Impact of theoretical performance models on the design of fog computing infrastructures

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Motivating sceanrio

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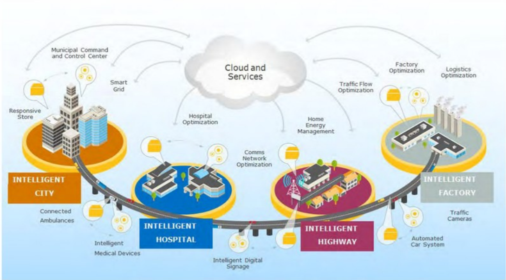
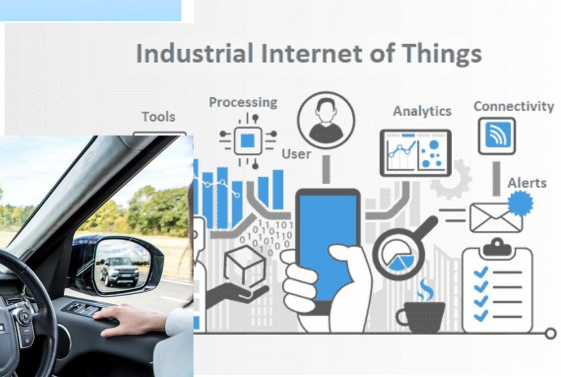
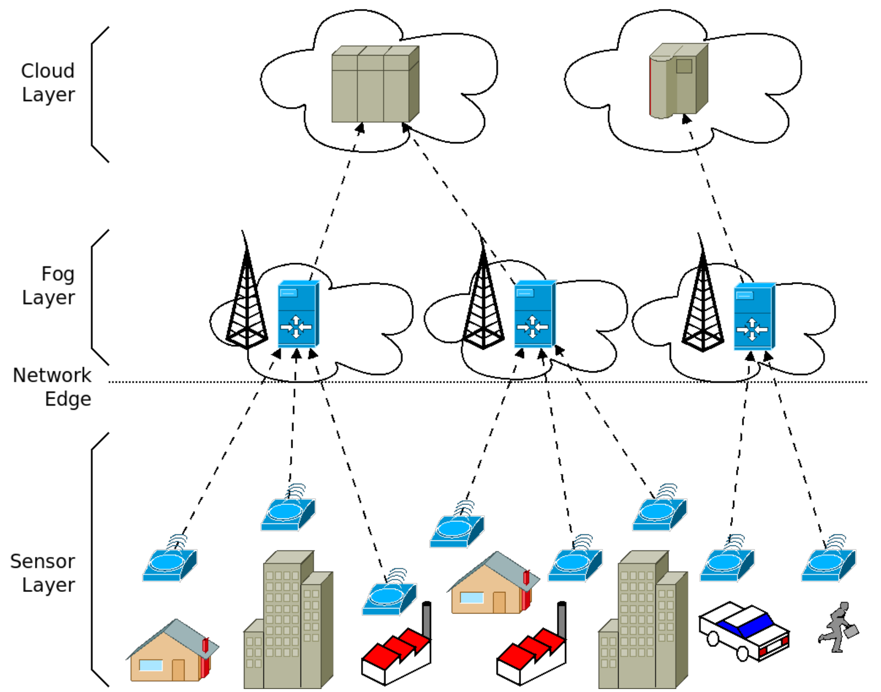
- Fog evolution motivated by new applications
- Several fields of application:
  - Smart cities
  - Industrial
  - Automotive
  - Healthcare
  - ...
- Data-intensive scenarios
- Distributed data sources
- Latency critical tasks





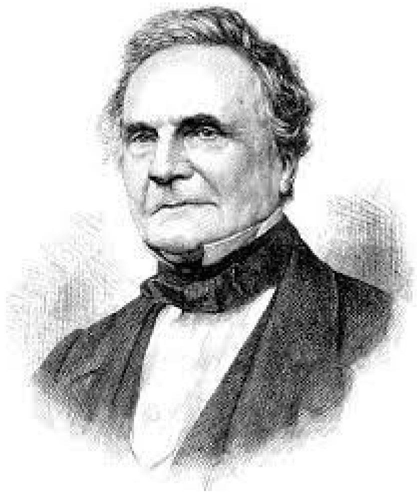
Fog infrastructure

- Cloud computing may not be suitable
  - High cost for data transfer → problem with huge data
  - High latency → not suitable for latency-bound applications
- Fog infrastructures
  - Close to end users
  - Distributed
- Can host
  - latency-critical tasks (e.g., autonomous driving)
  - Data aggregation and filtering (reduce data volume)



Quest for the right model

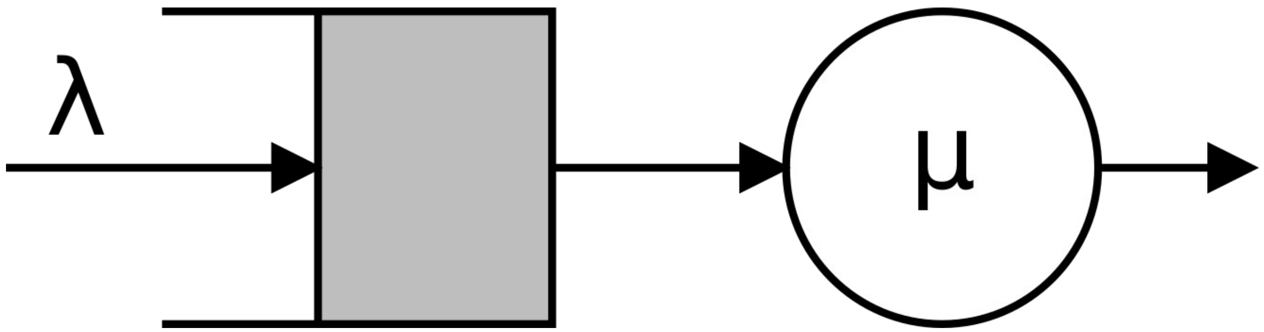
- Problem of performance evaluation in complex systems
  - Need accurate performance models
  - Inaccurate model leads to inaccurate evaluations
- Problem common to Fog and Cloud
- Actually the problem is much older…



“ I have been asked: ‘Mr. Babbage, if you put into the machine wrong figures, will the right answers come out?' I am not able rightly to apprehend the kind of confusion of ideas that could provoke such a question.”

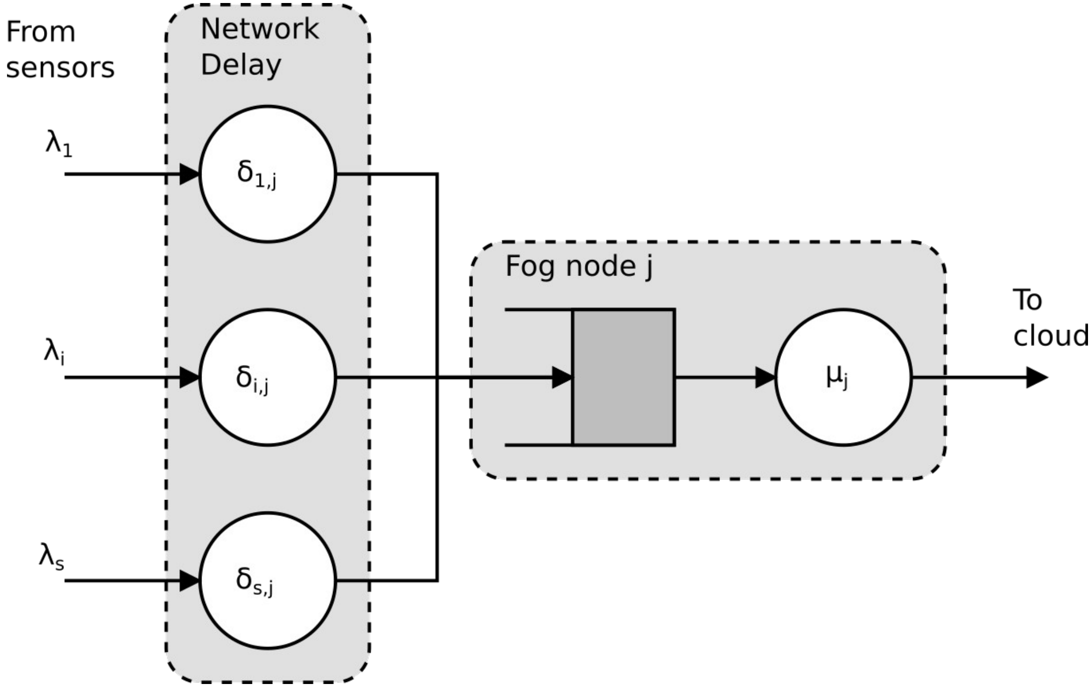
Quest for the right model

- Issues of Fog infrastructures
  - Significant network delays
  - Limited resources @ fog nodes
- Trade-off locality/load-balancing
- Typical approach (also in cloud computing)
  - Queuing theory
- Simplest model: M/M/1
  - Very simple: no parameters
  - Can be inaccurate!



Fog model overview

- Fog model overview
  - Main performance metric: response time
  - Two contributions: network delay and processing time
  - Still using queuing theory (not limited to M/M/1)



Optimization problem

- Two objective functions
  - Infrastructure cost
  - Response time
- SLA constraint $$T_{SLA} = K \cdot \frac{1}{\overline{\mu}} + \overline{\delta}$$
- Response time model
  - Network + Processing
  - M/M/1 or M/G/1 models

$$T_P = \frac{1}{\mu - \lambda}$$

$$T_P = \frac{1}{\mu}\left(1 + \frac{1 + \mathrm{CoV}^2}{2} \cdot \frac{\rho}{1-\rho}\right)$$

- Decision variable
  - Mapping of sensor→ fog data flows
  - Enabling of fog nodes
- Formalized problem

Minimize:

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

$$T_R = T_N + T_P$$

Subject to:

$$T_R \leq T_{SLA}$$

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

$$\sum_{j \in \mathcal{F}} x_{ij} = 1, \quad \forall i \in \mathcal{S},$$

$$E_j \in \{0,1\}, \quad \forall j \in \mathcal{F}$$

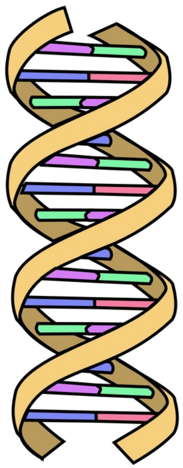
$$x_{ij} \in \{0,1\}, \quad \forall i \in \mathcal{S}, j \in \mathcal{F}$$

Infrastructure scaling

- Solving the problem
  - Estimation of minimum number of fog nodes N
  - Solution of problem with N nodes
  - In case of infeasibility, increase N and iterate
- Two approaches for N estimation (M/M/1 or M/G/1)

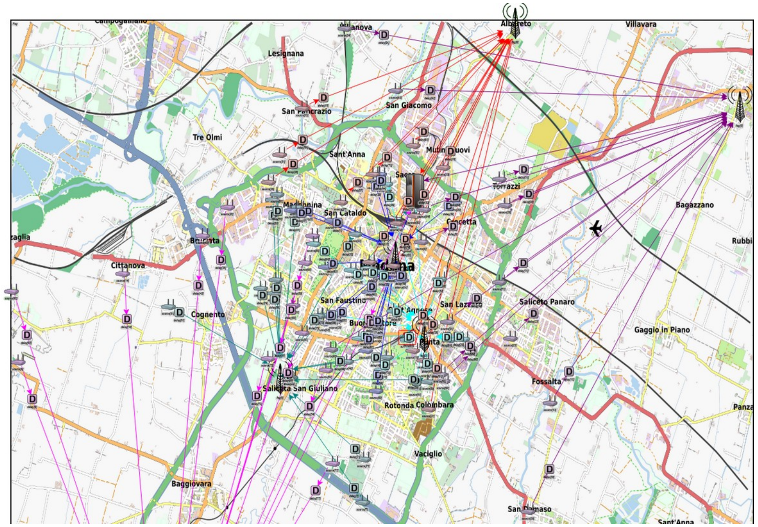
$$N = \sum_{j \in \mathcal{F}} E_j \geq \left\lceil \frac{\Lambda}{\mu} \cdot \frac{K-1}{K} \right\rceil \qquad N \geq \left\lceil \frac{\Lambda}{\mu} \cdot \frac{\mathrm{CoV}^2 - 2K - 1}{2K - 2} \right\rceil$$

- Solution based on heuristics
  - Genetic algorithm
  - Can use both M/M/1 or M/G/1 model for performance estimation



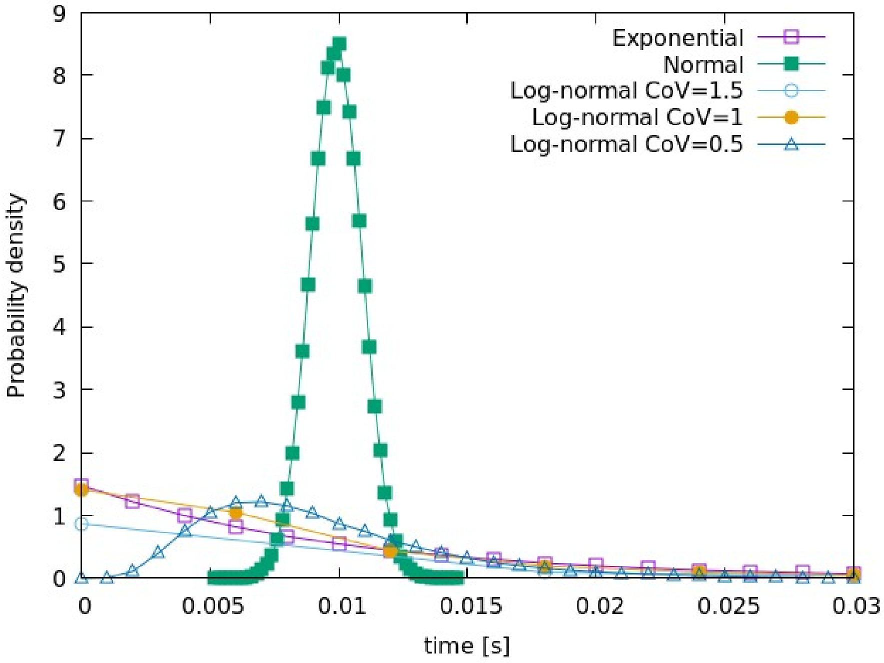
Simulation model

- Simulation based on Omnet++ simulation framework
- Integration with OSM
  - Fog nodes are geo-referenced
- Smart-city application scenario
  - Network delay increase with sensor-fog distance
  - LoRa-WAN model
  - Network delay comparable with processing time
- Simplified assumption
  - Homogeneous nodes
  - Easy to extend



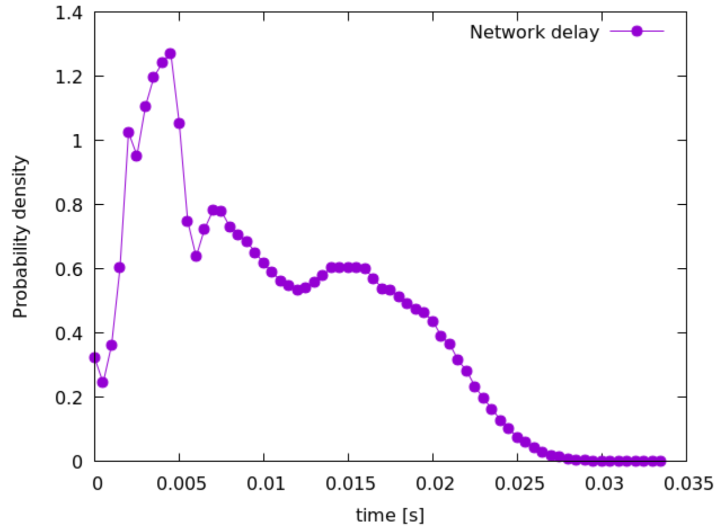
Simulation model

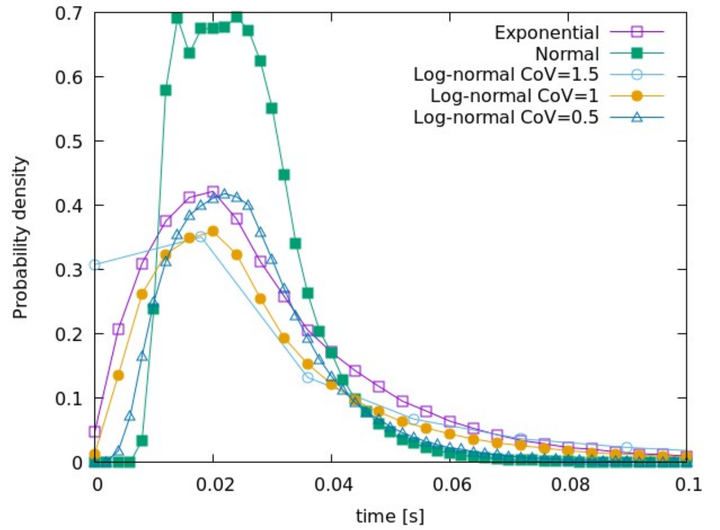
- Several models for service time
  - Exponential
  - Normal (Gaussian)
  - Log-normal
    CoV = [0.5, 1.0, 1.5]
- Medium-high load scenario
  - Same number of fog nodes
  - Load ρ=0.8
- Use of GA to map data flows
  - Load balancing
  - Locality of access



Response time

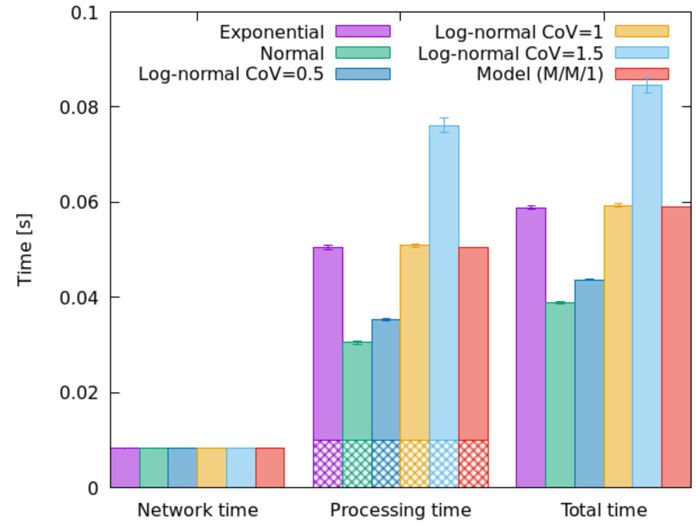
- Probability Density Functions
  - Use of histograms
- Network delay
  - Depends only on sensor→fog mapping
  - Same for every scenario
- Response time
  - Depends on service time model
  - In the following main focus on average values

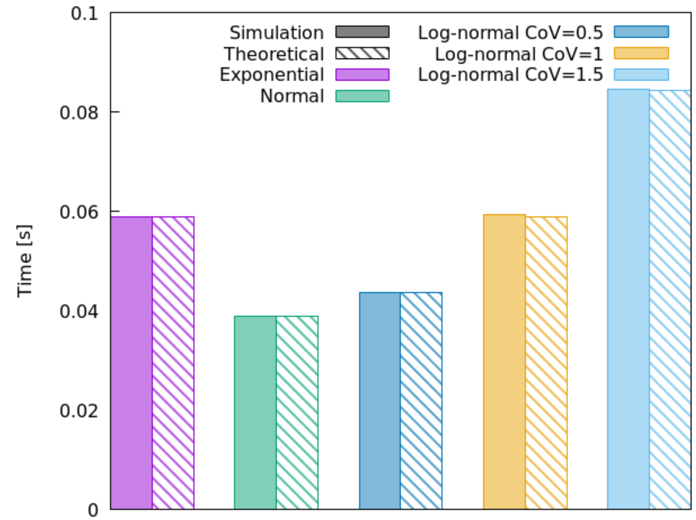




Average response time

- Comparison of average response time
  - Breakdown of components
  - Same time for network and service
  - Impact of queuing time
  - Depends on service time variance
  - Poor fitting of M/M/1 model
- Pollaczek Khinchin formula to predict response time
  - M/G/1 provides good fitting



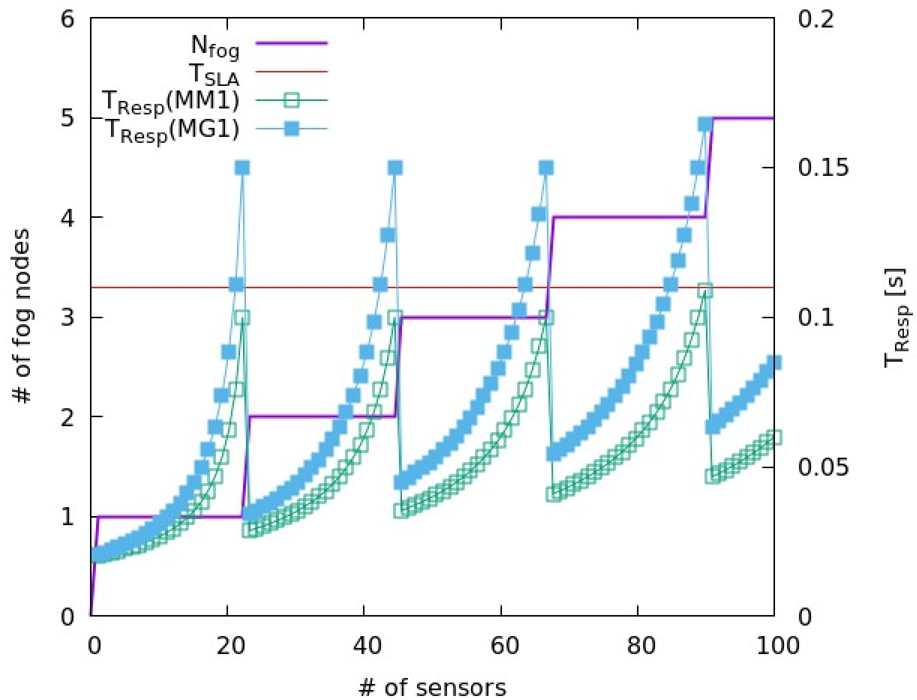


Infrastructure scaling

- Use of wrong model can affect infrastructure scaling
- Number of fog nodes based on sensors (purple line)
  - Use of M/M/1 model

$$N = \sum_{j \in \mathcal{F}} E_j \geq \left\lceil \frac{\Lambda}{\overline{\mu}} \cdot \frac{K-1}{K} \right\rceil$$

- Response time based on M/M/1 model (green line)
  - No SLA violations
- Service time is more skewed M/G/1 with σ>1(blue line)
  - SLA violations occur

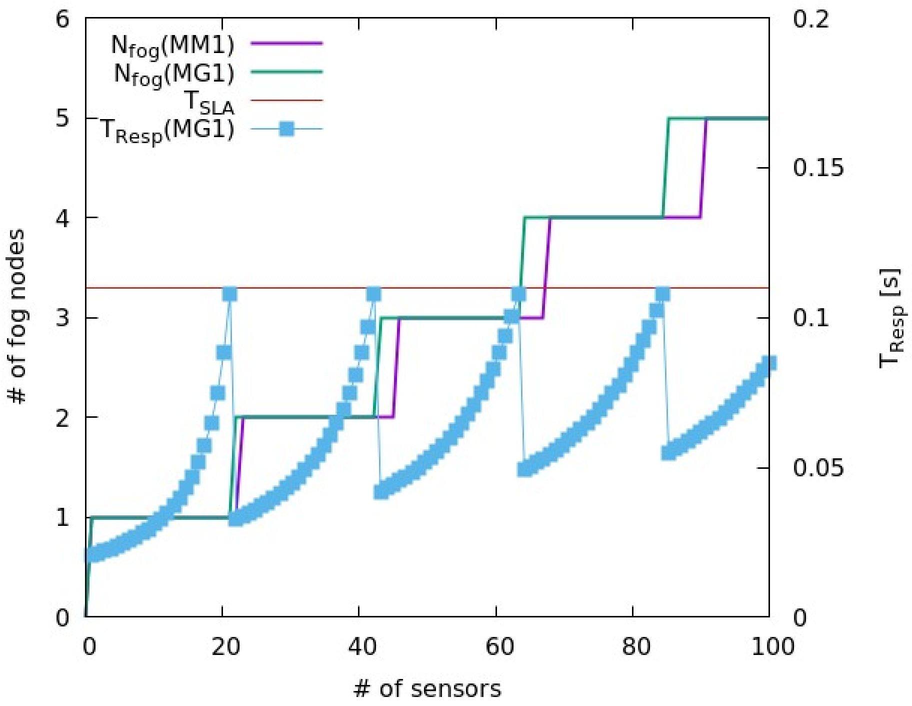


Applying the right model

- Adoption of the right model
- Infrastructure scaling based on M/G/1 model

$$N \geq \left\lceil \frac{\Lambda}{\overline{\mu}} \cdot \frac{\mathrm{CoV}^2 - 2K - 1}{2K - 2} \right\rceil$$

- Aggressive increase in number of fog nodes
  - Compare green and purple line
- No more SLA violations



Conclusions

- Key role of Fog computing in modern applications
- The need for accurate performance models in Fog systems
- Case study based on a smart-city application
  - Theoretical models (queuing networks)
  - Simulation
- Impact of over-simplifying:
  - Error in response time estimation (up to 50%)
  - Wrong infrastructure scaling (SLA violations)

Further questions to...

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