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A Location-Allocation model for Fog Computing Infrastructures

Thiago Alves de Queiroz
IMT, Federal University of Goiás

Claudia Canali,
Riccardo Lancellotti
DIEF, University of Modena and Reggio Emilia

Manuel Iori
DISMI, University of Modena and Reggio Emilia

New challenges

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- New paradigm: Smart cities large scale sensing applications
- Several fields of application:
  - Urban applications
  - Industrial
  - Automotive
  - Healthcare
  - ...
- New scenarios: Cyber-physical systems
  - Geographically distributed sensors
  - Huge amount of information produced

New challenges

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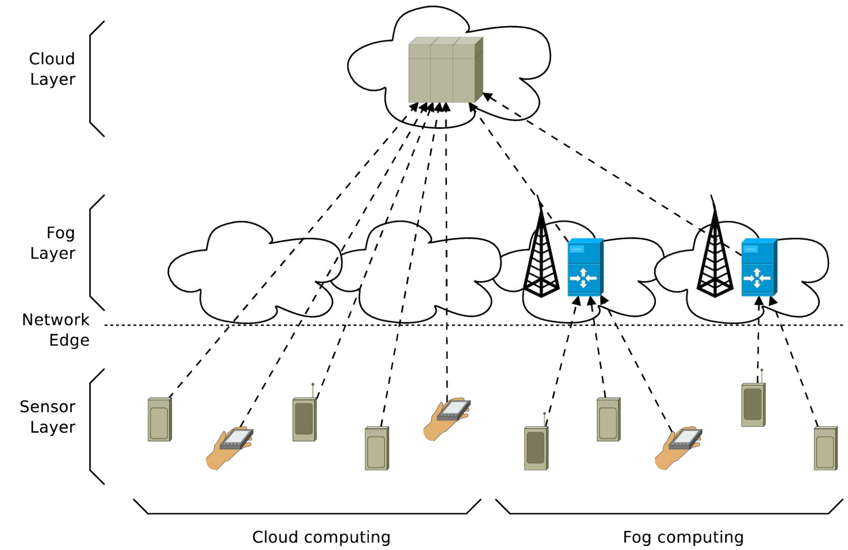
→ New requirements for the infrastructure

- Scalability challenge
  - Huge amount of data to transfer and process
  - Geographically distributed systems
  - Example: CPU- and bandwidth-bound applications
- Low latency challenge
  - Support for real time applications
  - Example: latency-bound applications
- Cloud computing is not enough
- *(5G alone is not an answer)*

Pros and Cons of Fog

- Benefits of Fog computing
- Scalability:
  - Pre-processing offloaded to fog nodes
  - Less strain on Cloud network links
- Latency:
  - Latency-critical tasks offloaded to Fog
  - Fog nodes are closer to the edge



- New open issues:
  → new Fog infrastructure
  - Fog node deployment
  - Sensors-to fog mapping
- Joint problem

Our contribution

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- Model for the design of Fog infrastructures
  - Based on location-allocation optimization problem
- Model decisions:
  - How many fog nodes do we need?
  - Which Fog nodes (among a set) turn on?
  - How to map sensors over fog nodes?
- Double optimization goal
  - Reduce infrastructure cost
  - Optimize performance
- Use of SLA constraints

Notation

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Model parameters	
$\mathcal{S}$	Set of sensors
$\mathcal{F}$	Set of fog nodes
$\mathcal{C}$	Set of cloud data centers
λ_i	Outgoing data rate from sensor i
λ_j	Incoming data rate at fog node j
$1/\mu_j$	Processing time at fog node j
δ_{ij}	Communication latency between sensor i and fog j
δ_{jk}	Communication latency between fog j and cloud k
c_j	Cost for locating a fog node at position j (or for keeping the fog node turned on)
Model indices	
i	Index for a sensor
j	Index for a fog node
k	Index for a cloud data center
Decision variables	
E_j	Location of fog node j
x_{ij}	Allocation of sensor i to fog j
y_{jk}	Allocation of fog node j to cloud k

Optimization problem

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- Objective function
  - → Cost for fog nodes
  - → Response time
- Contributions to response time:
  - Sensor → Fog avg net delay
  - Fog → Cloud avg net delay
  - Fog processing time
- Caveat: definition of λ_j
- Main constraints:
  - Response time < SLA
  - Load on nodes

$$C = \sum_{j \in \mathcal{F}} c_j E_j$$

$$T_R = T_{netSF} + T_{netFC} + T_{proc}$$

$$T_{netsf} = \frac{1}{\sum_{i \in \mathcal{S}} \lambda_i} \sum_{i \in \mathcal{S}} \sum_{j \in \mathcal{F}} \lambda_i x_{i,j} \delta_{i,j}$$

$$T_{netfc} = \frac{1}{\sum_{j \in \mathcal{F}} \lambda_j} \sum_{j \in \mathcal{F}} \sum_{k \in \mathcal{C}} \lambda_j y_{j,k} \delta_{j,k}$$

$$T_{proc} = \frac{1}{\sum_{j \in \mathcal{F}} \lambda_j} \sum_{j \in \mathcal{F}} \frac{\lambda_j}{\mu_j - \lambda_j}$$

$$\lambda_j = \sum_{i \in \mathcal{S}} x_{i,j} \cdot \lambda_i$$

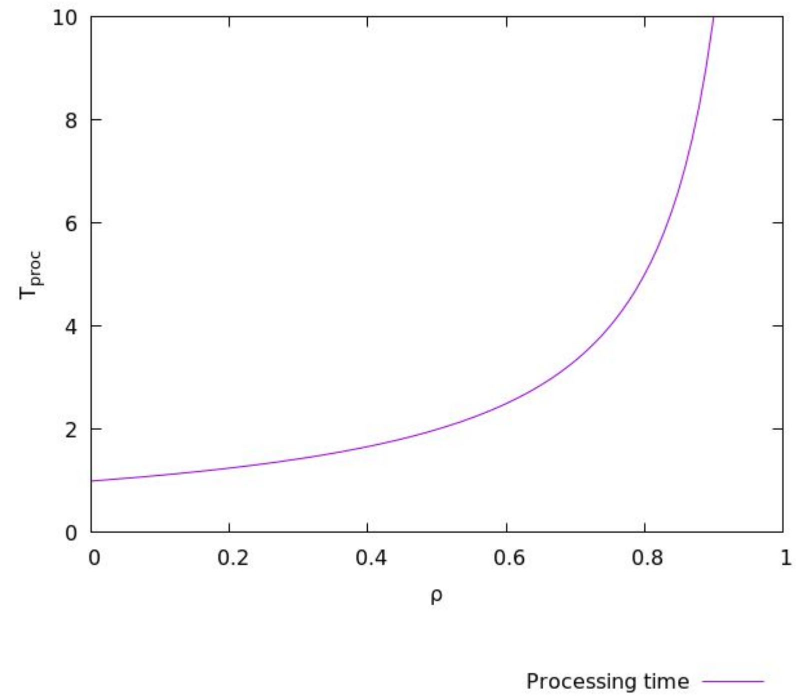
$$T_R \le T_{SLA}$$

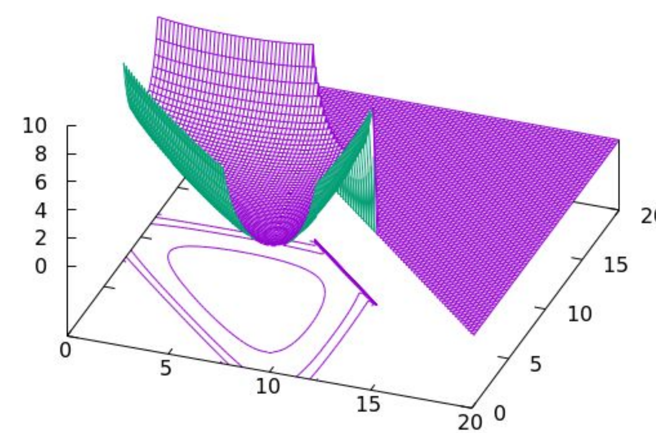
$$\lambda_j < E_j \mu_j, \quad \forall j \in \mathcal{F}$$

Processing time

- Based on queuing theory
  - M/G/1 models
  - Consistent with PASTA theorem
- Non linear model
- Response time as a function of system load

$$T_{proc} = \frac{1}{\mu - \lambda} = \frac{1}{\mu} \cdot \frac{1}{1 - \rho}$$





Scenario definition

- Parameters to describe scenarios
- Average network delay δ
- Network delay / Processing time balance δμ
  - Scenario CPU bound or Network bound
- System load ρ
  - Average load of fog nodes

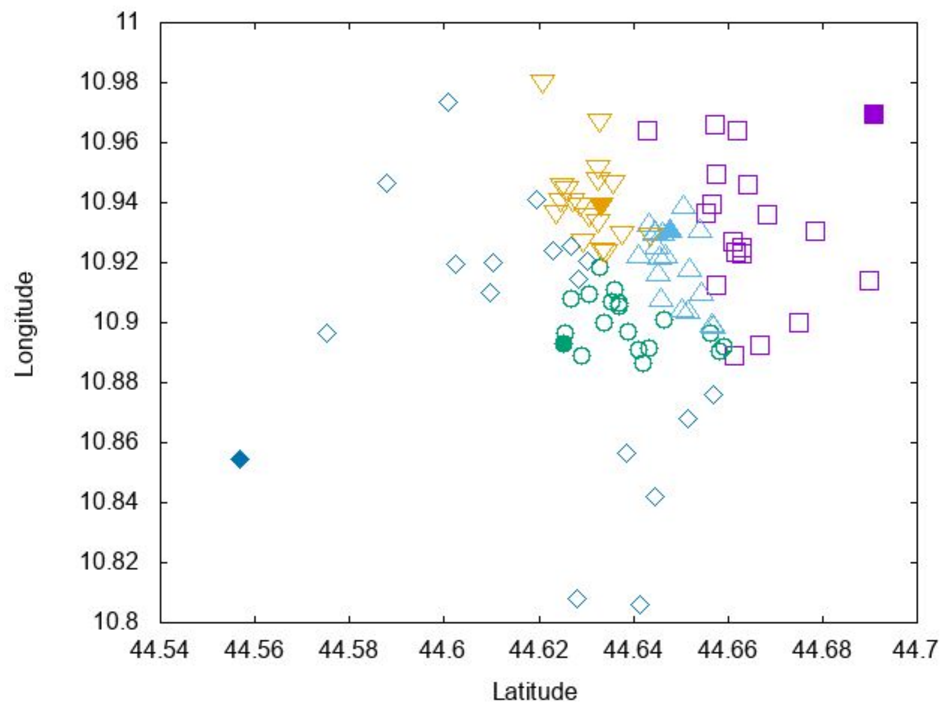
$$\delta = \frac{\sum_{i \in \mathcal{S}} \sum_{j \in \mathcal{F}} \delta_{i,j} + \sum_{j \in \mathcal{F}} \sum_{k \in \mathcal{C}} \delta_{j,k}}{|\mathcal{S}| \cdot |\mathcal{F}| + |\mathcal{F}| \cdot |\mathcal{C}|}$$

$$\delta\mu = \delta \cdot \frac{\sum_{j \in \mathcal{F}} \mu_j}{|\mathcal{F}|}$$

$$\rho = \frac{\sum_{i \in \mathcal{S}} \lambda_i}{\sum_{j \in \mathcal{F}} \mu_j}$$

Experimental scenario

- Smart City scenario based on real example
  - Italian city (Modena),
  - ~180,000 inhabitants
- Traffic monitoring case
  - Sensors on streets
  - Fog nodes in public buildings
  - LoRa connections
- Evaluation using solver (10 min)
- Comparison with:
  - Continuous model (no bool) ← (Ideal lower bound, used as baseline comparison)
  - Simplified model ($E_i = 1$)



Experimental results

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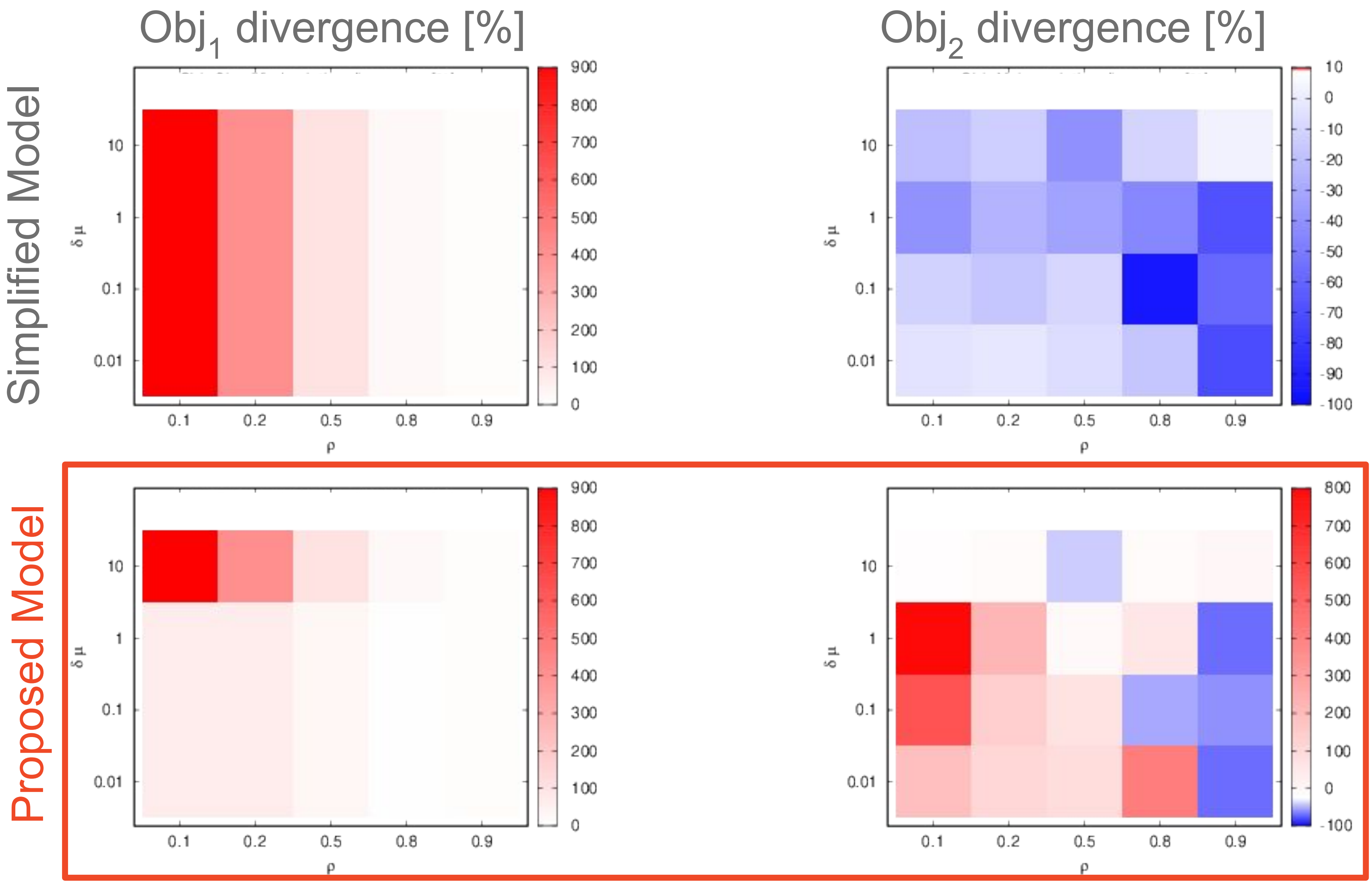

Conclusions

- Challenges of Fog computing
  - Selection of fog nodes and mapping of sensors
- Contribution: proposal of a model
  - Based on location-allocation optimization problem
  - Dual objective function
  - Non linear problem
- Validation of the model
  - Focus on a realistic scenario
  - Wide range of parameters considered
- Open issues
  - Heuristics (GA, Variable Neighborhood Search)
  - Dynamic scenarios

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