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Emulation of various radio access technologies for zero on site testing in the railway domain – The Emulradio4rail platforms

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Abstract

In order to assess the reliability, availability, and maintainability of wireless links for the rail sector in the laboratory, it is necessary to develop measurement platforms able to emulate real railway radio environments. This type of testing platform should combine very new approaches, the so-called system in the loop (SITL) and hardware in the loop (HITL). It allows connecting directly and coupling at radio frequency level (RF) the real equipment to be tested, the radio emulators (physical systems), and the simulators able to mimic the railway network and the railway channels' behavior, including interferences. The Emulradio4rail platforms will support multiple emulation instances such as LTE, Wi-Fi, and SatCom networks. The paper will present the architecture of the platforms under development and preliminary assessments.

Keywords: Channel emulator, Open Air Interface, Train to Ground communications, LTE, Satellite, Wi-Fi.

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1.1.1. Nomenclature

ACS	Adaptable Communication System
GSM-R	Global System for Mobile communication - Railway
LTE	Long term Evolution
HITL	Hardware- In- The- Loop
SITL	Software- In- The- Loop
ETCS	European Train Control System
CBTC	Communication Based Train Control
JU	Joint Undertaking
FRMCS	Future Railway Mobile Communication System
OAI	Open Air Interface
PLMN	Public Land Mobile Network
RF	Radio Frequency
MPLS	Multiprotocol Label Switching
UE	User Eqipment
MME	Mobility Management Entity
HSS	Home Subscriber Server
SGW	Serving Gateway
PGW	Packet Gateway

2. Introduction

Due to specific structural industry constraints (*e.g.:* national standardization and regulation fragmentation, market and solution fragmentations, and system complexity) and the long development of system lifecycles "service-proven" solutions, railway transportation systems have suffered from a limited adoption of novel technological advancements in electronic hardware and software, communication networks and embedded computing. For these reasons, Shift2Rail JU multi-annual action plan (Shift2rail MAAP (2015) has given high priority to the development of a new wireless communication system. This system must able to overcome the shortcomings in current ETCS (European Train Control System) and CBTC (Communications-Based Train Control). The system will provide an adaptable communications system (ACS) usable for train control applications in all market segments (mainline, regional, urban, freight), using packet switching/IP technologies in accordance with the specifications of the FRMCS (Future Railway Mobile Communication System) project (FRMCS (2019)). The system will enable an easy migration from existing systems (GSM-R). It will provide enhanced throughput, safety and security functionalities to support the current and future needs of signaling systems. This ACS will offer resilience to interferences and to radio technology evolution (Allen (2018)). The aim of this system is to support the shift from "network as an asset" to "network as a service" model vision. Backward compatibility with ETCS will be ensured as well.

The development of this new ACS is ongoing within the workpackage (WP) 3 of the X2RAIL-3 project (Geier (2019)). The outputs will consist of the development of three radio prototypes according to different markets (mainline, regional, urban) that should be tested and validated in various and representative railway scenarios. These tests aim to verify the functionality and capabilities of the ACS with multiple radio access technologies (RAT) and to reproduce the railway environment including radio link perturbations, overload scenarios and other events that affect the communication bearer and ultimately the applications. In this context, to avoid the complex and expensive installation and operation of various and complete real radio access equipment in the development laboratories, the Shift2rail project Emulradio4Rail (EMULation of RADIO access technologies for RAILway) will provide original testing and evaluation platforms. The platforms will rely on radio access and network behavior emulation at IP level, which can act as a flexible, configurable and programmable laboratory tool to support both the end-to-end validation and verification activities.

The technique of emulation is a hybrid experimentation technique intended to bridge the gap between simulation and real-world testing. Emulation inherits reproducibility and control from simulation but makes possible to include real components under test in the experiments, thus improving the realism of the observed results. The key idea of emulation is to reproduce in a controlled manner the essential functionality of a system, even allowing it to interact with other real systems maybe already deployed on the field. This is the reason why the present project addresses emulation, both at IP and Radio Frequency level, as the key technologies of the innovative platform for both tests and validation.

3. Emulradio4Rail platform architecture

Wi-Fi, LTE, and Satellite communications are the RAT considered. The platforms will combine very new approaches for testing so called system in-the-loop (SITL) and hardware-in-the-loop (HITL). The prototypes developed within X2RAIL3 WP3 will constitute the devices under test (DUT). The novelty proposed in the Emulradio4Rail project is to consider the integration of channel emulators and network emulators into a single emulation platform so that the testbed can offer a complete (from physical layer to IP level) test environment for Shift2Rail customers. Railway radio channels and interference models will be implemented in the channel emulators. To make the bridge between IP and RF levels, the project explore the capabilities of the junction between RIVERBED Modeler (discrete event simulator) (Riverbed (2019)) and Open Air Interface (OAI) (OAI (2019)). The complete emulation architecture will allow testing the IP level communication devices against a very realistic emulation platform in which radio bearers, RF channels and backhaul/PLMN networks will be emulated in real time

The IP packets generated by the DUT are converted to RF packets by real radio bearers, either commercial or implemented with OAI. The RF signal produced by the radio bearers is introduced in the channel emulator, which applies to it the same effects (delay, fading…) that a real channel would do. RF interferences are also added to this RF signal. Another radio bearer recovers the IP packets from the received RF signal. Some of these packets will be lost or delayed, due to the effects generated by the channel emulator. The recovered IP packets are introduced into the backhaul/PLMN network emulation in which other impairments at IP level, generated as a result of the emulation of other network users and network traffic, are introduced. Fig. 1 shows the block diagram of this architecture.

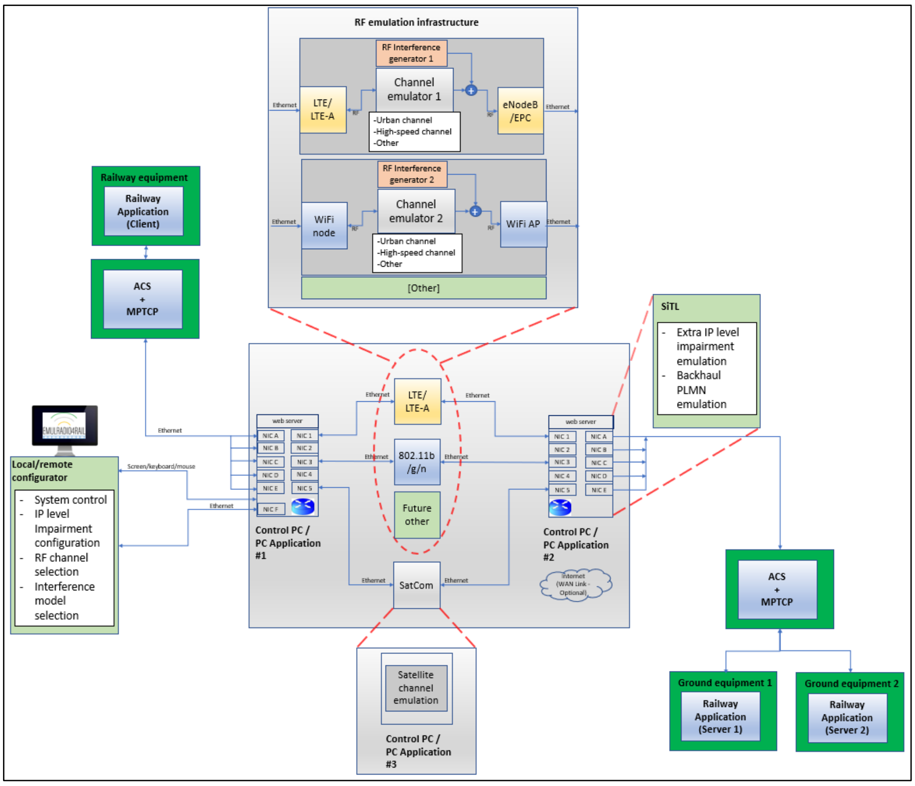

Fig. 1 General high level architecture of the EMULRADIO4RAIL platform

The Emulradio4Rail project will offer three testing approaches. One approach will allow connecting directly the ACS prototypes at RF level when considering Wi-Fi and LTE radio access technology. The ACS prototypes will be coupled at RF level to emulators of both the communication core network and the different radio access technologies thanks to the coupling among discrete event simulator such as RIVERBED modeler, Open Air

Interface (OAI), various radio channel emulators. The second approach is developed for satellite communications. The ACS prototypes will be connected at IP level. Finally, the third approach is based on the use of IP impairments models obtained by operating the platform with the first approach. Considering classical network emulator at the input of the different RAT, the Emulradio4Rail platforms will be operated to develop IP impairments models related to specific railway radio channel models and interference models. These models will be used with the ACS prototypes directly at IP level for easy laboratory tests. If the railway channel models and the perturbation models are good enough, the IP impairment models could be considered as reference models for the prototyping of future ACS.

The Backhaul/PLMN emulation platform module showed in Fig. 1 is implemented with Riverbed modeler. The backhaul network in the Riverbed modeler simulation environment contains two SITL (System In The Loop) interfaces for converting between the real traffic packet format and simulated packet format and two Ethernet switches for routing the traffic to the destination. A network consisting of 8 switches is simulated in the Riverbed Modeler. Two SITL gateways are connected as the real-sim/real-sim interfaces to the application service host. Different network topologies can be implemented (ring, star, etc.). In the simulation environment, the link performance parameters (*e.g.* link delay, loss, *etc.*) can be injected and tested. Different traffic types can be introduced into the scenario. The Quality of Service (QoS) function will be implemented in the multi-layer topology by using for example MPLS (Multiprotocol Label Switching) technology or others.

Four parts are included in the LTE emulation platform as shown in Fig. 2. The UE (User Equipment) part is a laptop with an LTE dongle. The eNodeB function is implemented in a PC with a software defined radio board, which provide radio access with the LTE dongle in UE. LTE EPC (Evolved Packet Core) is installed in a separate PC and acts as core network functions (*e.g.* MME, HSS, SGW and PGW). Communication links are established from the UE to the application server through a backhaul network. The complex backhaul network scenarios are achieved using a discrete-event network simulator. The combination of hardware emulation and software simulation is realized by using the SITL package in the Riverbed Modeler. IP packets are captured and transformed between real and simulated environments. The end-to-end communication has been achieved and tested as illustrated in Fig. 2. The ongoing project process is now to connect the OAI platform with the channel emulators (see Fig. 1) in order to obtain further investigation on the wireless link features (results are expected to be ready before April 2020). Different radio channel models and perturbation models will be implemented.

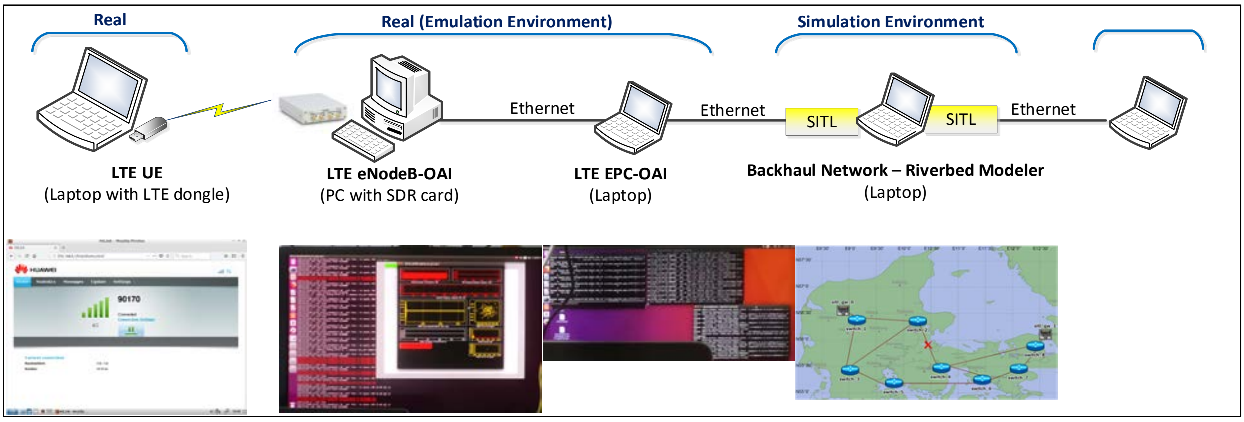

Fig. 2 OAI platform and screen shots showing UE and eNodeB interaction

4. Railway radio channel models

We consider several railway scenarios: urban, high speed, rural and regional. Each scenario is related to the type of trains, the speed and mainly the type of geographical environment. The geographical environments have a strong impact on the radio channel. The project investigate different railway communication scenarios covering degraded modes, outages, network overload scenarios, interferences and other perturbations. To emulate these scenarios, we choose various radio channel models available in the literature. They will be implemented in the radio channel emulators (see Fig. 1) (Diez (2018)). In addition, a RF interference generator allows to inject various type of interferences: perturbations coming from other wireless networks, perturbations coming from bad contact between the pantograph and the catenary (Hassan (2014)) and finally, intentional interferences created by jammers (Deniau (2017)).

An exhaustive survey of the state-of-the-art of radio channel models in railways has been done in the project. The outcome is that there are many different channel models in the literature but not all of them seem to be suitable or, more precisely, to provide a complete description of the channel for emulation purposes (i.e. many of them focus only on path-loss characterization only while some others lack substantial parameters like Doppler spectrum). Another important point is the fact that the channel emulators considered in the project are configured to have tapped-delay line (TDL) channel models only, this is, the channels shall be TDL-based (Salous (2013)). Moreover, there is a limitation in the number of taps that the emulators are able to handle. Therefore, a set of channel models has been chosen, with the most complete description possible in terms of: Number of taps, Delay associated to each tap, Power associated to each tap (relative to the 1rst one), Speed range of the vehicle, Doppler spectrum (*i.e.* distribution of the frequency shift in the Doppler domain), Frequency range, Bandwidth considered, Diversity (i.e. SISO, MIMO, *etc.*).

The literature mainly covers high-speed line scenarios, but not tunnels. We have selected: one model for hilly terrain, one model for rural area, one model for viaduct and a model for cutting. No model for tunnel scenario. The election of the models has been done based on the completeness of the information provided in the model, as well as the convenience for our purposes, in terms of both frequency bands and speed ranges. This is because we want to emulate both IEEE 802.11 and LTE so we need to carefully choose models that cover the bands where these two technologies work. The number of taps is also an influential parameter because our emulators are limited here to a certain number of taps. Given that both 3GPP LTE and IEEE 802.11 technologies use diversity, it is appreciated, but it is not a key aspect when we choose a channel model.

5. Perturbation models in the railway domains

Different types of perturbations can affect wireless communications and particularly in the Railway context. An example is a perturbation created by public communications in the E-GSM band on GSM-R communications in some places when the network is too close (UIC (2014)). The main sources of perturbations are:

- Electromagnetic (EM) environment: perturbations produced by non-communicating elements (e.g., supply substations, lightening, elevators, and escalators). They do not affect the communications significantly due to separation in frequency and also can be avoided if distances to the station's railway electromagnetic zone are respected enough.
- Network interference: perturbations produced by other communicating equipment. It can be intra-networks like signals from other cells in cellular networks or a Wi-Fi network. It can be between different networks (Wi-Fi, Bluetooth, Zigbee) in ISM bands. Network Interference is an important issue, both for cellular networks where adjacent cells can create interference, especially if a reuse factor of one is used. This is also a significant issue in Wi-Fi. The number of connected devices increases in train and station, and interference is a limiting factor, especially if some critical communications are planned in such bands.
- Natural EMI sources: from other sources like arcing produced by the sliding contact between the pantograph and the catenary or by the third rail. One source that definitely impacts the reliability of the communications is arcing produced by the sliding contact between the pantograph and the catenary or by the third rail. This gives rise to large pulses, short in time.
- Illegal jamming: the existence of telecommunication jammers is widely noticed, and it constitutes a risk for a large number of civilian communication services. Jamming tools that can be bought are frequency sweeping based solutions. They allow covering a rather wide bandwidth with a limited cost and can be very perturbing even with reduced transmission power. They will be included because they can be an important threat to communications.

The perturbations can be introduced at the channel emulator input or the receiver. We have identified three main scenarios:

Scenario Type I: Single Interfering Radio Signal. The interferer is emulated. We generate a true interfering signal either from a communications standard (e.g., Wi-Fi, LTE) or emulating a jammer (sweeping frequency – the exact parameters of this signal have to be defined).

Scenario Type I-m: Multiple Interfering Radio Signal. The interfering signal is modeled with a statistical model.

Different models, such as simple Gaussian mixtures (for instance, epsilon-contaminated), can be used. A Markov model can be considered to simulate the time dependence. This can arise in Wi-Fi or cellular networks where multiple interferers can affect communication. It is not reasonable to emulate each of these interferers. We propose to inject a model of this interference at the receiver side, preferably in the baseband. More sophisticated models like Middleton or alpha-stable and copulas for the dependence structure can also be considered.

Scenario Type II: Pantograph-catenary EM transients. In literature, many studies and measurements were carried out (Dudoyer (2012)), (Slimen (2009)), (Technical (2011)). EM transients coming from the pantograph-catenary slip can be fully modeled as a heavy-tailed impulsive noise. Authors in (Hassan (2014)) concluded that a symmetric alpha-stable distribution gives a perfect fit for the impulsive noise in such an environment, and the model is then used in later works (Kharbech (2018)). Thus, in baseband, the disturbing signal is generated as a symmetric alpha-stable process, or, a damped sine (with random amplitudes and inter-arrival rate) if it will be added to the RF signal at the receiver. In this scenario, a statistical model of the signal will be provided in order to describe the main characteristics of the damped sine, such as the statistical distribution of maximum amplitude, decay speed, and inter-arrival rate.

6. Channel emulators

Channel emulators are electronic devices capable of emulating, with a good level of accuracy, the physical effects in a radio-electric environment, which influence the behavior of wireless signals. It is able to reproduce the fading environments as defined for example in 3GPP (3GPP) considering various radio channel models. According to the field of operation, they can be distinguished between channel emulators, which work in the time domain and channel emulators, which work in the frequency domain. The first ((Val (2014), (Olmos (1999)) are based on the use of Finite Impulse Response (FIR) filters over the complex base-band signal to emulate the channel using a tapped delay line model (Proakis (2008)). On the contrary, the second makes intensive use of the Fast Fourier Transform (FFT) and the Inverse Fast Fourier Transform (IFFT) (Eslami (2007)).

According to antenna technologies, which emulators can support, they can be distinguished between SISO channel emulators (Val, 2014), (Olm1999) and MIMO (Esl, 2007), (Zhan, 2014). We can also mention very recent channel emulator that implements geometric based channel model (Hof, 2019). Academic/research emulators are based on reconfigurable hardware, typically FPGAs. Among commercial emulators, we can mention VERTEX from Spirent (Spirent, 2019), PROPSIM from Keysight/Anite (Keysight, 2019) and Elektrobit (Elektrobit, 2019). Channel emulators based on Software Defined Radio (SDR) boards are also common nowadays. An example is given in (Hof, 2019), (Vlas, 2015).

In the Emulradio4rail project, we consider channel emulators available in the partner laboratory. One channel emulator is a “home-made” one based on FPGA (Val, 2014) at IKERLAN. The other one is PXB N5106A from Keysight Technologies at University of Lille. We will focus on the later. The testbed is composed of a baseband (BB) generator and the channel emulator PXB N5106A. The main features of the PXB are the followings:

- Input and output bandwidth up to 160 MHz (80 MHz I + 80 MHz Q).
- Many predefined channel models (GSM, 802.16, WLAN, etc.), including LTE communications for high-speed trains (vehicle speed up to 864 kmph).
- Supports MIMO systems (up to 4x4) and considers antenna correlation.
- Adds additive white Gaussian noise.
- Many fading types (Rician, Rayleigh, etc.) and Doppler spectra (flat, Jakes, *etc.*).
- Up to 24 taps per fader.

As it is a BB emulator (Fig. 3), and to be able to work with RF signals, the PXB requires an RF modulator, i.e., a downconverter (e.g. PXA) at its input and an RF demodulator, i.e., an upconverter (*e.g.*, PSG, ESG, MXG) at its output. Fig. 3 and Fig. 4 give a view of the set up in laboratory.

Preliminary test is conducted on an end-to-end Wi-Fi communication while considering an 18-taps Rayleigh fading channel for different speeds, with a maximum delay of 1.76 ms. To model the channel time-variation, we make use of the well-known Jakes's Doppler spectrum. The emulated channel is that of the downlink. Iperf traffic is used to measure the bandwidth of communication. As shown in Fig. 5, the measured bandwidth for both TCP and UDP protocols becomes lower as the channel time variation (*i.e.*, the vehicular speed) increases.

Several tests are ongoing to evaluate the effect of different radio channels and perturbations on KPI such as throughputs, bandwidth, packet error rate, *etc*. Similar tests are planned when the channel emulator will be connected to the OAI platform described in section 4. The aim of the test is to obtain the IP impairments models as explained in section 3.

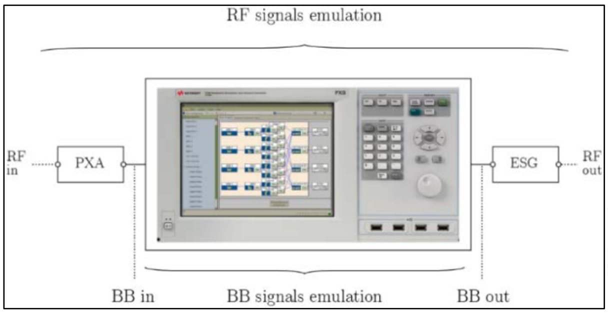

Fig. 3 Channel emulator in BB and RF mode.

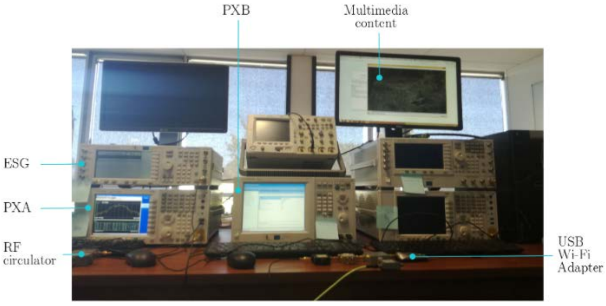

Fig. 4 Set up in the lab with PXB channel emulator

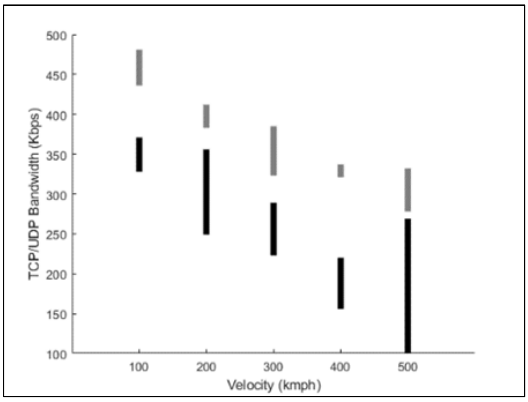

Fig. 5 TCP (black bars) and UDP (gray bars) bandwidths variation in terms of the vehicular speed

7. Satellite Link emulation

A special case has to be distinguished with regard to the satellite link emulation as RF emulation of this link will not be addressed in this project due to its complexity. However, Satellite Real Network Traffic can be represented through Satellite Network Emulator, allowing the end user to emulate application user experience on a satellite network. Satellite Network Emulation gives the opportunity to replicate different conditions of user experiences. Main applications are delivered to the end user over a specific network (as in the case of satellite) both in normal both in extreme conditions. The application test needs a real network in order to replicate the same real conditions. It brings several problems related to a typical real satellite network, because:

- It cannot be realistic due to the unavailability to put in the real traffic load.
- It is difficult to managed, especially in case of specific condition (e.g. bad weather).
- It is not possible to mimic the load or atmospheric conditions in a real satellite network in order to replicate the test.
- It is very expensive to replicate for testing activities.

The satellite network emulation proposed for in the Emulradio4Rail project will able to reproduce the satellite conditions without satellites, terminals or satellite simulator, and to emulate a real satellite network and measure the behavior in terms of QoS application key performance indicators (KPI) measured in all IP-based networks, as: latency, jitter, packet loss and bandwidth.

Settings will be adjustable by the end user for different satellite services (*e.g.* Inmarsat), as well as different satellite orbits (*e.g.* GEO, MEO and LEO) and control of different transmission/reception conditions at IP level. The solution for the satellite platform is illustrated on Fig. 6.

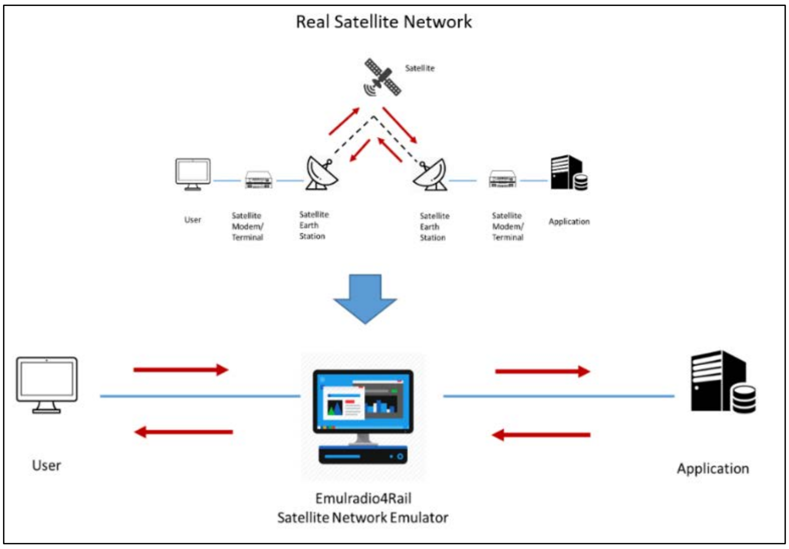

Fig. 6 Solution for the Satellite Network Emulation

The satellite emulator operates at IP elevel. The DUT acts as a client, injects IP packets at its input. The emulator applies to the input IP flow the envisaged impairments. In particular the emulator can account for the typical impairments of satellite links as seen at IP level. The most important KPI end-to-end delay and its variability, the Packet Loss, Jitter and Physical Link Bitrate (bandwidth). The impaired IP flow at the output of the satellite emulator is then delivered to the server running the railway applications (Sun (2003)). The main feautures of the satellite emulator are related to the possibility to add delay, packet loss, duplication and more other characteristics to packets outgoing from a selected network interface. This can be achivied through existing QOS and Differentiated Services (diffserv) facilities in the Linux kernel (Matasaru (2017)). In particular the main parameters managed by the Emulradio platform for the satellite link are:

- Delay (ms): can be added to the packets outgoing to a speficic network interface. The delay variation and correlation can be also set. Delay and jitter values are expressed in ms while correlation is percentage
- Distribution: allow the user to choose a specific delay distribution based on models known in literature (normal, Poisson, etc..)
- Packet Loss: adds an independent loss probability to the packets outgoing from the specific network interface
- Loss State: adds packet losses according to the 4-state Markov using the transition probabilities as input parameters
- Loss model: adds packet losses according to the Gilbert-Elliot loss model or its special cases (Gilbert, Simple Gilbert and Bernoulli)
- Packet tagging
- Packet Corruption: random noise can be emulated introducing an error in a random position for a chosen percent of packets
- Packet Duplication before queuing
- Packet reordering
- Rate: delay packets based on packet size and is a replacement for Token Bucket Filter (TBF). Rate can be specified in common units (*e.g.* 100 kbit). Optional Packet overhead (in bytes) specify an per packet overhead and can be.

In order to verify the functionality of the satellite component of the Emulradio4Rail platform, a first set of preliminary test has been performed. The overall satellite platform is running inside Vmware workstation and Ubuntu virtual machine have been installed on a windows10-based PC. Three different tests were performed

(PING command):

Test 1: The aim of test 1 is to verify the connectivity across the entire satellite transmission chain when fixed values of end-to-end delay and no packet loss value are considered. It is essentially composed by the following paths: Satellite trasmitter terminal-satellite gateway and Satellite gateway- Satellite receiver terminal. For each satellite path, both of transmission directions are considered: upstream and downstream. A typical Wide Area Network (WAN) connection is also modelled in order to consider a the situation where a satellite receiver terminal is connected to the earth station through an Internet connection. In the case of Test 1, the satellite link setup is characterized by the following values of delay and packet loss:

- Delays: 125 ms (upstream), 125 ms (downstream), 60 ms (Internet), no variation.
- Packet loss = 0%

The results obtained are:

- Received 20/20 ping attempts (PL=0%)
- Average delay: 621.5ms

When no Packet Loss is considered across the entire satellite transmission chain, the test result gives a successful reception of all ping command attempts (20 received over 20 sent). The average delay across the entire tranmission chain is also compliant with the test setting. Infact, it is equal to 621.5 ms. Considering the two-way connections (upstream and downstream), the end-to-end delay setting is 620 ms.

Test 2: The aim of test 2 is to verify the connectivity across the entire satellite transmission chain when fixed values of end-to-end delay are only considered fo the upstream and downstream sections. For the WAN Internet section an uniform distribution between 50 ms and 70 m. No Packet Loss is considered. The satellite link setup is characterized by the following values of delay and packet loss:

- Delays: 125 ms (upstream), 125 ms (downstream), Uniform variation in [50ms, 70ms] (Internet)
- Packet loss = 0%

The results obtained are:

- Received 60/60 ping attempts (PL=0%)
- Average delay: 623.4ms, Min/Max delay: 605.6/638.7ms

When no Packet Loss is considered across the entire satellite transmission chain, the test result gives a successful reception of all ping command attempts (60 received over 60 sent). The average delay across the entire transmission chain is also compliant with the test setting. In fact, it is equal to 623.4 ms. The minimal and maximal values are 605.6 ms and 638.7 ms. Considering the two-way connections (upstream and downstream), the initial end-to-end delay setting is 620 ms.

Test 3: The satellite link setup is characterized by the following values of delay and packet loss:

- Delays: 125 ms (upstream), 125 ms (downstream), 60 ms (Internet), no variation
- Packet loss = 10%

The results obtained are:

- Received 90/100 ping attempts (PL=10%)
- Average delay: 623.3ms

8. Conclusion

The Emulradio4Rail project intends to develop an innovative platform for tests and validation of various radio access technologies (Wi-Fi, LTE, LTE-A and Satellite). The proposed platform aims to couple channel emulators and network emulators into a single emulation platform so that a very realistic, testing platform from physical layer to IP level can be offered. The platform couples channel emulators, OAI, Riverbed modeler, and SITL module from Riverbed to convert real IP traffic into simulated ones. GSM-R is excluded from the emulation platform after preliminary discussions with X2RAIL-3 WP3 partners because GSM-R is not included in the ACS in development. Besides, due to non-maturity of 5G features today, 5G has also been excluded, although the methodology developed for LTE using OAI will be transposable to OAI 5G NR as well as OAI 5G Core, with basic software updates, when available.

We have presented in this paper the modular architecture that has been defined and the different configuration options. We have detailed the different bricks of the platform: radiochannel models, OAI platform, channel emulator. The platforms are in development and will be ready for the end of 2019 for integration. The prototypes developed within X2RAIl-3 WP3 project will be connected to the platform and tested, considering the selected set of Railway radio channel models and perturbation models representative of Railway environment.

Finally, due to the IP level nature of the emulation platform (at least in its full-architecture configuration) the possibility of remotely using and controlling the platform is foreseen. This would also enable the possibility of having a geographically distributed platform in which each of the sub-platforms (LTE emulation platform, Wi-Fi emulation platform, *etc*.) could be placed in a different country.

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References

Assessment report on GSM-R current and future radio environment, REFERENCE O-8736-2.0, 2014, UIC, 2014

Allen, B. et al., «Defining an Adaptable Communications System for all railways», 7th Transport Research Arena TRA 2018 (TRA 2018) (TRA2018), Vienna, 16-19 April 2018, DOI 10.5281/zenodo.1456472

Ben Slimen, N., Deniau, V., Rioult, J., Dudoyer, S. and Baranowski, S., “Statistical characterisation of the EM interferences acting on GSM-R antennas fixed above moving trains,” Eur. Phys. J. Appl. Phys., vol. 48, no. 2, Nov. 2009, Art. no. 21202.

Dudoyer, S. et al., “Study of the susceptibility of the GSM-R communications face to the electromagnetic interferences of the rail environment,” IEEE Trans. Electromagn. Compat., vol. 54, no. 3, pp. 667–676, Jun. 2012.

Eslami, H. and Eltawil, A. M. , "A Scalable Wireless Channel Emulator for Broadband MIMO Systems," in 2007 IEEE International Conference on Communications, 2007, pp. 2592-2597.

Elektrobit. (April 2019). Available: https://www.elektrobit.com/

FRMCS user requirements specifications, V4.0.0, FU-1700, Janvier 2019 – available at : https://uic.org/IMG/pdf/frmcs_user_requirements_specification_version_4.0.0.pdf

Geier, U., Mikulandra, M., Kernstock, K., Allen, B., “Adaptable Communication System for all Railways”, in proceedings WCRR2019, Tokyo 28-31/10/19

Hassan, K., Gautier, R., Dayoub, I., Berbineau, M. and Radoi, E., "Multiple-Antenna-Based Blind Spectrum Sensing in the Presence of Impulsive Noise," in IEEE Transac-tions on Vehicular Technology, vol. 63, no. 5, pp. 2248-2257, Jun 2014. doi: 10.1109/TVT.2013.2290839

Hofer, M., Xu, Z., Vlastaras, D., Schrenk, B., Löschenbrand, D., Tufvesson, F. et al., "Real-Time Geometry-Based Wireless Channel Emulation," IEEE Transactions on Vehicular Technology, vol. 68, pp. 1631-1645, 2019.

Keysight. (April 2019). Nemo Wireless Network Solutions. Available: https://www.keysight.com/en/pc-2767981/nemo-wireless-network-solutions?nid=-32104.0.00

Kharbech, S., Dayoub, I., Zwingelstein-Colin, M. and Simon, E.P., "Blind digital modulation identification for MIMO systems in railway environments with high-speed channels and impulsive noise," in IEEE Transactions on Vehicular Technology, vol. 67, no. 8, pp. 7370-7379, Aug. 2018.

Matasaru, P., Scripcariu, L. and Diaconu, F., "An up-to-date overview on QoS for Satellite IP networks," 2017 International Symposium on Signals, Circuits and Systems (ISSCS), Iasi, 2017, pp. 1-4. doi: 10.1109/ISSCS.2017.8034905

Olmos, J. J., Gelonch, A., Casadevall, F. J. and Femenias, G., "Design and implementation of a wide-band real-time mobile channel emulator," IEEE Transactions on Vehicular Technology, vol. 48, pp. 746-764, 1999.

OpenAirInterface. 5G software alliance for democratizing wireless innovation. Available: https://www.openairinterface.org

Proakis, J.G. and Salehi, M., Digital Communications: McGraw-Hill, 2008.

Railway noise measurement and reporting methodology, Can. Transp. Agency, Minister of Public Works and Government Services Canada, Tech. Rep. TT4-20/2011E-PDF, Aug. 2011.

Riverbed. (April 2019). RIVERBED MODELER. Available: https://www.riverbed.com/dk/products/steelcentral/steelcentral-riverbed-modeler.htmlOpenAirInterface - https://www.openairinterface.org/

Shift2rail MAAP, 2015, available at: https://shift2rail.org/wp-content/uploads/2013/07/S2R-JU-GB_Decision-N-15-2015-MAAP.pdf

Salous, Sana, Radio Propagation Measurement and Channel Modelling, 2013 John Wiley & Sons, Ltd, ISBN:9780470751848 |Online ISBN:9781118502280 |DOI:10.1002/9781118502280

Sun, Z. and Chai, WK., “Satellite emulator for IP networking based on LINUX”, 21st International Communications Satellite Systems Conference and Exhibit, 2003

Spirent. (April 2019). Available: https://www.spirent.com/

Val, I., Casado, F., Rodriguez, P. M. and Arriola, A., "FPGA-based wideband channel emulator for evaluation of Wireless Sensor Networks in industrial environments," in Proceedings of the 2014 IEEE Emerging Technology and Factory Automation (ETFA), 2014, pp. 1-7.

Vlastaras, D., Malkowsky, S. and Tufvesson, F., "Stress test of vehicular communication transceivers using software defined radio," in 2015 IEEE 81st Vehicular Technology Conference (VTC Spring), pp. 1-4.

Zhang, N., Yang, G., Zhai, J. and Hong, W., "Design and implementation of flexible 4Mx4N MIMO channel emulator," in 2014 IEEE Antennas and Propagation Society International Symposium (APSURSI), 2014, pp. 713-714.

3GPP TR 38.901 V14.2.0 (2017-09), 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on channel model for frequencies from 0.5 to 100 GHz (Release 14)