On Service Chaining using Virtual Network Functions in Operator Networks

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July 29, 2016

Acknowledgement: NSF Grant No. CNS-1217978
Network Function Virtualization (NFV)
Network-enabled Cloud

Service Chain Deployment (VNF Placement and Routing)

- Encryption service chain
- Virtualization resource
- ISI Delhi
- ISI Kolkata
- ISI Bengaluru
- Operator Network (BSNL, Airtel...)
- VNF Placement
- Routing
Problem Description

- **Given**
  - Network topology
  - Capacity of link
  - Set of DC locations
  - Set of NFV-capable nodes (in addition to the DC)
  - Traffic flows between source-destination pairs
  - Set of $k$-shortest paths between source-destination pairs
  - Set of required network functions (for the service chain)
  - The service chain to be deployed
  - Number of CPU cores present per NFV-capable node

- **Objective**
  - Minimize the bandwidth consumption in the network by optimal placement of the VNFs.
Constraints

- Single-path routing
- Capacity constraint for a link (bandwidth)
- Capacity constraint for a node (CPU cores)
- VNF sequence in the service chain (across nodes)
- VNF sequence in the service chain (inside a node)
Objective: Minimize Network Resource Consumption

Single-path routing constraint

Capacity constraint for link

Capacity constraint for node

VNF sequence in the service chain

VNF sequence in the service chain (inside a node)
CPU-core-to-throughput relationship of a VNF

<table>
<thead>
<tr>
<th>Applications</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<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>

VNF placement (on throughput and CPU cores)

Service Chaining Strategies

- **MB only** – Middle box (MB) used for service chaining

- **DC only (Centralized)** – Data center (DC) used for service chaining

- **DC NFV x (Best-Case scenario)** – Data center (DC) and ‘x’ NFV-capable nodes used for service chaining. `DC NFV ALL’ refers to situation where all network nodes are NFV-capable.

- **ALL NFV (Completely Distributed)** – A completely distributed strategy where all nodes are NFV-capable and there is no DC.
Simulation details

Enterprise WAN

Headquarter
Branch Office
NFV-capable nodes
Continued…

Service Chain 1

- NAT → Traffic Shaper → Application Optimization → Encryption → WAN Acceleration

Service Chain 2

- Firewall → Intrusion Detection System → Decryption → QoS

Traffic Flows

2 → 11 → 5 → 14
1 Gbps traffic
Continued…

Inflection point
Continued…

![Graph showing relative network resource consumption across different core counts and configurations. The graph highlights an inflection point at 4 cores with specific configurations.](image)

- **MB only**
- **DC only**
- **DC 1 NFV**
- **DC 2 NFV**
- **DC 3 NFV**
- **DC 4 NFV**
- **DC NFV ALL**
Inflection Point (DC NFV ALL)
2.5 Gbps traffic
Inflection Point (DC NFV ALL)

Normalized Network Resource Consumption vs Core Count for 1 Gbps and 2.5 Gbps.

The graph shows the normalized network resource consumption for different core counts. The 2.5 Gbps line indicates a point of inflection around 12 cores, where the consumption levels off.
Results

1 Gbps

2.5 Gbps

7.5 Gbps

5 Gbps

10 Gbps
Inflection points (DC NFV ALL)
ALL NFV (Completely-Distributed) vs DC NFV ALL

![Bar Graph]

- **Y-axis**: Relative Network Resource Consumption
- **X-axis**: Core Count (2, 4, 8, 12, 24, 48, 96, 192)
- **Legend**: 1 Gbps

The graph compares the relative network resource consumption across different core counts for 1 Gbps.
ALL NFV infeasible for these CPU core counts at 2.5 Gbps
Continued…

The chart depicts the relative network resource consumption across different core counts and bandwidth capacities. The x-axis represents the core count, ranging from 2 to 192. The y-axis shows the relative network resource consumption, with values ranging from 0.9 to 1.3.

Four bandwidth capacities are compared: 1 Gbps, 2.5 Gbps, 5 Gbps, 7.5 Gbps, and 10 Gbps. Each bandwidth capacity is represented by a different color:

- 1 Gbps: Blue
- 2.5 Gbps: Orange
- 5 Gbps: Gray
- 7.5 Gbps: Yellow
- 10 Gbps: Green

The chart illustrates how different bandwidth capacities affect network resource consumption at varying core counts.
Summary

- We formulated an optimization problem for the VNF placement and routing problem for service chain deployment by network operators.

- We defined different service chaining strategies and analyzed the network resource consumption across these strategies for different CPU core counts and traffic bales.

- We found that by determining the “inflection point” for core count and offered traffic, we can achieve close-to-optimal network resource consumption and reduce it by close to 50%.
Inferences

- **Congestion aspect**: In ‘DC-only’ strategy, all flows have to routed through a single node which will lead to congestion at DC nodes.
  - Congestion at DC nodes can be shown through the infeasibility of certain nodes to be DC in the ‘DC-only’ scenario in our ILP.
  - This infeasibility will occur at different traffic loads for different nodes in the network.

- **Load-balancing (Resource-contention?) aspect**: NFV-capable nodes help reduce the congestion problem on the single DC node and reduce the operating expenditure for the network operator.
  - Change in network resource between ‘DC-only’, ‘DC NFV 4’ and ‘DC NFV ALL’ for low, high and infeasible traffic loads for a particular traffic matrix
Network Topology (Internet2)

Network Topology (Geant)

Congestion aspect

- **Congestion point calculation**
  - Nodal degree * capacity < total flows in the network
  - Number of paths that include that node for each sd-pair that satisfy the capacity constraints
  - Some anomalies can be explained when the traffic flows terminate at a certain source or destination.

### NSF 14

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gbps</td>
<td>None</td>
</tr>
<tr>
<td>2.5 Gbps</td>
<td>1,2</td>
</tr>
<tr>
<td>5 Gbps</td>
<td>4,5,6,7</td>
</tr>
<tr>
<td>7.5 Gbps</td>
<td>11,12,13,14</td>
</tr>
<tr>
<td>10 Gbps</td>
<td>3,8,10</td>
</tr>
</tbody>
</table>

### For each of the Internet2, Geant

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Infeasible DC Nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TM1</td>
</tr>
<tr>
<td>1 Gbps</td>
<td>None</td>
</tr>
<tr>
<td>2.5 Gbps</td>
<td>1,2</td>
</tr>
<tr>
<td>5 Gbps</td>
<td>4,5,6,7</td>
</tr>
<tr>
<td>7.5 Gbps</td>
<td>11,12,13,14</td>
</tr>
<tr>
<td>10 Gbps</td>
<td>3,8,10</td>
</tr>
</tbody>
</table>
Continued..
Traffic Matrix? (TMx)

- 3 traffic matrices for each topology.
- Each traffic matrix will have 3 traffic loads.
  - Low, high and infeasible loads.
  - Infeasible load: traffic load at which ‘DC-only’ strategy is infeasible for all nodes in the network topology.
TM’s for Internet 2

TM1

TM2

TM3

NFV-capable nodes
TM’s for Geant
Load balancing aspect of an NeC

Maximum link occupation

Traffic Matrices with different Loads
Memory is more important than CPU core count

- Will be run on NSF 14 itself
- Memory requirement only there for initial installation (Inelastic)
- Memory requirement scales with increasing traffic (elastic)
- How to map the memory requirements of each of the VNF’s?
- Make it uniform like 1 GB for each or map mimicking the CPU core assigned to each VNF
Continued…

DC NFV ALL - memory based VNF characteristics

![Graph showing memory resource consumption for different VNF characteristics](image)

- Inelastic
- Elastic 1 Gbps
- Elastic 5 Gbps
- Elastic 10 Gbps

Memory

Relative network resource consumption

1 GB  2 GB  4 GB  8 GB  16 GB  32 GB  64 GB  128 GB
Thank You
Related Work


Ongoing Work

- A column-generation based optimization model for the current problem (in collaboration with Prof. Brigitte Jaumard, Concordia University, Montreal)
  - Model will scale to provide placement of VNFs for multiple service chains
  - More problem context like latency of VNFs, maximum number of VNF instances that can be deployed etc. will also be included

- In the problem definition stage for the next problem, “Towards a service-oriented virtual evolved packet core”, joint placement of VNFs for EPC functionalities and service chains deployed in the SGi-LAN (Service Gateway interface LAN)
Open Research Problems

- **Service chain composition** (formalize a request for chaining VNFs together)

- **Deployment of VNF service chains in Multi-Domain environments**

- **Virtualization of the mobile core**
  - EPC
  - SGi-LAN
  - IMS for VoLTE and video

References