MONROE

Measuring Mobile Broadband Networks in Europe

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Deliverable User manual
MONROE Platform User Manual

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Abstract

This document describes the processes that MONROE experimenters need to follow to create, run, monitor and collect results from their experiments.

Participant organisation name	Short name
SIMULA RESEARCH LABORATORY AS *(Coordinator)*	SRL
CELERWAY COMMUNICATION AS	Celerway
TELENOR ASA	Telenor
NETTET SVERIGE AB	NET1
NEXTWORKS	NXW
FUNDACION IMDEA NETWORKS	IMDEA
KARLSTADS UNIVERSITET	KaU
POLITECNICO DI TORINO	POLITO

Contents

1 Introduction

The purpose of this document is to guide MONROE experimenters through the process of creating, running and monitoring their experiments, and the subsequent collection of results. It first explains how the experiments must be prepared inside Docker containers, the testing process they must undergo before they can be deployed into MONROE's nodes, and how they must be uploaded to a repository for deployment into the nodes. Then, it explains the basics of the web interface that allows provision of resources and the scheduling of experiment executions. Finally, it shows how the experiment results can be retrieved either directly from the experiment itself or from the repository provided by MONROE.

1.1 MONROE nodes hardware

The MONROE platform has gone through a complete process of analysis and redesign to adapt to the new hardware available in the market and overcome some of the issues encountered in the first design. The following paragraphs explain the main characteristics of each design.

1.1.1 First design

Originally, the MONROE platform presented a set of homogeneous nodes, each of them with three MiFis. The nodes were based on a PC Engines APU1D4 board with the following characteristics:

- 1 GHz 64-bit dual core AMD Geode APU.
- 4 GiB RAM.
- 16 GiB SDD.
- Three miniPCIe slots, one of which supports a 3G/4G modem.

Each node had also one WiFi adaptor, an external USB hub with per-port-power-switching (PPPS) and three ZTE MF910 LTE CAT4 MiFis. Figure 1 shows the first design of the nodes.

1.1.2 Second design

The new MONROE design presents a heterogeneous set of nodes grouped in pairs:

- “Head,” with two Sierra Wireless LTE Cat6 modems.
- “Tail,” with one Sierra Wireless LTE Cat6 modem and one WiFi adaptor.

Figure 2 shows the current node design. Both types of nodes are based on a PC Engines APU2D4 motherboard with the following characteristics:

- 1 GHz 64-bit quad core AMD Geode APU.
- 4 GiB RAM.
- 16 GiB SDD.
- Three miniPCIe slots, two of which support a 3G/4G modem.

The new node design does not support a dedicated management MBB interface. Thus, additional measures have been taken to minimize the interference of background traffic with user experiments. In particular, most maintenance operations (except optionally the transfer of user results) are paused during experiment execution. Also, a fix hour is reserved for maintenance in all nodes every day.

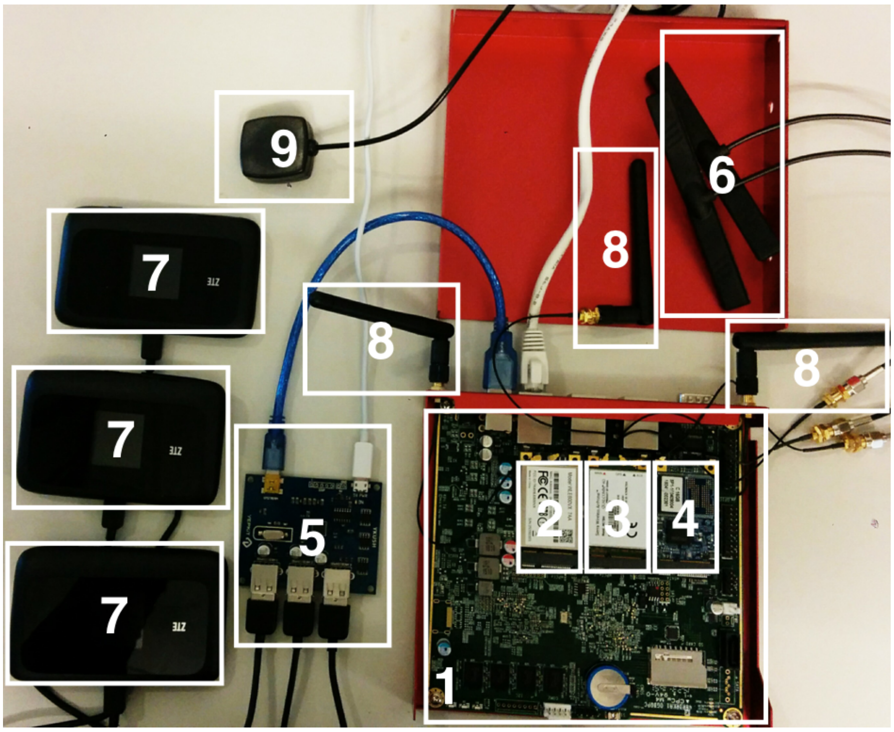


Figure 1: First system design. 1) PC Engines APU board. 2) WiFi adaptor. 3) Internal 4G Cat3 Sierra Wireless modem for management. 4) SSD. 5) USB hub. 6) Internal 4G modem antennas. 7) ZTE MF910 LTE Cat4 MiFis. 8) WiFi antennas. 9) GPS antenna.

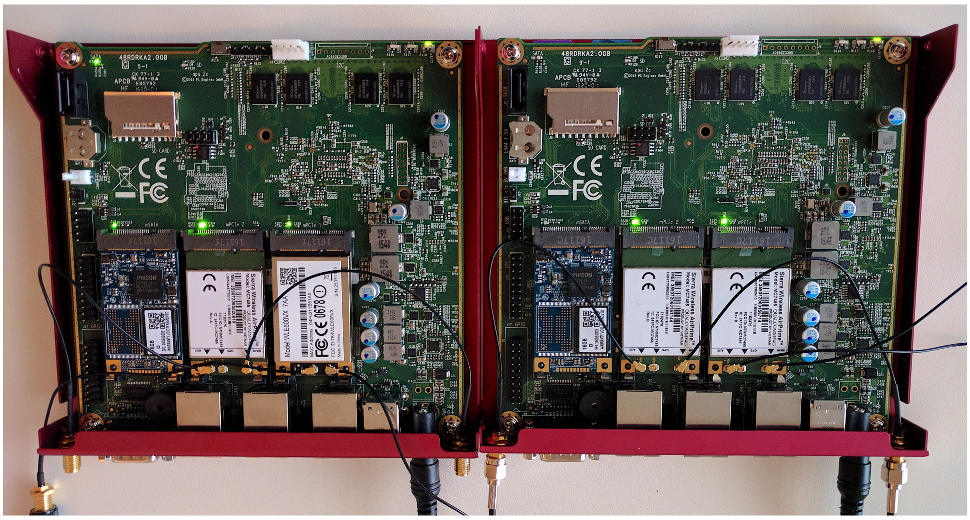


Figure 2: Second system design. Left: Tail node with one LTE Cat6 modem and one WiFi adaptor. Right: Head node with two LTE Cat6 modems.

1.2 Overview of the node configuration

MONROE nodes have been designed to have minimal impact on the experiments that run on them. Therefore, only one experiment can run at a given time in a node. Although the experiments are executed inside a Docker container, they have no quotas on CPU or memory usage, subject only to available node resources. Container image size and temporary storage in the node may be restricted, though.

Every MONROE node runs, in addition to user experiments, the following background processes:

- The experiment scheduler, which arbitrates the execution of user experiments in the node. The scheduler runs permanently in the background and contacts periodically the scheduling server, sending "heartbeats" and checking for new schedules for the node. When an experiment is not running, the scheduler may start the deployment of the containers for one or several experiments scheduled to be run in the immediate future, so that they are prepared on advance. The scheduler checks the duration of the slot assigned to an experiment; if the experiment does not finish on time, it stops the whole container.
- Synchronization (rsync) services to copy data files to the MONROE repository. This service copies user experiment results, the data collected by passive experiments and assorted metadata measurements. It runs continuously, transferring files to the server as they appear in the corresponding folders. This service uses the management interface, which is different from the interfaces available for the experiments. However, the management interface may share in some cases the same subscriber contract with one of the experiment interfaces; operators might restrict the total bandwidth available for all the SIMs linked to the same contract. Additionally, two modems (management plus experiment) using the same operator antenna may somehow affect the bandwidth available for the experiment. Therefore, experimenters should be aware of the small amount of data that can be transferred by this service in parallel to their experiments.
- Several systems run continuously in the background gathering information on the status of diverse components. Examples include a service to read the signal strength and network configuration of each of the experiment modems, the GPS data and various node parameters such as CPU load, memory usage or CPU temperature. These services run continuously in the background with a frequency that varies from one second up to several minutes. Although their impact on user experiments should be minimal, their existence must be known by the experimenters.
- In addition to the services that gather metadata, MONROE nodes keep several containers active all the time. These containers run experiments that are deemed basic for the MONROE platform and include:
  - A ping experiment. Container number 1 executes continuously an ICMP ping operation to a fixed external server (currently, Google's DNS at 8.8.8.8). The RTT values are collected and transferred to the servers. The ping experiment runs continuously with a frequency of one second, for every interface.
  - A container that runs Tstat, the passive mPlane monitoring probe that collects, for each interface, detailed flow level statistics. The Tstat container generates no traffic; flow level data is synchronized to the MONROE repository using the standard synchronization process described above.
- Finally, some built-in MONROE experiments run as scheduled containers. These experiments will not run at the same time than user experiments:

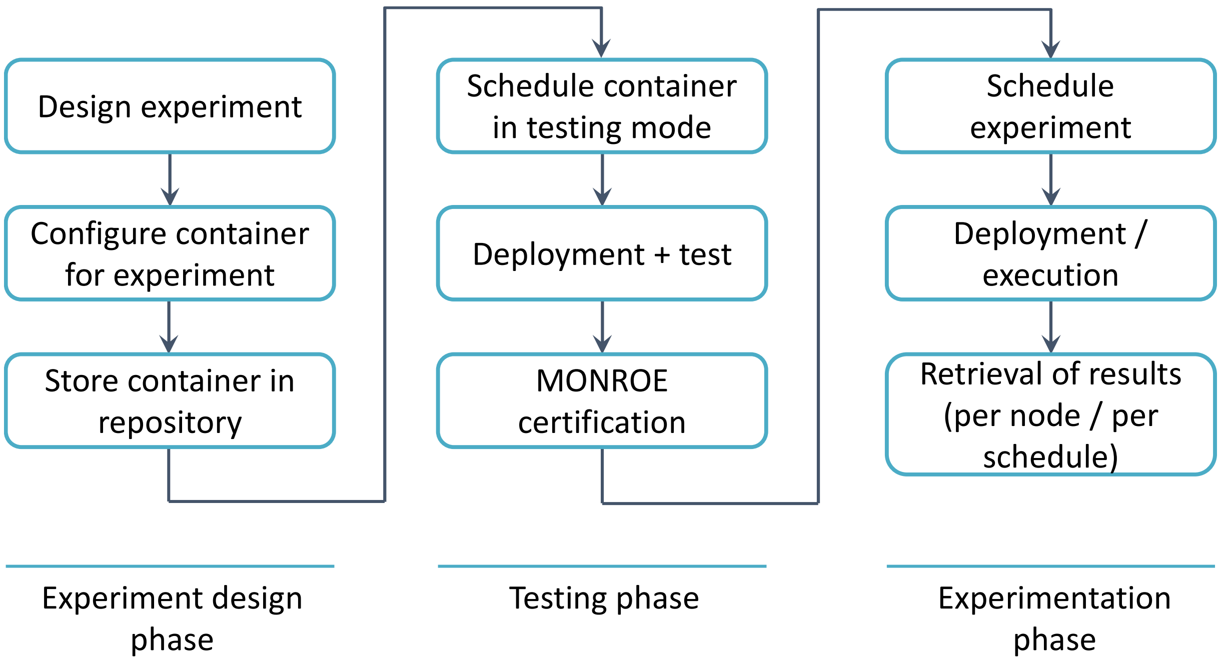


Figure 3: Experimental workflow.

- A bandwidth measurement test, which periodically downloads an object using the HTTP protocol to measure the achievable bandwidth. The test runs on each interface. The periodicity of this experiment and whether it can be run while user experiments are being executed are yet to be decided.
- A container that periodically executes a paris-traceroute to several popular websites recording information about all the intermediate hops. This container will in principle be run several times per day, but the interactions with user experiments are yet to be determined.

1.3 Overview of the experimental workflow

Experiments conducted in the MONROE platform follow the workflow shown in Figure 3, which consists of three phases: Experiment design, testing and experimentation. During the experiment design phase, the experiment goals and properties are defined and the container required to deploy it in MONROE nodes is configured. During the testing phase, the container is executed on nodes specifically devoted to testing new experiments. If the experiment passes all the safety and behavior tests, a MONROE manager will digitally sign the container image. Signed containers cannot be further modified without running again through the testing phase. Finaly, the experimenter is free to schedule the experiment container on any nodes, subject to the specific quotas assigned to their project.

2 Experiment preparation

2.1 General experiment notes

MONROE experiments run under the root user of a Docker container. Therefore, experimenters can design any kind of experiment within the security restrictions of the platform, including the configuration of routing tables, stopping or starting interfaces and executing any kind of applications. We assume the reader is familiar with the Docker technology. Otherwise, we suggest getting used to it by accessing the documentation at https://docs.docker.com/engine/understanding-docker/.

Creating and using containers is a two-step process. At design time, the experimenters create the image for the container in their local machine using a container-creation script. If necessary, they can install new packages (e.g., via apt-get) or copy libraries. The docker tools read the script and create the final image for the experiment, which will then have to be uploaded to a repository. At run-time, the nodes retrieve the container image from the repository and start it as scheduled.

During execution, the experiment should not install additional applications or download any data that is not part of the experiment itself (e.g., if the experiment uploads a file to a server to test upstream speed, either include the file to be uploaded in the container at design time or create it locally).

⇒ *Experiments will under no circumstances allow direct ssh access to the node or any other form of running interactive commands from outside the container that can pose a security risk for the platform.* ⇐

2.2 Container preparation

MONROE experiments are deployed in Docker containers (https://www.docker.com/). Preparing a new container from MONROE's base image is an easy process:

1. Install Docker in your machine. Do it preferably downloading the installation script from the web page, rather than through a package manager such as apt-get:

   ```
   $ wget https://get.docker.com -O install.sh
   $ chmod u+x install.sh
   $ ./install.sh
   ```

   You will have to run docker as root unless you add yourself to the docker group.

   Mac users: Download and install "Docker for MAC"
   (https://www.docker.com/products/docker#/mac)
   or the "Docker Toolbox"
   (https://docs.docker.com/toolbox/overview/), according to your OS version.

2. Test the Docker installation with the 'Hello world!' example:

   ```
   $ sudo docker run hello-world
   Unable to find image 'hello-world:latest' locally
   latest: Pulling from library/hello-world
   03f4658f8b78: Pull complete
   a3ed95caeb02: Pull complete
   Digest: sha256:xxxxxxxxxxxxxxxxxxxxxxxx
   Status: Downloaded newer image for hello-world:latest
   ```

   If everything has worked correctly up to here, you will see a welcome message similar to the following:

   ```
   Hello from Docker.
   This message shows that your installation appears to be working correctly.
   ...
   ```

   You can check which images are locally installed with:

   ```
   $sudo docker images
   REPOSITORY    TAG      IMAGE ID       CREATED        SIZE
   hello-world   latest   690ed74de00f   4 months ago   960 B
   ```

3. Now you are ready to download the MONROE base image:

```
git clone https://github.com/MONROE-PROJECT/Experiments.git
```

   This will fetch the repository with MONROE's example containers.

4. Head to `Experiments/experiments/template/`. Here, you will find the required files to prepare your image based on MONROE's base. You should care about four things: a) The contents of the `files/` folder, b) the `build.sh` file, c) the `push.sh` file and d) the `template.docker` script file that describes how to create your container. In the directory `files/` you can put all the files that are part of your experiment. As a simple example, we can use the following script:

```
$vi files/myscript.sh
  #!/bin/bash
  ls -lah > /monroe/results/listing.txt
```

   Any files that your experiment creates in `/monroe/results` are delivered to the repository, where you will be able to retrieve them. *Writes to any other part of the filesystem will be lost once the experiment is finished.* In periodic schedules, no data will survive from one execution to the next (i.e., the container is loaded fresh before each execution). If result persistence is needed, the experimenter will have to supply it by downloading the needed files from the network during the experiment itself.

5. You should not need to modify the `build.sh` file. The name of the container is the name of the current directory, and it must match the name of the `.docker` file (e.g., `template.docker` as we are in a folder named `template/`).

6. The file `template.docker` is the script used to build your container. You can modify it to:

   - Define the entry point of your experiment ("ENTRYPOINT").
   - Change the base image of the container, e.g., `monroe/base`.
   - Install additional packages or libraries.

   For example:

```
FROM monroe/base

MAINTAINER your-email-address

COPY files/* /opt/monroe/

#Default cmd to run.
ENTRYPOINT ["dumb-init", "--", "/bin/bash", "/opt/monroe/myscript.sh"]
```

   This example will copy the files in the `files/` directory to the one you specify *inside* the docker container (e.g., `/opt/monroe`).

   TIP: If you need to install additional packages in the container, be sure to clean any temporary files from the image. Also, notice that the Docker creation script analyses the contents of the container filesystem after every line in the .docker script is executed. That means that, even if you delete files at the end, Docker will create intermediate "layers" that will be downloaded and applied sequentially to build the final image of your container. Consider instead using one-liners such as the following:

```
    RUN apt-get update && apt-get install -y vim && apt-get clean
```

   This will ensure that the files are deleted before Docker analyses the filesystem.

7. Modify the file `push.sh` to reflect the name of your repository:

```
#!/bin/bash
DIR="$( cd "$( dirname "${BASH_SOURCE[0]}" )" && pwd )"

CONTAINER=${DIR##*/}

CONTAINERTAG=myuser/myrepo # --> Modify to your own dockerhub user/repo

docker login && docker tag ${CONTAINER} ${CONTAINERTAG} && docker push ${CONTAINERTAG} && \
    echo "Finished uploading ${CONTAINERTAG}"
```

   During the development phase of your experiment, follow these steps to make your container accessible for the testing nodes:

   - Create an account at Docker Hub.
   - Create your own repository (you can create one container as private; no limits for public ones). Containers for deployment on MONROE nodes must be public.
   - In your development machine, run: `docker login`. It will ask you for your credentials.

8. After populating the `files/` directory, modifying the .docker file and updating the `push.sh` file, you are ready to create the image:

```
$sudo ./build.sh
Using default tag: latest
latest: Pulling from monroe/base
Digest: sha256:6df1195a3cc3da2bfe70663157fddc42e174ec88761ead7c9a3af591e80ebbd5
Status: Image is up to date for monroe/base:latest
Sending build context to Docker daemon 11.26 kB
Step 1 : FROM monroe/base
---> d1b4f4baa60d
Step 2 : MAINTAINER mikepeon@imdea.org
---> Using cache
---> 0b05b5c453c7
Step 3 : COPY files/* /opt/monroe/
---> acc2df443070
Removing intermediate container 66a666516a27
Step 4 : ENTRYPOINT dumb-init -- /bin/bash /opt/monroe/myscript.sh
---> Running in f4b7a1ee804a
---> 096c7a56ff1c
Removing intermediate container f4b7a1ee804a
Successfully built 096c7a56ff1c
Finished building template
```

9. Test that your new docker container is available:

```
$sudo docker images
REPOSITORY                              TAG    IMAGE ID     CREATED         SIZE
hello-world                             latest 690ed74de00f 4 months ago    960 B
your_docker_account/your_experiment     latest xxxxxxxxxxxx 32 seconds ago  626.6 MB
monroe/base                             latest xxxxxxxxxxxx 12 days ago     626.6 MB
```

   Exact image ids and sizes will vary.

10. Push the container image to the repository:

```
$ sudo ./push.sh
Username (your-Docker-user-name):
Password: (type your DockerHub password)
WARNING: login credentials saved in /home/your-username/.docker/config.json
Login Succeeded
The push refers to a repository [docker.io/mikepeon/template]
5f339bfdaae2: Pushed
486ab26686cc: Layer already exists
034f70c0d9cd: Layer already exists
86b5acd8772a: Layer already exists
f03317610243: Layer already exists
50f6c1bd7ce6: Layer already exists
aec5953bffa2: Layer already exists
507169b05eea: Layer already exists
5d799297d10c: Layer already exists
759d76df9ac7: Layer already exists
5f70bf18a086: Layer already exists
12e469267d21: Layer already exists
latest: digest: sha256:c855de65307191b4832b2ec60a4401c1b63424827c29149703c5d7ef07b519f7
size: 3001
Finished uploading your-username/template
```

11. You can now test that your image runs correctly, even on your own PC (if the experiment logic and resource demands allow for it).

```
$mkdir /run/shm/myresults
$sudo docker run -v /run/shm/myresults:/monroe/results your_docker_account/your_experiment
    --> The output of your experiment will be in /run/shm/myresults/listing.txt
```

The docker command line allows you to specify a mapping between a directory inside the docker image and one in the host system. In this case, we have mapped `/monroe/results` from the container to `/run/shm/myresults`. This is useful if you are running the container locally in a normal PC for debugging purposes.

IMPORTANT: This process shows how to build and run a container *locally* in your workstation. However, experimenters do not have direct access to the MONROE nodes. Therefore, to execute your experiment *in* a MONROE node, you will follow the process just up to the `sudo ./push.sh` step and then use the web interface to upload and schedule the container into the nodes.

You may check the contents of `experiments/*` for more useful examples.
The following is a list of useful common Docker commands:

- To list installed/built images (and get their ids):

  `docker images`

- To list running containers and get their tags:

  `docker ps`

- To stop running containers:

  `docker kill container-tag`

- To delete images:

```
docker rm -f image_id
```

- To retrieve the latest version of an image (e.g., `monroe/base`):

```
docker pull monroe/base
```

- To attach to a running container and get an interactive shell:

```
docker exec -i -t container-tag bash
```

2.2.1 Package and tool installation

If you have to install extra packages, libraries or tools, do it from the `my_experiment.docker` file. You should never pull repositories or download libraries from inside your experiment as this will count against your data quota (and execution slot) for every instance of your experiment. Instead, modify the container configuration file as in the following example:

```
FROM monroe/base

MAINTAINER your-email-address

RUN apt-get update && apt-get install -y \
    python \
    python-pip \
    traceroute \
    && apt-get clean
RUN pip install pygame

RUN mkdir -p /opt/yourname
COPY files/* /opt/yourname/

#Default cmd to run
ENTRYPOINT ["dumb-init", "--", "/bin/bash", "/opt/yourname/myscript.sh"]
```

You may also download any files using `wget`, but you may simply put them in the `files/` folder as well. Remember, this happens during container creation on your PC, *not* during experiment execution on the nodes.

If you find the need for big libraries that you think should go into the base image, please contact MONROE's administrators.

TIP: The easiest way to find out which packages and versions are available in the MONROE base image is to create a simple container and run an interactive batch session inside it in your workstation. For example, assuming that you have a basic container that simply waits when run, you may follow the following steps:

```
mkdir /run/shm/myresults
docker run -v /run/shm/myresults:/monroe/results repository/your_container &
docker ps --> Look for the tag of your running container
docker exec -i -t container_tag bash
--> Here you are inside the container
dpkg -l > /monroe/results/package-listing.txt
exit
--> You'll find the output at /run/shm/myresults/package-listing.txt
```

For easier reference, Table 8 in Appendix A gives a detailed listing of packages available in `monroe/base` at the time of writing this text.

2.3 Optional interactive debugging

To speed up the process of debugging experiments in the nodes, three debugging paths are provided.

First, experimenters can order (buy) a number of "development" nodes to be hosted locally in their premises. These nodes, which will not be accessible through the standard scheduler and user interface, can be accessed through local interfaces (eth, serial console) and provide root access.

Second, and only for "testing" nodes, the user interface includes an option to provide an SSH public key to the container. Once the container starts, experimenters can connect to monitor experiment progress. The SSH session can extend until the container finishes or is stopped.

Finally, a virtual machine containing a "virtual MONROE node" has been designed to ease development and debugging on a local PC. This virtual node replays metadata previously recorded from a real one.

2.4 Mandatory certification process

MONROE experiments have to be certified before they can be executed by deployed nodes. A small number of nodes are available through the user interface so that experimenters can test their experiments before starting the certification process.

The certification process consists of the following steps:

1. The experimenter contacts their patron to inform them that a new version of their experiment is ready for certification.

2. The experimenter has to provide a summary of the experiment, i.e., overall purpose, design and implementation (reasonable length around 0.5 to 1 A4 pages).

3. The container should be submitted as source (i.e., build scripts for Docker, not tools source code) for easy inspection by the patron. Additionally, this will allow the MONROE administrators to update the containers when a new version of `monroe/base` is available.

4. The patron, or the maintenance team, will then build (or pull) the container, tag it as `partnername/experimentname`, and push it to the deployed docker repository.

Every experiment submitted to the MONROE testbed *must* first pass through a testing process to receive manual approval by a MONROE administrator. To submit your experiment for testing, you have to use the web interface specifying "testing" as the required node type.

2.5 Deployment

MONROE's scheduling system will automatically deploy experiments to the nodes before their execution time. The nodes will fetch the container image from the Docker repository, and the size of the download will be accounted in your data quota. Notice that in the case of periodic experiments, each time an experiment is run, the Docker container may have to be re-downloaded and its costs will be accounted in your quota.

2.6 Life cycle of monroe/base

The current version of `monroe/base` deployed on nodes is tagged as "latest." New versions will be tagged as "staging;" their existence will be announced on the experimenters mail list. Experimenters must check their experiments against the new stagging version to verify that no incompatibilities appear. Any relevant issues can be discussed with the MONROE administrators. After a reasonable period of time, the new version will

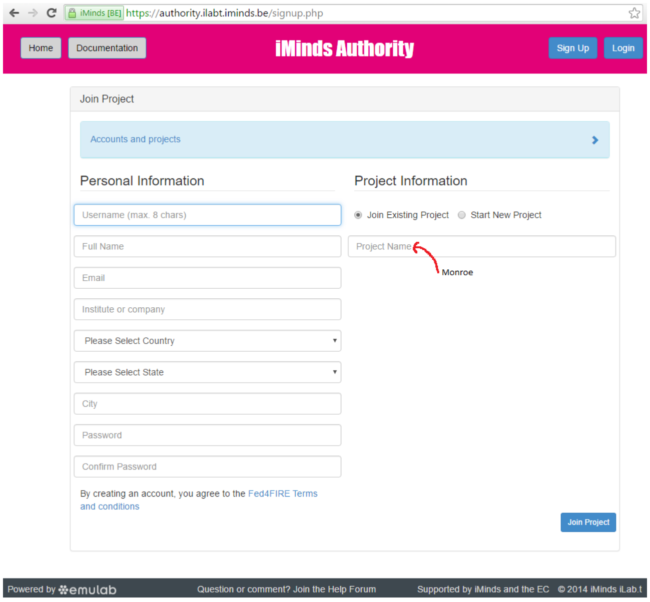


Figure 4: iMinds registration page to obtain FED4FIRE-compatible certificates for use with the MONROE platform.

be retagged as "latest," and deployed into the nodes. All the containers should have been built against the new version at this time to avoid wasting quota resources when they are deployed in the nodes.

3 Resource allocation, and experiment scheduling and monitoring

Once a experiment is configured as a Docker container, it can be scheduled multiple times under different conditions using the user client web located at https://www.monroe-system.eu.

3.1 User login and certificates

User identification in MONROE is achieved through client certificates. Every experimenter has their own certificate compatible with the FED4FIRE[1] federation. User certificates are issued by iMinds through the following URL: https://authority.ilabt.iminds.be/. New users must create a new account ("sign up"). Be sure to select the option "Join Existing Project" and type the name "Monroe" in the project name field (Figure 4). The authorization process involves a manual verification step by one of the MONROE administrators, so it will probably take one or two days.

Please, notice that the current policy for MONROE is to use one user certificate per project, shared between all the experimenters belonging to that project.

Once the identity of the experimenter is approved, they will receive an informative email. They should then log into the iMinds webpage to download the certificate files (PKCS12). These files must be installed in the experimenter browser. After that, the user should be able to access the user web directly. Upon request of the main (index.html) file, the browser will contact MONROE servers to verify that the user credentials are correct. In the case of any problems, the user will be presented with instructions on how to obtain a certificate. If the client certificate is verified successfully, they will be automatically redirected to the listing of their experiments.

[1] http://www.fed4fire.eu/

NOTE: User certificates are manually activated in the scheduling software. To use your certificate, please send its SSL ID (“fingerprint”) to one of the MONROE administrators (e.g., mailto:mikepeon@imdea.org). You may find it in the screen after pressing the “Try me” button, once the certificate is correctly installed in your browser:


```
{
"fingerprint": "c79f1967aea17811a1ebed39b7d718430904338a",
"user": {
    "id": 3,
    "name": "MONROE Test admin",
    "quota_data": 50000000000,
    "quota_storage": 500000000,
    "quota_time": 500000000,
    "role": "admin",
    "ssl_id": "c79f1967aea17811a1ebed39b7d718430904338a"
},
"verified": "SUCCESS"
}
```

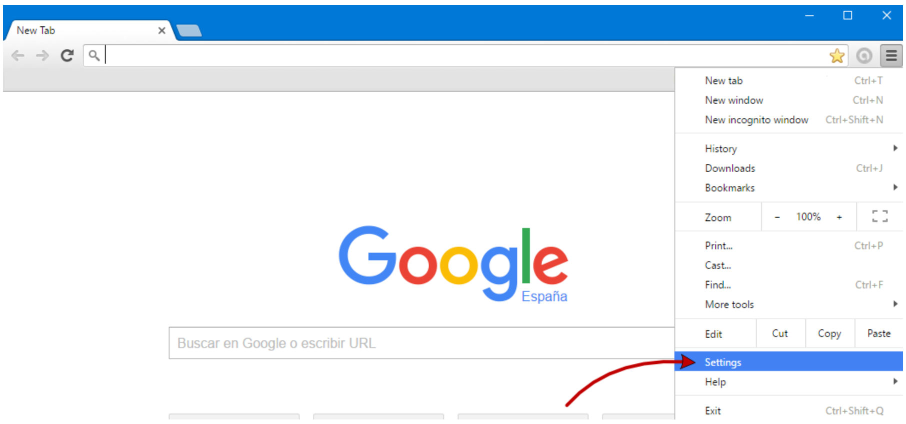

⇒ We have identified some common issues that are not yet solved. Below are some workarounds:

- For the first login, you may be asked for your user certificate and then your browser may show a security warning. This is due to the use of a self-signed server certificate. Please ask your browser to proceed. Then, you will probably see an error page from MONROE. Please, click the red button labeled “Try me” and check that you get a successful data output. Finally, please proceed again to the main page of the project. From that point, you should be able to access the system without further problems in future sessions. (Pointers on how to simplify this issue are welcome!)
- Firefox on OSX has an issue with CORS headers. Although the web and scheduling servers are running now on the same machine, you may still encounter this problem.

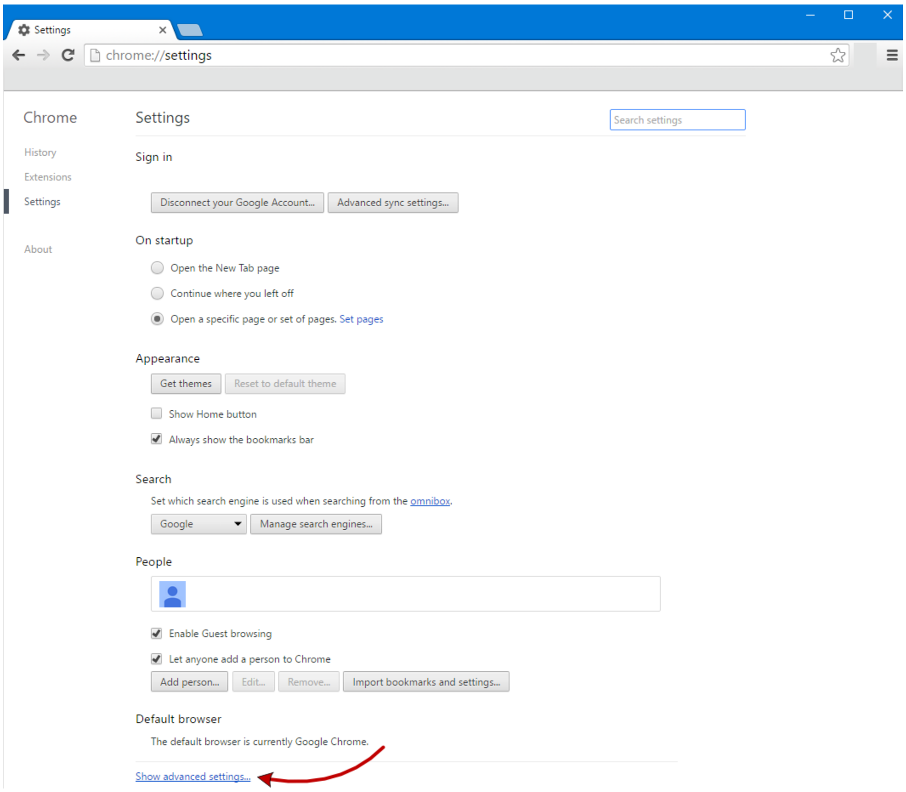
3.1.1 Installation of user certificates in Chrome

This section explains how to install the FED4FIRE-compatible user certificates used by the MONROE platform in Google Chrome for Windows. The procedure for other browsers and platforms should be similar.

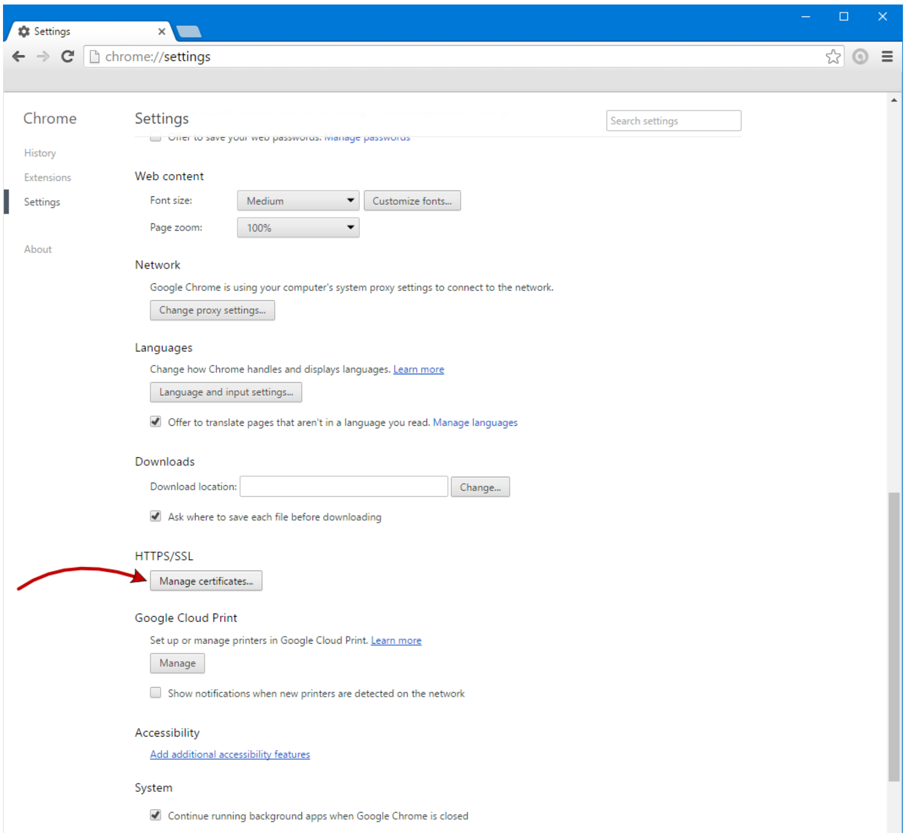
1. Go to your browser settings page:



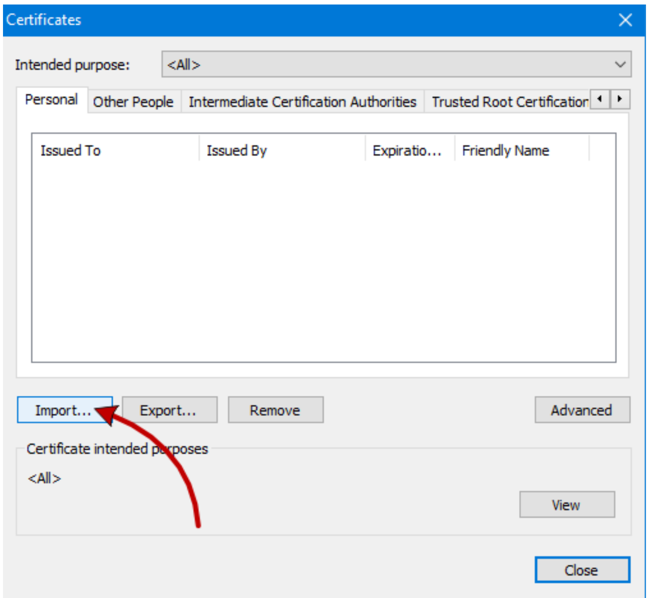
2. Display the advanced configuration settings:



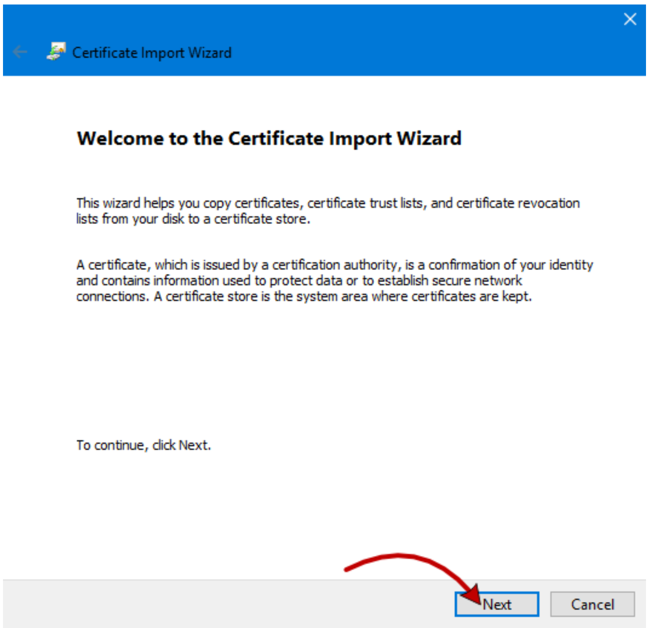
3. Go to the section labeled “HTTPS/SSL” and click the button “Manage certificates...”:



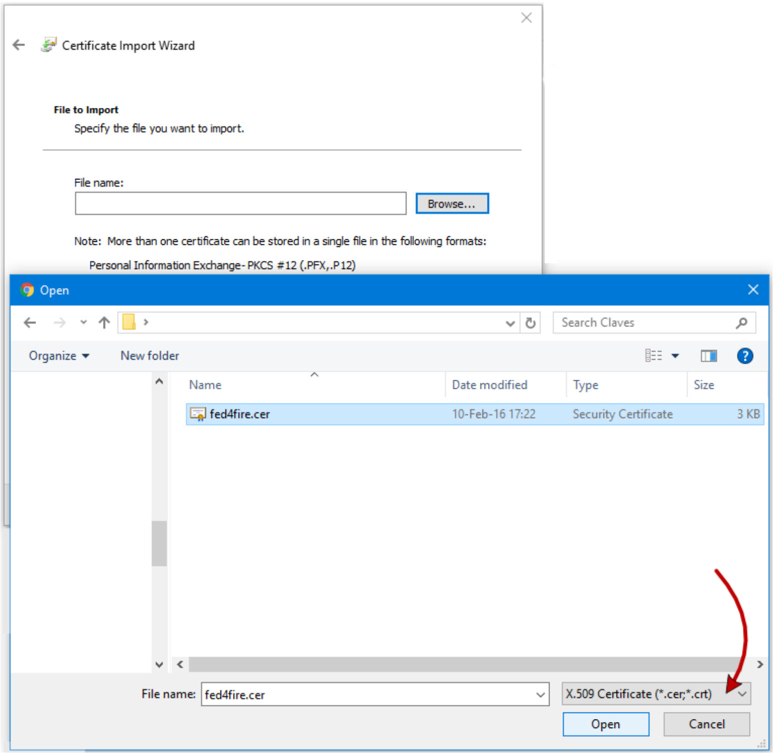
4. The dialog box for managing your certificates will be displayed. Press the button "Import..." to import your certificate:



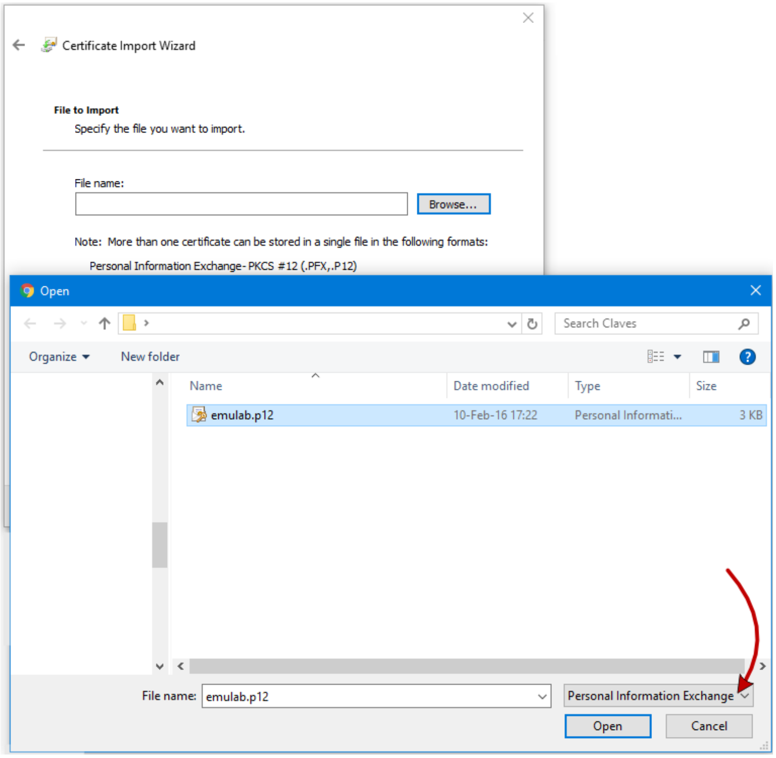
5. In the new dialog, click "Next":



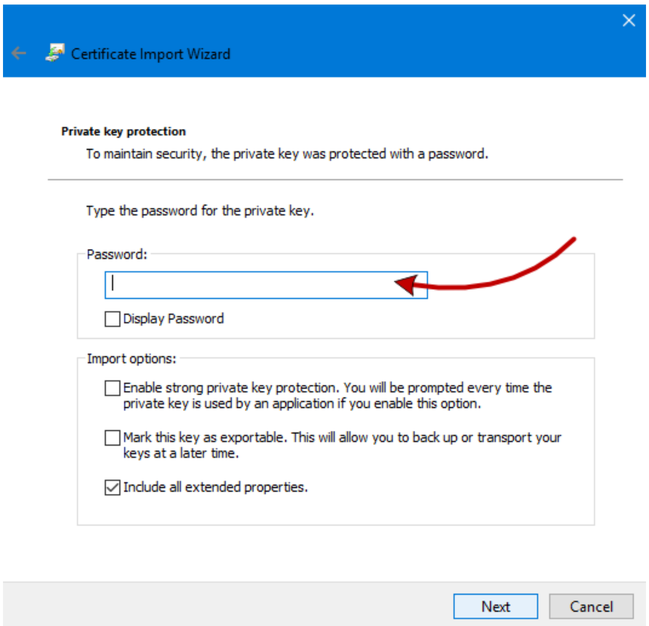
6. In the file-selection dialog that appears next, change the file type from “X.509 Certificate (*,cer;*.crt)” to “Personal Information Exchange”:



7. And select the file containing your certificate:



8. In the next dialog box, enter your certificate password:



9. If the import is successful, your certificate will be imported to your “Personal Store” and you will be able to access the MONROE user interface by selecting it when prompted by your browser. Notice that you may still get a warning about the validity of the server certificate.

3.2 Resource allocation

The "New" tab allows assigning resources and scheduling new experiments. Here, the user will be presented with a page similar to Figure 5.

To create a new experiment, at least the following parameters must be specified:

Name: A representative experiment description.

Script: A Docker hub path for the experiment container. In the previous example, it would be `your_docker_account/my_experiment`. Experiments on deployed nodes must be lodged in MONROE's repository: `monroe1.cs.kau.se:5000/my_experiment`.

Number of nodes: The number of nodes that must execute the experiment.

Duration: Length of the experiment execution, in seconds (excluding the time required to deploy the container). The node will kill the experiment after this time. The minimum slot that can be reserved is 5 min and the maximum, 24 h. However, because of the scheduling of MONROE experiments, the maximum possible duration is in practice slightly less than three hours.

If the starting date is fixed, the user can introduce it in the field "Start." All dates are introduced as UTC times; the interface presents alongside the corresponding local time for the user's browser. The scheduler will then try to satisfy the requirements.

Alternatively, if the starting date is not relevant, the user may leave this field empty and press the button "Check availability" to check the earliest available slot (add at least ten minutes to the proposed time to allow for container deployment into the nodes). If the user just wants to submit the experiment as soon as possible, they can just mark the option "As soon as possible" and leave the other fields empty when pressing the "Submit" button.

Additionally, the user may specify the following restrictions (Figure 6):

Country filter: The user may select nodes located in one or several countries, or they may choose to use nodes from any country indistinctly.

Node type: Currently available node types are deployed or testing. The testing nodes are reserved for experiments that must still be verified by a MONROE administrator. Experiments on deployed nodes must be lodged in MONROE's repository: `monroe1.cs.kau.se:5000/`.

Node model: Until complete retirement of the old MONROE nodes, experiments can run on old or new nodes. Eventually, all experiments will be run on new nodes.

Number of interfaces: New MONROE nodes come in pairs of co-located nodes, where one node ("head") has two 4G interfaces, and the other ("tail") has one 4G interface and one WiFi interface. Specifying the number of required interfaces for the experiment restricts the type of nodes that can be selected by the scheduler:

- One interface: The scheduler chooses only nodes with one 4G interface and WiFi (tails).
- Two interfaces: The scheduler chooses only nodes with two 4G interfaces (heads).
- Three interfaces: The scheduler chooses pairs of co-located nodes. In that case, the number of requested nodes must be even, as each pair is counted as two nodes. The assignment is atomic, i.e., either the complete pairs will be secured or the complete assignment will fail.

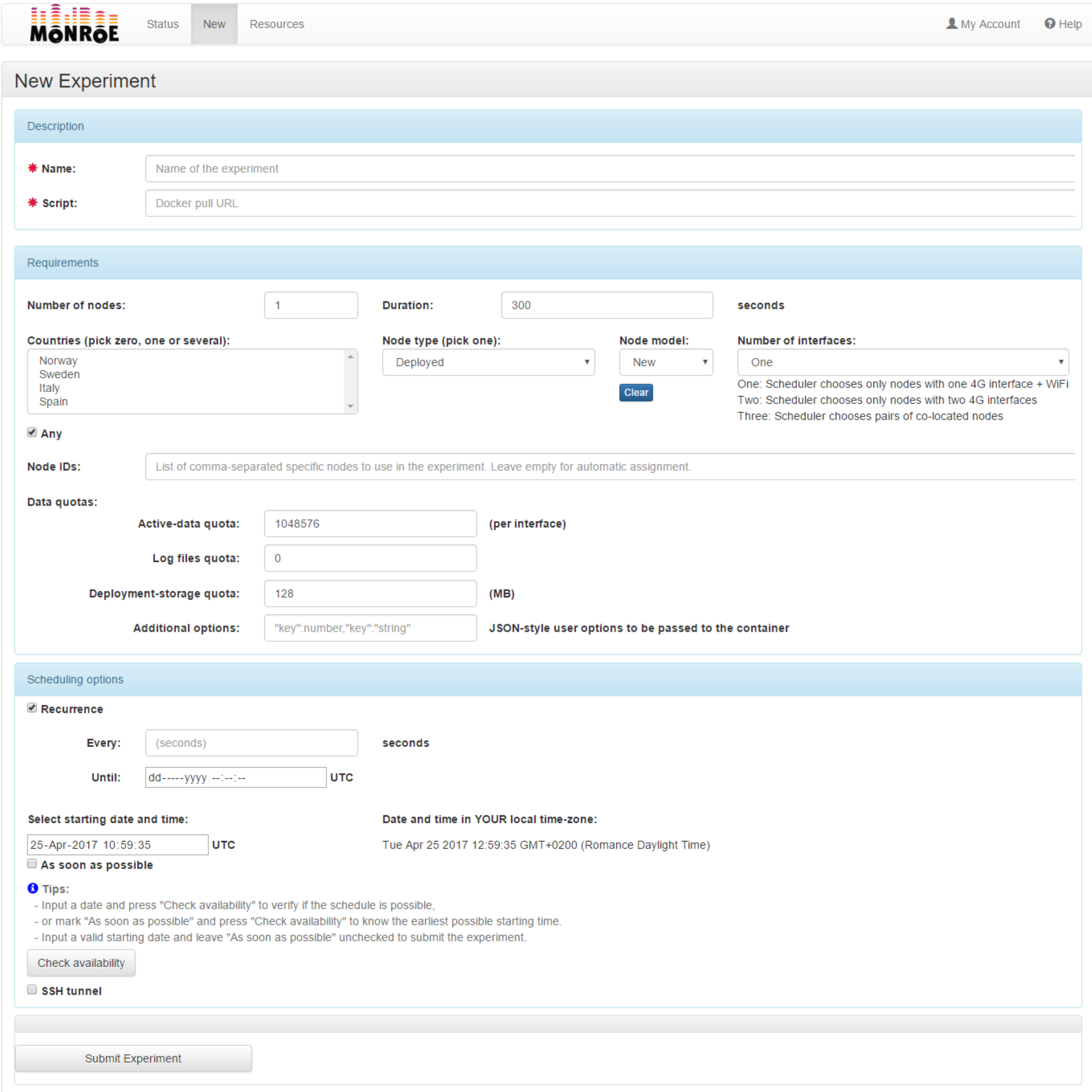


Figure 5: Example for the creation of a new experiment.

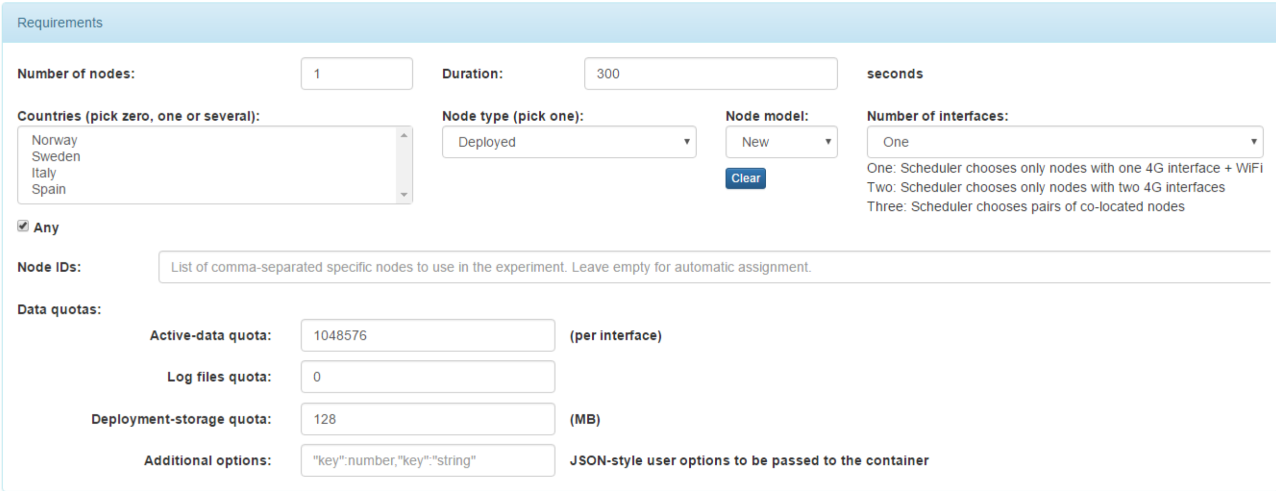


Figure 6: Filters for node selection.

The numbering of nodes follows the convention that the head in a pair receives number n and the co-located tail receives number $n+1$, where n is even.

Node IDs: If the experimenter wants to use a set of specific nodes, for example, to repeat one experiment under the very same conditions, it is possible to introduce a comma-separated list of required nodes, instead of accepting any available ones.

Active-data quota: The experimenter must specify the active-data quota for each interface, that is, the maximum amount of data that each interface can use. The scheduler checks this value against the quota available for the user.

Log files quota: The user may want to place an estimate on the maximum amount of data that may be generated as result files in `/monroe/results`. This is important because the size of the results is also counted against the user quota.

Deployment-storage quota: This is the size allocated for the container file system in the node. Bigger sizes require more time to deploy. The maximum limit is 1 GB.

Additional options: The user may provide a set of comma separated key-value pairs. These options will be appended to the JSON-formatted configuration file that can be read at run-time by the container at `/monroe/config`. This mechanism enables experiment parameterization.

3.3 Experiment scheduling

When all the requirements are specified, the user needs to click the “Submit experiment” button to submit to the scheduler. The experiments must respect several restrictions to be successfully scheduled:

- The starting time must be at least 10 min in the future, to allow time for container deployment.
- No experiment can be scheduled more than one month in advance.
- Periodic experiments must have a period greater than 3600 s. The finishing time must also obey the previous rule, that is, the last experiment instance in the recurrence must be scheduled in less than a month from the current time.

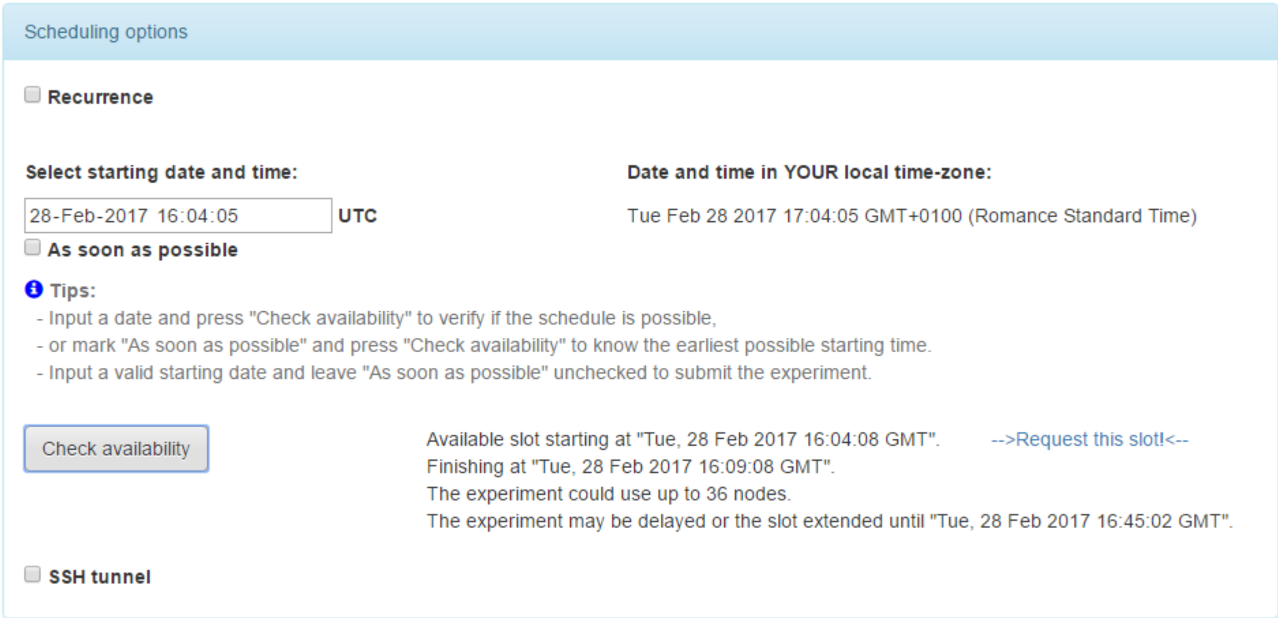


Figure 7: The scheduler may supply hints on the scheduling availability, including the earliest starting date that is possible, the end of the availability period for the required resources and the maximum number of nodes, with the specified requirements, that the experiment could reserve. In this example, the experiment can start on “2017-02-28 16:04:08 UTC” and can last until “2017-02-28 16:45:02 UTC.” The experiment can be scheduled with up to 36 nodes during this period.

- No experiment (or instance in a series) can last more than one day. In practice, the longest period that an experiment will be awarded is less than 3 h.
- If a list of specific nodes and a starting date are given, the scheduler may be unable to grant the required resources.

3.3.1 Recurrence

MONROE’s scheduler allows to specify experiments that need to be repeated periodically. In that case, the user has to specify the repetition period (≥ 3600 s) and the final stopping date. The scheduler will treat each repetition as a different experiment and will try to satisfy the requirements for each of them consecutively. However, the operation is atomic: Either all the repetitions are scheduled, or none are.

3.3.2 Checking availability

If the exact starting time is not relevant, the user can press the “Check availability” button. If the requirements can be satisfied, a message explaining when the experiment might be started will be displayed. Additionally, it will also inform of the maximum number of nodes that can be used during this period, and the maximum ending time. With these data, the experimenter may decide to increase the number of nodes that run the experiment, or increase its duration until the time that the scheduler is likely being able to grant. Figure 7 shows the answer of the scheduler for an availability query.

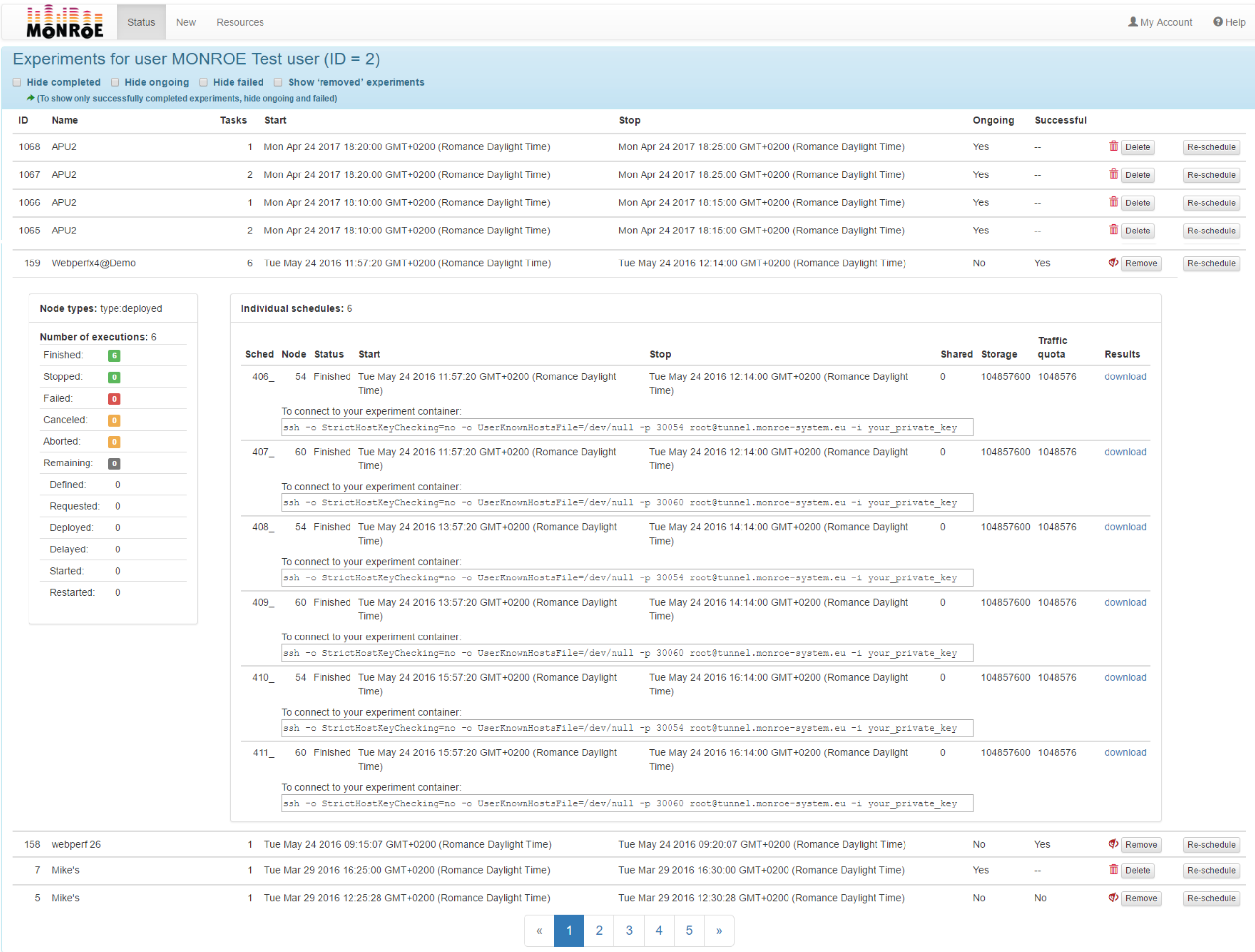


Figure 8: List of user experiments.

3.4 Experiment monitoring

Once an experiment is successfully submitted, the user can check its progress under the "Status" tab. Figure 8 shows an example of a list of experiments.

All the active (i.e., not completed) experiments for the user are shown. Experiments that have not yet been started can be canceled and deleted. However, the scheduler will try to stop experiments that have already started, but they will not be deleted from the list.

Clicking on any experiment displays the details for its individual schedules. There, the number of schedules that are defined but not yet deployed, the ones that are deployed and ready to be started, the ones that are currently running, etc., is summarized. One line is presented for each individual schedule on each MONROE node. Table 1 explains the states in which an individual task may be.

Some experiments may be designed to finish after completion. For those ones, the correct finishing state is "Finished." If they are stopped by the scheduler, they probably exceeded the execution time foreseen by the experimenter. However, other experiments may be designed to run continuously for a period of time. In those cases, the "Stopped" state could actually be the correct ending state as intended by the experimenter.

Table 1: Experiment states

STATE	DESCRIPTION
(Ongoing states)	
Defined	The experiment is created in the scheduler. If a task remains in this state past its starting time, the node was probably shut down and the task will not be executed anymore.
Requested	The node has requested the container and is deploying it.
Deployed	The node has already deployed the container and is waiting for its starting time.
Delayed	The scheduling process failed temporarily.
Started	The container is being executed in the designated node. The "download" link for the task results is already available.
Restarted	The node has restarted the experiment after a node failure.
(Final states)	
Finished	The task was correctly executed and it finished on its own before consuming the complete time slot.
Stopped	The task was correctly executed, but it was stopped by the scheduler at the end of the execution slot (correct for tasks designed to remain in execution until the end of their time slot).
Failed	The task stopped abnormally.
Canceled	The task was canceled by the user before being started (but other tasks in the experiment were already started).
Aborted	The task was aborted by the user after being started.

3.5 Command Line Interface

The MONROE scheduler REST API is normally used through the provided WEB interface. However, experimenters can use it directly to improve task automation. A complete command-line tool is available at https://github.com/ana-cc/monroe-cli.[2] The following paragraphs describe how to install and use the tool.

3.5.1 Installation

Installation prerequisites:

```
sudo apt-get install python3 python3-setuptools python3-cryptography
sudo pip install straight.plugin
```

From the directory that contains the tool sources:

```
python3 setup.py develop
```

The user certificate can be imported with:

```
$ monroe setup --cert MyCert.p12
Enter passphrase:
Your certificate files were stored in ~/.monroe
```

This feature depends on a recent version of OpenSSH. Alternatively, the cert/key files can be extracted manually and placed under `~/.monroe/` with the names `mnrCrt.pem` and `mnrKey.pem`.

[2]The command-line interface tool has been provided by Ana Custura, from the University of Aberdeen Court, in the context of the MONROE-PREC project.

3.5.2 Usage

The tool has integrated help:

```
$ monroe -h
 usage: monroe [-h] Command ...

 Monroe Cli

 optional arguments:
 -h, --help   show this help message and exit

 Experiment:
 The following commands can be used to create and submit experiments

 Command      Description
 create      Creates an experiment
 whoami      Displays MONROE user details
 quota       Displays MONROE quota details
 experiments
 Display recent experiments
 setup       Specifies MONROE user certificate to use for accessing the
 scheduler
 delete      Deletes an experiment
 results     Downloads the results for an experiment
```

Correct installation of the tool can be tested trying to retrieve the user identification:

```
$ monroe whoami
Authentication ID: 2, Name: MONROE Test user, Storage Quota remaining: 49597346816 bytes
```

User quotas can be easily retrieved:

```
$ monroe quota
2017-05-05 : Remaining time is 138888.00 hours.
2017-05-05 : Remaining storage quota is 46.00 GB.
2017-05-05 : Remaining data quota is 46.00 GB.
```

The tool allows retrieving the list of recent experiments:

```
$ monroe experiments
Experiment ID: 6798 Name: mike test on new nodes Script: steven76/headless Summary: {u'aborted': 1}
Experiment ID: 6799 Name: mike test on new nodes Script: steven76/headless Summary: {u'aborted': 1}
Experiment ID: 6800 Name: mike test on new nodes Script: steven76/headless Summary: {u'aborted': 1}
```

The results of an experiment can also be automatically retrieved:

```
$ monroe results --exp 6479
```

This command downloads the experiment results into `6479/sched_id`, for all the task IDs associated to that experiment.

For experiment creation, the tool supports defining SSH access to the container (in testing nodes), additional options and recurrence. Finally, the tool can be used as a library:

```
from monroe.core import *
```

4 Retrieval of metadata and experiment results

MONROE repositories contain two types of data: MONROE metadata itself and the results of user experiments.

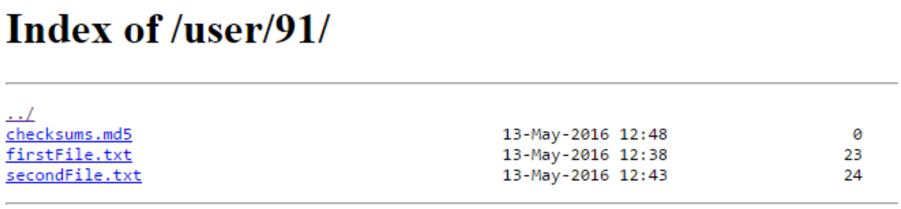


Figure 9: Folder containing the results of an individual schedule, transferred to MONROE's servers.

4.1 User experiment results

Any files written during the experiment to the `/monroe/results` directory will be synchronized to the experiment repository. This operation happens continuously during experiment execution and then upon its finalization. Therefore, it is advisable that only final files ready to be transferred are copied (indeed, mv'ed) to that location to avoid the system to sync temporary files and consume your quota or produce invalid results. This recommendation means that files in the results folder should not be updated; experimenters are encouraged to copy intermediate result files as soon as they are ready so they can retrieve partial results if the experiment fails in the middle of its execution.

The result files can be accessed through the user interface: For experiments that have already been started, the interface presents a link under the column "Results" that redirects the user to the HTTP folder (Figure 9) that contains the files already synchronized from the node where the experiment runs to the repository. In this way, the experimenter can retrieve result files even for partial experiments that fail or are canceled.

In addition, the experiment may use any network functionalities to communicate with outside servers as needed (e.g., `scp` some files to an external server). In order to improve safety, private keys should be restricted to the experiments and discarded after a reasonable time. Additionally, instead of saving your keys in the container itself, you may want to pass them as additional options during experiment scheduling. The values will be available during container execution as a JSON file at `/monroe/config`. Notice that this file is created by the node scheduler. The same effect is achievable when the containers are run manually in user development nodes adding the `-v` option to the command line. To map both a locally created config file and the results folder of the container to a node folder, in development nodes without a scheduler, the following command line fragment may be used:[3]

```
-v /monroe/results:/monroe/results -v /monroe/config:/monroe/config:ro
```

4.2 MONROE metadata

MONROE metadata can be freely accessed by two means. First, a CSV dump of all database tables is generated daily. The files can be accessed at the following URL (a valid user certificate is needed): https://www.monroe-system.eu/user/dailyDumps/. The dump files should be available every day after 12:00 CET (24-hour format). Each file covers the period [00:00, 00:00) GMT.

Our servers run on CET time, but metadata timestamps use GMT. Therefore, to cover "a day" of metadata using, e.g., the local time in Norway, two CSV files need to be combined. During Winter time, the needed metadata is in the period [day_0:01:00, day_1:01:00). During Summer time, the needed metadata is in the period [day_0:02:00, day_1:02:00).

[3]Thanks to Eneko Atxutegi Narbona and Jonas Karlsson for pointing this out.

Alternatively, metadata can be accessed directly in a replica of MONROE's Cassandra database, which is updated daily approximately at noon with the data from the previous (GMT) day. Access credentials for this server will be provided as requested. MONROE repositories include several examples on how to access the database.

5 Run-time considerations for experimenters

This section discusses several considerations that experimenters must take into account when designing and running their experiments on the MONROE platform.

5.1 Node identification

An experiment can identify the node it is running on by reading the contents of the `/nodeid` file:

```
cat /nodeid
54
```

5.2 Communication during the experiment

During execution, the experiment is free to establish any network communications through the available interfaces. The user can choose to bind explicitly from each command or application to a specific interface, or they may define default routes during the experiment:

```
route add default gw 172.16.0.1 eth0
```

5.3 Interface naming and default route

To offer a consistent view of the platform resources, whereas allowing flexibility for future changes in the platform configuration, the following naming scheme is used for each of the interfaces available for the experiments:

op0: First mobile interface.
op1: Second mobile interface.
op2: Only for old nodes, third mobile interface.
eth0: Ethernet (wired) network connection, when available.

The platform guarantees that a given op_i corresponds to the same operator during experiment execution. However, *the assignment may change* between nodes in the same country or even between successive executions in the same node. Therefore, *experiments must check the metadata stream* to select the correct interface associated to the desired operator.

Under some circumstances, the mobile devices used in the MONROE nodes may loose connectivity, reset themselves or undergo any other process that makes them temporarily unavailable for the experiments. To identify and tackle with these situations, experimenters are encouraged to build "robust" experiments subscribing to the corresponding metadata streams.

If the experimenter writes their own code:

1. Subscribe to the metadata broadcast.
2. Wait for a `MODEM.*.UPDATE` message for the modem(s)/operators of interest.
3. Once this information is obtained, use the desired interface and store the results with the corresponding ICCID or operator name.

4. Should the interface disappear (ENODEV error, "no such device"), start over at 2.

When using an external tool that does not handle ENODEV (e.g., "fping"), replace step 4 by:

- Monitor the metadata for a MODEM.*.CONNECTIVITY message indicating that connectivity was lost, or monitor the interface list to check if the device disappears. Upon either event, start over at 2.

Experimenters should take notice that an interface may not only go down, but it may actually disappear from the list of available interfaces (e.g., if the modem has to be restarted). Even if it reappears soon after, any existing network connections on the old interface will fail with ENODEV.

It is also possible to skip steps 1 and 2 when reconnecting to an interface after a failure, as the interface name corresponding to the desired operator is already known. It is still necessary to keep retrying to connect to the interface, until it comes up.

5.4 Interface binding

Experiments running in MONROE nodes have access to several network interfaces. By default, that is, if the experiment does not take any special configuration actions, the default route will be configured to one of the mobile broadband interfaces, if available. However, experimenters have the possibility of explicitly binding external tools or their programs to specific interfaces. Several options are available to bind an experiment to an interface.

1. Most standard tools can be instructed to use an specific interface:

```
ping -I op0 host_name
tcpdump --I op0 target
wget --bind-address ...
curl --interface ...
```

2. Explicit binding in the source code.
   - In C:

   ```
   snprintf(ifr.ifr_name, sizeof(ifr.ifr_name), "op0");
   setsockopt(s, SOL_SOCKET, SO_BINDTODEVICE, (void *)&ifr, sizeof(ifr))
   localaddr.sin_addr.s_addr = inet_addr("192.168.1.100");
   bind(sockfd, (struct sockaddr *)&localaddr, sizeof(localaddr));
   ```

   - In Python:

   ```
   s = socket.socket()
   s.bind('192.168.1.152', 0))
   ```

3. Library overloading the bind() and connect() functions through LD_PRELOAD:
   http://www.ryde.net/code/bind.c.txt
4. Changing the default route:

```
route del default gw ...; route add ...
```

5.5 Metadata at run-time

MONROE nodes retrieve constantly some metadata information concerning their own state and the network conditions. This information is continuously uploaded to the MONROE servers and stored in a database. One of the main goals of the MONROE project is to make all that information freely accessible. Therefore, experimenters may perform an off-line correlations of events in their experiment with the information in the MONROE database.

MONROE experimenters can also access all the metadata information at run-time from their experiments to achieve easy correlation of events or modify the behavior of the experiment during its execution. For example:

- Experiments that depend on external factors (location):
  - Round trip time vs. location.
  - Proactive HTTP caching according to location.
  - Round trip time vs. base station.
  - Round trip time vs. signal strength.
  - Route selection according to current conditions.
- Experiment validation:
  - Verify that node temperature is/was within limits.
  - Verify that system load is/was below threshold.

The metadata is broadcast locally using ZeroMQ. The following excerpt in Python shows how an application can subscribe to the metadata stream:

```
import zmq

context = zmq.Context()
socket = context.socket(zmq.SUB)
socket.connect ("tcp://172.17.0.1:5556")

# An empty string subscribes to everything:
topicfilter = ''   # E.g., use 'MONROE.META.DEVICE.GPS' for GPS-only metadata
socket.setsockopt(zmq.SUBSCRIBE, topicfilter)

while True:
  string = socket.recv()
  print string
```

5.5.1 Example: Correlate experiment results with metadata at run-time

The following example shows how to create an application that executes a ping to an external machine and saves the results alongside the node location:

- Pipe the ping command through a “ping formatter.”
- The “ping” formatter subscribes to a zmq socket and topic:
  - Socket : 'tcp://172.17.0.1:5556'
  - Topic : 'MONROE.META.DEVICE.GPS'
- Cache the GPS position received.
- Wait for output from the ping command (stdin).
- Store experiment information including the GPS position:
  - Use the “library” `monroe_exporter` (python only).
  - Call the `monroe_exporter` script via the command line.

Below is the corresponding source code:

```
socket.connect('tcp://localhost:5557')
socket.setsockopt(zmq.SUBSCRIBE, 'MONROE.META.DEVICE.GPS')
LAST_GPS_FIX = None
```

```
monroe_exporter.initalize('MONROE.EXP.PING', 1, 5.0)

'''fork and wait for for gps messages'''
while True:
  (topic, msgdata) = socket.recv_multipart()
  LAST_GPS_FIX = json.loads(msgdata)

'''main process waits for ping experiment output '''
while line:
  exp_result = r.match(line).groupdict()
  msg = {
    'InterfaceName': interface,
    'Bytes': int(exp_result['bytes']),
    'Host': exp_result['host'],
    'Rtt': float(exp_result['rtt']),
    'SequenceNumber': int(exp_result['seq']),
    'TimeStamp': float(exp_result['ts'])
  }
  if LAST_GPS_FIX != None:
    msg.update(
      {
        'GPSTimeStamp': LAST_GPS_FIX['TimeStamp'],
        'Latitude': LAST_GPS_FIX['Latitude'],
        'Longitude': LAST_GPS_FIX['Longitude'],
        'Altitude': LAST_GPS_FIX['Altitude'],
        'NumberofSatellites': LAST_GPS_FIX['NumberofSatellites']
          })

  monroe_exporter.save_output(msg)
  line = sys.stdin.readline()
```

5.5.2 Metadata information

Currently, the collected metadata includes:

- Node GPS.
- Node sensors (CPU temp) and probes (load, memory usage).
- Modem status and events.
- Continuous and scheduled internal experiments:
  - RTT (through ping).
  - Bandwidth (through HTTP download).

The following and some examples of the information received in the metadata stream:

- RTT experiment:


```
{"DataId": "MONROE.EXP.PING", "Bytes": 84, "NodeId": "54",
"SequenceNumber": 301, "DataVersion": 1, "Timestamp": 1465805479.747943,
"Rtt": 71.2, "Host": "8.8.8.8", "Operator": "Orange",
"Iccid": "8934014251541036013", "Guid":
"sha256:a9f9fb2c04bba3782ef2624e118faa18f16b08c826155cae5e1ea7e1d88832b5.0.54.3791"}
```


- Sensors, where each message may contain information about a different set of measurements:


```
{"DataId": "MONROE.META.NODE.SENSOR", "softirq": "205270", "SequenceNumber": 48581,
```

"DataVersion": 1, "b": "1059270", "b": "4885494", "guest": "0", "NodeId": "54",
"idle": "42657942", "user": "10480984", "irq": "0", "steal": "0",
"Timestamp": 1465786966.123456, "nice": "3063"}

{"DataId": "MONROE.META.NODE.SENSOR", "SequenceNumber": 48567, "DataVersion": 1,
"Timestamp": 1465786961.123456, "percent": "65.98", "NodeId": "54", "current": "302234",
"start": "1465484726", "total": "5246545.72", "id": "39"}

{"DataId": "MONROE.META.NODE.SENSOR", "SequenceNumber": 48460, "DataVersion": 1,
"Timestamp": 1465786926.123456, "apps": "3632746496", "NodeId": "54", "free": "483119104",
"swap": "0"}

- Modem events:

{"DataId": "MONROE.META.DEVICE.MODEM", "InterfaceName": "usb2", "CID": 72209509,
"DeviceState": 3, "SequenceNumber": 33548, "DataVersion": 1,
"Timestamp": 1465803136.123456,
"NWMCCMNC": 21404, "Band": 3, "RSSI": -80, "IPAddress": "10.33.101.173",
"IMSIMCCMNC": 21404, "DeviceMode": 5, "NodeId": "54", "IMEI": "864154023645179",
"RSRQ": -8, "RSRP": -85, "LAC": 28014, "Frequency": 1800,
"InternalIPAddress": "192.168.0.153", "Operator": "YOIGO",
"ICCID": "8934041514050774002", "IMSI": "214040113950108"}

- GPS:

{"DataId": "MONROE.META.DEVICE.GPS", "SequenceNumber": 34164, "DataVersion": 1,
"Timestamp": 1465805718.123456, "Altitude": -1455.900024, "NodeId": "63",
"Longitude": -3.777019, "NMEA":
"$GPGGA,081518.0,4020.002011,N,00346.621107,W,1,02,500.0,-1455.9,M,53.0,M,,*5D\r\n",
"SatelliteCount": 2, "Latitude": 40.333366}

5.5.3 Metadata format

Metadata and internal experiment results follow a JSON structure, as detailed in https://github.com/MONROE-PROJECT/Experiments/wiki:

- All Metadata messages have a topic according to Table 2. Appendix B gives the complete description of the meaning of all the metadata fields.
- All metadata topics are prefixed with "MONROE.META."
- All internal experiments are prefixed with "MONROE.EXP."
- Experiments receive metadata messages only for topics to which they subscribe.
- An empty string ("") subscribes to all topics.

5.6 Tstat at run-time

The Tstat (http://www.tstat.polito.it/) **runs** on all nodes in the mPlane container as one of the basic MONROE containers. The Tstat is a passive probe able to provide several insight on the traffic patterns at both the network and the transport levels. The Tstat generates two different types of logs.

Table 2: Metadata topics.

TOPIC	DESCRIPTION
*.DEVICE.MODEM.iccid.UPDATE	
*.DEVICE.MODEM.iccid.MODE	
*.DEVICE.MODEM.iccid.SIGNAL	
*.DEVICE.MODEM.iccid.LTEBAND	
*.DEVICE.MODEM.iccid.ISPNAME	
*.DEVICE.MODEM.iccid.IPADDR	
*.DEVICE.MODEM.iccid.LOCCHANGE	
*.DEVICE.MODEM.iccid.NWMCCMNCCHANGE	
*.DEVICE.GPS	
*.NODE.SENSOR.sensor_name	Temp sensor, running experiments, quotas, ...
*.NODE.EVENT	Power up events, etc, ...

5.6.1 Tstat Round Robin Database

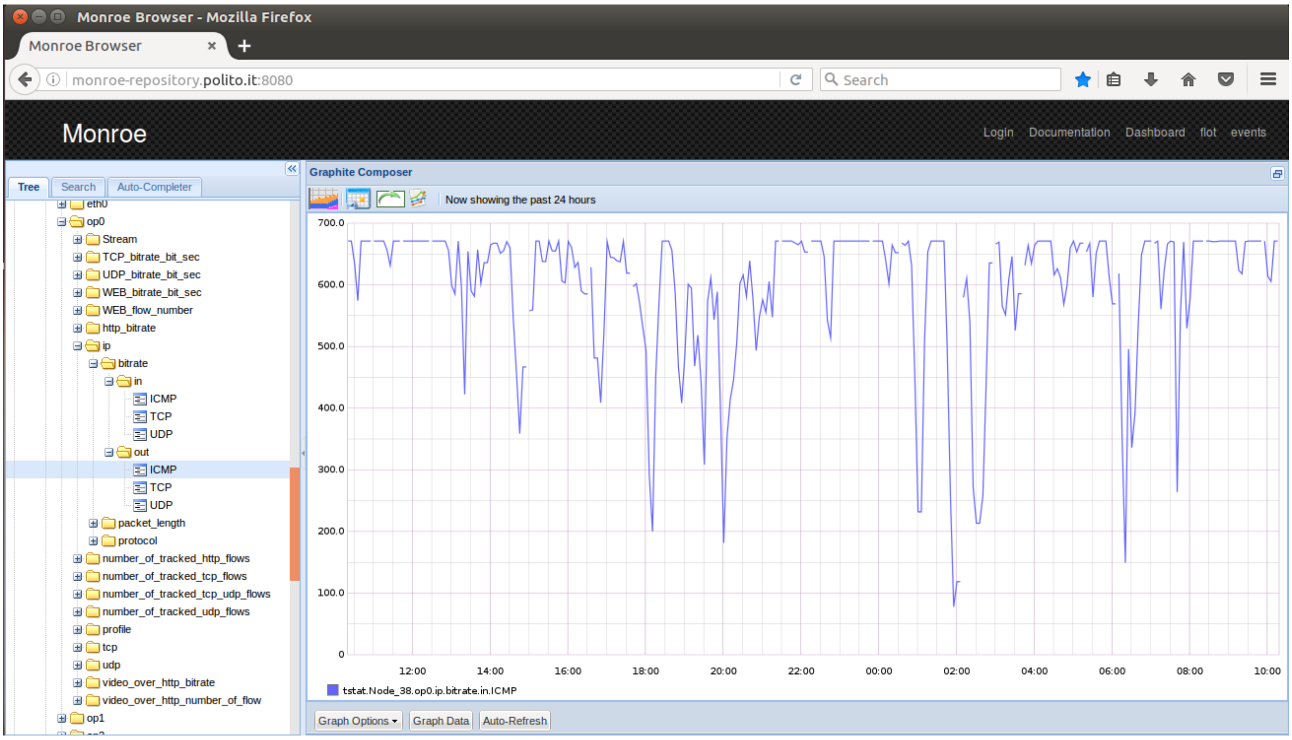


Figure 10: Graphite GUI of the Tstat RRD logs.

The RRD (Round Robin Database) logs is an average of samples of each packet in 5 minutes, it imposes at least 5 minutes delay to visualize RRDs. The detail description of the RRD logs is available on Tstat documentation(http://tstat.polito.it/HOWTO.shtml#RRD). RRD are available via the (http://monroe-repository.polito.it:8080/) and the Graphite GUI provides some tool to present RRD logs and save the interested plots. Fig. 10 shows the bit rate of the ICMP packet for the node #38 on interface *op0* over the last 24 hours. There is possibility to create a dashboard to monitor the experiments and interfaces' status. Fig. 11 illustrates an example of saved dashboard to monitor the volume of traffic on one node.

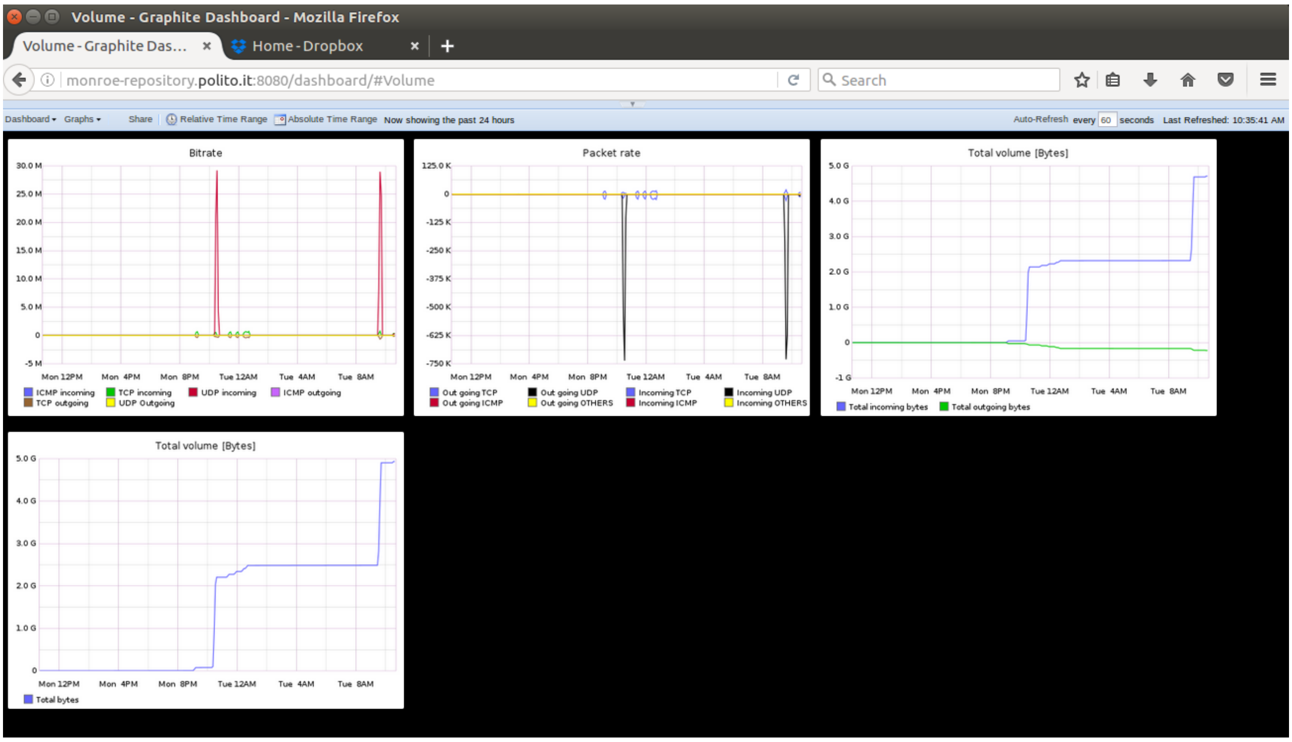


Figure 11: An example of dashboard on Tstat RRD GUI.

5.6.2 Tstat logs

Tstat generates detailed flow level logs for TCP, UDP, and HTTP flows. These are text file with more than 100 metrics, containing information about the client and server addresses, network and application level metrics, and DNS queries. The description of the metrics presents (http://tstat.polito.it/measure.shtml#LOG). In MONROE, the Tstat configure to generate 4 different logs as following:

Table 3: Tstat log types.

TYPE	DESCRIPTION
log_tcp_complete	Every TCP connection that has been tracked
log_tcp_nocomplete	All the connections for which the three way handshake is not properly seen
log_udp_complete	Every tracked UDP flow pair
log_http_complete	Information from every HTTP request and response

Logs are available in two ways,

1. Real time access on the node, logs for the last three generated are shared with MONROE experimenters on the "/monroe/tstat", it helps the MONROE users to use passive traces collected by Tstat during their experiment. The three logs can cover at most the last three hours.

2. On demand, all logs are imported into MONROE database for all node. The schema of the tables are available on github (https://github.com/MONROE-PROJECT/Database/blob/master/db_schema.cql). Three columns, (NodeId,Iccid,DataId) added to each table bring the possibility to join with metadata and collected data.

Table 4: Core TCP Set.

C2S	S2C	Short description	Unit	Long description
1	15	Client/Server IP addr	–	IP addresses of the client/server
2	16	Client/Server TCP port	–	TCP port addresses for the client/server
3	17	packets	–	total number of packets observed from the client/server
4	18	RST sent	0/1	0 = no RST segment has been sent by the client/server
5	19	ACK sent	–	number of segments with the ACK field set to 1
6	20	PURE ACK sent	–	number of segments with ACK field set to 1 and no data
7	21	unique bytes	B	number of bytes sent in the payload
8	22	data pkts	–	number of segments with payload
9	23	data bytes	B	number of bytes transmitted in the payload, including retransmissions
10	24	rexmit pkts	–	number of retransmitted segments
11	25	rexmit bytes	B	number of retransmitted bytes
12	26	out seq pkts	–	number of segments observed out of sequence
13	27	SYN count	–	number of SYN segments observed (including rtx)
14	28	FIN count	–	number of FIN segments observed (including rtx)
29		First time abs	ms	Flow first packet absolute time (epoch)
30		Last time abs	ms	Flow last segment absolute time (epoch)
31		Completion time	ms	Flow duration since first packet to last packet
32		C first payload	ms	Client first segment with payload since the first flow segment
33		S first payload	ms	Server first segment with payload since the first flow segment
34		C last payload	ms	Client last segment with payload since the first flow segment
35		S last payload	ms	Server last segment with payload since the first flow segment
36		C first ack	ms	Client first ACK segment (without SYN) since the first flow segment
37		S first ack	ms	Server first ACK segment (without SYN) since the first flow segment
38		C internal	0/1	1 = client has internal IP, 0 = client has external IP
39		S internal	0/1	1 = server has internal IP, 0 = server has external IP
40		C anonymized	0/1	1 = client IP is CryptoPAn anonymized
41		S anonymized	0/1	1 = server IP is CryptoPAn anonymized
42		Connection type	–	Bitmap stating the connection type as identified by TCPL7 inspection engine (see protocol.h)
43		P2P type	–	Type of P2P protocol, as identified by the IPP2P engine (see ipp2p_tstat.h)
44		HTTP type	–	For HTTP flows, the identified Web2.0 content (see the http_content enum in struct.h)

It is recommended to check the description of the logs on (`http://tstat.polito.it/measure.shtml#LOG`). Tables 4, 5 and 6 present the table describing of some interesting metrics in tcp and http logs.

5.7 Access to user-owned development nodes

This section refers to development nodes owned by external users under the dispositions of their specific MONROE agreement. Two options are possible for the management of those nodes:

1. The nodes join the pool of MONROE nodes. Experiments are scheduled through the MONROE scheduler and users, including the node owners, do not have direct SSH access to them. The metadata produced by these nodes will join the rest of the MONROE databases.
2. The nodes are considered "development nodes" for private use of their owners. In that case, they will not join the MONROE platform and will not be accessible through the MONROE scheduler, neither for their owners nor for other users. The nodes will be marked as "storage" or "development." Thus, users (again, only their owners) must log locally into the nodes to manually schedule their containers using Docker commands. The nodes will not run the base experiments; no metadata, or any other information produced by them will join the MONROE databases.

In essence, "managed" nodes are part of the testbed and work as any other ones, whereas "development" nodes are for private use of their owners. The following paragraphs provide relevant information for the use

Table 5: TCP End to End Set.

C2S	S2C	Short description	Unit	Long description
45	52	Average rtt	ms	Average RTT computed measuring the time elapsed between the data segment and the corresponding ACK
46	53	rtt min	ms	Minimum RTT observed during connection lifetime
47	54	rtt max	ms	Maximum RTT observed during connection lifetime
48	55	Stdev rtt	ms	Standard deviation of the RTT
49	56	rtt count	–	Number of valid RTT observation
50	57	ttl_min	–	Minimum Time To Live
51	58	ttl_max	–	Maximum Time To Live

Table 6: Core HTTP Set.

C2S	S2C	Short description	Unit	Long description
1	1	Client IP addr	–	IP addresses of the client (sending the request/receiving the response)
2	2	Client TCP port	–	TCP port addresses for the client
3	3	Server IP addr	–	IP addresses of the server (receiving the request/sending the response)
4	4	Server TCP port	–	TCP port addresses for the server
5	5	Segment time abs	s	Absolute time [s] (epoch) of the request/response
6		Request method	–	Request method (GET/POST/HEAD) [*]
7		Hostname	–	Value fo the “Host:” HTTP request field
8		FQDN	–	DN-Hunter cached DNS name [^]
9		URL Path	–	URL request path
10		Referer	–	Value of the “Referer:” HTTP request field
11		User agent	–	Value of the “User-Agent:” HTTP request field
12		Cookie	–	Value of the “Cookie:” HTTP request field
13		Do Not Track	–	Value of the “DNT:” HTTP request field
	6	Response string	–	Response identifier (always “HTTP”) [*]
	7	Response code	–	HTTP response code (2xx/3xx/4xx/5xx)
	8	Content len	B	Value of the “Content-Length:” HTTP response field
	9	Content type	–	Value of the “Content-Type:” HTTP response field
	10	Server	–	Value of the “Server:” HTTP response field
	11	Range	–	Value of the “Content-Range:” HTTP response field for partial content (Code 206)
	12	Location	–	Value of the “Location:” HTTP response field for redirected content (Code 302)
	13	Set Cookie	–	Value of the “Set-Cookie:” HTTP response field

Table 7: Node users

USER	PASSWORD	SUDO	USES
monroe	*[redacted]*	reboot	maintenance, troubleshooting
monroeSA	*[redacted]*	yes	administration, development

of development nodes.

5.7.1 Accessing user-owned development nodes

Development nodes can be accessed either through the management interface (the black wire connected to eth2) via SSH, or directly via the serial console (DB9 connector, using a null-modem cable). The necessary passwords will be provided on request through a secure channel. Table 7 explains the uses of each available user.

Do not distribute passwords or keys to unauthorized personnel. Do not send passwords or keys over insecure channels. Use of the administrator user ’monroeSA’ is allowed only for development on local nodes, unless granted permission to perform a specific task requiring this user. Creation of user accounts on nodes is forbidden. Modifying user accounts on nodes is forbidden. Modifying `authorized_keys` on nodes is forbidden. Be VERY careful if you change any firewall settings, and only do this on development nodes. Be smart.

Local access, which allows password authentication, can be achieved through the serial port and the management interface.

The APU’s third ethernet port (eth2), nearest the USB ports, has a default IP address, 172.16.254.1/24 for the Head and 172.16.254.2/24 for the Tail. The nodes can be accessed by setting up a static IP address in the 172.16.254.0/24 network span (e.g., 172.16.254.20) on the developer side of the link and establishing an SSH connection.

The DB-9 serial port (console) allows direct terminal access. The boot process and grub menu are visible and interactive through this connection; some kernel messages will be printed as well while connected. Connecting to the console port requires a **null modem** cable. In the following examples, `/dev/ttyS0` has to be substituted with the device path for the developer’s cable. A typical case for USB-to-serial adapters is `/dev/ttyUSB0`:

```
minicom -D /dev/ttyS0          ---or---          screen /dev/ttyS0 115200
```

6 Monitoring node status

The state of the nodes can be checked under the tab “Resources.” Figure 12 shows an example of the supplied information. Experimenters can use the operator codes and names to manually pick nodes with concrete operators.

Column “Location” opens a Google Maps window with the last known position of the node, when available. Similarly, column “Graphs” opens the visualization page for the selected node. There, experimenters can see the last known RTT and RSSI measures for the node, its current location and state.

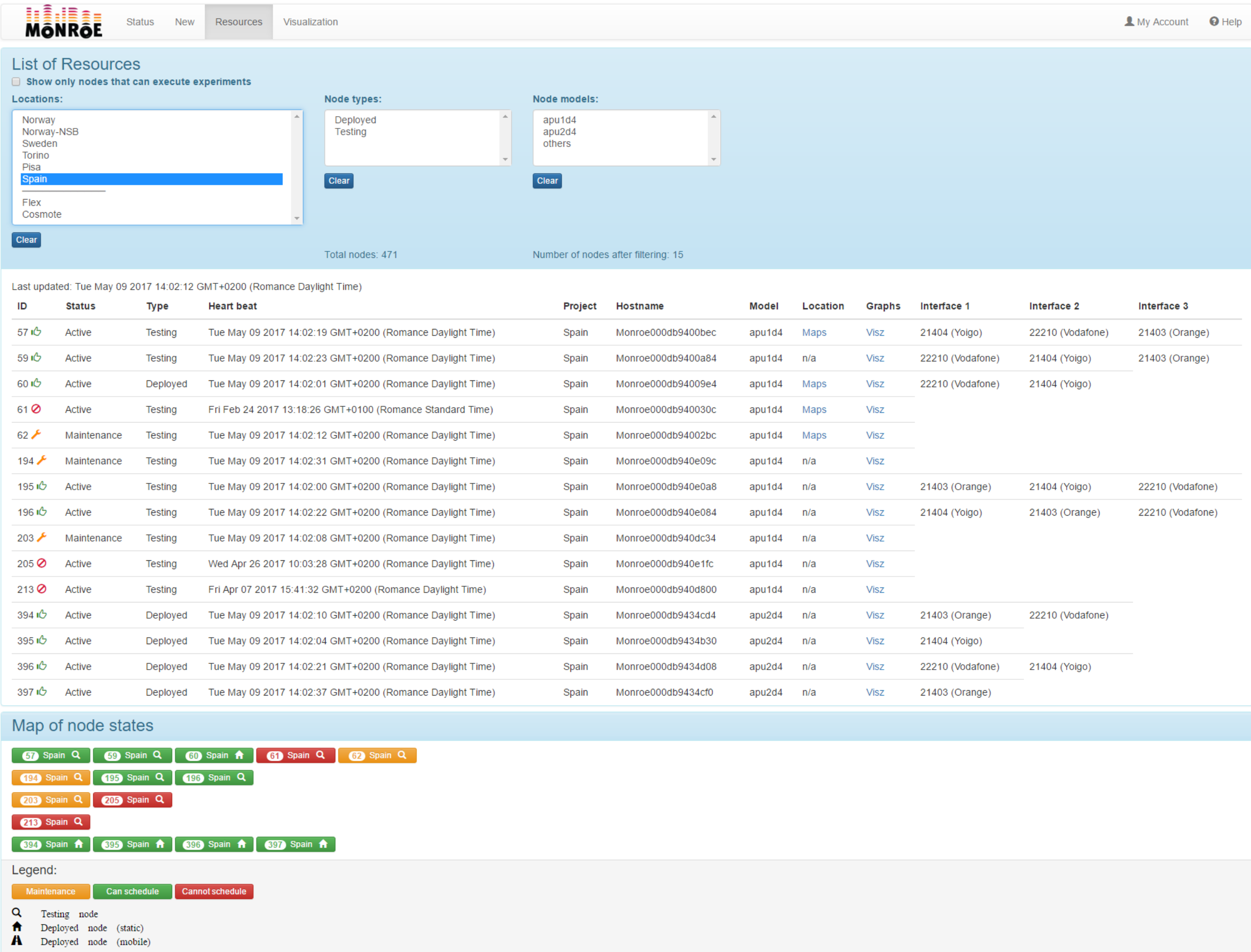


Figure 12: Status of the MONROE nodes. The screen capture shows all types of nodes in Spain. The green approval sign ("thumbs-up") close to the node IDs indicates that this node is capable of executing experiments. Clicking on the "Location" link for a node opens a Google Maps page showing the location of the node. Finally, the bottom part of the screen shows a "map" of nodes that allows users and MONROE administrators to quickly identify available (and problematic) nodes in the platform.

7 MONROE templates, examples and default experiments

This section details the template for building MONROE experiments, the experiments that run as part of the default MONROE platform and several additional examples that can be directly used or that can serve as the basis for new ones. The source code for the examples is publicly available at https://github.com/MONROE-PROJECT/Experiments.

7.1 Example template

This experiment template provides an extensive example to show the capabilities of the MONROE platform. The experiment will download a url (file) over http using `curl` from a configurable operator while at the same time recording the GPS positions of the node. If the operator is not available at the time of execution, the experiment will fail.

7.1.1 Usage

The configuration values can be supplied as a JSON string in the “Additional options” field of the web user interface. This allows to specify a different set of parameters for each execution of the experiment.

The values of the configuration parameters can be read by the experiment from the `/monroe/config` file. The following text shows a configuration file with per-execution (“additional options” field) options:[4]

```
{
"stop": 1486653420,
"start": 1486653120,
"traffic": 1048576,
"script": "mikepeon/mike-depurar",
"shared": 0,
"storage": 134217728,
"resultsQuota": 0,
"guid": "sha256:3796f833f55c8dbca7e9845ea06120ccebec85c2770c0de2deb57509300efa44.165695.48.1",
"option1": "value1",
"option2": "value2",
"nodeid": "48"
}
```

The default configuration values are as follows:

```
{
# The following values are specific to the monroe platform
"guid": "no.guid.in.config.file",               # Created by the scheduler
"nodeid": "no.nodeid.in.config.file",           # Created by the scheduler
"storage": 104857600,                           # Created by the scheduler
"traffic": 104857600,                           # Created by the scheduler
"script": "jonakarl/experiment-template",       # Created by the scheduler
"zmqport": "tcp://172.17.0.1:5556",
"modem_metadata_topic": "MONROE.META.DEVICE.MODEM",
"gps_metadata_topic": "MONROE.META.DEVICE.GPS",
# "dataversion": 1,                             # Version of the experiment
# "dataid": "MONROE.EXP.JONAKARL.TEMPLATE",     # Name of the experiment
"meta_grace": 120,                              # Grace period to wait for interface metadata
"exp_grace": 120,                               # Grace period before killing experiment
"meta_interval_check": 5,                       # Interval to check if interface is up
```

[4] Entries in the `/monroe/config` file may appear in different order.

```
"verbosity": 2,                                # 0="Mute", 1=error, 2=information, 3=verbose
"resultdir": "/monroe/results/",
# These values are specic for this experiment
"operator": "Telenor SE",
"url": "http://193.10.227.25/test/1000M.zip",
"size": 3*1024 - 1,                            # The maximum size in Kbytes to download
"time": 3600                                   # The maximum time in seconds for a download
}
```

The download will abort when either size OR time OR actual size of the “url” is downloaded. All debug/error information will be printed on `stdout`, depending on the “verbosity” variable.

7.1.2 Requirements

The following directories and files must exist and have read and write permissions for the user/process running the container:

- `/monroe/config`, supplied by the scheduler in the nodes.
- “`resultdir`,” according to the values supplied in the configuration string or the default ones (Section 7.1.1).

7.1.3 Output

The experiment will execute a statement similar to running `curl` with the following command line:

```
curl -o /dev/null --raw --silent --write-out "{ remote: %{remote_ip}:%{remote_port},
size: %{size_download}, speed: %{speed_download}, time: %{time_total},
time_download: %{time_starttransfer} }" --interface eth0 --max-time 100 --range 0-100
http://193.10.227.25/test/1000M.zip
```

The experiment will produce a single-line JSON object similar to this (pretty printed to improve readability):

```
{
"Bytes": 30720000,
"DataId": "313.123213.123123.123123",
"DataVersion": 1,
"DownloadTime": 2.716,
"GPSPositions": [
{
"Altitude": 225.0,
"DataId": "MONROE.META.DEVICE.GPS",
"DataVersion": 1,
"Latitude": 59.404697,
"Longitude": 13.581558,
"NMEA": "$GPGGA,094832.0,5924.281896,N,01334.893500,E,1,05,1.6,225.0,M,35.0,M,,*5D\r\n",
"SatelliteCount": 5,
"SequenceNumber": 14,
"Timestamp": 1465551728
},
{
"DataId": "MONROE.META.DEVICE.GPS",
"DataVersion": 1,
"Latitude": 59.404697,
"Longitude": 13.581558,
```

```
"NMEA": "$GPRMC,094832.0,A,5924.281896,N,01334.893500,E,0.0,,100616,0.0,E,A*2B\r\n",
"SequenceNumber": 15,
"Timestamp": 1465551728
}
],
"Guid": "sha256:15979bc2e2449b0011826c2bb8668df980da88221af3fc7916cb2eba4f2296c1.0.45.15",
"Host": "193.10.227.25",
"Iccid": "89460850007006922138",
"InterfaceName": "usb0",
"NodeId": "45",
"Operator": "Telenor SE",
"Port": "80",
"SequenceNumber": 1,
"SetupTime": 0.004,
"Speed": 11295189.0,
"TimeStamp": 1465551458.099917,
"TotalTime": 2.72
}
```

7.1.4 Overview of the code structure

The experiment consists of one main process and two sub processes, where one process listens to modem and gps information, and the other executes the experiment. The main process supervises the execution of its two children.

Information sharing between processes. Information is shared between processes via two thread-safe data structures (i.e., a Python "Manager" object). Regarding modem information, the latest metadata update (for the specified operator) is stored in a dictionary. The GPS information is continuously appended to a list as it is received.

The metadata sub-process. This process listens to GPS and modem messages sent on the ZeroMQ bus and updates the shared data structures.

The experiment sub-process. This process reads entries from the shared data structures, runs the experiment and saves its result when finished.

7.2 Docker miscellaneous usage notes

- List running containers:

  ```
  docker ps
  ```

- Debug shell:

  ```
  docker run -i -t --entrypoint bash --net=host template
  ```

- Normal execution with output to `stdout`:

  ```
  docker run -i -t --net=host template
  ```

- Attach to a running container (with shell):

  ```
  docker exec -i -t [container runtime name] bash
  ```

- Get container logs (stderr and stdout):

  ```
  docker logs [container runtime name]
  ```

7.3 Experiment: ping

This background experiment runs continuously an RTT estimate on each MBB operator on the node (one independent experiment is run per interface). The experiments measure IP RTT by continuously sending ping packets to a configurable server (by default 8.8.8.8, Google's public DNS server). The experiment will send one "Echo Request" (ICMP type 8) packet per second over the specified interface until aborted. RTT is measured as the time between the echo request is sent and the echo reply (ICMP type 0) is received from the server. The experiment runs on all interfaces in parallel.

7.3.1 Usage

The experiment is designed to run as a Docker container and will not attempt to do any active network configuration. If the specified interface does not exist (i.e., is not up) when the experiment starts, it will immediately exit.

The default parameter values are:

```
{
"guid": "no.guid.in.config.file",               # Created by the scheduler
"zmqport": "tcp://172.17.0.1:5556",
"nodeid": "fake.nodeid",
"modem_metadata_topic": "MONROE.META.DEVICE.MODEM",
"server": "8.8.8.8",                            # ping target
"interval": 1000,                               # time in ms between successive packets
"dataversion": 2,
"dataid": "MONROE.EXP.PING",
"meta_grace": 120,                              # Grace period to wait for interface metadata
"ifup_interval_check": 5,                       # Interval to check if interface is up
"export_interval": 5.0,
"verbosity": 2,                                 # 0="Mute", 1=error, 2=Information, 3=verbose
"resultdir": "/monroe/results/",
"modeminterfacename": "InternalInterface",
"interfacename": "eth0",                        # Interface to run the experiment on
"interfaces_without_metadata": ["eth0", "wlan0"] # Manual metadata on these interfaces
}
```

All debug/error information will be printed on stdout depending on the value of the "verbosity" parameter.

7.3.2 Requirements

The following directories and files must exist and have read and write permissions for the user/process running the container:

- /monroe/config, supplied by the scheduler in the nodes.
- "resultdir," according to the values supplied in the configuration string or the default ones (Section 7.1.1).

7.3.3 Output

The experiment will execute a statement similar to running `fping` with the following command line:

```
fping -I eth0 -D -c 1 -p 1000 -l 8.8.8.8
```

The experiment will produce one of the two following single-line JSON objects, depending on whether it got a reply form the server or not. If a reply was received:

```
{
"Guid": "313.123213.123123.123123", # exp_config['guid']
"Timestamp": 23123.1212, # time.time()
"Iccid": 2332323, # meta_info["ICCID"]
"Operator": "Telia", # meta_info["Operator"]
"NodeId" : "9", # exp_config['nodeid']
"DataId": "MONROE.EXP.PING",
"DataVersion": 2,
"SequenceNumber": 70,
"Rtt": 6.47,
"Bytes": 84,
"Host": "8.8.8.8",
}
```

If the reply was not received (Bytes and RRR values are not present):

```
{
"Guid": "313.123213.123123.123123", # exp_config['guid']
"Timestamp": 23123.1212, # time.time()
"Iccid": 2332323, # meta_info["ICCID"]
"Operator": "Telia", # meta_info["Operator"]
"NodeId" : "9", # exp_config['nodeid']
"DataId": "MONROE.EXP.PING",
"DataVersion": 2,
"SequenceNumber": 71,
"Host": "8.8.8.8",
}
```

7.4 Experiment: http_download

This is a periodically scheduled experiment that monitors the download speed of each MBB operator on the node. The experiment will, over each MBB operator in sequence, download the specified url (file) with `curl` (http), presenting one result per interface. The MONROE experiment template described in Section 7.1 corresponds to this experiment, therefore, it is not further detailed here.

7.5 Experiment: Tstat & mPlane

The mPlane protocol provides control and data interchange for passive and active network measurement tasks. It is built around a simple workflow that can interact with different frameworks to provide the results of the measurements. This package includes an mPlane proxy and generic configuration files for Tstat.

mPlane captures traffic flow on all interfaces with the Tstat (http://tstat.polito.it/) probe. The mPlane container is always running as one of the default experiments on all MONROE nodes. The Tstat passive traces are stored locally on the node and are accessible by the experimenters. A detailed description and the source code are available on github (https://github.com/MONROE-PROJECT/mPlane).

Tstat RRD logs and the compressed log are stored in the node at /experiments/monroe/mplane. Tstat logs are transfered to the MONROE server and imported into MONROE's (Cassandra) database. The structure of the database tables is available on github (https://github.com/MONROE-PROJECT/Database/blob/master/db_schema.cql).

During experiment execution, the last three Tstat logs are shared with the experiment at /monroe/tstat. Therefore, MONROE users can access the passive traces collected by Tstat during their experiments.

The data collected for a subset of the most relevant metrics for the HTTP experiments are visualized by the MONROE visualization tool. And example of the metrics contained in the Tstat logs can be seen here: http://213.182.68.136:8080/#/experiment/tstat.

7.5.1 Requirements

The script must have access to /nodeid and run get_nodeid.

7.5.2 Usage

Create your docker image normally and execute the container with the following command line:

```
docker run -i -t --net=host -d -v /mplane:/monroe/results -v /tstat:/monroe/tstat
-v /etc/nodeid:/nodeid:ro monroe/mplane
```

7.6 MONROE example: helloworld

This experiment provides an easy example for using the configuration options from the scheduler, listen to and record the metadata stream (e.g., GPS and operator information), and show the experiment log functionality on a MONROE node. The experiment listens to the metadata stream and records the nr_of_messages first messages. The metadata messages are saved in JSON format with a custom field ("Hello") in the output directory. Additionally, the experiment prints out some debugging messages to show how these messages are logged and later retrieved via the web user interface.

7.6.1 Usage

The experiment is configured with a JSON string introduced via the "Additional options" field in the web user interface. The configurable parameters and their default values are:

```
{
"zmqport": "tcp://172.17.0.1:5556",
"nodeid": "fake.nodeid",              # Needs to be overriden
"metadata_topic": "MONROE.META",
"verbosity": 2,                       # 0 = "Mute", 1=error, 2=Information, 3=verbose
"resultdir": "/monroe/results/",
"nr_of_messages": 3
}
```

7.6.2 Requirements

The following directories and files must exist and have read and write permissions for the user/process running the container:

- /monroe/config, supplied by the scheduler in the nodes.

- "`resultdir`," according to the values supplied in the configuration string or the default ones (Section 7.6.1).

7.6.3 Output

The experiment will produce a single-line JSON object similar to the following ones, depending on the metadata received ("pretty printed" here to improve readability):


```
{
"DataId": "MONROE.META.NODE.SENSOR",
"DataVersion": 1,
"SequenceNumber": 58602,
"Timestamp": 1465888420,
"NodeId": "9",
"Hello": "World"
}
```


The log file will contain records similar to these ones:

```
[2017-02-07 09:53:27.190338] Hello: Default config {
"metadata_topic": "MONROE.META",
"nodeid": "fake.nodeid",
"nr_of_messages": 3,
"resultdir": "/monroe/results/",
"verbosity": 2,
"zmqport": "tcp://172.17.0.1:5556"
}
[2017-02-07 09:53:27.20000] Hello: Start recording messages with configuration {
"metadata_topic": "MONROE.META",
"nodeid": "fake.nodeid",
"nr_of_messages": 3,
"resultdir": "/monroe/results/",
"verbosity": 2,
"zmqport": "tcp://172.17.0.1:5556"
}
[[2017-02-07 09:53:27.30000] Received message 1 with topic : MONROE.META.NODE.SENSOR
{
"DataId": "MONROE.META.NODE.SENSOR",
"DataVersion": 1,
"SequenceNumber": 58602,
"Timestamp": 1465888420,
"NodeId": "9",
"Hello": "World"
}
. # And so on for each metadata message received until the configured value of metadata messages
.
.
[2017-02-07 09:53:27.40000] Hello : Finished the experiment
```

7.7 MONROE example: paris-traceroute

This example showcases how to use the MONROE-modified version of paris-traceroute inside a container. The binary of this tool is included in the base image of MONROE.

The original version of paris-traceroute has no option to choose which interface should be used. In this version, flags to set the interface and source IP of the transmitted packets have been added. Setting the interface is obligatory; if it is not set, the program will crash (by design), since if the interface were chosen automatically, it would probably not be what the experimenter intended to use. The source IP flag is optional. Just setting the IP flag to the IP of an interface without setting the interface flag will not work either. This is done on purpose as well, as it might be possible for multiple interfaces to have the same IP within the MONROE network namespace. If the IP flag is not set, the source IP is set to the IP of the chosen interface.

7.7.1 Usage (inside a MONROE container)

The parameters of this experiment are provided as "Additional options" in the scheduling web interface. The following JSON string is an example of the additional options that can be passed to this container:

```
"interfaces": ["op1", "op2"], "targets": ["8.8.8.8", "www.uc3m.es"],
"traceAlgos": ["exh"], "protocol": "udp"
```

Flags:

```
-C  --nodeIPArgument              Source IP
-O  --nodeInterfaceArgument       Source interface (mandatory)
```

The paris-traceroute binary can be executed (as any normal Linux command) either without specifying a traceroute algorithm to perform a "simple" traceroute (similar to the output of the ordinary traceroute command), or with the flags `-n -a exh`, to perform an exhaustive traceroute. Exhaustive traceroutes provide more detailed and accurate paths between the host (MONROE node) and the target server that are able to detect, among others, the presence of load balancers, which create multiple paths between host and target.

7.7.2 Output

The experiment output is a text file:

```
root@b59e69a56297:/# paris-traceroute -O op2 -C 192.168.1.127 8.8.8.8
traceroute [(192.168.1.127:33456) -> (8.8.8.8:33457)], protocol udp, algo hopbyhop, duration 18 s
1  192.168.1.1 (192.168.1.1)  2.946 ms   0.553 ms   0.559 ms
2  * * *
3  10.133.17.29 (10.133.17.29)  83.259 ms   136.577 ms   82.050 ms
4  10.133.17.14 (10.133.17.14)  78.783 ms   131.510 ms   79.231 ms
5  10.133.17.236 (10.133.17.236)  84.243 ms   133.024 ms   79.785 ms
6  10.133.17.3 (10.133.17.3)  81.543 ms   139.381 ms   100.263 ms
7  83.224.40.186 (83.224.40.186)  89.319 ms   188.926 ms   179.963 ms
MPLS Label 24703 TTL=254
8  83.224.40.185 (83.224.40.185)  82.710 ms   172.438 ms   147.020 ms
9  85.205.14.105 (85.205.14.105)  85.179 ms   137.514 ms   125.869 ms
10  72.14.223.169 (72.14.223.169)  85.609 ms   137.363 ms   118.063 ms
11  216.239.47.128 (216.239.47.128)  79.567 ms   146.356 ms   145.285 ms
12  209.85.243.33 (209.85.243.33)  129.615 ms   198.938 ms   269.407 ms
MPLS Label 568892 TTL=1
13  64.233.174.143 (64.233.174.143)  108.599 ms   185.810 ms   246.661 ms
MPLS Label 692130 TTL=1
14  108.170.234.47 (108.170.234.47)  111.645 ms   825.615 ms   1424.942 ms
15  * * *
16  google-public-dns-a.google.com (8.8.8.8)  103.087 ms !T2   166.279 ms !T2   224.649 ms !T2
```

7.7.3 Additional remarks

Paris-traceroute instances should be run sequentially and preferably when the node is generating little traffic in general because it uses raw packet capture to detect the replies from intermediate nodes and background traffic might interfere with this process.

7.8 MONROE example: headlessbrowsing

This experiment evaluates the performance of different HTTP protocols (HTTP1.1, HTTP1.1/TLS, HTTP2) using the headless Firefox browser. It uses the Selenium browser-automation framework, which enables execution of web-browsing automation tests in different browsers such as Firefox and Chrome. The Selenium web-driver is used for Firefox. For a given url, HTTP protocol and source network interface, Selenium launches the native Firefox browser to visit that url.

7.8.1 Output

This experiment generates an HTTP ARchive (HAR) file during the download of a target url that helps to find afterwards the impact of different web-page features on its overall Page Load Time (PLT).

The experiment generates a single JSON file such as:

```
{
"DataId":"MONROE.EXP.FIREFOX.HEADLESS.BROWSING",
"ping_min":" 55.6",
"ping_max":"56.8",
"NumObjects":6,
"InterfaceName":"usb2",
"Web load time":196,
"PageSize":35641,
"DataVersion":1,
"Timestamp":1481536829.0814,
"NWMCCMNC":22210,
"Objects":[
{
"objectSize":1951,
"mimeType":"image/png",
"startedDateTime":"2016-12-12T10:00:21.293+00:00",
"url":"https://www.wikipedia.org/portal/wikipedia.org/assets/img/Wikipedia_wordmark.png",
"timings":{"receive":1, "send":0, "connect":1, "dns":0, "blocked":0, "wait":60},
"time":62
},
{
"objectSize":13196,
"mimeType":"image/png",
"startedDateTime":"2016-12-12T10:00:21.294+00:00",
"url":"https://www.wikipedia.org/portal/wikipedia.org/assets/img/Wikipedia-logo-v2.png",
"timings":{"receive":52, "send":3, "connect":59, "dns":2, "blocked":0, "wait":53 },
"time":169
},
{
"objectSize":9425,
"mimeType":"application/javascript",
"startedDateTime":"2016-12-12T10:00:21.295+00:00",
"url":"https://www.wikipedia.org/portal/wikipedia.org/assets/js/index-abc278face.js",
"timings":{"receive":3, "send":0, "connect":120, "dns":0, "blocked":0, "wait":65},
```

```
"time":188
},
{
"objectSize":1164,
"mimeType":"application/javascript",
"startedDateTime":"2016-12-12T10:00:21.296+00:00",
"url":"https://www.wikipedia.org/portal/wikipedia.org/assets/js/gt-ie9-c84bf66d33.js",
"timings":{"receive":0, "send":1, "connect":64, "dns":2, "blocked":0, "wait":70 },
"time":137
},
{
"objectSize":1590,
"mimeType":"image/png",
"startedDateTime":"2016-12-12T10:00:21.381+00:00",
"url":"https://www.wikipedia.org/portal/wikipedia.org/assets/img/sprite-icons.png?
27378e2bb51199321b32dd1ac3f5cd755adc21a5",
"timings":{"receive":1, "send":0, "connect":1, "dns":0, "blocked":0, "wait":49 },
"time":51
},
{
"objectSize":8315,
"mimeType":"image/png",
"startedDateTime":"2016-12-12T10:00:21.425+00:00",
"url":"https://www.wikipedia.org/portal/wikipedia.org/assets/img/sprite-project-logos.png?
dea6426c061216dfcba1d2d57d33f4ee315df1c2",
"timings":{"receive":2, "send":0, "connect":8, "dns":0, "blocked":0, "wait":54 },
"time":64
} ],
"IPAddress":"2.43.181.254",
"IMSIMCCMNC":22210,
"tracedRoutes":["192.168.96.1", "193.10.227.25", "xx.xx.xx.xx" ..... "192.168.96.1" ],
"InternalInterface":"op0",
"NodeId":"41",
"ping_exp":1,
"Protocol":"HTTP1.1",
"SequenceNumber":1,
"url":"www.wikipedia.org",
"ping_avg":"56.2",
"InternalIPAddress":"192.168.96.123",
"Operator":"voda IT",
"Iccid":"8939104160000392116"
}
```


7.9 MONROE example: pReplay

The pReplay experiment replays the dependency graph of a web site.

The traversal begins with the first activity: Loading the root HTML. After building the dependency graph, it acts for each task whose dependencies have already been met. For network tasks, it makes a request for the corresponding url; correspondingly, for computation activities, it waits for the amount of time mentioned in the graph. Once a particular activity is finished, pReplay checks if any activities depending on that one have already met all of their dependencies and must thus be triggered. pReplay walks through the dependency graph until all activities in the graph have been visited.

7.9.1 Usage

Execute pReplay on a command line inside a container as with any other Linux command:

```
./pReplay interface_name server testfile [http|https|http2] [max-connections] [cookie-size]
```

Parameters:

- **interface_name:** Source interface for outgoing traffic.
- **server:** DNS name or IP address.
- **testfile:** Relative path to test file in JSON format.
- **protocol:**
  - http: http 1.1
  - https: http 1.1 with SSL
  - http2: http 2
- **max-connections:** Maximum amount of concurrent connections.
- **cookie-size:** Size of cookie — works with http1 only.

7.10 MONROE example: astream

AStream is a Python based emulated video player to evaluate the performance of the DASH bitrate adaptation algorithms. The supported rate adaptation algorithms are:

- Basic adaptation.
- Segment Aware Rate Adaptation (SARA) [2].
- Buffer-Based Rate Adaptation (Netflix) [1].

7.10.1 Usage

The experimenter can choose the rate adaptation algorithm passing a JSON string to the scheduler through the user interface (e.g., `"playback":"NETFLIX"`). The default is the basic adaptation scheme. Additionally, the user can specify the target MPD file to play (e.g., `"mpd_file":"http://128.39.37.161:8080/BigBuckBunny_4s.mpd"`) and the number of segments to retrieve (e.g., `"segment_limit":10`).

7.10.2 Output

The astream container outputs two log files:

1. Buffer logs: Epoch time, current playback time, current buffer size (in segments), current playback state.
2. Playback logs: Epoch time, playback time, segment number, segment size, playback bitrate, segment duration, weighted harmonic mean average download rate.

7.11 MONROE example: udpbwestimator

Udpbwestimator is an experiment setup to estimate available bandwidth for a particular network interface. It consists of two applications, a receiver and a traffic generator (server). The receiver initiates connections and requests the server for traffic. Then, every second, the server sends a burst of UDP packets back to back to the receiver, which follows the packet arrival times and estimates the available bandwidth.

7.11.1 Usage

The receiver accepts the following command line parameters:

-c : Number of back-to-back packets to be sent in each second.
-b : Number of bursts to be sent.
-l : Payload length in bytes.
-s : Source IP to bind to.
-o : Source port.
-d : Destination IP.
-p : Destination port.
-w : Optional, filename for writing the packet arrival times.

7.11.2 Output

The experiment will produce a single-line JSON object similar to the following:


```
{
"CID" : 33346602,
"DataId" : "MONROE.EXP.UDPBWESTIMATOR",
"DataVersion" : 1,
"DeviceMode" : 5,
"DeviceState" : 3,
"Guid" : "sha256:872af8c8b8f1635be6936a111b5fa838071e6f42cb317e9db1d9bb0c7db31425.93321.204.1",
"IMEI" : "864154023639966",
"IMSI" : "240016025247086",
"IMSIMCCMNC" : 24001,
"IPAddress" : "78.79.63.124",
"Iccid" : "89460120151010468086",
"InterfaceName" : "usb0",
"InternalIPAddress" : "192.168.68.118",
"InternalInterface" : "op1",
"LAC" : 2806,
"NWMCCMNC" : 24202,
"NodeId" : "204",
"Operator" : "NetCom",
"RSRP" : -72,
"RSRQ" : -7,
"RSSI" : -49,
"SequenceNumber" : 1,
"Timestamp" : 1479312368.633218,
"bw" : "48.41 38.98 36.44 50.00 30.20 45.21 47.02 37.89 44.37 28.90 25.91 38.57 48.74
39.94 43.37 37.94 43.81 39.60 52.00 47.55 48.20 34.85 41.44 47.60 57.26 46.11
45.66 52.04 37.43 49.67 33.56 50.35 41.11 51.63 45.33 104.01 45.73 49.95 50.37
38.57 29.45 50.95 54.95 45.42 47.13 34.30 46.10 103.68 79.75 45.72 52.03 30.38
50.21 36.96 71.51 54.66 39.26 44.12 45.18 39.93"
}
```


7.12 MONROE example: traceroute_background_experiment

Performs traceroute periodically to various targets. This experiment is meant to be run in the background and can be run in parallel with experiments of other users. It uses the default traceroute binary distributed by the Debian repositories.

Each traceroute produces a text file that is parsed by `outputParser.py` to generate the JSON output of this experiment. The JSON file is then imported into the MONROE database.

7.12.1 Usage

To reduce experiment duration, the traceroutes can be run in parallel. The number of parallel traceroute instances is dictated by the `maxNumberOfTotalTracerouteInstances` parameter. It is possible to parallelize on a per-interface basis (i.e., `maxNumberOfTotalTracerouteInstances` per interface) or per the whole experiment (i.e., `maxNumberOfTotalTracerouteInstances` total in the experiment instance spread among all the interfaces). This behavior is controlled by the `executionMode` parameter. The available options are: serially, serialPerInterface and parallel.

Additionally, a flag can be provided to choose the protocol of the probes: default, udp, tcp and icmp.

The parameters of this experiment are provided as "Additional options" in the web user interface. An example JSON string that can be used with this container as additional options is:

```
"interfaces": ["op0", "op1", "op2"], "targets": ["www.ntua.gr", "www.uc3m.es", "Google.com",
"Facebook.com", "Youtube.com", "Baidu.com", "Yahoo.com", "Amazon.com", "Wikipedia.org",
"audio-ec.spotify.com", "mme.whatsapp.net", "sync.liverail.com", "ds.serving-sys.com",
"instagramstatic-a.akamaihd.net"], "maxNumberOfTotalTracerouteInstances": 5,
"executionMode": "parallel"
```

7.13 Other containers in the repositories

Our public repositories contain the source code for other Docker containers that perform varied tasks in the nodes. Although they are not intended as examples, users can take a look into them to gain a deeper understanding of the platform configuration.

7.13.1 Container: metadata-subscriber

The subscriber is designed to listen to ZMQ messages send out by the metadata-multicaster. The subscriber attaches to a configurable ZeroMQ socket and listens to all messages that begin with the topic "MONROE.META," except the ones whose topic ends with ".UPDATE" (rebroadcasts) and/or begins with "MONROE.META.DEVICE.CONNECTIVITY." as these are redundant. All messages are updated with NodeId, but are otherwise saved verbatim as a JSON formatted file suitable for later import in the MONROE databases.

7.13.2 Container: tunnelbox-server

This container acts as an SSH reverese tunnel endpoint that clients can use to directly connect to their experiment containers (on any MONROE node). The purpose is to provide experimenters an interactive way of accessing an experiment running on a real MONROE node during development or debugging. The client has to supply its own public SSH key to the experiment container using the web user interface. The web user interface provides further instructions (SSH command line) to connect to the experiment container using the provided key.

7.13.3 Container: monroe_base

This is the container upon which all user experiments *must* be built. The container is based on Debian "jessie" with (MONROE) common experiment tools added. For a list of the tools currently installed see the folder `monroe_base.docker` in our repositories.

8 List of known bugs and issues

- In general, Firefox does not render the date-time picker correctly. You will have to either enter the dates and times manually or use Chrome.
- Container deployment can take several minutes, particularly for nodes without an Ethernet management connection (e.g., mobile nodes in trains or buses). When scheduling an experiment, the user has to take into account the time needed for the deployment. The system will not automatically take care of this at this moment.
- Similarly, the button "Check availability" returns the earliest available slot. However, it does not account for the time needed to deploy the container. The user must manually account for that.
- Checking the option "ASAP" to schedule an experiment as soon as possible may fail due to lack of time to deploy the container. The system does add some slack in this case, but its length may need some adjustment according to the type of nodes and MBB characteristics.

A List of packages installed in monroe/base

Table 8: List of packages installed in `monroe/base` as of 2017-02-27.

Name	Version	Architecture	Description
acl	2.2.52-2	amd64	Access control list utilities
adduser	3.113+nmu3	all	add and remove users and groups
adwaita-icon-theme	3.14.0-2	all	default icon theme of GNOME
apt	1.0.9.8.4	amd64	commandline package manager
base-files	8+deb8u6	amd64	Debian base system miscellaneous files
base-passwd	3.5.37	amd64	Debian base system master password and group files
bash	4.3-11+b1	amd64	GNU Bourne Again SHell
bsdutils	1:2.25.2-6	amd64	basic utilities from 4.4BSD-Lite
bzip2	1.0.6-7+b3	amd64	high-quality block-sorting file compressor - utilities
ca-certificates	20141019+deb8u1	all	Common CA certificates
ca-certificates-java	20140324	all	Common CA certificates (JKS keystore)
coreutils	8.23-4	amd64	GNU core utilities
curl	7.38.0-4+deb8u5	amd64	command line tool for transferring data with URL syntax
d-itg	2.8.1-r1023-3	amd64	Distributed Internet Traffic Generator
dash	0.5.7-4+b1	amd64	POSIX-compliant shell
dbus	1.8.20-0+deb8u1	amd64	simple interprocess messaging system (daemon and utilities)
dconf-gsettings-backend:amd64	0.22.0-1	amd64	simple configuration storage system - GSettings back-end
dconf-service	0.22.0-1	amd64	simple configuration storage system - D-Bus service
debconf	1.5.56	all	Debian configuration management system
debconf-i18n	1.5.56	all	full internationalization support for debconf
debian-archive-keyring	2014.3	all	GnuPG archive keys of the Debian archive
debianutils	4.4+b1	amd64	Miscellaneous utilities specific to Debian
default-jre-headless	2:1.7-52	amd64	Standard Java or Java compatible Runtime (headless)
dh-python	1.20141111-2	all	Debian helper tools for packaging Python libraries and applications
diffutils	1:3.3-1+b1	amd64	File comparison utilities
dmsetup	2:1.02.90-2.2+deb8u1	amd64	Linux Kernel Device Mapper userspace library
dpkg	1.17.27	amd64	Debian package management system
dumb-init	1.2.0	amd64	wrapper script which proxies signals to a child
e2fslibs:amd64	1.42.12-2	amd64	ext2/ext3/ext4 file system libraries
e2fsprogs	1.42.12-2	amd64	ext2/ext3/ext4 file system utilities
findutils	4.4.2-9+b1	amd64	utilities for finding files–find, xargs
flent	0.15.0-1	all	The FLExible Network Tester
fontconfig	2.11.0-6.3+deb8u1	amd64	generic font configuration library - support binaries
fontconfig-config	2.11.0-6.3+deb8u1	all	generic font configuration library - configuration

Table 8: List of packages installed in `monroe/base`. (Continued)

Name	**Version**	**Architecture**	**Description**
fonts-dejavu-core	2.34-1	all	Vera font family derivate with additional characters
fping	3.10-2	amd64	sends ICMP ECHO_REQUEST packets to network hosts
gcc-4.8-base:amd64	4.8.4-1	amd64	GCC, the GNU Compiler Collection (base package)
gcc-4.9-base:amd64	4.9.2-10	amd64	GCC, the GNU Compiler Collection (base package)
glib-networking:amd64	2.42.0-2	amd64	network-related giomodules for GLib
glib-networking-common	2.42.0-2	all	network-related giomodules for GLib - data files
glib-networking-services	2.42.0-2	amd64	network-related giomodules for GLib - D-Bus services
gnupg	1.4.18-7+deb8u3	amd64	GNU privacy guard - a free PGP replacement
gpgv	1.4.18-7+deb8u3	amd64	GNU privacy guard - signature verification tool
gpsd	3.11-3	amd64	Global Positioning System - daemon
gpslogger-oml2	2.11.0-mytestbed2	amd64	Record and store GPS measurements using OML
grep	2.20-4.1	amd64	GNU grep, egrep and fgrep
gsettings-desktop-schemas	3.14.1-1	all	GSettings desktop-wide schemas
gzip	1.6-4	amd64	GNU compression utilities
hicolor-icon-theme	0.13-1	all	default fallback theme for FreeDesktop.org icon themes
hostname	3.15	amd64	utility to set/show the host name or domain name
httperf-oml2	2.11.0-mytestbed2	amd64	HTTP server performance tester, with OML support
httping	1.5.8-1	amd64	ping-like program for http-requests
inetutils-ping	2:1.9.2.39.3a460-3	amd64	ICMP echo tool
init	1.22	amd64	System-V-like init utilities - metapackage
init-system-helpers	1.22	all	helper tools for all init systems
initscripts	2.88dsf-59	amd64	scripts for initializing and shutting down the system
insserv	1.14.0-5	amd64	boot sequence organizer using LSB init.d script dependency information
iperf	2.0.5+dfsg1-2	amd64	Internet Protocol bandwidth measuring tool
iperf-oml2	2.11.0-mytestbed2	amd64	Internet Protocol bandwidth measuring tool, with OML support
iperf3	3.0.7-1	amd64	Internet Protocol bandwidth measuring tool
iproute2	3.16.0-2	amd64	networking and traffic control tools
iptables	1.4.21-2+b1	amd64	administration tools for packet filtering and NAT
java-common	0.52	all	Base of all Java packages
jq	1.4-2.1	amd64	lightweight and flexible command-line JSON processor
libacl1:amd64	2.2.52-2	amd64	Access control list shared library
libapt-pkg4.12:amd64	1.0.9.8.4	amd64	package management runtime library
libasound2:amd64	1.0.28-1	amd64	shared library for ALSA applications
libasound2-data	1.0.28-1	all	Configuration files and profiles for ALSA drivers
libasyncns0:amd64	0.8-5	amd64	Asynchronous name service query library
libatk-bridge2.0-0:amd64	2.14.0-2	amd64	AT-SPI 2 toolkit bridge - shared library
libatk1.0-0:amd64	2.14.0-1	amd64	ATK accessibility toolkit
libatk1.0-data	2.14.0-1	all	Common files for the ATK accessibility toolkit
libatspi2.0-0:amd64	2.14.0-1	amd64	Assistive Technology Service Provider Interface - shared library
libattr1:amd64	1:2.4.47-2	amd64	Extended attribute shared library
libaudit-common	1:2.4-1	all	Dynamic library for security auditing - common files
libaudit1:amd64	1:2.4-1+b1	amd64	Dynamic library for security auditing
libavahi-client3:amd64	0.6.31-5	amd64	Avahi client library
libavahi-common-data:amd64	0.6.31-5	amd64	Avahi common data files
libavahi-common3:amd64	0.6.31-5	amd64	Avahi common library
libblas-common	1.2.20110419-10	amd64	Dependency package for all BLAS implementations
libblas3	1.2.20110419-10	amd64	Basic Linear Algebra Reference implementations, shared library
libblkid1:amd64	2.25.2-6	amd64	block device id library
libbluetooth3:amd64	5.23-2+b1	amd64	Library to use the BlueZ Linux Bluetooth stack
libbsd0:amd64	0.7.0-2	amd64	utility functions from BSD systems - shared library
libbz2-1.0:amd64	1.0.6-7+b3	amd64	high-quality block-sorting file compressor library - runtime
libc-bin	2.19-18+deb8u6	amd64	GNU C Library: Binaries
libc6:amd64	2.19-18+deb8u6	amd64	GNU C Library: Shared libraries
libcairo-gobject2:amd64	1.14.0-2.1+deb8u1	amd64	Cairo 2D vector graphics library (GObject library)
libcairo2:amd64	1.14.0-2.1+deb8u1	amd64	Cairo 2D vector graphics library
libcap-ng0:amd64	0.7.4-2	amd64	An alternate POSIX capabilities library
libcap2:amd64	1:2.24-8	amd64	POSIX 1003.1e capabilities (library)
libcap2-bin	1:2.24-8	amd64	POSIX 1003.1e capabilities (utilities)
libcgi-fast-perl	1:2.04-1	all	CGI subclass for work with FCGI
libcgi-pm-perl	4.09-1	all	module for Common Gateway Interface applications
libcolord2:amd64	1.2.1-1+b2	amd64	system service to manage device colour profiles – runtime

Table 8: List of packages installed in `monroe/base`. (Continued)

Name	Version	Architecture	Description
libcomerr2:amd64	1.42.12-2	amd64	common error description library
libconfig-grammar-perl	1.10-2	all	grammar-based user-friendly config parser
libcroco3:amd64	0.6.8-3+b1	amd64	Cascading Style Sheet (CSS) parsing and manipulation toolkit
libcryptsetup4:amd64	2:1.6.6-5	amd64	disk encryption support - shared library
libcups2:amd64	1.7.5-11+deb8u1	amd64	Common UNIX Printing System(tm) - Core library
libcurl3:amd64	7.38.0-4+deb8u5	amd64	easy-to-use client-side URL transfer library (OpenSSL flavour)
libdatrie1:amd64	0.2.8-1	amd64	Double-array trie library
libdb5.3:amd64	5.3.28-9	amd64	Berkeley v5.3 Database Libraries [runtime]
libdbi1:amd64	0.9.0-4	amd64	DB Independent Abstraction Layer for C – shared library
libdbus-1-3:amd64	1.8.20-0+deb8u1	amd64	simple interprocess messaging system (library)
libdbus-glib-1-2:amd64	0.102-1	amd64	simple interprocess messaging system (GLib-based shared library)
libdconf1:amd64	0.22.0-1	amd64	simple configuration storage system - runtime library
libdebconfclient0:amd64	0.192	amd64	Debian Configuration Management System (C-implementation library)
libdevmapper1.02.1:amd64	2:1.02.90-2.2+deb8u1	amd64	Linux Kernel Device Mapper userspace library
libdigest-hmac-perl	1.03+dfsg-1	all	module for creating standard message integrity checks
libdrm2:amd64	2.4.58-2	amd64	Userspace interface to kernel DRM services – runtime
libedit2:amd64	3.1-20140620-2	amd64	BSD editline and history libraries
libencode-locale-perl	1.03-1	all	utility to determine the locale encoding
libexpat1:amd64	2.1.0-6+deb8u3	amd64	XML parsing C library - runtime library
libfcgi-perl	0.77-1+b1	amd64	helper module for FastCGI
libffi6:amd64	3.1-2+b2	amd64	Foreign Function Interface library runtime
libfile-listing-perl	6.04-1	all	module to parse directory listings
libflac8:amd64	1.3.0-3	amd64	Free Lossless Audio Codec - runtime C library
libfontconfig1:amd64	2.11.0-6.3+deb8u1	amd64	generic font configuration library - runtime
libfontenc1:amd64	1:1.1.2-1+b2	amd64	X11 font encoding library
libfreetype6:amd64	2.5.2-3+deb8u1	amd64	FreeType 2 font engine, shared library files
libgcc1:amd64	1:4.9.2-10	amd64	GCC support library
libgcrypt20:amd64	1.6.3-2+deb8u2	amd64	LGPL Crypto library - runtime library
libgdbm3:amd64	1.8.3-13.1	amd64	GNU dbm database routines (runtime version)
libgdk-pixbuf2.0-0:amd64	2.31.1-2+deb8u5	amd64	GDK Pixbuf library
libgdk-pixbuf2.0-common	2.31.1-2+deb8u5	all	GDK Pixbuf library - data files
libgfortran3:amd64	4.9.2-10	amd64	Runtime library for GNU Fortran applications
libgl1-mesa-glx:amd64	10.3.2-1+deb8u1	amd64	free implementation of the OpenGL API – GLX runtime
libglapi-mesa:amd64	10.3.2-1+deb8u1	amd64	free implementation of the GL API – shared library
libglib2.0-0:amd64	2.42.1-1+b1	amd64	GLib library of C routines
libgmp10:amd64	2:6.0.0+dfsg-6	amd64	Multiprecision arithmetic library
libgnutls-deb0-28:amd64	3.3.8-6+deb8u3	amd64	GNU TLS library - main runtime library
libgpg-error0:amd64	1.17-3	amd64	library for common error values and messages in GnuPG components
libgps21:amd64	3.11-3	amd64	Global Positioning System - library
libgraphite2-3:amd64	1.3.6-1 deb8u1	amd64	Font rendering engine for Complex Scripts – library
libgssapi-krb5-2:amd64	1.12.1+dfsg-19+deb8u2	amd64	MIT Kerberos runtime libraries - krb5 GSS-API Mechanism
libgtk-3-0:amd64	3.14.5-1+deb8u1	amd64	GTK+ graphical user interface library
libgtk-3-bin	3.14.5-1+deb8u1	amd64	programs for the GTK+ graphical user interface library
libgtk-3-common	3.14.5-1+deb8u1	all	common files for the GTK+ graphical user interface library
libgtk2.0-0:amd64	2.24.25-3+deb8u1	amd64	GTK+ graphical user interface library
libgtk2.0-common	2.24.25-3+deb8u1	all	common files for the GTK+ graphical user interface library
libharfbuzz0b:amd64	0.9.35-2	amd64	OpenType text shaping engine (shared library)
libhogweed2:amd64	2.7.1-5+deb8u1	amd64	low level cryptographic library (public-key cryptos)
libhtml-parser-perl	3.71-1+b3	amd64	collection of modules that parse HTML text documents
libhtml-tagset-perl	3.20-2	all	Data tables pertaining to HTML
libhtml-tree-perl	5.03-1	all	Perl module to represent and create HTML syntax trees
libhttp-cookies-perl	6.01-1	all	HTTP cookie jars
libhttp-date-perl	6.02-1	all	module of date conversion routines
libhttp-message-perl	6.06-1	all	perl interface to HTTP style messages
libhttp-negotiate-perl	6.00-2	all	implementation of content negotiation
libice6:amd64	2:1.0.9-1+b1	amd64	X11 Inter-Client Exchange library
libicu52:amd64	52.1-8+deb8u4	amd64	International Components for Unicode
libidn11:amd64	1.29-1+deb8u2	amd64	GNU Libidn library, implementation of IETF IDN specifications
libio-html-perl	1.001-1	all	open an HTML file with automatic charset detection
libio-socket-ssl-perl	2.002-2+deb8u1	all	Perl module implementing object oriented interface to SSL sockets

Table 8: List of packages installed in `monroe/base`. (Continued)

Name	Version	Architecture	Description
libiperf0	3.0.7-1	amd64	Internet Protocol bandwidth measuring tool (runtime files)
libjasper1:amd64	1.900.1-debian1-2.4+deb8u1	amd64	JasPer JPEG-2000 runtime library
libjbig0:amd64	2.1-3.1	amd64	JBIGkit libraries
libjpeg62-turbo:amd64	1:1.3.1-12	amd64	libjpeg-turbo JPEG runtime library
libjs-cropper	1.2.2-1	all	JavaScript image cropper UI
libjs-prototype	1.7.1-3	all	JavaScript Framework for dynamic web applications
libjs-scriptaculous	1.9.0-2	all	JavaScript library for dynamic web applications
libjson-c2:amd64	0.11-4	amd64	JSON manipulation library - shared library
libjson-glib-1.0-0:amd64	1.0.2-1	amd64	GLib JSON manipulation library
libjson-glib-1.0-common	1.0.2-1	all	GLib JSON manipulation library (common files)
libk5crypto3:amd64	1.12.1+dfsg-19+deb8u2	amd64	MIT Kerberos runtime libraries - Crypto Library
libkeyutils1:amd64	1.5.9-5+b1	amd64	Linux Key Management Utilities (library)
libkmod2:amd64	18-3	amd64	libkmod shared library
libkrb5-3:amd64	1.12.1+dfsg-19+deb8u2	amd64	MIT Kerberos runtime libraries
libkrb5support0:amd64	1.12.1+dfsg-19+deb8u2	amd64	MIT Kerberos runtime libraries - Support library
liblcms2-2:amd64	2.6-3+b3	amd64	Little CMS 2 color management library
libldap-2.4-2:amd64	2.4.40+dfsg-1+deb8u2	amd64	OpenLDAP libraries
liblinear1:amd64	1.8+dfsg-4	amd64	Library for Large Linear Classification
liblocale-gettext-perl	1.05-8+b1	amd64	module using libc functions for internationalization in Perl
liblua5.2-0:amd64	5.2.3-1.1	amd64	Shared library for the Lua interpreter version 5.2
liblwp-mediatypes-perl	6.02-1	all	module to guess media type for a file or a URL
liblwp-protocol-https-perl	6.06-2	all	HTTPS driver for LWP::UserAgent
liblzma5:amd64	5.1.1alpha+20120614-2+b3	amd64	XZ-format compression library
libmount1:amd64	2.25.2-6	amd64	device mounting library
libmpdec2:amd64	2.4.1-1	amd64	library for decimal floating point arithmetic (runtime library)
libncurses5:amd64	5.9+20140913-1+b1	amd64	shared libraries for terminal handling
libncursesw5:amd64	5.9+20140913-1+b1	amd64	shared libraries for terminal handling (wide character support)
libnet-http-perl	6.07-1	all	module providing low-level HTTP connection client
libnet-ssleay-perl	1.65-1+deb8u1	amd64	Perl module for Secure Sockets Layer (SSL)
libnettle4:amd64	2.7.1-5+deb8u1	amd64	low level cryptographic library (symmetric and one-way cryptos)
libnfnetlink0:amd64	1.0.1-3	amd64	Netfilter netlink library
libnspr4:amd64	2:4.12-1+debu8u1	amd64	NetScape Portable Runtime Library
libnss3:amd64	2:3.26-1+debu8u1	amd64	Network Security Service libraries
libocomm	2.11.1 rc-mytestbed1	amd64	OComm: O? Communications Library (metapackage)
libocomm-dev	2.11.1 rc-mytestbed1	amd64	OML measurement library headers
libocomm1	2.11.1 rc-mytestbed1	amd64	OComm: O? Communications Library
libogg0:amd64	1.3.2-1	amd64	Ogg bitstream library
liboml2	2.11.1 rc-mytestbed1	amd64	OML: The O? Measurement Library (metapackage)
liboml2-9	2.11.1 rc-mytestbed1	amd64	OML: The O? Measurement Library
liboml2-dev	2.11.1 rc-mytestbed1	amd64	OML measurement library headers
libp11-kit0:amd64	0.20.7-1	amd64	Library for loading and coordinating access to PKCS#11 modules - runtime
libpam-modules:amd64	1.1.8-3.1+deb8u1+b1	amd64	Pluggable Authentication Modules for PAM
libpam-modules-bin	1.1.8-3.1+deb8u1+b1	amd64	Pluggable Authentication Modules for PAM - helper binaries
libpam-runtime	1.1.8-3.1+deb8u1	all	Runtime support for the PAM library
libpam0g:amd64	1.1.8-3.1+deb8u1+b1	amd64	Pluggable Authentication Modules library
libpango-1.0-0:amd64	1.36.8-3	amd64	Layout and rendering of internationalized text
libpangocairo-1.0-0:amd64	1.36.8-3	amd64	Layout and rendering of internationalized text
libpangoft2-1.0-0:amd64	1.36.8-3	amd64	Layout and rendering of internationalized text
libpcap0.8:amd64	1.6.2-2	amd64	system interface for user-level packet capture
libpcre3:amd64	2:8.35-3.3+deb8u4	amd64	Perl 5 Compatible Regular Expression Library - runtime files
libpcsclite1:amd64	1.8.13-1	amd64	Middleware to access a smart card using PC/SC (library)
libpgm-5.1-0	5.1.118-1 dfsg-1	amd64	OpenPGM shared library
libpixman-1-0:amd64	0.32.6-3	amd64	pixel-manipulation library for X and cairo
libpng12-0:amd64	1.2.50-2+deb8u2	amd64	PNG library - runtime
libpopt0:amd64	1.16-10	amd64	lib for parsing cmdline parameters
libpq5:amd64	9.4.9-0+deb8u1	amd64	PostgreSQL C client library
libprocps3:amd64	2:3.3.9-9	amd64	library for accessing process information from /proc
libproxy1:amd64	0.4.11-4+b2	amd64	automatic proxy configuration management library (shared)
libpsl0:amd64	0.5.1-1	amd64	Library for Public Suffix List (shared libraries)
libpulse0:amd64	5.0-13	amd64	PulseAudio client libraries
libpython-stdlib:amd64	2.7.9-1	amd64	interactive high-level object-oriented language (default python version)

Table 8: List of packages installed in `monroe/base`. (Continued)

Name	Version	Architecture	Description
libpython2.7-minimal:amd64	2.7.9-2+deb8u1	amd64	Minimal subset of the Python language (version 2.7)
libpython2.7-stdlib:amd64	2.7.9-2+deb8u1	amd64	Interactive high-level object-oriented language (standard library, version 2.7)
libpython3-stdlib:amd64	3.4.2-2	amd64	interactive high-level object-oriented language (default python3 version)
libpython3.4-minimal:amd64	3.4.2-1	amd64	Minimal subset of the Python language (version 3.4)
libpython3.4-stdlib:amd64	3.4.2-1	amd64	Interactive high-level object-oriented language (standard library, version 3.4)
libquadmath0:amd64	4.9.2-10	amd64	GCC Quad-Precision Math Library
libreadline6:amd64	6.3-8+b3	amd64	GNU readline and history libraries, run-time libraries
librest-0.7-0:amd64	0.7.92-3	amd64	REST service access library
librrd4	1.4.8-1.2	amd64	time-series data storage and display system (runtime library)
librrds-perl	1.4.8-1.2	amd64	time-series data storage and display system (Perl interface, shared)
librsvg2-2:amd64	2.40.5-1+deb8u2	amd64	SAX-based renderer library for SVG files (runtime)
librsvg2-common:amd64	2.40.5-1+deb8u2	amd64	SAX-based renderer library for SVG files (extra runtime)
librtmp1:amd64	2.4+20150115.gita107cef-1	amd64	toolkit for RTMP streams (shared library)
libruby2.1:amd64	2.1.5-2+deb8u3	amd64	Libraries necessary to run Ruby 2.1
libsasl2-2:amd64	2.1.26.dfsg1-13+deb8u1	amd64	Cyrus SASL - authentication abstraction library
libsasl2-modules-db:amd64	2.1.26.dfsg1-13+deb8u1	amd64	Cyrus SASL - pluggable authentication modules (DB)
libsctp1:amd64	1.0.16+dfsg-2	amd64	user-space access to Linux Kernel SCTP - shared library
libselinux1:amd64	2.3-2	amd64	SELinux runtime shared libraries
libsemanage-common	2.3-1	all	Common files for SELinux policy management libraries
libsemanage1:amd64	2.3-1+b1	amd64	SELinux policy management library
libsepol1:amd64	2.3-2	amd64	SELinux library for manipulating binary security policies
libsigar	1.6.5-1ppa1o	amd64	System Information Gatherer And Reporter
libslang2:amd64	2.3.0-2	amd64	S-Lang programming library - runtime version
libsm6:amd64	2:1.2.2-1+b1	amd64	X11 Session Management library
libsmartcols1:amd64	2.25.2-6	amd64	smart column output alignment library
libsndfile1:amd64	1.0.25-9.1+deb8u1	amd64	Library for reading/writing audio files
libsnmp-session-perl	1.13-1.1	all	Perl support for accessing SNMP-aware devices
libsodium13:amd64	1.0.0-1	amd64	Network communication, cryptography and signaturing library
libsoup-gnome2.4-1:amd64	2.48.0-1	amd64	HTTP library implementation in C – GNOME support library
libsoup2.4-1:amd64	2.48.0-1	amd64	HTTP library implementation in C – Shared library
libsqlite3-0:amd64	3.8.7.1-1+deb8u2	amd64	SQLite 3 shared library
libss2:amd64	1.42.12-2	amd64	command-line interface parsing library
libssh2-1:amd64	1.4.3-4.1+deb8u1	amd64	SSH2 client-side library
libssl1.0.0:amd64	1.0.1t-1+deb8u5	amd64	Secure Sockets Layer toolkit - shared libraries
libstdc++6:amd64	4.9.2-10	amd64	GNU Standard C++ Library v3
libsystemd0:amd64	215-17+deb8u5	amd64	systemd utility library
libtasn1-6:amd64	4.2-3+deb8u2	amd64	Manage ASN.1 structures (runtime)
libtext-charwidth-perl	0.04-7+b3	amd64	get display widths of characters on the terminal
libtext-iconv-perl	1.7-5+b2	amd64	converts between character sets in Perl
libtext-wrapi18n-perl	0.06-7	all	internationalized substitute of Text::Wrap
libthai-data	0.1.21-1	all	Data files for Thai language support library
libthai0:amd64	0.1.21-1	amd64	Thai language support library
libtiff5:amd64	4.0.3-12.3+deb8u1	amd64	Tag Image File Format (TIFF) library
libtimedate-perl	2.3000-2	all	collection of modules to manipulate date/time information
libtinfo5:amd64	5.9+20140913-1+b1	amd64	shared low-level terminfo library for terminal handling
libtrace3	3.0.21-1	amd64	network trace processing library supporting many input formats
libudev1:amd64	215-17+deb8u5	amd64	libudev shared library
liburi-perl	1.64-1	all	module to manipulate and access URI strings
libusb-0.1-4:amd64	2:0.1.12-25	amd64	userspace USB programming library
libusb-1.0-0:amd64	2:1.0.19-1	amd64	userspace USB programming library
libustr-1.0-1:amd64	1.0.4-3+b2	amd64	Micro string library: shared library
libuuid1:amd64	2.25.2-6	amd64	Universally Unique ID library
libvorbis0a:amd64	1.3.4-2	amd64	decoder library for Vorbis General Audio Compression Codec
libvorbisenc2:amd64	1.3.4-2	amd64	encoder library for Vorbis General Audio Compression Codec
libwandio1	3.0.21-1	amd64	multi-threaded file compression and decompression library
libwayland-client0:amd64	1.6.0-2	amd64	wayland compositor infrastructure - client library

Table 8: List of packages installed in `monroe/base`. (Continued)

Name	Version	Architecture	Description
libwayland-cursor0:amd64	1.6.0-2	amd64	wayland compositor infrastructure - cursor library
libwrap0:amd64	7.6.q-25	amd64	Wietse Venema's TCP wrappers library
libwww-perl	6.08-1	all	simple and consistent interface to the world-wide web
libwww-robotrules-perl	6.01-1	all	database of robots.txt-derived permissions
libx11-6:amd64	2:1.6.2-3	amd64	X11 client-side library
libx11-data	2:1.6.2-3	all	X11 client-side library
libx11-xcb1:amd64	2:1.6.2-3	amd64	Xlib/XCB interface library
libxau6:amd64	1:1.0.8-1	amd64	X11 authorisation library
libxaw7:amd64	2:1.0.12-2+b1	amd64	X11 Athena Widget library
libxcb-dri2-0:amd64	1.10-3+b1	amd64	X C Binding, dri2 extension
libxcb-dri3-0:amd64	1.10-3+b1	amd64	X C Binding, dri3 extension
libxcb-glx0:amd64	1.10-3+b1	amd64	X C Binding, glx extension
libxcb-present0:amd64	1.10-3+b1	amd64	X C Binding, present extension
libxcb-render0:amd64	1.10-3+b1	amd64	X C Binding, render extension
libxcb-shm0:amd64	1.10-3+b1	amd64	X C Binding, shm extension
libxcb-sync1:amd64	1.10-3+b1	amd64	X C Binding, sync extension
libxcb1:amd64	1.10-3+b1	amd64	X C Binding
libxcomposite1:amd64	1:0.4.4-1	amd64	X11 Composite extension library
libxcursor1:amd64	1:1.1.14-1+b1	amd64	X cursor management library
libxdamage1:amd64	1:1.1.4-2+b1	amd64	X11 damaged region extension library
libxdmcp6:amd64	1:1.1.1-1+b1	amd64	X11 Display Manager Control Protocol library
libxext6:amd64	2:1.3.3-1	amd64	X11 miscellaneous extension library
libxfixes3:amd64	1:5.0.1-2+b2	amd64	X11 miscellaneous 'fixes' extension library
libxfont1:amd64	1:1.5.1-1	amd64	X11 font rasterisation library
libxi6:amd64	2:1.7.4-1+b2	amd64	X11 Input extension library
libxinerama1:amd64	2:1.1.3-1+b1	amd64	X11 Xinerama extension library
libxkbcommon0:amd64	0.4.3-2	amd64	library interface to the XKB compiler - shared library
libxkbfile1:amd64	1:1.0.8-1	amd64	X11 keyboard file manipulation library
libxml2:amd64	2.9.1+dfsg1-5+deb8u3	amd64	GNOME XML library
libxmu6:amd64	2:1.1.2-1	amd64	X11 miscellaneous utility library
libxmuu1:amd64	2:1.1.2-1	amd64	X11 miscellaneous micro-utility library
libxpm4:amd64	1:3.5.11-1+b1	amd64	X11 pixmap library
libxrandr2:amd64	2:1.4.2-1+b1	amd64	X11 RandR extension library
libxrender1:amd64	1:0.9.8-1+b1	amd64	X Rendering Extension client library
libxshmfence1:amd64	1.1-4	amd64	X shared memory fences - shared library
libxt6:amd64	1:1.1.4-1+b1	amd64	X11 toolkit intrinsics library
libxtables10	1.4.21-2+b1	amd64	netfilter xtables library
libxtst6:amd64	2:1.2.2-1+b1	amd64	X11 Testing – Record extension library
libxxf86vm1:amd64	1:1.1.3-1+b1	amd64	X11 XFree86 video mode extension library
libyaml-0-2:amd64	0.1.6-3	amd64	Fast YAML 1.1 parser and emitter library
libzmq3:amd64	4.0.5+dfsg-2+deb8u1	amd64	lightweight messaging kernel (shared library)
login	1:4.2-3+deb8u1	amd64	system login tools
lsb-base	4.1+Debian13+nmu1	all	Linux Standard Base 4.1 init script functionality
mawk	1.3.3-17	amd64	a pattern scanning and text processing language
mgen	5.02+dfsg2-3	amd64	packet generator for IP network performance tests
mime-support	3.58	all	MIME files 'mime.types' & 'mailcap', and support programs
mount	2.25.2-6	amd64	Tools for mounting and manipulating filesystems
multiarch-support	2.19-18+deb8u6	amd64	Transitional package to ensure multiarch compatibility
nano	2.2.6-3	amd64	small, friendly text editor inspired by Pico
ncurses-base	5.9+20140913-1	all	basic terminal type definitions
ncurses-bin	5.9+20140913-1+b1	amd64	terminal-related programs and man pages
net-tools	1.60-26+b1	amd64	NET-3 networking toolkit
netbase	5.3	all	Basic TCP/IP networking system
netperf	2.7.0-1	amd64	Network performance benchmark
nmap	6.47-3+deb8u2	amd64	The Network Mapper
nmetrics-oml2	2.11.0-mytestbed2	amd64	Measure and record system information from libsigar using OML
oml2	2.11.1 rc-mytestbed1	amd64	OML: The O? Measurement Library Suite (Metapackage)
oml2-apps	2.11.0-mytestbed2	amd64	Standalone OML2 applications (metapackage)
oml2-proxy-server	2.11.1 rc-mytestbed1	amd64	OML proxy server
oml2-proxycon	2.11.1 rc-mytestbed1	amd64	OML proxy server control script
oml2-server	2.11.1 rc-mytestbed1	amd64	OML measurement server
openjdk-7-jre-headless:amd64	7u111-2.6.7-2 deb8u1	amd64	OpenJDK Java runtime, using Hotspot JIT (headless)

Table 8: List of packages installed in `monroe/base`. (Continued)

Name	Version	Architecture	Description
openssh-client	1:6.7p1-5+deb8u3	amd64	secure shell (SSH) client, for secure access to remote machines
openssh-server	1:6.7p1-5+deb8u3	amd64	secure shell (SSH) server, for secure access from remote machines
openssh-sftp-server	1:6.7p1-5+deb8u3	amd64	secure shell (SSH) sftp server module, for SFTP access from remote machines
openssl	1.0.1t-1+deb8u5	amd64	Secure Sockets Layer toolkit - cryptographic utility
otg2-oml2	2.11.0-mytestbed2	amd64	Orbit Traffic Generator
passwd	1:4.2-3+deb8u1	amd64	change and administer password and group data
perl	5.20.2-3+deb8u6	amd64	Larry Wall's Practical Extraction and Report Language
perl-base	5.20.2-3+deb8u6	amd64	minimal Perl system
perl-modules	5.20.2-3+deb8u6	all	Core Perl modules
procps	2:3.3.9-9	amd64	/proc file system utilities
python	2.7.9-1	amd64	interactive high-level object-oriented language (default version)
python-chardet	2.3.0-1	all	universal character encoding detector for Python2
python-colorama	0.3.2-1	all	Cross-platform colored terminal text in Python - Python 2.x
python-distlib	0.1.9-1	all	low-level components of python distutils2/packaging
python-html5lib	0.999-3	all	HTML parser/tokenizer based on the WHATWG HTML5 specification (Python 2)
python-meld3	1.0.0-1	amd64	HTML/XML templating system for Python
python-minimal	2.7.9-1	amd64	minimal subset of the Python language (default version)
python-netifaces	0.10.4-0.1	amd64	portable network interface information - Python 2.x
python-pip	1.5.6-5	all	alternative Python package installer
python-pkg-resources	5.5.1-1	all	Package Discovery and Resource Access using pkg_resources
python-requests	2.4.3-6	all	elegant and simple HTTP library for Python2, built for human beings
python-rrdtool	1.4.8-1.2	amd64	time-series data storage and display system (Python interface)
python-scapy	2.2.0-1	all	Packet generator/sniffer and network scanner/discovery
python-setuptools	5.5.1-1	all	Python Distutils Enhancements
python-six	1.8.0-1	all	Python 2 and 3 compatibility library (Python 2 interface)
python-urllib3	1.9.1-3	all	HTTP library with thread-safe connection pooling for Python
python-zmq	14.4.0-1	amd64	Python bindings for 0MQ library
python2.7	2.7.9-2+deb8u1	amd64	Interactive high-level object-oriented language (version 2.7)
python2.7-minimal	2.7.9-2+deb8u1	amd64	Minimal subset of the Python language (version 2.7)
python3	3.4.2-2	amd64	interactive high-level object-oriented language (default python3 version)
python3-minimal	3.4.2-2	amd64	minimal subset of the Python language (default python3 version)
python3-netifaces	0.10.4-0.1	amd64	portable network interface information - Python 3.x
python3-six	1.8.0-1	all	Python 2 and 3 compatibility library (Python 3 interface)
python3-zmq	14.4.0-1	amd64	Python3 bindings for 0MQ library
python3.4	3.4.2-1	amd64	Interactive high-level object-oriented language (version 3.4)
python3.4-minimal	3.4.2-1	amd64	Minimal subset of the Python language (version 3.4)
readline-common	6.3-8	all	GNU readline and history libraries, common files
ripwavemon-oml2	2.11.0-mytestbed2	amd64	Report statistics from a Navini RipWave modem
rsync	3.1.1-3	amd64	fast, versatile, remote (and local) file-copying tool
ruby	1:2.1.5+deb8u2	all	Interpreter of object-oriented scripting language Ruby (default version)
ruby2.1	2.1.5-2+deb8u3	amd64	Interpreter of object-oriented scripting language Ruby
rubygems-integration	1.8	all	integration of Debian Ruby packages with Rubygems
sed	4.2.2-4+b1	amd64	The GNU sed stream editor
sensible-utils	0.0.9	all	Utilities for sensible alternative selection
shared-mime-info	1.3-1	amd64	FreeDesktop.org shared MIME database and spec
smokeping	2.6.9-1+deb8u1	all	latency logging and graphing system
startpar	0.59-3	amd64	run processes in parallel and multiplex their output
supervisor	3.0r1-1	all	A system for controlling process state
systemd	215-17+deb8u5	amd64	system and service manager
systemd-sysv	215-17+deb8u5	amd64	system and service manager - SysV links
sysv-rc	2.88dsf-59	all	System-V-like runlevel change mechanism
sysvinit-utils	2.88dsf-59	amd64	System-V-like utilities
tar	1.27.1-2+deb8u1	amd64	GNU version of the tar archiving utility
tcpdump	4.6.2-5+deb8u1	amd64	command-line network traffic analyzer
trace-oml2	2.11.0-mytestbed2	amd64	Measure and record libtrace data using OML

Table 8: List of packages installed in `monroe/base`. (Continued)

Name	Version	Architecture	Description
traceroute	1:2.0.20-2+b1	amd64	Traces the route taken by packets over an IPv4/IPv6 network
tzdata	2016j-0+deb8u1	all	time zone and daylight-saving time data
tzdata-java	2016j-0+deb8u1	all	time zone and daylight-saving time data for use by java runtimes
ucf	3.0030	all	Update Configuration File(s): preserve user changes to config files
udev	215-17+deb8u5	amd64	/dev/ and hotplug management daemon
util-linux	2.25.2-6	amd64	Miscellaneous system utilities
wget	1.16-1+deb8u1	amd64	retrieves files from the web
x11-common	1:7.7+7	all	X Window System (X.Org) infrastructure
x11-xkb-utils	7.7+1	amd64	X11 XKB utilities
xauth	1:1.0.9-1	amd64	X authentication utility
xkb-data	2.12-1	all	X Keyboard Extension (XKB) configuration data
xserver-common	2:1.16.4-1	all	common files used by various X servers
xvfb	2:1.16.4-1	amd64	Virtual Framebuffer 'fake' X server
zlib1g:amd64	1:1.2.8.dfsg-2+b1	amd64	compression library - runtime

B Description of metadata fields

The following description of metadata topics and fields is included here for convenience only. The updated version is kept at: https://github.com/MONROE-PROJECT/Experiments/wiki/Metadata

DataVersion was set to 1 until beginning of March, 2017. It was then set to 2 to signal the transition in timestamps that most tables underwent, when their precision was changed from an integer number of seconds (e.g., 1 400 475 869) to the number of seconds and microseconds since the (UNIX) Epoch (e.g., 1 400 475 869.123 456).

Table 9: Field description for metadata topic "MONROE.META.DEVICE.MODEM".

Name	Description
NodeId	Node numerical ID.
Timestamp	Entry timestamp (in seconds since UNIX epoch with microsecond precision).
DataId	Metadata topic.
DataVersion	Last version is 2.
SequenceNumber	Monotonically increasing message counter.
InterfaceName	Name of the interface in the MONROE node, e.g., "usb0", "usb1", "usb2", "eth0", …
InternalInterface	Name of the interface inside the containers, e.g., "op0", "op1", "op2", "eth0", "wlan0", … Experiments in containers have to bind to these interface names.
Cid	Cell ID.
DeviceMode	Connection mode of the modem (e.g., 2G, 3G, LTE) indicating the radio access technology the modem uses.
DeviceSubmode	Connection submode for 3G connections (e.g., CDMA, WCDMA, UMTS).
DeviceState	State of the device reported to the network: UNKNOWN (0) - Device state is unknwon; REGISTERED (1) - Device is registered to the network; UNREGISTERED (2) - Device is unregistered from the network; CONNECTED (3) - Device is connected to the network; DISCONNECTED (4) - Device is disconnected from the network.
Ecio	EC/IO, quality/cleanliness of signal from the tower to the modem (dB).
ENodebId	Evolved base station ID.
Iccid	Internationally defined integrated circuit card identifier of the SIM card.
Imsi	Internation Mobile Subscriber Identity.
ImsiMccMnc	Mobile Country Code (MCC) and Mobile Network Code (MNC).
Imei	International Mobile Station Equipment Identity.
IpAddress	IP address assigned to the modem by the operator.
InternalIpAddress	Internal IP address of the modem in the MONROE node.
MccMnc	Mobile Country Code (MCC) and Mobile Network Code (MNC).
Operator	Operator name as reported by the network for the interface in which the experiment was run.
Lac	Local Area Code for the current cell (hex).
Rsrp	Reference Signal Received Power (LTE).
Frequency	Frequency in MHz (e.g., 700, 800, 900, 1800 or 2600 in Europe).

Table 9: Field description for metadata topic "MONROE.META.DEVICE.MODEM". (Continued)

Name	Description
Rsrq	Reference Signal Received Quality (valid only for LTE networks). The RSRQ measurement provides additional information when Reference Signal Received Power (RSRP) is not sufficient to make a reliable handover or cell reselection decision. RSRQ considers both the Received Signal Strength Indicator (RSSI) and the number of used Resource Blocks (N) $RSRQ = (N * RSRP)/RSSI$ measured over the same bandwidth.
Band	Band corresponding to the frequency used (e.g., 3, 7 or 20 in Europe).
Pci	Physical Cell ID.
NwMccMnc	Mobile Country Code (MCC) and Mobile Network Code (MNC) from network (read from the network). The tuple uniquely identifies a mobile network operator (carrier) that is using the GSM (including GSM-R), UMTS, and LTE public land mobile networks.
Rscp	Received Signal Code Power (UMTS).
Rssi	Received Signal Strength Indicator.

Table 10: Field description for metadata topic "MONROE.META.DEVICE.GPS".

Name	Description
NodeId	Node numerical ID.
Timestamp	Entry timestamp (in seconds since UNIX epoch with microsecond precision).
DataId	Metadata topic.
DataVersion	Last version is 2.
SequenceNumber	Monotonically increasing message counter.
Longitude	Decimal degrees (WGS84).
Latitude	Decimal degrees (WGS84).
Altitude	Meters AMSL.
Speed	Speed over ground (knots; multiply by 1.852 to get $\mathrm{km\,h^{-1}}$).
SatelliteCount	Number of satellites being tracked.
Nmea	Raw NMEA string from the GPS receiver.

Table 11: Field description for metadata topic "MONROE.META.NODE.SENSOR".

Name	Description
NodeId	Node numerical ID.
Timestamp	Entry timestamp (in seconds since UNIX epoch with microsecond precision).
DataId	Metadata topic.
DataVersion	Last version is 2.
SequenceNumber	Monotonically increasing message counter.
Running	Comma separated list of experiment GUIDs.
Cpu	CPU temperature (°C).
Id	Session number (boot counter).
Start	Start time (Unix timestamp).
Current	Uptime (seconds since start of the session).
Total	Uptime (cumulative uptime of the node over all sessions).
Percent	Uptime (percent of uptime vs. total lifetime of the node).
System	CPU time spent by the kernel in system activities.
Steal	The time that a virtual CPU had runnable tasks, but the virtual CPU itself was not running.
Guest	The time spent running a virtual CPU for guest operating systems under the control of the Linux kernel.
IoWait	CPU time spent waiting for I/O operations to finish when there is nothing else to do.
Irq	CPU time spent handling interrupts.
Nice	CPU time spent by nice(1)d programs.
Idle	Idle CPU time.
User	CPU time spent by normal programs and daemons.
SoftIrq	CPU time spent handling "batched" interrupts.
Apps	Memory used by user-space applications.
Free	Unused memory.
Swap	Swap space used.
usb0	Battery level for MiFi at USB0 (0-100, -1 for inactive).
usb0charging	1 if USB0 battery is charging, 0 otherwise.
usb1	Battery level for MiFi at USB1 (0-100, -1 for inactive).
usb1charging	1 if USB1 battery is charging, 0 otherwise.
usb2	Battery level for MiFi at USB2 (0-100, -1 for inactive).

Table 11: Field description for metadata topic “MONROE.META.NODE.SENSOR”. (Continued)

Name	Description
usb2charging	1 if USB2 battery is charging, 0 otherwise.

Table 12: Field description for metadata topic “MONROE.META.NODE.EVENT”.

Name	Description
NodeId	Node numerical ID.
Timestamp	Entry timestamp (in seconds since UNIX epoch with microsecond precision).
DataId	Metadata topic.
DataVersion	Last version is 2.
SequenceNumber	Monotonically increasing message counter.
EventType	Watchdog.Failed: The system watchdog detected an error symptom.
	Watchdog.Repaired: The system watchdog resolved the issue.
	Watchdog.Status: Periodic status messages from the watchdog.
	Maintenance.Start: An interactive login on the node is registered.
	Maintenance.Stop: The interactive login session is closed.
	System.Halt: System halt is requested.
	Scheduling.Started: The node starts to query the scheduling server.
	Scheduling.Task.Deploying: A scheduling task passed checks and is being deployed.
	Scheduling.Task.Deployed: A scheduling task has been deployed.
	Scheduling.Task.Started: A scheduling task has started.
	Scheduling.Task.Stopped: A scheduling task has stopped and is being cleaned up.
Message	Extra key for some event types.
User	Extra key for some event types.
id	Extra key for Scheduling.Task.* events.

Table 13: Field description for metadata topic “MONROE.EXP.PING”.

Name	Description
NodeId	Node numerical ID.
Guid	Unique experiment identifier.
Timestamp	Entry timestamp (in seconds since UNIX epoch with microsecond precision).
SequenceNumber	Monotonically increasing message counter.
DataId	Metadata topic.
DataVersion	Last version is 2.
Operator	Operator name as reported by the network for the interface in which the experiment was run.
Iccid	Internationally defined integrated circuit card identifier of the SIM card.
Bytes	Size of the ping message payload.
Host	IP of the destination host of the ping probe.
Rtt	Round-Trip-Time of the ping probe.

Table 14: Field description for metadata topic “MONROE.EXP.HTTP.DOWNLOAD”.

Name	Description
NodeId	Node numerical ID.
Guid	Unique experiment identifier.
Timestamp	Entry timestamp (in seconds since UNIX epoch with microsecond precision).
SequenceNumber	Monotonically increasing message counter.
DataId	Metadata topic.
DataVersion	Last version is 2.
Operator	Operator name as reported by the network for the interface in which the experiment was run.
Iccid	Internationally defined integrated circuit card identifier of the SIM card.
TotalTime	Total experiment execution time (in fractional seconds).
Bytes	Total number of bytes downloaded.
SetupTime	Time required to set up the HTTP connection.
DownloadTime	Time spent doing the actual download.
Host	IP address of the remote host from which data was downloaded.

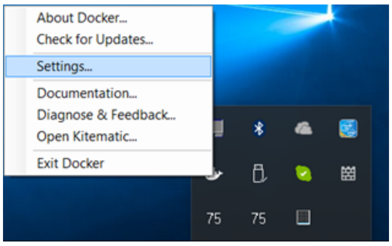
Table 14: Field description for metadata topic “MONROE.EXP.HTTP.DOWNLOAD”. (Continued)

Name	Description
Speed	Download speed in bytes/s as measured by the experiment.
Port	TCP port of the remote host from which data was downloaded.

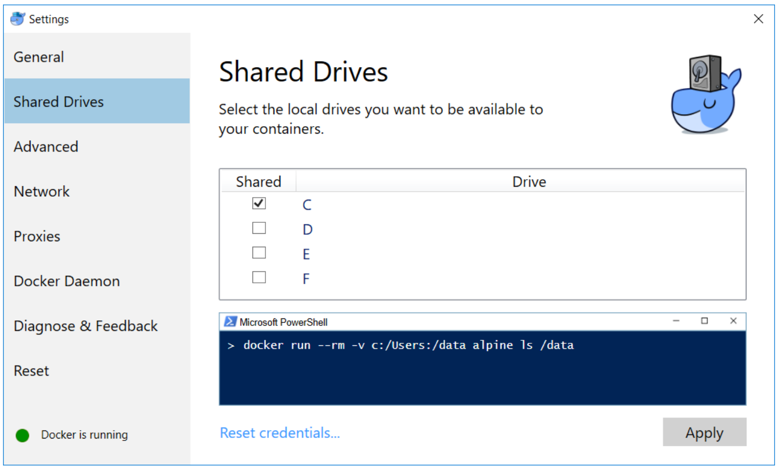
C How to map container folders to Windows paths

Before being able to access Windows (host) folders from a container, the drive has to be made available to the containers following these steps:[5,6]

1. Access the Docker settings dialog from its taskbar icon:

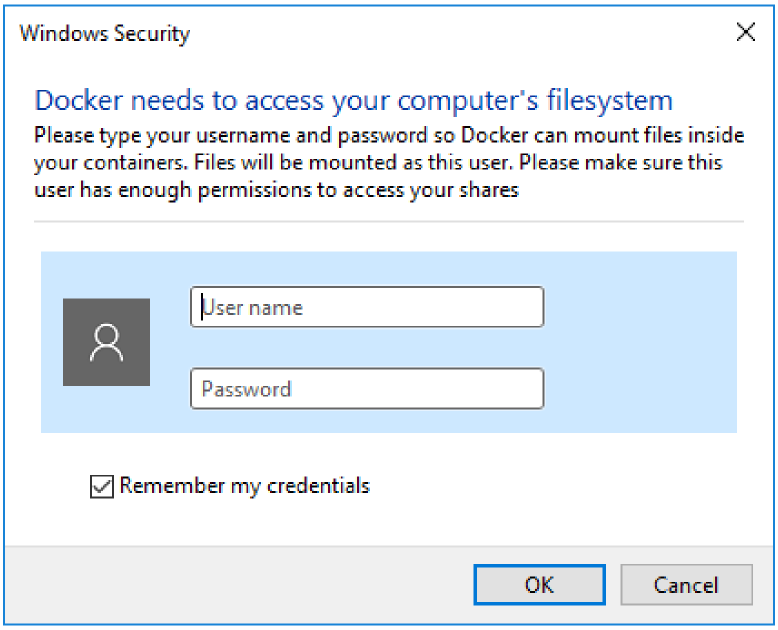


2. From the tab “Shared Drives”, select the drive you want to make available to the containers, e.g., “C”:



3. You will be prompted for login credentials to access the files:

[5] https://rominirani.com/docker-on-windows-mounting-host-directories-d96f3f056a2c#.pdeuy0c4o
[6] Thanks to Lena for pointing to the solution.

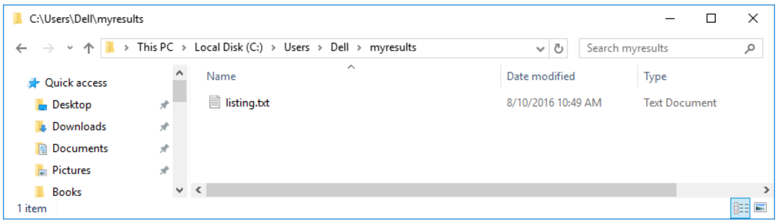


4. Start the container mounting the desired folder:

```
$ docker run -v c:/Users/Dell/myresults:/data container_name ls /data
```

   This command executes `ls /data` inside an instance of the container "container_name," after mounting "`C:/Users/Dell/myresults/`" into that path.

5. The folder can be accessed normally from Windows and will reflect changes to any files automatically.



References

[1] Te-Yuan Huang, Ramesh Johari, Nick McKeown, Matthew Trunnell, and Mark Watson. A buffer-based approach to rate adaptation: Evidence from a large video streaming service. In *Proceedings of the 2014 ACM Conference on SIGCOMM (SIGCOMM'14)*, pages 187–198, New York, NY, USA, 2014. ACM Press.

[2] Juluri P., Tamarapalli V., and D. Medhi. SARA: Segment aware rate adaptation algorithm for dynamic adaptive streaming over HTTP. In *ICC QoE-FI Workshop*, June 2015.

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