euros**. And as new needs emerge in connection with the digital railway, these figures will doubtless be exceeded in the long term. Roll-out is set to take place over a fairly lengthy period of at least **10 years between 2025 and 2035**.

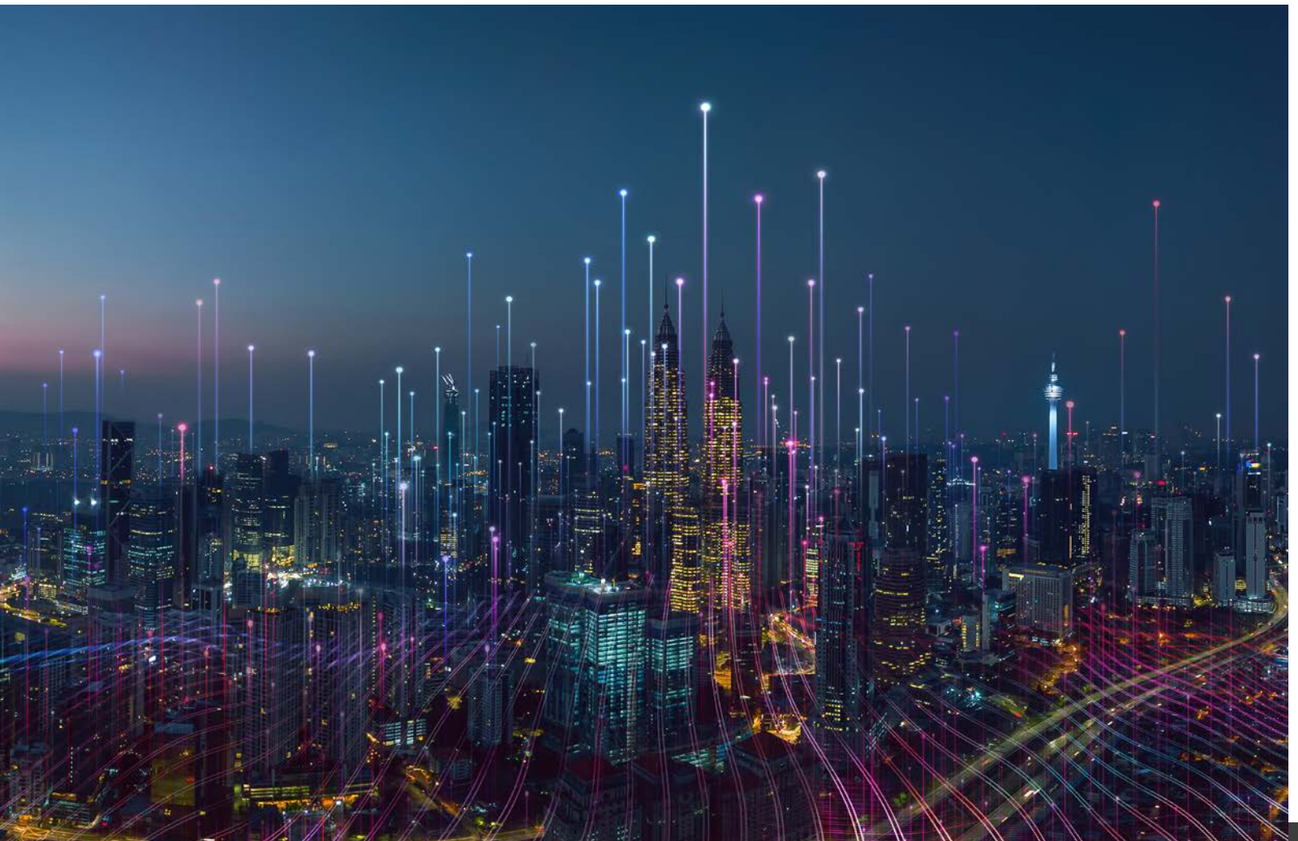
Consequently, the GSM-R and FRMCS networks will coexist for some time on each national network, so this coexistence will have to be transparent in use. All of this thus adds up to a huge workload and level of investment.

One recurring debate on the business model for the FRMCS roll-out is: should rail operators install their own dedicated networks or should they use the public networks belonging to telecoms operators?

While some consider this a purely technical question (since the "network slicing" offered by 5G allows the creation of networks which are virtually separate but attached to a shared architecture) and others see it as a matter of dogma, in fact framing it in this way is asking the wrong question.

The core issue the question ducks is that of the requisite quality of service. This will vary by line: some have high traffic densities and/or high speed services, while others are classed as "secondary".

The current business and technical model of mobile operators - whose strategy is predominantly focused on selling telecoms services to individuals - is nowhere near being able to offer the quality of service needed for critical railway communications on main lines, whether domestic or international.

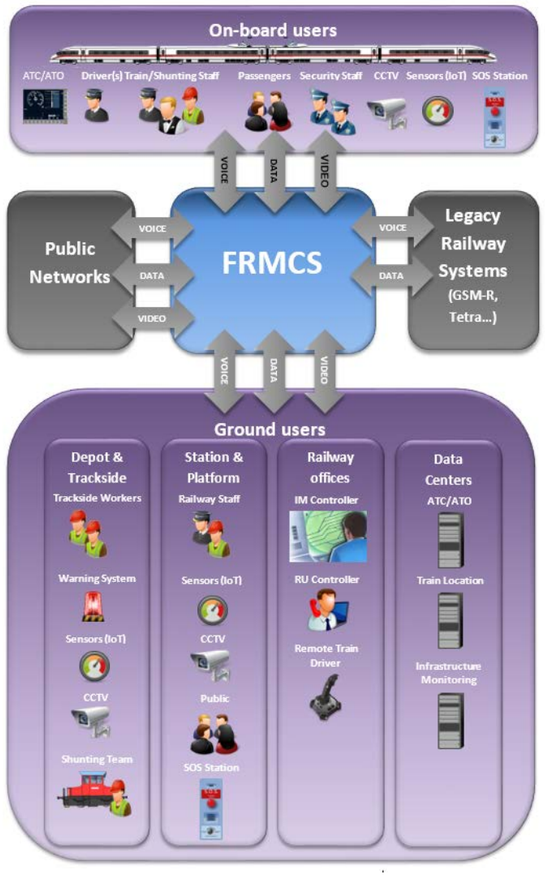


To offer such a level of service, which includes not only "perfect" coverage, very swift responsiveness in the event of a problem, shared risk and responsibility, as well as consideration of railway safety and certification rules requiring network equipment and software to remain highly stable over time, mobile operators will need to up their game and come up with a business model that caters to railways' needs.

This is far from impossible, but it is not a task to be taken lightly. Some "halfway houses" have already been explored, such as the PPP (Public Private Partnership) for GSM-R roll-out in France, which features a mobile operator among the stakeholders.

Nor does this mean that we must rule out using mobile telecoms operators' networks altogether, for instance on secondary lines not requiring the same level of quality of service. Indeed, this is already the case on some networks, including in France. As you can see, this is far more than a narrow technical debate!

Which applications will be supported by FRMCS? There are those we are already familiar with: GSM-R services and ETCS level 2 signalling. There are those which are already well advanced: train automation (ATO GoA1 and 2) and ETCS level 3. There are those on which work has begun: self-driving trains (ATO GoA3 and GoA4) of course, but also remote control and monitoring of on-board equipment (TCMS). Then there are those that are still pipe dreams: IoT (Internet of Things), use of video for safety, predictive remote maintenance, real-time passenger information, and so on - the list is already long. And of course, there will be plenty we have not yet imagined!



Beyond this list of applications, however, we see that something more far-reaching is at stake. **FRMCS will be a major trigger for the wide-ranging digitalisation of the rail sector**, since it will supply the environment, flexibility and capacity necessary to develop applications which will enable railways to optimise the cost of operations, improve service quality for passengers, offer greater agility for freight, and much more.

So then, in the final judgement: does FRMCS represent evolution or revolution?

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