PAFFI: Performance Analysis Framework for Fog Infrastructures in realistic scenarios

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Fog computing

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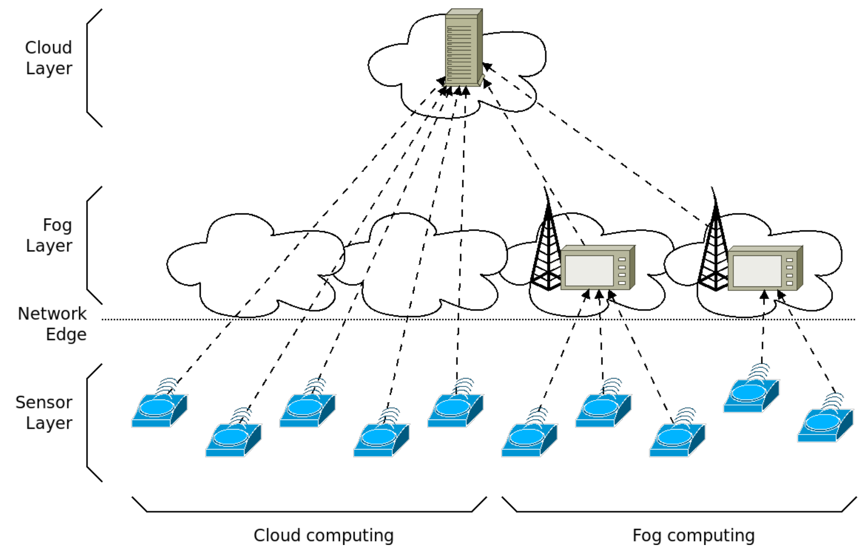
- Cyber-physical systems
  - Distributed sensors
  - → Huge amount of information to handle
- Cloud approach:
  - High latency
  - Risk of network congestion
- Some critical applications:
  - Autonomous driving
  - Support for smart cities



- Alternative paradigm → Fog computing
  - Presence of Fog nodes
  - Data aggregation and filtering
  - Latency-bound tasks

Challenges of Fog computing

- Service placement
  - Which services on fog / cloud
- Data flows mapping
  - Sensor nodes to fog nodes connection
- Adaptive load balancing
  - Cooperation strategies
- → Need for realistic scenarios
  - Use of geo-referenced data
  - Flexible generation of experimental setups
  - Help for performance evaluation

Introducing PAFFI

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- Performance Analysis Framework for Fog Infrastructures
- Realistic scenarios based on geographic data
- Support for performance analysis → OMNeT++ simulation framework
- Plugin-based approach for topology mapping → arbitrary connections among nodes
- Highly flexible and configurable → Python as main development tool

Performance model

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- Performance based on queuing theory
- 3 types of nodes: sensor, fog, cloud
- Description of node behavior:
  - Outgoing data rate from sensor i: λ_i
  - Processing rate at fog node j: μ_j
- Topology connections:
  - Sensor → Fog connections: $x_{i,j}$
  - Fog → Cloud connections: $y_{j,k}$
  - Network delay: $\delta_{i,j}$ $\delta_{j,k}$

Introducing PAFFI

- Contributions to response time:
  - Sensor → Fog avg net delay
  - Fog → Cloud avg net delay
  - Fog processing time

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

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

$$T_{proc} = \frac{1}{|\mathcal{F}|} \sum_{i \in \mathcal{S}} \sum_{j \in \mathcal{F}} x_{i,j} \cdot \frac{1}{\mu_j - \lambda_j}$$

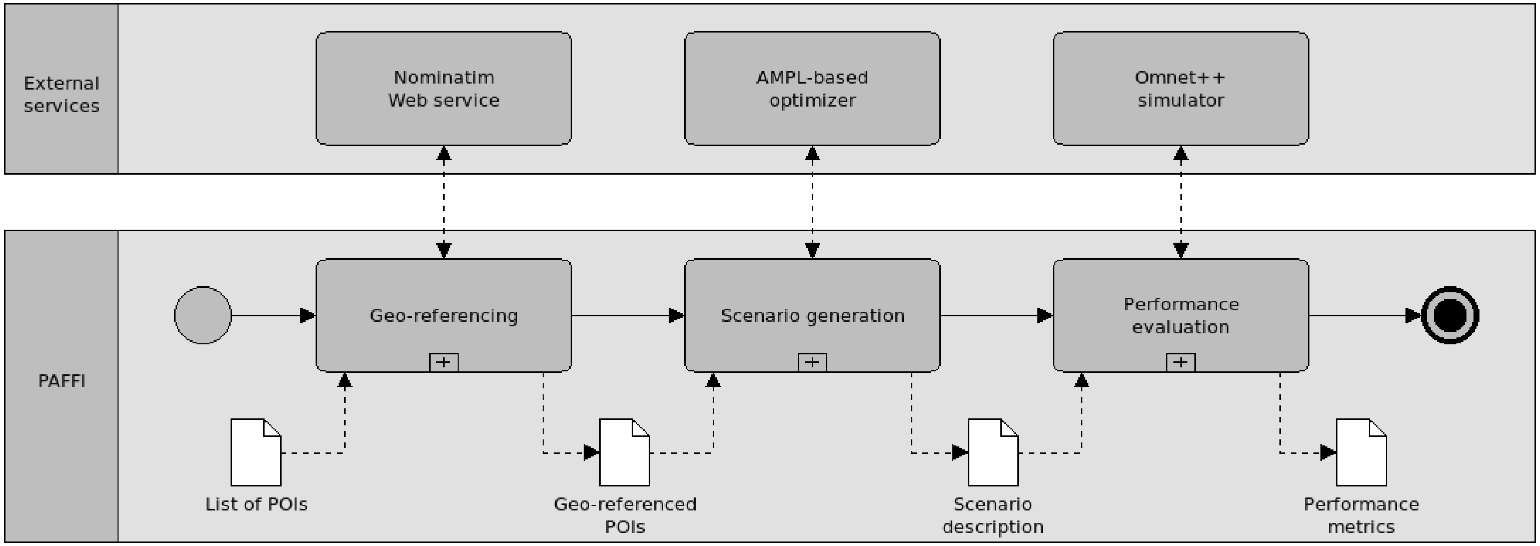
- Parameters to describe scenarios
  - Avg net delay
  - Net / Proc balance
  - System load

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

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

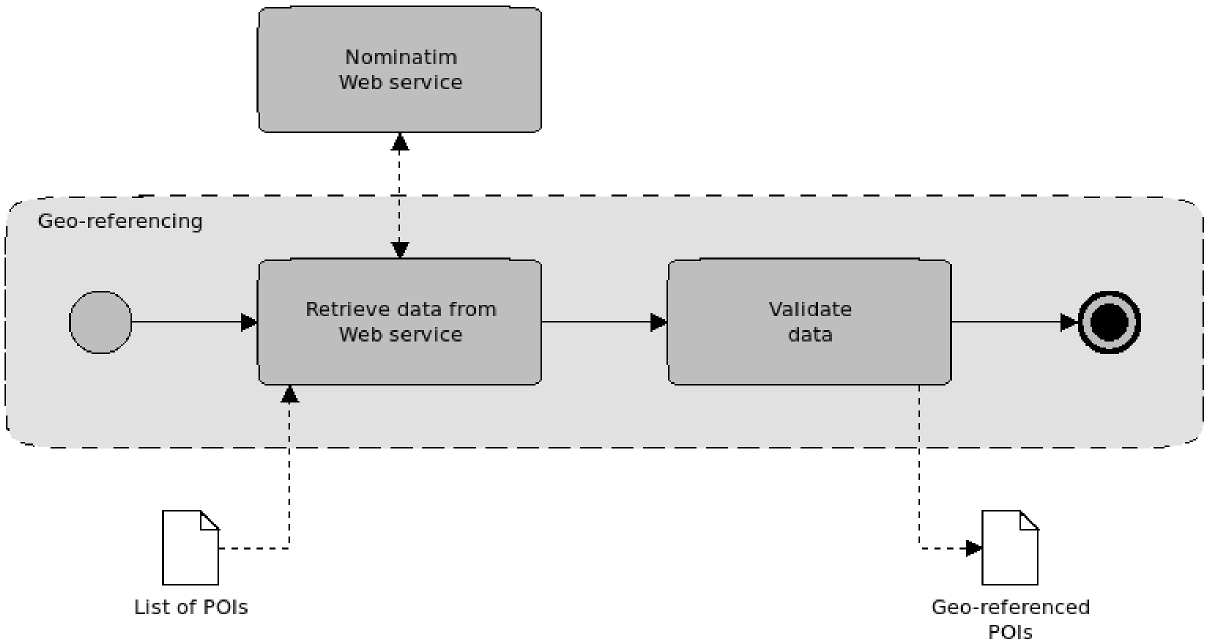
$$\rho = \frac{\sum_{i \in \mathcal{S}} \lambda_i}{\sum_{j \in \mathcal{F}} \mu_j}$$

Framework architecture



- 3 main components
- Use of external services
  - Nominatim API (Open Street Map)
  - AMPL optimization language
  - OMNeT++ simulation framework

Geo-referencing



- Input: list of POIs
- Output: geo-referenced and validated data

Scenario generation

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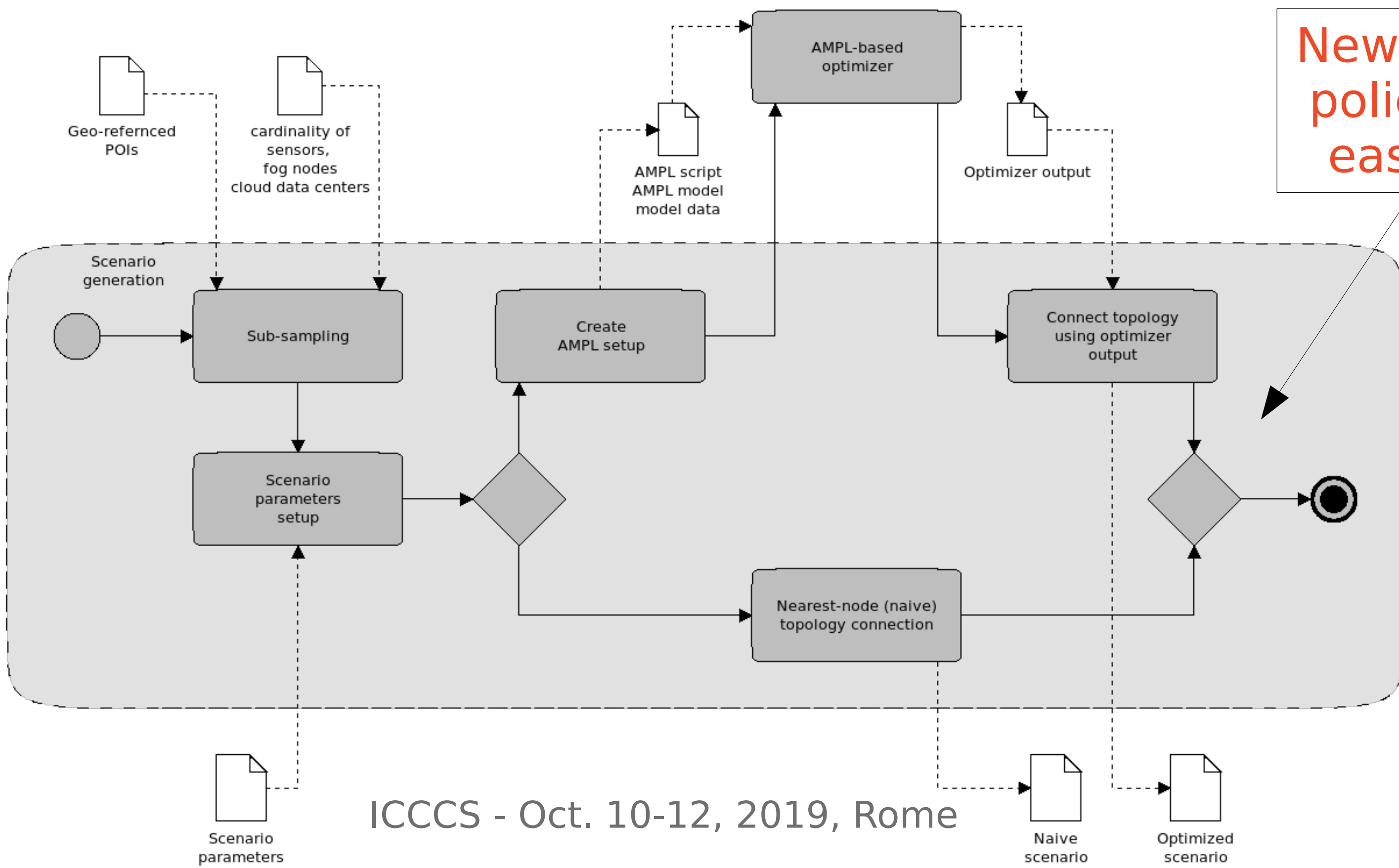
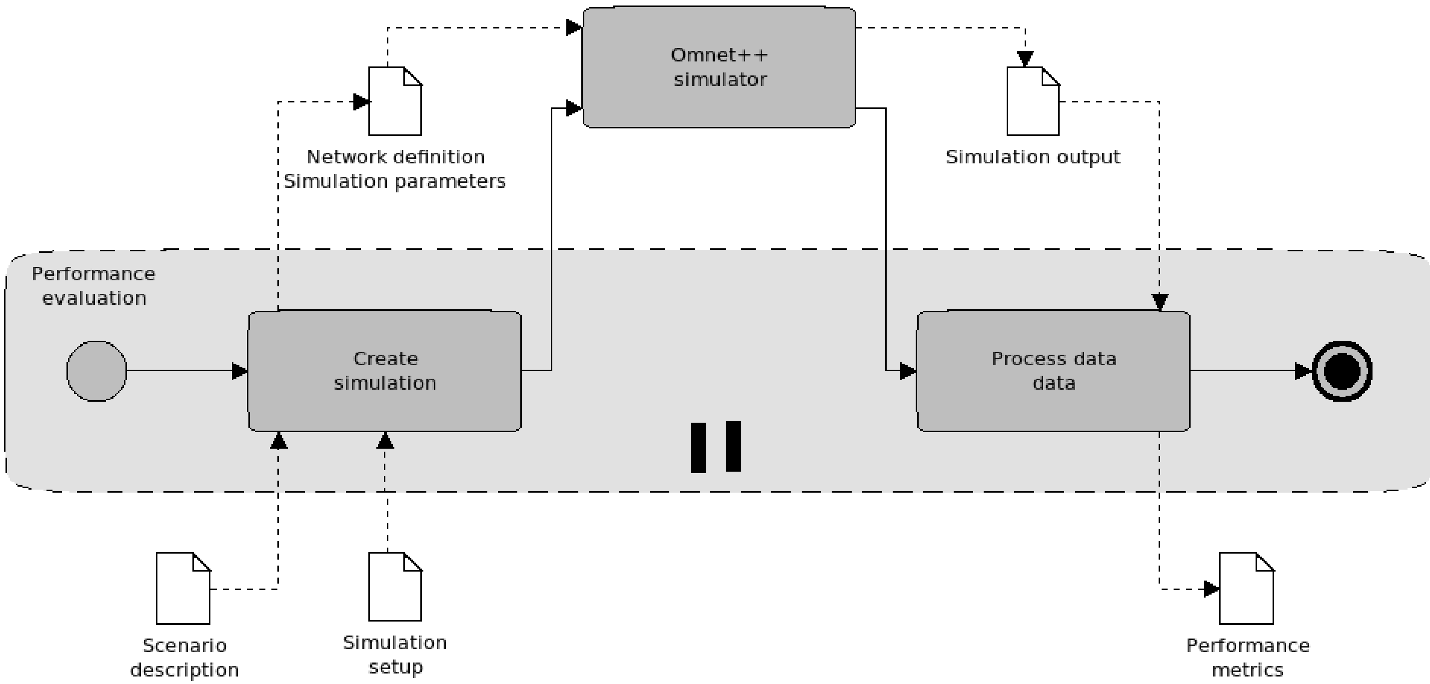
- Sub-sample data
- Create scenario ($\delta_{i,j}$ $\delta_{j,k}$ λ_i μ_j)

- Connect topology:
  - Naive connection (nearest node)
  - Optimized connection (AMPL)



New connection policies can be easily added

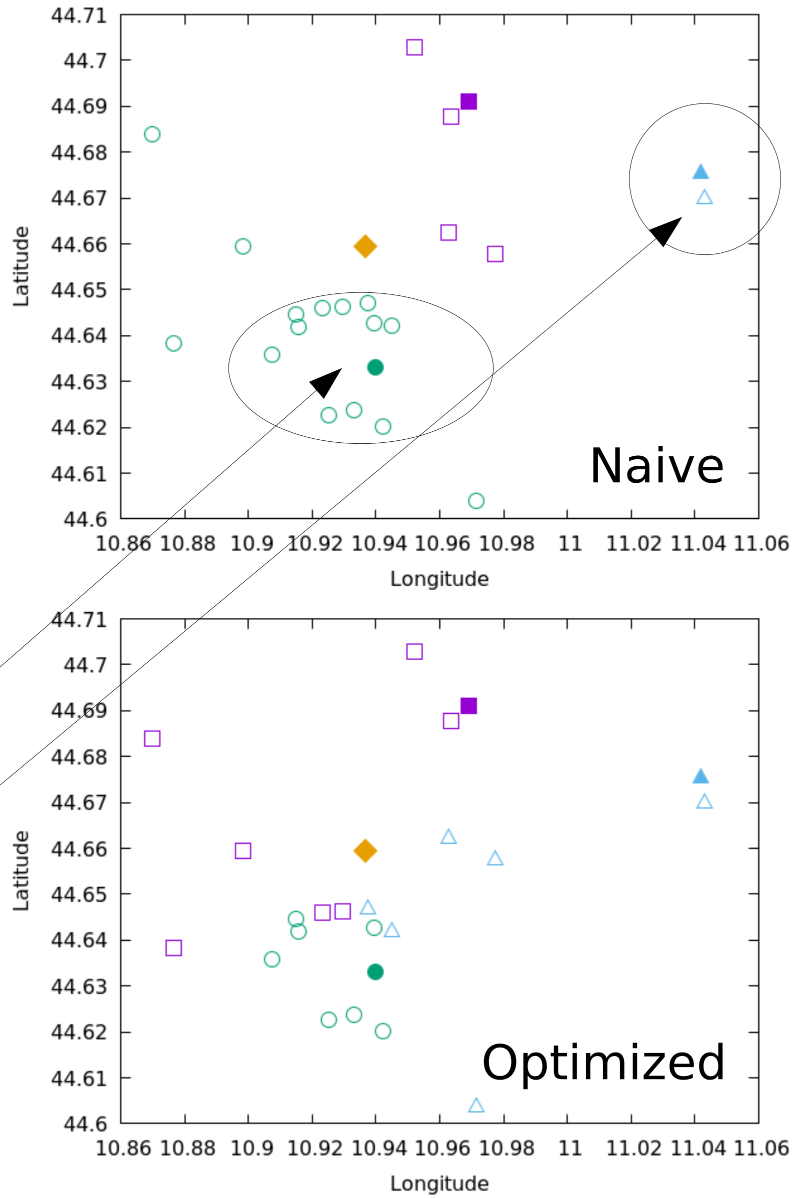
Performance evaluation



- Create OMNeT++ files:
  - Simulated network description (.ned)
  - Simulation parameters (.ini)
- Use of template files

PAFFI in action

- Use of geo-referenced data:
  - Traffic/Air pollution monitoring in Modena
- Scenario Comparison
  - Naive model
  - Optimized model
- Representation of sensor → fog mapping
- Uneven distribution of sensors over fog nodes



Simulations

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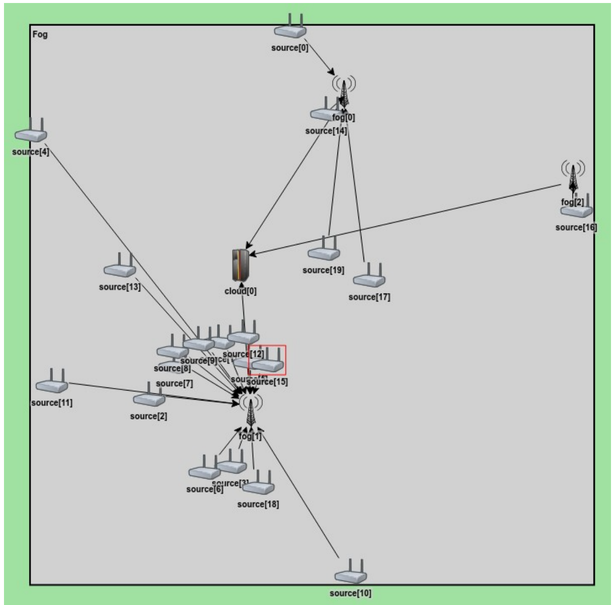
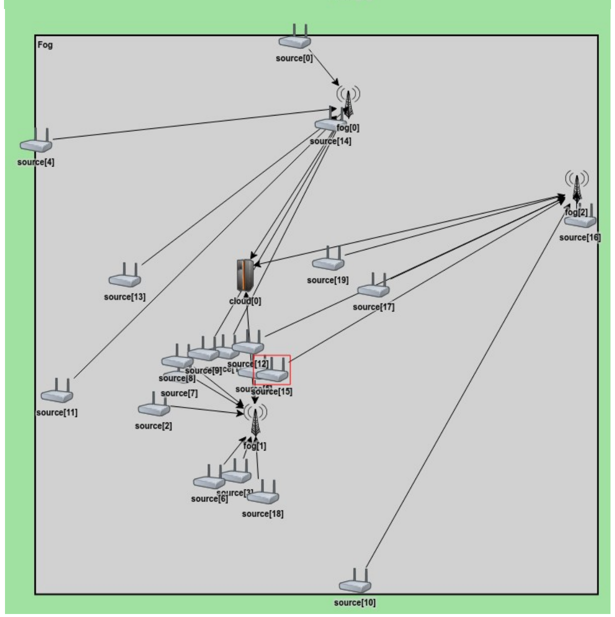
- Scenario:
  - Delay: $\delta \; \mu = 10$ms
  - Net/Proc: $\delta \; \mu = 1$
  - Load: $\rho = 0.5$
- Creation of simulation
  - Leverage OMNeT++ GUI
  - Built-in analysis tools

Naive



Optimized



Performance analysis

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	Parameter	Naive Mappping	Optimized mapping
Fog	Utilization	0.30, ~1, 0.075	0.54, 0.53, 0.45
	Queue length	0.07, >1987, 0.0031	0.33, 0.32, 0.19
	Queuing time [ms]	2.2, >17650, 0.41	6.0, 5.9, 4.1
Cloud	Response time [ms]	>12807	30.8
	Queuing time [ms]	>12786	5.4
	Processing time [ms]	10	10

- Preliminary performance comparison
  - Evidence of overload in a fog node for naive mapping
  - No performance degradation when connections are optimized

Performance analysis

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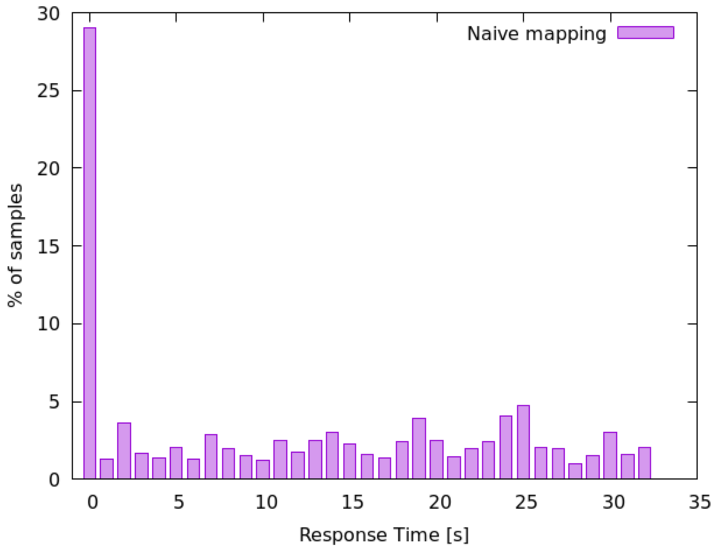
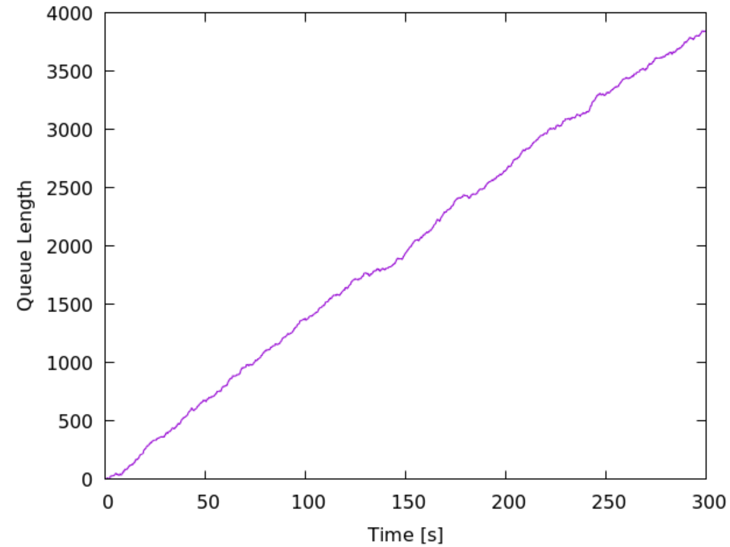
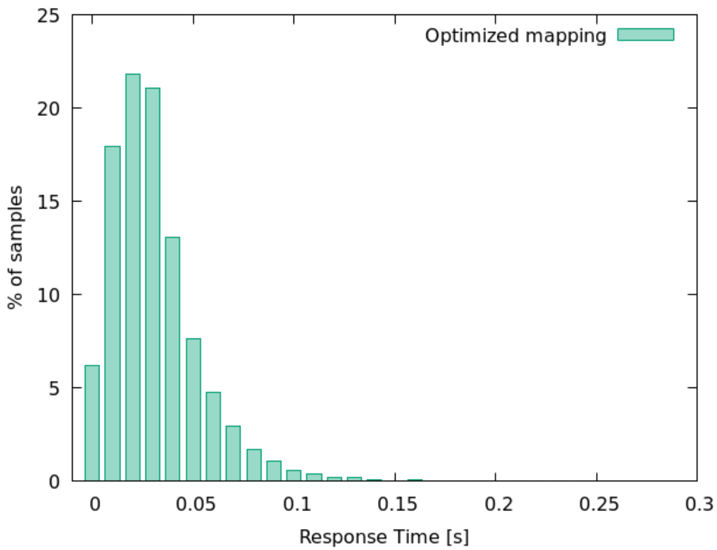
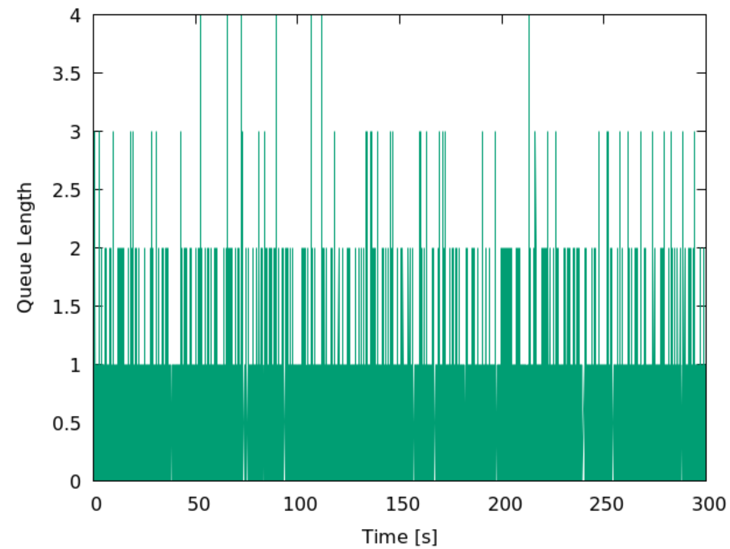
Naive





Optimized





Another example

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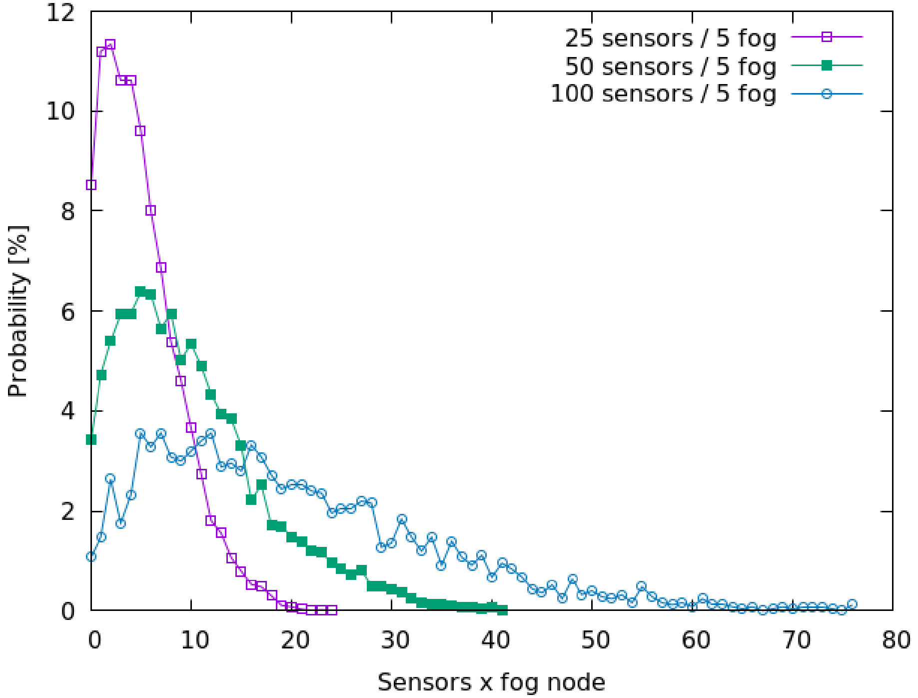
- Focus on naive mapping
- Given #sensors, #fog
  - Sensors for each fog node?
  - Probability distribution
- Analysis:
  - Estimate risk of congestion
  - Create realistic heterogeneous scenarios → for load sharing
- Just another script
  - Create topology
  - Collect data



- Observation:
  - Distribution: truncated Gaussian
  - Mean and variance can be quantified

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`http://web.ing.unimo.it/rlancellotti/`

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