

Andy Rodríguez Lorenzo, Nerea Fernández-Berrueta, Jaizki Mendizabal
CEIT-BRTA, Donostia/San Sebastián, Guipúzcoa, Spain

CEIT's Multiconnectivity Platform Laboratory Setup



ANDY RODRÍGUEZ LORENZO received the degree in telecommunications and engineering in 2020 from the Technological University of Havana and the M.Sc. degree in Physical Sciences in 2023 from the University of Havana. He joined CEIT-BRTA Research Centre, in 2023. His research activity as PhD student of the Transport and Sustainable Mobility group, CEIT-BRTA has been focused on communication systems for the railway industry, participating in the FP2-R2DATO project.

e-mail: andyrodlor@ceit.es



NEREA FERNÁNDEZ-BERRUETA received the M.Sc. degree in telecommunications engineering from the Faculty of Engineering, University of the Basque Country, Bilbao, in 2016 and the Ph.D. degree from the Universidad de Navarra in 2022. She joined the CEIT-BRTA Research Centre, in 2017. Her research activity lies in the field of railway signaling specially in zero on-site testing and adaptable communication systems in the Transport and Sustainable Mobility group, CEIT-BRTA Research Centre, San Sebastián. She is now actively participating in H2020 European funded, such as Shift2Rail projects in railway communications and testing: X2RAIL-5 and in projects related to 5G technology such as 5G Euskadi.

e-mail: nfernandez@ceit.es



JAIZKI MENDIZABAL received his M.Sc. and Ph.D. degrees in Electrical Engineering from TECNUN (University of Navarra, San Sebastián, Spain) in 2000 and 2006 respectively. He joined Fraunhofer Institut (Germany) and SANYO Electric Ltd, Japan as RF-IC designer. Nowadays, he is at CEIT-IK4, in San Sebastián (Spain) where his research interests include communications and electronic systems. He is lecturing “Communications Electronics” and “Communications via Radio” at TECNUN (University of Navarra).

e-mail: jmendizabal@ceit.es

Introduction

During a train journey, reliable communication between the train and trackside infrastructure is crucial to ensure safety and efficiency. As the number of trains and daily journeys has increased, so too have the demands for higher data reliability and availability. In the last years,

GSM-R has served as the primary communication system [1], closely tied to the European Rail Traffic Management System (ERTMS). However, as GSM-R is based on aging GSM technology, it is approaching obsolescence with its lifecycle expected to end by 2030 [2]. Maintaining it beyond that point poses cost and reliability challenges, prompting the need for a new standard. In response, the International Union of Railways (UIC), in collaboration with industry stakeholders, is developing the Future Railway Mobile Communication System (FRMCS) to replace GSM-R and drive the digitalization of railway communications [3].

In parallel with the development and standardization of FRMCS, the Adaptive Communication System (ACS) has emerged with a complementary purpose. ACS is designed to be a transparent system for railway applications, meaning it operates independently of the specific communication technologies used underneath. Its bearer-agnostic nature allows it to dynamically exploit the trade-offs between private and public networks, ensuring optimal performance, and cost-efficiency depending on the available infrastructure and operational needs [4]. Several research and innovation projects have been carried out within the ACS framework, including X2Rail-5 [5].

Additionally, the more recent project FP2-R2DATO [6] focuses its Work Package 28 on the development of a communication system, Multi-Connectivity Platform (MP) System, that enables seamless data exchange between on-board and trackside applications through the use of intelligent gateways. These gateways serve as intermediaries capable of managing communication across different network types, adapting to varying coverage conditions and requirements, and ensuring robust and continuous connectivity for critical railway services.

In this context, the work carried out by CEIT with the development of the Multi-Connectivity Platform (MP) system is being extended through the creation of an experimental laboratory setup aimed at conducting a series of functional tests. This laboratory setup serves as a cost-effective solution for testing new ideas and validating concepts, while also facilitating the integration of emerging technologies within a segment of the railway industry—train-to-trackside communications—that is currently undergoing standardization.

The present document provides a brief summary of the work carried out under WP28 by CEIT, focusing on the demonstration of the system's capabilities. The developed setup is presented first, followed by a short demonstration of the gateway's operation. Finally, conclusions are drawn and future directions are outlined.

CEIT Laboratory Setup

In the context of the Europe's Rail FP2-R2DATO project [6], CEIT has been developed a laboratory setup in order to deploy the implementation of Multi-Connectivity Platform (MP) System system. In general, to perform tests in real railway scenarios is costly, not only in the economic point of view but also in the sense that requires coordination among different parts such as trackside infrastructure administrations, train operators and system developers, which often requires a time and limited freedom to perform test.

This environment aims to simulate a railway On-Board and Trackside communication scenario, using dedicated hardware for each part of the communications connected by different wireless technologies. Figure 1 shows a simplified schematic of the setup in such a way that the principal components and its connections can be appreciated. For its part, figure 2 shows the

physical setup, presenting how the setup is exhibited in the Railway System Signalling Laboratory in CEIT's Miramon facility.

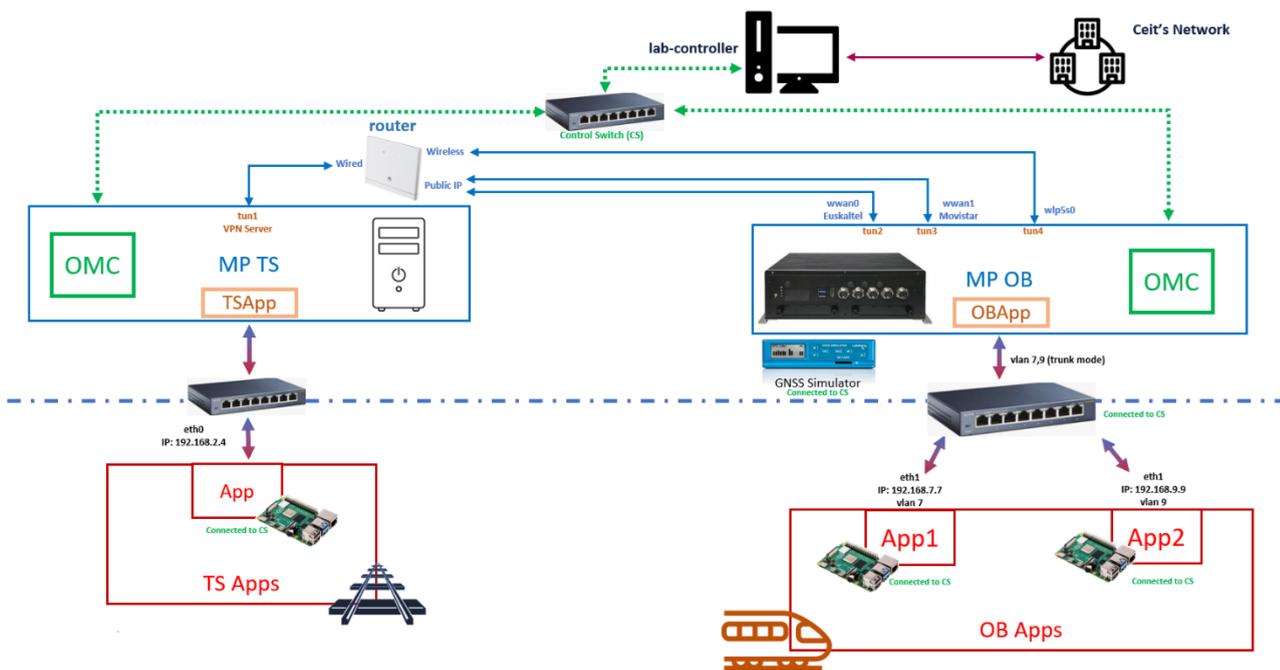


Figure 1: CEIT's MP Laboratory Setup Schematic



Figure 2: Ceit's MP Laboratory Setup Image

For an easier description the setup is split in the following component:

- MP OB: the On-Board gateway, it provides the communication services for the On-Board applications deployed in devices that cannot access directly to the network. The MP OB includes an application interface that supports registration and deregistration procedures when needed; this application interface is based on the one defined for FRMCS [7]. It also counts with radio interfaces to interact with several bearers from different technologies. In the setup described in this document, the radio bearers used include two different 5G MNOs, Euskaltel and Movistar, as well as Wi-Fi, establishing three different communication

paths to reach the trackside. Together with the above, an operation, maintenance and configuration interface with a human interface was included. In this setup, the MP OB is deployed in a NEXCOM nROK7270, which is a computer certified for train operation.

- **MP TS:** the Trackside gateway, it provides the communications services for the Trackside applications. Similar to the MP OB, the MP TS integrates the FRMCS registration and de-registration procedures for applications and a human interface to configure and interact with the system. The MP TS is the endpoint of the different communication paths that start in the MP OB, having the capability to reach the On-Board system for any of them. During the MP system operation, the MP TS acts as server, receiving requests from MP OB devices to establish sessions and start communications.
- **Router TS:** it is the point where the different communication paths converge, forwarding the OB packets to the TS, and the traffic generated on the TS is routed back to the OB through the corresponding communication path. It serves as a reference point for the MP OB, allowing the MP TS to operate within a private network. In this setup, this router has wired Ethernet interfaces, WLAN, and mobile network connections using a SIM card from the operator Vodafone.
- **On-Board Network:** it is the network that in a real scenario will be deployed over the train network. It allows the communication between the On-Board Applications and the MP OB. Over this network, the requirement of VLAN segmentation is imposed due to the undesirable and potential security risk. Without segmentation concept implemented, different points of the network can have access to the whole On-Board Network during train operation.
- **Trackside Network:** it is the network that connects the MP TS with the Trackside Applications. In this setup, it counts with a switch connecting both devices, a Raspberry Pi where the trackside application is running and the MP TS.
- **On-Board Applications:** it is the On-board part of a software that provides a solution for an specific railway operation need, e.g. implementations of Automatic Train Operation (ATO), European Train Control System (ETCS), CCTV, passenger announcements. A more comprehensive list of applications can be found in FRMCS User Requirements Specification [8]. In this setup, Raspberry Pi(s) were added for this end instead of an application implementation simulator considering their communication behavior.
- **Trackside Applications:** they consist of the trackside components of the on-board communication system. Each application defines the division of functionalities between both parts and how they communicate. The MP TS enables this communication.
- **Position Simulator:** the setup integrates a LabSat V3 [9] which simulates GNSS signals to test and validate positioning systems with repeatable, real-world scenarios.
- **Control Network:** in parallel with the aforementioned, another network is included, from which every device can be quickly accessed. This includes a computer with a screen from which the setup function can be controlled and it is interconnected with the CEIT's network allowing remote operation. This is not mandatory in a real deploy of the MP system.

MP Operation

Using the setup described in the previous section, the MP system was tested in several aspects in the context of the WP28 of the FP2-R2DATO project [6]. For this labor, a comprehensive suite of test cases was defined, to which CEIT's system was subjected. This section is a summary of the different functionalities that the system exhibited during the tests.

One of the main features of the MP OB must be the ability to select a communication path,

forward traffic over it, and, when necessary, switch paths while maintaining application communications. The MP OB operates by first selecting a specific train route and, prior to operation, analyzing the behavior of the communication networks available along that route. The results of this analysis are stored in a file that maps network performance throughout a regular journey. During train operation, the MP OB accesses this file in real time to select the most appropriate communication path at each point along the route, using the train's current position as a reference.

In this regard, in the static setup the information related to the León-Guardo route is stored in the GNSS simulator, which is connected to the MP OB. When the train operation is simulated with this GNSS simulator in the setup, the MP OB is going to receive continuous locations in the route and, using a file like the one in figure 3, it is capable of selecting a path to forward the application traffic via making a comparison of the current position and the file.

```

Stationary Information León-Guardo
{
  "Route": "Leon-Guardo",
  "Points": [
    {
      "id": 0,
      "lat": 42.6159717,
      "lon": -5.5662676,
      "ID_primary": "RB_5G_A",
      "ID_secondary": "RB_5G_B"
    },
    ...,
    {
      "id": 492,
      "lat": 42.796550893749995,
      "lon": -5.5073092062499995,
      "ID_primary": "RB_5G_B",
      "ID_secondary": "RB_WIFI_A"
    },
    ...,
    {
      "id": 870,
      "lat": 42.8548888,
      "lon": -5.4437981,
      "ID_primary": "RB_WIFI_A",
      "ID_secondary": "RB_5G_A"
    }
  ]
}

```

Figure 3 : Preloaded Pattern File for León-Guardo Line

Simulating the complete route operation, the system is capable of using the different communication paths available depending on the geographical position received from the LabSat. Using the system logs, the system is able to construct the map shown in figure 4; it shows the preferred bearer to forward traffic in each part of the line.

It is important to clarify that the results, shown in figure 4, do not correspond to a study of the behavior of the different networks around the line, the preloaded pattern has been constructed based on the available bearers in the laboratory setup.

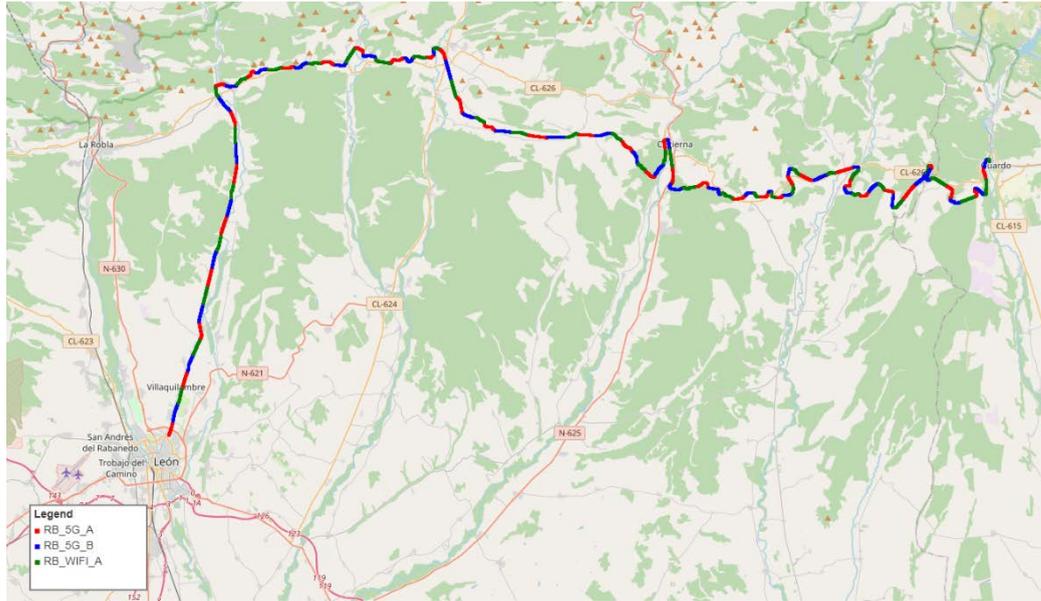


Figure 4 : Communication paths preferred in the Leon-Guardo line simulation

For traffic application registration, as explained in the previous section, the FRMCS procedure must be followed. Each MP device listens on a specific port, and the application must send a POST request to initiate registration (or de-registration) to the applications interface. Figure 5 illustrates how this procedure should work according to the FRMCS FFFIS [7]. Figures 6 and 7 show the registration and de-registration process, respectively executed from the console on one of the application devices.

Once the registration POST sent by the application is successfully received, an internal process in the MP device is triggered, and packets from the application begin to be accepted and forwarded to the other side of the system. On the other hand, the de-registration DELETE request terminates the acceptance of those packets, and that traffic no longer enters the system. This ensures that only authorized applications can use the system's services.

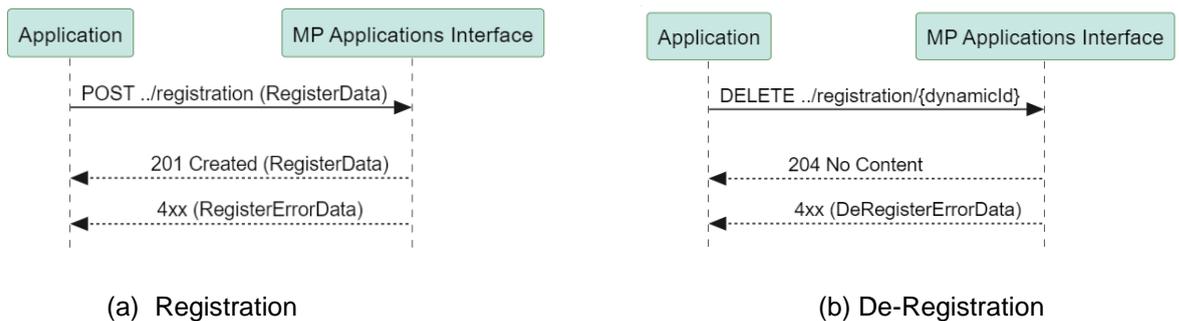


Figure 5 : Sequence diagrams of the registration process

```

pi@app-ob-1:~/client_etcs $ curl -i -X POST https://192.168.7.10:8080/obapp/v1.2/registrations \
--cert Certs/client.crt \
--key Certs/client.key \
--cacert Certs/ca.crt \
-H "Content-Type: application/json" \
-d '{"appCategory": "etcs", "staticId": "etcs-77", "couplingMode": "loose"}'
HTTP/2 201
content-type: application/json
content-length: 54
vary: Origin
date: Fri, 23 May 2025 15:19:36 GMT
server: hypercorn-h2

{"dynamicId": "efd0edf1-fc37-4cb0-8926-dc3e6cb94695"}

```

Figure 6 : Registration process from the application side.

```

pi@app-ob-1:~/client_etcs $ curl -i -X DELETE https://192.168.7.10:8080/obapp/v1.2/registrations/efd0edf1-fc37-4cb0-8926-dc3e6cb94695 \
--cert Certs/client.crt \
--key Certs/client.key \
--cacert Certs/ca.crt
HTTP/2 204
content-type: text/html; charset=utf-8
vary: Origin
date: Fri, 23 May 2025 15:20:08 GMT
server: hypercorn-h2

```

Figure 7 : De-registration process from the application side

Finally, in order to handle configurations and maintenance operations through a human-friendly graphical interface, each MP integrates its own interface, a module known as OMC (Operation, Maintenance and Configuration). The graphical interface is based on a web page, from which a proper user with registered credentials can access and perform a series of operations, such as:

- Upload a new preloaded pattern file: In a real or simulated scenario, the MP system's operation over a line requires the use of specific information about the route being used. This implies that a file, similar to the one shown in Figure 3, may need to be replaced frequently. This file handling is carried out in a specific option of the OMC of the MP OB, where the current preloaded pattern file is replaced with a new one corresponding to the new scenario. Figure 8 shows the screenshot from where a new preloaded pattern can be uploaded. This option is only available in the MP OB, as the MP TS does not implement this function.



Figure 8 : Preloaded pattern uploading window in OMC

- Upload or modify system and network configurations: in parallel with the route information, both MPs must be configured. For example, the MP OB must be configured to specify which MP TS should initiate communication with. Additionally, general data related to the involved applications, as well as the wireless and local interfaces, can be managed through this OMC. Figure 9 shows the screenshot from where a new system configuration can be added.

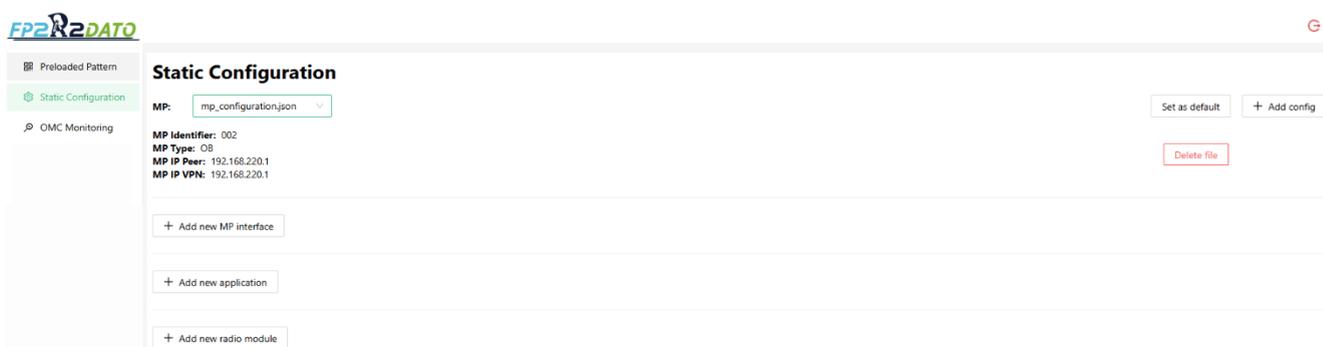


Figure 9 : System configuration window in OMC

- Check the currently registered applications: the OMC is also capable of displaying, during train and MP operation, which applications are currently registered and able to use the system's communication services. For this feature, the OMC communicates directly with the applications interface, which maintains an up-to-date list of authorized

applications in a database.

- Obtain information regarding bearer status: the OMC also provides the user with the ability to collect data about the bearers currently in use. Each time the user submits a request, a query is sent to a process that monitors RF parameters of each modem, which responds with an updated list of parameters related to the bearer status. Figure 10 shows the results received after requesting the status of two different mobile networks used as bearers. The same figure also displays the information about the registered applications.

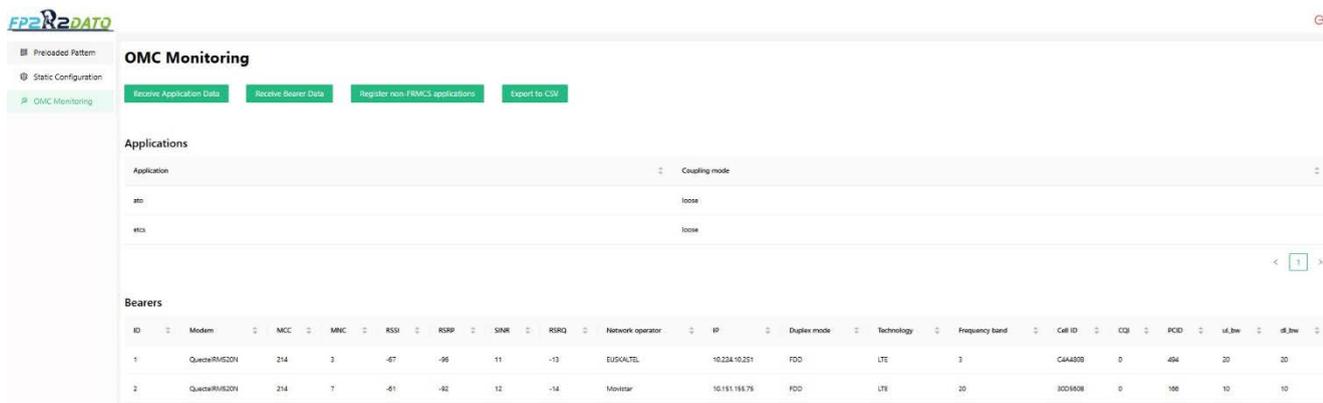


Figure 10 : Monitoring window in OMC

Conclusions

The railway industry is facing a pressing need to modernize its Train-Trackside communication systems due to the obsolescence of GSM-R. Gateway-based solutions have emerged as a viable alternative, enabling applications that cannot directly access the network to use communication services.

CEIT's work within the Europe's Rail FP2-R2DATO WP28 [6] project aligns with this evolution by designing and prototyping the Multi-Connectivity Platform (MP) system, evolving the directives of the former ACS approach. To address the challenges of testing in real-world scenarios, a dedicated laboratory setup has been developed, incorporating all the critical components that interact within the MP.

Using this setup, both the MP OB and MP TS functionalities have been tested, and this document presents some of the key features demonstrated during those tests. Future work will focus on expanding the system's capabilities, including the integration of new radio technologies and support for a wider range of applications with varying requirements. Additionally, the architecture is expected to evolve to support multiple MP OB units managed by a single MP TS, further enhancing scalability and flexibility.

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