6G-SANDBOX

Supporting Architectural and technological Network evolutions through an intelligent, secureD and twinning enaBled Open eXperimentation facility

1st Open Call

Deliverable D3.1

Description of functionalities/infrastructures and user manual

6G-LoRaGRAN project:
Integration of the University of Granada's LoRaWAN network in the 6G SANDBOX connectivity infrastructure

University of Granada

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Abstract

The 6G-LoRaGRAN project, granted to the WiMuNet research group (code TIC-235 of the Scientific Information System of Andalusia) of the University of Granada (Spain), is intended to integrate the University of Granada's LoRaWAN network with the 6G-SANDBOX pilot sites. Additionally, it enables researchers from 3rd parties to conduct experiments using this infrastructure.

The objective of this deliverable is to provide a comprehensive description of the project's functionalities, encompassing the infrastructure used and the user manual.

Keywords

6G-SANDBOX, 6G-LoRaGRAN, LoRaWAN, N3IWF, 5GC, Network Slicing

Glossary

5GC	5G Core network
AMF	Access and Mobility Management Function
BW	Bandwidth
CR	Coding Rate
eNB	3GPP 4G evolved Node B
IKEv2	Internet Key Exchange version 2
IPSec	Internet Protocol Security
ISM	Industrial, scientific, and medical
gNB	3GPP 5G next Generation Node B
LoRa	Long Range modulation
LoRaWAN	Long Range Wide Area Network
MQTT	Message Queuing Telemetry Transport
N3IWF	Non-3GPP InterWorking Function
N6	Interface between the Data Network (DN) and the UPF
NWu	Reference point between the UE and N3IWF for establishing secure tunnel(s)
UPF	User Plane Function
RAN	Radio Access Network
REST API	REpresentational State Transfer Application Programming Interface
SF	Spreading Factor
UE	User Equipment
VPN	Virtual Private Network

1 INTRODUCTION

The 6G-LoRaGRAN project [1], granted to the WiMuNet research group [2] (code TIC-235 of the Scientific Information System of Andalusia) of the University of Granada (Spain), integrates the University of Granada's LoRaWAN network into the 6G-SANDBOX connectivity infrastructure.

6G-LoRaGRAN enables researchers to conduct experimental campaigns using the University of Granada (UGR) LoRaWAN infrastructure, comprising a LoRaWAN Radio Access Network (RAN) with gateways and nodes, as well as a LoRaWAN backend with network and application servers. These components are integrated with the 5G cores situated at one of the 6G-SANDBOX pilot sites, facilitating the transmission of all LoRaWAN traffic across the 5G network. In this way, a mobile network operator would be able to offer LoRaWAN (a non-3GPP network) services to their customers. For that purpose, 6G-LoRaGRAN equipment can connect to the 5G cores 1) via the N3IWF (Non-3GPP InterWorking Function) entity (using a NWu emulator) or 2) by emulating a UE/gNB, depending on the 6G-SANDBOX pilot sites framework.

To enable third parties to conduct experiments on our testbed, we have developed a web UI for our Experiment Manager (EM). Within this interface, researchers can reserve time slots for their experiments and customize the required parameters. This includes the ability to modify node traffic patterns and create network slices. Nodes will transmit frames based on a customizable frame arrival pattern and with a customizable frame size distribution.

Additionally, researchers are able to create various network slices, each comprising one or more channels that are not shared between slices. Slice assignment to the nodes is initially assigned through the web interface but it can be modified in real-time using a REST API (REpresentational State Transfer Application Programming Interface). This enables adjustments on the channel assignment based on real-time metrics, thus allowing researchers to implement their own assignment strategies.

Finally, researchers can subscribe to LoRaWAN metrics and data from the application server, which includes radio statistics, transmission parameters, transmitted data, etc. As stated before, this information can be used for real-time resource assignment algorithms or for performance evaluation analysis.

1.1 OBJECTIVES AND SCOPE OF THIS DOCUMENT

In accordance with the terms of the call, the objective of this deliverable is the description of the functionalities and infrastructure made available to researchers through the 6G-LoRaGRAN project and the provision of a user manual.

1.2 DOCUMENT STRUCTURE

The rest of this document is structured as follows:

- Section 2: Overview of the functionalities and infrastructure of the 6G-LoRaGRAN project. This section describes in detail the infrastructure in the University of Granada for 6G-LoRaGRAN, which can be used by researchers.
- Section 3: User manual. This section provides a detailed description of how a researcher can carry out experimentation using the UGR LoRaWAN network integrated with the 6G-SANDBOX pilot sites.

- Section 4 draws the main conclusions from this document.

2 Description of functionalities/infrastructure

The following subsections describe the infrastructure and the functionalities developed during the 6G-LoRaGRAN project.

2.1 6G-LoRaGRAN infrastructure

As described in Section 1, the 6G-LoRaGRAN infrastructure comprises a LoRaWAN Radio Access Network, a LoRaWAN backend and an Experiment Manager. Both the LoRaWAN backend and the Experiment Manager are executed on a Kubernetes [3] cluster to simplify management and improve reliability. In addition, another computer provides connectivity towards the 5G cores from the 6G-SANDBOX sites using a UE/gNB emulator or a NWu client.

The RAN includes:

- LoRaWAN nodes: 25 Pycom Fi-Py [4] and 15 TTGO LoRa32 [5] devices. These nodes connect via Wi-Fi to the EM to receive their transmission parameters (e.g. channel, spreading factor, slice) and traffic patterns to accordingly generate LoRaWAN traffic. Their firmware includes watchdog timers to automatically recover after non-expected failures and can be updated over-the-air (OTA) to simplify updates.

Figure 1. PyCom FiPy and TTGO LoRa32 nodes.

- LoRaWAN gateways:
    - One outdoor gateway. As part of this project, UGR has deployed a CISCO IXM-LPWA-800-16-K9 [6], a carrier-grade product specifically designed for outdoor environments. It has been deployed to enhance coverage around the School of Technology and Telecommunications Engineering (ETSIIT-UGR) and the Research Center for Information and Communication Technologies (CITIC-UGR).

Figure 2. CISCO gateway at the roof of ETSIIT-UGR.

- Several indoor gateways. Several IMST Lite Gateway [7] and Pycom Pygate [8] gateways have been deployed in the WiMuNet laboratory as well as in different offices of the ETSIIT-UGR and CITIC-UGR buildings (see an example in Figure 3). They are placed as pairs for redundancy.

Figure 3. Pair IMST Lite and Pycom Pygate gateways (example of gateways located at CSIC-UGR).

The location of the gateways deployed is summarized in Figure 4, and is included in the home page of the web UI for reference.

Figure 4. Location of 6G-LoRaGRAN gateways.

Regarding our LoRaWAN backend, we employ the ChirpStack platform [9], which has been curstomized to be executed on a Kubernetes cluster, to automatize deployment, scaling, and management of the containerized applications as well as to provide high availability. Kubernetes also manages data persistence and automatic recovery. The cluster is composed of three Intel NUCs with i7-10710U processors and 16 GB of RAM, in addition to the required Ethernet switches.

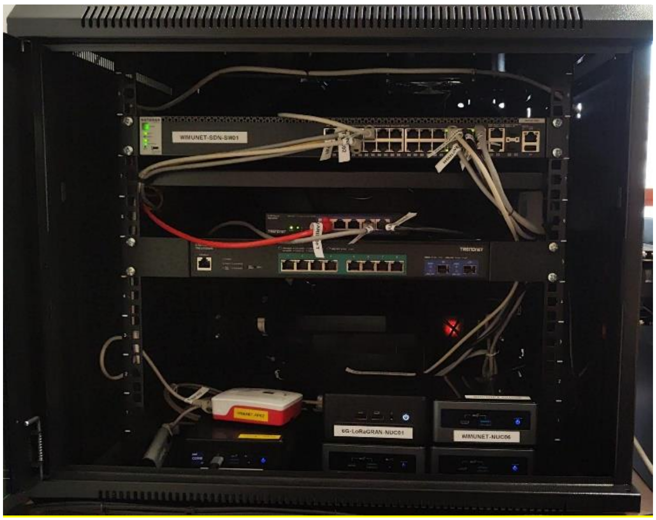

Figure 5. Rack cabinet with 6G-LoRaGRAN cluster.

We also employ another Intel NUC, acting as N3IWF (Non-3GPP InterWorking Function) client or gNB/UE emulator, to provide connectivity towards the 6G-SANDBOX sites. Finally, an Intel Core i3 desktop provides connectivity from our private network to the Internet.

Figure 6 provides an overview of the 6G-LoRaGRAN testbed architecture. As previously mentioned, the Radio Access Network (RAN) is attached to a computer, which then directs LoRaWAN traffic through a 5G core to the cluster housing the LoRaWAN backend. This integration seamlessly combines both LoRaWAN and 5G functionalities within the 6G-LoRaGRAN framework.

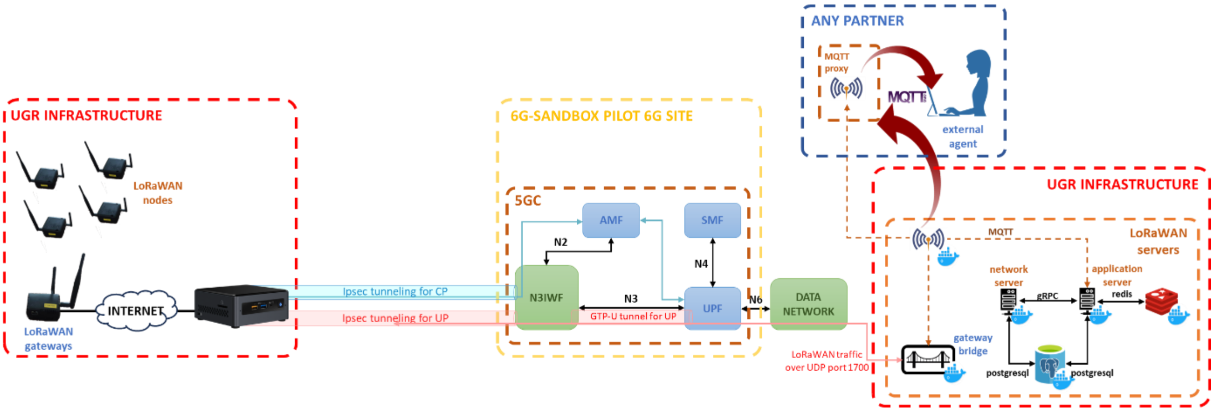

Figure 6. 6G-LoRaGRAN testbed architecture.

2.2 6G-LoRaGRAN Functionalities

The functionalities achieved within this project can be categorized as:

1) Connectivity to 6G-SANDBOX pilot sites.
2) Deployment and operation of the LoRaWAN network.
3) Execution of experiments

Regarding the connectivity to 6G-SANDBOX pilot sites, the objective is to connect the LoRaWAN RAN to the LoRaWAN backend via the 5G cores in the different sites. Since LoRaWAN is a non-3GPP network, it can be connected 1) via N3IWF or 2) emulating a UE/gNB, depending on the selected 5G core. The web UI of the Experiment Manager allows the researcher to select the 6G-SANDBOX pilot site to integrate with.

Regarding the deployment and operation of the LoRaWAN network, we employ the ChirpStack platform [9] in a Kubernetes cluster. Our implementation, using Kubernetes and the ChirpStack API, automatizes the deployment of the ChirpStack platform, the automation to the creation/modification of security credentials, and the automation of the configuration of the LoRaWAN network (including the definition of tenants, applications, gateways, nodes, and LoRaWAN network slices).

Regarding the execution of experiments, 6G-LoRaGRAN allows researchers to perform campaigns of experiments using UGR's LoRaWAN testbed. The Experiment Manager includes a web UI which allows users to define, modify and delete the required parameters for the experiments. This includes the booking of a time slot for the experiment, selecting a 6G-SANDBOX pilot site to be integrated into. For the sake of fairness, researchers are initially allocated a maximum of 48 hours for experimentation, meaning they have to wait for the experiments to finish before being able to reserve more time. A user can contact the 6G-LoRaGRAN team (loragran@ugr.es) if he/she requires further resources.

During an experiment, traffic generation can be customized. This is done by defining traffic patterns for the nodes. Nodes will generate one frame following a frame arrival distribution (currently uniform and normal distributions are supported) with a given frame size (also following a uniform or a normal distribution).

Also, LoRaWAN network slices are used during the experiment. In the 6G-LoRaGRAN platform, network slices are defined as a set of channels that cannot be shared between slices. The slice assignment to the nodes, as well as the initial channel and spreading factor, is done via the web UI. A

REST API is also available which allows researchers to modify the slices and the channel assignment in real-time based on metrics. These metrics can be obtained by subscribing to the MQTT (Message Queuing Telemetry Transport) broker [10] executed along the ChirpStack platform, which publishes LoRaWAN frames with metadata information (reception time, RSSI, SNR, channel, spreading factor, frame counter, etc.).

The following section summarizes the guidelines to use the 6G-LoRaGRAN platform.

3 USER MANUAL

This section provides a step-by-step guide for users that want to use the 6G-LoRaGRAN platform. As a summary, the next subsections will introduce how to:

a) Register a new user
b) Book a time slot for experimentation, i.e. create an experiment
c) Create traffic patterns for the LoRaWAN devices
d) Create network slices for the different service operators
e) Assign traffic patterns and network slices to specific devices
f) Enable or disable the LoRaWAN gateways
g) Check the status of devices, gateways and connectivity towards pilot sites
h) View LoRaWAN frames (including radio link conditions, transmission parameters, transmitted data) in the ChirpStack platform
i) Subscribe to an MQTT broker to receive LoRaWAN frames in real time
j) Use the REST API to check, verify or modify the settings of the experiment in real time

3.1 REGISTER A NEW USER

Open a browser and connect to https://loragran.ugr.es. If you have not registered/logged in before, it will show the login page (Figure 7a). There, you shall select “Create an account”, which will forward to the registration page (Figure 7b). It will ask for a username, an e-mail address, a tenant name (which may be shared between researchers from the same team), an organization and a password. All these settings can be later modified along with other related information such as first/last names, address, phone, avatar picture, etcetera.

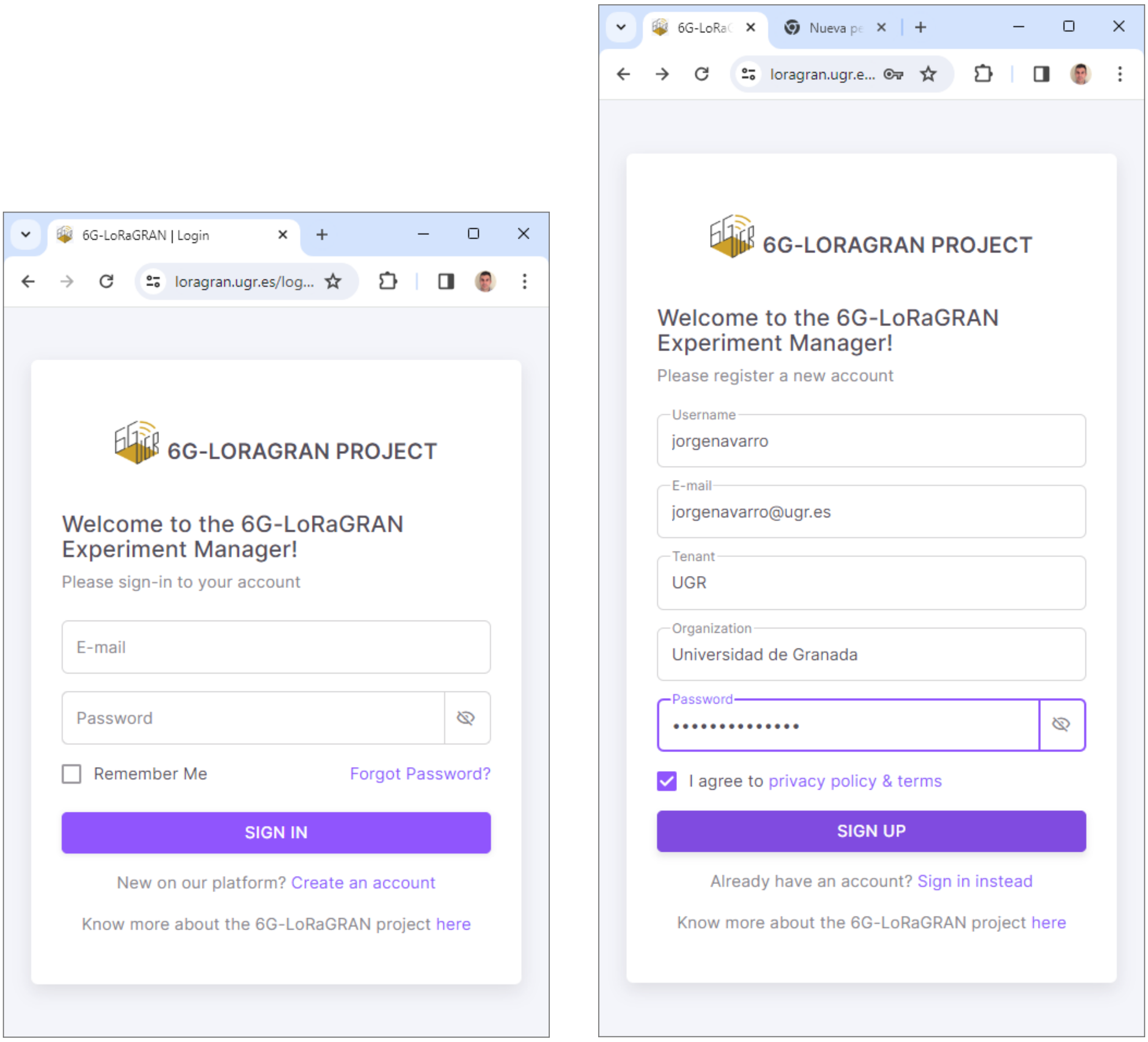

Figure 7. a) Login and b) registration pages.

An e-mail (Figure 8a) will be sent to verify that the user owns that address.

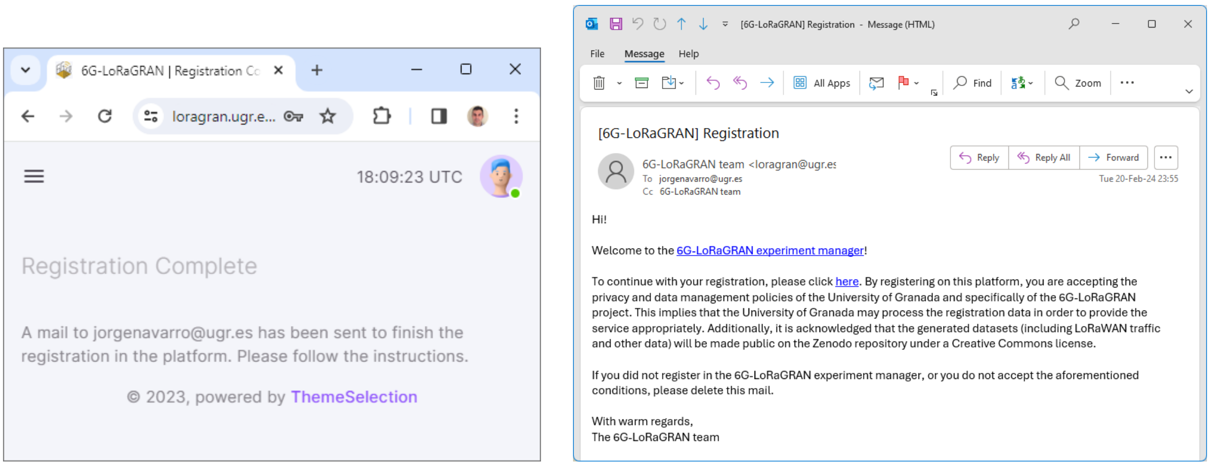

Figure 8. a) Registration complete pages and b) mail sent to the user.

Once the user has clicked the link in the mail (Figure 8b), the user will be notified that the administrator has to approve the request. This is to avoid spam or unwanted behaviors.

When the administrator approves your request, you will be notified by mail, and you will be able to login using the login web page (https://loragran.ugr.es/login.php). The home page will be shown (Figure 9).

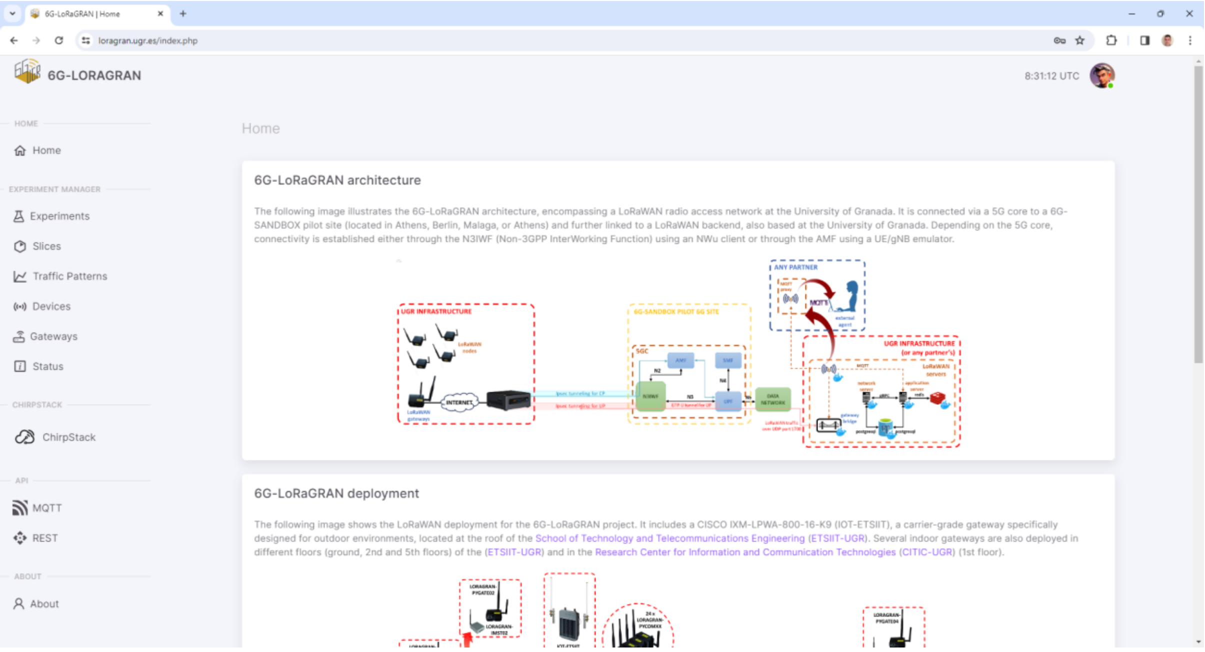

Figure 9. Home web page.

The home page includes 1) a menu on the left, 2) a navigation bar at the top right and 3) the web content. The pages included in the menu are categorized in “Home”, “Admin” (only for administrators), “Experiment Manager”, “ChirpStack”, “API” and “About”, which will be described in the next subsections. The navigation bar allows the user to log out or to modify the user’s profile (Figure 10a). The user can also delete his/her account on this page.

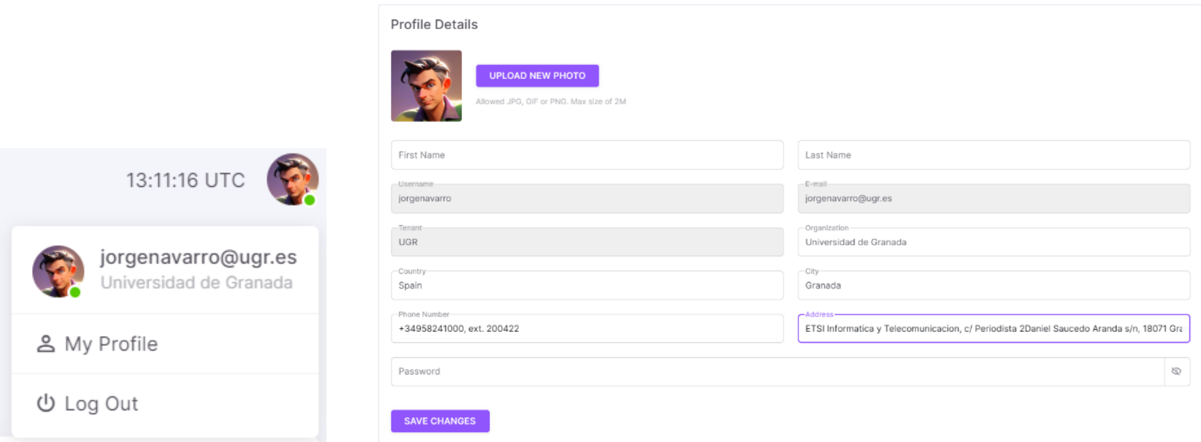

Figure 10. a) Navigation bar and b) profile details.

3.2 Create an experiment

To book a time slot to experiment with the 6G-LoRaGRAN platform, the user has to select “Experiment” in the menu. There, the user will see his/her experiments as well as those from other users (anonymized), allowing the user to determine when the platform is busy. An “instructions” button will summarize what the user can do in this page, which is also available in all the pages related to the Experiment Manager. If the user presses “Add new experiment”, he/she can select the start and stop times of the experiment and the pilot site to be integrated into, as well as its title and its description (Figure 11).

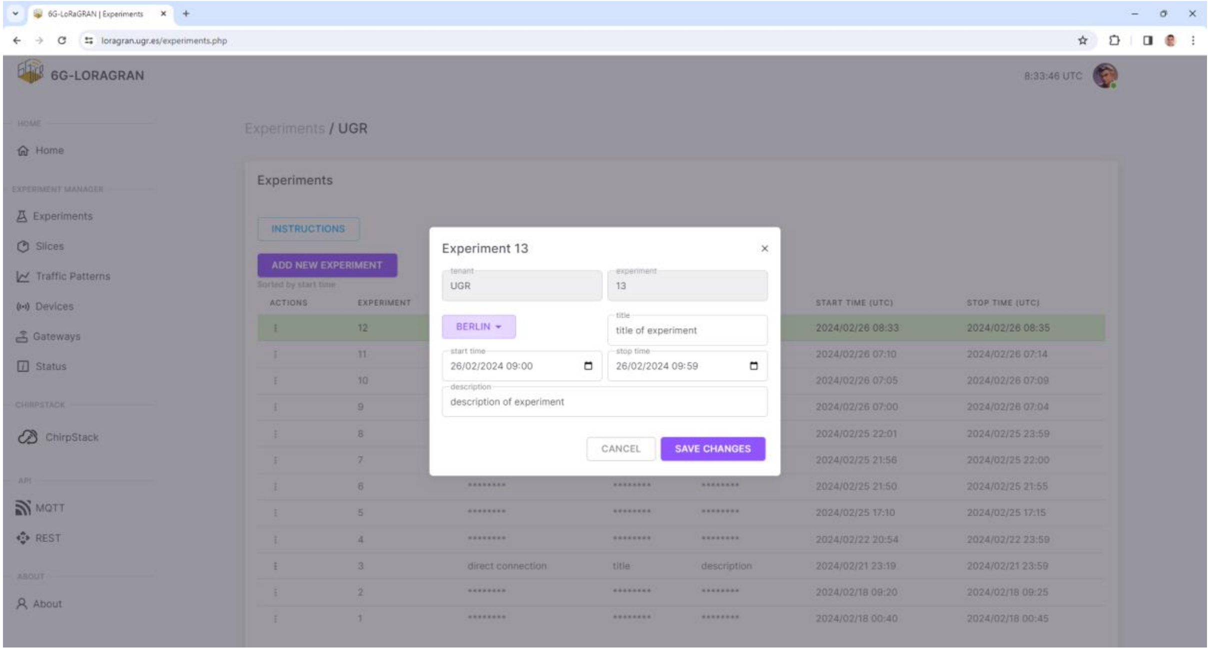

Figure 11. Creation of a new experiment.

If the user’s time slot overlaps with other experiments, an alert will be shown, allowing the user to modify the start and stop times.

This page also allows the user to modify or delete his/her existing experiments. Note that, to allow fair use of the platform, each user can create experiments for a maximum duration of 48 hours. This applies to both current and future experiments, excluding those already completed.

3.3 CREATE TRAFFIC PATTERNS

By default, a traffic pattern with a uniform distribution for the frame arrivals (min 300 seconds, max 600 seconds) and a uniform distribution for the frame size (min 10 bytes, max 20 bytes). This default traffic pattern is not modifiable. But the user can create, modify and delete other traffic patterns by selecting the “Traffic Patterns” menu and then pressing the “Add new pattern” button. The user can select uniform or normal distribution for frame arrivals and for frame sizes. For the uniform distribution, param1 is the minimum value and param2 is the maximum value. For the normal distribution, param1 is the mean and param2 is the standard deviation.

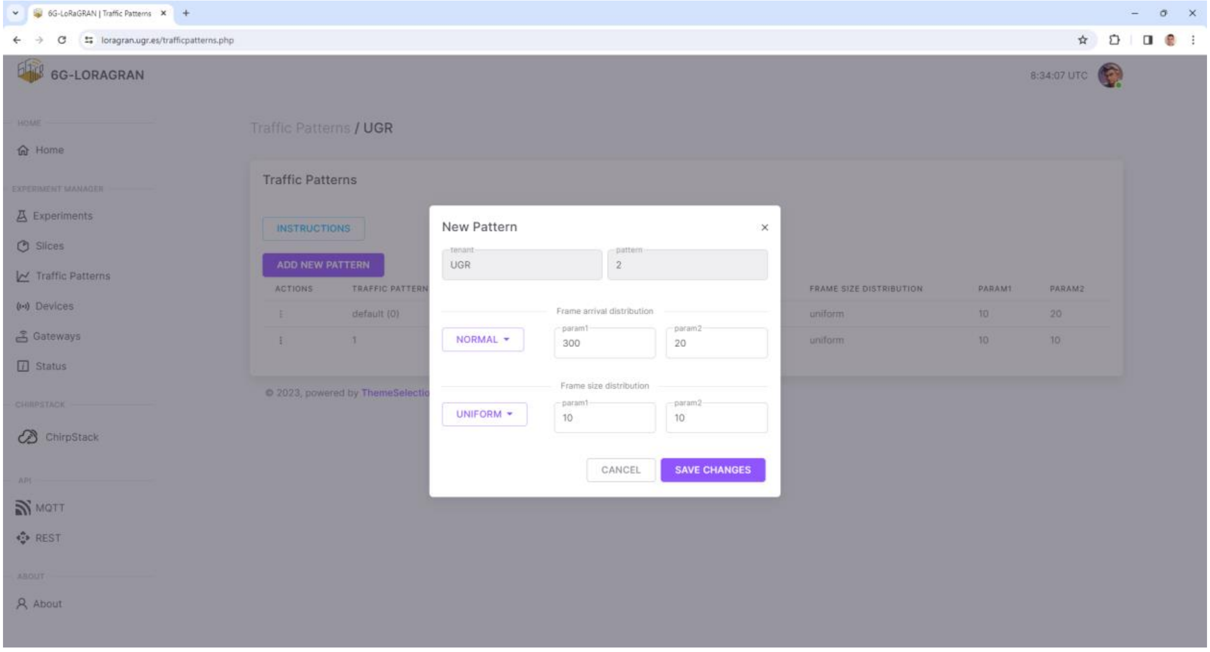

Figure 12. Creation of a new traffic pattern.

3.4 CREATE LORAWAN NETWORK SLICES

As described before, the platform allows the users to create network slices (Figure 13), each comprising one or more channels that are not shared between slices. To define a slice, we employ the concept of channel mask, which is a binary mask in which each bit represents one channel of the eight channels used for LoRaWAN in the in the 868 MHz band. For example, a channel mask of 15 (00001111 in binary representation) means that the slice includes channels 1, 2, 3, and 4; and a channel mask of 255 (11111111 in binary representation) means that all the channels are included in the slice. Note that it is up to the researcher whether slices share or not channels. To achieve isolation, slices shall not have common bits set to 1.

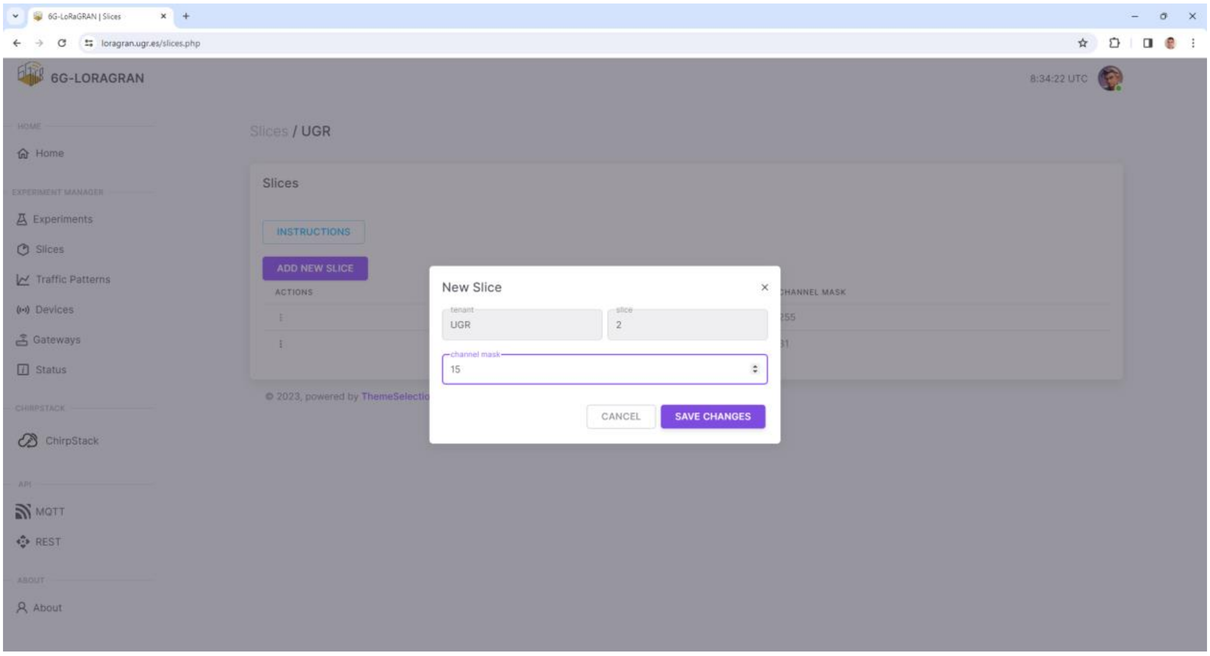

Figure 13. Creation of a new network slice.

3.5 ASSIGN TRAFFIC PATTERNS AND NETWORK SLICES TO SPECIFIC DEVICES

Once the user has created and customized traffic patterns and network slices, he/she has to assign them to specific devices for a particular experiment (Figure 14). For that, the user can select the "Devices" menu, which will show the configuration of the devices for future experiments (past experiments are not shown). There, the user can select the slice and traffic pattern for each device or select several devices and apply the same configuration (traffic pattern and network slice) for the selected devices. The user can also select the spreading factor to be employed for each device. Similarly, the user can select the channel used for transmission or "periodic", which means that the device will hop between the channels included in the selected slice.

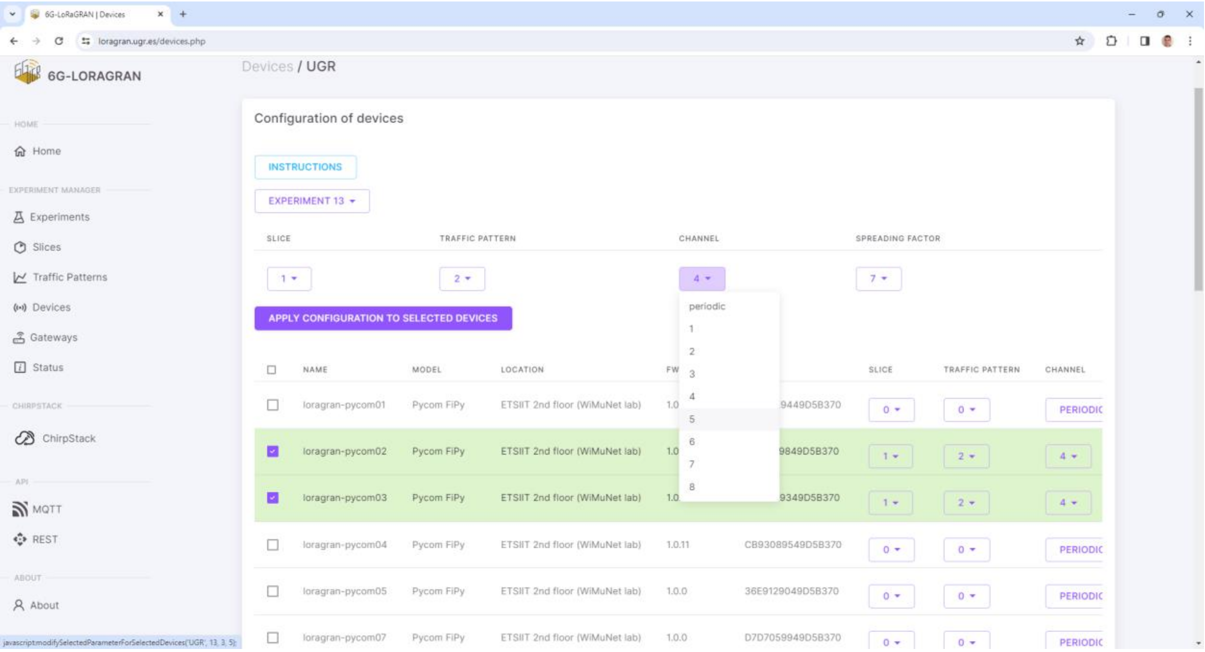

Figure 14. Assignment of traffic patterns and network slices to devices.

Please note that these device settings are for a specific experiment, so the user has to repeat this procedure for each experiment (unless the user wants all the devices to use the default traffic pattern and network slice).

3.6 ENABLE OR DISABLE THE LORAWAN GATEWAYS

By default, all the LoRaWAN gateways belonging to the 6G-LoRaGRAN platform are enabled during the experiment. These gateways are located in the School of Technology and Telecommunications Engineering (ETSIIT-UGR) of the University of Granada and in the Research Centre for Information and Communications Technologies (CITIC-UGR), as shown in Figure 4.

The 6G-LoRaGRAN platform allows the users to select which gateways are enabled or disabled for a given experiment (Figure 15). This increases the possibilities of experimentation by being able to vary radio conditions based on whether closer or more distant gateways are enabled. This can be customized by selecting the "Gateways" menu, selecting the required location (which can be "All" to enable all the gateways) and pressing the "Activate gateways" button. The user can also enable/disable each gateway individually.

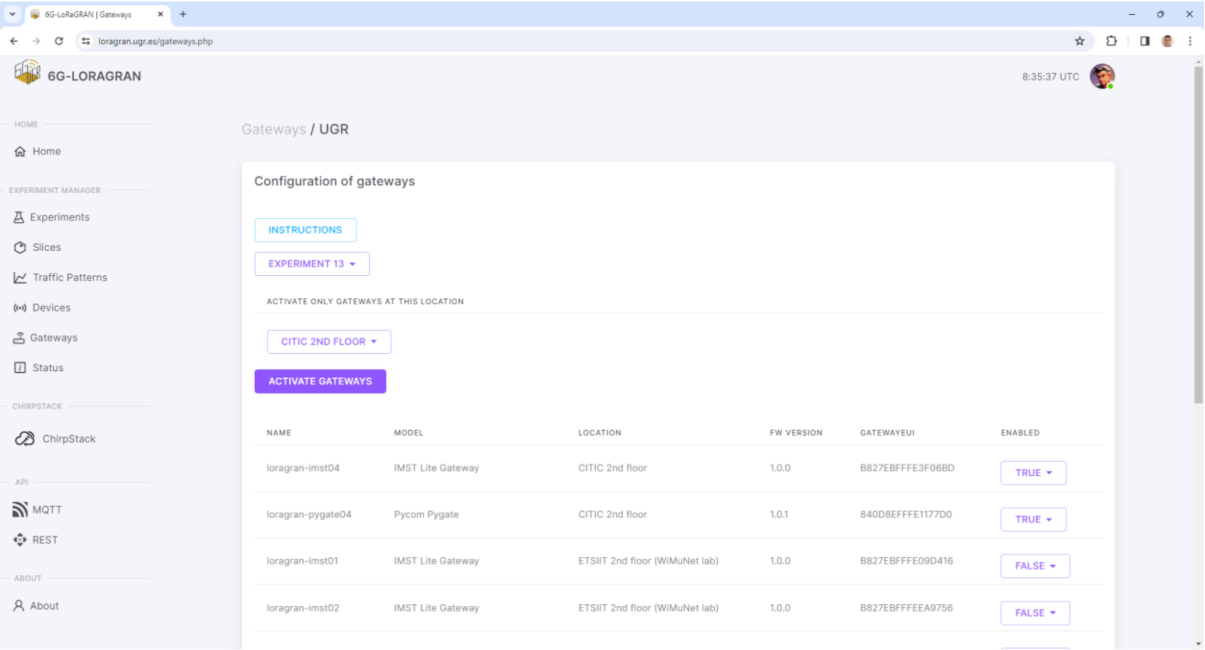

Figure 15. Configuration of LoRaWAN gateways.

3.7 VIEW STATUS OF DEVICES, GATEWAYS AND CONNECTIVITY TOWARDS PILOT SITES

The 'Status' menu allows to check that the devices (Figure 16. Status of devices.) and gateways are working properly (tabs 'Devices' and 'Gateways'). In case there is some failure, the user can contact the LoRaGRAN team (loragran@ugr.es) for assistance. Similarly, the user can check that the 6G-LoRaGRAN platform is connected to the 5G cores from the different 6G-SANDBOX pilot sites ('Pilot Sites' tab). This allows to confirm the correct behavior of the platform during your experiments (for this, the user can also use the REST API, see Section 3.10).

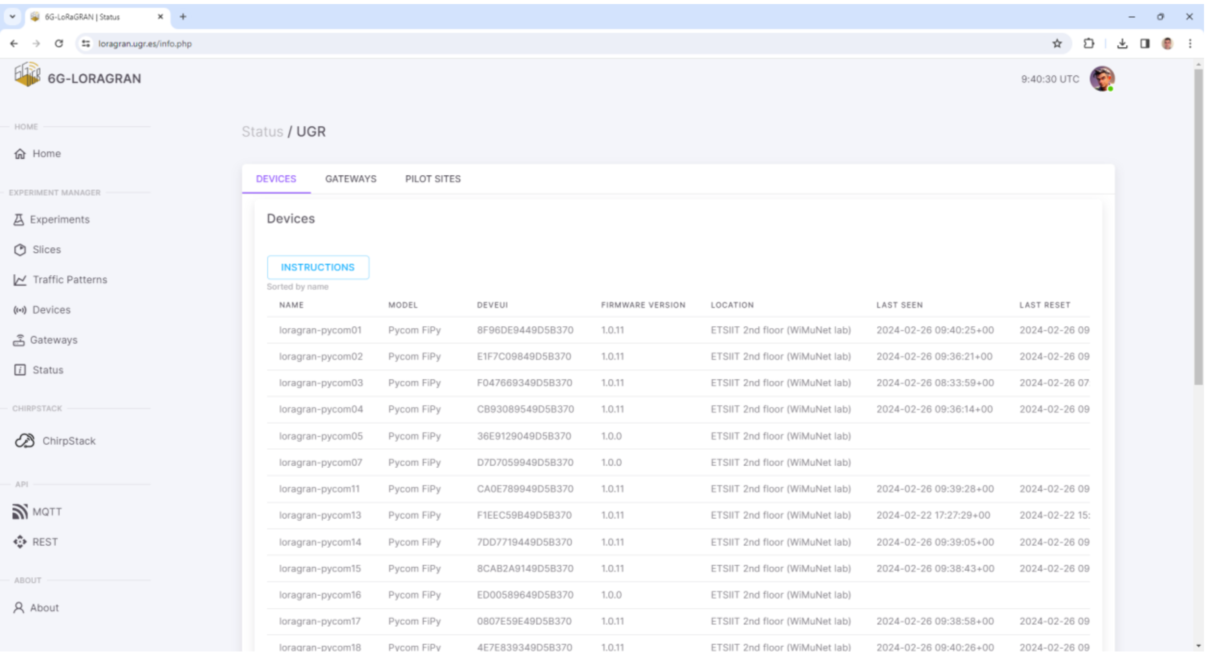

Figure 16. Status of devices.

3.8 VIEW LoRaWAN FRAMES IN THE CHIRPSTACK PLATFORM

The 6G-LoRaGRAN platform uses ChirpStack as the LoRaWAN backend, which includes the functionalities of the network and application servers, among others. Users can open the ChirpStack platform web page by selecting "ChirpStack" in the menu (or directly https://loragran.ugr.es:8443/). If it is the user's first time, he/she can log in by using the 6G-LoRaGRAN username and password that he/she selected in the registration (Section 3.1).

After the start time of the experiment, the platform will automatically configure the pilot site, the traffic patterns and the network slices for the devices and enable/disable the required gateways. Devices and gateways are automatically assigned to the user's tenant in ChirpStack, which allows he/she to see the LoRaWAN frames in the gateways (ciphered) and in the application (deciphered).

For example, users can see whether the gateways are active or not (Figure 17 was taken with IOT-ETSIIT gateway enabled and other gateways disabled). Or the LoRaWAN frames received by the application server (Figure 18).

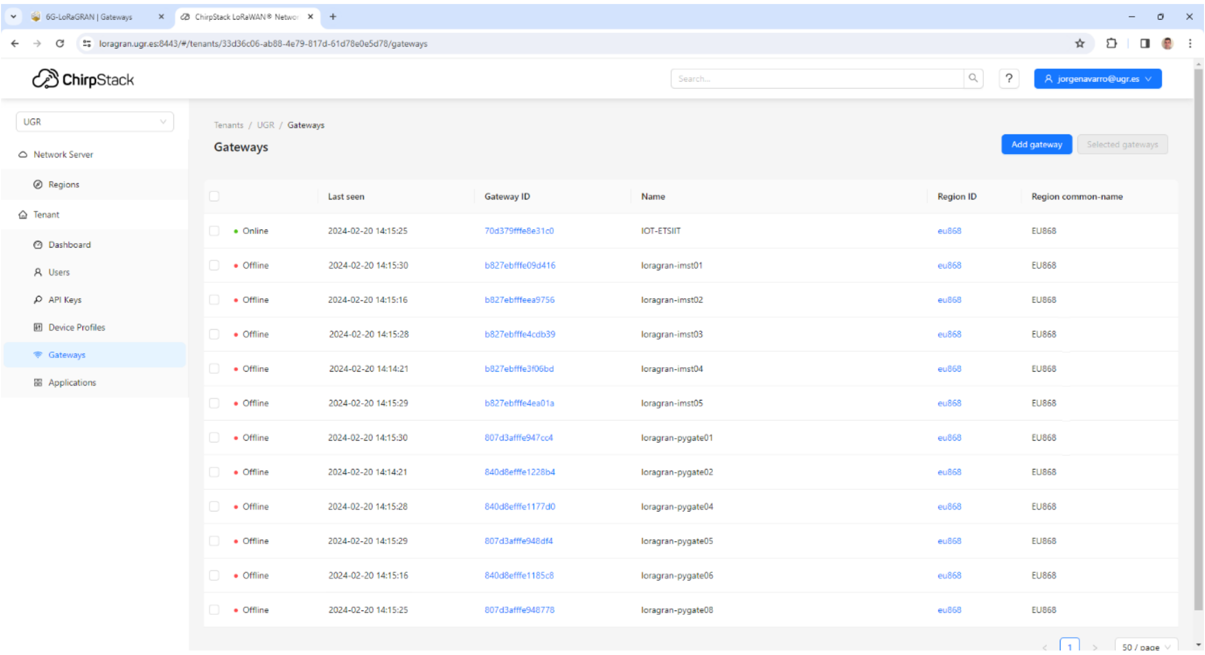

Figure 17. ChirpStack – Status of gateways.

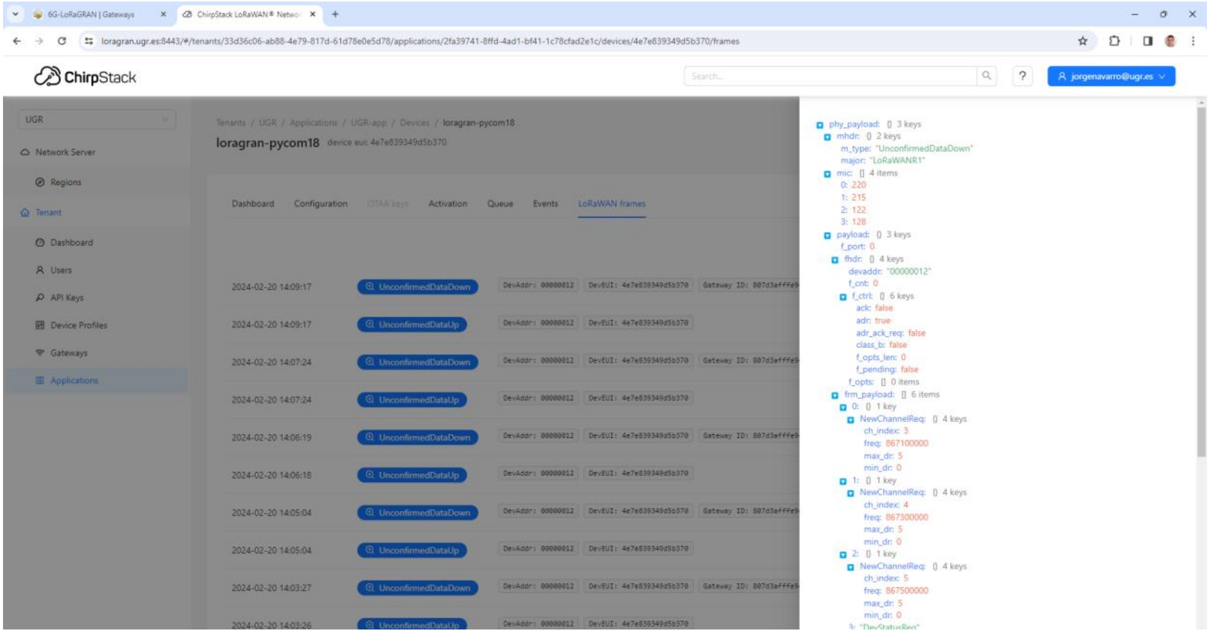

Figure 18. ChirpStack – LoRaWAN frames of one device in the application server.

For more information about the functionalities of the ChirpStack platform, please refer to its web page [9].

3.9 Subscribe to an MQTT broker to receive LoRaWAN frames in real-time

The ChirpStack platform [9] includes the publication of LoRaWAN frames received by the application server (which includes the radio link conditions and the transmission parameters) to an MQTT broker [10]. In our case, it publishes these frames onto the MQTT broker of the 6G-LoRaGRAN platform, which has been customized so that users will only see the frames from your experiments.

Users can use any MQTT client to subscribe (receive) to these frames. For that, they will have to download the MQTT broker certificate at https://loragran.ugr.es/libs/ca.crt and configure their MQTT client with their username and password from the 6G-LoRaGRAN platform. As an example, users could use the following commands in Ubuntu:

```
$ sudo apt-get update
$ sudo apt-get install mosquitto-clients
$ mosquitto_sub -h loragran.ugr.es -p 31883 -u <username> -P <password>
  -t "application/<application ID in ChirpStack>/#" --cafile <path to ca.crt>
```

This information, including user's `application ID`, is included on the home page (Figure 19). Last 10 MQTT messages are also included.

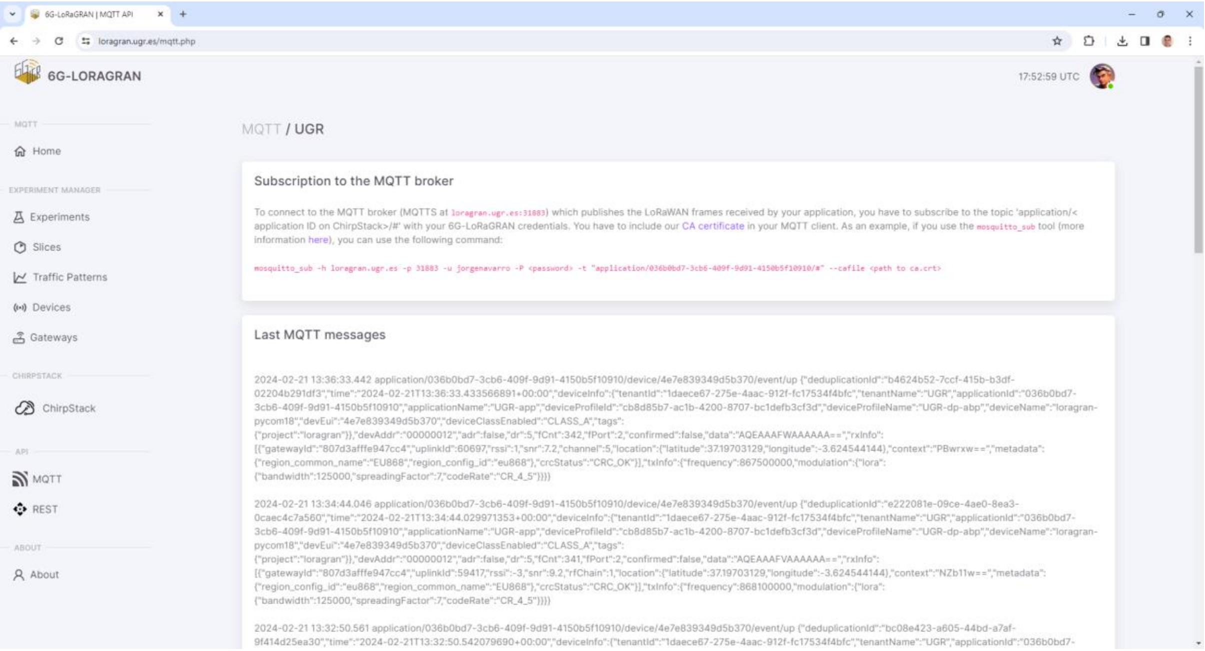

Figure 19. Instructions on the home page to subscribe to the user's MQTT topic.

With these frames, users can check the transmission parameters (e.g. the channel, the spreading factor, etc.) employed by each device and its radio link conditions (e.g. RSSI, SNR, etc.). You may use this information for resource allocation algorithms considering network slicing or for any other research, for example, by implementing a Python program with the *paho-mqtt* library [11]. In the next subsection we will explain how to obtain information from the 6G-LoRaGRAN platform and modify its parameters in real-time.

3.10 Use the REST API to check, verify or modify the settings of the experiment in real time

The 6G-LoRaGRAN platform includes a REST API which allows users to request the status and configuration of the Experiment Manager and to modify its parameters. This REST API can be tested directly using the "REST API" menu or by sending HTTP requests from, for example, a Python program (which may receive MQTT data as commented).

To use the web interface for the REST API ("REST API" menu, or directly https://loragran.ugr.es:9443/docs), a user has first to "authorize" its usage, i.e. press the "Authorize" button and enter his/her username and password from the 6G-LoRaGRAN platform (Figure 20). The authorization token required for the REST API can also be obtained using the "GET /token" request with the user's username and password. This is required for any other REST API request.

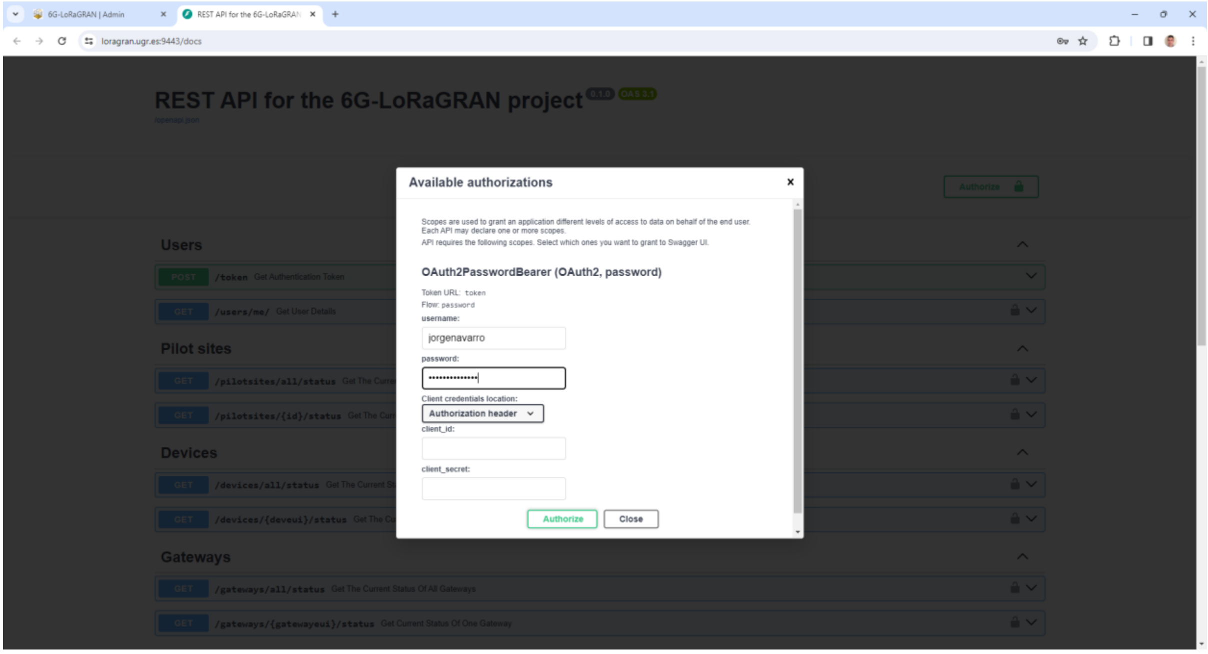

Figure 20. REST API – Authorization.

After that, the user can select any of the following methods:

- Users:
  - GET /token (get authentication token)
  - GET /users/me (get user details)
- Pilot sites:
  - GET /pilotsites/all/status (get the current status of the connectivity towards all pilot sites)
  - GET /pilotsites/{id}/status (get the current status of the connectivity towards one pilot site)
- Devices:
  - GET /devices/all/status (get the current status of all devices)
  - GET /devices/{deveui}/status (get the current status of one device)
- Gateways:
  - GET /gateways/all/status (get the current status of all gateways)
  - GET /gateways/{gatewayeui}/status (get the current status of one gateway)
- Experiments:
  - GET /experiments/all (get all experiments data)
  - GET /experiments/current (get the current experiment)
  - GET /experiments/{experiment} (get one experiment data from this tenant)
  - GET /experiments/{experiment} (get the slices and traffic patterns of all devices for a given experiment)
  - GET /experiments/{experiment}/devices/{deveui} (get the slices and traffic patterns of one device for a given experiment)
  - POST /experiments/{experiment}/devices/{deveui}/slices/{slice_id} (set the slice for one device during a given experiment, and set channel to periodic (0))

  - POST /experiments/{experiment}/devices/{deveui}/channel/{channel} (set the channel for one device during a given experiment (0 to periodically hop between all channels))
  - POST /experiments/{experiment}/devices/{deveui}/trafficpatterns/{pattern_id} (set the traffic pattern of one device for a given experiment)
- Traffic patterns:
  - GET trafficpatterns/all (get all traffic patterns data from this tenant)
  - GET /trafficpatterns/{pattern_id} (get one traffic pattern data from this tenant)
  - POST /trafficpatterns/{pattern_id} (create or modify one traffic pattern for this tenant)
  - DELETE /trafficpatterns/{pattern_id} (delete one traffic pattern from this tenant)
- Slices:
  - GET /slices/all (get all slices data from this tenant)
  - GET /slices/{slice_id} (get one slice data from this tenant)
  - POST /slices/{slice_id} (create or modify one slice for this tenant)
  - DELETE /slices/{slice_id} (delete one slice from this tenant)

Figure 21 presents these methods in the web UI.

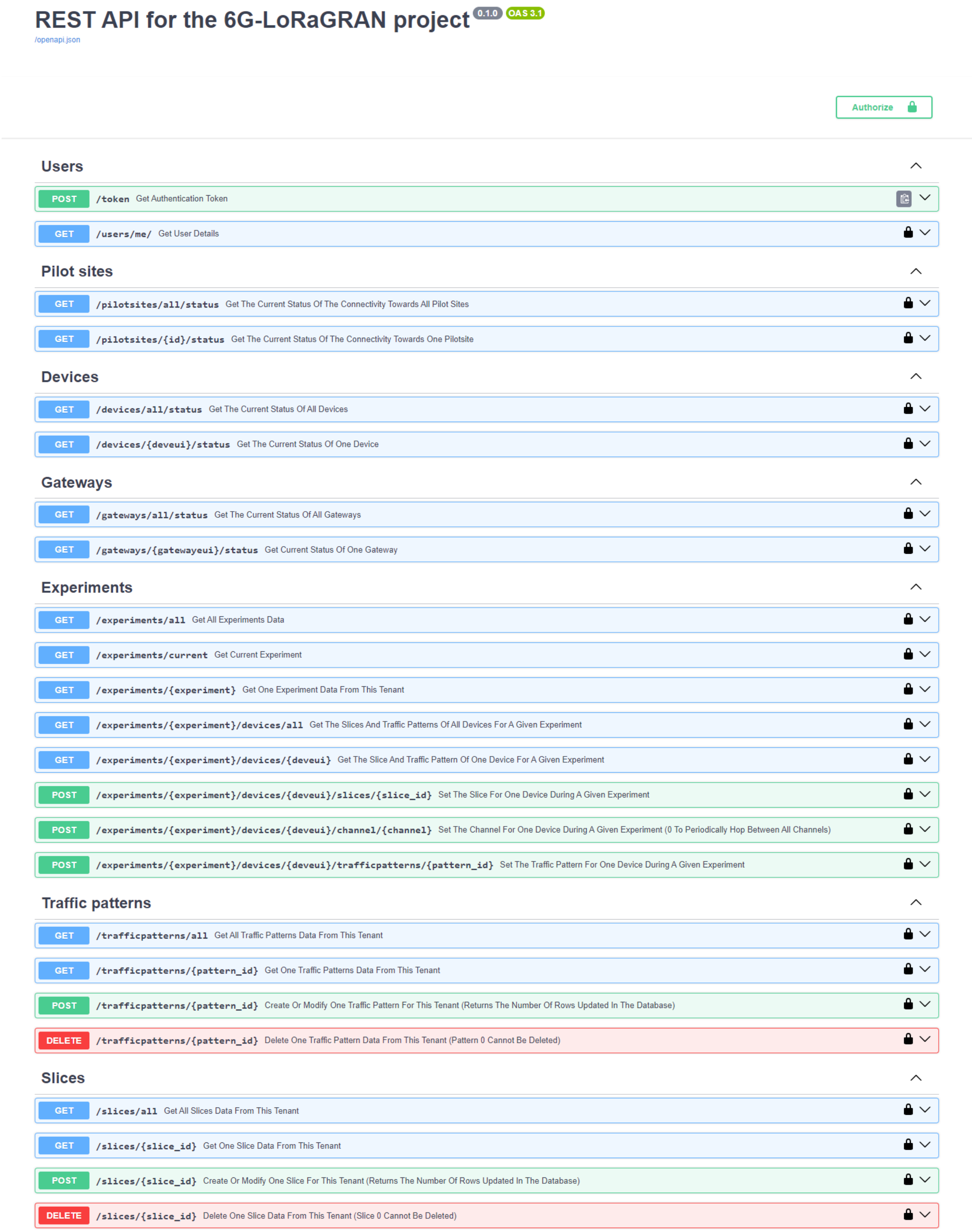

Figure 21. REST API methods for 6G-LoRaGRAN.

As examples, Figure 22 shows the status of the connectivity towards the supported pilot sites (direct connection, Berlin and Malaga). As shown, the web UI includes the HTTP command (using the *curl* tool) to receive this information from, for example, a Python program. Similarly, Figure 23 shows the data (pilot site, start and stop times) of all the experiments (anonymized if the tenant is different).

Finally, Figure 24 shows how to modify the channels assigned to a network slice in real-time using the REST API.

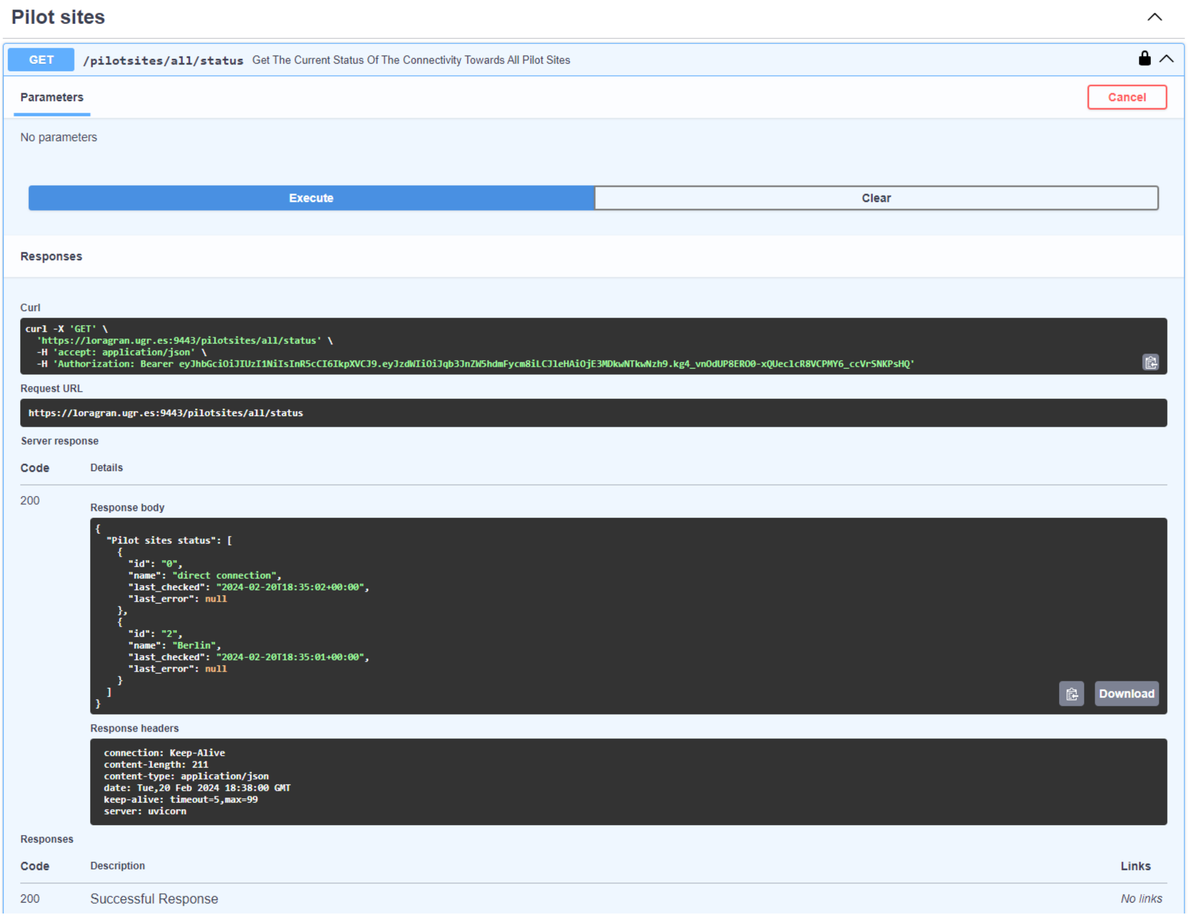

Figure 22. REST API – GET /pilotsites/all/status.

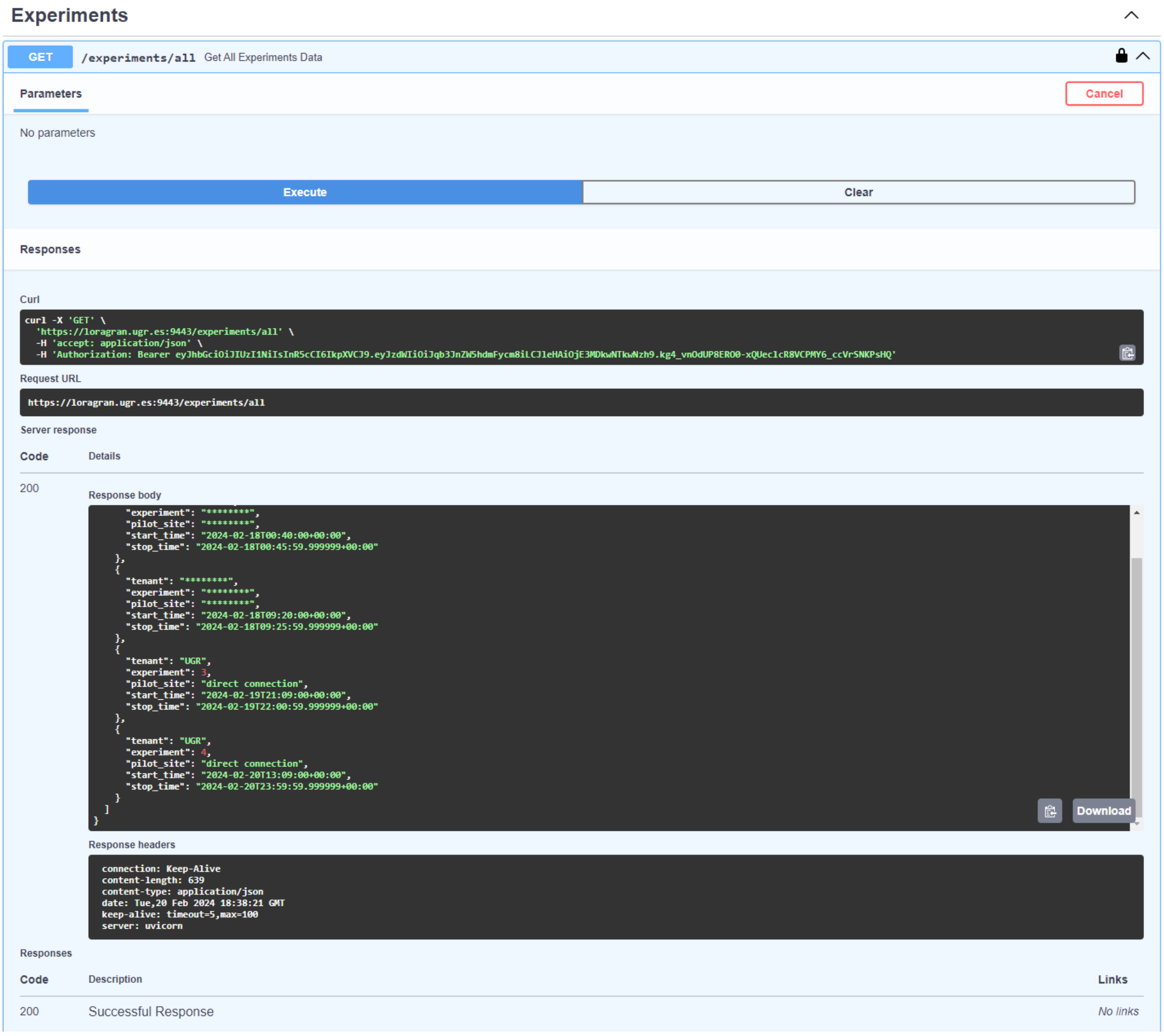

Figure 23. REST API – GET /experiments/all.

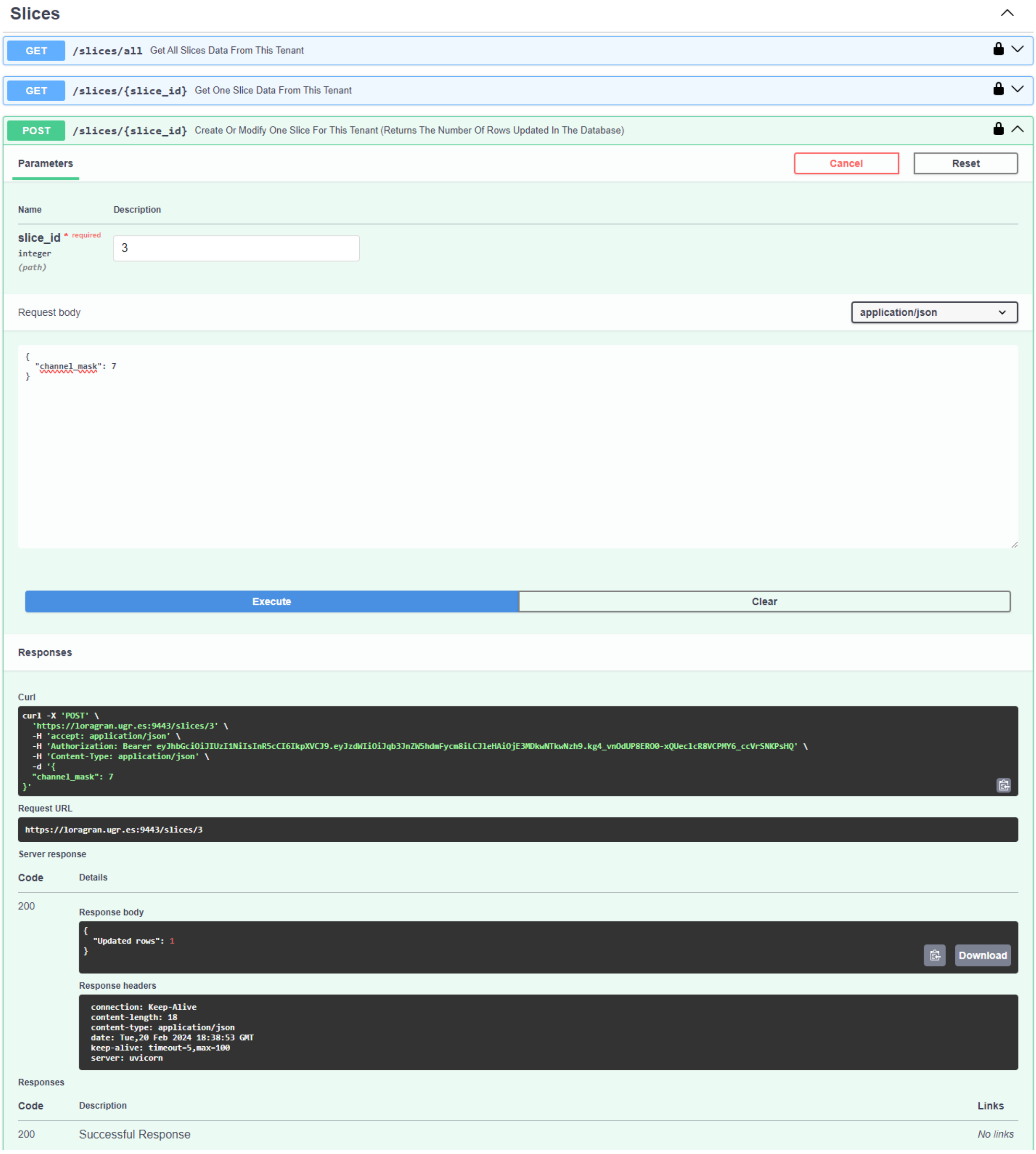

Figure 24. REST API – POST /slices/{slice_id}.

4 Conclusions

This document offers an overview of the infrastructure and functionalities integrated into the 6G-SANDBOX project's portfolio through collaboration with the 6G-LoRaGRAN project. Furthermore, it includes a comprehensive user manual for researchers interested in utilizing the 6G-LoRaGRAN platform.

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