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Deliverable User manual
MONROE Platform User Manual

Editor(s): Miguel Peón-Quirós, Özgü Alay, Vincenzo Mancuso
Contributor(s): Miguel Peón-Quirós, Thomas Hirsch, Ali Safari Khatouni

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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 (<i>Coordinator</i>)	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	5
1.1	Overview of the node configuration	5
1.2	Overview of the experimental workflow	6
2	Experiment preparation	6
2.1	General experiment notes	6
2.2	Container preparation	7
2.2.1	Package and tool installation	11
2.3	Optional interactive debugging in MONROE nodes	12
2.4	Mandatory testing process	12
2.5	Deployment	12
3	Resource allocation, and experiment scheduling and monitoring	12
3.1	User login and certificates	12
3.1.1	Installation of user certificates in Chrome	14
3.2	Resource allocation	18
3.3	Experiment scheduling	20
3.3.1	Checking availability	20
3.4	Experiment monitoring	21
4	Retrieval of metadata and experiment results	21
4.1	User experiment results	21
4.2	MONROE metadata	23
5	Run-time considerations for experimenters	24
5.1	Communication during the experiment	24
5.2	Interface naming and binding, and default route	24
5.3	Metadata at run-time	25
5.3.1	Example: Correlate experiment results with metadata at run-time	25
5.3.2	Metadata information	26
5.3.3	Metadata format	28
5.4	Tstat at run-time	28
5.4.1	Tstat Round Robin Database	28
5.4.2	Tstat logs	29
5.5	Access to user-owned development nodes	30
5.5.1	Accessing user-owned development nodes	30
6	Monitoring node status	33
7	MONROE templates, examples and default experiments	33
7.1	Example template	33
7.1.1	Usage	33
7.1.2	Requirements	34
7.1.3	Output	34
7.1.4	Overview of the code structure	35

7.2	Docker miscellaneous usage notes	36
7.3	Experiment: ping	36
7.3.1	Usage	36
7.3.2	Requirements	37
7.3.3	Output	37
7.4	Experiment: http_download	38
7.4.1	Usage	38
7.4.2	Output	38
7.5	Experiment: Tstat & mPlane	39
7.5.1	Requirements	39
7.5.2	Usage	39
7.6	MONROE example: helloworld	39
7.6.1	Usage	40
7.6.2	Requirements	40
7.6.3	Output	40
7.7	MONROE example: paris-traceroute	41
7.7.1	Usage (inside a MONROE container)	41
7.7.2	Output	42
7.7.3	Additional remarks	42
7.8	MONROE example: headlessbrowsing	42
7.8.1	Output	42
7.9	MONROE example: pReplay	44
7.9.1	Usage	44
7.10	MONROE example: astream	44
7.10.1	Usage	45
7.10.2	Output	45
7.11	MONROE example: udpbwestimator	45
7.11.1	Usage	45
7.11.2	Output	45
7.12	MONROE example: traceroute_background_experiment	46
7.12.1	Usage	46
7.13	Other containers in the repositories	46
7.13.1	Container: metadata-subscriber	47
7.13.2	Container: tunnelbox-server	47
7.13.3	Container: monroe_base	47
8	List of known bugs and issues	47
A	List of packages installed in monroe/base	47
B	Description of metadata fields	56
C	How to map container folders to Windows paths	59

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 for the 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 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 of 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 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 full paris-traceroute to several popular websites and records information about all the intermediate hops. This container will in principle be run three times per day, but the interactions with user experiments are yet to be determined.
- A container that runs Tstat, the passive monitoring tool 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.

1.2 Overview of the experimental workflow

Experiments conducted in the MONROE platform follow the workflow shown in Figure 1. They consist 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. Finally, 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 inside a Docker container under the root user of the container. Therefore, the 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. If not, we strongly 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.* ⇐

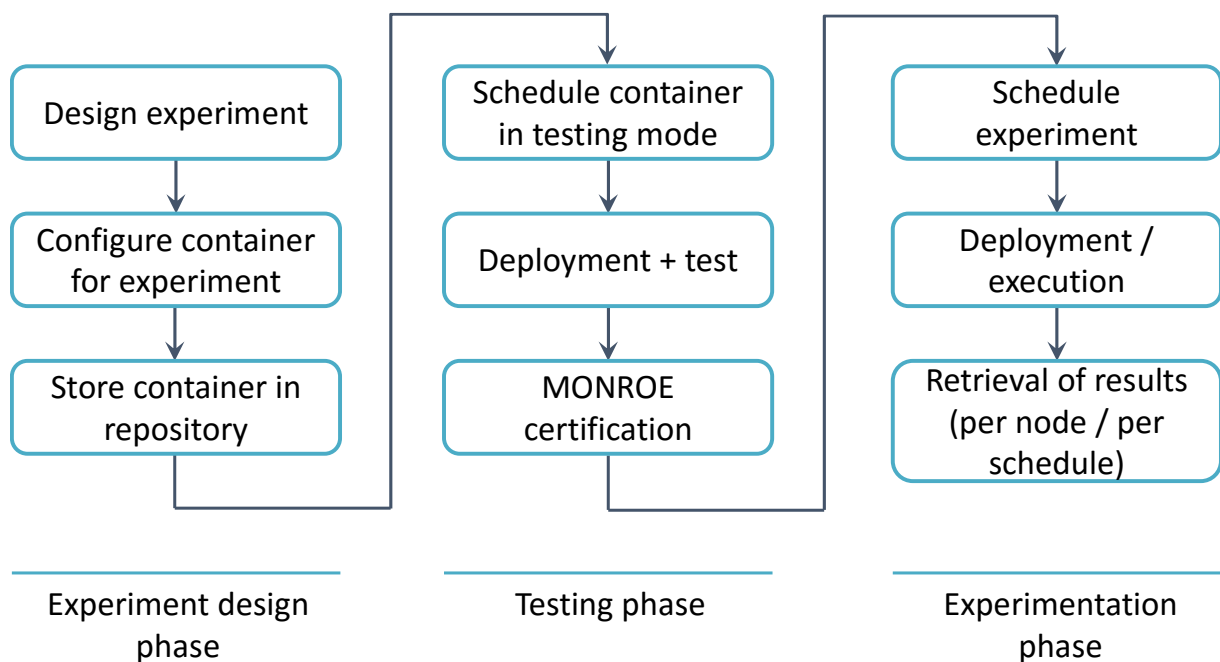


Figure 1: Experimental workflow.

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 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:xxxxxxxxxxxxxxxxxxxxxxxxxxxx
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` will be retrieved after its completion and delivered to the repository, where you will be able to finally 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 prototype phase of the system, please follow these additional steps to make your container available:

- Create an account at Docker Hub.
- Create a private repository (you can create one container as private; no limits for public ones).
- 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 f4b7alee804a
--> 096c7a56ff1c
Removing intermediate container f4b7alee804a
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 in MONROE nodes

To make the process of debugging experiments in the nodes, a small number of development nodes will be supplied. Experimenters will be able to schedule their containers to one of these nodes (even before getting their container signed) and, once the container is started, connect to it through an inverse SSH tunnel. Then, they will be able to interactively modify their scripts or applications and execute them until the allocated slot expires.

The exact technical procedures and reservation policies are still to be defined by the MONROE consortium.

2.4 Mandatory testing process

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 will possibly be re-downloaded and its costs will be accounted in your quota.

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 FED4FIRE¹ 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 2). 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/>

Figure 2: iMinds registration page to obtain FED4FIRE-compatible certificates for use with the MONROE platform.

NOTE: User certificates are manually activated in the scheduling software. To use your certificate, please send its “ssl_id” 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": 5000000000,
    "quota_storage": 500000000,
    "quota_time": 500000000,
    "role": "admin",
    "ssl_id": "c79f1967aea17811a1ebed39b7d718430904338a"
  },
  "verified": "SUCCESS"
}
```

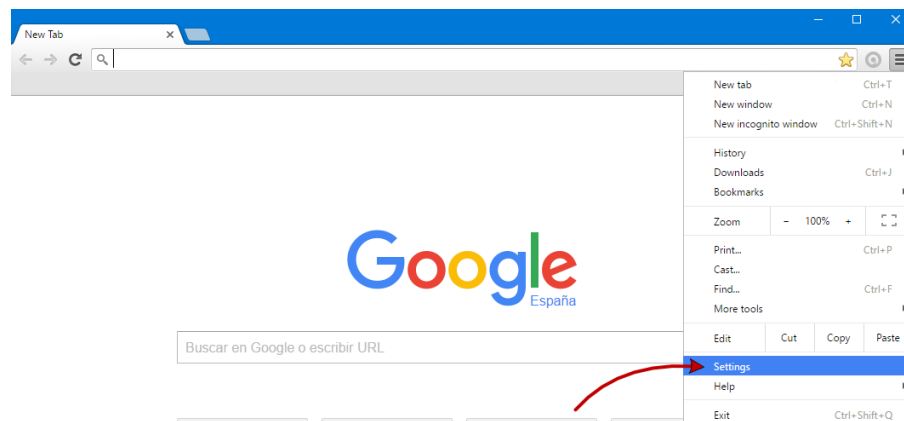
⇒ We have identified some common issues that are not yet solved. Below are some workarounds:

- 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.

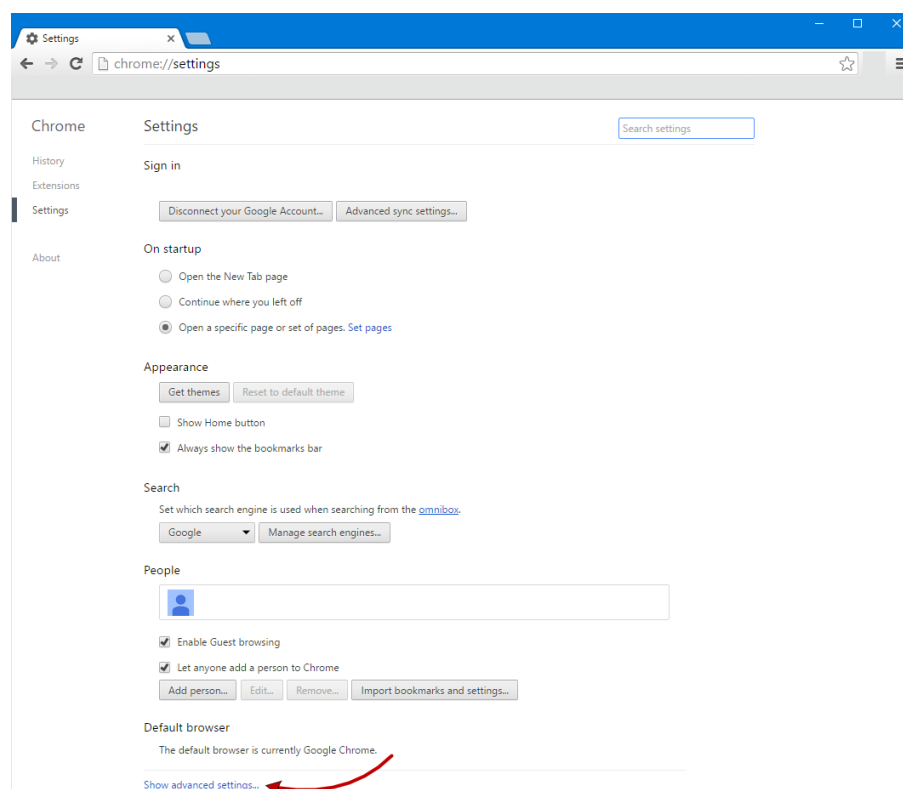
3.1.1 Installation of user certificates in Chrome

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.

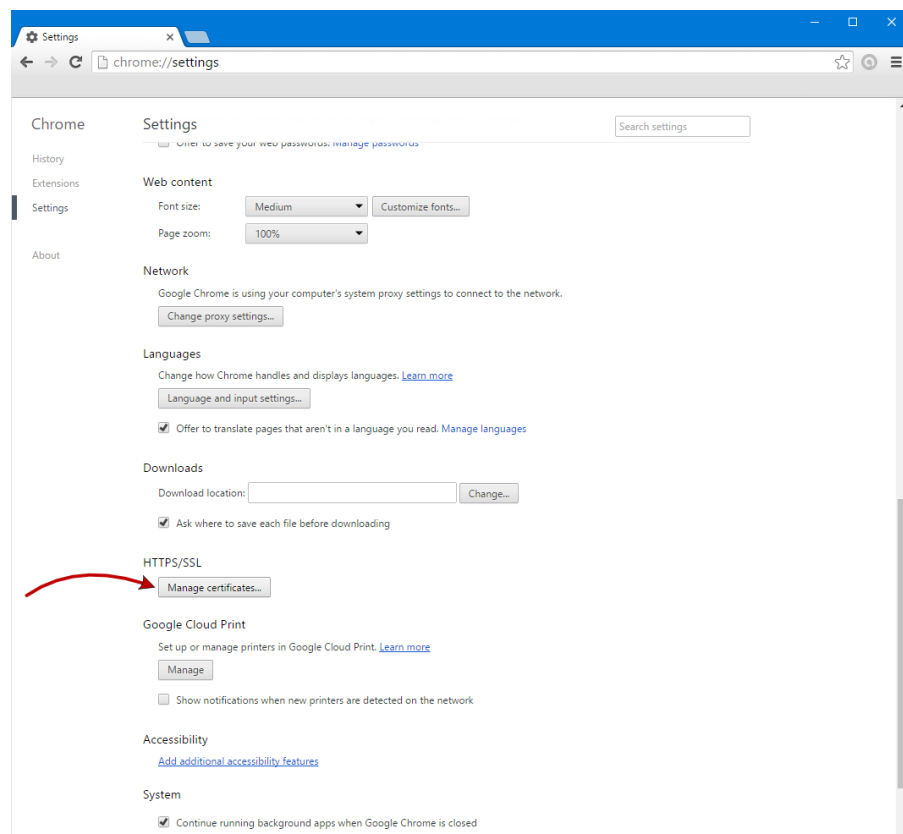
1. Go to your browser settings page:



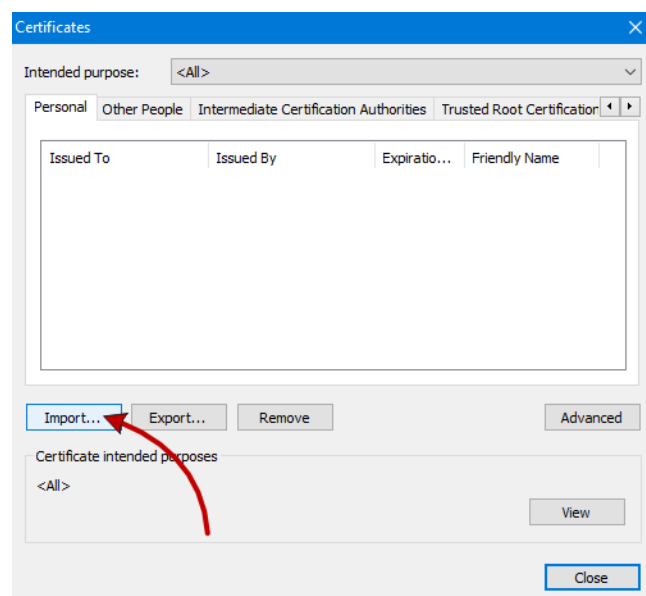
2. Display the advanced configuration settings:



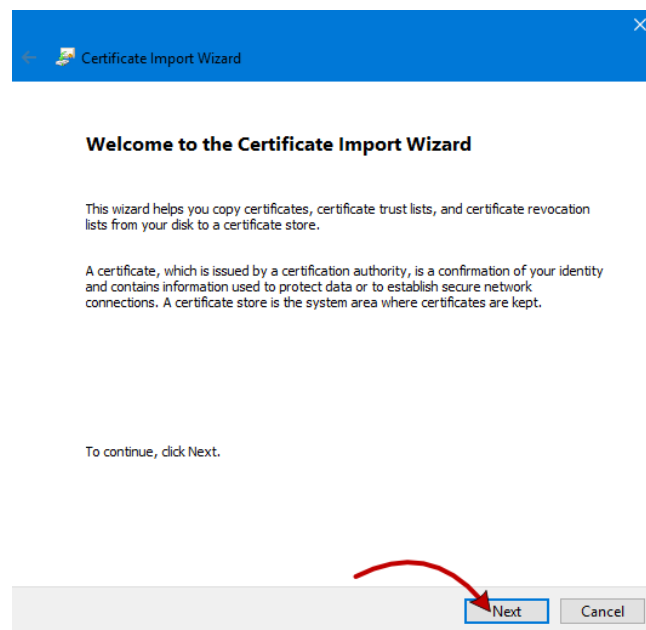
3. Go to the section labeled “HTTPS/SSL” and click the button “Manage certificates...”:



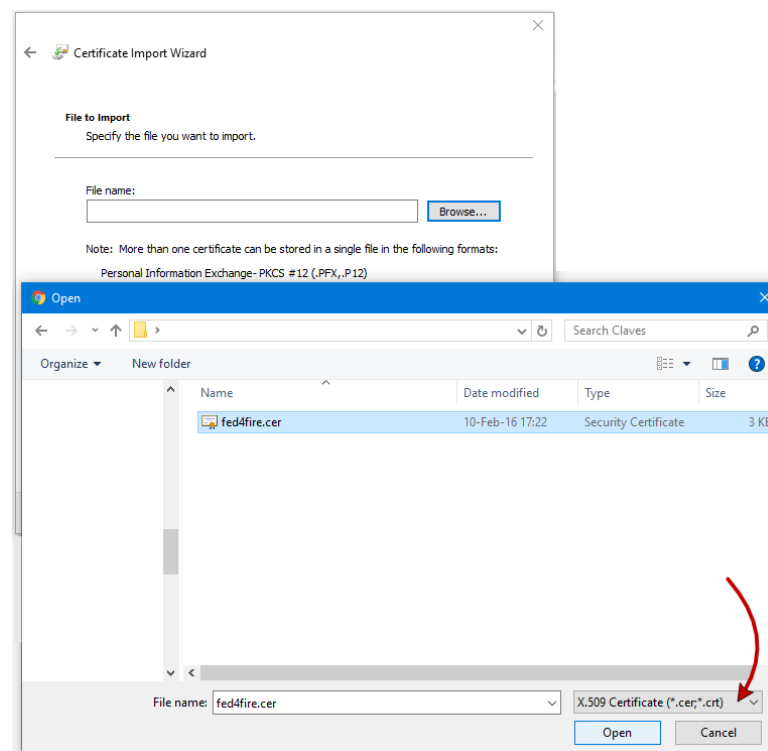
4. The dialog box for managing your certificates will be displayed. Press the button “Import...” to import your certificate:



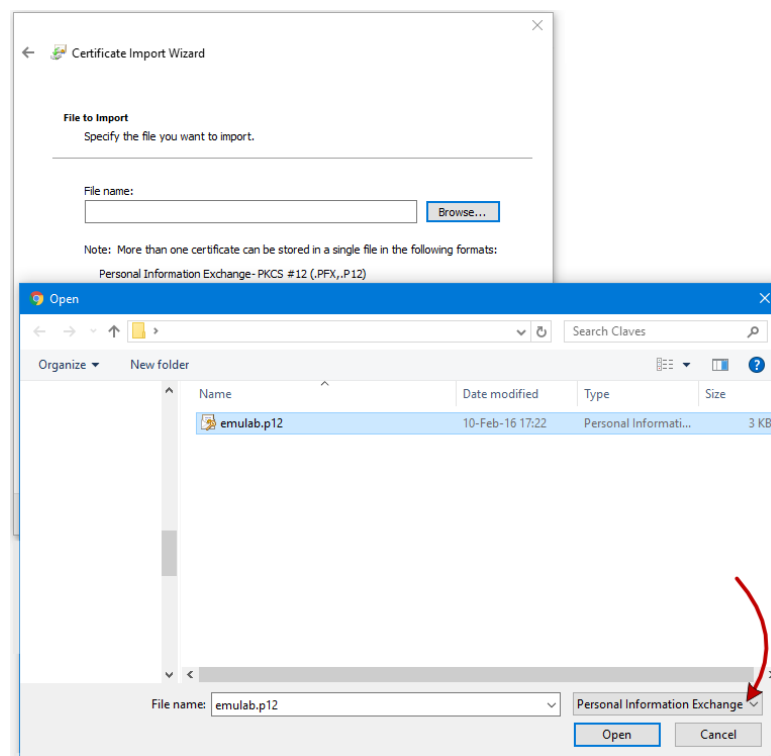
5. In the new dialog, click “Next”:



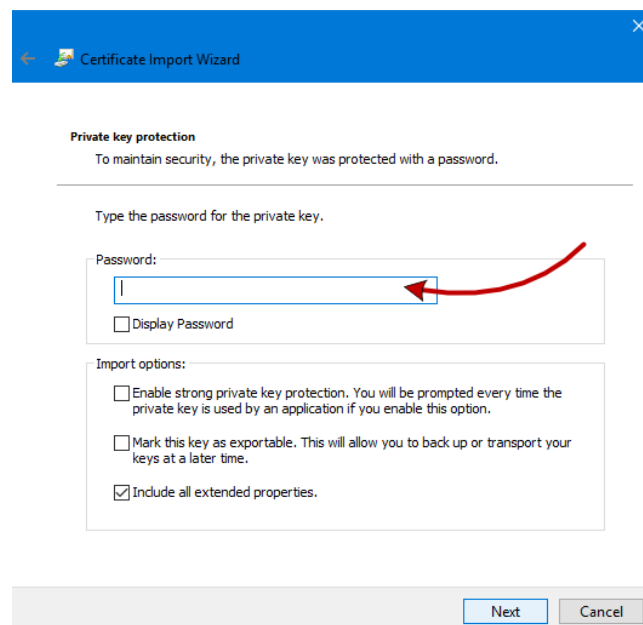
6. In the file-selection dialog that appears next, change the file type from “X.509 Certificate (*.cer;*.crt)” to “Personal Information Exchange”:



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

New instances of experiments are created, assigned resources and scheduled under the tab “New.” Here, the user will be presented with a page similar to Figure 3.

To create a new experiment, the user must specify at least the following parameters:

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`.

Number of nodes: The number of nodes that will 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, 24h.

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 (please, 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 4):

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.

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.

Required interfaces and active-data quota: By default, experiments do not have access to the node network interfaces. The experimenter must explicitly select those interfaces that they want to be available for their container. The selected interfaces will be mapped one-to-one from the physical ones. The experimenter must also specify the active-data quota for each interface, that is, the maximum amount of data that each interface can use. The scheduler multiplies this value by the number of interfaces used and checks the result 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.

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



StatusNewResources

Help

New Experiment

Description

*** Name:**

*** Script:**

Requirements

Number of nodes: **Duration:** **seconds**

Countries (pick zero, one or several):

Node type (pick one):

☐ Any

Node IDs:

Required interfaces: ☒ **Interface 1** ☒ **Interface 2** ☒ **Interface 3**

Data quotas:

Active-data quota: **(per interface)**

Log files quota:

Deployment-data quota: **(bytes)**

Scheduling options

☒ **Recurrence**

Every: **seconds**

Until: **UTC** **Fri May 20 2016 02:00:00 GMT+0200 (Romance Daylight Time)**

Select starting date and time: **UTC** **Date and time in YOUR local time-zone:** **Wed May 18 2016 02:00:00 GMT+0200 (Romance Daylight Time)**

☐ **As soon as possible**

Tips:

- Input a date and press "Check availability" to verify if the schedule is possible,
- or mark "As soon as possible" and press "Check availability" to know the earliest possible starting time.
- Input a valid starting date and leave "As soon as possible" unchecked to submit the experiment.

Figure 3: Example for the creation of a new experiment.

The screenshot shows a web form titled "Requirements". It contains several sections for configuring an experiment:

- Number of nodes:** A text input field with the value "1".
- Duration:** A text input field with the value "300" and a label "seconds".
- Countries (pick zero, one or several):** A multi-select dropdown menu showing "Norway", "Sweden", "Italy", and "Spain".
- Node type (pick one):** A dropdown menu with the value "Deployed".
- Node IDs:** A text area with placeholder text: "List of comma-separated specific nodes to use in the experiment. Leave empty for automatic assignment."
- Required interfaces:** Three checkboxes labeled "Interface 1", "Interface 2", and "Interface 3", all of which are checked.
- Data quotas:**
 - Active-data quota:** A text input field with the value "1048576" and a label "(per interface)".
 - Log files quota:** A text input field with the value "0".
 - Deployment-data quota:** A label "(bytes)".

Figure 4: Filters for node selection.

of them consecutively. However, the operation is atomic: Either all the repetitions are scheduled, or none are.

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.
- No experiment (or instance in a series) can last more than one day.
- 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 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 5 shows the answer of the scheduler for an availability query.

Scheduling options

☐ **Recurrence**

Select starting date and time:

18/05/2016 14:43:38
UTC

☐ **As soon as possible**

ⓘ Tips:

- Input a date and press "Check availability" to verify if the schedule is possible,
- or mark "As soon as possible" and press "Check availability" to know the earliest possible starting time.
- Input a valid starting date and leave "As soon as possible" unchecked to submit the experiment.

Date and time in YOUR local time-zone:

Wed May 18 2016 16:43:38 GMT+0200 (Romance Daylight Time)

Check availability

Available slot starting at "Wed, 18 May 2016 14:45:00 GMT". -->Request this slot!<--

Finishing at "Wed, 18 May 2016 15:45:00 GMT".

The experiment could use up to 109 nodes.

The experiment may be delayed or the slot extended until "Sat, 18 Jun 2016 14:44:00 GMT".

Figure 5: 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 “2016-05-18 14:45:00 UTC” and can last until “2016-06-18 14:44:00 UTC.” The experiment can be scheduled with up to 109 nodes during this period.

3.4 Experiment monitoring

Once an experiment is successfully submitted, the user can check its progress under the “Status” tab. Figure 6 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 at the bottom of the page. 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.

4 Retrieval of metadata and experiment results

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

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

ID	Name	Start	Stop	Completed
304	Test reporting	Mon Jun 27 2016 15:17:02 GMT+0200 (Romance Daylight Time)	Mon Jun 27 2016 15:22:02 GMT+0200 (Romance Daylight Time)	Yes
302	Test reporting	Mon Jun 27 2016 13:54:25 GMT+0200 (Romance Daylight Time)	Mon Jun 27 2016 13:59:25 GMT+0200 (Romance Daylight Time)	Yes
159	Webperf4@Demo	Tue May 24 2016 11:57:20 GMT+0200 (Romance Daylight Time)	Tue May 24 2016 12:14:00 GMT+0200 (Romance Daylight Time)	Yes
158	webperf 26	Tue May 24 2016 09:15:07 GMT+0200 (Romance Daylight Time)	Tue May 24 2016 09:20:07 GMT+0200 (Romance Daylight Time)	Yes
157	HTTP on 10 nodes	Mon May 23 2016 19:10:51 GMT+0200 (Romance Daylight Time)	Mon May 23 2016 19:27:31 GMT+0200 (Romance Daylight Time)	No
156	webperf for mplane	Mon May 23 2016 18:21:33 GMT+0200 (Romance Daylight Time)	Mon May 23 2016 18:26:33 GMT+0200 (Romance Daylight Time)	Yes

Hide Completed

« 1 2 3 4 5 »

Details for experiment "Webperf4@Demo"

Node types: type: deployed

Number of executions: 6

Finished: 6

Stopped: 2

Failed: 0

Canceled: 0

Aborted: 0

Remaining: 0

Defined: 0

Deployed: 0

Started: 0

Individual schedules: 6

Schedule ID	Node ID	Status	Start	Stop	Shared	Storage	Traffic quota	Results
406	54	Finished	Tue May 24 2016 11:57:20 GMT+0200 (Romance Daylight Time)	Tue May 24 2016 12:14:00 GMT+0200 (Romance Daylight Time)	0	104857600	1048576	download
407	60	Finished	Tue May 24 2016 11:57:20 GMT+0200 (Romance Daylight Time)	Tue May 24 2016 12:14:00 GMT+0200 (Romance Daylight Time)	0	104857600	1048576	download
408	54	Finished	Tue May 24 2016 13:57:20 GMT+0200 (Romance Daylight Time)	Tue May 24 2016 14:14:00 GMT+0200 (Romance Daylight Time)	0	104857600	1048576	download
409	60	Finished	Tue May 24 2016 13:57:20 GMT+0200 (Romance Daylight Time)	Tue May 24 2016 14:14:00 GMT+0200 (Romance Daylight Time)	0	104857600	1048576	download
410	54	Finished	Tue May 24 2016 15:57:20 GMT+0200 (Romance Daylight Time)	Tue May 24 2016 16:14:00 GMT+0200 (Romance Daylight Time)	0	104857600	1048576	download
411	60	Finished	Tue May 24 2016 15:57:20 GMT+0200 (Romance Daylight Time)	Tue May 24 2016 16:14:00 GMT+0200 (Romance Daylight Time)	0	104857600	1048576	download

Figure 6: List of user experiments.

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.

Index of /user/91/

../		
checksums.md5	13-May-2016 12:48	0
firstFile.txt	13-May-2016 12:38	23
secondFile.txt	13-May-2016 12:43	24

Figure 7: Folder containing the results of an individual schedule, transferred to MONROE's servers.

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.

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 7) that contains the files that have already been 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 guarantee a better privacy, 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 manually 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:²

```
-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, and thus CSV filenames, use GMT. Thus, 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 [day₀:01:00, day₁:01:00). During Summer time, the needed metadata is in the period [day₀:02:00, day₁:02:00).

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.

²Thanks to Eneko Atxutegi Narbona and Jonas Karlsson for pointing this out.

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 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
```

5.2 Interface naming and binding, and default route

⇒ *This section contains technical details that are currently subject to evaluation by the MONROE consortium. Comments from experimenters on this section are welcome.* ⇐

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. For example, the standard “ping” tool can be forced to use an specific interface with the following command:

```
ping -I eth0 host_name
```

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 operator for the nodes in the given country.
- op1**: Second operator for the nodes in the given country.
- op2**: Third operator for the nodes in the given country.
- eth0**: Ethernet (wired) network connection, when available.

For a given country, the platform guarantees that a given op_i does always correspond to the same 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. If the interface should disappear (`ENODEV` error, “no such device”), start over at 2.

When 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 (if the modem has to be restarted, or anything similar happens in the USB stack). 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.

5.3 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
```

5.3.1 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.initialize('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()
```

5.3.2 Metadata information

Currently, the collected metadata includes:

- Node GPS.
- Node sensors (CPU temp) and probes (load, memory usage).

- Modem events.
- Modem connectivity status.
- 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, "nice": "3063"}
```

```
{"DataId": "MONROE.META.NODE.SENSOR", "SequenceNumber": 48567, "DataVersion": 1,  
"Timestamp": 1465786961, "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, "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,  
"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"}
```

- Connectivity:

```
{"DataId": "MONROE.META.CONNECTIVITY", "InterfaceName": "usb2", "SequenceNumber": 41412,  
"DataVersion": 1, "Timestamp": 1465805641, "NodeId": "54", "MCCMNC": 21404,  
"Mode": 6, "RSSI": -80, "ICCID": "8934041514050774002"}
```

- GPS:

```
{"DataId": "MONROE.META.DEVICE.GPS", "SequenceNumber": 34164, "DataVersion": 1,  
"Timestamp": 1465805718, "Altitude": -1455.900024, "NodeId": "63",  
"Longitude": -3.777019, "NMEA":
```

Table 2: Metadata topics.

TOPIC	DESCRIPTION
*.CONNECTIVITY.iccid	Interface, connection events, IP
*.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, ...

```
"$GPGLGA,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}
```

5.3.3 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.

5.4 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.

5.4.1 Tstat Round Robin Database

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. 8 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. 9 illustrates an example of saved dashboard to monitor the volume of traffic on one node.

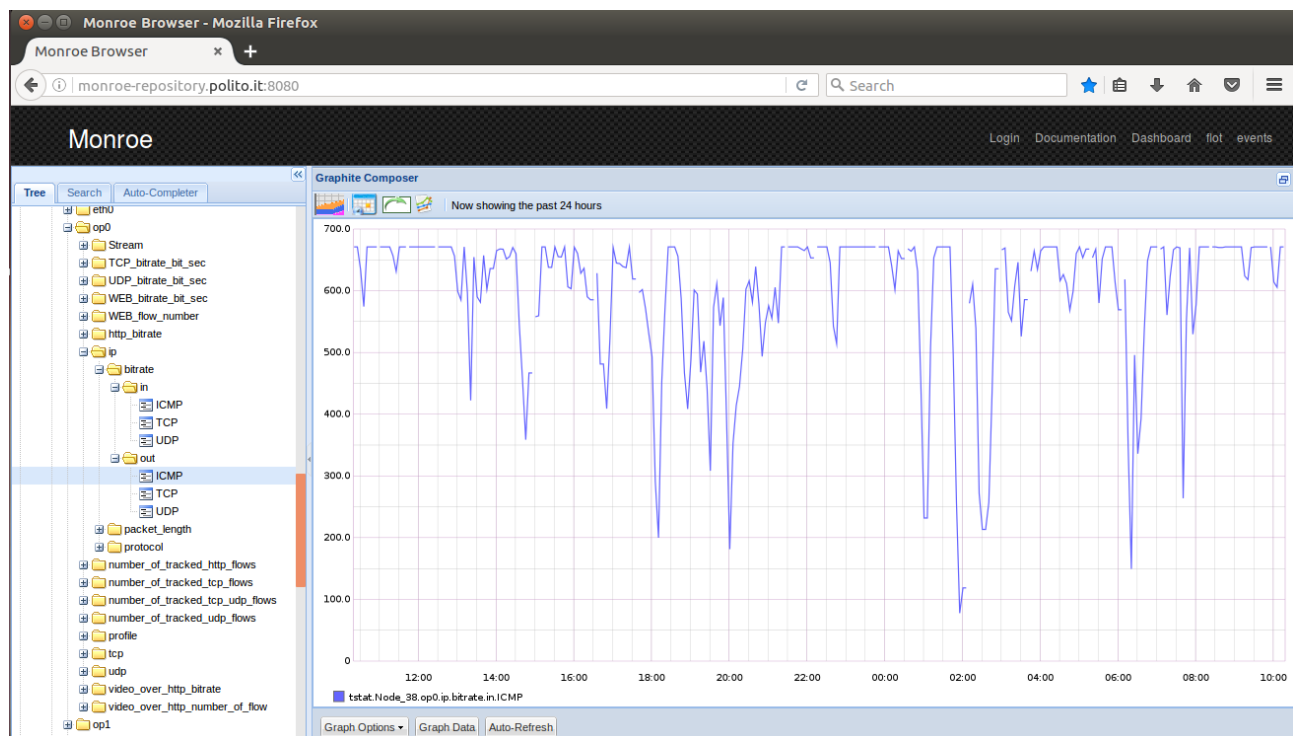


Figure 8: Graphite GUI of the Tstat RRD logs.

5.4.2 Tstat logs

Tstat generates detailed flow level logs for TCP, UDP, and HTTP flows. These are text files 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.

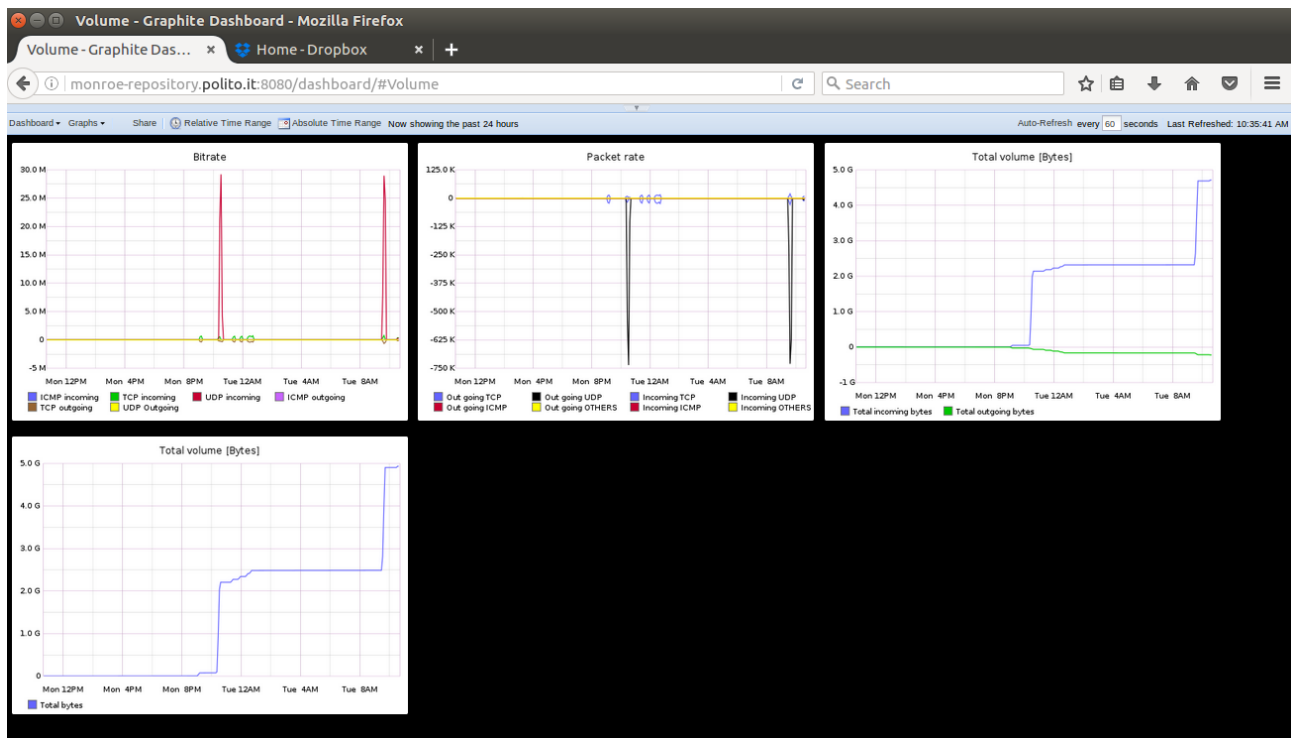


Figure 9: An example of dashboard on Tstat RRD GUI.

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.

5.5 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 of development nodes.

5.5.1 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

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)

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

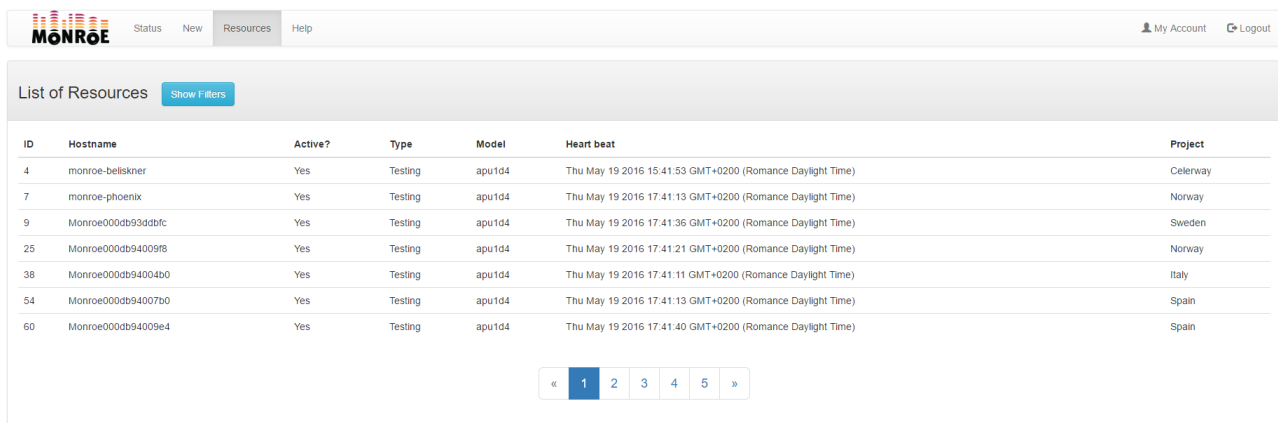
passwords will be provided on request through a secure channel. Table 7 explains the uses of each available user.

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 the IP address 172.16.254.1/24. The node can be accessed setting a static IP address in the 172.16.254.0/24 network span (e.g., 172.16.254.2) 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`:



ID	Hostname	Active?	Type	Model	Heart beat	Project
4	monroe-beliskner	Yes	Testing	apu1d4	Thu May 19 2016 15:41:53 GMT+0200 (Romance Daylight Time)	Celerway
7	monroe-phenix	Yes	Testing	apu1d4	Thu May 19 2016 17:41:13 GMT+0200 (Romance Daylight Time)	Norway
9	Monroe000db93dbfc	Yes	Testing	apu1d4	Thu May 19 2016 17:41:36 GMT+0200 (Romance Daylight Time)	Sweden
25	Monroe000db94009f8	Yes	Testing	apu1d4	Thu May 19 2016 17:41:21 GMT+0200 (Romance Daylight Time)	Norway
38	Monroe000db94004b0	Yes	Testing	apu1d4	Thu May 19 2016 17:41:11 GMT+0200 (Romance Daylight Time)	Italy
54	Monroe000db94007b0	Yes	Testing	apu1d4	Thu May 19 2016 17:41:13 GMT+0200 (Romance Daylight Time)	Spain
60	Monroe000db94009e4	Yes	Testing	apu1d4	Thu May 19 2016 17:41:40 GMT+0200 (Romance Daylight Time)	Spain

Figure 10: Status of the MONROE nodes.

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

6 Monitoring node status

The user can check the state of the nodes under the tab “Resources.” Figure 10 shows an example of the information that is supplied.

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:³

```
{
  "stop": 1486653420,
  "start": 1486653120,
```

³Entries in the `/monroe/config` file may appear in different order.

```
"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  
"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 up-

date (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 from 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.

7.4.1 Usage

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

```
curl -o /dev/null --raw --silent --write-out "{ Host: %{remote_ip}, Port :%{remote_port},
Bytes: %{size_download}, Speed: %{speed_download}, TotalTime: %{time_total},
SetupTime: %{time_starttransfer}, Url: %{url_effective} }" --interface IFNAME --max-time 3600
--range 0-3071 http://193.10.227.25/test/1000M.zip
```

The default parameter values are:

```
{
"guid": "no.guid.in.config.file",           # Created by the scheduler
"url": "http://193.10.227.25/test/1000M.zip",
"size": 3*1024,                             # Maximum size in Kbytes to download
"time": 3600,                               # Maximum time in seconds for a download
"zmqport": "tcp://172.17.0.1:5556",
"modem_metadata_topic": "MONROE.META.DEVICE.MODEM",
"dataversion": 2,
"dataid": "MONROE.EXP.HTTP.DOWNLOAD",
"nodeid": "fake.nodeid",
"meta_grace": 120,                          # Grace period to wait for interface metadata
"exp_grace": 120,                           # Grace period before killing the experiment
"ifup_interval_check": 5,                   # Interval to check if interface is up
"time_between_experiments": 30,
"verbosity": 2,                             # 0="Mute", 1=error, 2=Information, 3=verbose
"resultdir": "/monroe/results/",
"modeminterfacename": "InternalInterface",
"disabled_interfaces": ["lo", "metadata", "eth0",
"wlan0"],                                   # Interfaces to NOT run the experiment on
"interfaces_without_metadata": ["eth0", "wlan0"] # Manual metadata on these interfaces
}
```

7.4.2 Output

The experiment will produce a single-line JSON object for each interface similar to this:

```
{
"Guid": "313.123213.123123.123123",        # exp_config["guid"]
"Timestamp": 23123.1212,                    # time.time() when curl download starts
}
```

```
"Iccid": 2332323,                                # meta_info["ICCID"]
"Operator": "Telia",                              # meta_info["Operator"]
"DownloadTime": 49.12,                            # "TotalTime" - "SetupTime"
"SequenceNumber": 1,                              # Static
"Host": "193.10.227.25",
"Port": "80",
"Speed": 256.2,
"Bytes": 101,
"TotalTime": 50.1,
"SetupTime": 3,
"Url": "http://193.10.227.25/test/1000M.zip",
"NodeId" : "9",                                  # exp_config["nodeid"]
"DataId": "MONROE.EXP.HTTP.DOWNLOAD",
"DataVersion": 2,
"ErrorCode": 0                                   # curl command error code.
}
```

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 by means of 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 transferred 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. An 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 function-

ality 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 overridden
  "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. The experiment 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?
dea6426c061216dfcbald2d57d33f4ee315df1c2",
"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/BigBuck-Bunny_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: udpwestimator

Udpwestimator 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.UDPWESTIMATOR",
  "DataVersion" : 1,
  "DeviceMode" : 5,
  "DeviceState" : 3,
  "Guid" : "sha256:872af8c8b8f1635be6936a11b5fa838071e6f42cb317e9db1d9bb0c7db31425.93321.204.1",
  "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 reverse 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`.

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
apache2	2.4.10-10+deb8u4	amd64	Apache HTTP Server

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

Name	Version	Architecture	Description
apache2-bin	2.4.10-10+deb8u4	amd64	Apache HTTP Server (modules and other binary files)
apache2-data	2.4.10-10+deb8u4	all	Apache HTTP Server (common files)
apache2-utils	2.4.10-10+deb8u4	amd64	Apache HTTP Server (utility programs for web servers)
apt	1.0.9.8.3	amd64	commandline package manager
base-files	8+deb8u4	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
bind9-host	1:9.9.5.dfsg-9+deb8u6	amd64	Version of 'host' bundled with BIND 9.X
blt	2.5.3+dfsg-1	amd64	graphics extension library for Tcl/Tk - run-time
bsdutils	1:2.25.2-6	amd64	basic utilities from 4.4BSD-Lite
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+deb8u3	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)
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)
diffutils	1:3.3-1+b1	amd64	File comparison utilities
dmssetup	2.1.02.90-2.2	amd64	Linux Kernel Device Mapper userspace library
dnsutils	1:9.9.5.dfsg-9+deb8u6	amd64	Clients provided with BIND
dpkg	1.17.26	amd64	Debian package management system
e2fslibs:amd64	1.42.12-1.1	amd64	ext2/ext3/ext4 file system libraries
e2fsprogs	1.42.12-1.1	amd64	ext2/ext3/ext4 file system utilities
echoping	6.0.2-8	amd64	Small test tool for TCP servers
file	1:5.22+15-2+deb8u1	amd64	Determines file type using "magic" numbers
findutils	4.4.2-9+b1	amd64	utilities for finding files—find, xargs
flent	0.14.0-1	all	The FLExible Network Tester
fontconfig	2.11.0-6.3	amd64	generic font configuration library - support binaries
fontconfig-config	2.11.0-6.3	all	generic font configuration library - configuration
fonts-dejavu-core	2.34-1	all	Vera font family derivate with additional characters
fonts-lyx	2.1.2-2	all	TrueType versions of some TeX fonts used by LyX
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)
geoip-database	20150317-1	all	IP lookup command line tools that use the GeoIP library (country database)
gnupg	1.4.18-7+deb8u1	amd64	GNU privacy guard - a free PGP replacement
gpgv	1.4.18-7+deb8u1	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
gststreamer1.0-plugins-base:amd64	1.4.4-2	amd64	GStreamer plugins from the "base" set
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
httpperf-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

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

Name	Version	Architecture	Description
iptables	1.4.21-2+b1	amd64	administration tools for packet filtering and NAT
iso-codes	3.57-1	all	ISO language, territory, currency, script codes and their translations
java-common	0.52	all	Base of all Java packages
javascript-common	11	all	Base support for JavaScript library packages
krb5-locales	1.12.1+dfsg-19+deb8u2	all	Internationalization support for MIT Kerberos
libacl1:amd64	2.2.52-2	amd64	Access control list shared library
libalgorithm-c3-perl	0.09-1	all	Perl module for merging hierarchies using the C3 algorithm
libapr1:amd64	1.5.1-3	amd64	Apache Portable Runtime Library
libaprutil1:amd64	1.5.4-1	amd64	Apache Portable Runtime Utility Library
libaprutil1-dbd-sqlite3:amd64	1.5.4-1	amd64	Apache Portable Runtime Utility Library - SQLite3 Driver
libaprutil1-ldap:amd64	1.5.4-1	amd64	Apache Portable Runtime Utility Library - LDAP Driver
libapt-pkg4.12:amd64	1.0.9.8.3	amd64	package management runtime library
libarchive-extract-perl	0.72-1	all	generic archive extracting module
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
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
libattr1:amd64	1:2.4.47-2	amd64	Extended attribute shared library
libaudio2:amd64	1.9.4-3	amd64	Network Audio System - shared libraries
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
libauthen-sasl-perl	2.1600-1	all	Authen::SASL - SASL Authentication framework
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
libbind9-90	1:9.9.5.dfsg-9+deb8u6	amd64	BIND9 Shared Library used by BIND
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+deb8u4	amd64	GNU C Library: Binaries
libc6:amd64	2.19-18+deb8u4	amd64	GNU C Library: Shared libraries
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)
libcdparanoia0:amd64	3.10.2+debian-11	amd64	audio extraction tool for sampling CDs (library)
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
libclass-c3-perl	0.26-1	all	pragma for using the C3 method resolution order
libclass-c3-xs-perl	0.13-2+b1	amd64	Perl module to accelerate Class::C3
libcomerr2:amd64	1.42.12-1.1	amd64	common error description library
libconfig-grammar-perl	1.10-2	all	grammar-based user-friendly config parser
libcpan-meta-perl	2.142690-1	all	Perl module to access CPAN distributions metadata
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+deb8u3	amd64	easy-to-use client-side URL transfer library (OpenSSL flavour)
libdata-optlist-perl	0.109-1	all	module to parse and validate simple name/value option pairs
libdata-section-perl	0.200006-1	all	module to read chunks of data from a module's DATA section
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)
libdebconfclient0:amd64	0.192	amd64	Debian Configuration Management System (C-implementation library)
libdevmapper1.02.1:amd64	2:1.02.90-2.2	amd64	Linux Kernel Device Mapper userspace library
libdigest-hmac-perl	1.03+dfsg-1	all	module for creating standard message integrity checks

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

Name	Version	Architecture	Description
libdns100	1:9.9.5.dfsg-9+deb8u6	amd64	DNS Shared Library used by BIND
libdrm-intel1:amd64	2.4.58-2	amd64	Userspace interface to intel-specific kernel DRM services – runtime
libdrm-nouveau2:amd64	2.4.58-2	amd64	Userspace interface to nouveau-specific kernel DRM services – runtime
libdrm-radeon1:amd64	2.4.58-2	amd64	Userspace interface to radeon-specific kernel DRM services – runtime
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
libelf1:amd64	0.159-4.2	amd64	library to read and write ELF files
libencode-locale-perl	1.03-1	all	utility to determine the locale encoding
libexpat1:amd64	2.1.0-6+deb8u1	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
libfont-afm-perl	1.20-1	all	Font::AFM - Interface to Adobe Font Metrics files
libfontconfig1:amd64	2.11.0-6.3	amd64	generic font configuration library - runtime
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+deb8u1	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+deb8u4	amd64	GDK Pixbuf library
libgdk-pixbuf2.0-common	2.31.1-2+deb8u4	all	GDK Pixbuf library - data files
libgeoip1:amd64	1.6.2-4	amd64	non-DNS IP-to-country resolver library
libgfortran3:amd64	4.9.2-10	amd64	Runtime library for GNU Fortran applications
libgl1-mesa-dri:amd64	10.3.2-1+deb8u1	amd64	free implementation of the OpenGL API – DRI modules
libgl1-mesa-glx:amd64	10.3.2-1+deb8u1	amd64	free implementation of the OpenGL API – GLX runtime
libglade2-0:amd64	1:2.6.4-2	amd64	library to load .glade files at 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
libglib2.0-data	2.42.1-1	all	Common files for GLib library
libglu1-mesa:amd64	9.0.0-2	amd64	Mesa OpenGL utility library (GLU)
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
libgstreamer-plugins-base1.0-0:amd64	1.4.4-2	amd64	GStreamer libraries from the "base" set
libgstreamer1.0-0:amd64	1.4.4-2	amd64	Core GStreamer libraries and elements
libgtk2.0-0:amd64	2.24.25-3+deb8u1	amd64	GTK+ graphical user interface library
libgtk2.0-bin	2.24.25-3+deb8u1	amd64	programs for the 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-form-perl	6.03-1	all	module that represents an HTML form element
libhtml-format-perl	2.11-1	all	module for transforming HTML into various formats
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-daemon-perl	6.01-1	all	simple http server class
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
libidn11:amd64	1.29-1+b2	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-inet6-perl	2.72-1	all	object interface for AF_INET6 domain sockets
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)
libisc95	1:9.9.5.dfsg-9+deb8u6	amd64	ISC Shared Library used by BIND
libisccc90	1:9.9.5.dfsg-9+deb8u6	amd64	Command Channel Library used by BIND
libiscfg90	1:9.9.5.dfsg-9+deb8u6	amd64	Config File Handling Library used by BIND
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-jquery	1.7.2+dfsg-3.2	all	JavaScript library for dynamic web applications
libjs-jquery-ui	1.10.1+dfsg-1	all	JavaScript UI library for dynamic web applications
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
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
liblapack3	3.5.0-4	amd64	Library of linear algebra routines 3 - shared version
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
libllvm3.5:amd64	1:3.5-10	amd64	Modular compiler and toolchain technologies, runtime library
liblocale-gettext-perl	1.05-8+b1	amd64	module using libc functions for internationalization in Perl
liblog-message-perl	0.8-1	all	powerful and flexible message logging mechanism
liblog-message-simple-perl	0.10-2	all	simplified interface to Log::Message
liblua5.1-0:amd64	5.1.5-7.1	amd64	Shared library for the Lua interpreter version 5.1
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
liblwres90	1:9.9.5.dfsg-9+deb8u6	amd64	Lightweight Resolver Library used by BIND
liblzma5:amd64	5.1.1alpha+20120614-2+b3	amd64	XZ-format compression library
libmagic1:amd64	1:5.22+15-2+deb8u1	amd64	File type determination library using "magic" numbers
libmailtools-perl	2.13-1	all	Manipulate email in perl programs
libmngl1:amd64	1.0.10+dfsg-3.1+b3	amd64	Multiple-image Network Graphics library
libmodule-build-perl	0.421000-2	all	framework for building and installing Perl modules
libmodule-pluggable-perl	5.1-1	all	module for giving modules the ability to have plugins
libmodule-signature-perl	0.73-1+deb8u2	all	module to manipulate CPAN SIGNATURE files
libmount1:amd64	2.25.2-6	amd64	device mounting library
libmro-compat-perl	0.12-1	all	mro::* interface compatibility for Perls < 5.9.5
libmysqlclient18:amd64	5.5.47-0+deb8u1	amd64	MySQL database client 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-smtp-ssl-perl	1.01-3	all	Perl module providing SSL support to Net::SMTP
libnet-ssleay-perl	1.65-1+b1	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)
libnfnlink0:amd64	1.0.1-3	amd64	Netfilter netlink library
libnspr4:amd64	2:4.10.7-1+deb8u1	amd64	NetScape Portable Runtime Library
libnss3:amd64	2:3.17.2-1.1+deb8u2	amd64	Network Security Service libraries
libocomm	2.11.1 rc-mytestbed1	amd64	OCComm: O? Communications Library (metapackage)
libocomm-dev	2.11.1 rc-mytestbed1	amd64	OML measurement library headers
libocomm1	2.11.1 rc-mytestbed1	amd64	OCComm: 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
liborc-0.4-0:amd64	1:0.4.22-1	amd64	Library of Optimized Inner Loops Runtime Compiler
libp11-kit0:amd64	0.20.7-1	amd64	Library for loading and coordinating access to PKCS#11 modules - runtime
libpackage-constants-perl	0.04-1	all	List constants defined in a package
libpam-modules:amd64	1:1.8-3.1+deb8u1+b1	amd64	Pluggable Authentication Modules for PAM

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

Name	Version	Architecture	Description
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
libparams-util-perl	1.07-2+b1	amd64	Perl extension for simple stand-alone param checking functions
libpcap0.8:amd64	1.6.2-2	amd64	system interface for user-level packet capture
libpciaccess0:amd64	0.13.2-3+b1	amd64	Generic PCI access library for X
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
libpixmap-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
libpod-latex-perl	0.61-1	all	module to convert Pod data to formatted LaTeX
libpod-readme-perl	0.11-1	all	Perl module to convert POD to README file
libpopt0:amd64	1.16-10	amd64	lib for parsing cmdline parameters
libpq5:amd64	9.4.6-0+deb8u1	amd64	PostgreSQL C client library
libprocps3:amd64	2:3.3.9-9	amd64	library for accessing process information from /proc
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)
libpython2.7:amd64	2.7.9-2	amd64	Shared Python runtime library (version 2.7)
libpython2.7-minimal:amd64	2.7.9-2	amd64	Minimal subset of the Python language (version 2.7)
libpython2.7-stdlib:amd64	2.7.9-2	amd64	Interactive high-level object-oriented language (standard library, version 2.7)
libqt4-dbus:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 D-Bus module
libqt4-declarative:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 Declarative module
libqt4-designer:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 designer module
libqt4-help:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 help module
libqt4-network:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 network module
libqt4-opengl:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 OpenGL module
libqt4-script:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 script module
libqt4-scripttools:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 script tools module
libqt4-sql:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 SQL module
libqt4-sql-mysql:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 MySQL database driver
libqt4-svg:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 SVG module
libqt4-test:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 test module
libqt4-xml:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 XML module
libqt4-xmlpatterns:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 XML patterns module
libqtassistantclient4:amd64	4.6.3-6	amd64	Qt Assistant client library (runtime)
libqtcore4:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 core module
libqtdbus4:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 D-Bus module library
libqtgui4:amd64	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 GUI module
libqtwebkit4:amd64	2.3.4.dfsg-3	amd64	Web content engine library for Qt

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

Name	Version	Architecture	Description
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
libregexp-common-perl	2013031301-1	all	module with common regular expressions
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)
librtmp1:amd64	2.4+20150115.gita107cef-1	amd64	toolkit for RTMP streams (shared library)
libruby2.1:amd64	2.1.5-2+deb8u2	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:amd64	2.1.26.dfsg1-13+deb8u1	amd64	Cyrus SASL - pluggable authentication modules
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
libsocket6-perl	0.25-1+b1	amd64	Perl extensions for IPv6
libsodium13:amd64	1.0.0-1	amd64	Network communication, cryptography and signaturing library
libsoftware-license-perl	0.103010-3	all	module providing templated software licenses
libsqlite3-0:amd64	3.8.7.1-1+deb8u1	amd64	SQLite 3 shared library
libss2:amd64	1.42.12-1.1	amd64	command-line interface parsing library
libssh2-1:amd64	1.4.3-4.1+deb8u1	amd64	SSH2 client-side library
libssl1.0.0:amd64	1.0.1k-3+deb8u4	amd64	Secure Sockets Layer toolkit - shared libraries
libstdc++6:amd64	4.9.2-10	amd64	GNU Standard C++ Library v3
libsub-exporter-perl	0.986-1	all	sophisticated exporter for custom-built routines
libsub-install-perl	0.928-1	all	module for installing subroutines into packages easily
libsystemd0:amd64	215-17+deb8u4	amd64	systemd utility library
libtasn1-6:amd64	4.2-3+deb8u1	amd64	Manage ASN.1 structures (runtime)
libtcl8.6:amd64	8.6.2+dfsg-2	amd64	Tcl (the Tool Command Language) v8.6 - run-time library files
libterm-ui-perl	0.42-1	all	Term::ReadLine UI made easy
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-soundex-perl	3.4-1+b2	amd64	implementation of the soundex algorithm
libtext-template-perl	1.46-1	all	perl module to process text templates
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
libtheora0:amd64	1.1.1+dfsg.1-6	amd64	Theora Video Compression Codec
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
libtk8.6:amd64	8.6.2-1	amd64	Tk toolkit for Tcl and X11 v8.6 - run-time files
libtrace3	3.0.21-1	amd64	network trace processing library supporting many input formats
libtxc-dxtn-s2tc0:amd64	0 git20131104-1.1	amd64	Texture compression library for Mesa
libudev1:amd64	215-17+deb8u4	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
libvisual-0.4-0:amd64	0.4.0-6	amd64	Audio visualization framework
libvisual-0.4-plugins:amd64	0.4.0.dfsg.1-7	amd64	Audio visualization framework plugins
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
libwebp5:amd64	0.4.1-1.2+b2	amd64	Lossy compression of digital photographic images.

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

Name	Version	Architecture	Description
libwebpdemux1:amd64	0.4.1-1.2+b2	amd64	Lossy compression of digital photographic images.
libwebpmux1:amd64	0.4.1-1.2+b2	amd64	Lossy compression of digital photographic images.
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
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
libxft2:amd64	2.3.2-1	amd64	FreeType-based font drawing library for X
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
libxml2:amd64	2.9.1+dfsg1-5+deb8u1	amd64	GNOME XML library
libxmuu1:amd64	2:1.1.2-1	amd64	X11 miscellaneous micro-utility 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
libxslt1.1:amd64	1.1.28-2+b2	amd64	XSLT 1.0 processing library - runtime library
libxss1:amd64	1:1.2.2-1	amd64	X11 Screen Saver extension library
libxt6:amd64	1:1.1.4-1+b1	amd64	X11 toolkit intrinsics library
libxtables10	1.4.21-2+b1	amd64	netfilter xttables 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)
lksctp-tools	1.0.16+dfsg-2	amd64	user-space access to Linux Kernel SCTP - commandline tools
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+deb8u4	amd64	Transitional package to ensure multiarch compatibility
mysql-common	5.5.47-0+deb8u1	all	MySQL database common files, e.g. /etc/mysql/my.cnf
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
ndiff	6.47-3	all	The Network Mapper - result compare utility
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+b1	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	7u95-2.6.4-1 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+deb8u2	amd64	secure shell (SSH) client, for secure access to remote machines
openssl	1.0.1k-3+deb8u4	amd64	Secure Sockets Layer toolkit - cryptographic utility
otg2-oml2	2.11.0-mytestbed2	amd64	Orbit Traffic Generator
paris-traceroute	0.92-dev-2	amd64	New version of well known tool traceroute
passwd	1:4.2-3+deb8u1	amd64	change and administer password and group data
perl	5.20.2-3+deb8u4	amd64	Larry Wall's Practical Extraction and Report Language
perl-base	5.20.2-3+deb8u4	amd64	minimal Perl system
perl-modules	5.20.2-3+deb8u4	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-cairo	1.8.8-1+b2	amd64	Python bindings for the Cairo vector graphics library
python-dateutil	2.2-2	all	powerful extensions to the standard datetime module
python-glade2	2.24.0-4	amd64	GTK+ bindings: Glade support
python-gobject-2	2.28.6-12+b1	amd64	deprecated static Python bindings for the GObject library
python-gtk2	2.24.0-4	amd64	Python bindings for the GTK+ widget set
python-imaging	2.6.1-2+deb8u2	all	Python Imaging Library compatibility layer
python-lxml	3.4.0-1	amd64	pythonic binding for the libxml2 and libxslt libraries
python-matplotlib	1.4.2-3.1	amd64	Python based plotting system in a style similar to Matlab
python-matplotlib-data	1.4.2-3.1	all	Python based plotting system (data package)
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-mock	1.0.1-3	all	Mocking and Testing Library
python-nose	1.3.4-1	all	test discovery and running of Python's unittest
python-numpy	1:1.8.2-2	amd64	Numerical Python adds a fast array facility to the Python language
python-pil:amd64	2.6.1-2+deb8u2	amd64	Python Imaging Library (Pillow fork)
python-pkg-resources	5.5.1-1	all	Package Discovery and Resource Access using pkg_resources
python-pyparsing	2.0.3+dfsg1-1	all	Python parsing module
python-qt4	4.11.2+dfsg-1	amd64	Python bindings for Qt4
python-sip	4.16.4+dfsg-1	amd64	Python/C++ bindings generator runtime library
python-six	1.8.0-1	all	Python 2 and 3 compatibility library (Python 2 interface)
python-support	1.0.15	all	automated rebuilding support for Python modules
python-tk	2.7.8-2+b1	amd64	Tkinter - Writing Tk applications with Python
python-tz	2012c+dfsg-0.1	all	Python version of the Olson timezone database
python-zmq	14.4.0-1	amd64	Python bindings for 0MQ library
python2.7	2.7.9-2	amd64	Interactive high-level object-oriented language (version 2.7)
python2.7-minimal	2.7.9-2	amd64	Minimal subset of the Python language (version 2.7)
qdbus	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	amd64	Qt 4 D-Bus tool
qtchooser	47-gd2b7997-2	amd64	Wrapper to select between Qt development binary versions
qtcore4-l10n	4:4.8.6+git64-g5dc8b2b+dfsg-3+deb8u1	all	Qt 4 core module translations
readline-common	6.3-8	all	GNU readline and history libraries, common files
rename	0.20-3	all	Perl extension for renaming multiple 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+deb8u2	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
sgml-base	1.26+nmu4	all	SGML infrastructure and SGML catalog file support
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
ssl-cert	1.0.35	all	simple debconf wrapper for OpenSSL
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+deb8u4	amd64	system and service manager
systemd-sysv	215-17+deb8u4	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

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

Name	Version	Architecture	Description
tar	1.27.1-2+b1	amd64	GNU version of the tar archiving utility
tcpd	7.6.q-25	amd64	Wietse Venema's TCP wrapper utilities
tcpdump	4.6.2-5+deb8u1	amd64	command-line network traffic analyzer
tk8.6-blt2.5	2.5.3+dfsg-1	amd64	graphics extension library for Tcl/Tk - library
trace-oml2	2.11.0-mytestbed2	amd64	Measure and record libtrace data using OML
traceroute	1:2.0.20-2+b1	amd64	Traces the route taken by packets over an IPv4/IPv6 network
tzdata	2016d-0+deb8u1	all	time zone and daylight-saving time data
tzdata-java	2016d-0+deb8u1	all	time zone and daylight-saving time data for use by java run-times
ucf	3.0030	all	Update Configuration File(s): preserve user changes to config files
udev	215-17+deb8u4	amd64	/dev/ and hotplug management daemon
util-linux	2.25.2-6	amd64	Miscellaneous system utilities
x11-common	1:7.7+7	all	X Window System (X.Org) infrastructure
xauth	1:1.0.9-1	amd64	X authentication utility
xdg-user-dirs	0.15-2	amd64	tool to manage well known user directories
xml-core	0.13+nmul2	all	XML infrastructure and XML catalog file support
zlib1g:amd64	1:1.2.8.dfsg-2+b1	amd64	compression library - runtime

B Description of metadata fields

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).
DataId	Metadata topic.
DataVersion	Set to 1.
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 unknown; 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	International 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).
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.

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

Name	Description
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).
DataId	Metadata topic.
DataVersion	Set to 1.
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 kmh ⁻¹).
SatelliteCount	Number of satellites being tracked.
Nmea	Raw NMEA string from the GPS receiver.

Table 11: Field description for metadata topic “MONROE.META.CONNECTIVITY”.

Name	Description
NodeId	Node numerical ID.
Timestamp	Entry timestamp (in seconds since UNIX epoch).
DataId	Metadata topic.
DataVersion	Set to 1.
SequenceNumber	Monotonically increasing message counter.
Iccid	Internationally defined integrated circuit card identifier of the SIM card.
InterfaceName	Name of the interface in the MONROE node (outside containers), e.g., “usb0”, “usb1”, “usb2”, “eth0”, ...
MccMnc	Mobile Country Code (MCC) and Mobile Network Code (MNC).
Mode	The connection mode: UNKNOWN (1), DISCONNECTED (2), NO SERVICE (3), 2G (4), 3G (5), LTE (6).
Rssi	Signal strength.

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

Name	Description
NodeId	Node numerical ID.
Timestamp	Entry timestamp (in seconds since UNIX epoch).
DataId	Metadata topic.
DataVersion	Set to 1.
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.

Table 12: Field description for metadata topic “MONROE.META.NODE.SENSOR”. (Continued)

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

Table 13: Field description for metadata topic “MONROE.META.NODE.EVENT”.

Name	Description
NodeId	Node numerical ID.
Timestamp	Entry timestamp (in seconds since UNIX epoch).
DataId	Metadata topic.
DataVersion	Set to 1.
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.
Message	Extra key for some event types.
User	Extra key for some event types.

Table 14: 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).
SequenceNumber	Monotonically increasing message counter.
DataId	Metadata topic.
DataVersion	Set to 1.
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 15: Field description for metadata topic “MONROE.EXP.HTTP.DOWNLOAD”.

Name	Description
NodeId	Node numerical ID.
Guid	Unique experiment identifier.
Timestamp	Entry timestamp (in fractional seconds since UNIX epoch).
SequenceNumber	Monotonically increasing message counter.
DataId	Metadata topic.
DataVersion	Set to 1.
Operator	Operator name as reported by the network for the interface in which the experiment was run.

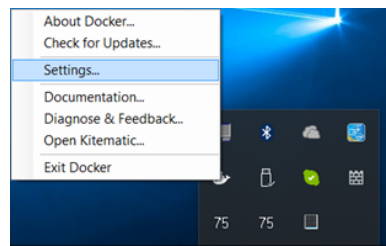
Table 15: Field description for metadata topic “MONROE.EXP.HTTP.DOWNLOAD”. (Continued)

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

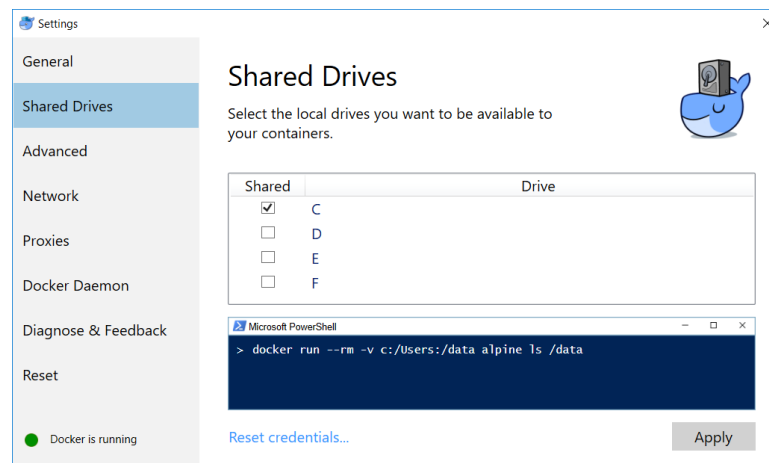
C How to map container folders to Windows paths

Before being able to access Windows (host) folders from a container, the drive has to be made available to the containers following these steps:^{4,5}

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



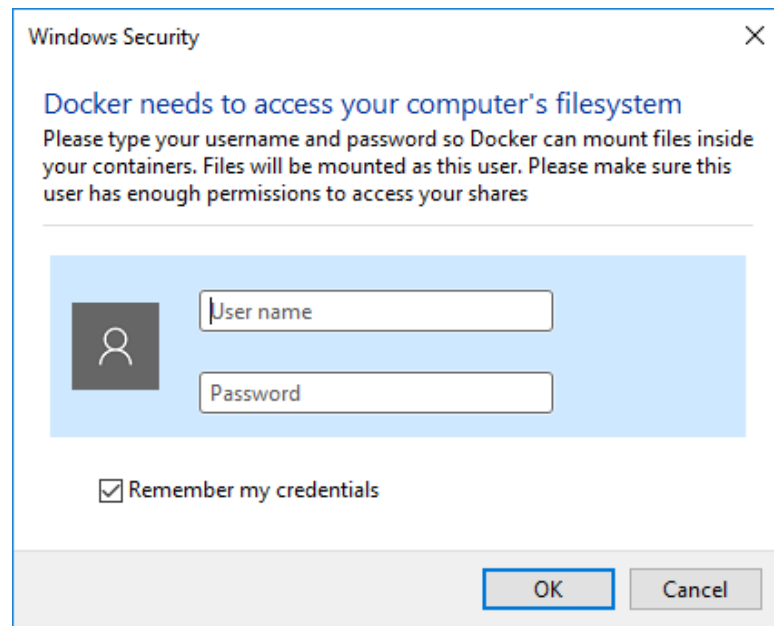
2. From the tab “Shared Drives”, select the drive you want to make available to the containers, e.g., “C”:



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

⁴<https://rominirani.com/docker-on-windows-mounting-host-directories-d96f3f056a2c#.pdeuy0c4o>

⁵Thanks to Lena for pointing to the solution.

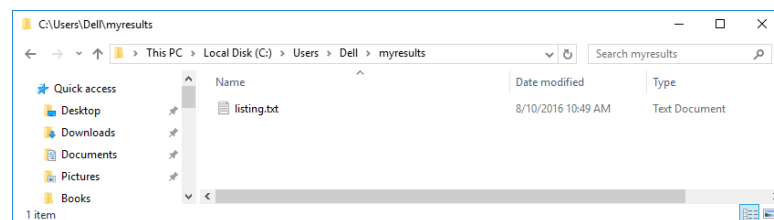


4. Start the container mounting the desired folder:

```
$ 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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