HOW TO ASSESS AND OPTIMIZE THE ENERGY EFFICIENCY OF MICROSERVICES PLACEMENT

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Profile and scope of the thesis

- Thesis framework
  - Scientific priority of the LUDI Institute: sustainability and digital technologies.
  - Objectives: produce tools to model and analyse the energy consumption of microservices-based applications and optimise their placement.
  - Funding: doctoral contract.

Cloud limits: Introduction to Fog/Edge

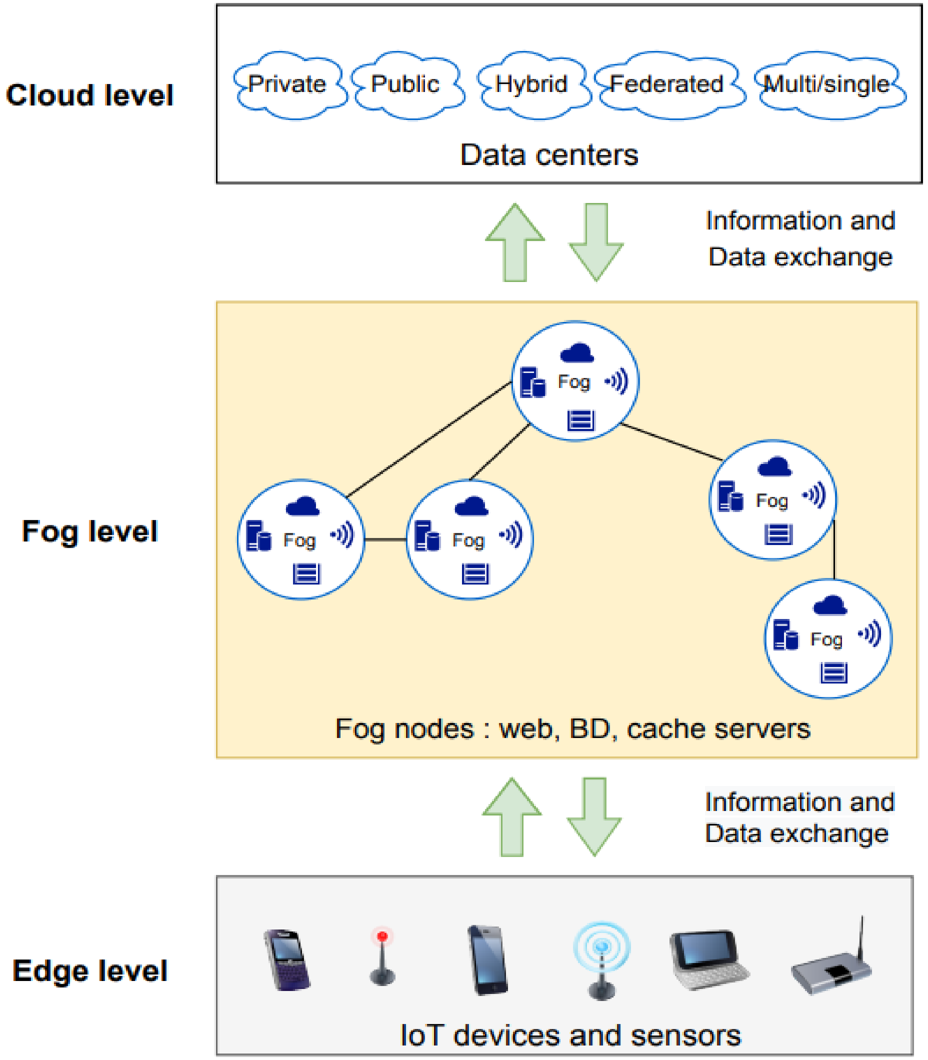
Cloud

- Centralized data processing and storage, away from users.
- Highlight limitations, such as latency, bandwidth, and privacy concerns.

Fog/Edge

- Fog Computing brings resources closer to the cloud, while Edge Computing brings them even closer to the data source.
- Bandwidth and latency Reduction.
- Local Availability
- The state of the Internet connection and its speed are less taken into account.

Cloud-Fog-Edge Continuum



Centralized
- analytics
- processing
- storage
- warehousing

Decentralized
- local data analytics
- monitoring
- data processing
- storage
- execution

Local
- monitoring
- real time processing
- micro storage
- execution

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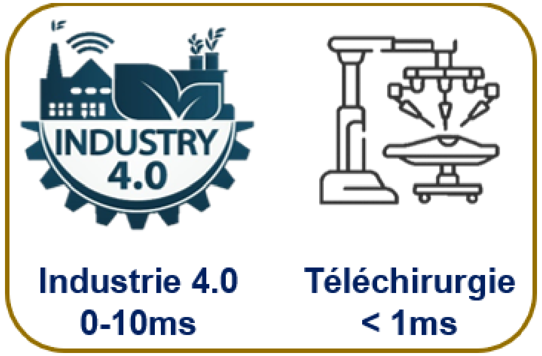
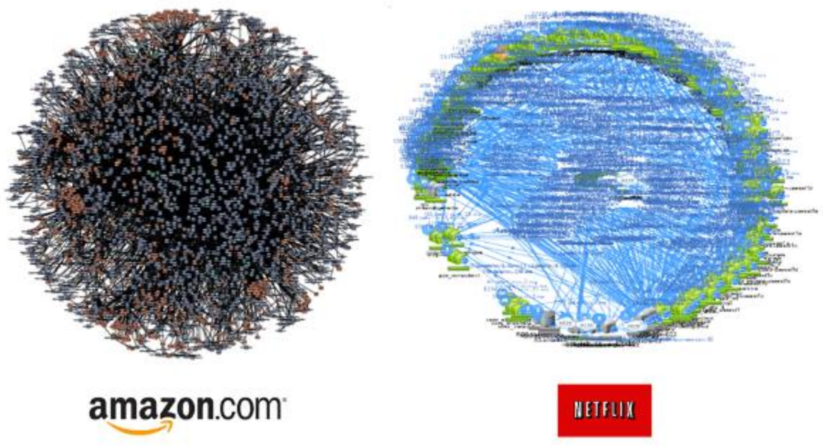
Microservices approach

- Fast, interchangeable components, easy to adapt and to scale.

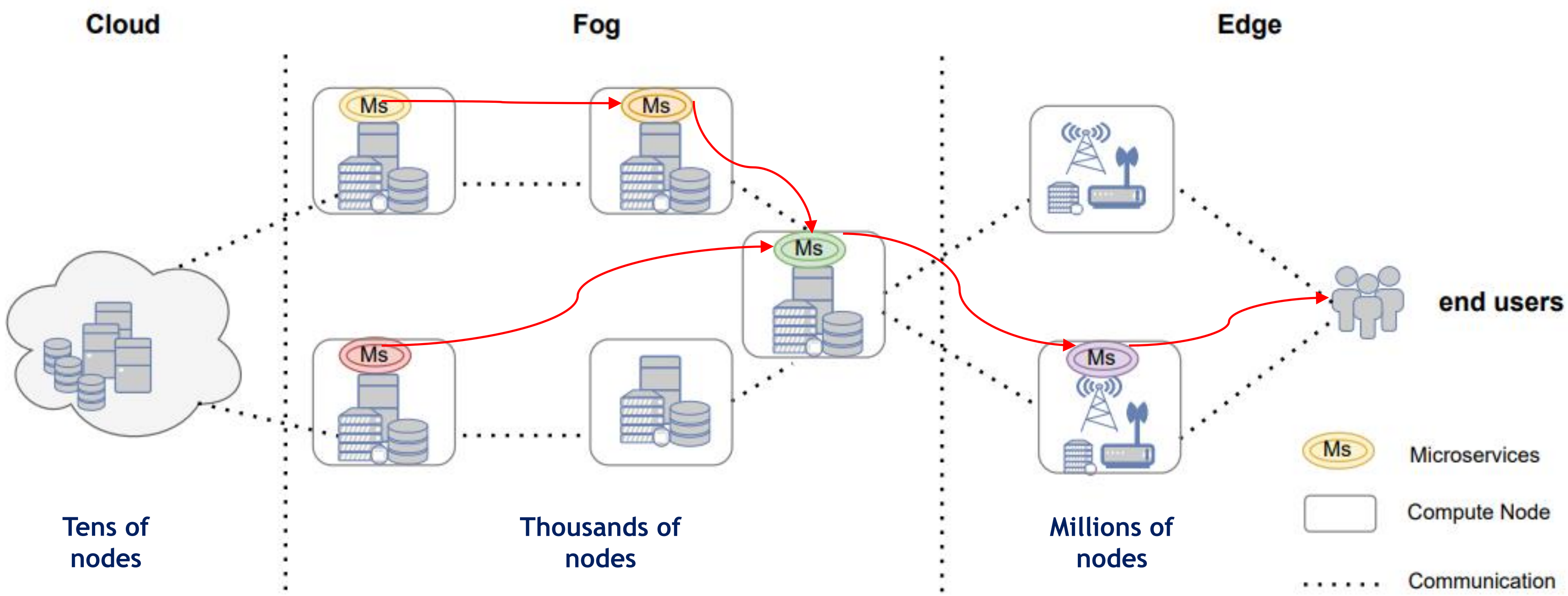
- An effective solution to provide services requiring low communication delay and high quality of service.

- Limited transit time in the network infrastructure.



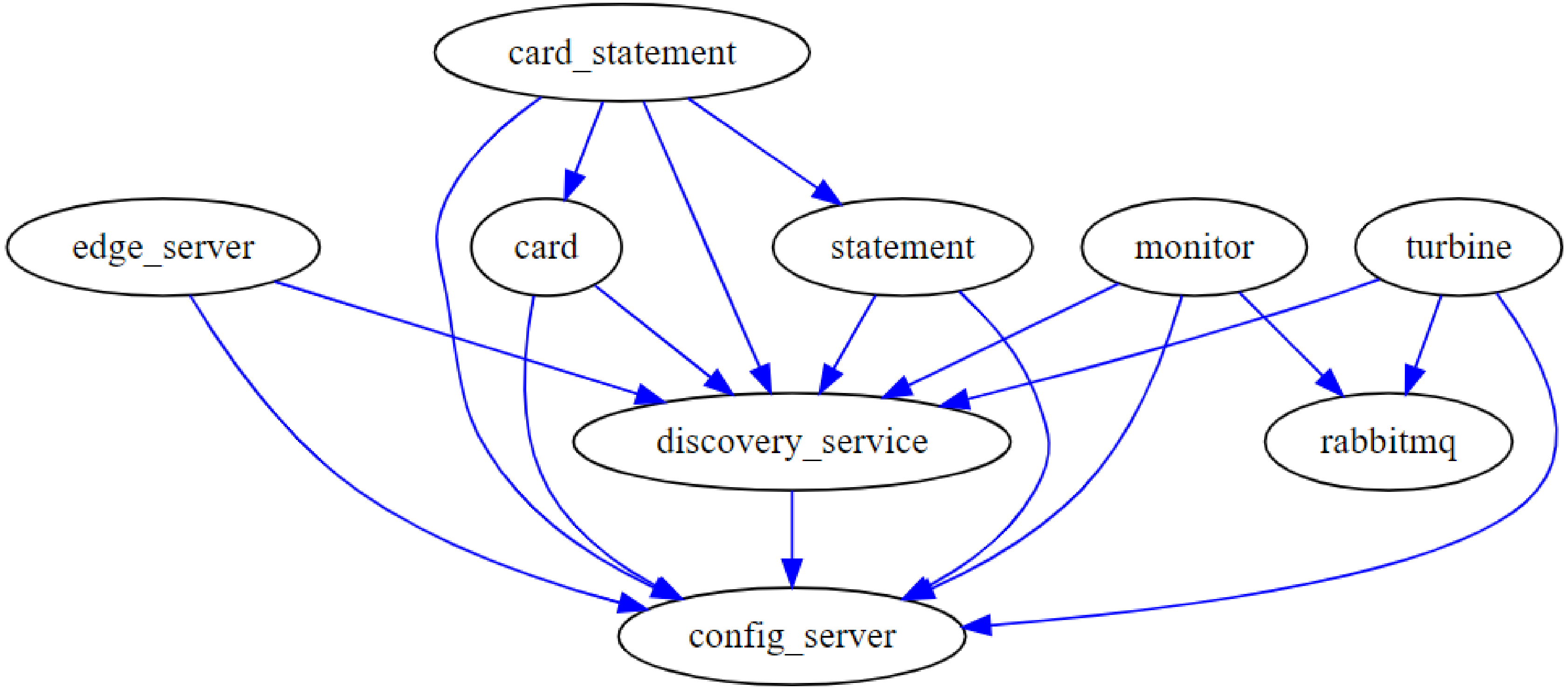


Microservices placement in Fog/Edge



Network infrastructure

Microservices Graph representation



A typical application based on MS architecture
(a DAG representation)

Characteristics and constraints

Infrastructure characteristics

- Geo-distributed infrastructure with a large number of nodes.
- Heterogeneous nodes in terms of location and resources (process, storage).
- Dynamic infrastructure (failure, mobility, network congestion).

Microservices characteristics

- Several dependencies and function calls between microservices.
- Heterogeneous microservices in terms of required resources.

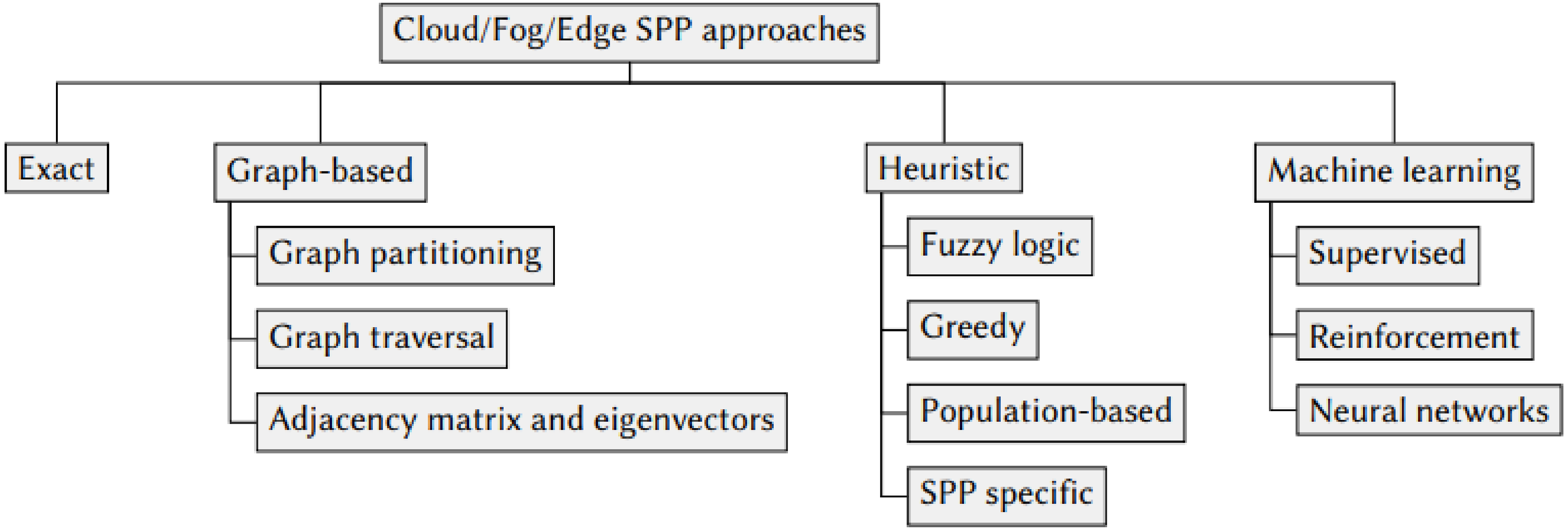
➔ Misplacing microservices network induces congestion and increase latency, energy consumption, cost and service availability (QoS).

Microservices placement in Fog/Edge

- Problem 1: How to place a microservices-based application to optimize latency and energy consumption?
  - A multi-criteria discrete optimization problem.
  - It is an **NP-hard** class problem.

- Problem 2: Which metrics are considered to evaluate the energy efficiency of microservices placement?
- Problem 3: How can we limit the exchange of data between microservices in the network?
- Problem 4: How to distribute load among microservices instances? (Long-term).

SPP placement and chaining approach



Categorization of approaches used to solve the SPP

SPP criteria

Criteria	# of articles
Latency	24
Cost	19
Quality of Service	19
Energy	14
Resources	10
Others (incl. performance)	18

- A multi-criteria discrete optimization problem (combinatorial optimisation)
- NP-hard class

Discussions

- A lack of public repositories providing microservices dependencies and workload datasets.
- Comparing microservices SFC's placement and chaining results with monolithic VNFs (in the telecommunication context).
- Rahman et al. (1) have introduced a small dataset of 20 microservices graphs dependencies to address this gap.
- Random graphs network dependencies: Barabasi-Albert networks, growing random networks (2).
- Mobility trajectories like the San Francisco Taxi dataset used to dynamically address the SPP.

Problem modelling

Network infrastructure

We model the physical topology of Cloud-Fog-Edge architecture as a connected graph $\mathcal{G} = (\mathcal{N}, \mathcal{L})$ where vertices represent execution nodes and edges are network links.

Physical nodes

Each node $n_i \in \mathcal{N}$ has the following characteristics:

- A speed of processing capacity cpu_i in MIPS.
- A storage size $storage_i$ in TB.
- A memory size ram_i in GB.
- A power consumption characteristics of when the device in not used p_i^{idle} and when it used to the maximum p_i^{max}.

Network infrastructure

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Links

Network communication links can be physical or virtual. Each link is identified by the two nodes $\{n_i, n_j\}$ it connects and has the following characteristics:

- A physical link l is characterized by a bandwidth bw_l and a latency lc_l.
- A logical link l' represents the optimal path L composed of physical links between two nodes. $bw_{l'} = min_{l \in L}(bw_l)$ and $lc_{l'} = \sum_{l \in L}(lc_l)$, i.e. the minimum bandwidth on the path and the sum of the latencies on the path.
- A power consumption characteristics of the devices n_i and n_j: p_i^{idle}, p_j^{idle} p_i^{max}, p_j^{max} This can be considered to determine the unit cost of the link energy consumption.

Microservices applications

A micro-services application $\mathcal{A} = (\mathcal{S}, \mathcal{M})$ can be modeled as a directed acyclic graph (DAG) where the nodes represent the services $\mathcal{S} = (s_1, s_2, ..., s_t)$ and the edges represent dependencies requests between the services.

Nodes characteristics

Each service $s_i \in S$ requires some resources consumption:

- A requested CPU mi_i in million instructions.
- A requested RAM ram_i in GB.
- A requested storage size $storage_i$.

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Links

Each directed edge $\mathcal{M}_{s_i,s_j}$ that connect s_i to s_j represent the request need and the data dependencies between this microservices. It is characterised by:

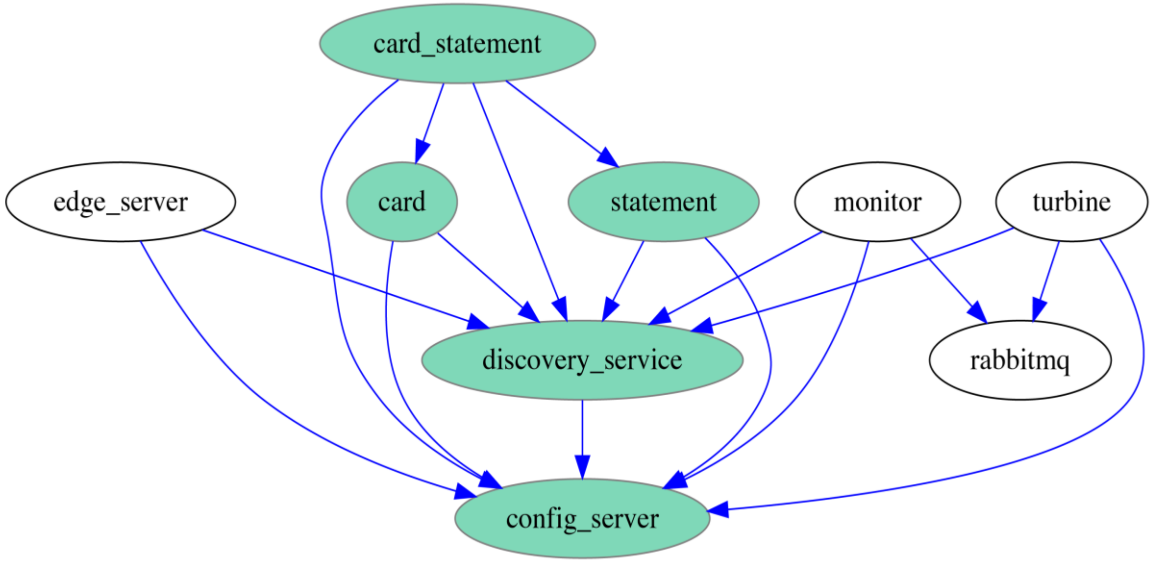
- A source and a destination
- A message size $Mess_{i,j}$

Problem statement

- Objective: MFP placement to reduce latency and energy consumption

$$\begin{cases} \text{Minimize } E_{tot} \\ \text{where} \quad E_{tot} = E_{nod} + E_{com} \end{cases} \quad \text{s.t.} \quad Lat_{dep} <= Lat_{req}$$

- E_tot: energy total
- E_nod: energy node treatment
- E_com: energy communication between microservices
- Lat_dep: deployement latency
- Lat_rep: required latency



- Microservices Function Paths (MFP) from DAG microservices dependencies

The total energy consumption is the sum of the energy from the node execution and the energy from network communication.

$$\begin{cases} \textit{Minimize } E_{tot} \\ \text{where} \quad E_{tot} = E_{nod} + E_{com} \end{cases} \text{s.t.} \quad Lat_{dep} <= Lat_{req}$$

$$\mathrm{E_{nod}} = \sum_{i=0}^{S-1} \sum_{j=0}^{N-1} \overbrace{\frac{\text{cpu(required by a service}_i)}{\text{cpu(max of a node}_j)}}^{\text{CPU consumption}} \underbrace{\left(p_j^{\text{max}} - p_j^{\text{idle}}\right) + p_j^{\text{idle}}}_{\text{Electric power of the execution node}}$$

The total energy consumption is the sum of the energy from the node execution and the energy from network communication.

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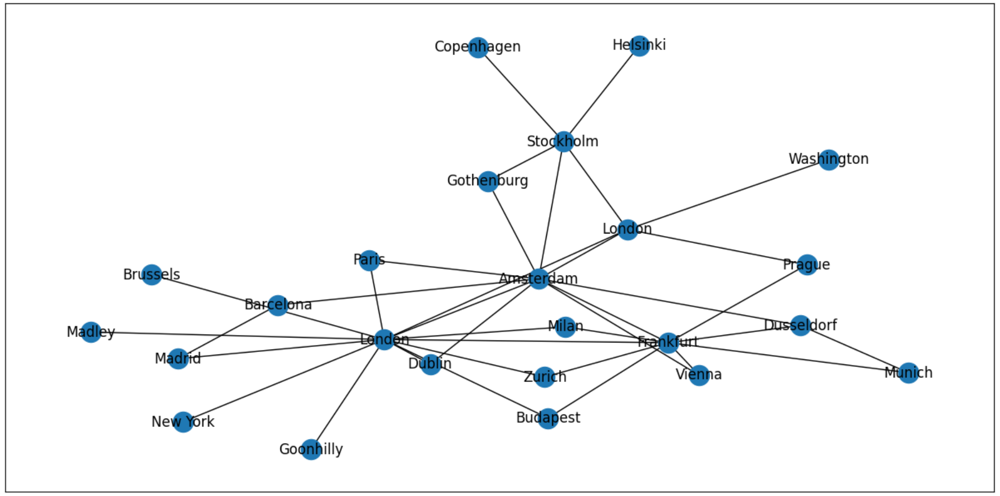
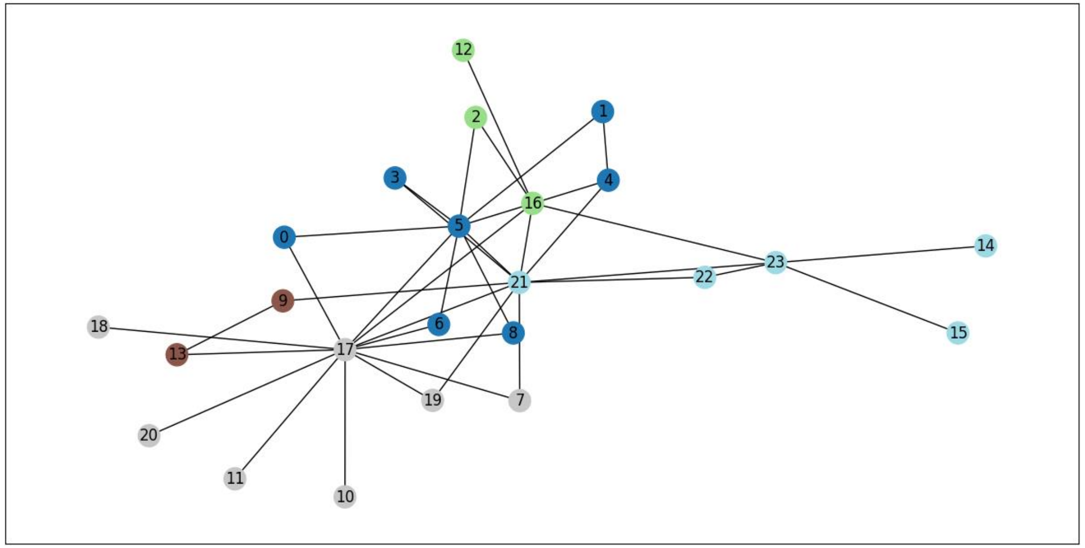
$$\mathrm{E_{nod}} = \sum_{i=0}^{S-1} \sum_{j=0}^{N-1} \frac{\text{cpu(required by a service}_i)}{\text{cpu(max of a node}_j)} \left(p_j^{\text{max}} - p_j^{\text{idle}}\right) + p_j^{\text{idle}}$$

$$\mathrm{E_{com}} = \sum_{(i,l)\in S} \sum_{(j,p)\in N} \overbrace{\frac{data_{(i,l)}}{bw_{(j,p)}} + lc_{(j,p)}}^{\text{Data transmission capacity}} \underbrace{\left[p_j^{\text{max}} + p_p^{\text{max}} - p_j^{\text{idle}} - p_p^{\text{idle}}\right]}_{\text{Electrical power between two nodes}}$$

Community detection





Louvain Community detection

- Heuristic placement based on community detection
  - *A community of network nodes represent a cluster where the power electric cost is minimal compared to outside communities.*

[1] The internet topology zoo

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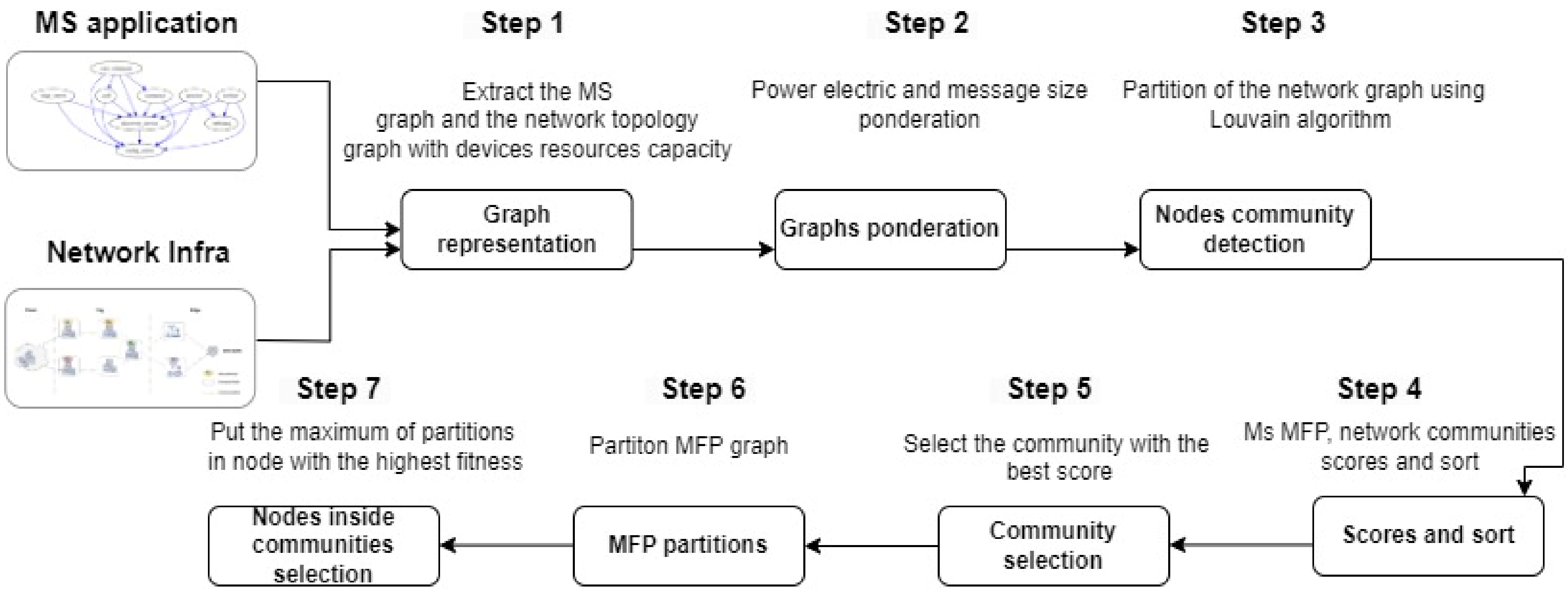
Microservices heuristic placement



Microservices heuristic placement

- Allocate entire MFP microservices within a single community to minimize inter-community exchanges (Placing the largest MFP in the smallest community).

- Assumption is based on the notion that the most energy-intensive.

- Placing as many microservices as possible in the same node to reduce communication overhead.

Experiment scenario

Network topology

- Network topology Zoo Dataset / SDNlib
- > Topologies with [14,90] nodes > 1 Cloud (highest betweenness centrality), 50 % Fog, 50%Edge
- > Resource capacity: Cloud > Fog > Edge

Microservices MFPs

- > 20 Microservices applications
- > Service number [2-15] depending on MFPs YAFS

Simulator

- Python Fog simulator (4)

Future work

- Include users nodes in the network topology.
- Microservices instances management (microservices used by several users in different communities).
- Ensure a dynamic placement according to the user requests and resources changes.
- Include another metrics in the model: Global MS environmental footprint that includes : gray energy, resources, primary energy equivalent in Kwh, manufacturing equipment, energy consumption in DCs, networks(Switches, routers), water, greenhouse gas, etc.

Conclusion

- **Context:**
  - Fog-Edge computing provides a platform to deploy Microservice-based applications.
  - Microservices and data misplacement can result in an increase in latency, energy consumption.
- **Problems:**
  - How to manage Microservices placement in Cloud-Fog-Edge continuum infrastructure in order to optimize latency and energy consumption?
- **Contributions:**
  - An under construction method to manage microservices placement
- **Future work:**
  - Consider the availability and partition tolerance when placing microservices instances and data replicas.

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