Revenue Maximization in a Cloud Federation

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CLOUD FEDERATION ADVANTAGES:

1. Cloud federation is an additional paradigm that can be used to increase revenue of providers through sharing of free resources;
2. Federation can make the cloud computing business more profitable in supporting multiple concurrent services;
3. Cloud Federation leads to reduce investments and operational costs;
4. Cloud federation leads to gain access to a larger customer base;
5. etc . . .
Light Federation Description

1. A federation in which providers are not forced to engage in a complex and compelling federation level agreement;
2. Providers only need to announce their prices to each other;
3. The proposed algorithm operates at the federation level only from the dynamic pricing standpoint and used by each provider locally to take decisions;
4. Cloud providers involved in the federation solve individually their resource sharing problem to obtain their individual optimum.
**PROVIDERS’ COOPERATION**

1. Providers rely on insourcing and outsourcing transactions in addition to serving users from within;

2. A given provider will outsource only if the outsourcing costs are lower than the expense of providing the services from their own infrastructure;

3. Providers can take advantage by putting to "sleep mode" machines that are unused whenever appropriate to reduce costs and energy consumption;

**OBJECTIVE**

Identify the conditions that lead to higher revenues and propose an exact mathematical solution for the cloud federation optimization problem.
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STATE OF THE ART

SOME REFERENCES

1. J. Goiry, et al. (2010): Authors compare the outcome of several predetermined actions (out-in-sourcing and power-on-off) instead of relying on a global optimization that finds the best solutions when combining the different actions.

2. M. Mazzucco et al. (2010): Authors maximize cloud providers’ revenues by dynamically powering-on or off servers and show significant increase in providers’ revenues. They do not address federation as a means to increase revenues.

3. Q. Zhang et al. (2011): Authors deal with a dynamic resource allocation problem in which the objective is to draw an optimal model to achieve high revenues while minimizing energy costs. The proposed study is in a single cloud provider scenario.

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\(^{a}\) Characterizing Cloud Federation for enhancing providers’ profit, IEEE Comp-Soc

\(^{b}\) Maximizing cloud providers revenues via energy aware allocation policies, Int.Conf.Cloud.Comput

\(^{c}\) Dynamic resource allocation for spot markets in cloud computing environments, UCC
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Our Contribution:

1. Propose an exact model based on linear integer programming to identify the most appropriate strategies and decisions (serving users directly, outsourcing and insourcing decisions);

2. Propose a near complete convex hull of the problem leading in few seconds to optimal solutions for practical instances;

3. Propose a dynamic pricing model;
Resource Allocation in a Cloud Federation: Problem Statement

Problem Statement

**Problem’s Input:**

- A cloud federation of $K$ providers;
- Each provider $i$ has a limited amount of CPU, Memory and Storage resources to share;
- End-users and providers demands are given by:
  - $d_u^{(small)}$, $d_u^{(large)}$, $d_u^{(xlarge)}$, ... and $d_p^{(small)}$, $d_p^{(large)}$, $d_p^{(xlarge)}$, ... respectively;
- For sake of simplicity, we reference all instances to the small instance size that we use as a reference metric;
**Space of Decisions**

1. **Typical:** Activating an optimal number of resources for use within the cloud provider infrastructure to serve some of the requests;

2. **Outsourcing:** If the cloud provider maximum serving capacity (or if financially beneficial), a fraction of the the requests are programmed for outsourcing to other federation members;

3. **Insourcing:** Cloud providers that have not used all their resources can envisage insourcing some of their available nodes to increase their own revenues;

4. **Putting to sleep or shutting down nodes:** Nodes are put to sleep mode or shut down if unused, to save power.
RESOURCE ALLOCATION IN A CLOUD FEDERATION: PROBLEM STATEMENT

**Problem Statement**

**Variables definition**

- $x_{ji}$ represents the number of resources to outsource from provider $j$ to provider $i$;
- $x_{ii}$ the number of resources served by provider $i$;
- We note by $\mu_{ji}^{(in)}$ is the price per hour per resource of instance $(in)$ outsourced to a provider $j$ by a provider $i$;
- $x_{ij}$ the number of resources rent by provider $i$ to provider $j$;
- $y_{il}$ is a binary variable indicating if a node $l$ of provider $i$ is ON ($y_{il} = 1$) or OFF ($y_{il} = 0$);

**Constraints definition**

- User satisfaction constraints:
  \[
  x_{ii}^{(in)} + \sum_{j \sim i}^{K} x_{ji}^{(in)} = d_u^{(in)}, \forall in \in I
  \]  
  (1)

- Insourcing demands constraints:
  \[
  \sum_{j \sim i}^{K} x_{ij}^{(in)} \leq d_p^{(in)}, \forall (in) \in I
  \]  
  (2)

- Resource limitation constraints:
  \[
  \sum_{in \in I} \alpha_r^{(in)} \left( x_{ii}^{(in)} + \sum_{j \sim i}^{K} x_{ij}^{(in)} \right) \leq \sum_{l=1}^{L_i} \gamma_{il}y_{il}, \forall r \in RES
  \]  
  (3)
Resource Allocation in a Cloud Federation: Problem Statement

Mathematical Model

\[
\max R_i = \Delta(t) \left[ \sum_{in \in I} \left( \mu_{ii}^{(in)} x_{ii}^{(in)} + \sum_{j \sim i}^{K} \left( \mu_{ij}^{(in)} - \mu_{ji}^{(in)} \right) x_{ij}^{(in)} \right) + \sum_{j \sim i}^{K} \mu_{ij}^{(in)} x_{ij}^{(in)} \right] - c_i \sum_{l=1}^{L_i} \gamma_{i\|l} y_{i\|l} \\
S.T.: \\
\begin{cases}
\ x_{ii}^{(in)} + \sum_{j \sim i}^{K} x_{ji}^{(in)} = d_{u}^{(in)}, \forall in \in I \\
\ \sum_{j \sim i}^{K} x_{ij}^{(in)} \leq d_{p}^{(in)}, \forall in \in I \\
\ \sum_{in \in I} \alpha_{r}^{(in)} \left( x_{ii}^{(in)} + \sum_{j \sim i}^{K} x_{ij}^{(in)} \right) \leq \sum_{l=1}^{L_i} \gamma_{i\|l} y_{i\|l} \\
\ \forall r \in \text{RES} \\
\ \Delta(t) \left[ \sum_{in \in I} \left( \mu_{ii}^{(in)} x_{ii}^{(in)} + \sum_{j \sim i}^{K} \left( \mu_{ij}^{(in)} - \mu_{ji}^{(in)} \right) x_{ij}^{(in)} \right) + \sum_{j \sim i}^{K} \mu_{ij}^{(in)} x_{ij}^{(in)} \right] - c_i \sum_{l=1}^{L_i} \gamma_{i\|l} y_{i\|l} \right] \geq R_{i0} \\
\end{cases}
\]

\begin{align*}
0 \leq x_{ij}^{(in)} & \leq b_{j}^{(in)}, \forall j = 1, \ldots, K, j \neq i, \forall in \in I \\
x_{ij}^{(in)} & \in \mathbb{Z}^{+}, \forall j = 1, \ldots, K, j \neq i, \forall in \in I \\
y_{i\|l} & \in \{0, 1]\}, \forall l = 1, \ldots, L_i
\end{align*}
PROPOSITION

Assuming that the overall demand from users and providers is less than the available resources from a provider $i$, i.e.,

$$N\tilde{u}^{(in)} + (K - 1)\bar{p}^{(in)} \leq R_{\text{avail}}^{(in)}$$

the following inequality is valid for our model for each instance $(in) \in \mathcal{I}$:

$$\mu^*(in) = \min_{j \neq i, j = 1, \ldots, K} \left\{ \frac{C^{(in)} + \varphi^{(in)}(K - 1)\bar{p}^{(in)}}{N\tilde{u}^{(in)} + (K - 1)\bar{p}^{(in)}} \right\}$$

(6)
**A Simple Pricing Model**

**Sketch of Proof**

\[
N\tilde{u}^{(in)}\mu^{(in)} + (K - 1)\tilde{p}^{(in)}\mu^{(in)}' \geq C^{(in)} \quad (7)
\]

\[
\begin{cases}
N\tilde{u}^{(in)} + (K - 1)\tilde{p}^{(in)} \leq R^{(in)}_{\text{avail}};

N\tilde{u}^{(in)}\mu^{(in)} + (K - 1)\tilde{p}^{(in)}\mu^{(in)}' \geq C^{(in)}.
\end{cases} \quad (8)
\]

\[
\left( N\tilde{u}^{(in)} + (K - 1)\tilde{p}^{(in)} \right)\mu^{(in)}' \geq C^{(in)} - \phi^{(in)}N\tilde{u}^{(in)} \quad (9)
\]

\[
\mu^{(in)}' \geq \frac{C^{(in)} - \phi^{(in)}N\tilde{p}^{(in)}}{N\tilde{u}^{(in)} + (K - 1)\tilde{p}^{(in)}} \quad (10)
\]
A Simple Pricing Model

**Pricing Properties**

- \[ \lim_{K \to +\infty} \mu^*(in) = \varphi(in) \] (11)
- For small values of \( K \):
  \[ \mu^*(in) = \frac{C(in)}{\bar{u}(in)} \] (12)
- If \( N\bar{u}(in) \leq \frac{C(in)}{\varphi(in)} \): the price \( \mu^*(in) \) decreases towards \( \varphi(in) \).
- If \( N\bar{u}(in) \geq \frac{C(in)}{\varphi(in)} \): the price \( \mu^*(in) \) increases towards \\
  \[ \varphi(in) + \frac{C(in)}{(K-1)p(in)} \].
- \[ \lim_{N \to +\infty} \mu^*(in) = 0^+ \] (13)
A Simple Pricing Model

Algorithm’s Full Description

1. **Input:** Proposed prices by all other providers \((j \neq i)\) at \(l\Delta t\), service requests from all other providers, provider \(i\)'s users demands.

2. **Output:** New prices of cloud provider \(i\) at \((l + 1)\Delta t\) and optimal multi-criteria insourcing/outsourcing/typical decisions for provider \(i\) for round \((l + 1)\Delta t\).

3. **Step 1:** Collect all prices proposed by the other cloud providers \(j\) \((j \neq i)\);

4. **Step 2:** Collect all insourcing and end-users demands for resource instance type (in) within \([l\Delta t, (l + 1)\Delta t]\);

5. **Step 3:** Provider \(i\) applies Proposition (6) to derive the best prices to propose to other providers and the end users;

6. **Step 4:** Solve the constrained Integer Program (4) to find the optimal amount of end users requests to serve from within, the amount to outsource and the other providers requests to accept (insourcing).
Simulation Parameters

- Our algorithm was evaluated using 2.4 GHz server with 8 Gb of RAM;
- We considered a scenario with 25 cloud providers each with a quota of 1000 PMs;
- Each PM has a capacity in small VMs uniformly distributed in [10; 200];
- Insourcing prices are lower than proposed prices to end-users;
- We considered Small, Large and XLarge instances, and compute, memory and storage resources;
Evolution of the workload distribution

- **When demands exceed maximum available capacity**: Provider $i$ outsources part of the demand to other providers to honor the requests, maintain its reputation while attempting to increase revenue;

- **When incoming workload is lower than maximum available capacity**: The decision often consists of executing the demand entirely at the provider without any outsourcing. The provider $i$ will however opportunistically outsource part of the demand when proposed insourcing offers are more profitable.
In-and-Out-sourcing benefits

- When providers use the outsourcing only mode, they typically activate less resources than the mode combining in and outsourcing;
- Providers combining in and outsourcing will typically activate more resources so they can serve requests from providers willing to pay a price higher than their own costs;
It is only when cloud provider \( i \) elects to use the optimal mix of the four possible decisions, that the highest benefits are reached; Combining both outsourcing, insourcing and typical modes of operations leads to the highest benefits and a minimum loss in customers;
Combining insourcing and outsourcing leads to 8% of nodes turned off and results from a tradeoff or opportunistic balancing between insourcing other cloud providers’ requests and outsourcing user requests to other providers according to proposed prices.
**How to join a federation?**

- A federations should be built with a limited number of providers, and there is an optimal number, with the amount of several shared resources in line with the user demands.

![Graph](image-url)
**SELFISH OR COOPERATIVE PROVIDER?**

Table: Revenue gap between selfish and cooperative providers

<table>
<thead>
<tr>
<th>Provider</th>
<th>Servers</th>
<th>Selfish gains</th>
<th>Cooperative gains</th>
<th>Gap (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl-Pro 1</td>
<td>2500</td>
<td>20489.8</td>
<td>68856.9</td>
<td>70.24</td>
</tr>
<tr>
<td>Cl-Pro 2</td>
<td>3500</td>
<td>80250.1</td>
<td>83221.9</td>
<td>3.57</td>
</tr>
<tr>
<td>Cl-Pro 3</td>
<td>4500</td>
<td>93991.3</td>
<td>94952.1</td>
<td>1.01</td>
</tr>
<tr>
<td>Cl-Pro 4</td>
<td>2800</td>
<td>38318.5</td>
<td>70445.6</td>
<td>45.60</td>
</tr>
<tr>
<td>Cl-Pro 5</td>
<td>6000</td>
<td>113338.4</td>
<td>114425.4</td>
<td>0.95</td>
</tr>
</tbody>
</table>
**CONCLUSIONS**

- The model recommends cloud providers to engage in outsourcing, insourcing and power management simultaneously,
- The results motivate cooperation of cloud providers to decide when insourcing is relevant along with other possible actions,

**FUTURE WORK**

- Extend the model to address elasticity through predictions of dynamic incoming workload variations or stochastic behavior.
- Propose new scalable solutions based on game theory to cope with providers revenues sharing in the federation.
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