A Simple ILP Simulation for CSO Joint Optimization

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The ultimate goal of Cross Stratum Optimization
- Finding the optimal solution to better serve the network and the application simultaneously

Problem Statement for Network Aware Application Resource Assignment and Mobility (NA-ARAM) in Data Center Environments

draft-so-network-aware-application-problem-02.txt
• Focusing on a simplified use case mentioned in the draft: Data Center selection problem
  – Multiple users using a application that is offered by multiple data centers

• Initial problem formulation based on ILP formulation
DC Selection: Status Quo

• Today’s Solution:
  – Network Stratum driven: choose the closest DC based on shortest path or hop count irrespective of the load of the DC (solution A)
  – Application Stratum driven: choose DC in order to optimize (load balance) load at DC, then run shortest path in the network to reach the DC (solution B)

• CSO-based Solution: selection optimized for both stratum
DC Selection: Problem Assumptions 1

- Network is modeled as a graph $G(N, L)$
- A subset of nodes $U$ is the set of users
- A subset of nodes $J$ is the set of DCs
- Each link $l \in L$ has a maximum bandwidth $BW_l$
- DC at node $j$ has a maximum CPU capacity $CPU_j$
- Users $i$ generates service requests towards DCs
- Each service request can choose any of the DCs
- Each service $(s)$ is characterized by:
  1. Bandwidth requirement $b_i^{(s)}$
  2. CPU requirement $c_i^{(s)}$
After DC at node $j$ is selected

1. Bandwidth $b_{ij}^{(s)} \leq b_i^{(s)}$ is assigned to service (s)

2. CPU $c_{ij}^{(s)} \leq c_i^{(s)}$ is assigned to service (s)

3. $QoE_{BW} = \frac{b_{ij}^{(s)}}{b_i^{(s)}}$

4. $QoE_{CPU} = \frac{c_{ij}^{(s)}}{c_i^{(s)}}$
DC Selection: Problem Definition

- Maximize $QoE = \min(QoE_{BW}, QoE_{CPU})$ given:
  - A network $G(N, L)$
  - A set of requests $T^{(s)}$
DC Selection ILP: Input

• Given:
  - $b_{i}^{(s)}$: required bandwidth for service $(s)$ originating at node $i$
  - $c_{i}^{(s)}$: required CPU for service $(s)$ originating at node $i$
  - $p_{ij}$: shortest path from node $i$ to node $j$
  - $x_{lij}$: binary; 1 if $p_{ij}$ is routed on link $l$, 0 otherwise
  - $BW_{l}$: bandwidth capacity of link $l$
  - $CPU_{j}$: CPU capacity of the DC at node $j$
DC Selection ILP: Variables

- Variables:
  - $y_{ij}^{(s)}$: binary; 1 if service $(s)$ uses DC $j$ and as a result is routed using the shortest path $p_{ij}$, 0 otherwise
  - $0 \leq bx_{ij}^{(s)} \leq 1$: fraction of the required bandwidth for service $(s)$ that can be routed in the network
  - $QoE_{BW}$: quality of experience indicator for bandwidth
  - $0 \leq cx_{ij}^{(s)} \leq 1$: fraction of the required CPU for service $(s)$ that can be allocated
  - $QoE_{CPU}$: quality of experience indicator for CPU
  - $QoE$: quality of experience indicator
DC Selection ILP: Formulation 1

• Objective Function:

\[ \text{Max: } K \cdot QoE + QoE_{BW} + QoE_{CPU} \]

• Subject to:

\[
\begin{align*}
  b x_{ij}^{(s)} & \leq 1 & \forall i, j, (s) \\
  b x_{ij}^{(s)} & \leq K y_{ij}^{(s)} & \forall i, j, (s) \\
  \sum_{j,(s)} y_{ij}^{(s)} & \leq 1 & \forall i, j, (s)
\end{align*}
\]
\[
\sum_{i,j,(s)} x_{lij} \cdot bx_{ij}^{(s)} \cdot b_i^{(s)} \leq BW_l \quad \forall l \in L
\]

\[
QoE_{BW} \leq \sum_j bx_{ij}^{(s)} \quad \forall i, (s)
\]

\[
 cx_{ij}^{(s)} \leq 1 \quad \forall i, j, (s)
\]

\[
 cx_{ij}^{(s)} \leq K \gamma_{ij}^{(s)} \quad \forall i, j, (s)
\]
DC Selection ILP: Formulation 3

\[ \sum_{i,(s)} c x_{ij}^{(s)} \cdot c_i^{(s)} \leq \text{CPU}_j \quad \forall j \in J \]

\[ QoE_{CPU} \leq \sum_j c x_{ij}^{(s)} \quad \forall i, (s) \]

\[ QoE \leq QoE_{BW} \]

\[ QoE \leq QoE_{CPU} \]
DC Selection ILP: Sample Topology

- DC: red nodes
- Users: grey nodes
DC Selection ILP: Sample Traffic
## DC Selection ILP: Results

### Fixed Traffic

<table>
<thead>
<tr>
<th></th>
<th>QoE</th>
<th>QoE_BW</th>
<th>QoE_CPU</th>
<th>BWUsage</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.567374</td>
<td>0.567374</td>
<td>0.894203</td>
<td>0.227653</td>
</tr>
<tr>
<td>B</td>
<td>0.487873</td>
<td>0.487873</td>
<td>1</td>
<td>0.335471</td>
</tr>
<tr>
<td>C</td>
<td>0.995088</td>
<td>0.996078</td>
<td>0.99901</td>
<td>0.424703</td>
</tr>
</tbody>
</table>

### Random Traffic

<table>
<thead>
<tr>
<th></th>
<th>QoE</th>
<th>QoE_BW</th>
<th>QoE_CPU</th>
<th>BWUsage</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.52293</td>
<td>0.52293</td>
<td>0.866666</td>
<td>0.220614</td>
</tr>
<tr>
<td>B</td>
<td>0.474624</td>
<td>0.474624</td>
<td>0.985605</td>
<td>0.332219</td>
</tr>
<tr>
<td>C</td>
<td>0.985618</td>
<td>1</td>
<td>0.985618</td>
<td>0.431867</td>
</tr>
</tbody>
</table>
DC Selection ILP: Conclusions

• Joint ILP optimization (C) shows significant benefit over solution A or solution B
• Good potential to improve network operation and QoE
• ILP not a scalable solution
Problem Extensions

- Service’s CPU and bandwidth requirements are correlated
- CPU, memory and storage sharing policies: guaranteed, best effort, etc.
- Network technologies: IP, MPLS, MPLD-TP, OTN, WDM, etc.
- IP bandwidth sharing policies: TCP, UDP, etc.
- Routing options: SP, ECMP, constrained routing, etc.
- Multiple service types
- Multiple classes of service (QoS)
- Multiple levels of service availability/reliability
- Time variant traffic demand distribution
- Scalability and multiple providers for DCs and networks
- Latency constraints: expected, jitter
- Security in DC and network