FRMCS White Paper

Spectrum and Migration Strategies

GSM-R to FRMCS migration strategy by Kontron Transportation

A ticket to FRMCS

GSM-R was standardized at the end of the 1990's. The FRMCS standard launch began in the early 2020s to allow the evolution of GSM-R to 5G.

The current GSM-R based railway systems are mainly focused on voice communication and railway signaling needs. With FRMCS (Future Railway Mobile Communication System), built on 5G and MCX technologies defined by 3GPP, they will evolve towards higher degrees of automation, integrate video capabilities and offer more flexibility in terms of throughput and latency, especially for signaling and control aspects.

We propose, through this white paper, to help railway players to lead the transition they have to make in the coming decade. Beyond the long and boring presentation of the main 3GPP technologies selected for the new system, this document highlights two key points: spectrum and migration strategies and tries to answer the question: " What could be reasonably envisaged to move smoothly from a 2G railway world to another one being more 5G ? "

You have a GSM-R network, you dream of FRMCS, Kontron Transportation makes your dreams come true.

Long Live the FRMCS !

Content

Table of Contents

Table of Illustrations

Introduction

The railway communication networks will undergo a real revolution in the coming decade. Current rail networks are based on GSM-R technology, which deployment began in 1999 and is expected to stay in service until at least the mid-2030s, with intermediate renewals to be planned. Existing railway services are mainly focused on voice communication and railway signaling needs. Soon, they will have to evolve towards higher degrees of automation, integrate video capabilities and offer more flexibility in terms of throughput and latency, especially for signaling aspects.

This digital transformation of railway organizations will enable the introduction of new services in multiple areas: video surveillance inside or outside the train, automated operation or remote control of the train, delivery of information to passengers, sensor measurements collected by the train and efficiently reported to the network, and highly reliable rail communication services to manage safe operations in shunting areas or to improve safety when the train is moving. With this in mind, FRMCS (Future Railway Mobile Communication System) was defined. Building on the 5GS and MCX technologies defined by 3GPP, the FRMCS System will introduce Service centric communication capabilities based on MCX technology, starting with Voice and Data services including support for major railway specific services (like ETCS), and extended to enhanced data and video communication capabilities. Beyond these MBB-type evolutions, 5G will allow the railway sector to enter the IoT era either by using the train as object collecting metrics (positioning information, temperature, pollution, ...) and transferring them to external IoT servers in a 5G mMTC logic or by allowing it to be remotely controlled in a 5G uRLLC logic.

The global picture regarding current and future railway networks is presented below:

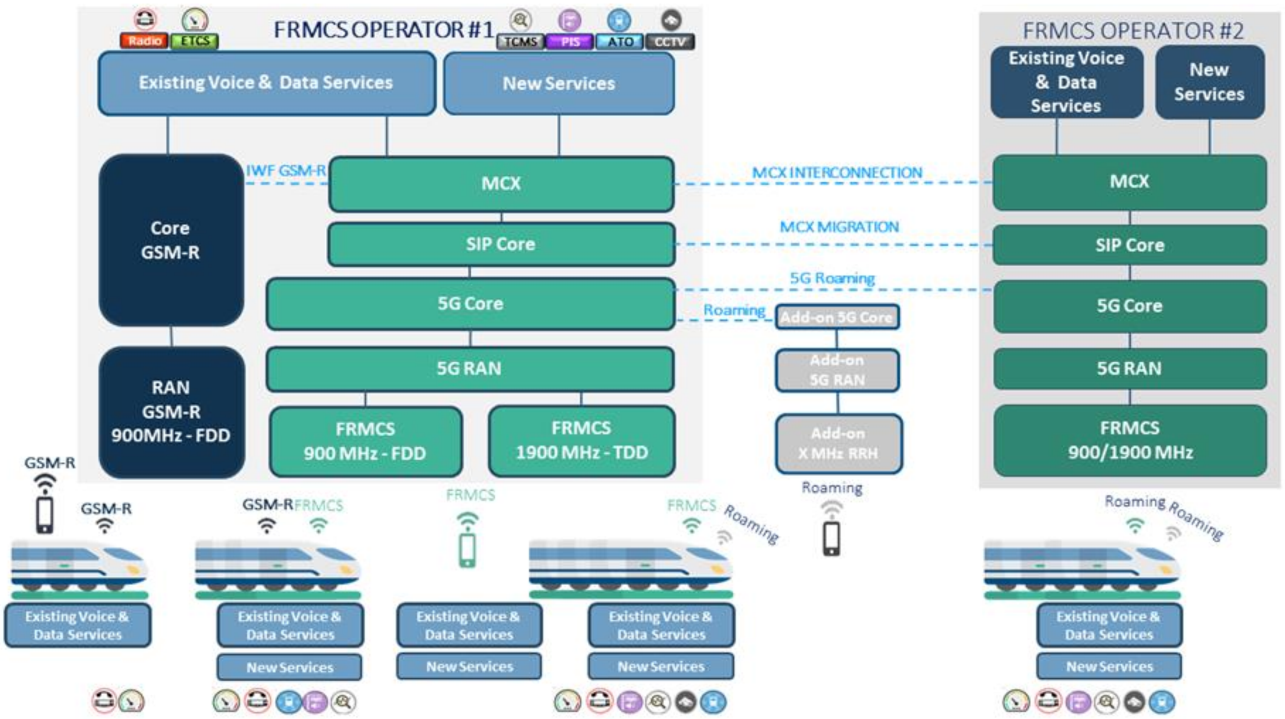

Figure 1 - FRMCS architecture migration

Several aspects shall be considered:

- The **architectural aspects** with two distinct access networks facing each other: the first one, inherited from 2G with an integration of voice services within the native circuit-switched core network and complemented by the capability to operate data services either over circuit bearers or over packet bearers through the GPRS evolution and a second one, full IP centric and based on recent 3GPP 4G and 5G evolutions. This 5G approach allows the introduction of a full IP centric access network dissociated from the service domain and capable of controlling the QoS levels required for the different services.
- The **deployment scenario** proposed by the standard allows a split between the FRMCS transport layer and the FRMCS service layer, and different models of hosting and ownership of these layers can be considered for the FRMCS network. The different deployment scenarios proposed are represented in following figure (from TS 23.289 used as reference for the support of MC services applicable to FRMCS over 5GS). It provides a flexibility of usage between operators but does not simplify the management of the resulting networks. The preferred solution is to manage the service layer with the sip core (#1 below) and avoid the use of public network operators as transport in order to retain control of the resources end to end, and thus guarantee Mission Critical services. But operational constraints, the lack of owned spectrum (or the need for sharing spectrum), the overall capacity required for the services considered, and the cost of capex and opex will influence the final choice of implementation by each operator.

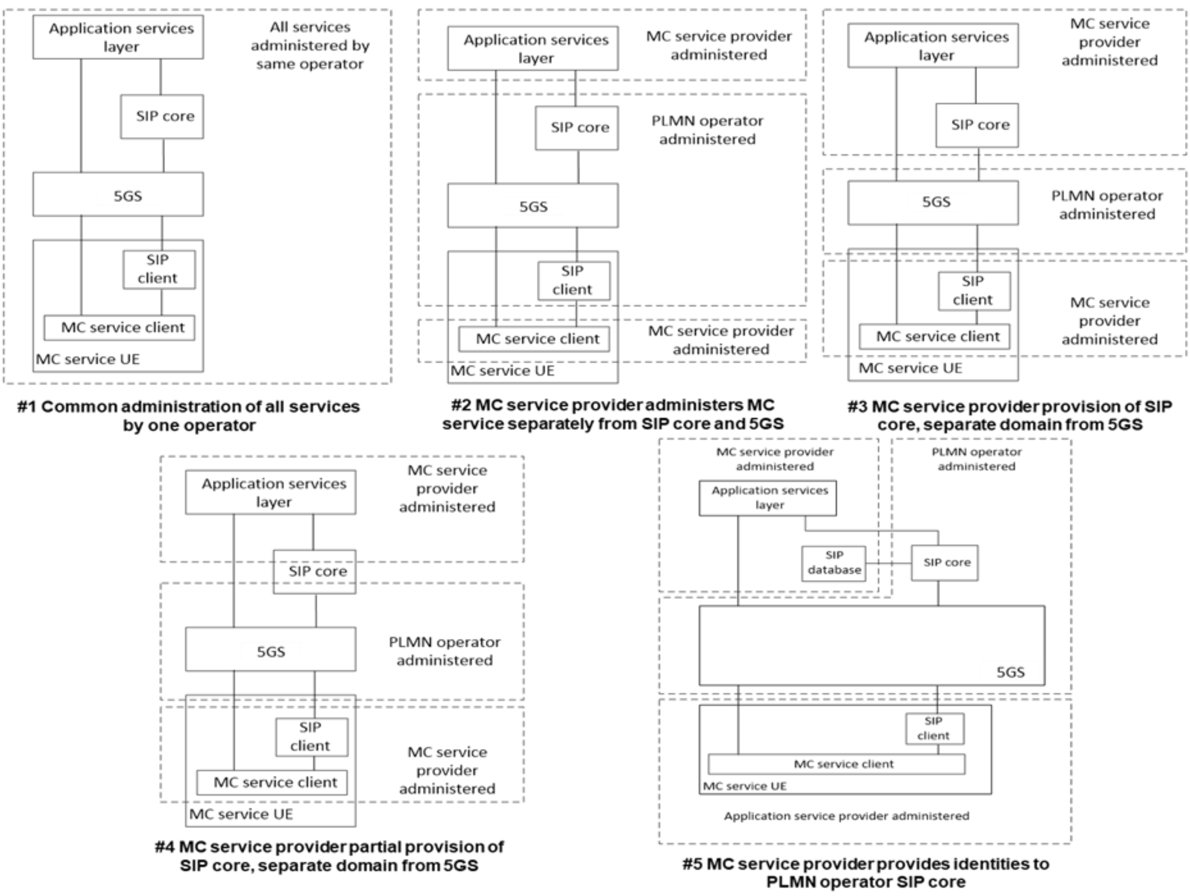

Figure 2 - MC Service (applicable to FRMCS) deployment models proposed in the standard

- The **radio aspects** for which the spectrum shall be carefully considered. To manage the railway network evolution, the historical GSM-R 900 MHz frequency band, operated in FDD mode, is now complemented by new frequencies recently allocated in the 1900MHz band for which the TDD mode is required. How these two bands devoted to railway shall be managed remains an open question. But in a more practical approach, given the wish expressed by some railway operators to reuse some of their existing GSM-R assets, the possible unavailability of this new 1900 MHz frequency band in some countries, the effective throughput required for new rail services or the GSM-R/FRMCS migration strategy envisaged by the different railway players, a dual logic 900 MHz / 1900 MHz shall be proposed for FRMCS. Thus, in a very direct way, the problem of radio coexistence between GSM-R and FRMCS in the native 900 MHz frequency is posed. Should we favor a classic coexistence scheme based on a static separation between the spectrum devoted to 5G and the one used by GSM-R? Or should we consider a more dynamic approach by allowing intelligent sharing of the spectral band by the two railway technologies? It is of course this more promising approach that shall be preferred. In this way, migration strategies and service management are significantly simplified.

- The **service aspects** for which the dissociation between what is critical and what is not shall be clearly stated. Beyond this split, we shall also consider the QoS aspects by defining the exact QoS need for each of the envisaged services. FRMCS services are all using MCX services. It may be possible to consider non MCX services (like AI on Edge for video treatment for example), but in that case such services are not considered as being part of FRMCS. In the given example, a MCX client is of interest for providing results of AI analysis to a dispatcher, a train or a station with MCX services. The throughput needs for future railway services are directly associated with the amount of spectrum the railway operators could deploy. It is possible that in certain circumstances and situations, the spectrum resource becomes insufficient to manage all railway services. Therefore, a complementary approach can be envisaged. Private or public external operators owning spectrum and access infrastructure can offer their facilities to the railway domain. The exact role these external actors could play, remains to be defined. It will be highly dependent on their ability to commit on the coverage, resiliency and redundancy and critical service management aspects. Those things remain to be proven. Nevertheless, the least critical railway services could benefit quickly from these alternatives.

- The **multi-networking and multi-connectivity aspects** for which we have to consider the multiple bands, the multiple technologies (3GPP including GSM-R or not 3GPP such as Wi-Fi), and the multiple operator models that could be used in the FRMCS system: A wide range of solutions are available to manage these multi-networking aspects. FRMCS standardization is still ongoing for these solutions, which include Carrier aggregation or dual connectivity offered at the 5G RAN level, roaming principles between different technologies and operators, Multi-Access and Multi-Path solutions (such as ATSSS at CN 5G level or MAMS IETF at the application level) allowing several radio technologies to be simultaneously used to manage the traffic of the same session, and the use of a multi-sim modem or several single-sim modems.

- The resiliency and redundancy aspects and more generally the **Criticality** of Private networks and FRMCS specifics: Basic principles based on the presence of geo-redundant infrastructure, the use of active-active configuration, the introduction of dual radio coverage schemes, the dualization of certain nodes (at radio or transport level) are of course present. But innovative approaches shall be envisaged in a 5G context especially thanks to the virtualization, as opposed to slicing which is not deemed to tackle such aspects. A key asset of 5G technology will be the interoperability and **Interworking** of 5G networks that allow to support hybrid solutions as well as Interworking at the FRMCS Service Layer.

- Since FRMCS is a communication network used for railway mission critical services and by safety critical systems, special attention must be paid to cybersecurity in terms of availability, confidentiality and integrity. Threats related to these criteria must be assessed in the frame of railway operation. Based on this assessment, relevant requirements from railway and industrial cybersecurity standards (namely EN TS 50701 and IEC 62443) need to be considered and properly implemented in the FRMCS portfolio in addition to the 3GPP security requirements. On top of these intrinsic security features, "environmental" protection measures including network isolation devices and security monitoring systems (Detection and Response) should also be considered.

- The **migration aspects**, which shall consider the radio part as explained previously, but also the services: The interworking of voice services between GSM-R and FRMCS users is a key point. If the 3GPP addresses this point from a standard point of view through interworking and migration mechanisms operated between GSM-R and FRMCS networks, railway operators will address this point in a more practical way considering the maturity of the proposed solution from a technical and an economical point of view. The FRMCS migration of existing data services operated over GSM-R is a second key point to consider Behind this point lies the potential opportunities given by external private/public actors. Ultimately, the introduction of new railway services over the FRMCS system will be addressed.

FRMCS Architecture

A global view of FRMCS architecture is given in below figure :

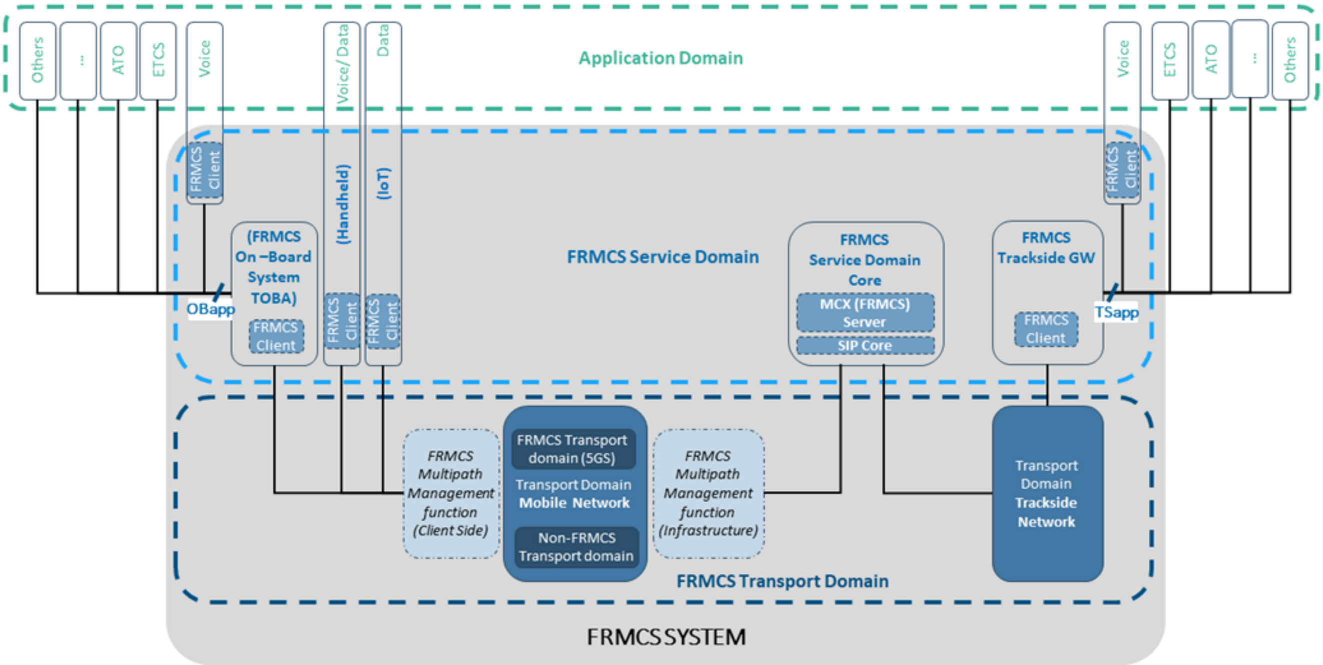

Figure 3 - FRMCS architecture

The main principles of the FRMCS architecture are the following:

- Separation of FRMCS system architecture in two layers shown in the grey area of the figure:
  - **FRMCS Service domain** which provides the MCX services with global QoS and priority control of the different clients located either at mobile side (on terminals with -in general- application clients) or at trackside (on trackside infrastructure terminals with -in general- application servers). Typically, trackside terminals are fixed and inside infrastructure, while mobile terminals can be mobile devices (in train, handheld, tablet, or IoT) or fixed device (like IoT sensors for example).
  - **FRMCS Transport Domain**, in charge of mobile and trackside networks. Trackside network consists in general of a fixed transport network. Mobile Network consists basically in 5GS (standard FRMCS) network. Nevertheless non FRMCS transport networks can also be considered, typically in the case of multipath considerations. The benefits of multipath will be explained further in the document, but, at a high level, it helps to enhance the capacity or the coverage of FRMCS networks with multiple access networks, for example with the help of other Private networks or even MNOs. In any case, MCX needs to control the multiple access, to guarantee Mission Critical services and QoS.

    Note that **Application Domain** is not part of the FRMCS System, but consists in end applications, like ETCS on-board and trackside (EVS/CBR, etc…).
- On the **mobile side**, the format of the terminal can differ:
  - **On board gateway** (TOBA) for trains (An MCX based client that connects different applications with mobile transport networks using one or more modems). A specific interface has been setup by FRMCS standard (OBapp on Board gateway) in order to support an MCX based solution with 2 possibilities:
    - with an MCX client co-located inside the end terminal with Application, called *tight interface* (case CAB radio with PTT, or data (video) user interface provided),
    - with a MCX client located within TOBA called *loose interface* for applications located in specific

and different HW than TOBA (case distant data video, or ETCS, ATO, …).

- **Handhelds for pedestrians** In which the MCX client is integrated, and for which touchscreen (smartphone, tablet) and peripherals (PTT button, alarm button, micro headset, sensors if any) are used at Human interface. In general basic functionality is Voice with PTT, but image data and video are possible.
- Some **IoT** (fixed or mobile) **terminals**, such as smartphone, in which MCX can be embedded for data or video communications. Those terminals can communicate with a Trackside application server via MCX services (Machine to Machine mode).

- On **track side** different MCX users can be:
  - **Dispatcher or fixed terminal user** with PTT / Data / Video communications. Human interface is required.
  - Any **server** for IOT or Train communications control, like ETCS, ATO

The FRMCS architecture is based on 5G architecture evolution and is strongly coupled to SDN (Software Defined Network) and NFV (Network Functions Virtualization) concepts. With SDN, the control of the transport layer is logically centralized in software-based controllers (the control plane), and transport part is ensured by packet forwarding devices (the data plane) that can be programmed via an external interface. With such splitting, forwarding decisions are flow-based, instead of destination-based. A flow is broadly defined by a set of packet field values acting as a match (filter) criterion applied on IP/Ethernet tags and a set of actions (instructions). Moreover the SDN control part having few real time constraints can be virtualized in a sense that it can run on a virtual machine independently from any hardware constraint and be physically located on any generic x86 machine. The hardware constraints are hidden from the main application through the introduction of the virtual HW layer (into the virtual machine) and the Hypervisor layer (into the x86 server).

Generalizing the virtualization ideas for any kind of function is possible. Making this exercise on 5G core network functions present in the architecture may reveal some potential simplifications. Via SDN, control plane and user plane, 5G core functions can be virtualized in NFV mode. From 5G, the whole architecture is revisited in an SDN way, with NFV model and orchestrator. Nevertheless the orchestrator functions offered by 5G architecture to MNO operators may be used in a more ‘static’ (or less dynamic) model in FRMCS, at least for railways track side functions that do not require mobility.

Which Spectrum for Railway ?

Railway Available Spectrum

Current GSM-R networks are deployed using FDD mode in a 900 MHz harmonized frequency band of 2 x 4 MHz (876-880 MHz uplink / 921-925 MHz downlink – R-GSM 900). If this spectral area is, in Europe, entirely devoted to the needs of GSM-R, some European countries have been authorized to take benefit from a spectral complement.

This is particularly the case in Germany, Austria, Liechtenstein, Switzerland where the 873-876 MHz (uplink) and 918-921 MHz (downlink) frequencies may also be used for railways needs (ER-GSM Band). In 2020, the CEPT has decided to conclude the harmonization of this 900 MHz frequency band allocating 2 x 5.6 MHz, (874.4-880 MHz uplink / 919.4-925 MHz downlink), always operated in FDD mode, for current and future railway needs.

This band has been allocated at 3GPP (Q2 2022) as band **5GNR n100 , so called "RMR 900".**

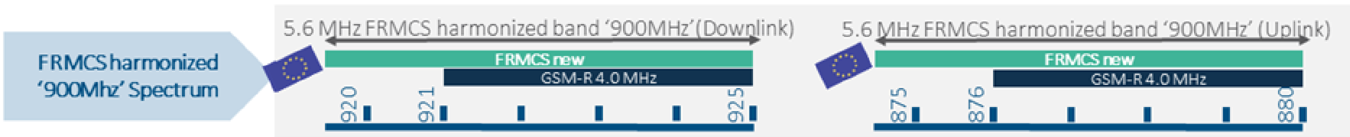

Figure 4 - Harmonized FRMCS 900MHz spectrum

This decision implies that the railway community has to address the coexistence issue between the current GSM-R systems and the future FRMCS standard.

Moreover, in order to allow the introduction of new services that the future FRMCS system is supposed to offer, a need for additional spectrum has clearly been identified.

Therefore, CEPT has decided to complement this native railway spectrum by adding an additional spectral band located in the 1900 MHz range introducing a block of 1 x 10 MHz TDD (1900-1910 MHz) managed in a TDD way.

This band has been allocated at 3GPP (Q1 2022) as band **5GNR n101, so called "RMR 1900"**.

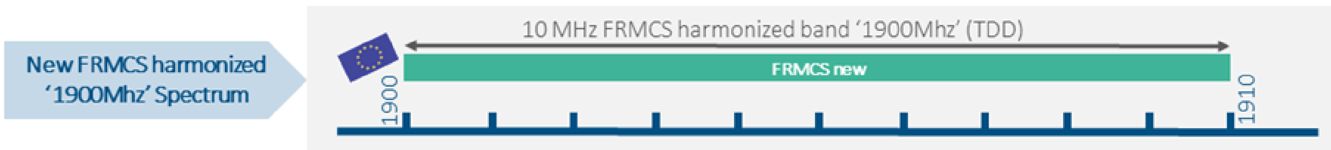

Figure 5 - Harmonized FRMCS 1900MHz spectrum

By this decision, the classical mono-layer GSM-R based railway system suddenly becomes a dual-layer system for which coexistence aspects in term of deployment and service management shall be carefully considered.

The existing radio towers of the current GSM-R can be re-used for FRMCS in the 900 MHz and 1900 MHz frequency bands with additional radio towers deployed if needed, to obtain, a continuous coverage for the 1900 MHz layer. If the average inter-site distance (ISD) is around 8 km in rural area for a 900 MHz deployment it decreases to 4 km for the 1900 MHz band, while for urban cases the 900 MHz ISD of 4 km becomes around 2 km for the 1900 MHz case. This over-densification of radio sites for the future 1900 MHz FRMCS deployment implies a huge investment for railway operators. Moreover, with two frequency bands, the inter-band carrier aggregation principles as well as dual connectivity mechanisms shall be allowed in the 3GPP standard for these two specific railway bands. These mechanisms are more than useful to manage efficiently the throughput and capacity needs as well as mobility aspects.

GSM-R & FRMCS coexistence in 900 MHz band

To enable the coexistence between the GSM-R and the 5G FRMCS systems in the 900 MHz frequency band a simple approach could be proposed. Considering the 2 x 5.6 MHz FDD part devoted to railway usage in the 900 MHz band a GSM-R re-farming could be envisaged to release a minimum bandwidth of 2 x 3 MHz, in uplink and downlink, on which a reduced 5G system could operate. As illustrated in the picture below, a narrowband 5G system is introduced adjacent to the GSM-R carriers that have been re-farmed.

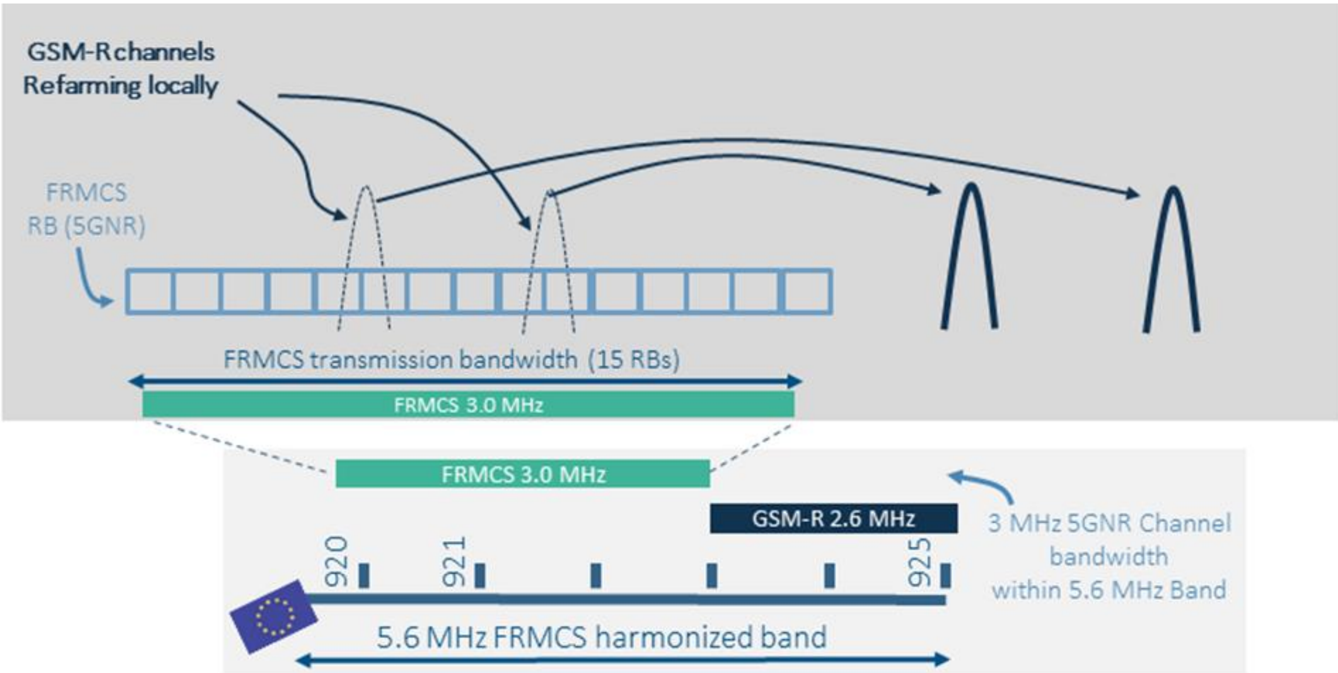

Figure 6 - FRMCS GSM-R 900Mhz coexistence

With this approach, two problems arise. The first one is relative to the re-farming work that shall be done for the GSM-R being invited to migrate from a 2x4 MHz frequency part to a more reduced 2x2.6 MHz band. This work will force the railway operators to revisit their overall GSM-R network deployment. The second one is relative to the capability to deploy a 3.0 MHz system for FRMCS. The minimum channel bandwidth supported by the current 5G NR specifications is 5 MHz and some initiatives are required from the UIC to introduce the concept of narrowband 5G-NR into the 3GPP standard promoting the usage of 5G channels having less than 5 MHz as bandwidth. But no work item regarding that point has currently been identified and if such concept is integrated into the standard it will not be finalized for R18 or even R19 in other words not before 2025.

An innovative way: Whitespace Concept in 900 MHz band

A more innovative approach could consist in deploying a 2x5 MHz 5G-NR system overlapping the current 2x4 MHz GSM-R system as presented in the figure below.

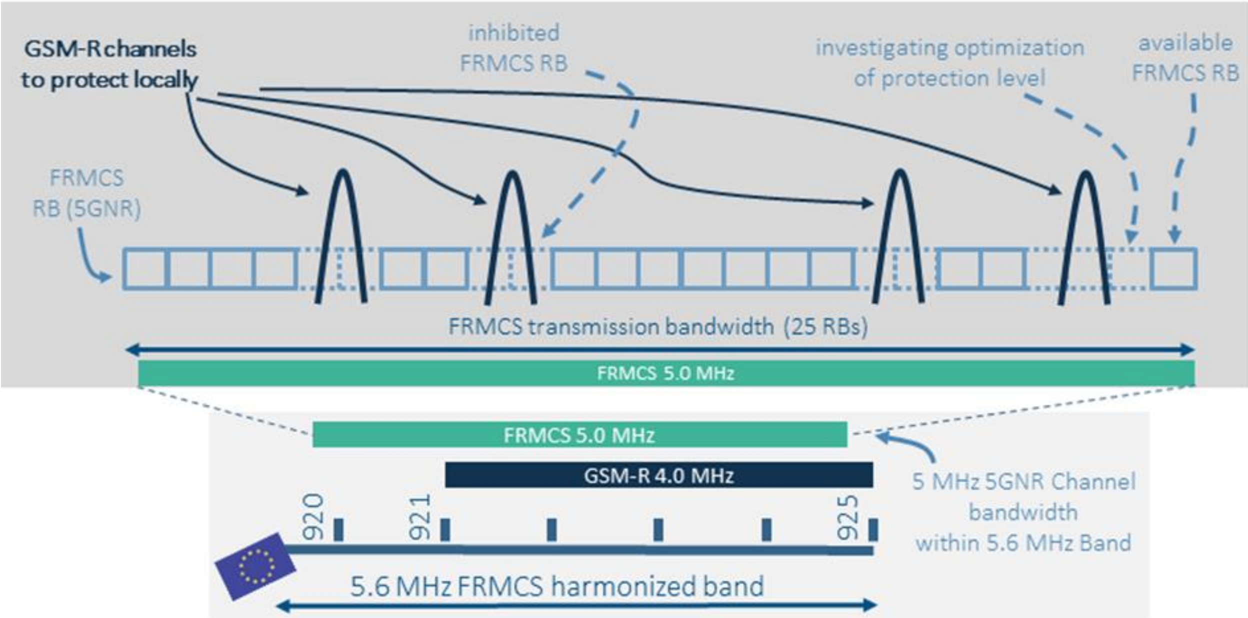

Figure 7 - 900MHz coexistence with White Space

Thanks to the flexible 5G OFDM structure, this 2G-5G coexistence is possible. Similarly, to what has been proposed in NB-IoT, especially for in-band mode, existing GSM-R carriers coexist with a 5G system for which the mapping of the logical channels is done with consideration of the presence of the 2G carriers. Considering the GSM channel bandwidth (271 kHz – Nyquist bandwidth), the RB size (180 kHz for 15 kHz sub carrier spacing) used in 5G and the capabilities to map the 5G logical channels at any time on the 5G allocated carrier, it becomes possible to separate the two technologies located in the same radio channel. The first principle of this spectrum sharing is to preserve the GSM-R for both UL and DL. To manage that, a specific RB puncturing mechanism managed by a suitable scheduler algorithm aware of the unused RB is proposed. The second principle consists in accepting some form of GSM-R to 5G interference but refusing 5G to GSM-R interference. 5G is strong enough in term of channel coding mechanisms (LDPC, HARQ) to support this kind of additional interferer and for the SSB and RACH channels, the synchronization and initial access timing can be slightly increased by the presence of such GSM-R carrier. The resulting 5G throughput is of course dependent on the number of punctured RB.

For that innovative solution we speak about ”**Whitespace**“. This concept entails deploying a 5G NR carrier over the GSM-R spectrum on GSM-R sites and peacefully coexisting with the GSM-R system by minimizing inter-system interference. This is achieved through advanced scheduling techniques in the base station to protect GSM-R carriers while remaining fully compatible with standard 5G NR FRMCS handsets and cab radios (meaning no change on mobile devices required, standard RMR 900 UE used). With “Whitespace FRMCS”, **railway infrastructure operators can efficiently introduce FRMCS** and decide **if, where and when to invest** further in densification as digitalization takes off.

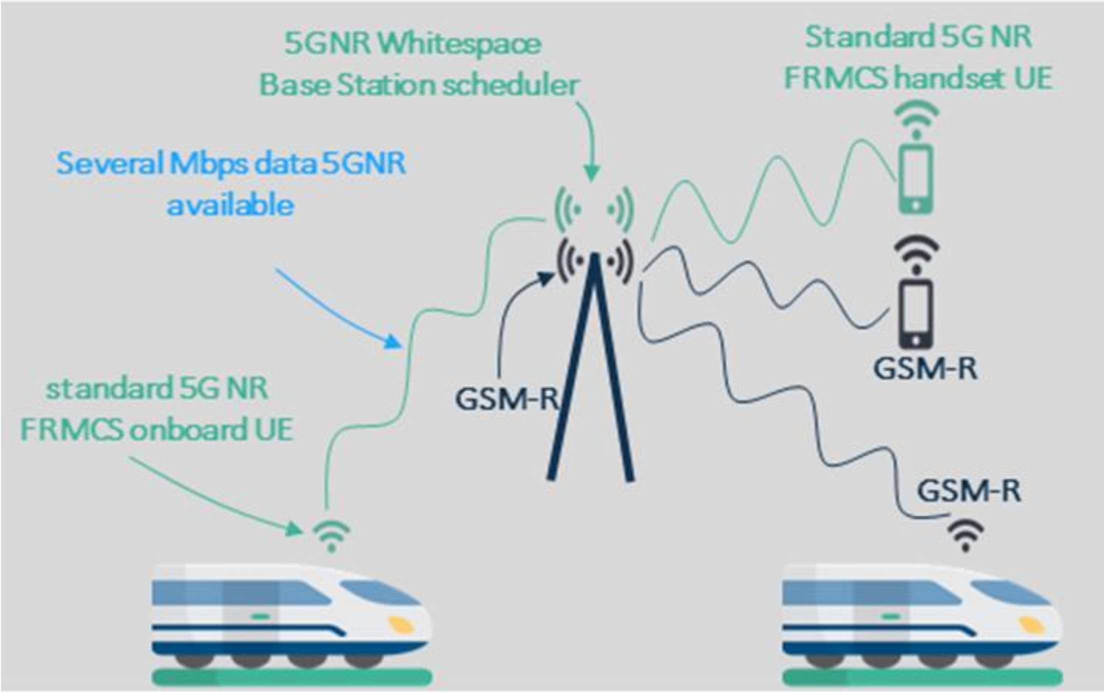

Figure 8 - 900MHz White Space use cases

New spectrum for Railway: 1900 MHz

Selecting 1900 MHz spectrum operated in TDD mode force railway operators to face multiple challenges.:

1. Intra or inter networks interference due to the use of a common spectrum, like cross boarder or inter-railways area transition.
2. Intra or inter network interferences due to adjacent spectrum usage (with large 5G TDD bandwidth such as MNO).
3. Intra or inter networks interferences due to TDD pattern heterogeneity (DL-UL TDD collision schemes).

In order to meet points 1 and 2 above, the phase and time synchronization requirements of 5G TDD systems either GNSS (Global Navigation Satellite System) based or PTP (Precision Time Protocol) based mechanisms shall be introduced. The third point forces us to manage the balance between UL and DL traffic and select a TDD pattern matching the railway traffic model constraints. Fully synchronized networks shall be consequently deployed in order to limit the effects of interference

If for public MNO, the traffic is more DL driven leading to select TDD pattern exhibiting more DL resources than UL, the traffic model for railway and more generally critical systems (Public Safety) is more UL driven, especially considering video services: "**Pertinent and critical information is coming from the field and not from the network** ".

MNO and FRMCS operator traffic models are strongly different. While MNOs offer Internet like services strongly DL oriented (up to 80% in time) railways operators expect a more UL oriented model. (above 60% in time). These two contradictory needs have been confirmed by the existing 4G TDD deployments for which big RAN solution providers focus their systems and configuration on strong DL oriented modes, 4G TDD configuration #1 and above, forgetting **the 4G TDD configuration #0** more UL oriented as suggested in the picture below:

4G TDD: 7 configurations

	TDD	Config	DL	UL
Vertical UL	Vertical UL	0	36%	64%
Vertical 50/50	Vertical 50/50	1	57%	43%
MNOs preferred	MNO TDDa	2	77%	23%
		3	68%	32%
	MNO TDDb	4	78%	22%
		5	88%	12%
		6	46%	54%

Figure 9 - TDD UL/DL configuration (4G based)

The huge level of flexibility offered by 5G-NR can, in theory, help railway operators to select the most appropriate TDD pattern according to their UL-DL needs for the different areas where FRMCS will be deployed. Even if 5G offers a large panel of TDD patterns, and due to their large spectrum access, MNOs will likely end-up with a reduced set of static TDD configurations strongly DL driven similarly to 4G (80% DL) – as already experienced in 4G networks.

Note that this impacts also any hybridization with MNO to support UL oriented FRMCS services.

Since the UL-DL throughput needs are not the same in railway stations, in main lines or in shunting areas, a very heterogeneous network in term of TDD pattern have to be considered for such global railway deployment. Such TDD heterogeneity requires some innovative solutions to manage efficiently the transition between different TDD areas not operated with the same pattern generating potentially UL-DL conflict. Moreover this TDD pattern transition shall also be considered at country boundaries between two railway operators not managing the same TDD UL-DL balance as illustrated below

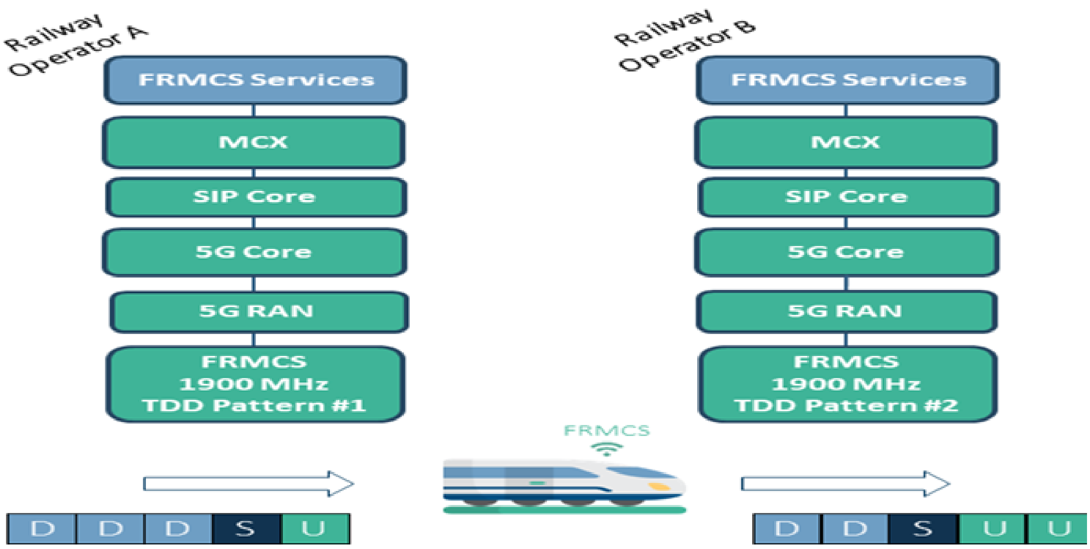

Figure 10 - TDD UL/DL configuration (4G based)

The 10 MHz bandwidth considered for the 5G TDD channel offered to FRMCS operators at 1900 MHz can be easily misinterpreted. This amount of spectrum suggests that the expected throughput will be significant referring directly to Shannon's capacity formula (C = Wlog2(1+SNR)) or in any case much higher than what we could reach with a 5 MHz support operated in FDD mode. This is without counting on the TDD aspect which strongly impacts the effective DL and UL flow that we could have. With a 50% UL-DL TDD distribution, the DL or UL throughputs will not be greater than those offered by a 5G system deployed in FDD mode on a 5 MHz channel. It may be even worse if we consider the losses associated to the mandatory DL to UL transition symbols that shall be integrated into each TDD pattern. In other words, the 10 MHz TDD and the 5 MHz FDD throughput figures shall be carefully compared.

Another challenge to have in mind with a 1900 MHz TDD deployment is the densification of the railway radio sites which could have a huge economic impact for railway operators. This densification, compared on a 900 MHz deployment, is of course due to the doubling of the frequency range. Compared to 900 MHz, the 1900 MHz channel propagation model impacts the path loss and consequently the coverage but also the penetration margin figure, the delay spread, the fading effect and the behavior of the system in case of high speed.

Our FRMCS deployment approach is global as indicated in the picture below. Existing GSM-R sites are reused on which whitespace concept can be applied in order to start the FRMCS story. This existing coverage can be operated with GSM-R not impacted by the presence of a 5G-NR solutions deployed on the same channel. Then **the 1900 MHz densification can start in parallel to increase the capacity required by new railway services**. Of course, dual connectivity and carrier aggregation mechanisms can be introduced to manage efficiently this global dual layer railway system. If additional spectrum is required, public or private partners can be selected and integrated in the system carefully selecting the kind of railway services they might address.

Note that for MNOs the network coverage is highly depending on the users density they address. Moreover, MNO users are never managed in a pre-emptive way, making difficult the access to guaranteed resources for critical needs. As this density and usage are very fluctuant within a day, the real coverage and capacity cannot be precisely predicted for critical services and users in a MNO network used for critical services.

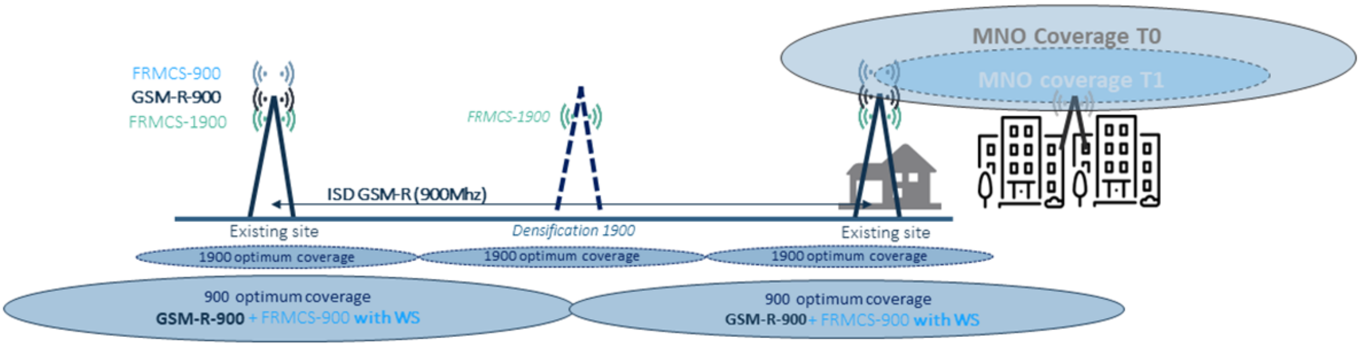

Figure 11 - FRMCS Spectrum, densification and coverage

Migration & Interworking Strategies

For each customer, migration from GSM-R towards FRMCS will differ due to its own constraint and policy: start date, timing for roll out, decommissioning date and end of life of its GSM-R system, available FRMCS spectrum (900Mhz, 900MHz and 1900MHz), reuse of site and assets, investment period, use cases envisaged and associated densification (MNO, Additional spectrum, …), etc.

Independently of each FRMCS customer, the installation of embedded modems in train and the mobility of these between different networks, in addition to the cross border agreement between different networks will also impact the speed and paths of migration of the different networks.

The intend of this section is first to present the interworking proposed by the standard with GSM-R, and then to present an example of implementation of the smoothest transition acceptable by a customer. Indeed , different paths are possible and available, and also homogeneity of realization of a given step within a complete network is not required before moving to the next step. For instance, 1900 MHz densification can be done on some specific areas (and not nationwide in a row) requiring additional capacity, like shunting areas.

Note also that MCX/GSM-R interworking will be required whatever the network due to transition period for migration of the whole networks, and indeed for migration of the pending part on-board trains

GSM-R Interworking

In order to facilitate the migration between GSM-R and FRMCS systems, some decisions have been recently taken by UIC and ETSI. The FRMCS (on-board side) system should as far as possible be developed independently of GSM-R. Thus, in this context, the service migration functionality should be part of the Application layer and not part of the FRMCS Service layer, as depicted in the figure below. Interworking is of course possible at Core and Service level reusing in that case what have been proposed in the 3GPP TS 23.283 “Mission Critical Communication Interworking with Land Mobile Radio Systems” (R17) specifically enhanced with GSM-R interworking cases. Note that Kontron is leading as rapporteur at ETSI to define the FRMCS/GSM Interworking function, currently finalizing Technical Report TR103768 and heading towards definition of the respective Technical Standard.

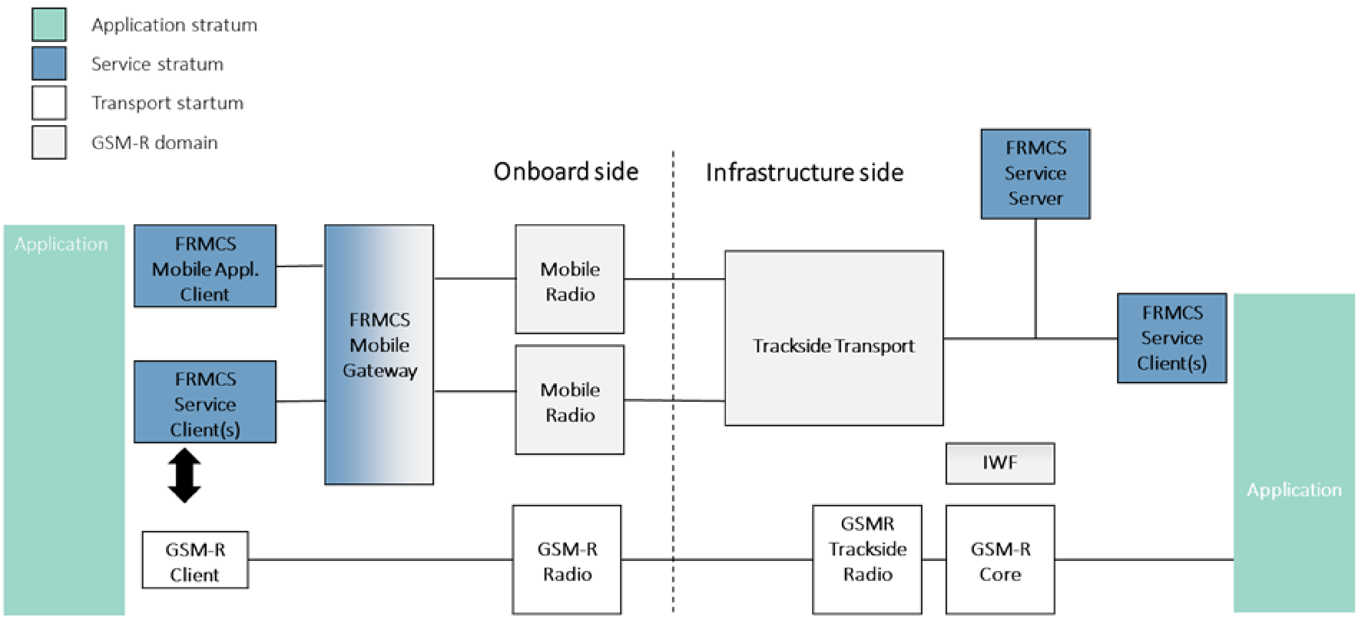

Figure 12 - GSM-R Inter-working with FRMCS

Initial step

The initial step is to start from GSM-R, with 900MHz sites, GSM-R Core and RAN. Services are based on existing GSM-R services such as voice (REC, …), ETCS, ATO, …

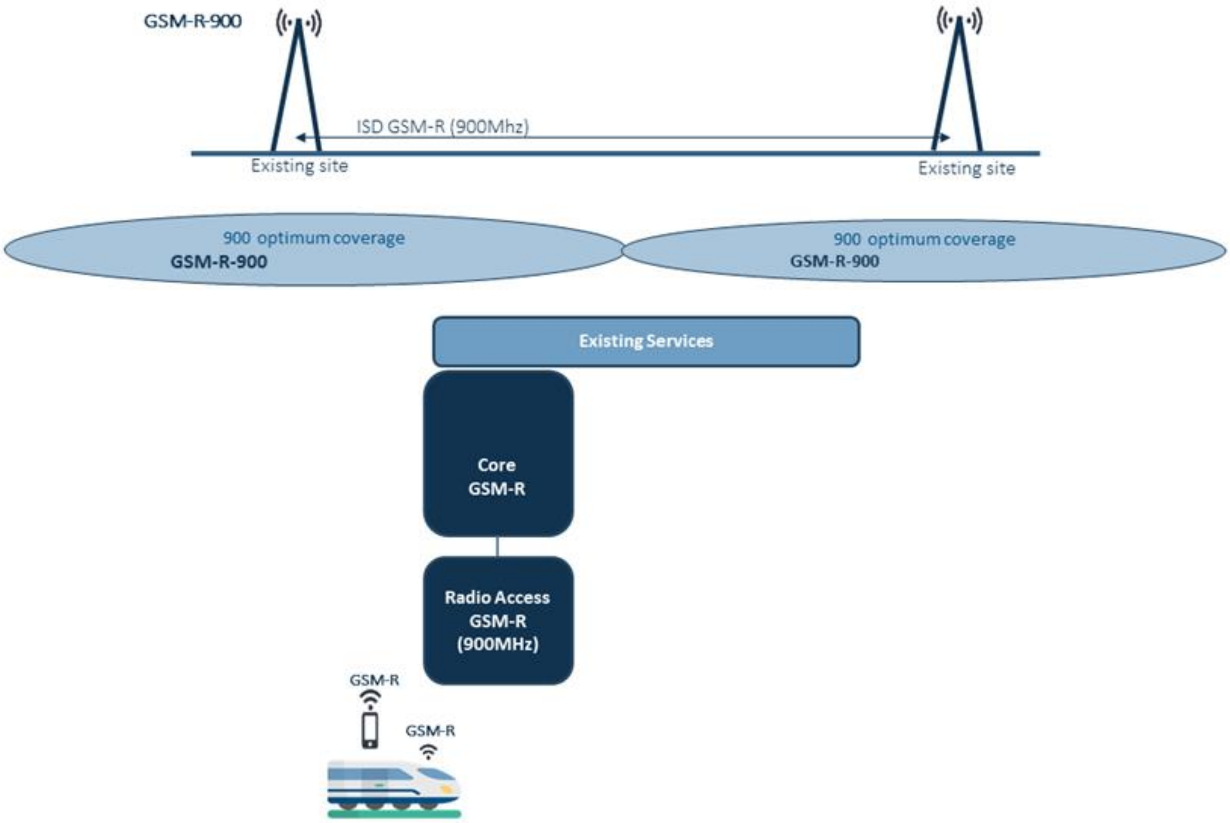

Figure 13 - GSM-R Inter-working with FRMCS

At this step, embedded modems or even portables are only provided with GSM-R technology. It does not preclude any interoperability (of services or dispatchers) between the different technologies like tetra, UHF, fixed/PSTN telephony, etc... Indeed, any interoperability may persist at FRMCS introduction during some period, but this is not the focus area of this paper.

Step1: Introduction and interoperability of MCX and CN

The first step of introducing FRMCS requires to interoperate MCX services and users with GSM-R Services and Users. The interest of this first step is to be able to introduce 5G users smoothly while GSM-R will remain in service until its last users. Such a transition from GSM-R mobile to FRMCS 5GNR Mobile can be managed smoothly by group of users (common function like security or maintenance, or by geographic areas like lines, stations, …) for example.

The new MCX Server has to integrate existing Services, and potentially to consider new services as required by customer. MCX clients will have to be considered at the Trackside Gateway located at the Service server side, but also (not represented below) at end user side, including Trains.

In order to interwork with existing GSM-R service, MCX server has also to support interface with core GSM-R: typically when group calls occur, groups of MCX users and groups of GSM-R users will have to communicate together within common calls. The more the migration of users from GSM-R to FRMCS will advance, the more the usage of MCX will take importance.

A this step, (can also be considered as an earlier step) introduction of a MCX based dispatcher is required, with:

- Common call control between fixed dispatcher and MCX users, with no more need for dedicated FTS Core.
- Interworking to GSM-R Dispatchers via the same interworking function as for mobile users.
- Migrating GSM-R dispatchers to MCX dispatchers.
- Simplification of the whole architecture for dispatchers with a single point of access to both systems, legacy and new MCX one, including new services.

In addition, new services not supported over GSM-R network will be added, like Video services.

At this stage, MCX being full IP , a Sip core and a 5G core will be required for access to mobile users located on 5GNR RAN. The blue box below are pure software solutions that can benefit of NFV/SDN and orchestration support.

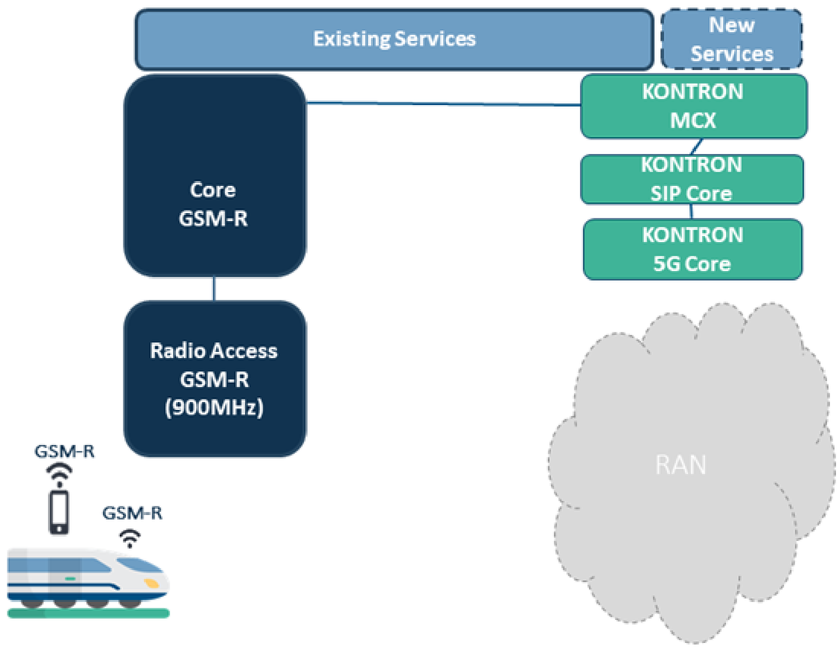

Figure 14 - FRMCS Migration - MCX services introduction

Step2: introduction of RAN 900MHz with White Space

As seen in previous chapters the main cost of transition to FRMCS resides on the RAN part, and being able to reuse, from day1 of the FRMCS introduction the GSM-R assets and typically the radio sites in use, is a key point for FRMCS Operators.

Kontron's solution proposes to re-use existing radio sites for GSM-R and set an overlay 5GNR 900MHz (with same coverage as GSM-R), without any impact on GSM-R performances.

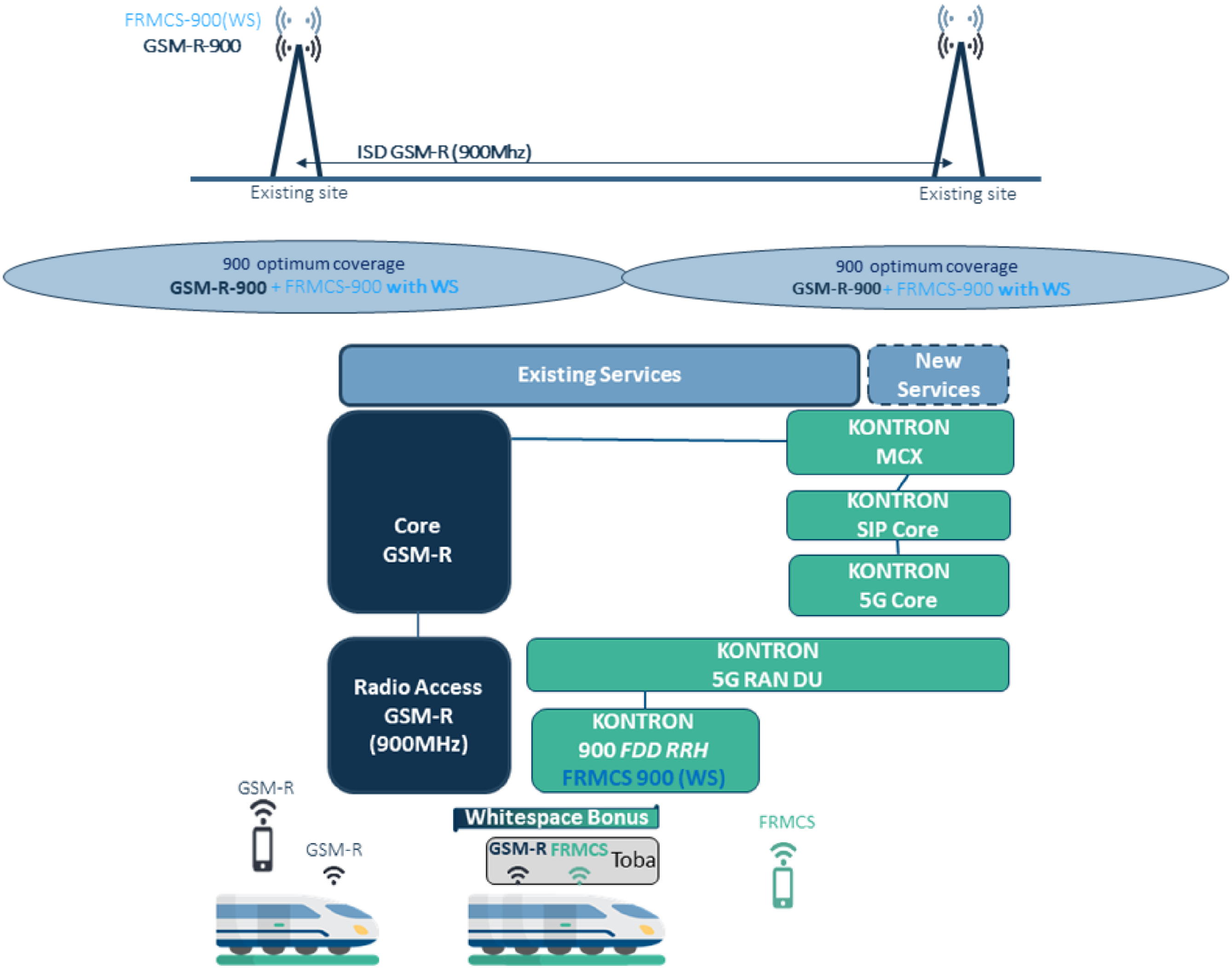

Figure 15 - FRMCS Migration - 900MHz RAN with White Space introduction

This White Space solution is a pure RAN scheduling feature, totally transparent for any 5GNR FRMCS UE in 900MHz band.

Indeed, it requires preliminary installation on train of multi-access modem, typically GSM-R + FRMCS (900, …). Note that ETSI standard proposes multi-RAT access solution for train communication based on 'Toba'. For individual mobile users a smartphone able to access to FRMCS 5GNR 900Mhz is used. All of these users will be able to communicate via FRMCS and MCX communication. If exchanges are required with GSM-R users, MCX is able to setup communication to GSM-R via the Interworking Function.

As both networks are able to be used simultaneously on train, train Application (ETCS, ATO, …) will be able to migrate from GSM-R to FRMCS application per application, and at the speed and choice of the operator.

Step3: Need for densification 1900Mhz 'on purpose'

When FRMCS 900Mhz operates, it is possible to start to setup 1900Mhz network, where increased capacity or higher density of operation (in addition to already in use 900MHz) is required. In that case, additional sites may be requested, but the benefit is again to first re-use GSM-R sites, and then to add densification (if required) between GSM-R sites, considering an averaged ISD (inter sites distance) ratio of two between 1900Mhz and 900 MHz radio sites. Indeed, Ran DU are able to manage FDD/TDD cells simultaneously, and also starting from one DU single band to manage clusters of one RU 900 MHz band and two RUs 1900 MHz band (1 RU for same site as 900, and one in additional site for 1900). If needed several clusters can be managed by the same DU, but in general and depending on services delay requests, it may be recommended to limit a cluster to ~15km along tracks.

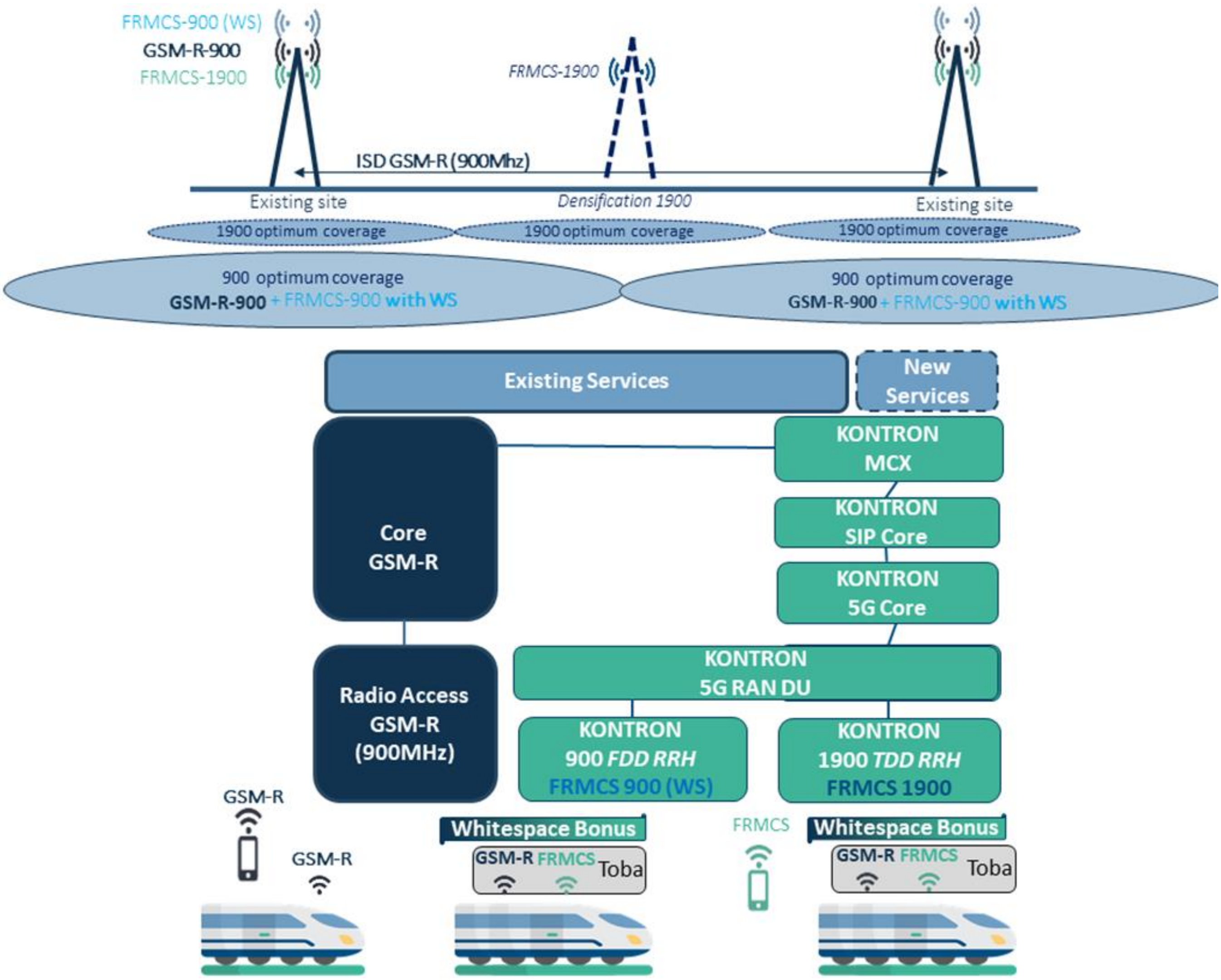

Figure 16 - FRMCS Migration - 1900Mhz RAN on purpose densification

Indeed, in that configuration, the FRMCS UE (within train or within smartphones or modem) manages 5GNR FRMCS 900MHz and 1900Mhz.

At this step, the overall capacity of both FRMCS and GSM-R can be used simultaneously. Services can migrate from GSM-R to 900MHz FRMCS and/or to 1900MHz FRMCS, depending on operator constraints.

Then, the commissioning for extension of 900Mz with WS and 1900Mhz sites and coverage can be realized area per area as decided by the operator and as required by services in a very flexible manner.

And if additional capacity is required ?

Moving towards 5G technology with limited spectrum can be frustrating, as the capacity may be reduced. Thanks to enhanced possibilities offered by the 5G technology, it can be considered, where possible to support non-critical services based on third party networks, like MNO or MVNO. Note that, if private partners support critical 5G infrastructure (like huge industrial areas like ports, big factory, ….) and have specific agreement with FRMCS operator, it can be used also for additional critical services.

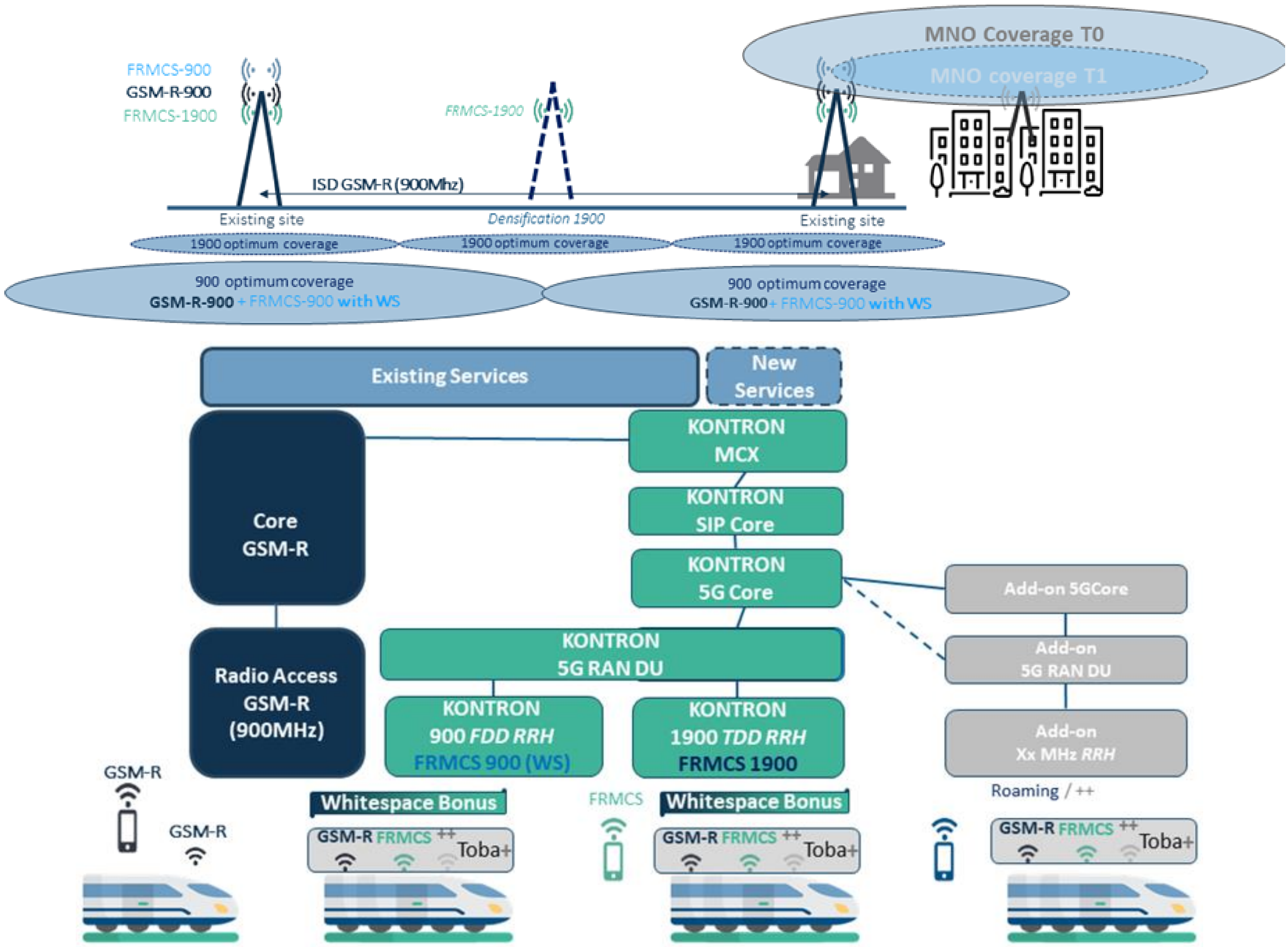

Figure 17 - FRMCS Migration - Hybridization introduction for non MC services (with MNO)

As long as the control of all of the services is managed by FRMCS operator, usage of additional resources can be supported by the 5Gcore and MCX. Roaming (plain line between 5G core in figure 17), Ran Sharing (dotted line between Add-on 5G RAN DU and FRMCS 5G Core in figure 17), multi access modems, are options of add-on connectivity supported by Kontron solution for access of FRMCS clients to their servers.

Note also that MNO capacity can differ (on coverage and on capacity) depending on the time and the load of the MNO network (at time T0 and T1 in figure 17 – top right hand). This is one more reason why it is strongly recommended to use that kind of add-on network only for non-critical services.

Last step: GSM-R decommissioning

When FRMCS coverage is implemented and the migration of services to FRMCS is completed, the GSM-R network can be decommissioned.

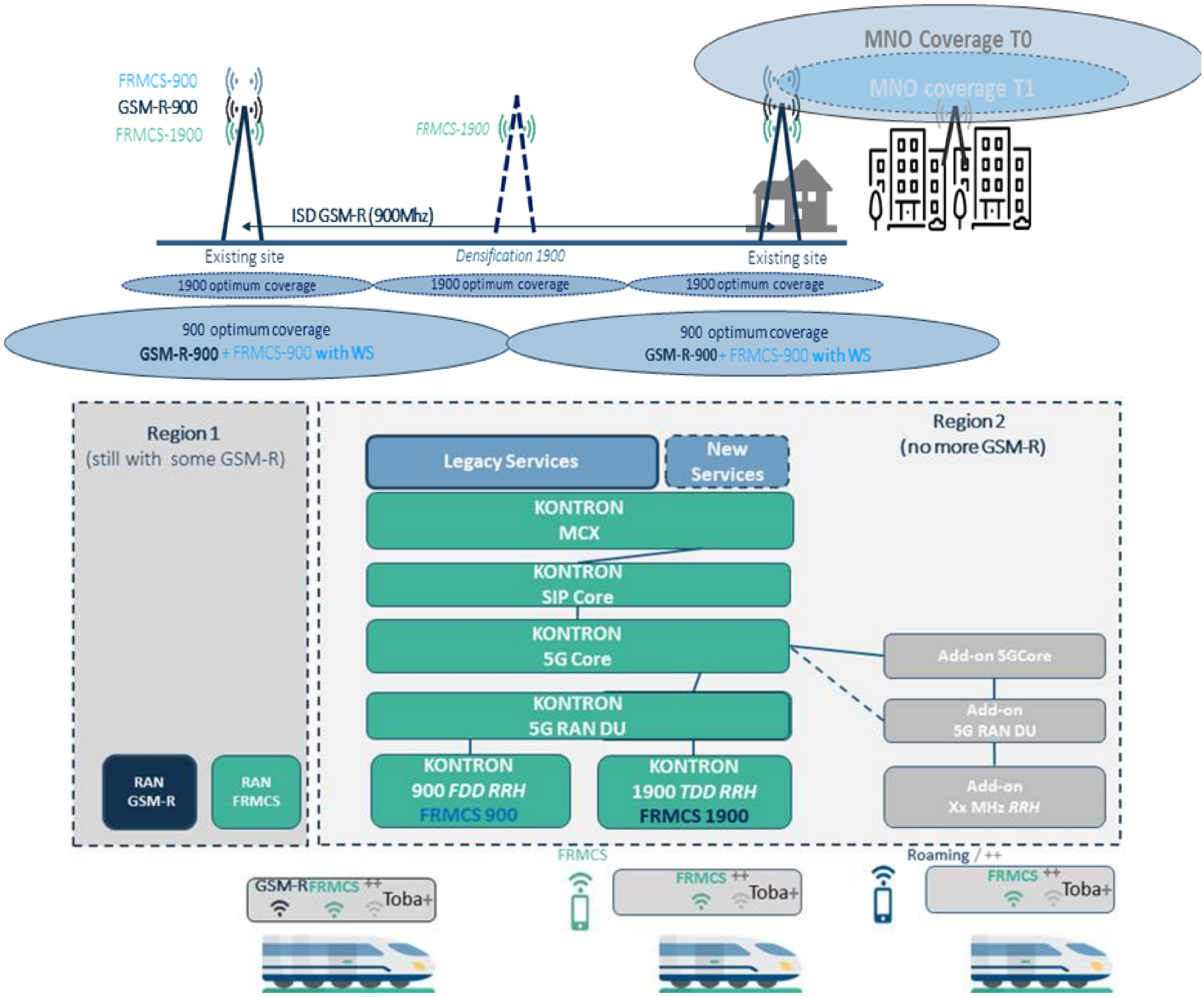

Figure 18 - FRMCS migration - GSM-R decommissioning per region

Decommissioning can be realized by contiguous regions or areas, but as long as trains have to operate through both not-fully-migrated area (i.e.: still some GSM-R required) and already-decommissioned area (i.e.: no more GSM-R), trains will have to keep GSM-R connectivity.

When all areas travelled by the train are fully migrated, the on-board GSM-R modem will be decommissioned leading finally to a pure FRMCS network.

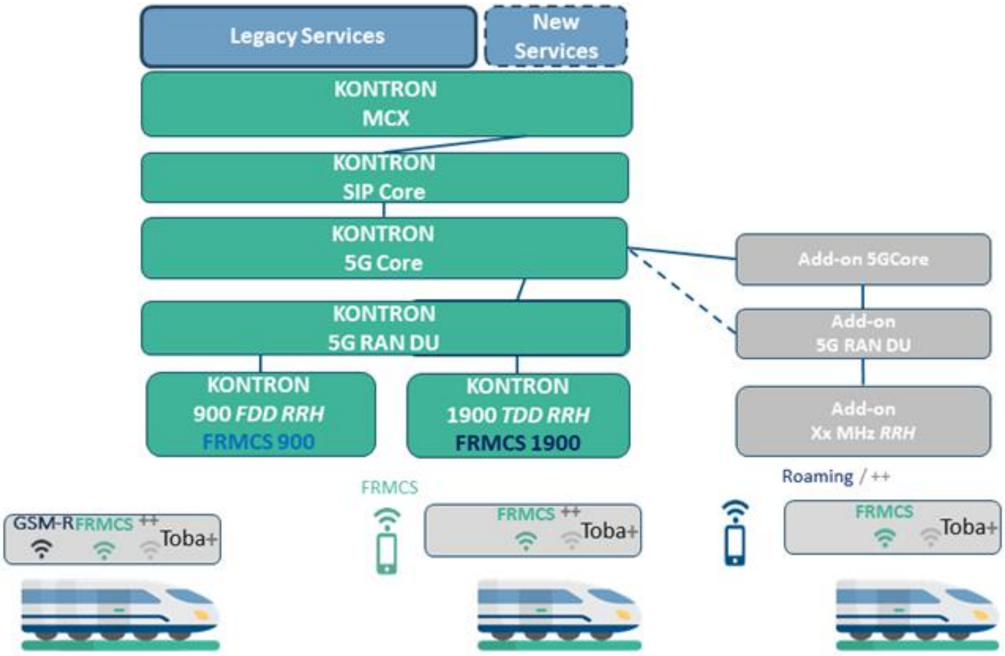

Figure 19 - FRMCS migration finished - GSM-R fully decommissioned

To Conclude

Conclusion

- This article is intended to guide the reader through some key end to end aspects of FRMCS, including a smooth migration path from legacy GSM-R onward.
- Of course different Railway Operators will face different challenges: it still remains that we are establishing pillars that can be used (even partially) by any Customer to forge his own ad hoc strategy.
- Kontron has always demonstrated premium leadership and expertise in the GSM-R domain and is now mastering to its whole extent the FRMCS architecture and ecosystem, based on years of continuous collaboration and contribution to Railway and FRMCS standardization bodies and innovation projects. All forecasted impacts are continuously monitored and anticipated along with the development of our Railway systems, from upper applicative service levels down to the infrastructure physical nodes.

If one needs more details especially (but not limited to) on key areas such as Kontron White Space solution, Cybersecurity and criticality of FRMCS Networks, FRMCS TDD spectrum and cross borders, Transmission Impacts of FRMCS, … please contact your Kontron representative or stay tuned, since this article is intended to be the first one of more advanced and in depth articles to come.

About Kontron Transportation

Kontron Transportation GmbH is a global leading supplier of dedicated end-to-end communication solutions for mission-critical networks that offers tailor made solutions to support its customers with their communication challenges.

The company´s focus is to produce, transport and process voice, data and video information reliably and securely in an efficient and sustainable way. The core product portfolio includes GSM-Railways, FRMCS (future railway mobile communication system), MCx (mission-critical over public networks), 4G/5G public network solutions and IIoT solutions focusing on data processing. Main customers are railways and public transport operators all over Europe. Kontron Transportation drives the evolution into the next generation of broadband solutions for mission-critical networks, for instance as an associated member of the European research initiative Shift2Rail.

The company has more than 550 employees, 11 sites all over Europe and is headquartered in Vienna.

For more information, please visit: www.kontron.com/ktrdn

Your Contact

Kontron Transportation GmbH

Lehrbachgasse 11
1120 Vienna, Austria
Tel.: + 43 1 25 33 700
kta_office@kontron.com

www.kontron.com/ktrdn