Exit Seminar:
Minimizing Operating Expenditure of Cloud and Communication Networks using Virtualization Technologies

By
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Outline

1. Cost-Efficient Live VM Migration based on Varying Electricity Cost in Optical Networks


3. On Service-Chaining Strategies using Virtual Network Functions in Operator Networks

4. A Scalable Approach for Service Chain (SC) Mapping with Multiple SC Instances in a Wide-Area Network

5. Virtual-Mobile-Core Placement for Metro Network
Cost-Efficient Live VM Migration based on Varying Electricity Cost in Optical Cloud Networks
Motivation – Information and Communication Technology (ICT) 
energy usage on the rise

Worldwide IT Spending on Servers, Power and Cooling, and 
Management/Administration, 1996–2012

Source: IDC, 2008

Virtualization

• To increase utilization of physical servers, virtualization is employed

• Virtualization creates duplicate “virtual” instances of underlying hardware. These instances are called Virtual Machines (VMs)

• Workloads in Data centers (DCs) are virtualized into VMs

• Energy consumption from running VMs on physical servers

• Increasing VM density per server
  • Reduces energy consumption – less server’s used
  • Decreases server deployment rate
Dynamic Electricity Pricing in Independent System Operator (ISO) / Regional Transmission Organization (RTO)

[Map of various regions including California ISO, ERCOT, SPP, MISO, PJM, NYISO, New England, among others]

Cost of electricity ($/MWh) vs Hour

- CAISO
- ERCOT
- SPP
- MISO
- PJM
- NYISO
- New England

[Graph showing the cost of electricity ($/MWh) over 24 hours for different regions]

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Live VM Migration

Using VM migration to exploit variation in electricity prices

- Migration time
- Resource consumption
- VM Downtime
Power Model

• Pack servers and racks (VM consolidation).

• Switching off racks and servers at source DC.

• Switching on racks and servers at destination DC.
Research Contributions

• We propose using dynamic electricity pricing and Live VM migration to reduce VM operating cost.

• We have presented a Mixed-Integer Linear Program (MILP) for VM migration over a multi-hour period, which makes decisions on VM migration based on migration cost and cost of operating VMs at source DC and destination DC.

• We are first to consider the cost incurred at the source DC (due to racks and servers that will be switched off) during VM migration.
Tradeoffs

• Energy consumption at source DC

• Energy consumption at destination DC

• Energy consumption by network resources

• VM consolidation in racks and servers
4 hour simulation

- Hourly price of electricity across the DC nodes.
- Prices have been synchronized with Eastern Standard Time (EST).

<table>
<thead>
<tr>
<th>Hour</th>
<th>DC node 2</th>
<th>DC node 5</th>
<th>DC node 6</th>
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<tr>
<td>0400</td>
<td>$37.46</td>
<td>$21.99</td>
<td>$18.79</td>
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<td>0500</td>
<td>$29.82</td>
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0700 - 0800

<table>
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<tr>
<th>Node 2</th>
<th>Node 5</th>
<th>Node 6</th>
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<tbody>
<tr>
<td>$35.12</td>
<td>$27.01</td>
<td>$27.51</td>
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DC

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Publications


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How to Reduce Operating Costs of Communication Networks? 
Network Function Virtualization (NFV)
Motivation

Operator Network (AT&T, Verizon …)

Proprietary Network Appliances

Also, affects deployed service in terms of
• Scalability
• Agility

Incoming Traffic
Increasing Traffic

Difficulty in
• Upgrade
• Replacement
• Maintenance
Continued…

Traditional Network Appliances

Network Function Virtualization

Firewall

NAT

Virtual Firewall (VNF 1)

Virtual NAT (VNF 2)

Standard High Volume x86 Servers
NFV framework and role of VNFs
“Service Chain (SC)” is used “to describe the deployment of service functions, and the network operator’s process of specifying an ordered list of service functions that should be applied to a deterministic set of traffic flows”[10]

A “Service Chain (SC)” specifies a set of network functions configured in a specific order.

With NFV, service functions are realized as Virtual Network Functions (VNFs). In the following contributions, SCs are configured from VNFs.

Challenges of Service Chaining

• Service Chain Instance Deployment
  • Building appropriate NFV Infrastructure
  • Service Chain Placement and Routing
  • Modular design of VNFs

• Service Chain Description
  • Service Description
  • Service Composition (Dynamic/Static)
  • Service Scalability

• Continuous Network Service Delivery

• Security Considerations
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On Service-Chaining Strategies using Virtual Network Functions in Operator Networks
Motivation

• Reduce bandwidth consumption for fulfilling service demands by deploying VNF service chains on the shortest paths between source and destination (number of hops)

• Look at different deployment strategies (here, service-chaining strategies) for minimizing bandwidth consumption
  • These strategies are various ways of distributing VNFs

• In this study, we are dealing with an Enterprise WAN scenario
Service Chain Placement and Routing

Wan acceleration service chain

Virtualization resource

VNF Placement

Routing

Branch 1

Branch 2

Operator Network (AT&T, Verizon...)

HQ
Network-enabled Cloud

Network-enabled Cloud

Cloud Computing Environment

Backbone Optical Network

Service Chaining Strategies

- MB Service Chain
- DC Node
- NFV Node
- VNF Service Chain

- "MB" Strategy
- "DC only" Strategy
- "NFV ALL" Strategy
- "DC x NFV" Strategy (x=2)
CPU-core-to-throughput relationship of a VNF

<table>
<thead>
<tr>
<th>Applications</th>
<th>Throughput</th>
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<tr>
<td></td>
<td>1 Gbps</td>
</tr>
<tr>
<td>NAT</td>
<td>1 CPU</td>
</tr>
<tr>
<td>IPsec VPN</td>
<td>1 CPU</td>
</tr>
<tr>
<td>Traffic Shaper</td>
<td>1 CPU</td>
</tr>
</tbody>
</table>

Research Contributions

• We investigate different service-chaining strategies for VNF service chains to *reduce bandwidth consumption* in operator networks.

• We formulate an **Integer Linear Program (ILP)** which explicitly ensures service chaining for each service request while minimizing bandwidth consumption and satisfying the CPU core requirements for each service request.
Tradeoffs

- CPU cores per NFV node
- Number of NFV nodes
- Location of NFV nodes
Bandwidth vs CPU cores per node

“DC x NFV” Strategy (x=1)
Bandwidth Vs Number of NFV nodes

“DC x NFV” Strategy (x=1)

“DC x NFV” Strategy (x=2)
Bandwidth Vs Location of NFV nodes

“DC x NFV” Strategy (x=1)

CPU Cores: y

Traffic: x

DC Node

NFV Node

VNF Service Chain
No DC Vs DC

DC Node
NFV Node
VNF Service Chain

“NFV ALL” Strategy
CPU Cores per node: y
Traffic: 2x

“DC NFV ALL” Strategy
CPU Cores per node: y
Traffic: 4x
Simulation Scenario 1

Service Chain 1
- NAT
- Traffic Shaper
- Application Optimization
- Encryption
- WAN Acceleration

Service Chain 2
- Firewall
- Intrusion Detection System
- Decryption
- QoS
Scenario 1 – 1 Gbps traffic
Continued…

[Graphs showing relative network resource consumption across various core counts and configurations. Each graph compares different scenarios such as MB only, DC only, DC 1 NFV, DC 2 NFV, DC 3 NFV, DC 4 NFV, and DC NFV ALL.]
Scenario 1 - Results

1 Gbps

2.5 Gbps

7.5 Gbps

5 Gbps

10 Gbps

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41
Other Scenarios

[Diagrams of network scenarios with labeled nodes and connections, showing NFV-capable nodes and headquarters/branch offices.]
Conclusions

• DC must be part of NFV infrastructure (NFVI)
• NFVI with few NFV nodes with high nodal degree can give bandwidth consumption close to that achieved by shortest path routing


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A Scalable Approach for Service Chain (SC) Mapping with Multiple SC Instances in a Wide-Area Network
Single Instance per Service Chain (SC)

Service Chain 1

1. Demand Requests SC1
   \[ r_1 = 14 \rightarrow 1, SC1 \]
   \[ r_2 = 4 \rightarrow 7, SC1 \]

Service Chain 2

2. Demand Requests SC2
   \[ r_3 = 14 \rightarrow 2, SC2 \]
   \[ r_4 = 7 \rightarrow 4, SC2 \]

NFV node

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Multiple Instances per SC

2 Demand Requests SC1
\[ r_1 = 14 \rightarrow 1, SC1 \]
\[ r_2 = 4 \rightarrow 7, SC1 \]

2 Demand Requests SC2
\[ r_3 = 14 \rightarrow 2, SC2 \]
\[ r_4 = 7 \rightarrow 4, SC2 \]
Tools Used: Column Generation

• Generates multiple configurations for each service chain

• Each configuration is a tuple consisting of
  1. VNF Placement for the SC
  2. Routing from the 1st VNF of the SC to the last VNF of the SC

• A column generation framework consists of the master problem and pricing problem

• The pricing problem generates configuration while master problem selects the optimal configuration and routing from source to 1st VNF and last VNF to destination
Continued…

Path determined in master problem

Configuration generated in pricing problem
Research Contributions

• We **reduce bandwidth consumption** for operator networks while ensuring service-chaining for multiple service chains by using multiple instances for each SC

• We formulate a **column generation framework** which minimized the bandwidth consumption for operator networks by holistically mapping SC instances taking into account
  • Number of SC instances allowed
  • Number of NFV Nodes allowed
Tradeoffs

• Bandwidth Vs Number of SC instances deployed
• Bandwidth Vs Number of NFV nodes allowed
Results – NSFNet (BW vs. Instances)
NSFNet (BW vs Instances vs NFV nodes allowed)

Number of NFV Nodes
- K=14
- K=5
- K=4
- K=3
- K=2
- K=1

BW Used (Gbps)

Number of Instances

48%
22%
10%
5%
1%

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Conclusion

• Near optimal bandwidth consumption achieved by using relatively small number of SC instances and NFV Nodes
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Virtual-Mobile-Core Placement for Metro Network
Mobile Core Architecture (Evolved Packet Core (EPC))
Control and Data Plane Elements of EPC

• Exclusively Control Plane Elements
  • Mobility Management Element (MME)
  • Policy and Charging Rules Function (PCRF)
  • Home Subscriber Server (HSS)

• Data Plane Elements
  • Serving Gateway (SGW)
  • Packet Data Network Gateway (PGW)
Motivation

• Volume of data to be transported across a mobile network keeps increasing

• Traditional EPC is centralized and requires constant upgrading of mobile core (both EPC functions and backhaul)
### Control Plane Interactions

**EPC Non-Access Stratum (NAS) Procedures Summary**

<table>
<thead>
<tr>
<th>Event Type</th>
<th>MME</th>
<th>HSS</th>
<th>S-GW</th>
<th>P-GW</th>
<th>PCRF</th>
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<tbody>
<tr>
<td>Attaches</td>
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<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
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<tr>
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<td>1</td>
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<td>0</td>
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<tr>
<td>Connected-to-Idle</td>
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<td>X2-based Handovers</td>
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<tr>
<td>S1-based Handovers</td>
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<td>3</td>
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<tr>
<td>Tracking Area Updates</td>
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<td>0</td>
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<tr>
<td><strong>Total</strong></td>
<td>34</td>
<td>2</td>
<td>14</td>
<td>6</td>
<td>3</td>
</tr>
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</table>

**TABLE I. TRANSACTION PER NAS EVENT BY EPC ELEMENT**
Control- and Data-plane interactions as Service Chains (SCs)

Control Plane - NAS Attach Procedure as SC (with EPC elements only)

MME → HSS → MME → PGW → MME → SGW → MME

Data Plane - Download
PGW → SGW

Data Plane - Upload
SGW → PGW
Difference from previous work

- Mobile core is critical for connecting User Equipment (UE) to Internet and vice-versa

- Mobile core is also critical for functioning of the Radio Access Network (RAN)

- Here, Service Chains (SCs) result from looking at interaction of various mobile core elements whereas earlier SCs were actual value-added services
Research Contributions

• We **reduce bandwidth consumption** in metro networks by distributing EPC VNFs in the metro network.

• We develop an **Integer Linear Program (ILP)** which places EPC VNFs based on control- and data-plane interactions, NFV nodes available, VNF replicas, latency requirement of control signaling, latency requirement of services and processing delay of VNFs.
Conclusion

• Only SGW and PGW need to be replicated in the metro core network to minimize bandwidth consumption
References


[19] Introduction to Evolved Packet Core (EPC) – EPC elements, protocols and procedures – Alcatel Lucent

[20] Understanding the bottlenecks in Virtualizing Cellular Core Network Functions – Intel Labs, Connectem, AT&T Labs

[21] https://sites.google.com/site/amitsciscozone/home/te-notes/default-bearer-setup