Online Strategies for Intra and Inter Provider Service Migration in Virtual Networks

or/and: How to migrate / allocate resources when you don’t know the future?

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Network Virtualization: Motivation

Success of the Internet architecture:
- This morning: continued success of *IP protocol*!
- nice: supports arbitrary applications
  „creativity on the edge“!
- even applicable to LANs and telephony

But still: same ‚dial tone‘ optimal for everything?
- *innovation* is only possible at lower and higher layers
- cannot experiment with different network cores
  (*ossification*)...
- different applications need *different technologies*: bulk data transfers vs social networking vs gaming vs live streaming... (distributions news vs social networking?)

Stefan Schmid @ IPTComm, 2011
Network Virtualization: High-level Concepts

Virtualisation concept: **decouples** services from physical infrastructure (e.g., OpenFlow)
- Vision: on-demand, QoS, service-tailored VNets (e.g., 9-1-1 VNets, Internet itself), ...
- Also a way „to route money“ (accounting and responsibilities)?

**Example 1:** A mobile service provider can move services to locations where they are most useful: **QoS**

**Example 2:** Virtual networks (VNets) can be allocated where the least resources are used, or where most energy can be saved, or...: **flexibility in spec**
Previous Work: New Business Opportunities!

Actors in the Internet today: service providers and ISPs

- **ISP**: provide access (own infrastructure, rental, or combination), „connectivity service“ (e.g., Telekom, AT&T, ...)
- **Service provider**: offers services (e.g., Google)
- **More roles exist today, often hidden in one company**

Envisioned hierarchical business roles

<table>
<thead>
<tr>
<th>Role</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Physical infrastructure provider (PIP):</strong></td>
<td>owns and manages physical infrastructure („substrate“), supports network virtualization (e.g., GENI: no federation, one PIP only)</td>
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<td><strong>Virtual network provider (VNP):</strong></td>
<td>assembles virtual resources from PIPs into virtual topology, makes negotiations, etc. (e.g., GENI clearinghouse)</td>
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<tr>
<td><strong>Virtual network operator (VNO):</strong></td>
<td>installation and operation of VNet according to SP needs, e.g., triggering cross-PIP migration, etc.</td>
</tr>
<tr>
<td><strong>Service provider (SP):</strong></td>
<td>uses VNet to offer services (application or transport service)</td>
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This Paper: Online Service Migration for better QoS

When and where to move the service, to maximize QoS and taking migration cost into account?

Access pattern changes, e.g., due to mobility (commuter scenario), due to time-of-day effects (time-zone scenario), etc.
Dealing with Unpredictable Demand?

How to deal with dynamic changes (e.g., mobility of users, arrival of VNets, etc.)?

**Online Algorithm**

Online algorithms make decisions at time $t$ without any knowledge of inputs / requests at times $t' > t$.

**Competitive Ratio**

Competitive ratio $r$,

$$r = \frac{\text{Cost}(\text{ALG})}{\text{cost}(\text{OPT})}$$

Is the price of not knowing the future!

**Competitive Analysis**

An $r$-competitive online algorithm $\text{ALG}$ gives a worst-case performance guarantee: the performance is at most a factor $r$ worse than an optimal offline algorithm $\text{OPT}$!

In virtual networks, many decisions need to be made online: online algorithms and network virtualization are a perfect match! 😊

No need for complex predictions but still good! 😊
Online Service Migration

Assume: one service, migration cost $m$ (e.g., service interruption cost), access cost 1 per hop (or sum of link delays along migration path).

When and where to move for \textit{offline algorithm} or \textit{optimal competitive ratio}?
Optimal Offline Algorithm

Can be computed using **dynamic programming** (optimal substructures)!
Filling out a for optimal server configuration (at node $u$ at time $t$):

$$\text{opt}[u,t] = \min_{v \in V} \{ \text{opt}[t-1][v] + \text{MIG}(v,u) + \text{ACC}(u,t) \}$$

Visualization:
Online Algorithm

Idea: Migrate to center of gravity when access cost at current node is as high as migration cost!

Time between two migrations: phase, multiple phases constitute an epoch:
In each phase go to center of nodes which are better!

Center of Gravity

For each node \( v \), use \( \text{COUNT}(v) \) to count access cost if service was at \( v \) during entire epoch. Call nodes \( v \) with \( \text{COUNT}(v) < \frac{m}{40} \) active. If service is at node \( w \), a phase ends when \( \text{COUNT}(w) \geq m \): the service is migrated to the center of gravity of the remaining active nodes („center node“ wrt latency or hop distance). If no such node is left, the epoch ends.
Online Algorithm: Visualization

Before phase 1:
Online Algorithm: Visualization

Before phase 2:
Online Algorithm: Visualization

Before phase 3:
Epoch ends!

Of course, not converging if demand is dynamic!
(Simplified example.)
Online Algorithm: Analysis

Competitive analysis?

\[ r = \frac{\text{ALG}}{\text{OPT}} \leq ? \]

**Lower bound cost of OPT:**
In an epoch, each node has at least access cost \( m \), or there was a migration of cost \( m \).

**Upper bound cost of ALG:**
We can show that each phase has cost at most \( 2m \) (access plus migration), and there are at most \( \log(m) \) many phases per epoch!

**Theorem**

ALG is \( \log(m) \) competitive!
Reality is more complex...: Multiple PIPs

Migration across provider boundary costs transit/roaming costs, detailed topology not known, etc.

Theorem
Competitive ALGs still exist!
Reality is more complex...: Multiple Servers

Multiple servers allocated and migrated dynamically depending on demand and load, servers have running costs, etc.

Theorem
Competitive ALGs still exist!
Summary of Theoretical Contribution

Cost model

- migration cost: service interruption (duration: depends on bandwidth)
- access costs: latency (triangle inequality)
- roaming costs: inter-provider migration

Contribution

- online and offline algorithms for various scenarios
- take-aways: under what dynamics is flexibility better?
On the Benefit of Flexibility: Dynamics Scenarios*

**Commuter Scenario**
Dynamics due to mobility: requests cycle through a 24h pattern: in the morning, requests distributed widely (people in suburbs), then focus in city centers; in the evening, reverse.

**Time Zone Scenario**
Dynamics due to time zone effects: request originate in China first, then more requests come from European countries, and finally from the U.S.

* Predictable scenarios, but we do not exploit. Reality less predictable!

**Static Algorithm**
Algorithm which uses optimal static server placements for a given request seq.
Time Zone Scenario with Different Request Correlations

Ratio relatively low and not increasing much in „average case“. Higher correlation increases ratio.
Increasing demand triggers creation of **additional servers** (more for faster growing **load functions**): have **running costs** (will be shut down again), maybe **standby** for faster/cheaper startup.
Conclusion and Takeaways

- Flexible server allocation for network virtualization and beyond (e.g., cloud): generalized model for a challenging problem

- **Online perspective**: algorithms have to decide without knowing the future; relevant for many aspects of network virtualization

- **When useful?** Depends on dynamics!

- Streaming migration demonstrator for our network virtualization prototype (VLAN based):

![Diagram of TESTBED VNET with SN A, SN B, and SN C connected to SERVER and AP1, AP2, AP3 with Clients 1, 2, 3, 4, 5, 6, 7, 8, 9]
Outlook: Competitive VNet Embedding

VNet

Access Control

100 $

accept or reject?

Physical Network
Outlook: Competitive VNet Embedding

Cheap realization => Yes!

VNet

Access Control

Physical Network

100 $

accept or reject?
Outlook: Competitive VNet Embedding

Expensive $\Rightarrow$ No!

VNet

100 $

Access Control

accept or reject?

Physical Network
Outlook: Competitive VNet Embedding

Expensive => No!

Online primal-dual framework by Buchbinder and Naor: log competitive!
Thank you!

Further reading: Project website!
http://www.net.t-labs.tu-berlin.de/~stefan/virtu.shtml
Comparison to Related Work

- Conservative **online perspective** on resource management: no predictions possible, but with worst-case guarantees

- Detailed costs model for **VNet application** (multiple PIPs with transit costs, costs depending on scenario: shared NFS, etc.)

- Allows to study the „use of flexibility“ (compared to **static algorithms**)  

- Like dynamic facility location problems where additional facilities can be **created, migrated and closed** (at non-zero cost) and where facilities have **running costs** and access costs that depend on **load**

- Often a special case of **metrical task systems** but sometimes better bounds can be obtained for the more specific model!