5G-VICTORI: Future Railway Communications Requirements Driving 5G Deployments in Railways

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Abstract. The complete transformation of the ICT domain driven by 5G network principles and capabilities, will impact significantly the path towards digitalization of many vertical industries, with modern railway transportations being one of them. In this context, Future Railway Mobile Communication System (FRMCS) service requirements and system principles are very well mapped to 5G service and network concepts associated with network performance, technology neutrality at various levels as well as network planning and deployment options. However, the flexibility of 5G networks implies that concepts are pinned down to deployment paradigms so that afore assertions are proved. The 5G-PPP project 5G-VICTORI aims at delivering a complete 5G solution suitable for railway environments and FRMCS services, along with experimentation deployments for testing and evaluation in operational railway environments. This paper discusses the service Key Performance Indicators (KPIs) and technical requirements and provides an overview of the proposed experimental deployment in an operational railway environment in the area of Patras, Greece.

Keywords: 5G, Railway Communications, FRMCS, Edge Computing, vertical services.

1 Introduction

The explosive growth in the demand for broadband and mobile services is visible in all environments of human activity. In this landscape, modern railway transportation environments, present huge demand for network deployments to support a broad range of novel services addressing various end-user categories.

Existing telecommunications infrastructures deployed in the railway environment includes several flexible technologies and different public and private network deployments to serve the demand for versatile services from various end-users. However, rail service requirements are pushing existing networks deployed in the railway environment to their limits, making total coverage for all services along the extensive railway tracks very challenging. This effect is further emphasized when considering current sub-optimal utilization of resources and slow service deployment. The Future Railway Mobile Communication System (FRMCS) standard [10], succeeding GSM-R, aims to address these inefficiencies and meet future service requirements. FRMCS is considered as a key enabler for rail transport digitalization and reflects the technology neutrality and network services approach of 3GPP 4G/5G standards, tailored to the service specificities and deployment challenges of the railway environment. The FRMCS and 3GPP collaboration as defined in the specification series [1]-[4] fulfills the expectations of both worlds.

A number of projects and programmes (EU, national funded, equipment vendor supported, etc., e.g. [5], [14]) are focusing on the technical realization of the FRMCS concepts and principles, in delivering deployment paradigms and evaluating FRMCS services over these. In this landscape, the 5G-PPP 5G-VICTORI project [6] is extending existing 5G experimentation facilities towards adopting a novel 5G solution for FRMCS. The project focuses on delivering two implementation paradigms, available for experimentation at railway operational sites in Greece and Germany. This paper aims at providing an overview of the FRMCS services that drive the deployment and that will be demonstrated at a railway facility in Patras, Greece, as well as a discussion on the underlying challenges.

This paper is organized as follows: initially, the service and network deployment requirements and options are discussed on the basis of key railway vertical services. An overview of the 5G-VICTORI experimentation network deployment in Patras facilities -covering these requirements- is presented in the subsequent section. Following these, aspects related to the operational adoption of such solutions are discussed, while conclusions are drawn at the end.

2 Railway Vertical Services and Requirements in 5G-VICTORI

2.1 Vertical Services, Requirements and KPIs

In modern railway transportation facilities, there is a demand for a broad range of novel services addressing various end-users and rail related operational services. These, collectively denoted as FRMCS services are applications for passengers, critical services and emergency services for stakeholders engaged in train operation, as well as complementary services related to optimization of train operation. Detailed information on the railway environment requirements and vertical applications is provided in [3] and [16], along with their typical categorization into “Business”, “Performance” and “Critical” services. The 5G-VICTORI project includes services that represent all FRMCS service types and aggregates their requirements.

In particular, “Business services” refer to communication and broadband connectivity services provided to passengers present at railway facilities, i.e. at the train stations/

platforms, on-board. These services include infotainment, digital mobility, travel information services etc. Indicatively wireless internet, infotainment services, Video on Demand (VoD) and linear TV services are used at Patras 5G-VICTORI facilities, imposing the following service requirements (aligned with [1]):

- Support for High-resolution Real-time Video Quality of video content/ TV streaming channels, implying jitter limits below 40ms, end-to-end latency below 100ms and guaranteed datarates of 5-10Mbps per stream.
- Low Channel/ Stream Switching time, corresponding to the time between the triggering of channel switching and the presentation of the new channel on screen; typically to be under the 1-2 sec, corresponding to end-to-end network latency below 150ms.
- Total Wagon Traffic Density accounting for 100-300 users per train (peak time) for this service, requiring in total 500Mbps even 1Gbps at large, highly congested trains.

The “Performance services” category includes non-critical services related to train operation, and can be sub-grouped into: i) passenger information services, ii) advisory services, iii) telemetry services and iv) infrastructure monitoring and maintenance services. Usually these services are deployed and consumed inside the railway facilities environment. In the context of 5G-VICTORI (at Patras facilities), CCTV services for supervision of the rail tracks quality and provision of maintenance when needed will be used as example. Cameras mounted on the train will be capturing images/video of the tracks, viewed in real time at an emulated Railway Operations/Monitoring Center. Such services pose requirements related to:

- High-resolution Real-time Video Quality of CCTV camera stream, implying jitter limits below 40ms, end-to-end latency below 150ms and guaranteed bit rate of 3-15Mbps per stream depending on the required picture resolution.
- High availability and seamless service provisioning under speed high mobility for critical CCTV services related to real-time monitoring for next generation trains and railway facilities.
- In operational cases ([3], [1]) one can consider also asynchronous operation of CCTV/ data monitoring/etc. for services based on post-processing of (video) captures, that further introduces the requirement for bulk transfer of infrastructure monitoring data (e.g. CCTV archives), collected over time. Depending on the scheduling of the transfer, and the coverage footprint of the network, this may impose a requirement of uploading several GB-TB of data (towards an Operations’ center), introducing the need for network data rates exceeding 500Mbps (500Mbps-1Gbps) at specific network coverage areas.

“Critical services” are related to train operation/movement, railway automation and operation control systems, trackside maintenance, emergency and safety services, etc., and involve information exchange between various users/ stakeholders, e.g. railway infrastructure operators, train operators, railway staff, railway first responders, etc. Usually, these services are deployed and consumed inside the railway facilities environment. However, there is a critical requirement for service availability at any part of the facilities, including the extensive railway tracks. Mission-Critical Push-to-Talk (MCPTT) and

Mission Critical Data (e.g. between the controller(s) at the train/ operations center and the driver/ on-board staff etc.) are used as indicative applications of this type in the context of 5G-VICTORI. Such services impose requirements (aligned with [1], [3]) related to:

- Intelligible Voice Quality of MCPTT session, that implies extensive network coverage with adequate signal quality to support it.
- Communication session Setup time, which given the criticality of the service, needs to be very fast, not exceeding 1 sec.
- Low Session Loss Rate (SLR) (number of sessions released due to failure over a specific time window) which is practically impacted by network availability and reliability over the railway facilities. SLR of 10^{-2} sessions/h is the target for operational network deployments.
- High Service Reliability, which reflects general critical services reliability levels of 99,99% (up to 99,9999%), depending on the criticality of use of MCPTT, and relates to network availability and service reliability levels.

In addition, the following generic requirements have been identified commonly for all services of the railway transportations vertical. In particular,

- Service Availability on board the train, whenever it resides along the tracks (and at station platforms), for synchronous service operation is required, implying network coverage at the vertical premises. In the railway environment vertical premises include the extensive network of railway tracks and the railway stations/ platforms). The exact Service Availability levels (target values) depend on the nature of the services supported and vary between low levels for Business to very high for Critical services.
- Service Availability with significantly high network performance requirements at specific facility areas is required for asynchronous service operation.
- Seamless service provisioning to train wagons at high speeds is required, reflecting the vertical specific requirement for mobility at trains velocity (reaching 100 km/h and in cases 250 km/h), for all services provided on-board.

The key characteristic of the aggregate traffic patterns in this environment is that they are predictable; at access network level they are limited by the passenger capacity of one train, they follow a specific route along the tracks and they are restricted to the facilities of the railway.

2.2 Network Deployment Requirements and Options

To meet the FRMCS service requirements and KPIs, novel architectural solutions and network deployment options tailored to the railway environment need to be considered. The access network deployment (coverage) involves the application of common network planning principles, starting with the characterization of the area under study. In practice, area characteristics along the railway tracks may vary from remote, isolated areas, with challenging terrain for radio coverage (e.g. mountainous, with many curves, tunnels, etc.) to metropolitan areas (e.g. with high buildings, with many curves, tunnels etc.). Considering the access network capacity, as aforementioned aggregate data rates of at least 300Mbps-1Gbps are required at train level, and in cases that this is not possible, data rates of 1-1.5 Gbps are required at places where the train resides for some time, e.g. at platforms, train depots, etc. Apparently, there is no single solution to address such environment. In addition, considering the FRMCS principle of technology neutrality [16], solutions comprising different wireless access technologies shall be considered, both 3GPPP and non-3GPPP, not necessarily provisioned by a common 3GPP 5G core network (5GCN).

Consecutively, at the transport network layer, multiple solutions can be considered. 5G-PICTURE [5] proposed a converged Optical-Wireless solution. However, where fiber deployment is not possible or cost-effective, deployments with multiple wireless transport hops can provide an alternative solution [11]. Adhering to FRMCS technology neutrality principle, at transport network segments, solutions comprising different technologies and aggregating backhaul traffic from multiple technologies access network nodes can be considered.

Currently, private GSM-R networks serve part of the railway communication needs - the Rail-critical services part of FRMCS services- while public telecom networks serve another part. The fact that most FRMCS services are deployed and consumed in the railway facilities environment, makes this environment best suited to determine the end-to-end network architecture and deployment options. In practice, this means that private network deployments for FRMCS is a valid option as long as service continuity is ensured for “Business services” consumed across private and public networks. At this point, spectrum availability is a key factor that will impact the deployment models for railway communications. In case spectrum allocation policies for FRMCS follow the GSM-R ones -characterized by very short bandwidth allocations dedicated to Railway Operators-, the available bandwidth may be sufficient to cover the needs of Rail Critical Services, but it might not be enough to serve additional “Business” or “Performance” services.

Other business factors may as well lead to public networks being extended to the railway facilities for FRMCS service provisioning. In these cases, a distributed core network deployment allowing service deployment and processing at edge compute resources, and traffic offloading at Mobile Edge Computing (MEC) components can serve well the purpose of meeting the performance requirements (especially for low latency), while optimizing public network utilization and performance. Moving one step further, for services that are consumed/ processed/ stored at train level, the inclusion of on-board edge resources in the distributed network and service deployment setup will be considered.

The performance requirements and the diversity of services included in the complete FRMCS service set as well as the need to support multiple tenants on top of a single infrastructure necessitates the adoption of the 5G concept of network slicing at service and tenant level. In general, FRMCS services can be well-mapped to the 3GPP distinction of services to uRLLC (ultra-Reliable Low Latency), and eMBB (enhanced Mobile Broadband), as basis for network layer slicing, over either a single private network deployment or a distributed public one.

3 5G-VICTORI Deployment for FRMCS

Considering the FRMCS services as well as the deployment requirements and challenges related to the railway environment, 5G-VICTORI has proposed a disaggregated, layered experimentation framework [11]. Based on 5G-VICTORI proposed approach, leveraging on the findings of [5], appropriately extending the 5G-VINNI experimentation facility in Patras, Greece [12] the project develops an FRMCS deployment in an operational rail environment in Patras presented in Fig. 1.

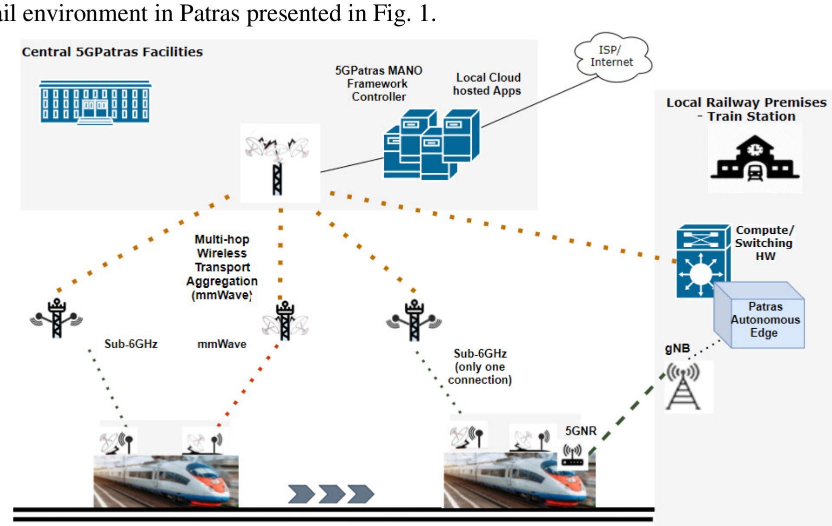

Fig. 1. Blueprint of 5G-VICTORI deployment for FRMCS in Patras

Last mile Transport and Access Network: In this context, the deployment includes a multi-technology dense transport network providing transport coverage along a high-speed railway track in the area of Patras. In particular, to demonstrate multi-technology track-to-train (as last-mile transport network) communication, the proposed setup comprises both mmWave and Sub-6 track-side Access Points (APs) to be deployed along the track between two stations. The mmWave (V-Band, 60GHz) APs feature beam steering capabilities for the train-to-track connectivity and are capable to provide up to 1Gbps data rates. The Sub-6 APs allow for wider sector coverage, suitable for more challenging parts of the route.

Each trackside stanchion of the rail facility includes a pair of mmWave and/or Sub-6 APs, each one facing the each opposite directions of the track, since APs are quite highly directional to maximize performance. To ensure connectivity also as the train moves between the trackside APs, the proposed scheme suggests that antenna modules are installed at the front as well as at the rear part of the train rooftop. Seamless service and session continuity are ensured between the multi-technology APs by employing mobility-support functions, leveraging Software Defined Network (SDN) programmability for the established end-to-end flows.

An on-board train installation is foreseen to allow connectivity of various access network technologies (WiFi APs or gNBs) available to the end-users as well as to provide compute capabilities for applications' edge processing.

As aforementioned, there are areas where trackside network deployment is not feasible, hence certain asynchronous FRMCS services can rely on high speed access network connectivity at train stations' platforms. To experiment with such deployments, the 5G-VICTORI setup will include also a 3GPP 5G NR node at a train station in Patras' train facility. This complements the picture of multi-technology 3GPPP and non-3GPP access in the railway environment.

Transport Aggregation: The transport aggregation network part relies on state-of-the-art Point-to-Point Ethernet mmWave links at 70/80 GHz (E-Band) providing a total of up to 10 Gbps capacity towards the cloud/central facilities. The transport network nodes feature SDN capabilities providing support for network slicing.

Edge Computing: For the deployment of services, cloud compute resources are available at the central cloud infrastructure of the 5GPatras facility (University of Patras premises). However, to achieve high network performance and to optimize resource utilization, private network deployment and edge computing are considered in various ways apart from the central cloud option.

In particular, edge computing is considered at the on-board train installation, to provide the necessary storage and compute capabilities for asynchronous "business" and "performance" services. Virtualization of the edge resources allows the use for various applications/services, and the integration at various layers with the rest of the multi-technology, multi-layer network setup. In practice, virtualized edge resources can be integrated with the non-3GPP last-mile transport and WiFi access connectivity layer for hosting part of the synchronous applications. At the same time virtualized edge resources can be used for hosting components of the asynchronous services (e.g. storage of CCTV captures, storage/processing of measurements etc.) temporarily, during the periods that 5G access network coverage is unavailable.

At the 3GPP network layer, MEC is considered via the deployment of the complete 5GCN close to the vertical premises. The implementation is based on the Patras 5G Autonomous Edge, which is a portable "box", ideal for on-premise 5G deployments, containing everything from the 5G NR and 5GCN and Service Orchestrations on a Virtualized environment based on OpenStack. The Patras 5G Autonomous Edge is currently deployed in an indoor configuration, and it will be setup to provide the full stack of 5G NR in a standalone configuration with 100 MHz bandwidth along with a single cell at the train station. All services are orchestrated via Openslice ([13], [8]) and monitoring is available through Grafana, Prometheus and Netdata.

Network Management, Orchestration and Slicing: Adhering to the 5G-VICTORI architecture, a network management and service orchestration layer operates on top of the aforesaid dense, multi-technology Patras 5G facility, to ensure that use cases and FRMCS services are delivered through multiple slices across the distributed compute resources in the railway environment. This layer is based on Open Source MANO (OSM) [9] and Openslice ([13], [8]), and it assumes automated deployment of end-to-end services and multiple customized-slices over the complete infrastructure (access, transport and core).

In particular, the Patras 5G facility service offering is based on Openslice which follows the Network Slice as a Service (NSaaS) paradigm. The Patras 5G facility service derives content from a 5G Service Catalogue of offerings -which advertises various 5G and generic NFV services to verticals/customers that can be included in their service order towards the facility. The service order of the vertical is then passed to the Openslice Service Orchestrator (SO) in the Patras5G facility [15]. The SO then instantiates the network slice by subsequent calls to the respective network function virtualization orchestrator (NFVO). Moreover, the deployed software stack at the Patras 5G facility can be used to orchestrate services both at the central facility as well as the connected edge sites in the city.

In the context of 5G-VICTORI railway use case, compute and network resources are included in the orchestration domain Patras5G facility NFVO and Openslice instance. The FRMCS application components are managed as 3rd party virtual network functions (VNFs)/ Network Service Descriptors (NSDs) by the Patras5G facility NFVO, thus automated deployment of these services across the distributed compute resources is supported, along with creation of an end-to-end slice.

4 Further Challenges and Requirements

Different end-to-end network architecture designs and various deployment options (e.g. integration of public and private networks) are feasible for offering FRMCS services in the railway facilities environment. The fact that FRMCS services are deployed and consumed inside the railway facilities environment, can define the future end-to-end network architecture and deployment options. In some cases it is expected that FRMCS will be provided over distributed public networks as separate, virtualized network instances or simply as separate network service slices. In other cases, private 5G networks may be deployed to cover the service needs in the railway environment. Several business aspects underpin these decisions, and several business requirements revolve around them.

In all cases, the physical network infrastructure will be a critical investment aspect. In some cases, incumbents may undertake the physical network infrastructure deployment. However, in other cases, considering the spatial and temporal constraints character of these services established telecom operators may express low interest in getting involved in such infrastructure deployments. On the contrary, business-wise, exploiting the lack of high competition, stakeholders of the railway industry (e.g. railway operators and/or other engineering companies) are expected to have high interest in investing in private network infrastructures towards the digitalisation of their own business activities, leveraging on their existing experience in operating private networks. At the same time, ownership of facilities is a significant asset for railway operators considering the site acquisition costs necessary in any infrastructure deployment. An expansion of these activities, together with the exploitation of these investments by opening them up to passenger services and to other stakeholders (e.g. content providers, telecom operators) can generate new revenue streams. Such deployments can be considered as niche 5G provisioning systems, fostering the smaller telecom operator industry. As aforementioned, spectrum allocation policies is a key factor to enable the support of highly demanding Business and Performance services apart from Critical ones over a single network.

In such niche 5G networks deployed by the vertical at issue, additional challenges may arise, that need to be tackled. Indicatively, the deployment options to be followed at the access network layer, as well as the distribution and orchestration of multiple MEC resources in the extensive infrastructure of railway tracks entail significant network planning challenges. For services that are not locally restricted to railway facilities, it is needed to ensure continuity outside the boundaries of the niche 5G systems, which will involve the interconnection or even tighter interoperability with public ones (e.g. in the form of national roaming, or even in the form of service migration across networks). Last but not least, licensing aspects related to networks service provisioning to the public and access network deployment need also to be dealt with. At this point, a policies framework fostering the deployment and operation of small-scale networks is key.

5 Conclusions

This paper has provided an overview of the FRMCS service requirements and KPIs, on the basis of key applications spanning across all identified FRMCS service categories: “business”, “performance”, “critical”. These applications have been used as a basis for the definition of system specifications of the 5G-VICTORI solution. Delivering a high-performance deployment for this demanding vertical entails detailed network coverage planning based on various technologies and on the placement of compute resources at the right proximity to the end user.

To this end, specifications have been nailed down to an experimentation deployment for testing and evaluation service performance in operational railway environment in the area of Patras, Greece. The latter entails a multi-technology environment, comprising various wireless technologies at last mile and aggregation transport segments, incorporating edge capabilities at various network parts, as well as 3GPP and non-3GPP access. On top of such infrastructure, designing, instantiating and orchestrating critical and non-critical services oven a multi-layer edge processing architecture, especially when various quality is required via slices is a key challenge that 5G-VICTORI will address in the next years.

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two levels of headings should be numbered. Lower level headings remain unnumbered; they are formatted as run-in headings.

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