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Zero on site testing of railway wireless systems: the Emulradio4Rail platforms

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Abstract— The European Train Control System (ETCS) relies today on the 2nd generation cellular system GSM-R. GSM-R obsolescence has triggered the evolution of the current European Railway Traffic Management System (ERTMS) to the Future Railway Mobile Communication System (FRMCS), under development. FRMCS considers the use of several radio access technologies such as Wi-Fi, LTE, Satellite and 5G. Testing new communication systems along railway tracks is time and money consuming. Consequently, it is important to develop a zero-on-site-testing approach thanks to the development of emulation platforms. These platforms, combining hardware and software, are able to reproduce in laboratory real railway infrastructure behavior and scenarios. This paper presents the EMULRADIO4RAIL platforms, developed in the framework of Shift2Rail program and gives examples of results obtained.

Keywords—wireless communication, emulation platform, SDR, radio bearer, OAI, railway

I. 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 cycles of “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.

As a result, Shift2Rail JU multi-annual action plan [1] has given high priority to the development of a new Communication System (TD 2.1). This system must be able to overcome the shortcomings in current ERTMS and CBTC (Communications-Based Train Control). The aim is for an adaptable train-to-ground (T2G) communication system, usable for train control applications in all market segments (urban, regional, high speed, freight), using packet switching/IP technologies and being neutral to any access technology (5G, 4G, Wifi, Satellite, etc.). This is in accordance with the results of the past NGTC project (<http://www.ngtc.eu/>) and the first specifications of the FRMCS project (<https://uic.org/frmcs>) also called FRMCS-V1.

FRMCS will enable migration from existing systems (GSM-R) and provide enhanced throughput, safety and security functionalities to support the current and future needs

of signaling systems. FRMCS will also offer extra resilience to interferences and will be open to future radio technology evolution. The focus will be as well in supporting the shift from “network as an asset” to “network as a service” model vision. The development of a new adaptable communication system is ongoing within Shift2Rail program and prototypes are available [2]. These prototypes consider multiple radio access technologies (RAT) in parallel.

Testing new wireless technologies in real conditions along railway tracks is highly time consuming and very expensive. To solve this drawback, the EMULRADIO4RAIL (EMULation of RADIO access technologies for RAILway) project has developed an original testing and evaluation laboratory platform, configurable and programmable to support zero-on-site-testing of new wireless systems in representative Railway radio environments

II. EMULRADIO4RAIL PLATFORM DESCRIPTION

As illustrated on Fig. 1, EMULRADIO4RAIL platform combines very new approaches for testing, so called System in the loop (SITL) and Hardware in the loop (HITL), in order to be able to connect directly and to couple the real radio access equipment, the radio emulators (physical systems) and the simulators able to mimic the railway network and the radio channels behavior. The EMULRADIO4RAIL platform supports currently three emulation instances:

- Two LTE emulation platforms (one to emulate LTE private deployment and one for LTE public deployment). Both platforms are built using the same software version.
- One Wi-Fi emulation platform that is connected to the RF (radio frequency) part of the radio technology.
- The satellite emulation platform operating only at IP level.

For LTE and Wi-Fi, we consider real bearers (commercial modems and Open Air Interface [3]). IP frames from an application are transmitted via RF (radio frequency) signals, which are fed through the channel emulator and then are converted again into IP frames after the radio access segment. The satellite emulation is IP native. It means that the satellite IP communication is emulated through Ethernet-based communications, without RF conversion and can run on

different Linux-based PCs or one single PC, adopting well-known virtualization techniques (e.g. Containers)

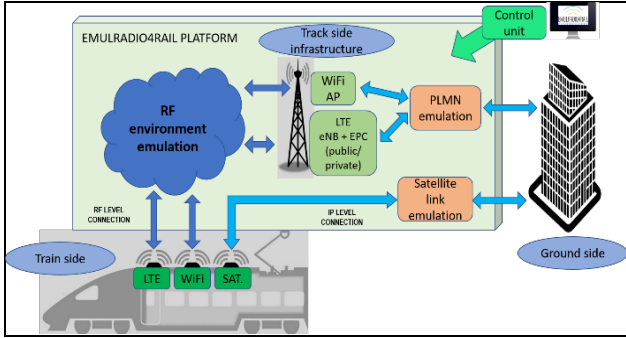


Fig. 1. Emulradio4Rail platform

The emulation of representative railway RF environments is performed thanks to channel emulators. Two types of radio channel emulators are available in the project: an FPGA-based emulator built specifically by IKERLAN [4] and a Prosim F32 channel emulator from Keysight [5]. Various representative railway channel models have been identified during the project duration for different environments, mainly in high speed lines with cutting, rural and hilly terrain. Thanks to their simplicity, well known Tapped Delay Line (TDL) models were considered for the proof of concept of the Emulradio4Rail project [6][7]. In addition, due to the absence of a valid channel model related to railway tunnels, a TDL model in tunnel (for both high speed and metro) has been also developed specifically [8]. At the same time, in order to take into account the characteristics of railway environments in a realistic way, different types of perturbations have been identified and also injected at RF level in the platforms [9]. The three main types of interferences are: network interferences, unintentional jamming and illegal jamming are considered in the tests.

As shown in Fig. 1., the two LTE platforms and the Wi-Fi platform are controlled by a control PC with a Graphical User Interface (control unit). This is also illustrated in Fig. 2. The control principle can be extended to the satellite emulation if needed, when the prototypes consider in parallel Wi-Fi, LTE and satellite bearers.

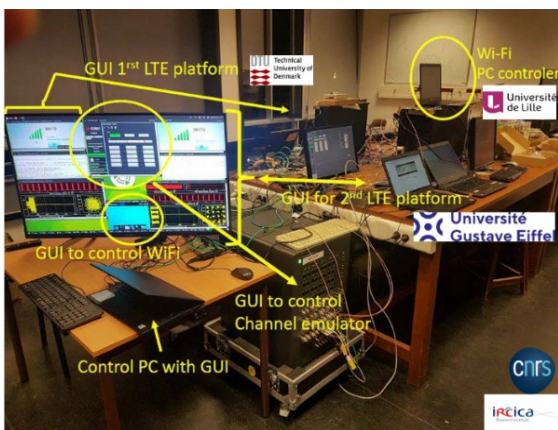


Fig. 2. Wi-Fi and two OAI platforms control with a unique PC and GUI for the final integration

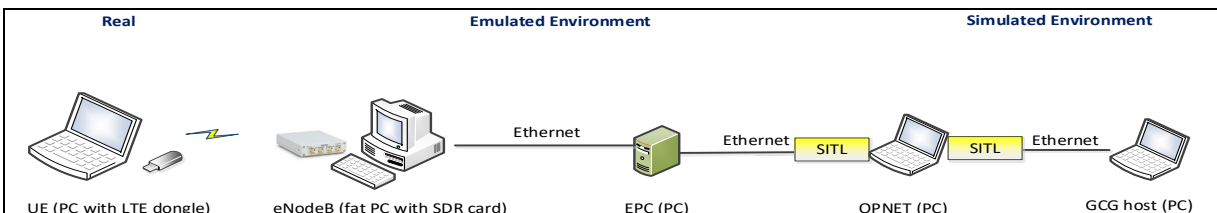


Fig. 4. Schematic view of one LTE-OAI platform

A. Wi-Fi emulation platform

The Wi-Fi emulation platform is made of commercial Wi-Fi nodes and a RF channel emulator. Frames at IP level enter the platform through the Wi-Fi node, which converts them into RF Wi-Fi frames. These frames are fed to the radio channel emulator, which modifies them according to the channel model programmed in it. The output Wi-Fi frames from the channel emulator are fed into a Wi-Fi AP that converts them back to IP frames. This platform also includes the possibility of injecting an interfering signal through a jammer. Fig. 2. shows the Wi-Fi emulation platform implemented with IKERLAN’s RF channel emulator.

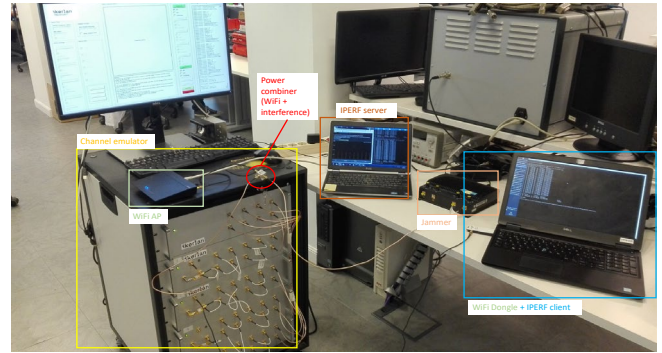


Fig. 3. Wi-Fi emulation platform with the IKERLAN RF channel emulator

B. LTE emulation platform

The LTE emulation platform is setup to validate the communication with an LTE terminal, through an end to end communication path formed by an OAI emulation (LTE eNodeB + LTE Evolved Packet Core) and a Riverbed Modeler (OPNET PC) simulation of the backhaul network as illustrated on Fig. 4. The SITL (System In the Loop) licenses from Riverbed allows to inject IP packets from ongoing real transmissions into a simulation. A USB dongle, Huawei 8372-h-153 [10] is used for the RF part of the LTE UE (User Equipment). An SDR (Software-Defined Radio) board B210 from Ettus or USRP 2901 from NI [11] acts as eNodeB. The platform is configured to operate as a Release 8 3GPP LTE eNodeB in Band 7 (2.66 GHz for the DL and Uplink (UL) at 2.54 GHz) and using Transmission Mode 1 in SISO (Single Input Single Output).

As part of the LTE emulation platform, an original backhaul/PLMN (Public Land Mobile Network) emulation module is implemented in the “OPNET PC” (see Fig. 4.) and running *Riverbed modeler* tool to mimic various PLMN load configurations. This mimics a load at network level in the network connecting the LTE subsystem to the receiver in ground.

The platform installed in the testing laboratory is shown on Fig. 5.

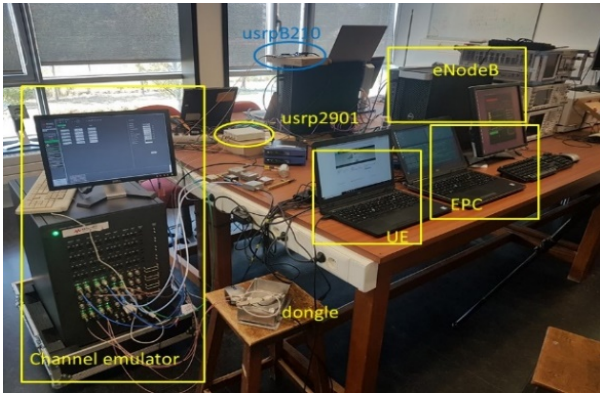


Fig. 5. LTE platform view deploy at IRCICA – The second LTE platform also connected to the channel emulator is seen on the back of the photography.

C. Satellite emulation platform

The considered satellite emulator operates at IP level. This means the Device Under Test (DUT) acting as a client, injects IP packets at its input [12][13][14]. The emulator applies to the IP input 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 metrics considered are end-to-end delay (E2E delay) and its variability, the Packet Loss Rate (PLR), jitter and physical link bitrate (bandwidth or throughput). The impaired IP flow at the output of the satellite emulator is then delivered to the server running the railway applications. The main features 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 achieved through existing Quality of Service (QoS) and Differentiated Services (diffserv) facilities in the Linux kernel.

The considered satellite link transmission is shown in Fig.6. From a client point of view, the user terminal is connected to the satellite earth station through a satellite modem. The same scheme is adopted on the server side. The IP packets are sent from the client to server (and vice versa) in end-to-end way. The IP emulated Satellite link transmission through the satellite platform is shown in Fig. 7. The platform implements the interfaces on which IP packets are sent in end-to-end way. The platform is shown on Fig. 8.

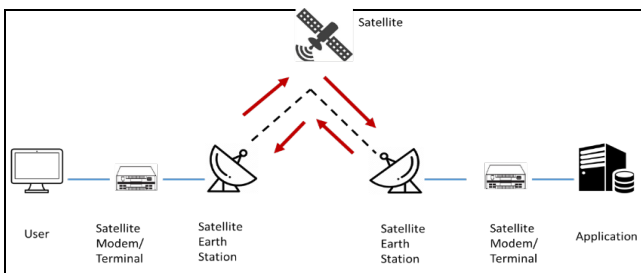


Fig. 6. Considered satellite link transmission

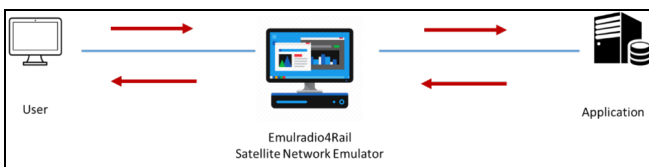


Fig. 7. IP emulated Satellite link transmission

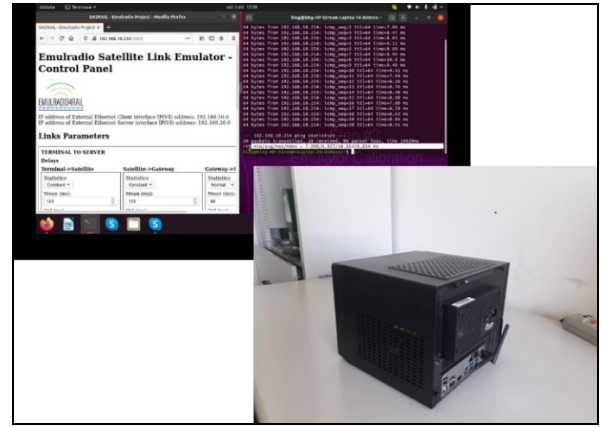


Fig. 8. Satellite emulator and Linux interface

III. RESULTS

A. Tests methodology

Two different approaches have been considered in the use of the emulation platform:

- Real-time use of the emulation platform: The platform is connected to the real radio bearers on-train and to the ground equipment and it emulates in real time the statistical radio behavior in different railway environments
- “Offline” use of the emulation platform as IP impairment model generator: Controlled IP traffic is injected into the platform and statistical characterization of the IP metrics for different railways environments is carried out. The obtained IP impairment models can be later used in an IP level channel emulator

This section will present some of the results obtained when injecting controlled IP traffic into the different platforms and for different channel models. The chosen metrics are the followings: TCP/UDP throughputs in UL and DL, Packet error rate (PER), Jitter, E2E delay.

Fig. 9. shows the workflow adopted by the Emulradio4rail platform to emulate LTE, Wi-Fi and satellite IP bearers. The possibility to insert several IP impairments directly is also provided by the emulation platform. The iperf tool [15] has been used to inject IP traffic into the emulation platform and to measure the obtained metrics. This tool is able to generate both UDP and TCP traffic.

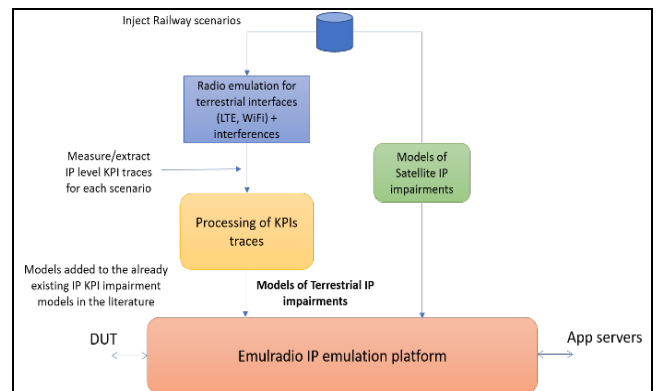


Fig. 9. Test methodology

B. Wi-Fi results

Table I presents the results obtained through the WiFi emulation platform. IP traffic has been injected into the platform and throughput, jitter and PER have been measured for different environments: ideal environment with a flat channel, 5 tap cutting channel environment [16] and 5 tap cutting channel environment with a jamming interference. The maximal delay in the 5 taps cutting channel is equal to 1180 ns with a relative power of -12.83 dB from the first tap.

TABLE I. RESULTS WITH WI-FI IN SEVERAL ENVIRONMENTS

WiFi results				
Test1 – Ideal channel	Max.	Min.	Average	Std Deviation
UDP throughput (Mbps)	35.6	26.5	32.5	1.87
TCP throughput (Mbps)	30.1	20.9	27.6	1.28
UDP PER (%)	0	0	0	0
UDP jitter (ms)	4.7	2.7	3.4	0.35
Test2 – cutting channel	Max.	Min.	Average	Std Deviation
UDP throughput (Mbps)	24.7	12.4	19	2.6
TCP throughput (Mbps)	18.6	15.6	16.7	0.65
UDP PER (%)	0	0	0	0
UDP jitter (ms)	7.3	3.8	4.7	0.52
Test3 – cutting channel + jammer	Max.	Min.	Average	Std Deviation
UDP throughput (Mbps)	23	5.7	11.1	2.9
TCP throughput (Mbps)	17.6	5.2	8.9	2.3
UDP PER (%)	0	0	0	0
UDP jitter (ms)	1379	4.1	86	179.9

As can be observed, each of the tests offer different behavior of the measured metrics. As expected, the metrics get worse as the radio environment gets worse. These results can also be obtained versus time, as shown in Fig. 10. for the TCP throughput in test 3 in which the jammer is enabled in the window between 100 and 500 seconds.

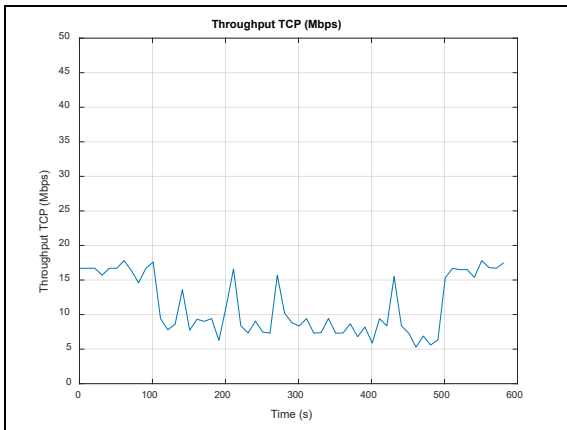


Fig.10. TCP throughput vs. time in Wi-Fi test3

C. LTE results

As for Wi-Fi tests described previously, several tests were performed with the LTE platform considering the different TDL channels in the channel emulator. The aim of this experimental assessment is to obtain statistical behavior of the different metrics versus speed and throughputs. Based on a large number of tests, statistical models of the different metrics that can be extracted at the end as IP impairment models. This IP impairment can be then injected directly at IP level of the railway prototypes instead of connecting them at RF level. This IP impairment model are an alternative for the Wi-Fi and LTE platforms.

Table II and Table III illustrate the results obtained at different train speed, respectively in DL and UL, when UDP traffic of 1 Mbits/s is sent with a 1450 Bytes packet length. A Rural channel model with 3 taps is implemented in the channel emulator. This model is extracted from [17] and the main parameters are presented in Table IV. The maximum delay is equal to 600 ns with a relative power of -22.2 dB from the first tap. The Doppler spectrum for each tap is the “classical” one. We can observe the different variations of the metrics at different speed. We remind here that the final goal is not to test LTE but to analyze the behavior of the railway applications in different railway environments, emulated by the channel models. The different experiments has proven the feasibility of zero on site testing in laboratory.

TABLE II. RESULTS IN DL WITH 1 MBITS/S WITH RURAL 3 TAPS ENVIRONMENT AND SEVERAL SPEEDS

Rural 3Taps					
UDP DOWNLINK IPERF traffic 1 Mbits/s	Speed (km/h)	Min	Max	Average	Std Deviation
Jitter (ms)	0	34.63	40.25	36.18	1.43
PER (%)		0	1.3	0.42	0.62
Throughput (Mbits/s)		0.905	0.905	0.905	0
Jitter (ms)	100	35.10	40.15	37.51	1.38
PER (%)		0	1.3	0.25	0.52
Throughput (Mbits/s)		0.905	0.905	0.905	0
Jitter (ms)	150	35.64	108.78	56.22	16.60
PER (%)		0	22	7.36	5.60
Throughput (Mbits/s)		0.905	0.905	0.905	0
Jitter (ms)	200	36.46	596.43	178.69	119.27
PER (%)		0	50	26.32	12.33
Throughput (Mbits/s)		0.905	0.905	0.905	0
Jitter (ms)	250	109.18	3165.37	654.93	634.37
PER (%)		22	87	49.40	14.84
Throughput (Mbits/s)		0.905	0.905	0.905	0

TABLE III. RESULTS IN UL WITH 1 MBITS/S WITH RURAL 3 TAPS ENVIRONMENT AND SEVERAL SPEEDS

Rural 3 taps					
UDP UPLINK IPERF traffic: 1 Mbits/s	Speed (km/h)	Min	Max	Average	Std Deviation
Jitter (ms)	0	33.24	5281.94	503.55	1040.64
PER (%)		0	98	17.05	27.20
Throughput (Mbits/s)		893	921	908.01	8.29
Jitter (ms)	100	434.72	4963.37	1613.50	1007.42
PER (%)		0	99	70.88	12.58
Throughput (Mbits/s)		894	920	906.63	7.94
Jitter (ms)	150	937.86	4093.95	2351.97	690.29
PER (%)		60	95	81.21	6.6
Throughput (Mbits/s)		893	920	907.55	7.91
Jitter (ms)	200	2161.03	4961.31	3754.64	637.23
PER (%)		80	99	91.23	4.14
Throughput (Mbits/s)		893	920	907	8.70
Jitter (ms)	250	3593.21	4961.79	4525.36	381.13
PER (%)		80	99	95.15	3.52
Throughput (Mbits/s)		894	920	907.92	8.42

TABLE IV. TDL RURAL CHANNEL MODEL IN HSL FROM ETSI [17]

Parameter	Value		
Center frequency	2.1 – 2.6 GHz		
Bandwidth	5 MHz		
Speed	240 km/h		
Antenna configuration	SISO		
Scenario	Tap	Delay (µs)	Relative power (dB)
Rural	1	0	0
	2	0.3	-12.9
	3	0.6	-22.9

D. Satellite results

In Fig. 11., we report the results obtained when an uniform distribution is considered for IP delay. In it we considered fixed delays for US and DS satellite links equal to 125 ms. For the terrestrial section we consider a variable delay randomly generated according to a Uniform distribution between 50 and 70 ms. Results (from the last line of the figure) show an average delay of 623.5 ms with minimal and maximal experienced delays of 605.3 and 638.7 ms, respectively. As set, experienced PLR is null.

```

64 bytes from 192.168.2.1: icmp_seq=45 ttl=61 time=638 ms
64 bytes from 192.168.2.1: icmp_seq=46 ttl=61 time=615 ms
64 bytes from 192.168.2.1: icmp_seq=47 ttl=61 time=627 ms
64 bytes from 192.168.2.1: icmp_seq=48 ttl=61 time=605 ms
64 bytes from 192.168.2.1: icmp_seq=49 ttl=61 time=614 ms
64 bytes from 192.168.2.1: icmp_seq=50 ttl=61 time=622 ms
64 bytes from 192.168.2.1: icmp_seq=51 ttl=61 time=630 ms
64 bytes from 192.168.2.1: icmp_seq=52 ttl=61 time=613 ms
64 bytes from 192.168.2.1: icmp_seq=53 ttl=61 time=613 ms
64 bytes from 192.168.2.1: icmp_seq=54 ttl=61 time=624 ms
64 bytes from 192.168.2.1: icmp_seq=55 ttl=61 time=632 ms
64 bytes from 192.168.2.1: icmp_seq=56 ttl=61 time=627 ms
64 bytes from 192.168.2.1: icmp_seq=57 ttl=61 time=625 ms
64 bytes from 192.168.2.1: icmp_seq=58 ttl=61 time=622 ms
64 bytes from 192.168.2.1: icmp_seq=59 ttl=61 time=609 ms
64 bytes from 192.168.2.1: icmp_seq=60 ttl=61 time=623 ms
--- 192.168.2.1 ping statistics ---
60 packets transmitted, 60 received, 0% packet loss, time 59057ms
rtt: min/avg/max/mdev = 605.634/623.353/638.733/8.880 ms
francogooooo@Emulradio/TestTAPS

```

Fig. 11. Variable delays for satellite links and terrestrial network.

We have then considered fixed values for delays in the three sections but we set the PLR to 10 %. As expected, the average delay is approximately 621 ms, which is the sum of 125 ms + 125 ms + 60 ms x 2. After 100 sent packets, the received packets are 90.

In Fig. 12. we report the results from the satellite emulator for a variable PLR profile. In this case, we considered the following values: PLR = 1 % for 20 s (GOOD), PLR = 10% for 20s (BAD), PLR = 1% for 10s (GOOD), and finally, PLR = 10 % for 10 s (BAD), for fixed values of delays in the three sections (i.e. 125 ms in upstream, 125 ms in downstream and 60 ms in Internet (equal to a total of about 620 ms in round trip time). From the figure, it is possible to note the lost PING packets reported in red “*”, well evident when the BAD channel is set.

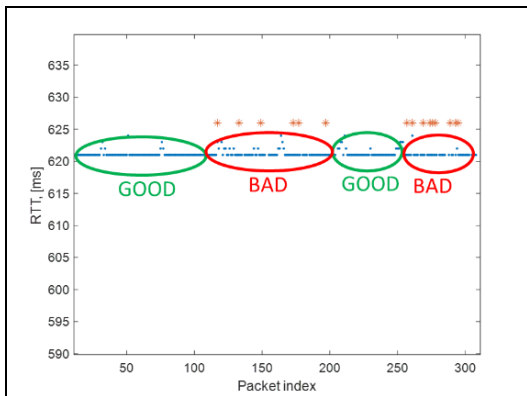


Fig. 12. Results with variable profile of PLR

IV. CONCLUSION

This paper has described the EMULRADIO4RAIL platform able to perform laboratory tests of wireless communication system in the railway domain. We have presented some results as a proof of concept of the platform. The subsystems are controlled by a single PC with a GUI. They are now available for testing with the industrial prototypes developed within Shift2Rail. A set of representative railway environments have been selected in the literature but it is now important to launch experimental characterization of other type of environments, for example related to urban and freight trains. The evolution of the platform to take into account 5G is also planned, thanks to the potentialities of OAI.

ACKNOWLEDGMENT

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