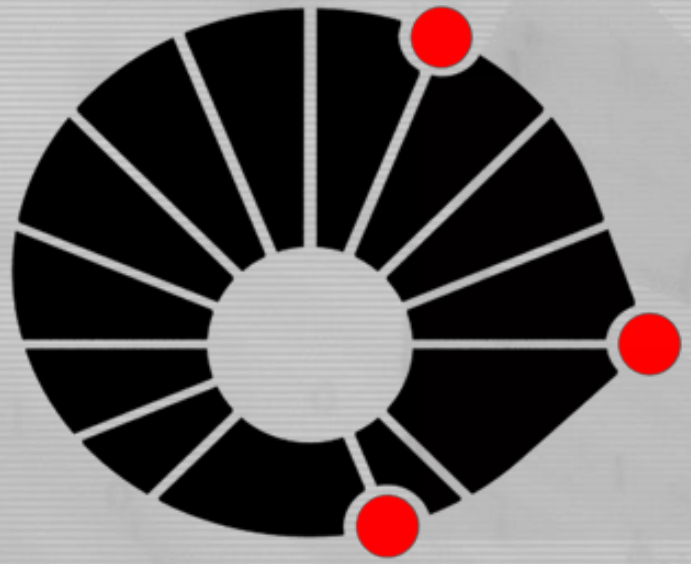
Edge Computing: Service Orchestration and Dynamic Network Slices

Edmundo R. M. Madeira
IC – Instituto de Computação
UNICAMP

New York, September 14th, 2023

International Event on Industry 5.0 to Enhance Cooperation among Academic and Industry Promoted by UNIBO, Cornell, and Campinas

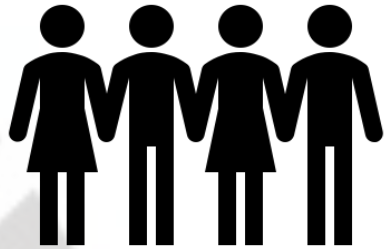


UNICAMP


UNICAMP

Unicamp

1,900+ Faculty



8,000+ Staff

36,000+ Students

- **17,000+** Grad
- **19,000+** Undergrad

#1 University in Patent Filings

#1 pub/professor rate

Annual Budget
~0.9 Billion USD

Innovation

- More than 1000 companies created within Unicamp or by alumni
- In 2020-21 they generated a R$ 16 billion gross annual income (U$3.1 billion).
  - Unicamp annual budget is around R$3 billion

- 40% are in IT business, and 60% of the income come from IT.
- Total number: 1019 (aprox. 13% created by IC alumni)

https://www.unicamp.br/unicamp/noticias/2021/10/21/faturamento-de-empresas-filhas-da-unicamp-dobra-e-chega-16-bilhoes-de-reais

The Institute

A little bit of our Journey

1969

First Bachelor's degree in Computer Science in Brazil

1977

Grad School Starts

1996

IC Foundation

2023

54 years

Excellence Undergraduate Courses

Bachelor in
Computer Science

Computer engineering

enade

Best Evaluation

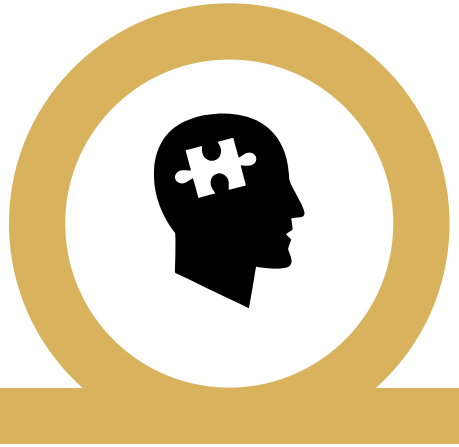
90+

Gradutes/year

Postgraduate Excellence

CAPES

7 CONCEITO MÁXIMO



Computation Theory

Algorithms and Optimization
Bioinformatics and Computational Biology
Cryptography
Graphs, Combinatorics and Computation Theory

Information Engineering

Visual Computing
Software Engineering
Large Data Management
Human-Computer Interaction
Robotics and Machine Intelligence

Computing Systems

Computer Systems Design
Computer network
Information and Systems Security
Distributed systems

Postgraduate Excellence

1075

M.Sc.

313

Ph.D

Research Projects – last 5 years

+500

Scholarships

+70 M

Projects

6

Fapesp

15

Industry Projects

Industry Partener

IC's alumni founded companies

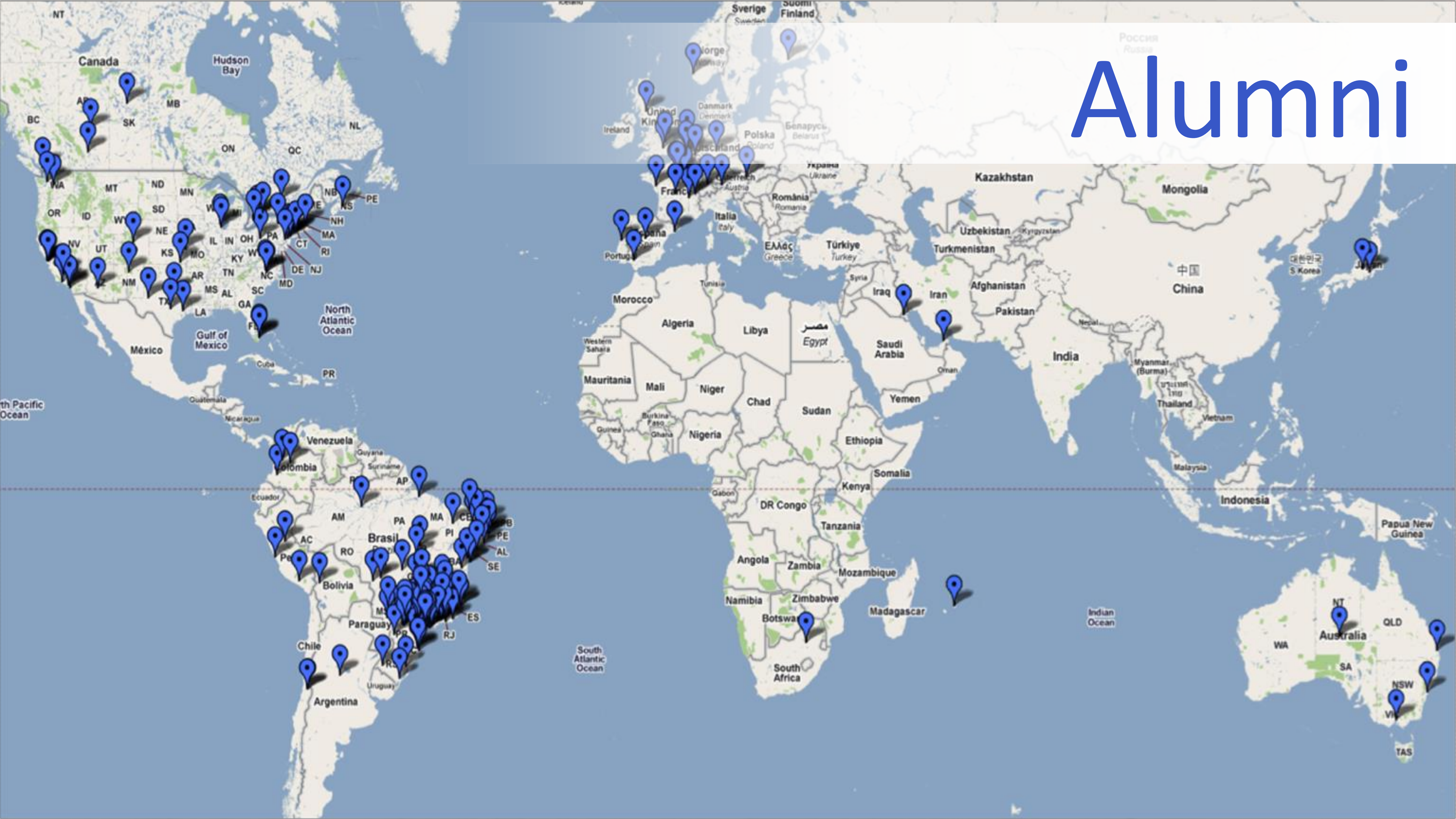
Continued Education

350+

Year

- SOFTWARE ENGINEERING
- COMPUTER NETWORK
- CLOUDS AND NETWORK VIRTUALIZATION
- INTERNET OF THINGS
- COMPLEX DATA MINING

Alumni


Canada
Hudson Bay
BC
AB
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QC
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NS
PE
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WA
OR
ID
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KY
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AR
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AL
GA
SC
NC
NM
TX
LA
FL
PA
NH
MA
CT
RI
DE
NJ
MD
México
Gulf of Mexico
North Atlantic Ocean
Cuba
PR
Guatemala
Nicaragua
Venezuela
Guyana
Suriname
Colombia
Ecuador
AM
PA
MA
AP
PI
CE
PE
AL
SE
AC
RO
Brasil
Peru
Bolivia
Paraguay
Chile
Argentina
Uruguay
ES
RJ
RS
South Atlantic Ocean
Sverige
Suomi Finland
Norge
Ireland
United Kingdom
Danmark
Polska
Deutschland
France
España
Portugal
Italia
România
Україна
Ελλάς
Türkiye
Россия
Kazakhstan
Mongolia
Uzbekistan
Turkmenistan
Afghanistan
Pakistan
Iraq
Iran
Syria
中国
China
대한민국
S Korea
Japan
India
Nepal
Myanmar (Burma)
Thailand
Vietnam
Malaysia
Indonesia
Papua New Guinea
Morocco
Algeria
Libya
مصر
Egypt
Tunisia
Western Sahara
Mauritania
Mali
Niger
Chad
Sudan
Saudi Arabia
Oman
Yemen
Ethiopia
Somalia
Kenya
Nigeria
Ghana
Guinea
Burkina Faso
Gabon
DR Congo
Tanzania
Angola
Zambia
Mozambique
Madagascar
Namibia
Zimbabwe
Botswana
South Africa
Indian Ocean
Australia
NT
QLD
WA
SA
NSW
VIC
TAS

Computer Networks
Laboratory

http://www.lrc.ic.unicamp.br

PI

- Nelson L. S. da Fonseca, PhD from the University of Southern California,
- Supervised 80+ graduate thesis, Published 450+ Papers
- Large experience as PI of research projects including chairing networks of research groups (USP, UFMG, UFRJ, UFRGS, UFAM, UFBA among others) and industry such as Motorola, NET-Claro, CISCO and CPqD and international cooperations
- Served as IEEE ComSoc VP Confferences, VP Publications, VP Technical and Educational Activities and Vpmembers, EiC IEEE Communnications Surveys and Tutorials
- Current Dean of Research, Institute of Computing
- https://www.ic.unicamp.br/~nfonseca/

Faculty members

Edmundo Madeira

Leandro Villas,
IC Director

Carlos Astudillo

Luuiz Fernando Bittencourt,
Dean of Graduate Program

- Juliana F. Borin

Allan Souza

Current Areas of Interest

- 5G/6G
- Artificial Intelligence Applied to Communications and Networking
- Network Virtualization
- Edge Computing
- IoT and Cellular IoT
- Vehicular Communications
- Network Management
- Wireless networks
- Optical networkss

Computer Network LAB

- Over 200 graduate thesis developed in the lab
- International cooperation with Canada, Italy, German, France, UK and Portugal
- Lader in research Project composed of network of research groups with other universities
- Relationship with Industry: Samsung, Motorola, Ericsson among others
- Always sponsored by goverment research agencies

Outline

- Edge Computing

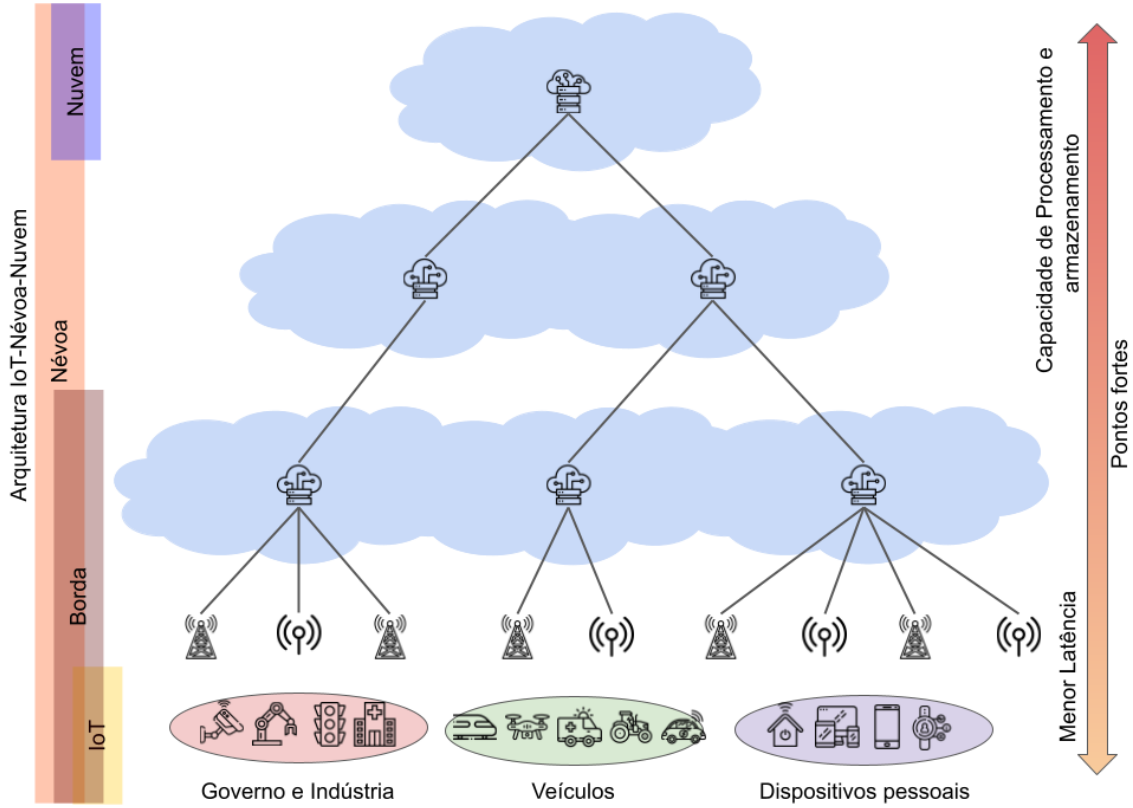
- Dynamic Network Slicing in Fog Computing for Mobile Users;
- Federated Learning for Traffic Prediction in 5G Network Slicing;
- Multilayer Edge-Fog-Cloud Orchestration for Services and Data Collocation in Industrial Internet of Things.

Edge Computing

Cloud

Fog

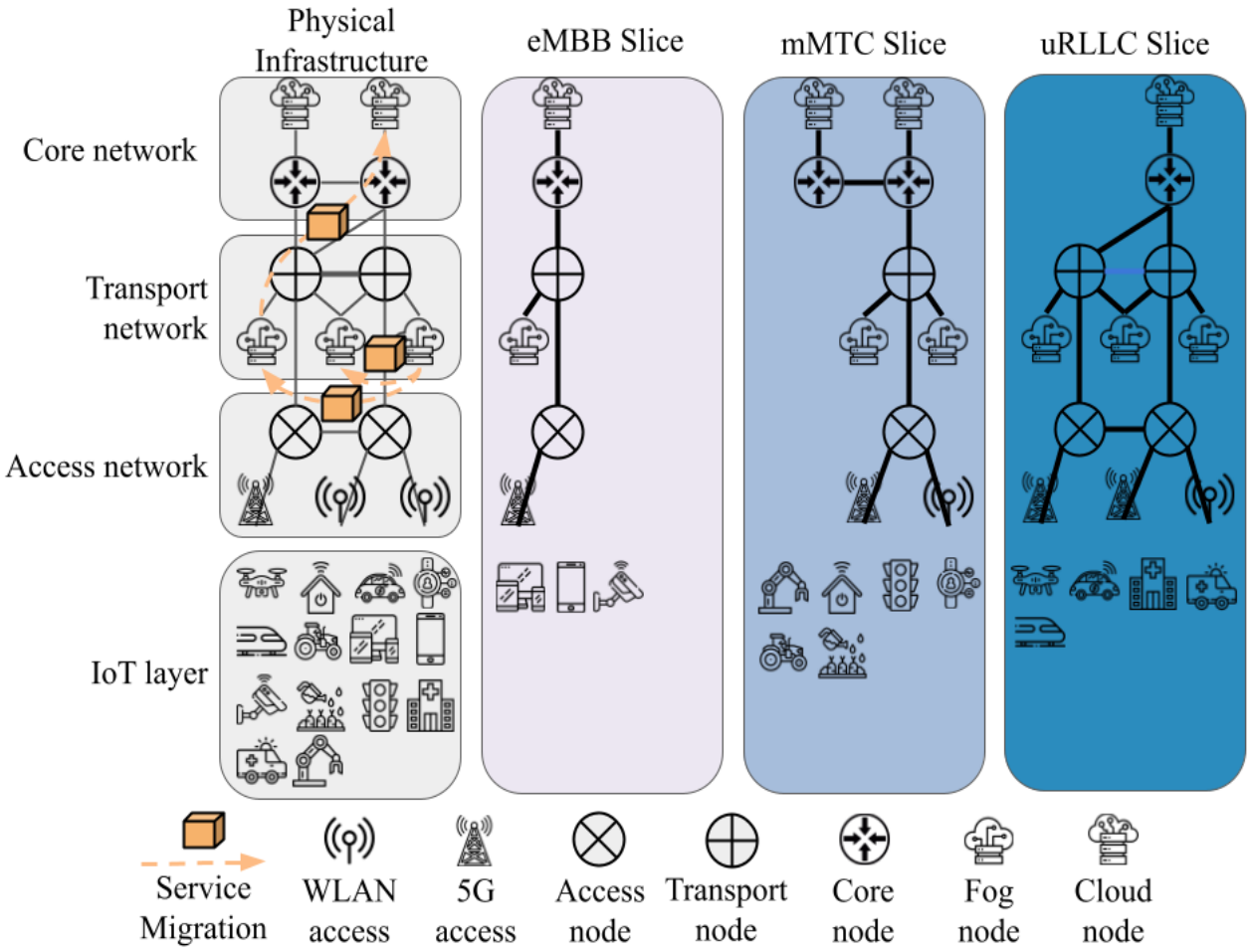
Edge



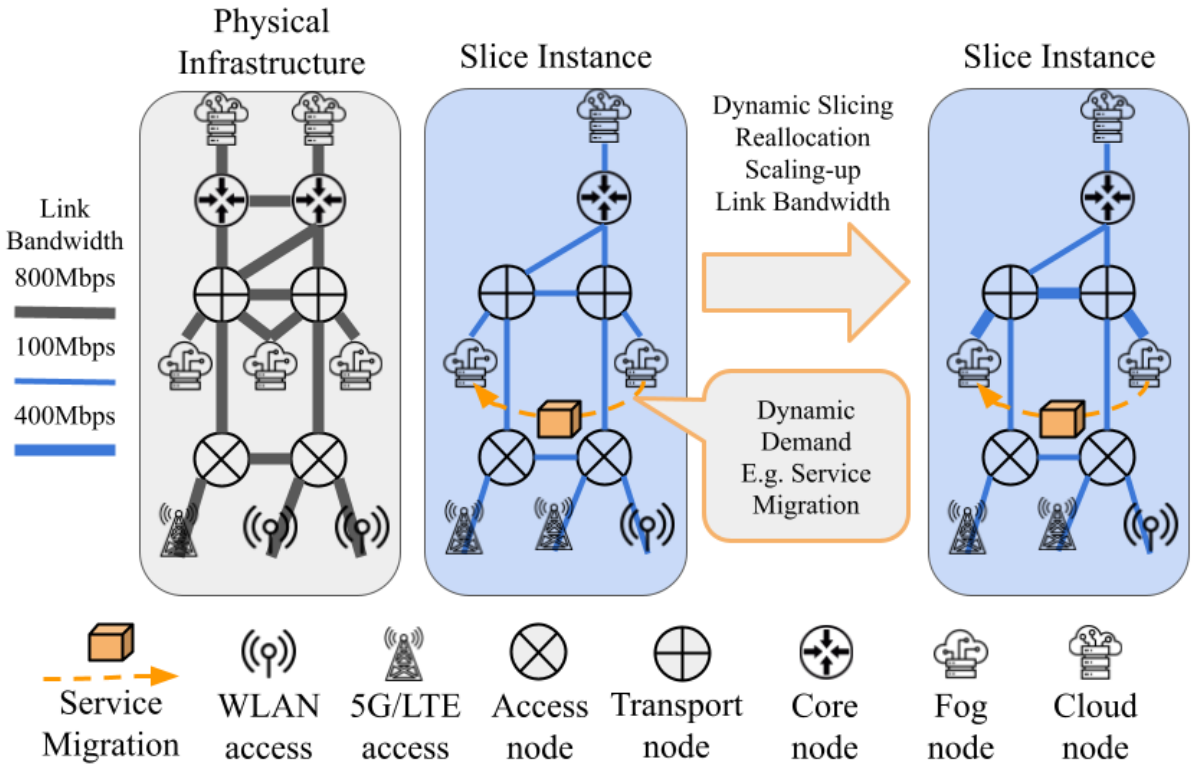
Edge-Fog-Cloud Architecture

Dynamic Network Slicing in Fog Computing for Mobile Users

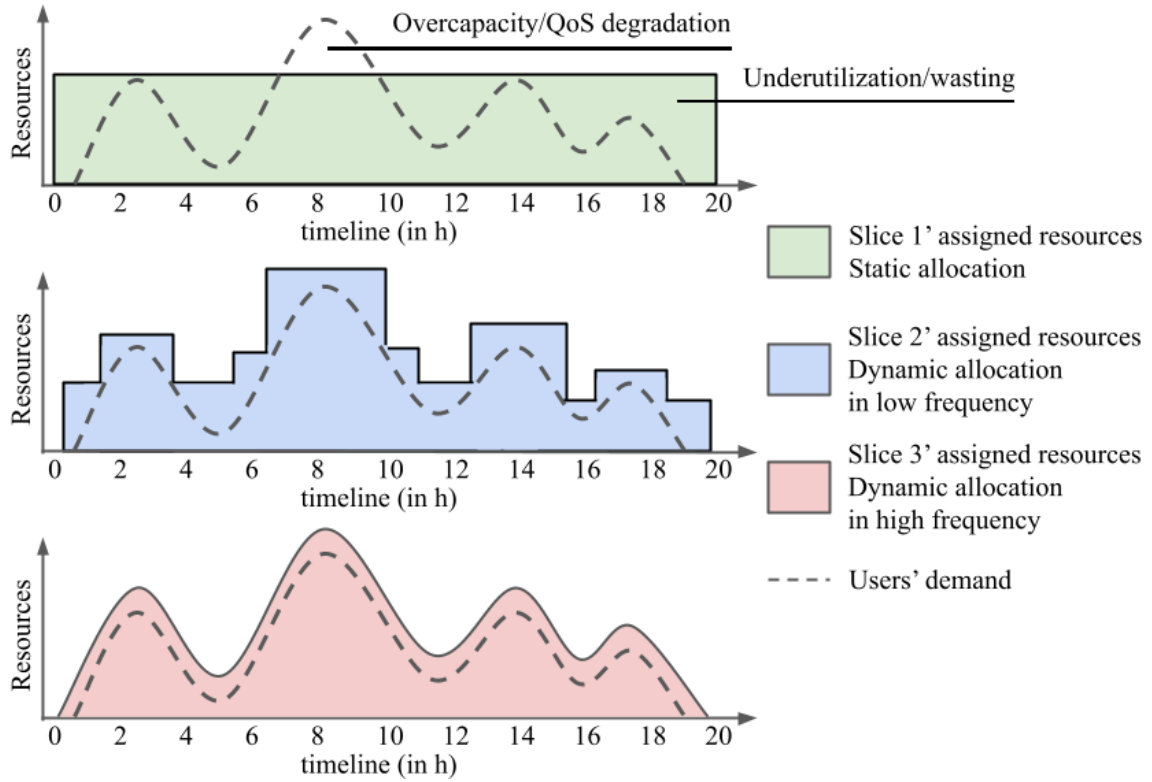
Network Slicing – Concept and Architecture



Dynamic Network Slicing



Dynamic Slicing reallocation
Scalling-up link bandwidth



Dynamic Slicing reallocation
Frequency

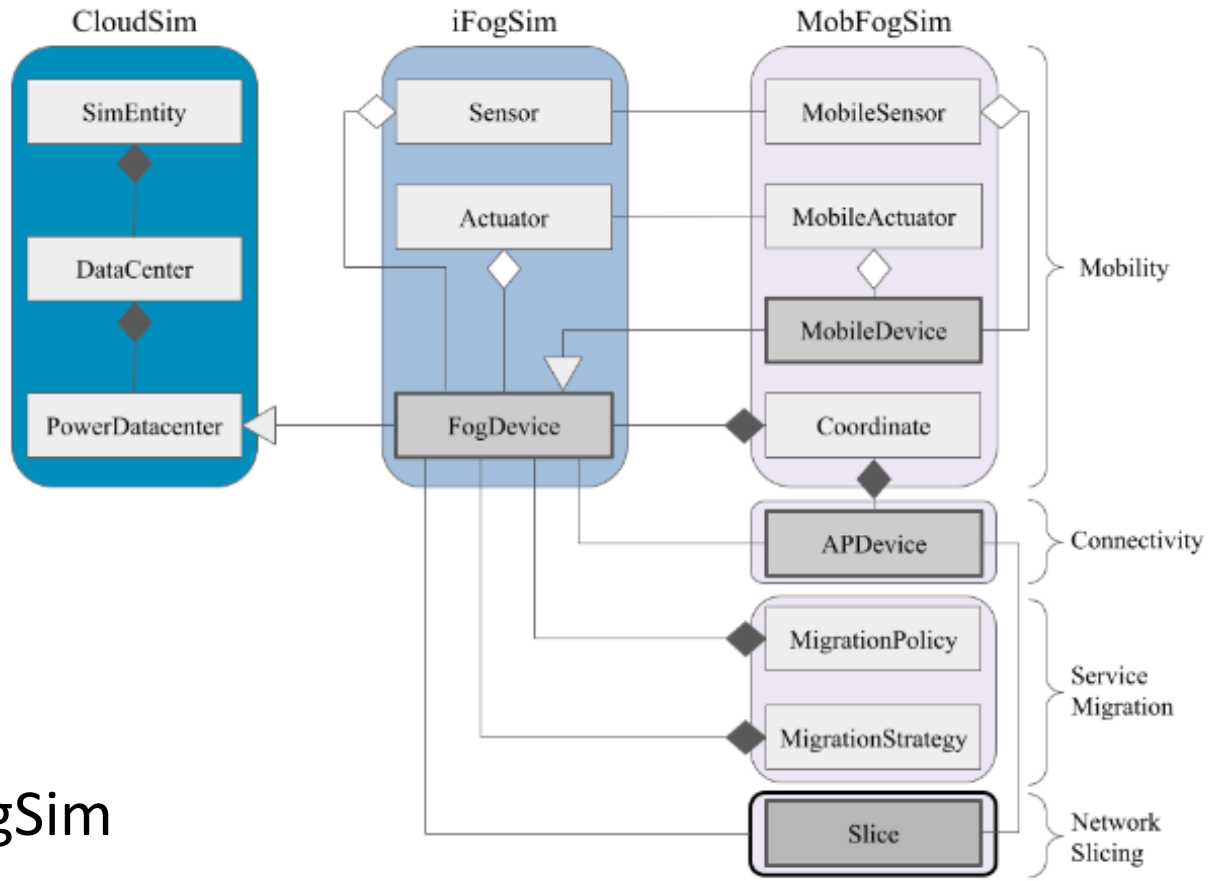
MobFogSim – Environment for validation

MobFogSim simulates mobile IoT devices on Fog Computing environment

MobFogSim supports:

- VM/container migration;
- Realistic mobility support;
- End-to-end Dynamic Network Slicing;
- VANETs.

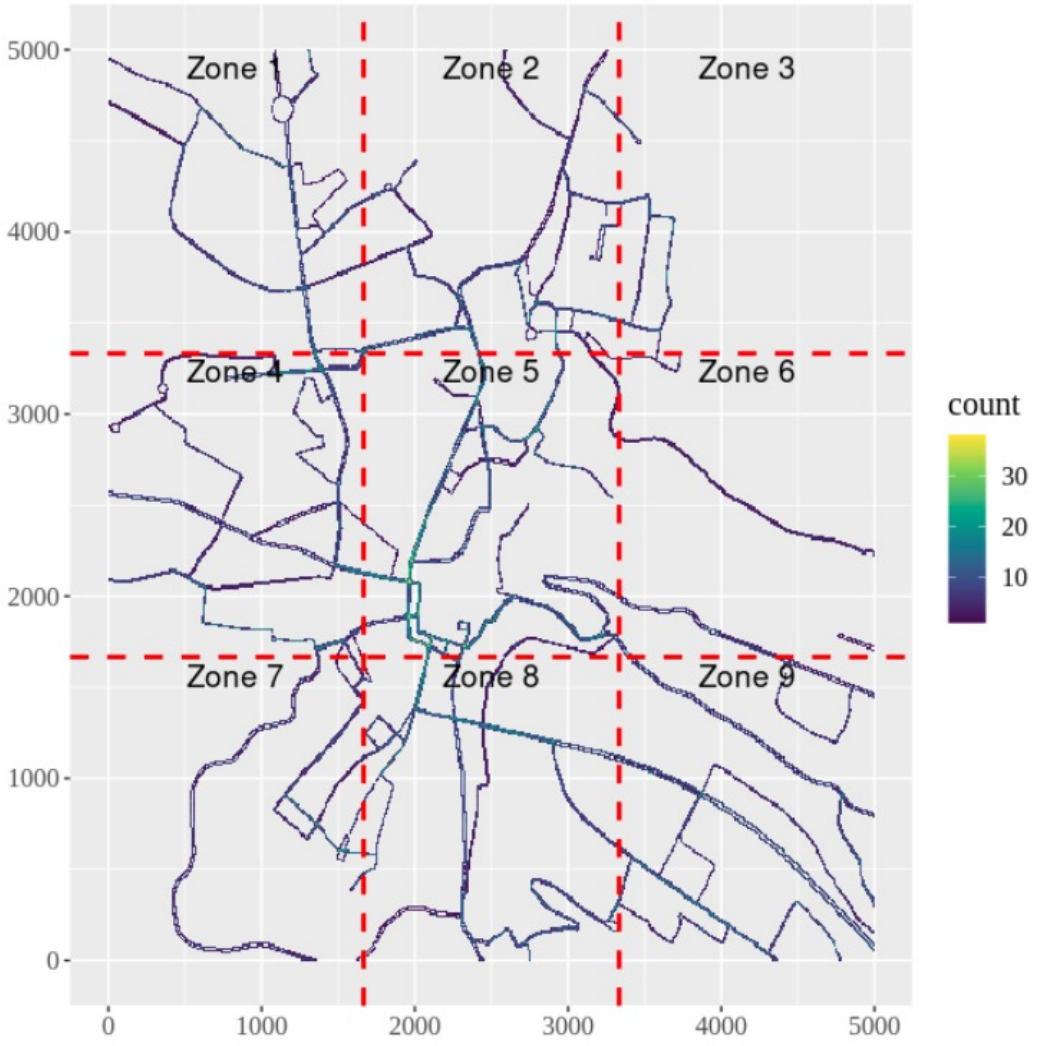
Availabe at github.com/diogomg/MobFogSim



MobFogSim Architecture

Dynamic Slicing for VANETs

- 80 vehicles from Luxembourg;
- Vehicular clouds by zones;
- Slices use resources from edge-only, vehicular-only or hybrid;
- Follow-me cloud approach;
- 3 Slices prioritising processing, bandwidth or latency.



Dynamic Slicing for VANETs

Service placement based on resource availability

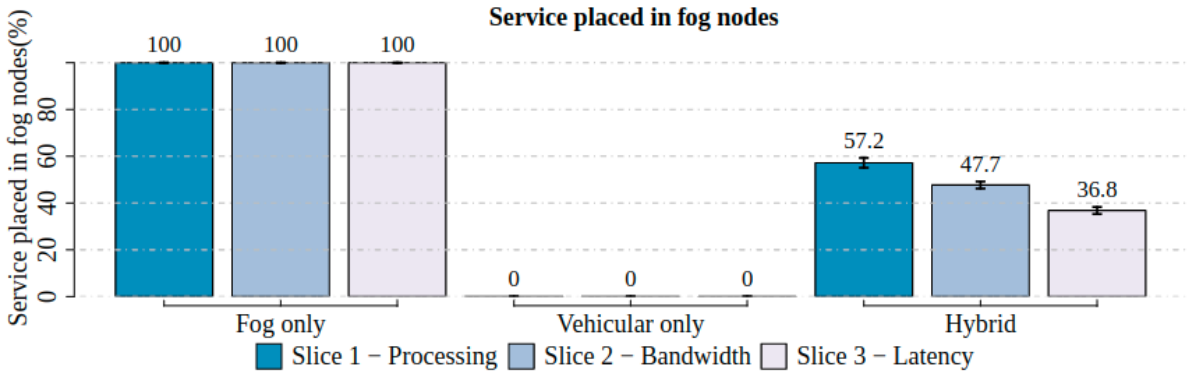


Figure 9: Percentage of fog services placed on fog nodes.

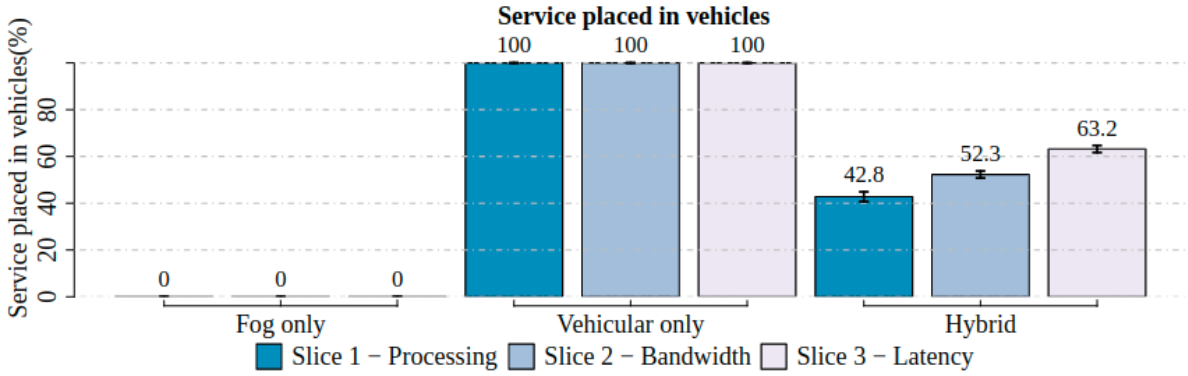


Figure 10: Percentage of fog services placed on vehicles.

Dynamic Slicing for VANETs –

Resource usage by each Slice

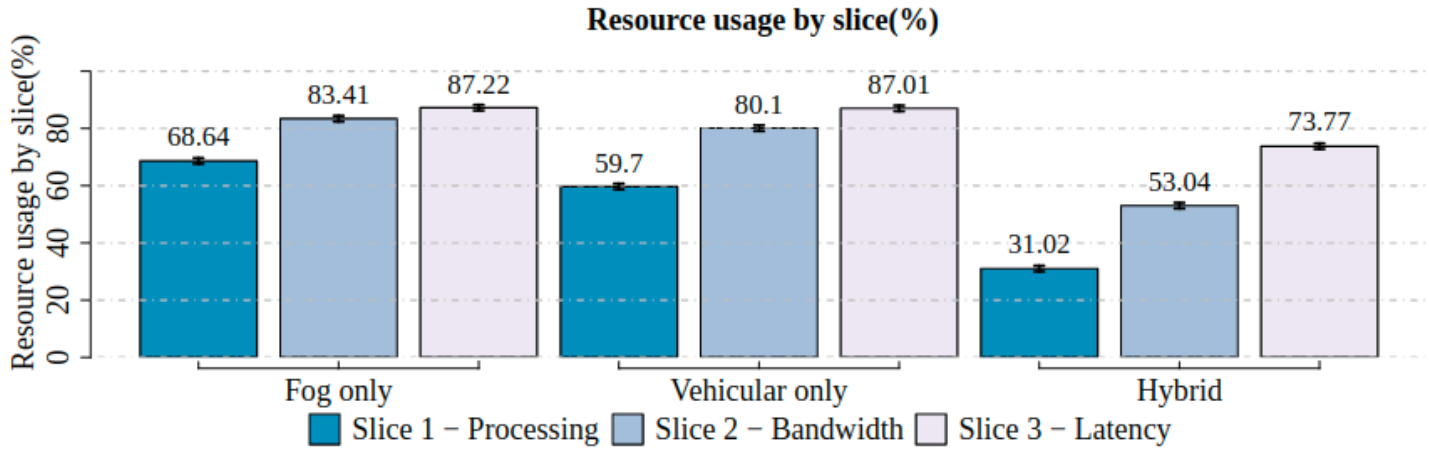


Figure 11: Percentage of resource usage in each slice.

Service latency based on slice resources and the service placement

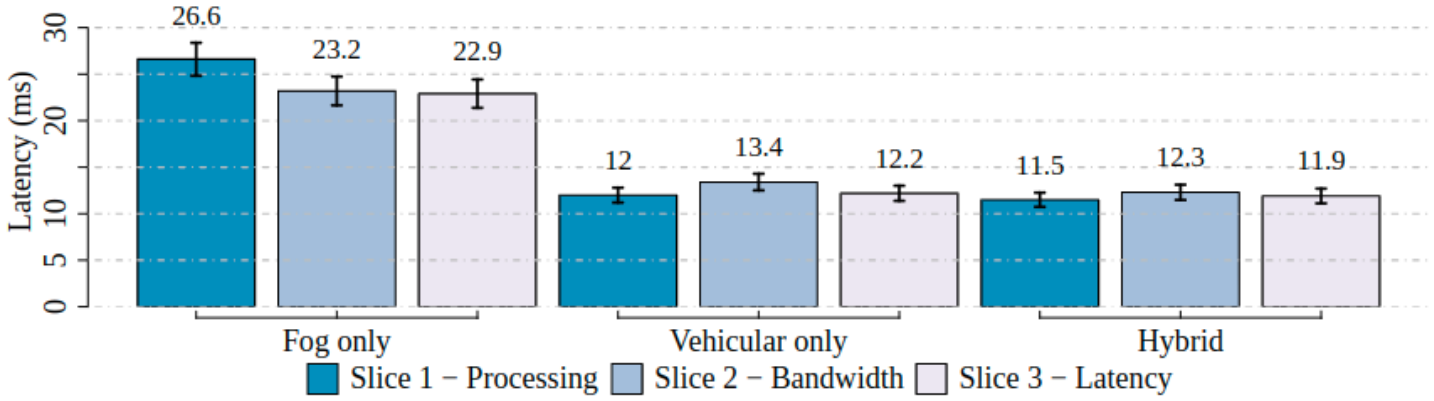
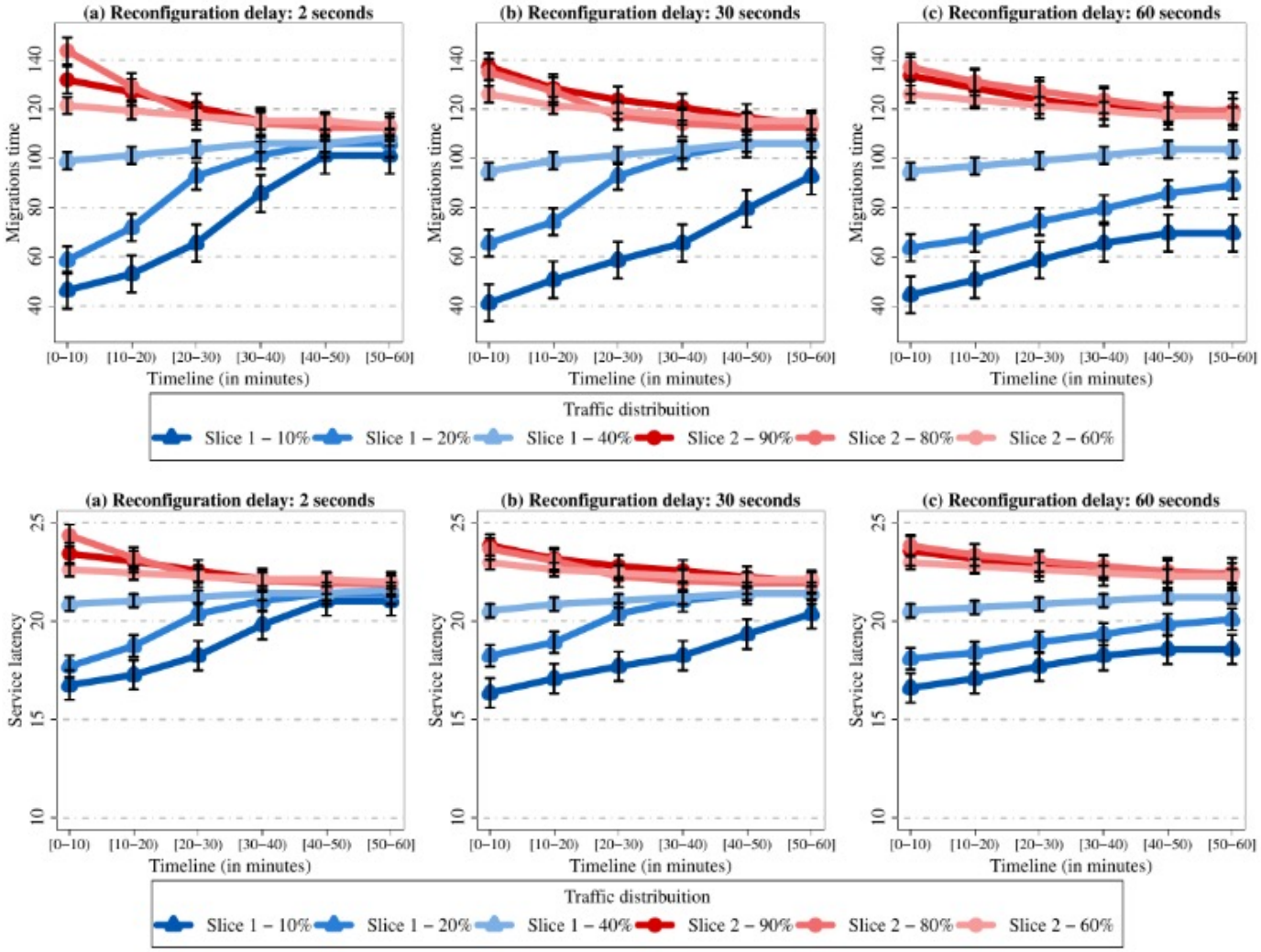


Figure 14: Service latency delivered by each slice.

Dynamic Slicing overhead

It impacts network metrics like migration time and service delay.



Federated Learning for Traffic Prediction in 5G Network Slicing

Federated Learning

- Steps:
  1. Initialization of the model and its hyperparameters (number of participants, number of training periods, training batch size, etc.).
  2. Central server sends the initial model to all participants.
  3. Training and update of the local models, in which each participant user their own local data to train their local model.
  4. Participants send their local models to the central server.
  5. Aggregation of the local models and update of the global model.
- This process is repeated periodically.

Aveiro Tech City Living Lab (ATCLL)

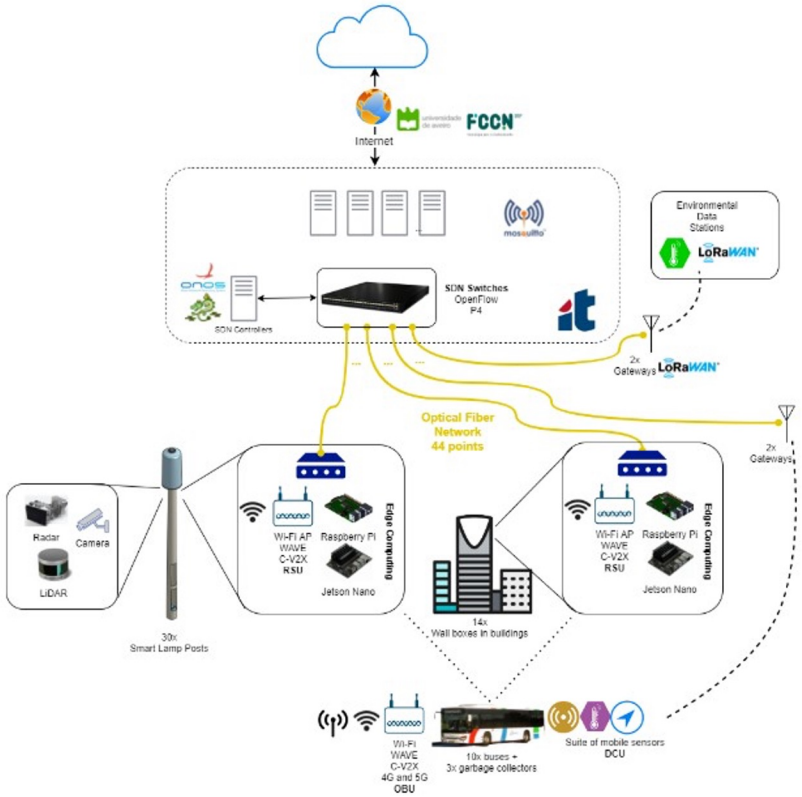
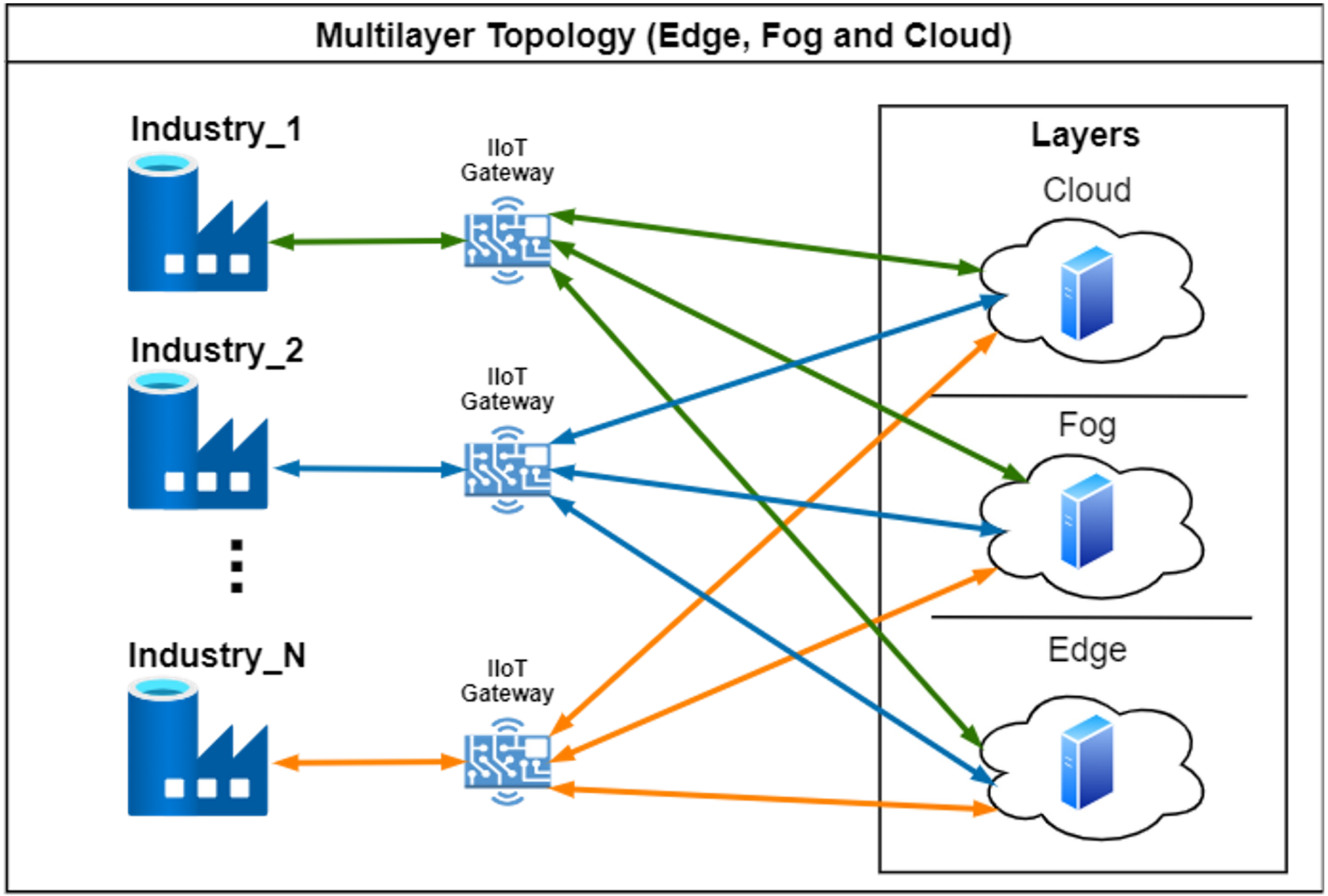
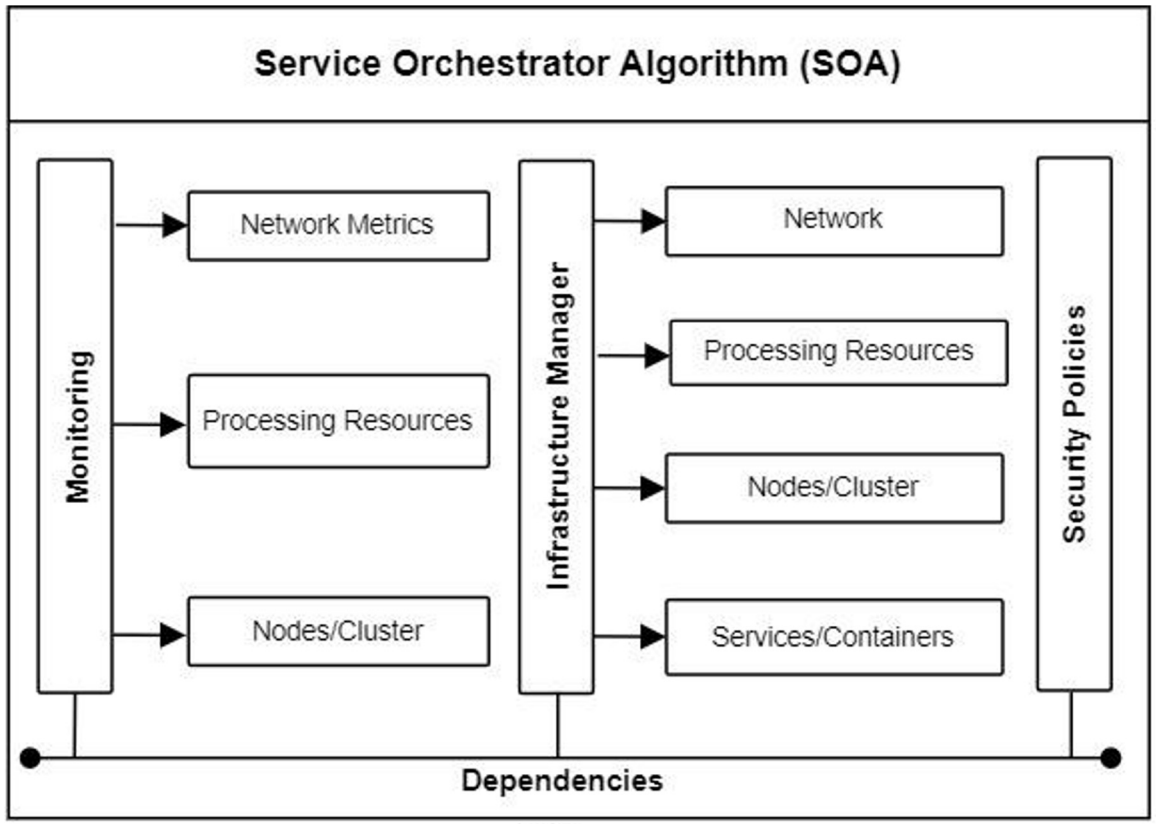


Figure 4.6: Aveiro Tech City Living Lab infrastructure.

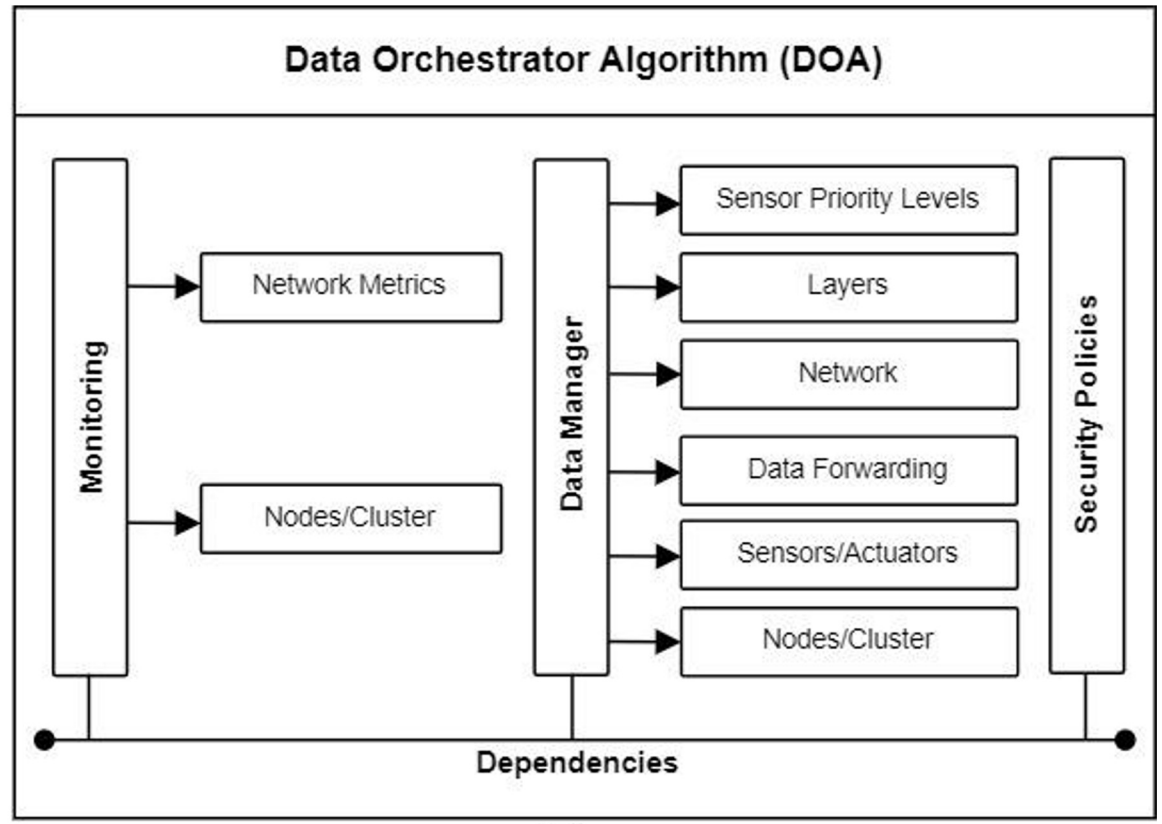
D. Dias, et al. "A Software Defined Vehicular Network using Cooperative Intelligent Transport System Messages." IEEE Transactions on Network and Service Management, (2022).

Multilayer Edge-Fog-Cloud Orchestration for Services and Data Collocation in Industrial Internet of Things

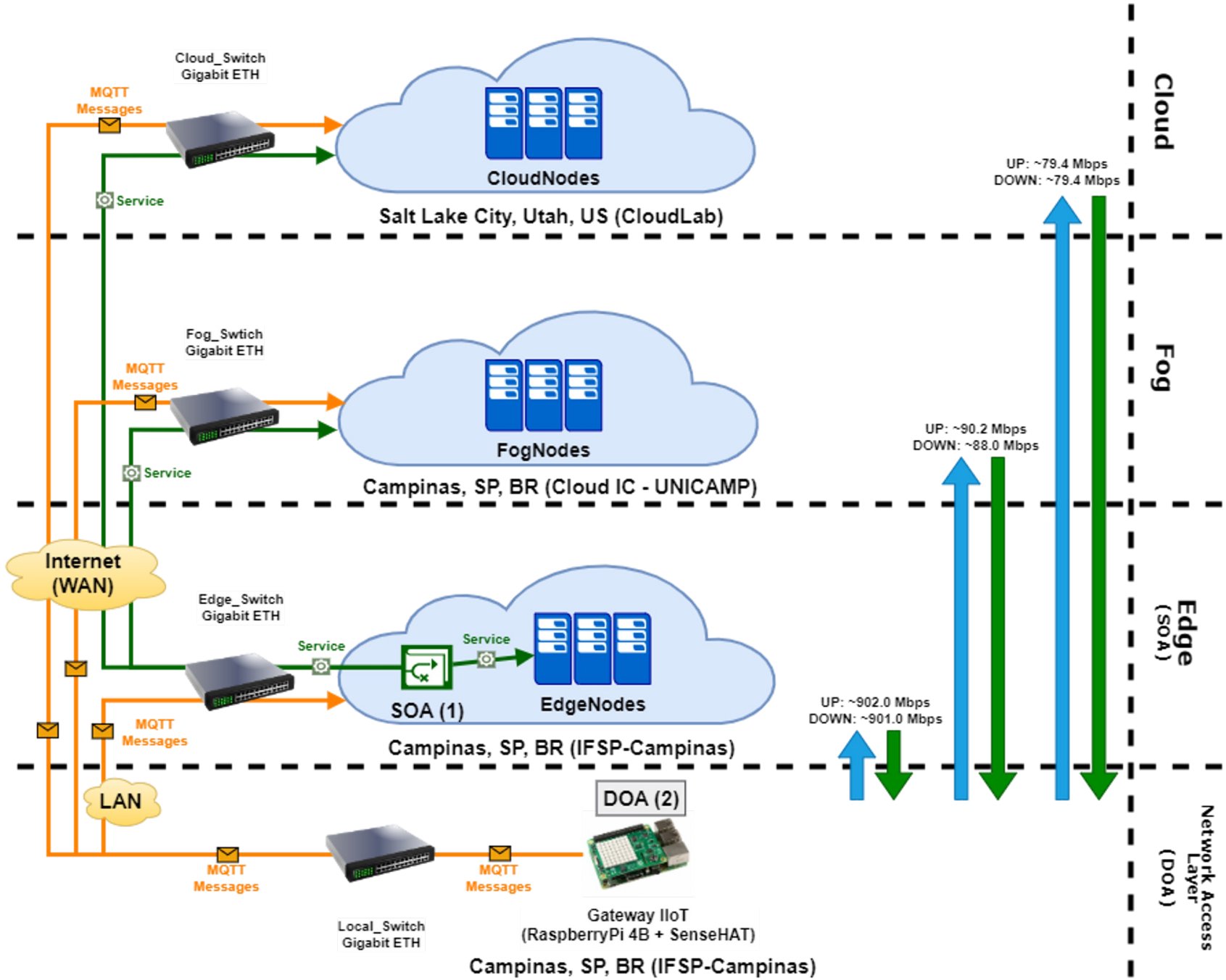

Multilayer Topology (Edge, Fog and Cloud)
Industry_1
Industry_2
Industry_N
IIoT Gateway
IIoT Gateway
IIoT Gateway
Layers
Cloud
Fog
Edge


Service Orchestrator Algorithm (SOA)
Monitoring
Network Metrics
Processing Resources
Nodes/Cluster
Infrastructure Manager
Network
Processing Resources
Nodes/Cluster
Services/Containers
Security Policies
Dependencies

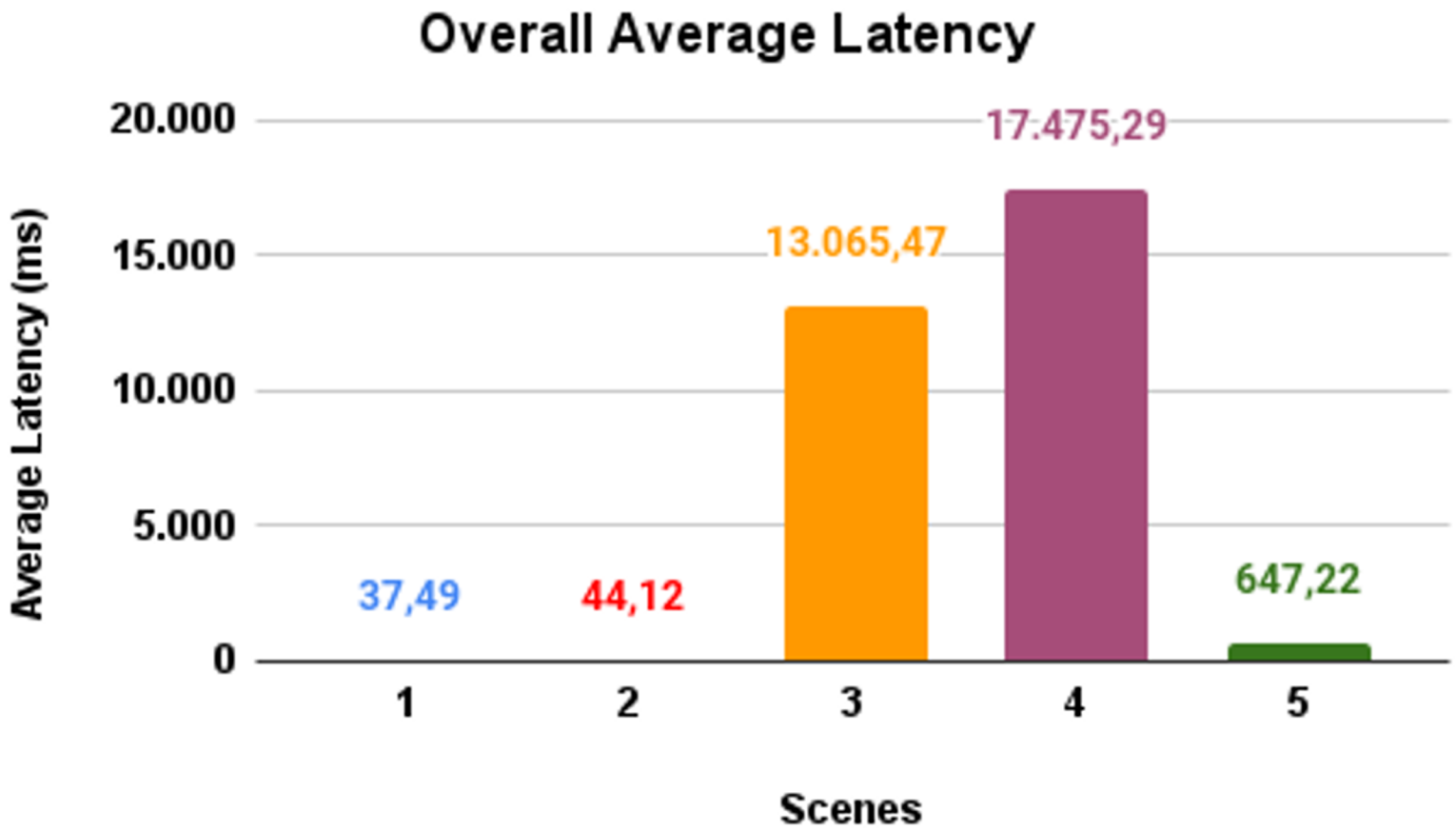
(a)


Data Orchestrator Algorithm (DOA)
Monitoring
Network Metrics
Nodes/Cluster
Data Manager
Sensor Priority Levels
Layers
Network
Data Forwarding
Sensors/Actuators
Nodes/Cluster
Security Policies
Dependencies

(b)


Cloud_Switch
Gigabit ETH
MQTT
Messages
Service
CloudNodes
Salt Lake City, Utah, US (CloudLab)
Fog_Swtich
Gigabit ETH
MQTT
Messages
Service
FogNodes
Campinas, SP, BR (Cloud IC - UNICAMP)
Internet
(WAN)
Edge_Switch
Gigabit ETH
Service
Service
SOA (1)
EdgeNodes
MQTT
Messages
Campinas, SP, BR (IFSP-Campinas)
LAN
DOA (2)
MQTT
Messages
MQTT
Messages
Local_Switch
Gigabit ETH
Gateway IIoT
(RaspberryPi 4B + SenseHAT)
Campinas, SP, BR (IFSP-Campinas)
UP: ~79.4 Mbps
DOWN: ~79.4 Mbps
UP: ~90.2 Mbps
DOWN: ~88.0 Mbps
UP: ~902.0 Mbps
DOWN: ~901.0 Mbps
Cloud
Fog
Edge
(SOA)
Network Access
Layer
(DOA)

Scenario	Layer	# Sensors	Orchestration Mechanisms	# Conteiners
1	Edge	3	No	1
2	Fog	3	No	1
3	Cloud	3	No	1
4	Edge, Fog and Cloud (General Cluster)	3	Swarm	3
5	Multilayer organized in Groups	9	MSOFEC	3


Overall Average Latency
20.000
15.000
10.000
5.000
0
Average Latency (ms)
37,49
44,12
13.065,47
17.475,29
647,22
1
2
3
4
5
Scenes

Computer Networks Laboratory

Questions?

Thanks !!!

- Email: edmundo@ic.unicamp.br