Energy-efficient and SLA-Aware Management of IaaS Clouds

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FoSII Infrastructure – Autonomic Computing, Goals

Goals:
• Few SLA violations
• High utilization of resources
• Energy-efficient usage
  • Few reconfigurations actions (e.g., migrations)
  • Good power management

Service Level Agreement (SLA)

<table>
<thead>
<tr>
<th>Resource</th>
<th>Requirement</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU Power</td>
<td>≥ 512</td>
<td>MIPS</td>
</tr>
<tr>
<td>Memory</td>
<td>≥ 1024</td>
<td>MB</td>
</tr>
<tr>
<td>Storage</td>
<td>≥ 1000</td>
<td>GB</td>
</tr>
<tr>
<td>Incoming Bandwidth</td>
<td>≥ 10</td>
<td>Mbit/s</td>
</tr>
<tr>
<td>Outgoing Bandwidth</td>
<td>≥ 20</td>
<td>Mbit/s</td>
</tr>
</tbody>
</table>
Complexity of Management

- Escalation levels
Complexity of Management

- Escalation levels
  - Do nothing
Complexity of Management

- Escalation levels
  - Do nothing

1. Change VM configuration
Complexity of Management

- Escalation levels
  - Do nothing
  1. Change VM configuration
  2. Migrate applications from one VM to another.
Complexity of Management

- Escalation levels
  - Do nothing
  1. Change VM configuration
  2. Migrate applications from one VM to another.
  3. Migrate one VM from one PM to another or create new VM on appropriate PM. (BIP problem, NP-hard)
Complexity of Management

- Escalation levels
  - Do nothing
1. Change VM configuration
2. Migrate applications from one VM to another.
3. Migrate one VM from one PM to another or create new VM on appropriate PM. (BIP problem, NP-hard)
4. Turn on/off PM.
Complexity of Management

- Escalation levels
  - Do nothing
  1. Change VM configuration
  2. Migrate applications from one VM to another.
  3. Migrate one VM from one PM to another or create new VM on appropriate PM. (BIP problem, NP-hard)
  4. Turn on/off PM.
  5. Outsource to other Cloud provider.
Using Autonomic Computing and Knowledge Management

- Analysis: queries for action
- Planning: schedules execution of actions
- Monitoring: gathers and inserts new measurement
- Execution: executes actions

Knowledge base

- Second level
- Third level
- Fourth level
- Fifth level
Using Autonomic Computing and Knowledge Management

- Analysis: queries for action
- Monitoring: gathers and inserts new measurement
- Knowledge base
- Execution: executes actions
- Planning: schedules execution of actions

1. receiveMeasurement()
2. recommendAction()
3. Actions
4. changed configuration is reflected in KB
Using Autonomic Computing and Knowledge Management
Using Autonomic Computing and Knowledge Management

- Analysis
  queries for action

- Monitoring
  gathers and inserts new measurement

- Knowledge base

- Actions
  recommendAction()

- Planning
  schedules execution of actions

- Quality of recommended actions: violations vs wastage vs actions

- Execution
  executes actions

- Federated Cloud
  - CPU
  - mem

- VM
  - CPU
  - mem

- PM
  - CPU
  - mem

- SLA
  - SL01
  - SL02

- Measurement

- Decision mechanism

- Second level
- Third level
- Fourth level
- Fifth level
Escalation Level 1: VM Reconfiguration

- Click to edit Master text styles

Speculative approach:
May we allocate less resources then agreed, but more than actually utilized at the specific point in time – and not violate SLAs?

Storage

<table>
<thead>
<tr>
<th>What do we provide?</th>
<th>What does the consumer utilize?</th>
<th>What was agreed in the SLA?</th>
<th>Violation?</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 GB</td>
<td>400 GB</td>
<td>&gt;= 1000 GB</td>
<td>NO</td>
</tr>
<tr>
<td>500 GB</td>
<td>510 GB</td>
<td>&gt;= 1000 GB</td>
<td>YES</td>
</tr>
<tr>
<td>1000 GB</td>
<td>1010 GB</td>
<td>&gt;= 1000 GB</td>
<td>NO</td>
</tr>
</tbody>
</table>
Knowledge Management Techniques

• Case Based Reasoning (CBR), Rule-based approach
  • Threat Thresholds
  • Self-adaptive
Modeling Migrations and Power Management

• Power consumption, migration and power management models
• Heuristics for VM migration and PM power management
  • Initial allocation of VMs
  • Re-allocations of VMs
Decision: Migrate VM1 from PM1 to PM2!
Powering on PM

Decision: Power on PM1!

PM1: not available for VMs, but consuming full energy level (Cmax)

PM1: Ready for allocation of VMs, but able to run VM only at t+3 (cf. migration)
Powering off PM

Decision: Power off PM1!
Precondition: No VMs are executing on PM1

Precondition: 
not available for VMs, but consuming full energy level (Cmax)

PM1 powered off
VM-PM Allocation Heuristics

- **First Fit**
  - **Initial allocation:** Try to allocate on smallest max power consumption first.
  - **Re-allocation:**
    - Pick most loaded PM, distribute 50% of load in First Fit Fashion.
    - Pick least loaded PM, distribute 100% of load in First Fit fashion.
VM-PM Allocation Heuristics

• Round Robin
  • Initial allocation: Iterate through PMs sorted by their max power consumption and allocate one VM each.
  • Re-allocation:
    • Pick most loaded PM, distribute 100% of load in Round Robin fashion among non-empty PMs
    • Pick 1 VM on each PM and allocate it on empty PM
VM-PM Allocation Heuristics

• Monte Carlo
  • Initial allocation: Round Robin
  • Re-allocation:
    • Calculate cost of possible allocations
    • Evaluate multiple random configurations

• Vector Packing
  • Initial allocation: Allocate VMs with highest resource needs to PMs with smallest max power consumption. Pick VM that counter imbalance in PM resource load.
  • Re-allocation:
    • Consolidate VMs in Vector Packing fashion
    • Load balance VMs on non-empty PMs in the future
PM Power Management

- PM power management
- **Power off**
  - # PMs to power off = # empty PMs / a
- **Power on**
  - Any threshold for average resource utilization is exceeded
  - E.g., Power on as many PMs such that \( \text{Avg}(CPU\_utilization) > 80\% \).
  - Power on machines with least max power consumption first
Visualization
Visualization

Cloud Visualization

![Cloud Visualization Diagram]

- VM0 (CPU)
- VM0 (Memory)
- VM1 (CPU)
- VM1 (Memory)
- VM2 (CPU)
- VM2 (Memory)
- VM3 (CPU)
- VM3 (Memory)
- VM4 (CPU)
- VM4 (Memory)
- VM5 (CPU)
- VM5 (Memory)
- VM6 (CPU)
- VM6 (Memory)
- VM7 (CPU)
- VM7 (Memory)
- VM8 (CPU)
- VM8 (Memory)
- VM9 (CPU)
- VM9 (Memory)
- VM10 (CPU)
- VM10 (Memory)
- VM11 (CPU)
- VM11 (Memory)
- free (CPU)
- free (Memory)
- powering on (CPU)
- powering on (Memory)
- powering off (CPU)
- powering off (Memory)
- off (CPU)
- off (Memory)
Visualization

Cloud Visualization

Resource / PM

VM0 (CPU) VM0 (Memory) VM1 (CPU) VM1 (Memory) VM2 (CPU) VM2 (Memory) VM3 (CPU)
VM3 (Memory) VM4 (CPU) VM4 (Memory) VM5 (CPU) VM5 (Memory) VM6 (CPU) VM6 (Memory)
VM7 (CPU) VM7 (Memory) VM8 (CPU) VM8 (Memory) VM9 (CPU) VM9 (Memory) VM10 (CPU)
VM10 (Memory) VM11 (CPU) VM11 (Memory) free (CPU) free (Memory) powering on (CPU)
powering on (Memory) powering off (CPU) powering off (Memory) off (CPU) off (Memory)
Visualization

Cloud Visualization

t-1  t=4 (Max t = 181)  t+1

Cloud Visualization

Utilization

Resource / PM

VM0 (CPU)  VM0 (Memory)  VM1 (CPU)  VM1 (Memory)  VM2 (CPU)  VM2 (Memory)  VM3 (CPU)  VM3 (Memory)  VM4 (CPU)  VM4 (Memory)  VM5 (CPU)  VM5 (Memory)  VM6 (CPU)  VM6 (Memory)  VM7 (CPU)  VM7 (Memory)  VM8 (CPU)  VM8 (Memory)  VM9 (CPU)  VM9 (Memory)  VM10 (CPU)  VM10 (Memory)  VM11 (CPU)  VM11 (Memory)  free (CPU)  free (Memory)  powering on (CPU)  powering on (Memory)  powering off (CPU)  powering off (Memory)  off (CPU)  off (Memory)
Evaluating Energy Impact of VM Reconfiguration

- VM reconfiguration indeed saves energy

![Graphs showing energy and SLA violations for different allocation methods](image)
Evaluating Allocation Heuristics

- Energy consumption and SLA violations for various workloads
Evaluating Scalability

- Scalability

![Graph showing scalability over VM number]
Conclusion and Outlook

- Enacting SLAs and reducing energy consumption on several levels
  - VM resource reconfiguration
  - VM allocation and migration
  - PM power management

- Realizing energy efficiency not only as best effort, but as strict energy cap
- Focus on the heterogeneity of the systems
- Integrating into real-world Cloud environment
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