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Fogify: A Fog Computing Emulation Framework

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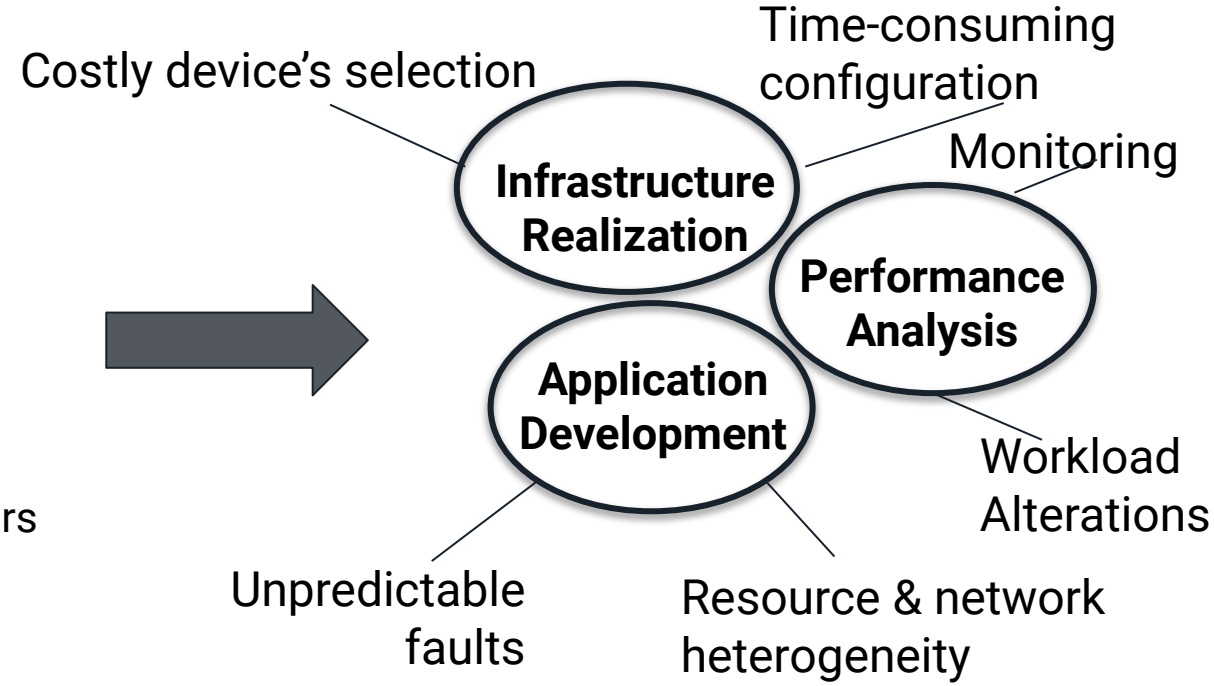
Fog Design and Deployment Challenges

Fog Ecosystem Roles

IoT Service Developers

Academic Researchers

Fog Computing Operators



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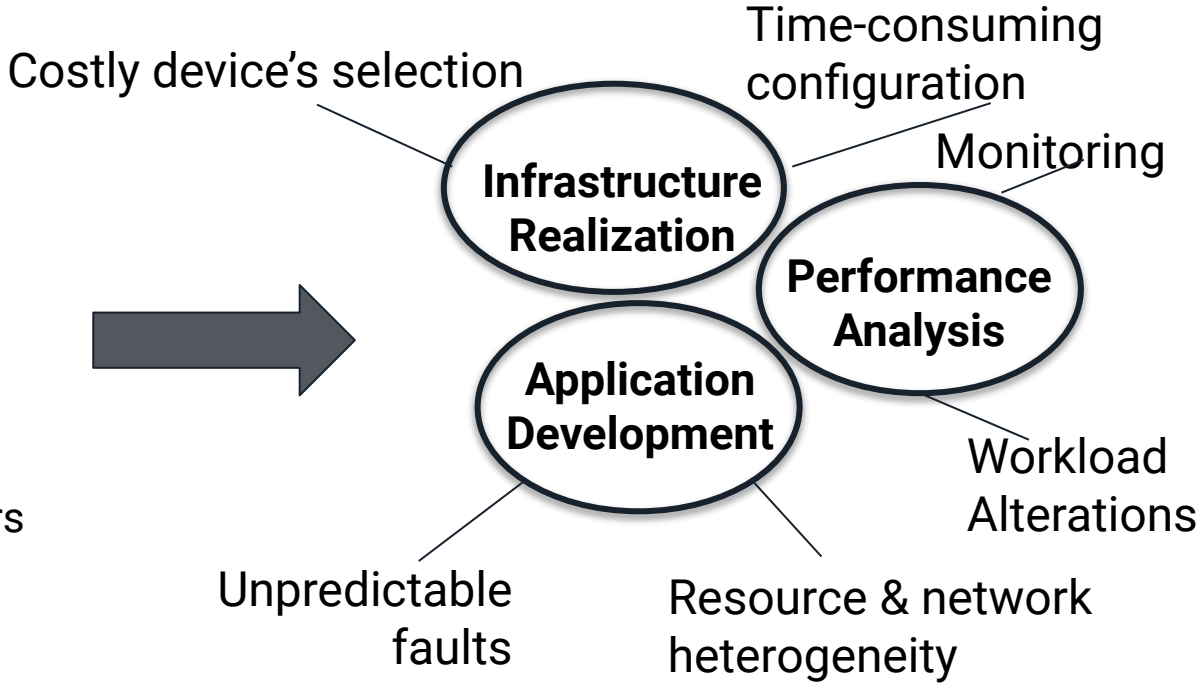


To this end, the users seek solutions to model and analyze the behavior of Fog infrastructure and IoT services…

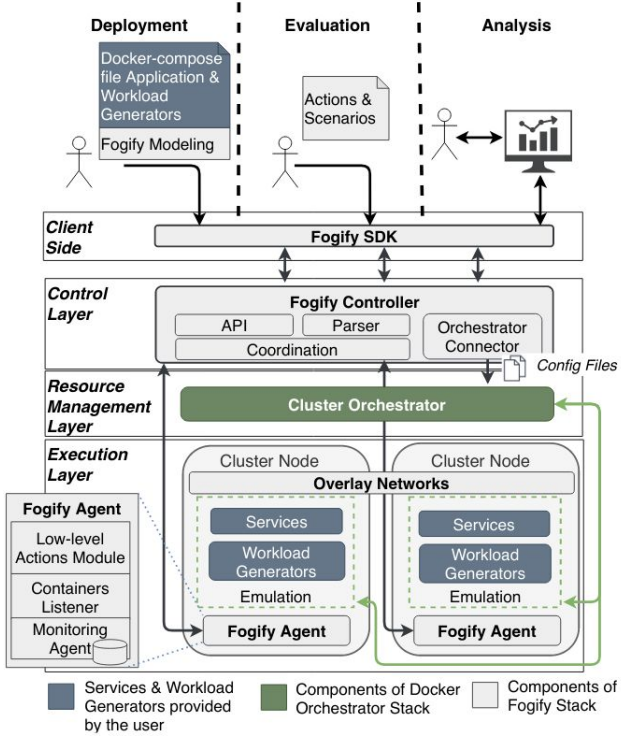
Fog Emulators

Emulators provide resource and network heterogeneity[1][2] **but**…

- usually, they do **not** provide **ad-hoc network changes** and **device failures**
- lack in applying fog-specific functions such as **node mobility**
- either do **not** provide **multi-host scalability** or are tightly-coupled with **specific cloud environments**[3]
- And *most importantly*, none of them supports...
  - **monitoring** of the emulated devices
  - **automated deployment**

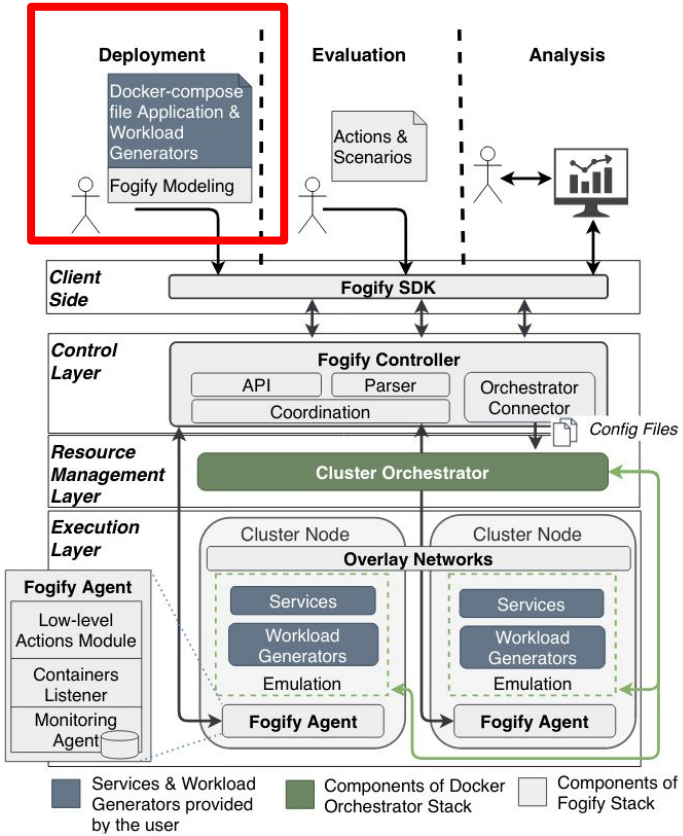
[1] Fogbed: A rapid-prototyping emulation environment for fog computing, A. Coutinho et al. IEEE International Conference on Communications (ICC), 2018
[2] Emuedge: A hybrid emulator for reproducible and realistic edge computing experiments, Y. Zeng IEEE International Conference on Fog Computing (ICFC), 2019
[3]MockFog: Emulating Fog Computing Infrastructure in the Cloud, J. Hasenburg et al. IEEE International Conference on Fog Computing (ICFC), 2019

Fogify: Fog Emulation Framework

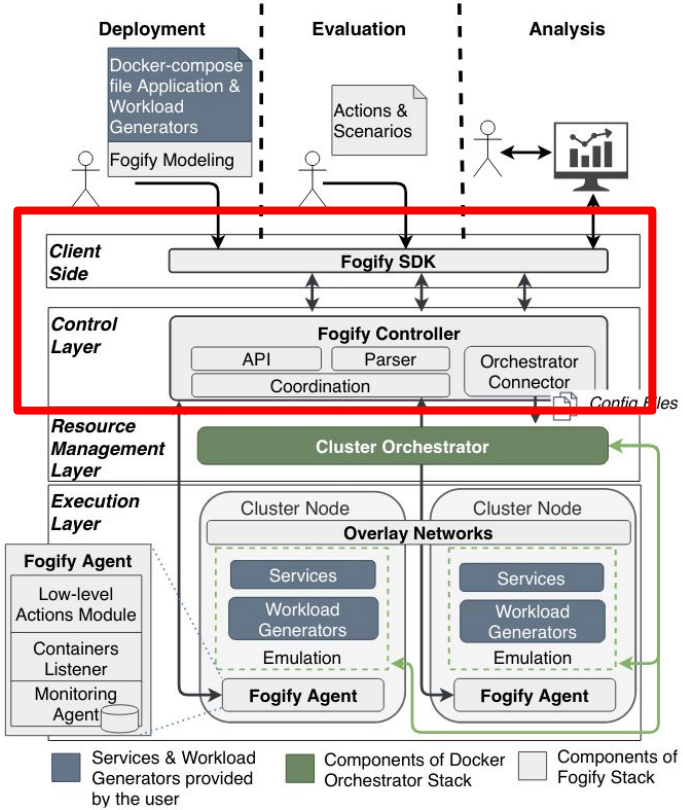


- Resource Heterogeneity
- Network Link Heterogeneity
- Controllable Faults and Alterations
- Any-scale Experimentation
- Monitoring Capabilities
- Rapid Application Deployment

Fogify workflow



Fogify workflow



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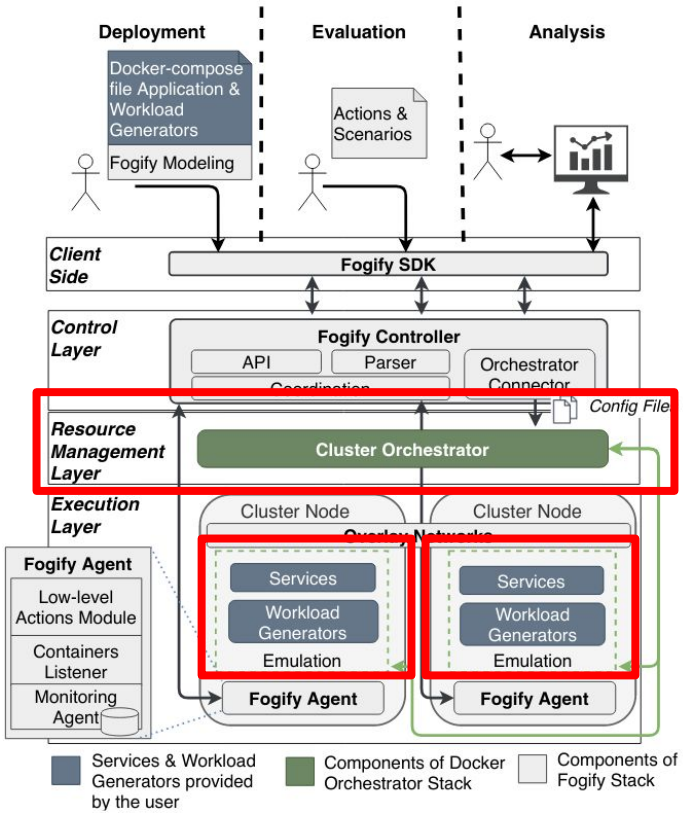

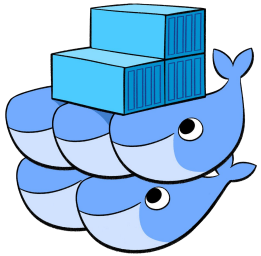

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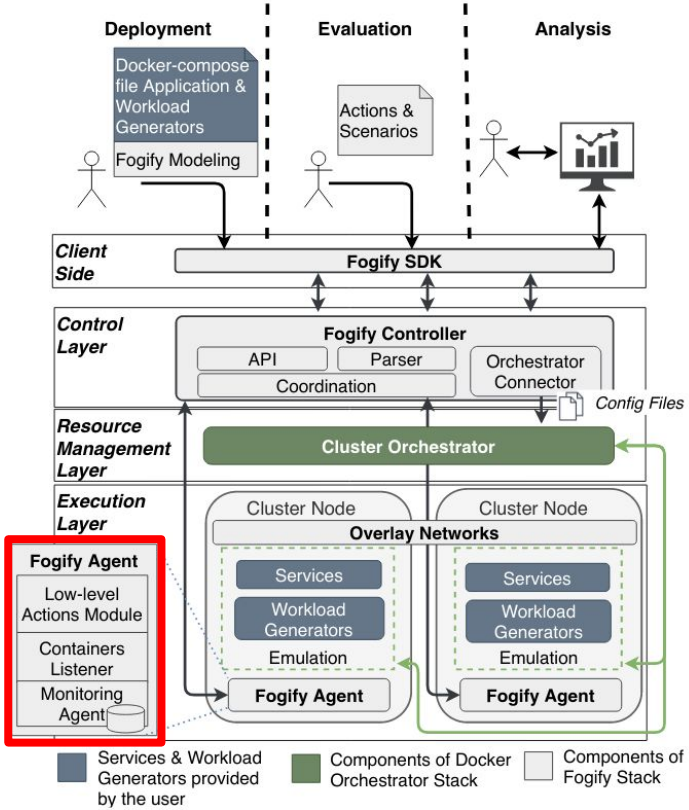

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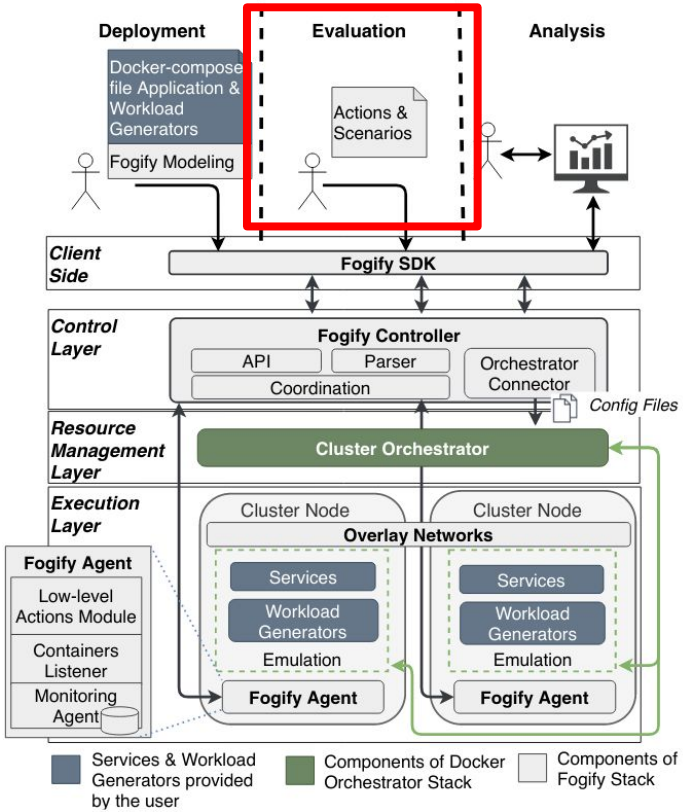

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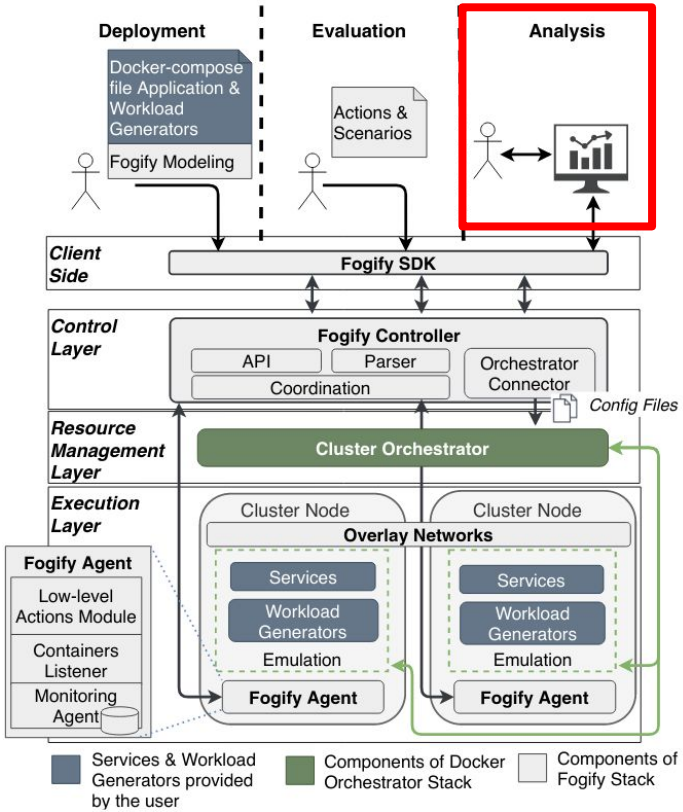


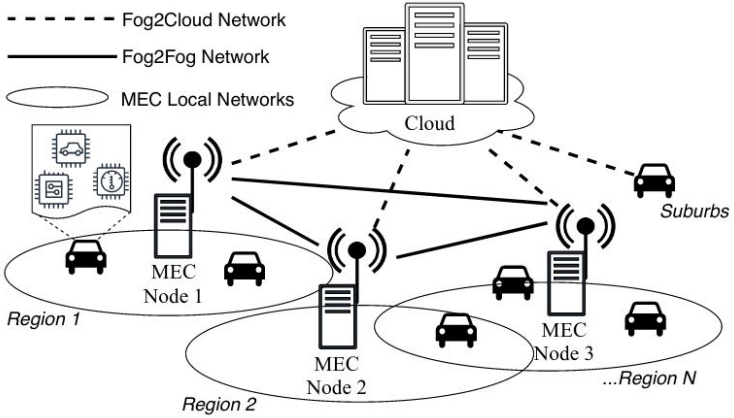
Modeling

Motivating Example

Use-case: A taxi company wants to analyse **region-based data** from its fleet.

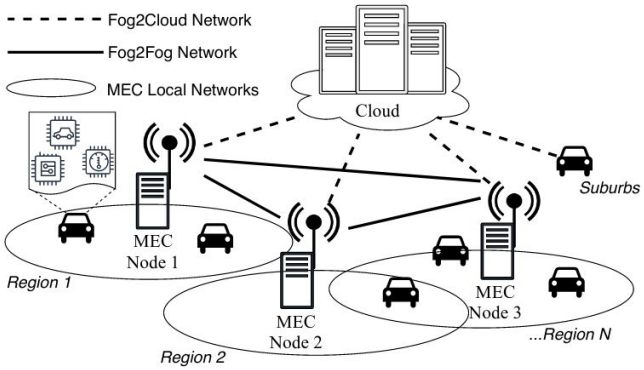
In a **real testbed**, the company should:

- **Purchase** MECs and taxis sensors
- **Configure** the MECs and **place** them at their physical location
- Setup the **network components**
- **Monitor** the "health" of the infrastructure



At the end, the developers will **not be sure if they tackle every single obstacle of network changes and device's failures**.

Use-case Modeling in Fogify




```
services: ......
x-fogify:
  nodes: ......
  networks: ......
  topology:
    - label: mec-node-1
      service: mec-svc
      node: mec-node
      networks:
      - name: mec-net-1
        links:
          car-node-at-mec-1:
            downlink: {
              latency: 50ms}
      - name: mec-2-cloud-net
      - name: mec-2-mec-net
      replicas: 1
    - label: mec-node-2
      service: .....
```

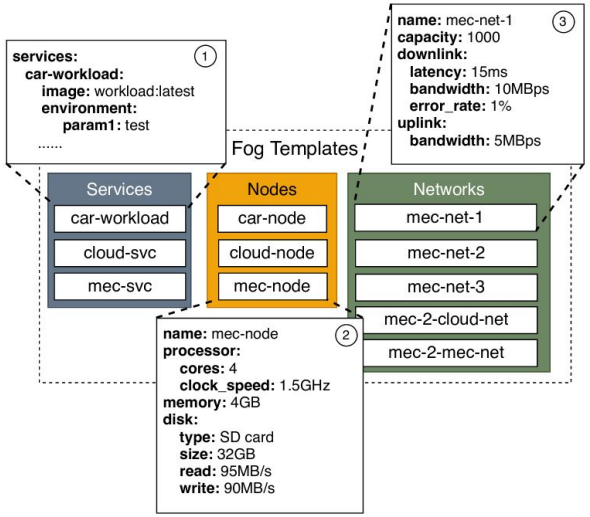
For the Fog Nodes:

- **5 MECs** (4 cores@1.4GHz, 4GB RAM) are placed in 5 different regions (*region-{1-5}*)
- **Taxis/car-node** (1 core@700MHz, 256MB RAM) sending sensed data to nearby MEC
- **Cloud server** (8 cores@2.4GHz, 8GB RAM) computes the final results.

According to the **Network QoS**:

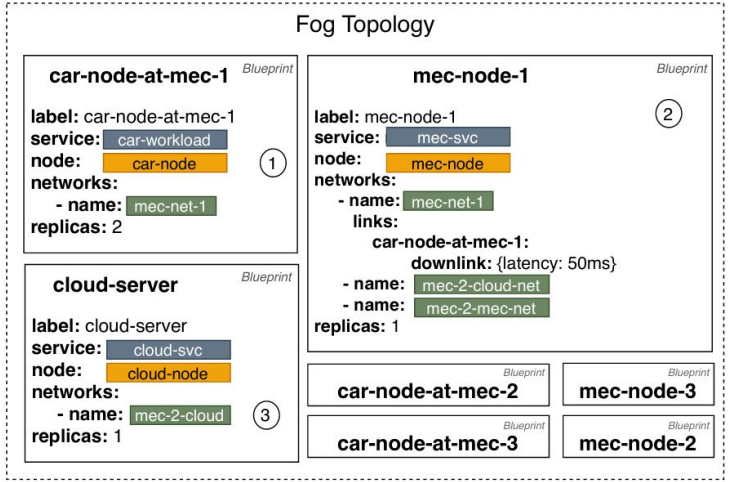
- **Regional Network:** *15ms latency* and up to *10Mbps bandwidth*
- **Edge-Cloud connection:** *100ms latency* and up to *5Mbps bandwidth*

Fog Topology



The initial **Fog Templates** of Fogify consist of:

- a set of *Services*,
- a set of *Nodes*,
- a set of *Networks*



A **Fog Topology** consists of Blueprints.

- A **Blueprint** is a combination of a *Node*, *Service*, set of *Networks*, *replicas* and a *label*

*Blueprints support the **overriding** of **network-level QoS** and **specific links** between Fog Nodes.*

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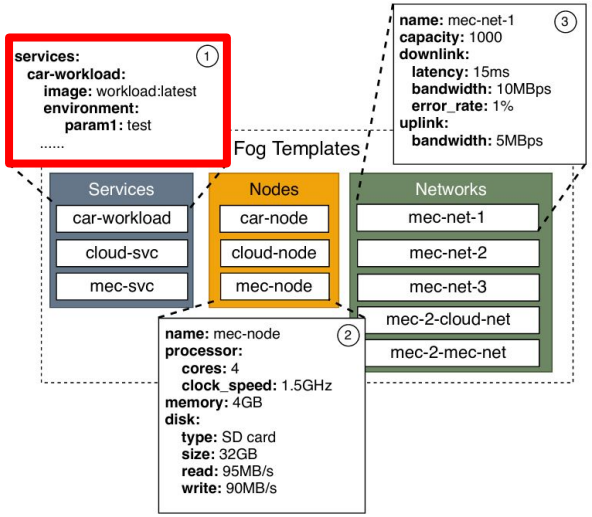

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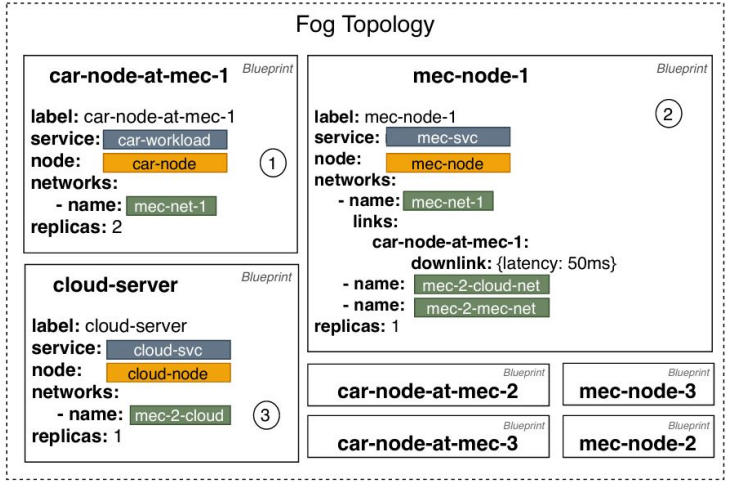

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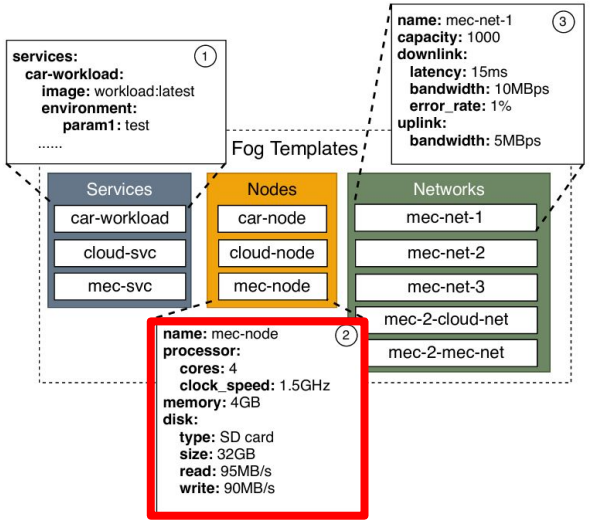

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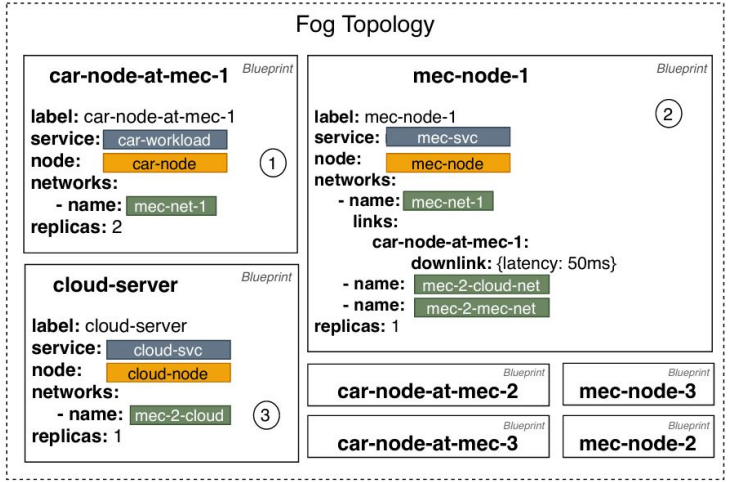

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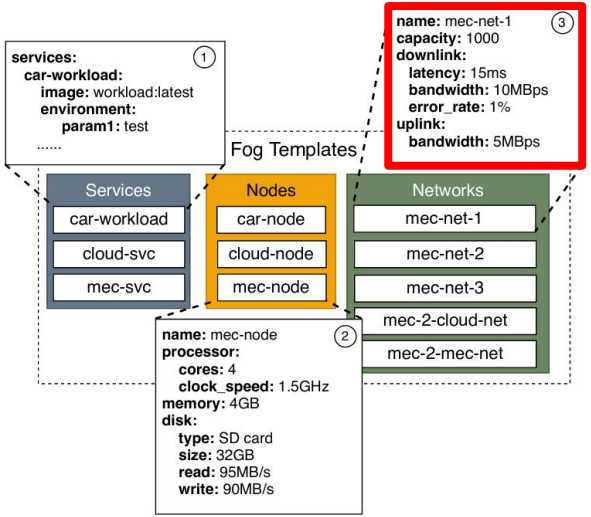

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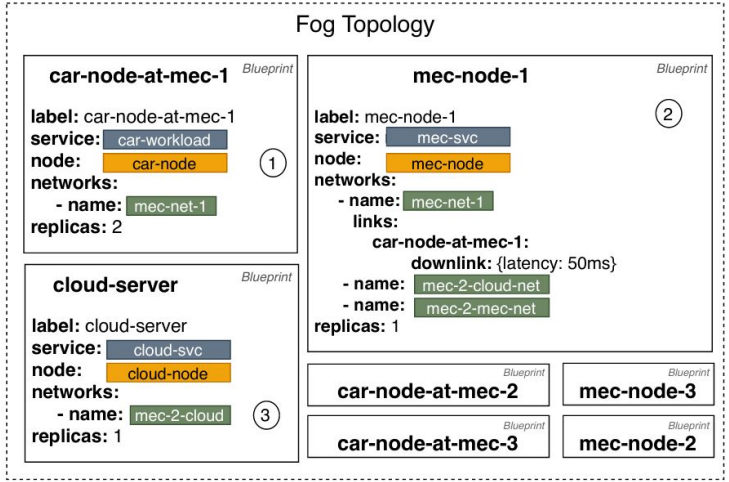

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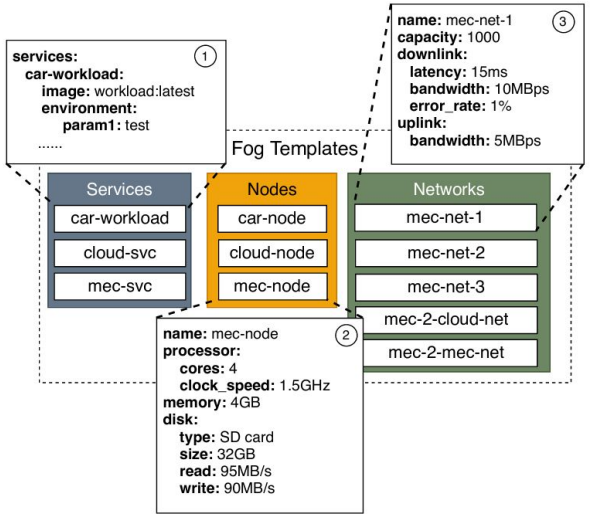

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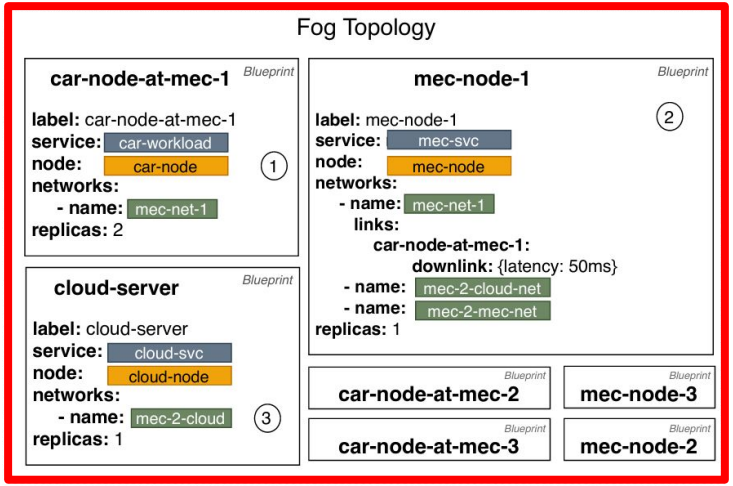

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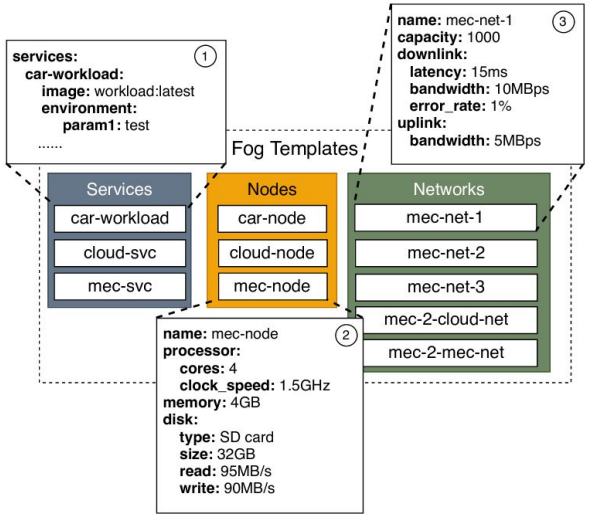

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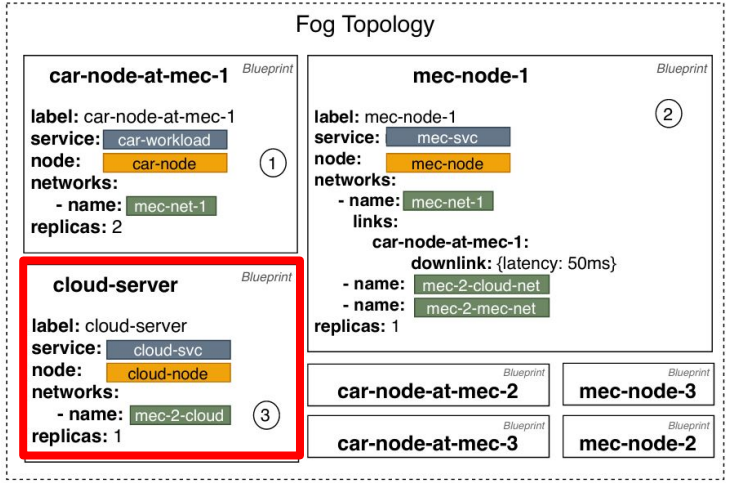

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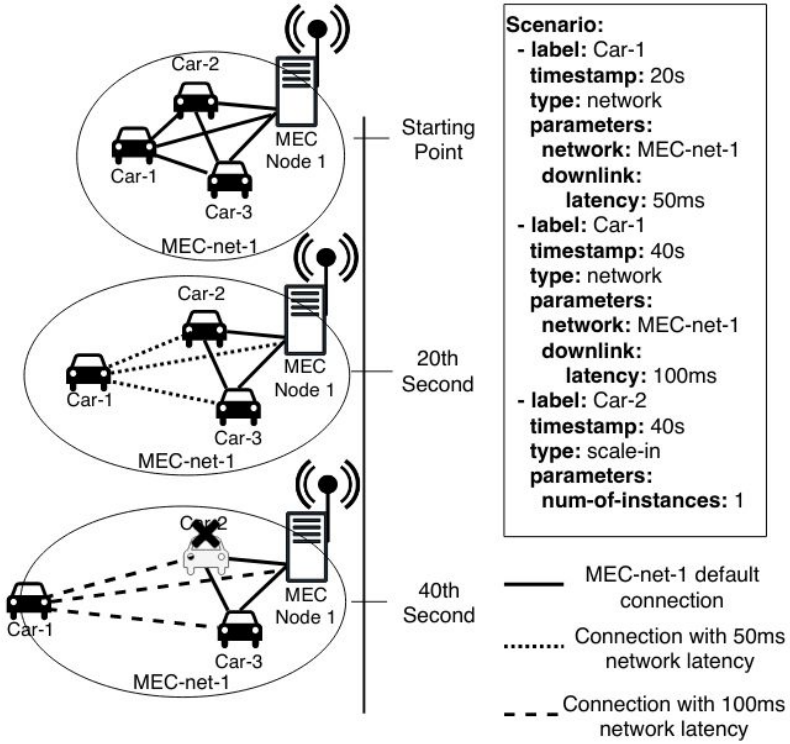
Runtime Evaluation Model

The evaluation model consists of:

- **Actions** that change properties of a running Fog Topology. Actions can be:
  - *Scaling Actions* (horizontal or vertical)
  - *Network Actions*
  - *Stress Actions*
- **Scenario** is a *sequence of time scheduled actions* that Fogify will execute to emulate more complex user-driven experiments.



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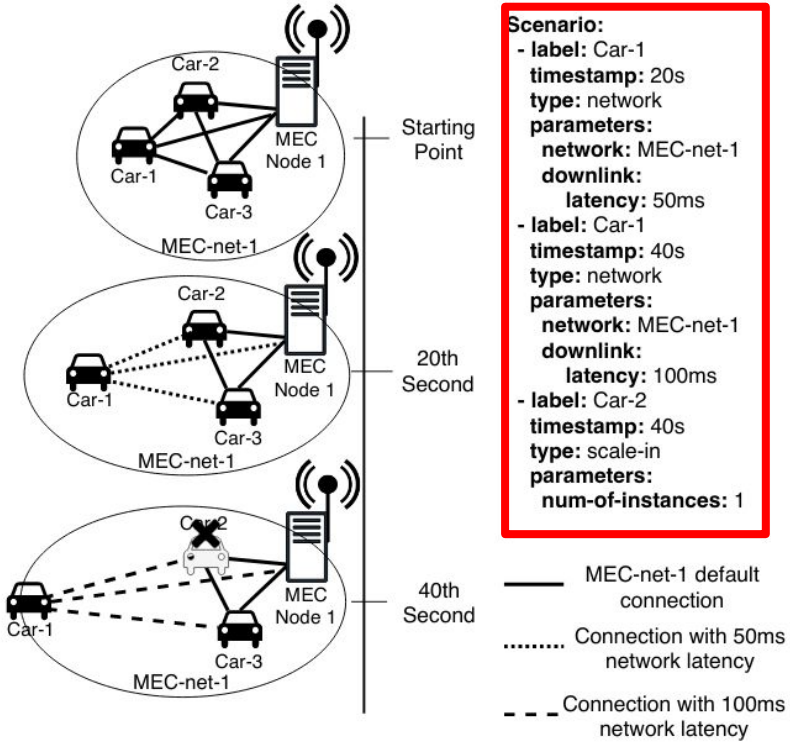

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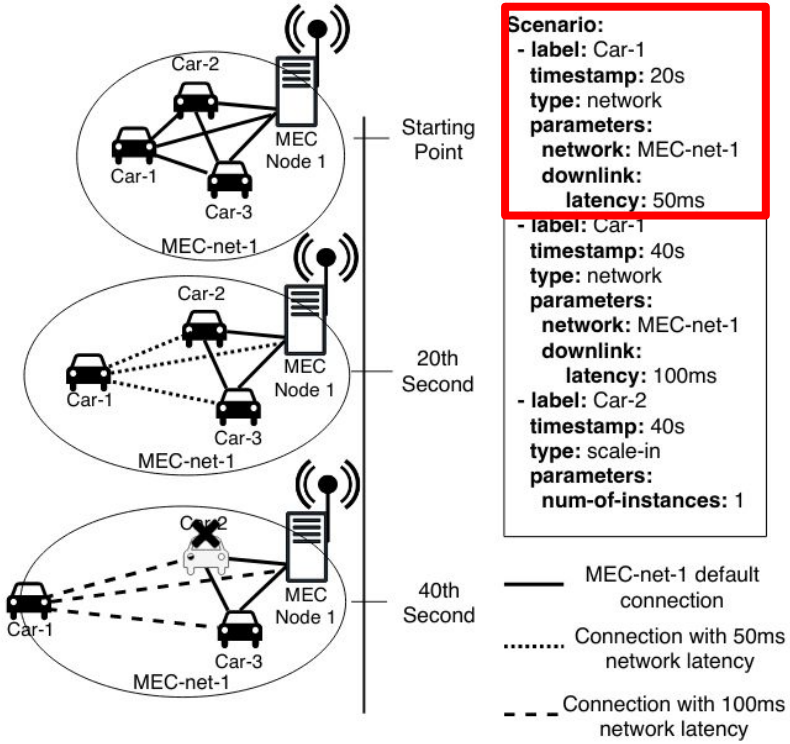

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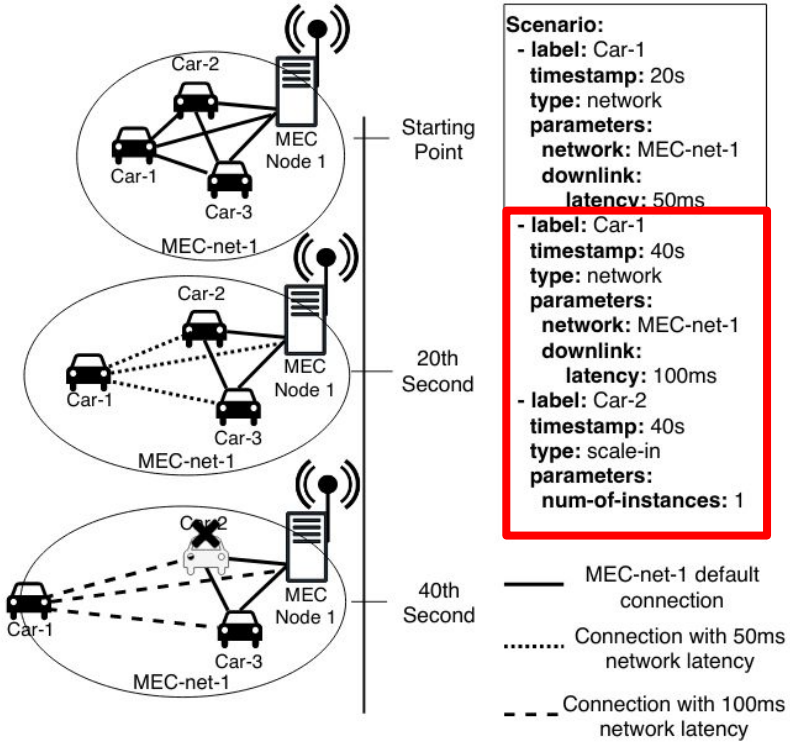


System Details

Computational Resources

Fogify utilizes the **containers** as execution platform while they achieve *isolation*, through linux namespaces, and resource constraining by using Linux Control Groups *(cgroups)*. Fogify maps the high-level device's template to the host's capabilities.

For CPU cgroups give us only the ability to set a portion of host CPU. For that:

- Fogify computes the **cumulative clock rate (CCR)** for both host and model as:

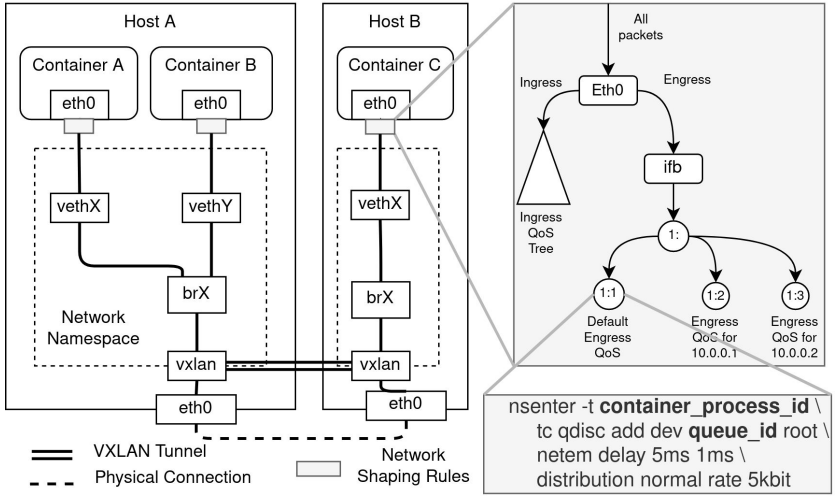
$$CCR = Cores \times Cycles$$

- Then, it specifies the rate of the processing power that the emulated device will occupy from host:

$$CPU_{rate} = \frac{emu\_node_{CCR}}{host_{CCR}}$$

Network Shaping

- Fogify realizes a virtual overlay mesh network (*Virtual Extensible Lan (VXLAN)*) per network description
- Then, Fogify agents apply the **network QoS**:
  - Separate the *incoming and outcoming traffic*
  - Build a *tree-base structure* by utilizing Classful Queuing Disciplines (qdisc)
  - Traffic from root, follows the *filtering (based on containers' IPs)* and reaches the leaves
  - Each leaf is represented by a *QoS Queue*, that is created by the *tc-tool[5]*

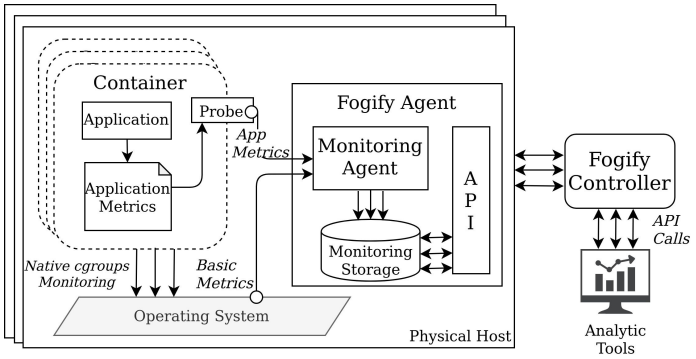


[5] linux tc-tool, https://linux.die.net/man/8/tc

Monitoring System

A **Monitoring Agent** retrieves:

- *Basic Metrics* (CPU, RAM, network, disk)
- *Application's metrics*

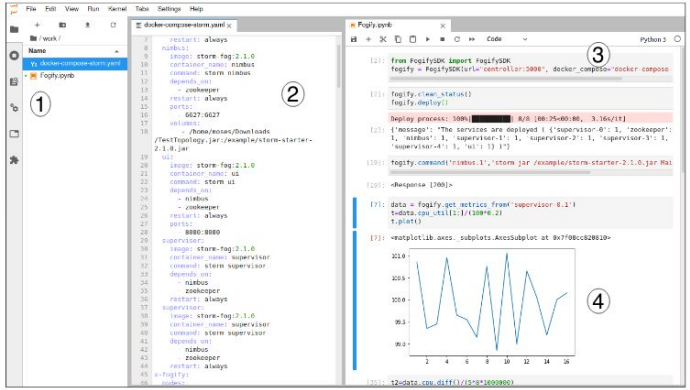


Monitoring System

Fogify SDK

FogifySDK is a **python library** that provides:

- *Deployment* of Topologies, Actions & scenarios
- Retrieval of the Monitoring data in a *High-performance data* structure
- Out-of-the-box *exploratory analysis*
- Connectivity with tools like *jupyter*

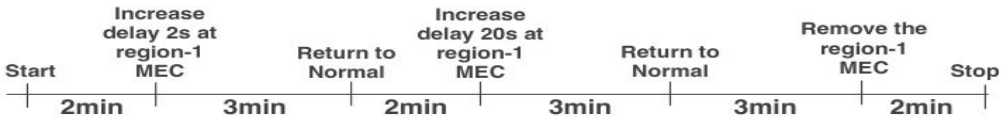


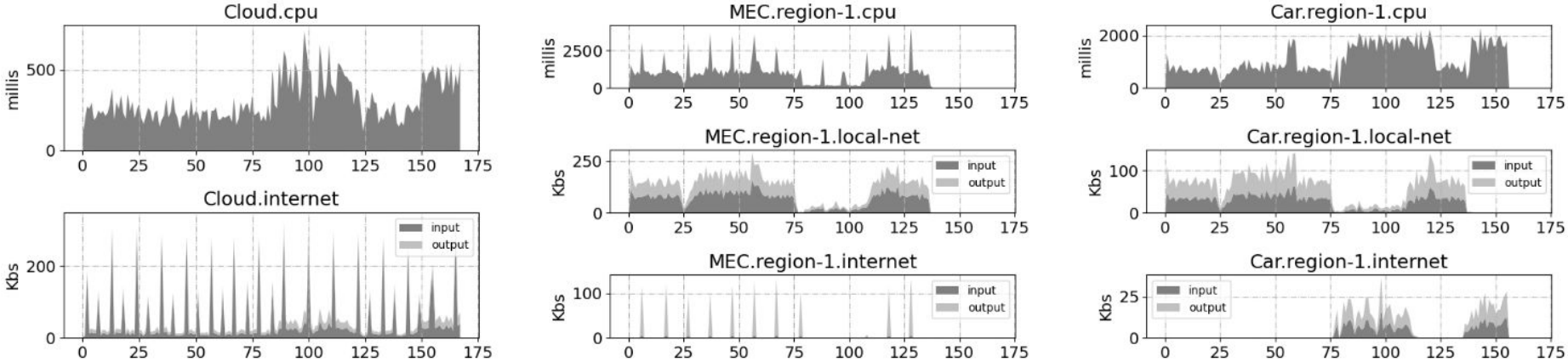
Jupyter Integration

[6] Demo: Emulating Geo-Distributed Fog Services, M. Symeonides et al, ACM/IEEE Symposium on Edge Computing (SEC), 2020

Evaluation

Scenario - Network Uncertainties





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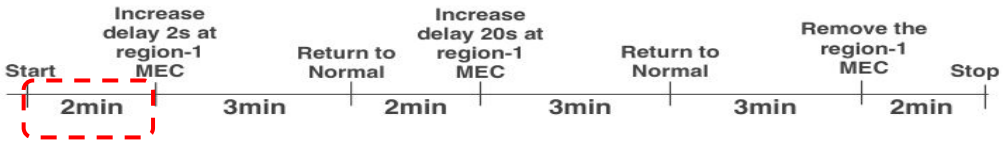
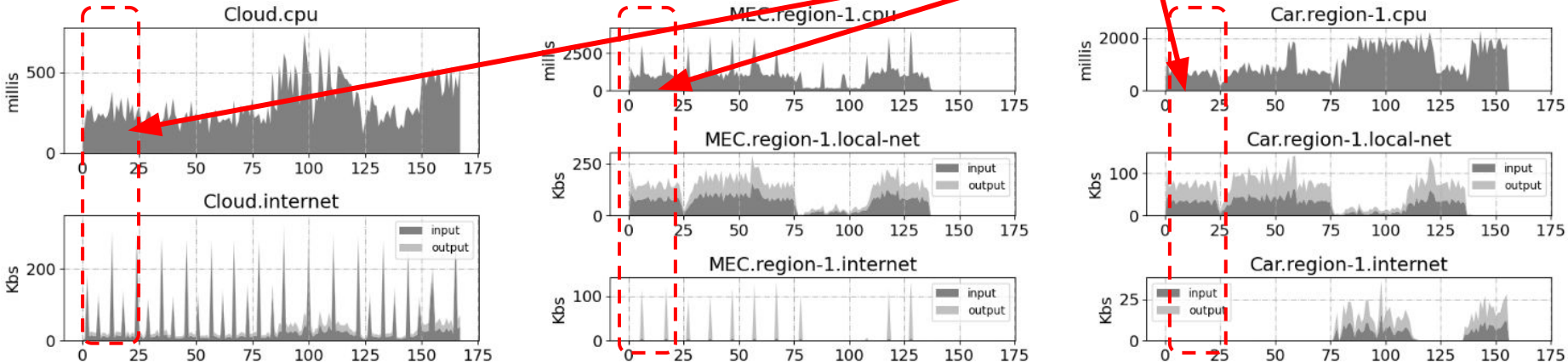


Common execution of the infrastructure.

We can observe the minimum execution utilization of all services and Fog nodes.



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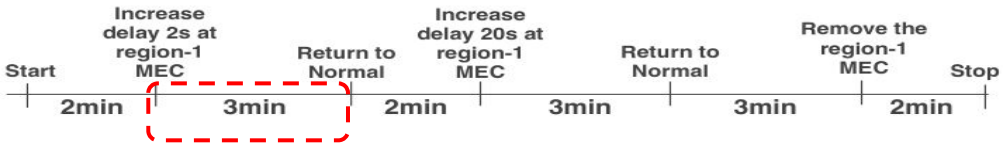
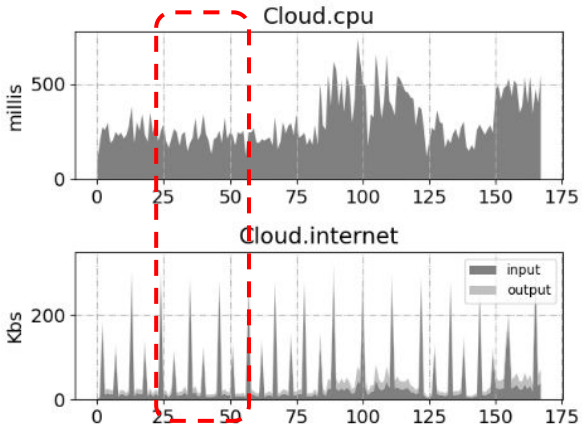
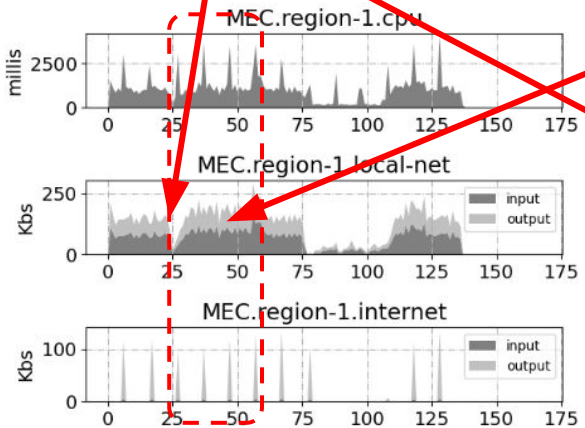


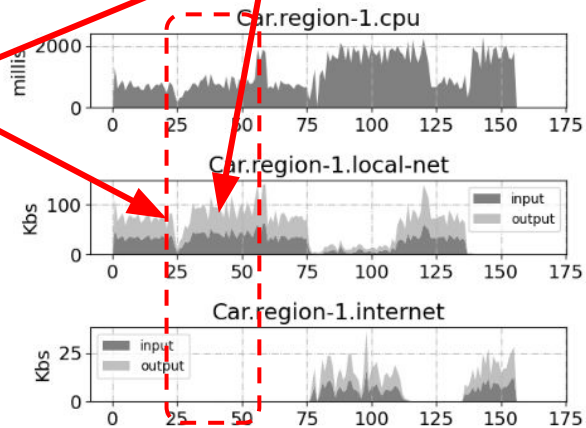
2s network delay at MEC region-1 for 3 minutes

We identify a throughput degradation

Network traffic increases to the previous level, since the latency does not exceed the pre-defined 10s disconnect limit







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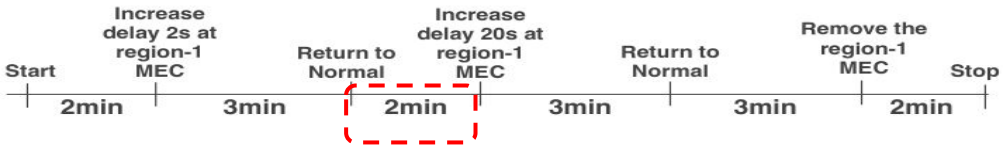
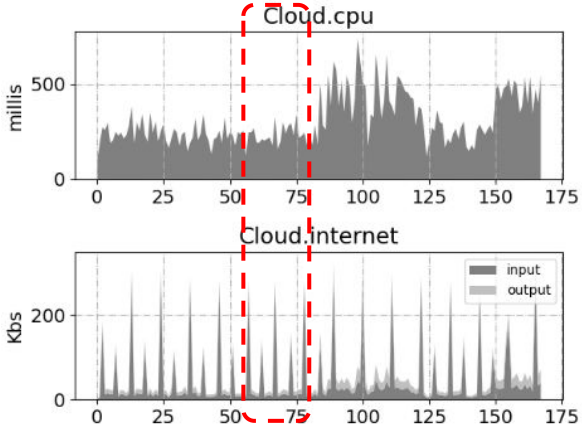
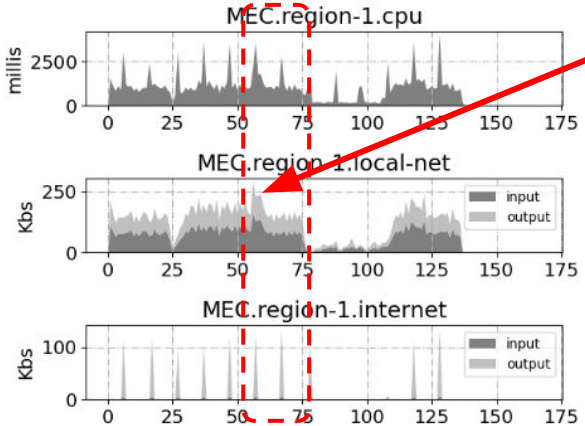
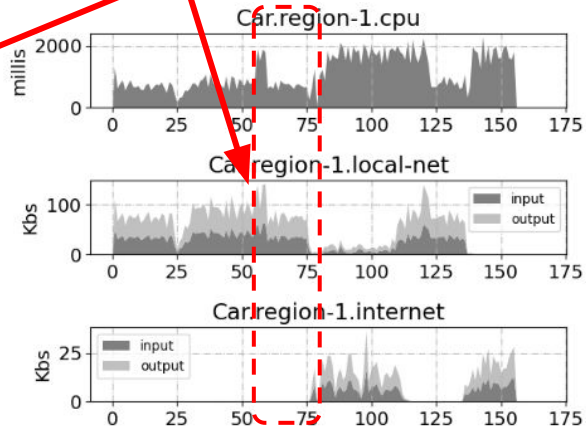


Common execution for 3 minutes

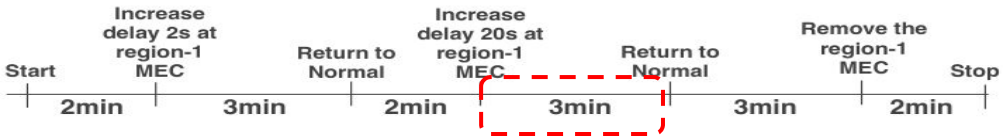
A data transfer spike is appeared for the MEC and Car nodes due to queued requests.





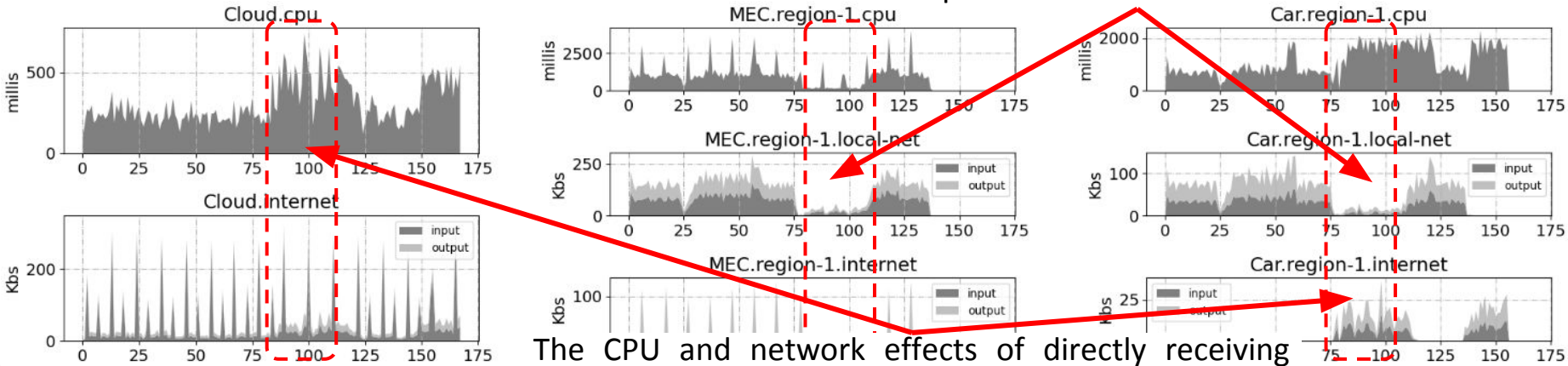


Scenario - Network Uncertainties



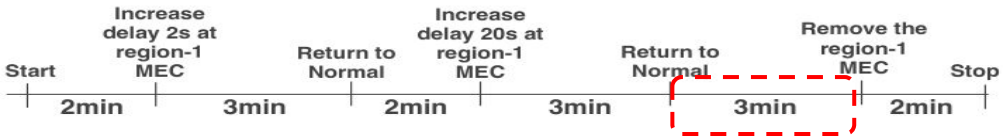
20s network delay at MEC region-1 for 3 minutes

When the network latency is boosted to 20s, every Car node request to the MEC fails

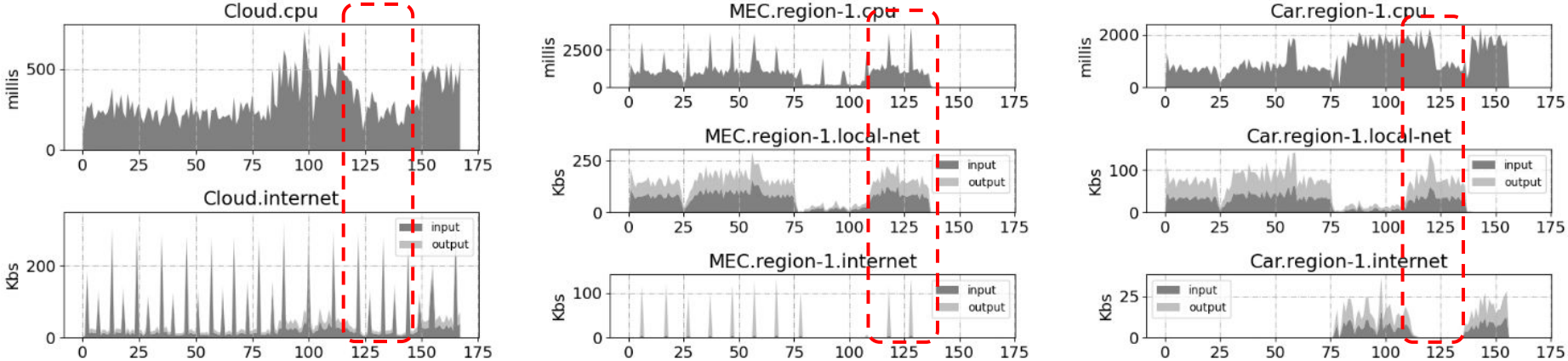


The CPU and network effects of directly receiving requests from the taxis operating in region-1

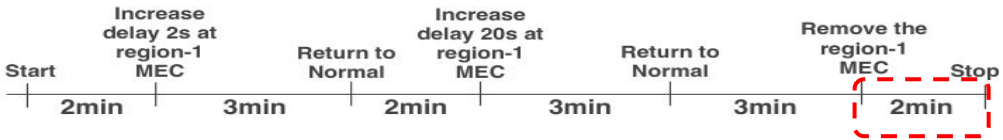
Scenario - Network Uncertainties



Common execution for 3 minutes

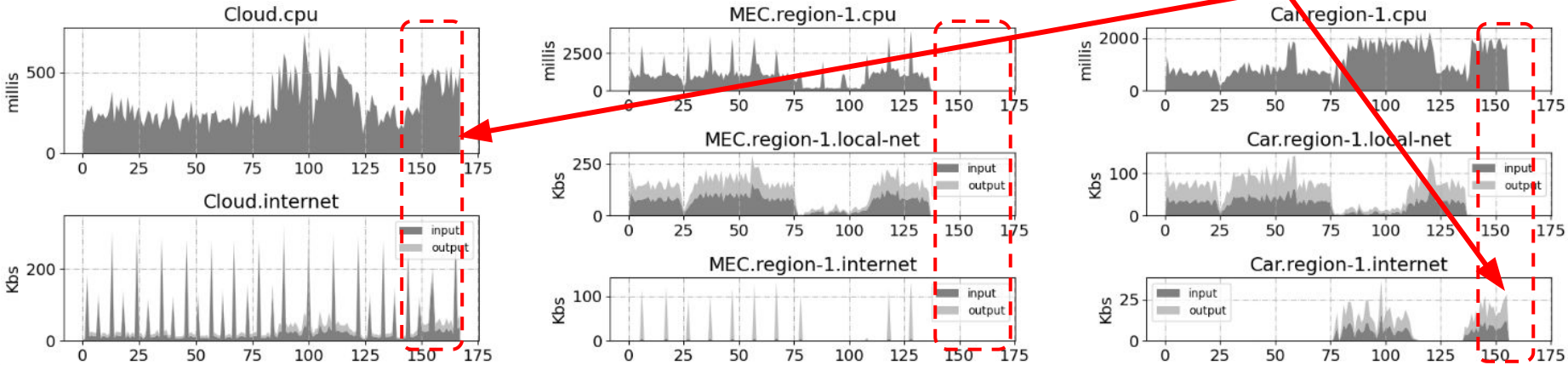


Scenario - Network Uncertainties



We observe a similar increase in the cloud CPU load and network traffic as in the previous period (75-110th interval)

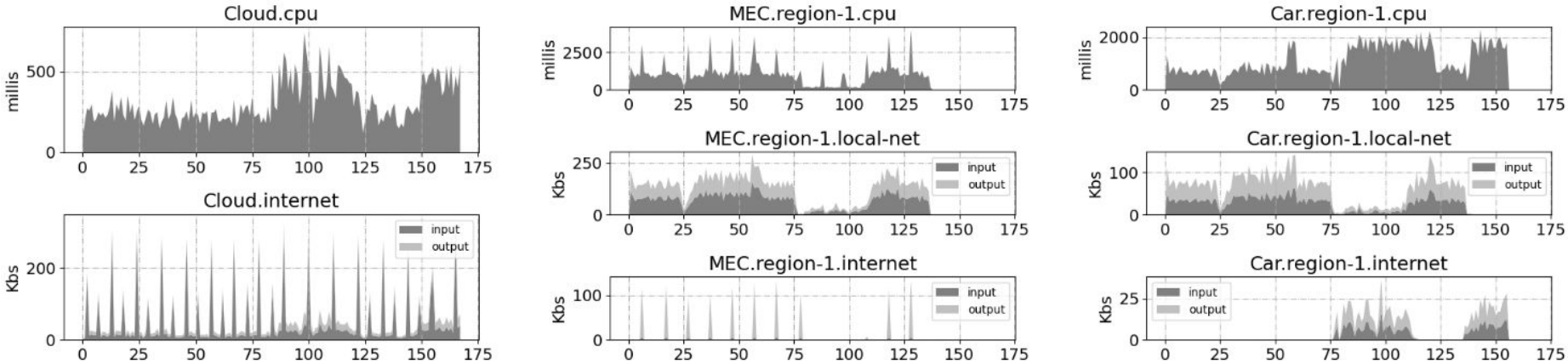
Disconnection of the MEC in region-1



Scenario - Network Uncertainties

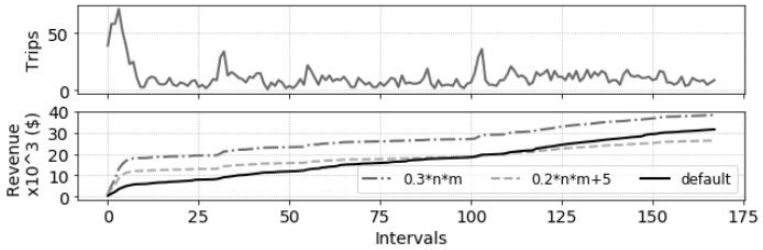
In conclusion, with **network alterations** and **fault injections,** users:

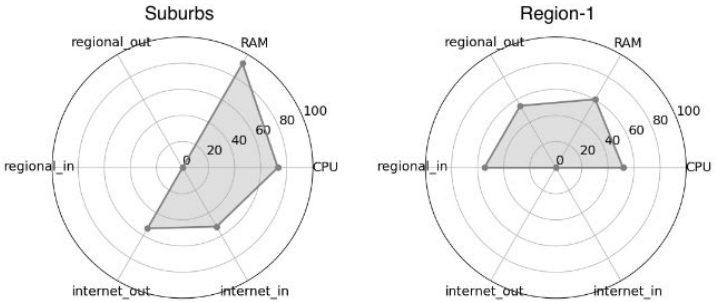
- evaluate the execution of their services under *extreme conditions*
- identify *unpredictable outcomes* of imposed uncertainties to the service behavior



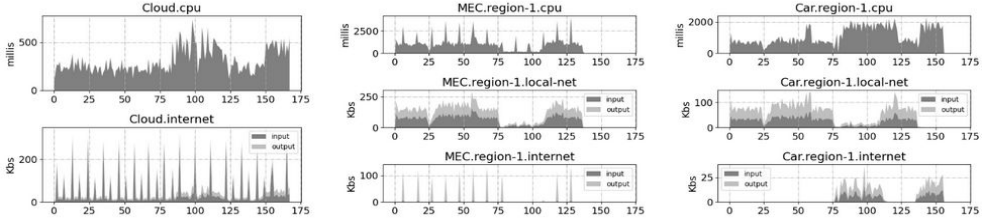
Other Scenarios

Application-level metrics: Operators can employ Fogify to produce and evaluate analytic insights, implementing adequate app-level metrics.



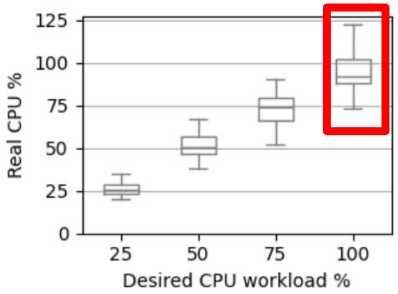


Node profiling: insights are highly beneficial to engineers for capacity planning, optimizing service and resource placement.

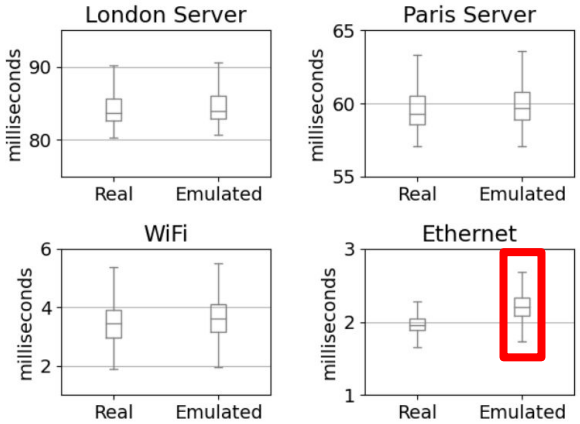


Scaling Actions & Workload Changes: released insights about service performance and resources utilization.

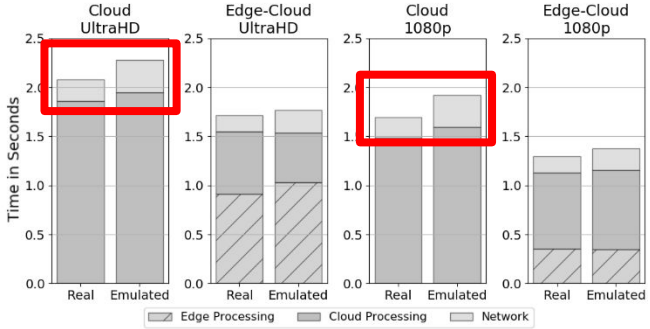
Emulation Accuracy



The **emulated computing resources** has only a *small performance degradation* for workloads approaching 100% CPU usage



Fogify achieves near to **real-world network link capabilities**, with *only outliers* not captured and a *slight overhead in low-latency connections*



The emulation results **closely follow the real measurements** with a *5%-8% deviation* of the overall experiment time.

Conclusion

- We introduced **Fogify**: an **open-source** & **all-in-one Fog emulator.**
  - features a powerful **model specification for Fog Deployments**,
  - allows the controllable **Faults** and **Alterations**,
  - offers enablers for **Any-scale Experimentation**, and
  - provides **Monitoring Capabilities**

- We provided a detailed description of the implementation aspects, such as **resource management**, **network shaping** and **monitoring**.

- The **evaluation** illustrates:
  - We introduced r**eal-world IoT applications** that demonstrate the **usability**, **extensibility**, and **observability** of Fogify.
  - The **error displayed 3-8% deviation** between emulated and real Infrastructures.

- Our **future work** includes an extensive *scalability evaluation*, implementation of *new actions* and the evaluation of more *real-world scenarios*

This work is partially supported by the EU Commission through RAINBOW 871403 (ICT-15-2019-2020) project and by the Cyprus Research and Innovation Foundation through COMPLEMENTARY/0916/0916/0171 project.

Thank You

You are welcome to our live demonstration (**Demo: Emulating Geo-Distributed Fog Services, Thursday, Nov 12, Poster Session II**) and you will find the code of the Fogify at the following link https://github.com/UCY-LINC-LAB/fogify

Documentation: https://ucy-linc-lab.github.io/fogify/
Demo: https://github.com/UCY-LINC-LAB/fogify-demo
Video: https://www.youtube.com/watch?v=PthMM6rC89o