# WiP: Pricing Mechanism and Workload Scheduling to Optimize Social Welfare and Cost for Fog Computing Systems

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# Introduction

- The successive (however, overlapping) phases of computing paradigm
  - Mainframe computers → Personal computers → Network/Internet computing → Grid computing → Cloud computing
- Cloud Computing
  - Widely deployed
  - Huge number of devices
  - It is expected that by 2020
    - nearly **50 billion** devices will be connected to the Internet
    - generating an economy of exceeding **3 trillion**
    - data volume of more than **43 trillion gigabytes**
  - Issues
    - Huge amount of data → tremendous network bandwidth
    - Large latency
    - Energy Consumption

# Fog Computing

- Addresses the inherent issues of cloud computing
- Pushes applications, services, computing, and decision making near to the devices where data is being generated
- Offers the benefits of the cloud computing systems to the real-time applications
- Complementary not a replacement

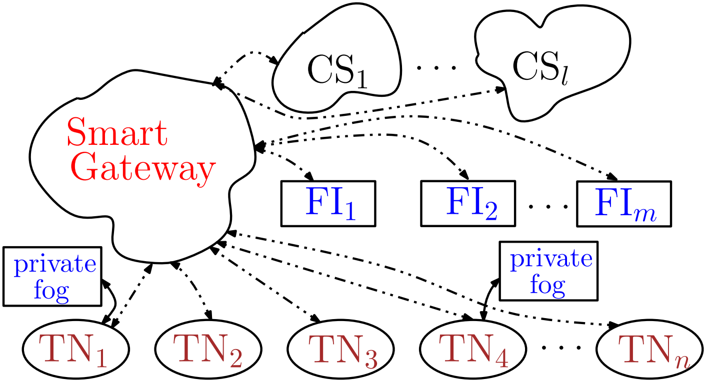
# Problem Formulation

- Cloud computing: *a few centralized* servers
- Fog computing systems: a **large** number of **geographically separated** fog devices
- A major challenge: offloading of tasks with various constraints
- Another major challenge: set up a pricing mechanism for the usage of resources/services
  - as usually the fog devices are owned by different parties
- Cloud computing
  - well-accepted and established computing model
  - pricing problem has been widely studied

# Problem Formulation

- Only a few elementary works deal with the pricing for fog computing systems
- Common practice: either of the two problems
  - pricing and offloading
- The pricing strategy of service providers → objective is to maximize the profit
- Users → timely execution of the workload (with certain constraints), however with minimum cost
- *social welfare* → an inclusive parameter
- Assumption: service providers fix the prices independently, the two problems becomes strongly related
  - which is realistic for highly distributed systems such as fog computing systems

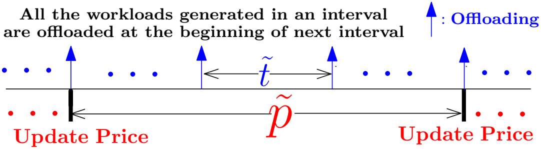
# Architecture



# Architecture

- 3-layer fog architecture
- Each terminal node is a device generating a workload
- A fog instance consists of one or multiple fog devices that acts as a unit
- Each workload is to be scheduled on a fog instance
  - that promises timely execution with the least cost
- The fog devices are geographically separated
  - not every fog instance is reachable from each terminal node
- Smart gateway selects the most appropriate fog/cloud node to execute the workload

# Model




- $\gamma_j(\tilde{t})$ and $\delta_j(\tilde{t}) \rightarrow$ computational capacity and cost of execution per unit time during $\tilde{t}$ at $\mathrm{FI}_j(\tilde{t}) \in \mathbb{F}(\tilde{t})$
- $\mathrm{TN}_i(\tilde{t}) \in \mathbb{T}(\tilde{t})$ generates a workload $w_i(\tilde{t})\langle\, in(i,\tilde{t}),\, out(i,\tilde{t}),\, C_i(\tilde{t}),\, D_i(\tilde{t})\rangle$
    - input and output data $in(i,\tilde{t})$ bytes and $out(i,\tilde{t})$ bytes, respectively
    - $C_i(\tilde{t}) \rightarrow$ required number of computation cycles
    - $D_i(\tilde{t}) \rightarrow$ deadline
- $\alpha_{ij}(\tilde{t}) \rightarrow$ transmission rate

# Formulation

- $\beta_{ij}(\tilde{t}) \rightarrow$ connected
- $\Theta_i(\tilde{t}) \rightarrow$ reachable
- $\sigma_{ij}(\tilde{t}) \rightarrow$ allocated
- *accepted workload*

$$\sum_{\forall j | \mathsf{FI}_j(\tilde{t}) \in \Theta_i(\tilde{t})} \sigma_{ij}(\tilde{t}) = 1$$

- communication time

$$\lambda_i(\tilde{t}) = \sum_{\forall j | \mathsf{FI}_j(\tilde{t}) \in \Theta_i(\tilde{t})} \sigma_{ij}(\tilde{t}) \left( \frac{in(i, \tilde{t}) + out(i, \tilde{t})}{\alpha_{ij}(\tilde{t})} \right)$$

- computation time

$$\mu_i(\tilde{t}) = \sum_{\forall j | \mathsf{FI}_j(\tilde{t}) \in \Theta_i(\tilde{t})} \sigma_{ij}(\tilde{t}) * \frac{C_i(\tilde{t})}{\gamma_j(\tilde{t})}$$

# Formulation

- Output available time $\mathrm{OAT}(i, \tilde{t})$

$$\lambda_i(\tilde{t}) + \mu_i(\tilde{t}) + wait(i, \tilde{t}) \leq D_i(\tilde{t})$$

- Cost of execution

$$cost(i, \tilde{t}) = \sum_{\forall \mathrm{FI}_j(\tilde{t}) \in \Theta_i(\tilde{t})} \sigma_{ij}(\tilde{t}) * \frac{C_i(\tilde{t})}{\gamma_j(\tilde{t})} * \delta_j(\tilde{t})$$

- User surplus at $\mathrm{TN}_i(\tilde{t})$ during $\tilde{t}$ is

$$\Upsilon_i(\tilde{t}) = util(i, \tilde{t}) - cost(i, \tilde{t})$$

- $P_j(\tilde{t}) \rightarrow$ profit at $\mathrm{FI}_j(\tilde{t})$ in interval $\tilde{t}$
- Social welfare during $\tilde{t}$ is

$$SW(\tilde{t}) = \sum_{\forall j | \mathrm{FI}_j(\tilde{t}) \in \mathbb{F}(\tilde{t})} P_j(\tilde{t}) \quad + \quad \sum_{\forall i | \mathrm{TN}_i(\tilde{t}) \in \mathbb{T}(\tilde{t})} \Upsilon_i(\tilde{t})$$

- Compute $SW(p)$

# Proposed Approach

**Algorithm 1:** *hCost*

**for** *each* $w_i(t) \in \mathbb{W}(t)$ **do**
  $proximity(i,t) \leftarrow \emptyset$
  **for** *each* $FI_j(t) \in \Theta_i(t)$ **do**
    **if** $\frac{in(i,t)}{\alpha_{ij}(t)} + \frac{C_i(t)}{\gamma_j(t)} + \frac{out(i,t)}{\alpha_{ij}(t)} \leq D_i(t)$ **then**
      $proximity(i,t) = proximity(i,t) \bigcup \mathrm{FI}_j(t)$
  **end**
**end**
**for** *each* $w_i(t) \in \mathbb{W}(t)$ **do**
  $cand(i,t) \leftarrow \emptyset$
  **for** *each* $FI_j(t) \in proximity(i,t)$ **do**
    if Eq. (5) holds for $w_i(t)$ and existing workloads on $\mathrm{FI}_j(t)$ then add $\mathrm{FI}_j(t)$ to $cand(i,t)$
  **end**
  Allocate $w_i(t)$ to the fog instance $\mathrm{FI}_j(t) \in cand(i,t)$ with least execution cost
**end**

# Proposed Approach

| $cfg$ | $\#f$ | $\%Impr$ | $\%Reject$ | |
|---|---|---|---|---|
| | | | $hUtil$ | $hCost$ |
| 1 | 100 | 0.81 | 4.23 | 4.61 |
| 2 | 150 | 14.86 | 1.99 | 0.21 |
| 3 | 200 | 24.36 | 1.14 | 0.11 |
| 4 | 250 | 31.72 | 0.86 | 0.09 |
| 5 | 300 | 35.97 | 0.75 | 0.07 |

# Conclusion and Future Work

- Addresses pricing and the offloading problem in an integrated manner for the real-time tasks
- Objective is to maximize the social welfare, whereas minimize the cost
- Future Works
  - Include the cloud layer
  - Obtaining an optimal solution
  - Pricing mechanism
    - devise the price at the beginning of each interval
    - must examine the interplay of revenue and profit with other parameters
    - further exploration on computing $util(i, \tilde{t})$

*Thanks*