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Emulator for Railway and Road Communication Coexistence Scenarios in FRMCS Validation.

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Abstract

5G is getting roll-out and is considered a significant technology for autonomous vehicles to communicate and navigate. Future Railway Mobile Communication System (FRMCS) is looking into wireless technologies such as 5G, LTE, and WiFi to leverage them for railways (5GRAIL) (5GRai). In this paper, a sandbox for emulating coexistence scenarios for railway and road communication infrastructure is presented. A concrete case is presented for demonstrative purposes and for validation of the proposal, detailing the different considered elements: a topological setup, SDN-based traffic slicing and hand-over functionality, and traffic generation.

Keywords: 5G, multi bearer, railway, emulation, FRMCS, SDN, Mininet-WiFi Integration, Edge Computing, Network Slicing, etc..

1. Introduction

Facing the planned obsolescence of the Global System for Mobile - Railway (GSM-R) communication system, supporting the current European Railway Traffic Management System (ERTMS), the railway industry launched a redefinition of a communication system for railways, coping with modern service capabilities, safety and robust to accommodate multiple current and future radio-access technologies. Termed FRMCS system (ETSI TR103 333) has reached the level of specification of User Requirements (UIC FU-7100) and Use Cases (UIC-MG-7900). As part of this specification process, a series of test cases and functional validation by means of prototyping is required (Mandoc et al. 2019). A current EU H2020 ICT project, 5G for FRMCS (5GRAIL) (5GRai), aims to verify the first set

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of FRMCS specifications and standards (FRMCS V1) by developing and testing prototypes of the FRMCS ecosystem. Within 5GRAIL a specific research oriented work package, WP6, was defined in order to analyse scenarios for railway and road communication systems coexistence, based on simulation or emulation techniques, and as part of the project's overall testing and prototyping efforts.

Although FRMCS is based on 5G (3GPP R17 and successive), by using Mission Critical (MCX) services, railway on-board systems will be allowed to additionally use a number of other radio access technologies (Wi-Fi, LTE, and satellite) to ensure flexibility and availability. In parallel, the automotive industry is working on technical solutions for connected vehicles. Intelligent Transportation System (ITS)-G5 has been standardized for several years, and solutions to allow hybridization with cellular systems such as LTE-V2X or C-V2X (Cellular Vehicle-to-Everything) and future 5G NR technology are under development. In this context, the cohabitation of the rail and road communication systems in the ITS band is very important in a context of spectrum scarcity and resource savings. A comprehensive process to define coexistence scenarios between railway and road, from the point of view of telecommunication infrastructure sharing, was followed. The variables considered are:

- Services (specific rail and road applications).
- Telecommunication network components, both radio access and core.
- Civil-engineering topological components

The range of values considered for the network and topological components are:

- Single versus multiple (radio technologies), shared (with public ones) versus dedicated (private) networks.
- Highway versus road versus urban train versus regional train vs high-speed train (given by the speed of the vehicles considered).
- Open vs bridge vs tunnel (transport infrastructure elements).

As a result, nearly 400 coexistence scenarios were defined. From them, a set of representative scenarios were selected as interesting targets for experimentation (Deliverable D6.1). Figure 1 shows three considered scenarios.

The paper presents in the following sections the emulation sandbox built-up to enable this experimentation: an outline of the target scenarios is presented in Section 2. Description of requirements for the design of the emulator is given in Section 3. Components of the emulation platform are elaborated in Section 4 and an example implementation for one of the selected scenarios is presented in Section 5. The paper closes with a set of critical conclusions and a description of future work that are presented in section 6.

2. Initial Demonstration Scenarios

The following considerations guided the selection of a set of cases, initially chosen as target for demonstration of scenarios of coexistence of Rail and Road:

1. The telecommunication infrastructure state is defining the Case baseline. The different topological configuration of the road and railway infrastructure (number of lanes, number of tracks, speeds, parallel or perpendicular) define just variations of what we could term "environment conditions" which do not alter the essence of the case from a Telecommunications point of view. As a result the base cases reduce to:

    - Case A: where the different road and railway domains keep all telecommunication infrastructure (access + core networks) separated from each other.
    - Case B: where the backhaul and core network for Road and Railway domains is common and shared, while the radio access networks serving each of the domains are kept separated.
    - Case C: where all telecommunication infrastructure (access and core networks) is common and shared.
    - Case D: where the radio access is shared for both domains, but they have different backhaul and core networks. This case was considered as a combination of cases A and C and discarded in the following. Cases A, B and C are illustrated in Figure 1.

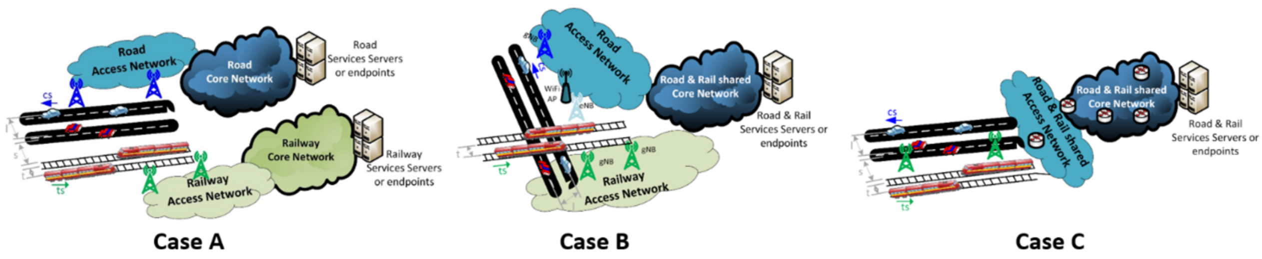

Fig. 1. Coexistence cases A, B and C, from a Telco-Infrastructure point of view

2. The coexistence scenarios to concentrate would be those that maximize the duration of this coexistence: low speeds and longer duration, from a mobility and topology levels. With this in mind, it was decided that, regarding topological elements, the most relevant cases are those where railways are parallel to road-lanes or perpendicular as one domain operation may directly impact the other (level crossings), and with the case of tunnels as a special variation of those.

As a result, the selection of priority targets for emulation where the following (scenario nomenclature, SXYZ, is defined in (Deliverable D6.1)):

1. Scenario 1 (S1(5/6)(1/4)): This case is the baseline reference for performance comparison with the rest of cases. It is compliant with case A as defined above. The topological elements could be parallel or perpendicular to each other.
2. Scenario 2 (S2(5/6)1): Compliant with case B as defined in the previous section, it focuses on Road and Tram / or Urban Train.Track parallel to road, open air or bridge and on the same vertical plane as topological setup. A variation is the same case with rail and road perpendicular to each other.
3. Scenario 3 (S4(5/6)1): Compliant with case C as defined in the previous section , it focuses on Road and Tram / Urban Train. Track parallel to road, open air or bridge and on the same vertical plane as topological setup. The Radio Access Network (RAN) is shared, and both share also the core network. A variation, is the same case with rail and road perpendicular to each other.

For all the scenario, the challenge is common: for the operator or infrastructure manager to be able to deal with the data traffic flows from the two different domains and without mutual impact at the radio access or the core network. Consequently, the adopted strategy was to aim to data traffic segmentation based on network slicing at the network and validate it by end to end performance testing for selected services in each of the domains.

3. Requirements for the Emulation Platform:

The presented chosen scenarios, provided a set of functional requirements from different perspectives. These requirements are presented in the following:

From the end-nodes capabilities:

1. It should be possible to define mobility for endpoints (speed, positioning / trajectory), frequency, quantity, etc.
2. It should be possible to define multiple wireless network interfaces for endpoints.
3. It should be possible to define / generate traffic from endpoints, with differential characteristics mapping to different types of services: Critical Data Communication vs. Messaging vs. Very Critical Video vs. Voice Communication for Operational Purposes.
4. It should be possible to define radio channel characteristics for the radio link or to “modulate” traffic to mimic those characteristics (packet losses, delays, etc.).
5. Wi-Fi-based connectivity should be available or emulated to endpoints.
6. 5G-based connectivity should be available or emulated to endpoints.

7. It should be possible to define different network typologies both for wireless "access points" and fixed network components. From a network management perspective, it should be possible to programmatically control the behaviour of network elements.
8. Network entities should provide Software Define Network (SDN) (OpenFlow) interfaces.
9. Virtual Local Area Network (VLAN) tagging/un-tagging and tag-based routing should be supported.
10. Mechanisms allowing non-(domain/address), context based routing would be desirable, in order to support situations where the destination of the transmission is determined by context (i.e. a level crossing) and not the origin or domain of the transmission (cars vs trains). From the perspective of the operator of the emulator:
11. It would be nice to have a graphical interface, which we can use to enhance the "marketing" value when presenting emulation results.

4. Components of the Initial Emulator Proof of Concept

The emulator was conceived as a composite of existing elements, since budgeting in the project prevented from a development from scratch. As a result, a search from existing open source and commercial products tried to match features against the presented requirements. As a result, the following form the main skeleton of the emulator, over which the different presented scenarios can be built and operated:

4.1. Mininet-WiFi

Mininet-WiFi (Github) is a branch of the popular network emulator Mininet (Mininet), with all the features of the root project (flexible network topologies scripting and configuration, traffic generation from linux-based applications, and network control programmability based on SDN (OpenFlow v1 to v5). Furthermore, Mininet-WiFi, allows to emulate mobile hosts, and to define multiple wireless network interfaces for each of them, as well as other radio parameters (propagation models, frequency bands, transmission power) which makes it suitable for the network emulation part of the target emulator. A drawback of Mininet-WiFi though is that the wireless interfaces are based only on the Linux wireless drivers and the 80211_hwsim wireless simulation driver (wireless.wiki), so only requirement 6 is not covered from the range [1-10] of those presented in the previous section.

4.2. SUMO-Simulation of Urban Mobility

SUMO (Behrisch et.al. 2011) is an open source and portable traffic simulator widely used by the research community interested in wireless communication networks. This tool seems to be able to meet two of the requirements presented in the previous section. First, SUMO is designed for multi-modal, microscopic and continuous mobility. This tool allows to manage in a specific way the speed of each entity (car, train, bicycle, pedestrian, etc.), its route and possibly its behavior (driver's aggressiveness). The number of entities and the intersections (traffic lights, level crossings, crosswalks, etc.) can also be simply managed. Finally, the simulation area can be directly extracted from real data (Open Street Map). Therefore, SUMO is perfectly suited for defining the mobility of endpoints (requirement 1). We can also add that SUMO includes a graphical interface to visualize the experimental area (map area). In this interface, a lot of information can be displayed: endpoints, traffic signs, roads and railroads, points of interest, etc. Information about the coverage areas of the different network access points can also be displayed on another SUMO interface (telemetry). SUMO is therefore an interesting tool to promote the results obtained during the emulation and to illustrate the relevance of our proposals (requirement 11). SUMO thus appears to be an ideal tool for modeling mobility in our emulator. Different projects have already used this tool in similar works (Kendziorra et.al.2019) (Lopez et.al.2018). They highlighted the high level of accuracy of this tool for public transport modelling: specific traffic signs (rail signals for example), stop stations, intersections management (level crossing for example), modeling of multiple types of devices (high speed train, tramway, etc.), etc. This tool can therefore be used to model realistic coexistence scenarios between trains and cars. It will therefore allow us to reach our goal.

4.3. ONOS SDN Controller

The Open Network Operating System (ONOS) is a reference carrier grade and open source Software Defined Networking Controller (SDNC), allowing for programmability of complex network applications over OpenFlow compliant network elements. Using ONOS, the behaviour of the network can be defined programmatically. Based on this feature two main pieces of functionality have been developed for the implementation of the scenarios: a traffic slicing mechanism, based on VLAN tagging, that allows to discriminate traffic from/to trains or cars and to route it accordingly in the network to appropriate destinations, as well as a handover application, that informs ONOS of the changes in the network attachment point of endpoints (cars or trains) due to their mobility patterns (ONOS). These elements conform the core of the initial proof of concept for the emulator and enable to create scenarios where the main objective (discriminate traffic from the different rail and road domains at different segments of the networking infrastructure, to conduct analysis of traffic coexistence from road and railway services, enabling the optimization of services performance and the use of network resources) can be demonstrated.

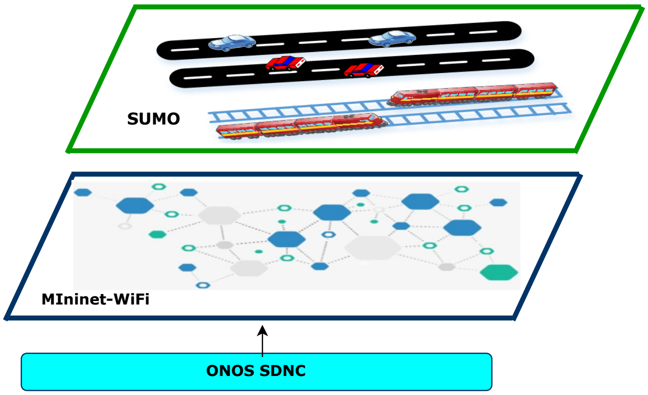

Fig. 2. Implementation Overview

The observant reader may have realised already that the presented elements do not provide features compliant with requirement 6, that is 5G radio access technology emulation. Due to this, different components are under consideration in order to add the possibility to emulate or to attach real 5G equipment to the emulator setup, in a stage 2-version. Some of the elements under consideration are Simu5G (Simu5G) as an emulator as well as different subcomponents of Open Air Interface (OpenAirInterface), as gNB and UE emulators. In the meantime, in order not to stall the development, the current 5Grail train-car coexistence emulator differentiates radio access technologies by configuring different frequency bands within Mininet-WiFi, although the mechanisms are based solely on the WiFi driver as explained previously. Effects at the radio-access segment (losses, noise, interference) are emulated based on the resulting impact on the considered traffic and at the traffic generation stage, at IP-level instead, as previous studies in the literature, using Mininet-WiFi, have demonstrated previously.

5. Example of an Emulated Scenario

To examine the capabilities of the emulator a scenario compliant with case B (different access network, common core network) is considered, as shown in Figure 3. Each of the domains (trains vs cars) communicate to different service servers through the core network.

5.1. Topology

To mimic the real case scenario, the network topology is created using python scripts in the Mininet-WiFi emulator. Where radio access points Ap1 and Ap3 are assigned for railways and access points Ap2 and Ap4 are assigned for roadways/cars. In this topology, cars are represented by hosts Car1 and Car2, and trains are represented by hosts Tra1,

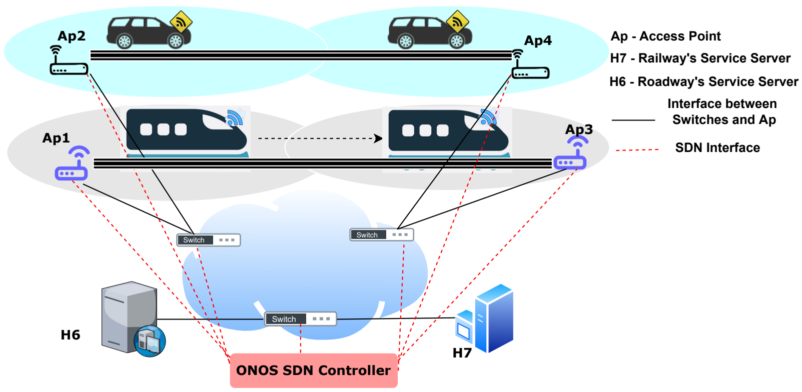

Fig. 3. Considered Scenario

Tra2, and Tra3. Host 6 (H6) is assigned for the roadway's service server and host 7 (H7) is assigned for the railway's service server. Network switches are represented by S2, S3, and S4 as shown in Figure 4.

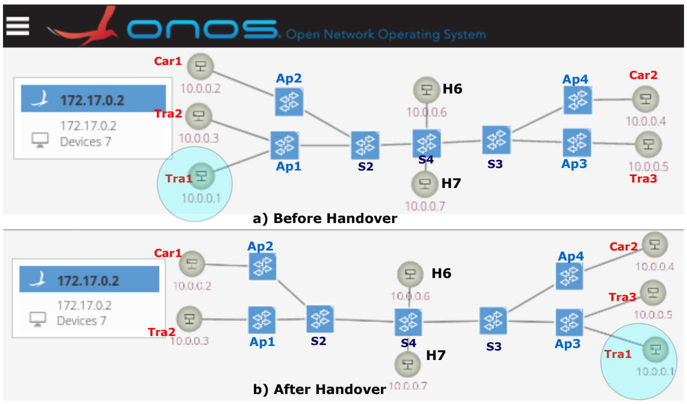

Fig. 4. Topology-ONOS GUI Screenshot

The main objective of this emulation test is to differentiate the traffic from/to roadways and railways in the core network. To achieve this objective logic is implemented by leveraging the network slicing concept. Two network slices are developed, the first one to handle the roadways data traffic and the second one to handle the railways' data traffic. Different VLAN tags are used to differentiate the data traffic of each of those slices. These tags are used to determine the forwarding path towards the corresponding service server. Therefore, in the considered topology Car1 and Car2 should have the accessibility to communicate with each other and with the assigned service server i.e H6. Similarly, trains Tra1, Tra2, and Tra3 should have accessibility to communicate with each other and with the railway's server i.e H7.

To demonstrate the mobility and handover scenario, all vehicles are configured with moving capabilities. Though, for simplicity, in the concrete example illustrated herein, only Tra1 is moving: Tra1 starts moving towards access point Ap3, while communication with the corresponding server. A Virtual LAN (VLAN) tag is used to tag the data packets when they arrive at the edge switch or the access point, and based on it the application logic routes it towards the server. Likewise with the reverse path, from server to Tra1.

5.2. *Design And Implementation*

An application is developed in ONOS, enabling the network slicing and managing the handover between cells/access points. This application is implemented in such a way that it can work with any kind of topology. This

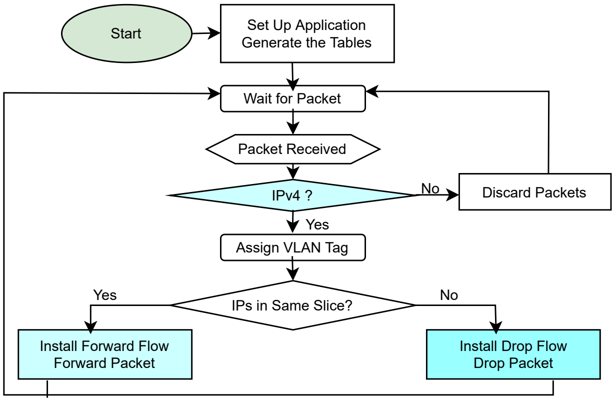

Fig. 5. Flowchart

forwarding application determines whether or not the IPv4 data packets should be forwarded between the hosts. The implemented application works as illustrated in Figure 5: when a packet arrives at a switch or at an access point , it looks into their forwarding tables/rules. If no forwarding rules exist for a given source and destination pair in that switch or access point, the arrived packet is sent to the ONOS controller for processing and It is also checked whether the source and destination IP addresses are in the same slice. If IP addresses are in the same slice, the packet forwarding rules are installed into the switches or to the access points using the OpenFlow13 protocol for that given IP address pair and date packet is forwarded based on the VLAN tag. Along with this, a forwarding rule for the reverse path is also installed. If IP addresses are not in the same slice, the packet drop rule is installed and the packet is dropped.

6. Result and Discussion

To emulate different application traffic for railways and cars, based on a preliminary analysis (Deliverable D6.1), different traffic is generated form trains and cars towards the servers. In the concrete example illustrated here, the iperf3 tool (iperf) is used for transferring User Datagram Protocol (UDP) packets from vehicles (trains and cars) to the assigned service server. Along with this, the objective of this test is to find out network Key Point Indicators (KPIs) such as bitrate, Jitter, and packet loss between the vehicles and assigned server and match then to the applications target. The overall objective of this test to generate the data traffic compliant with real application such as audio/video streaming or critical data communication.

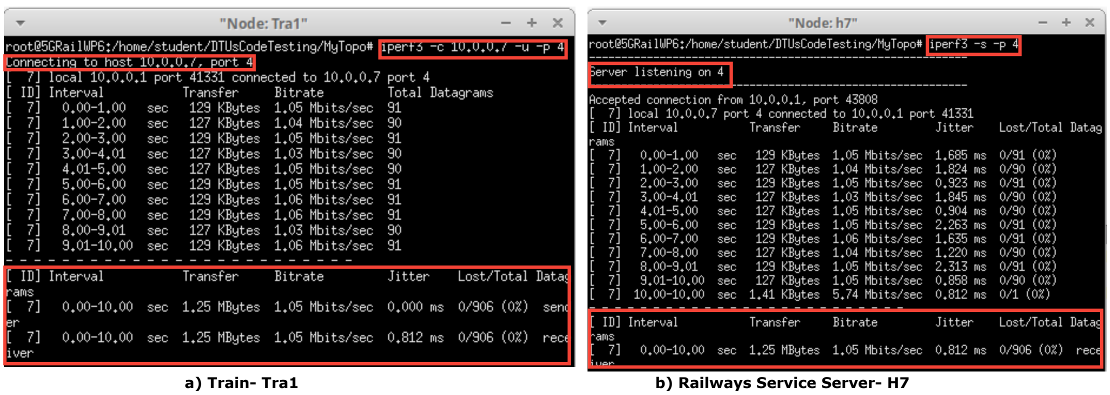

Fig. 6. Screenshot of Mininet-WiFi CLI for iperf3 Test

Figure 6 shows the screenshot of Mininet-WiFi CLI for the iperf3 test executed at the railways' server and at host Tra1. For the considered topology, emulated network has 1.05 Mbps of data rate, 0.812 ms of jitter and it has no packet loss. It shows that, considered emulator has ability to emulate data traffic from/to railways and roadways to create and validate the service functionality such as transmitting the real-time video/audio, critical data or for messaging.

7. Conclusion and future works

The primary objective of this paper is to evaluate the considered emulation platform to emulate the roadways and railways coexistence and validate its operation by defining some scenario and data traffic for railways and roadways coexistence. The outcome of this emulation works conclude that considered emulation tools are competence enough to emulate and validate the different service requirements for the roadways and railways coexistence and help to fortify the considered services before the actual deployment.

In future steps, different scenario with moving host capability will be considered and different service requirements will be emulated. It will be also interesting to integrate the considered scenario with SUMO traffic simulator to visualize the emulation work in a effective way, as well as adding concrete 5G radio access capability.

Acknowledgements

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