On Service Chaining using Virtual Network Functions in Operator Networks

By
Abhishek Gupta
Department of Computer Science
University of California, Davis

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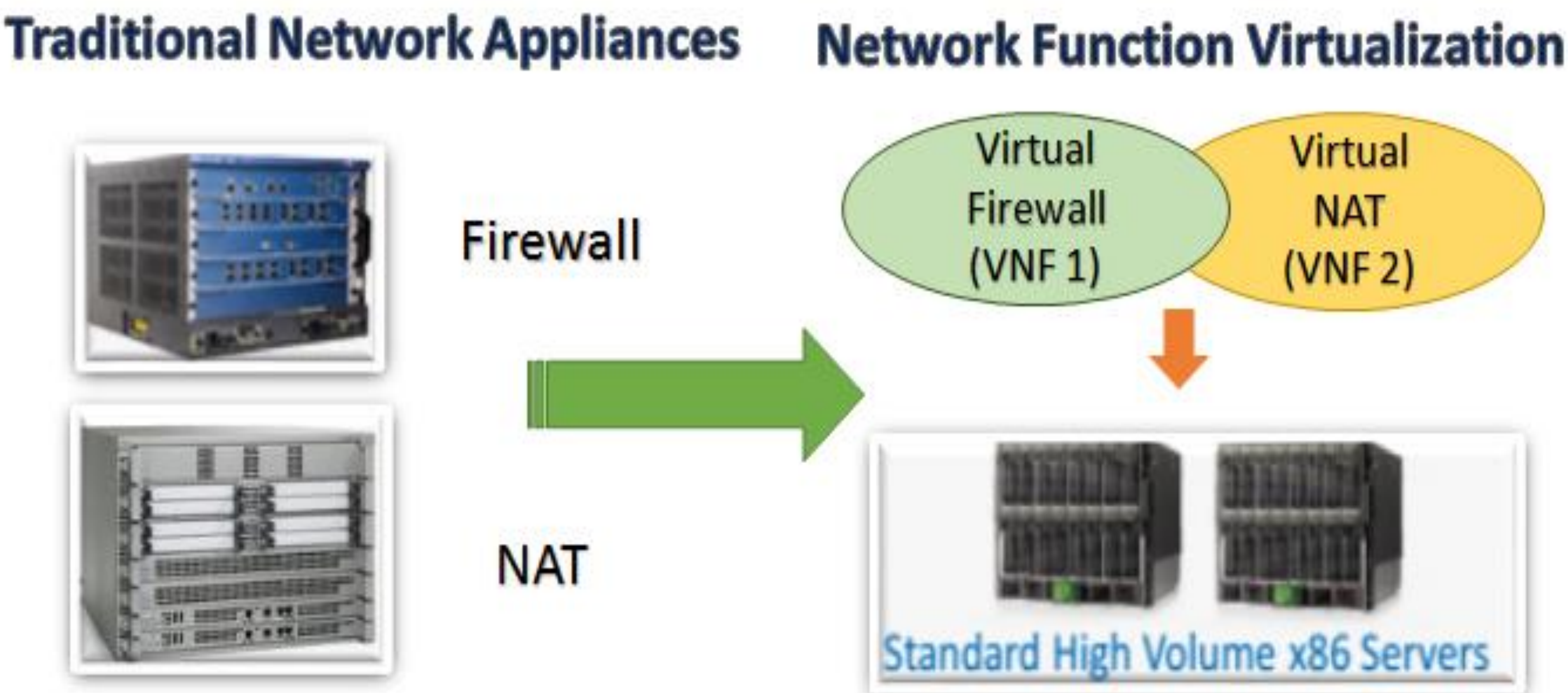
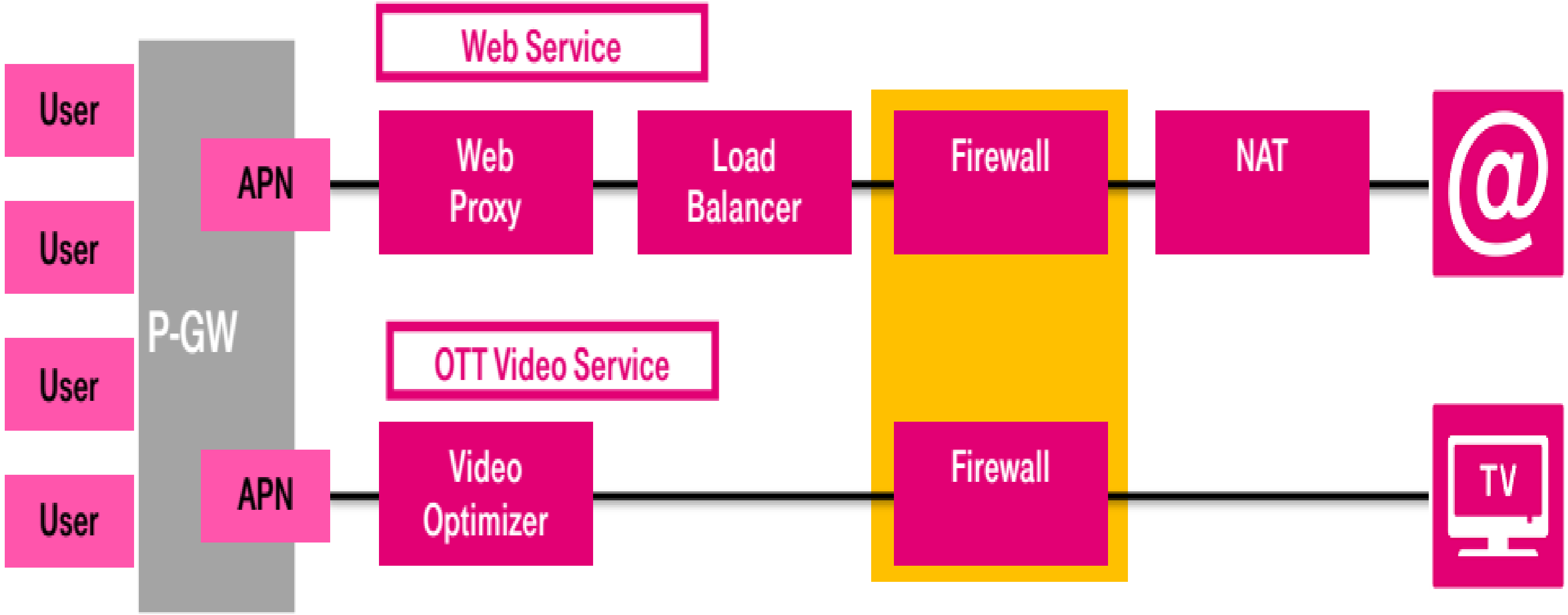
Network Function Virtualization (NFV)

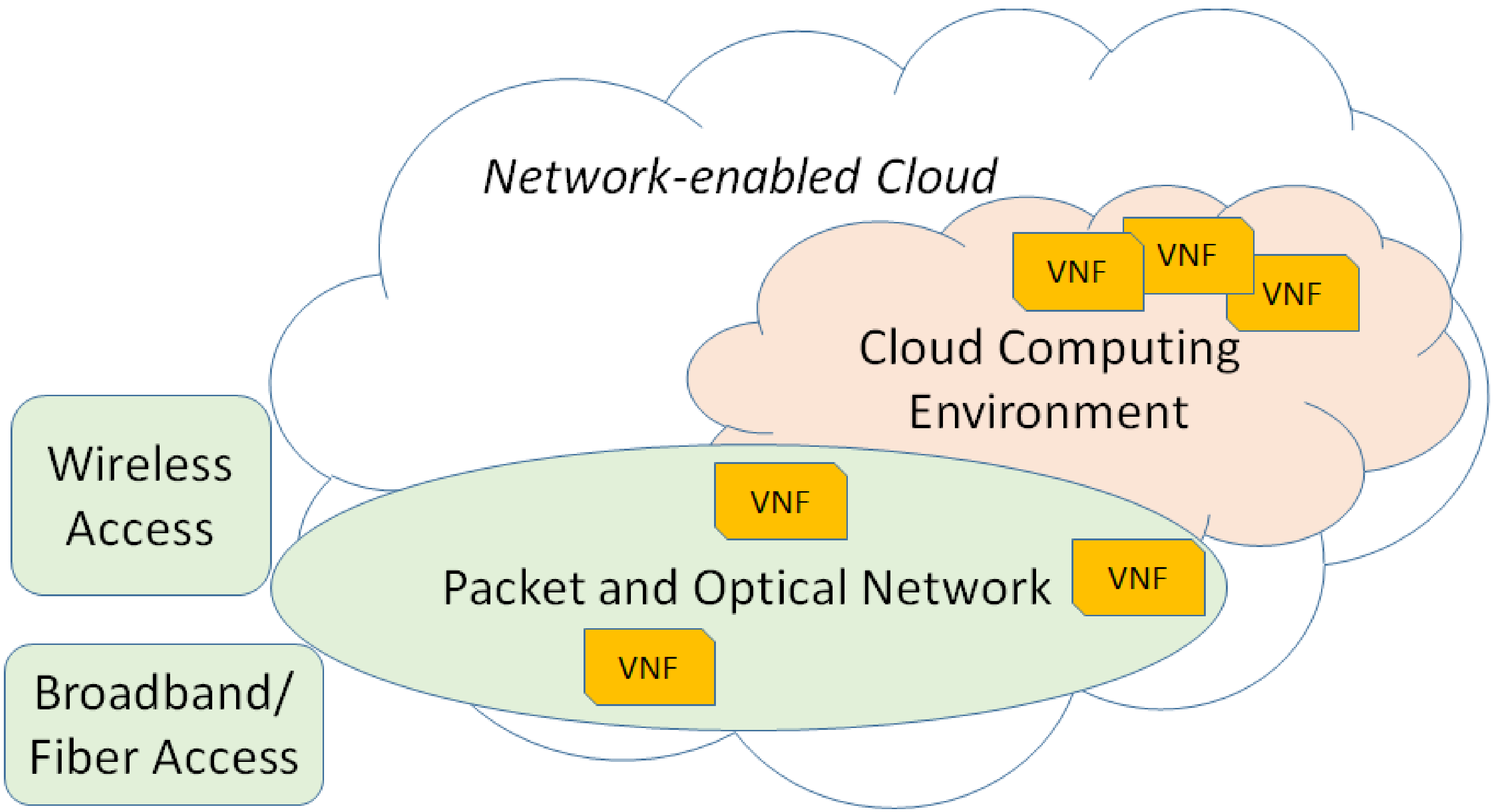


Service Chain

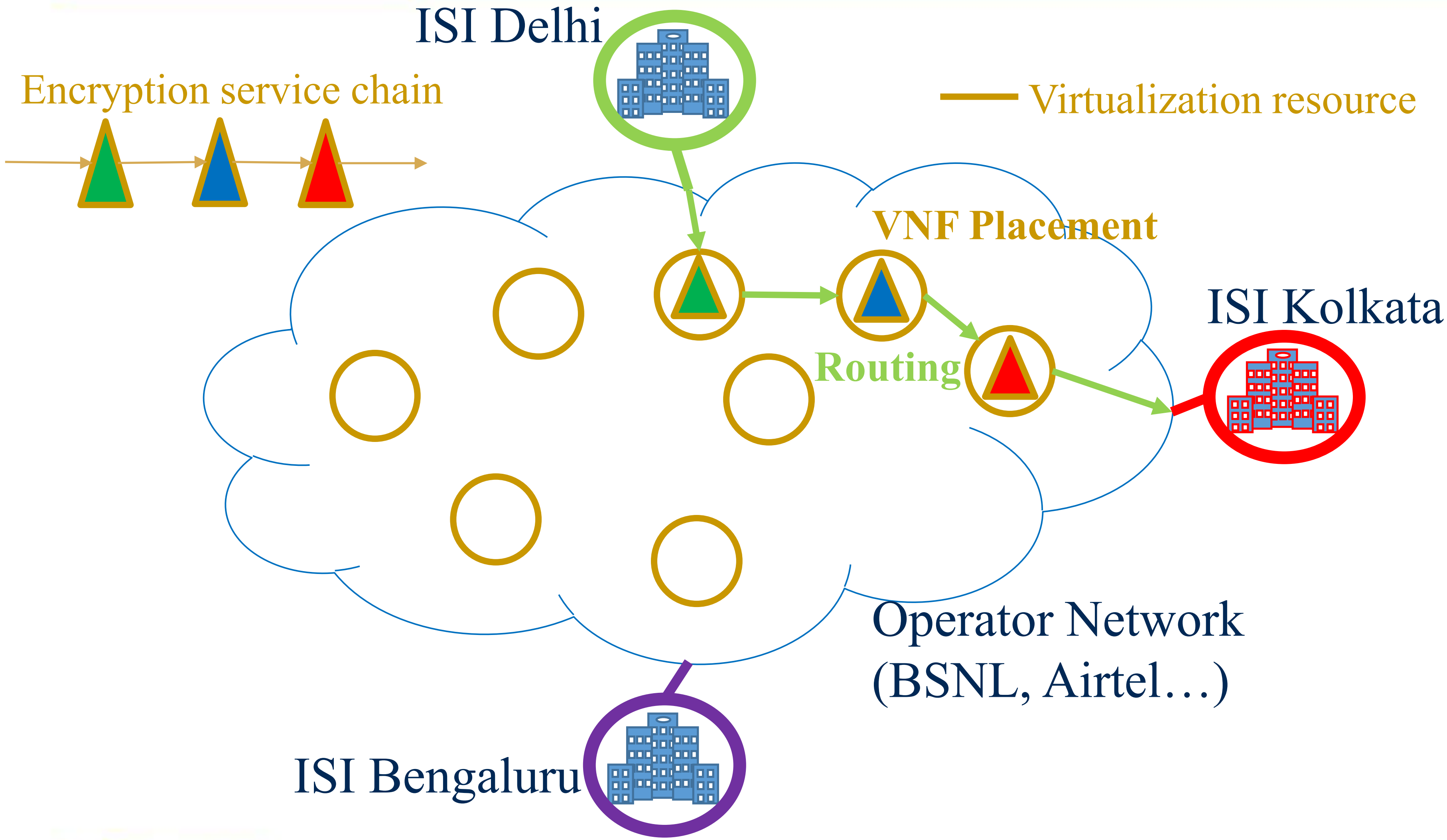


[1] Deutsche Telekom, “Flexible Service Chaining : Requirements and Architecture”, 2014

Network-enabled Cloud



Service Chain Deployment (VNF Placement and 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.**

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[4]A. Gupta et al., "Joint Virtual Network Function Placement and Routing of Traffic in Operator Networks," *Technical Report, UC Davis*

Continued…

- **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)**

[4]A. Gupta et al., "Joint Virtual Network Function Placement and Routing of Traffic in Operator Networks," *Technical Report, UC Davis*

Integer Linear Program

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)

$$\text{Minimize}: \quad \sum_{(s,d)\in\Psi_{s,d}} \sum_{p\in K_{s,d}} r_p^{(s,d)} \times L_{s,d}^{p} \times \Phi_{s,d} \tag{1}$$

$$\sum_{p\in K_{s,d}} r_p^{(s,d)} = 1 \qquad \forall (s,d)\in\Psi_{(s,d)} \tag{2}$$

$$\sum_{(s,d)\in\Psi_{s,d}} \sum_{r_p^{(s,d)}\in R_{(s,d)}^{(i,j)}} r_p^{(s,d)} \times \Phi_{s,d} \le C_{(i,j)} \qquad \forall (i,j)\in E \tag{3}$$

$$\sum_{(s,d)\in\Psi_{s,d}} \sum_{f} l_{v,(s,d)}^{f} \times \Phi_{s,d} \times N_f \le \Theta \qquad \forall v\in V_{NF} \tag{4}$$

$$q_{p,(s,d)}^{f,v} = l_{v,(s,d)}^{f} \cap r_p^{(s,d)} \qquad \forall (s,d)\in\Psi_{(s,d)}, \quad \forall f\in\Gamma, \quad \forall p\in K_{s,d}, \quad \forall v\in p \mid v\in V_{DC}\cup V_{NF} \tag{5}$$

$$\sum_{p\in K_{s,d}} q_{p,(s,d)}^{f,v} >= 1 \qquad \forall f\in\Gamma, \quad \forall (s,d)\in\Psi_{(s,d)}, \quad \forall v\in p \mid v\in V_{DC}\cup V_{NF} \tag{6}$$

$$j_{p,(s,d),(u,u)}^{(f_1,f_2)} \ge q_{p,(s,d)}^{f_1,u} \qquad \forall (s,d)\in\Psi_{(s,d)}, \quad \forall p\in K_{s,d}, \quad \forall u\in p \mid u\in V_{DC}, \quad \forall (f_1,f_2)\in\Gamma \mid (f_1\to f_2)\in\Pi \tag{7}$$

$$j_{p,(s,d),(u,v)}^{(f_1,f_2)} = q_{p,(s,d)}^{f_1,u} \cap q_{p,(s,d)}^{f_2,v} \qquad \forall p\in K_{s,d}, \quad \forall (f_1,f_2)\in\Gamma \mid (f_1\to f_2)\in\Pi, \quad \forall (s,d)\in\Psi_{(s,d)}, \quad \forall (u,v)\in S_{u,v} \tag{8}$$

$$\boxed{\sum_{p\in K_{s,d}} \sum_{(u,v)\in p} j_{p,(s,d),(u,v)}^{(f_1,f_2)} >= 1 \qquad \forall (u,v)\in S_{u,v}, \quad \forall (s,d)\in\Psi_{(s,d)}, \quad \forall (f_1,f_2)\in\Gamma \mid (f_1\to f_2)\in\Pi} \tag{9}$$

$$\sum_{t} j_{p,(s,d),(t,u)}^{(f_1,f_2)} \ge j_{p,(s,d),(u,v)}^{(f_2,f_3)} \qquad \forall p\in K_{s,d}, \quad \forall (s,d)\in\Psi_{(s,d)}, \quad \forall (f_1,f_2,f_3)\in\Gamma \mid (f_1\to f_2\to f_3)\in\Pi, \quad \forall (t,u,v)\in p \mid ((t,u)\in V_{NF}, v\in V_{DC}\cup V_{NF}) \tag{10}$$

$$\sum_{(u,v)} j_{p,(s,d),(u,v)}^{(f_1,f_2)} <= 1 \qquad \forall p\in K_{s,d}, \quad \forall (s,d)\in\Psi_{(s,d)}, \tag{11}$$

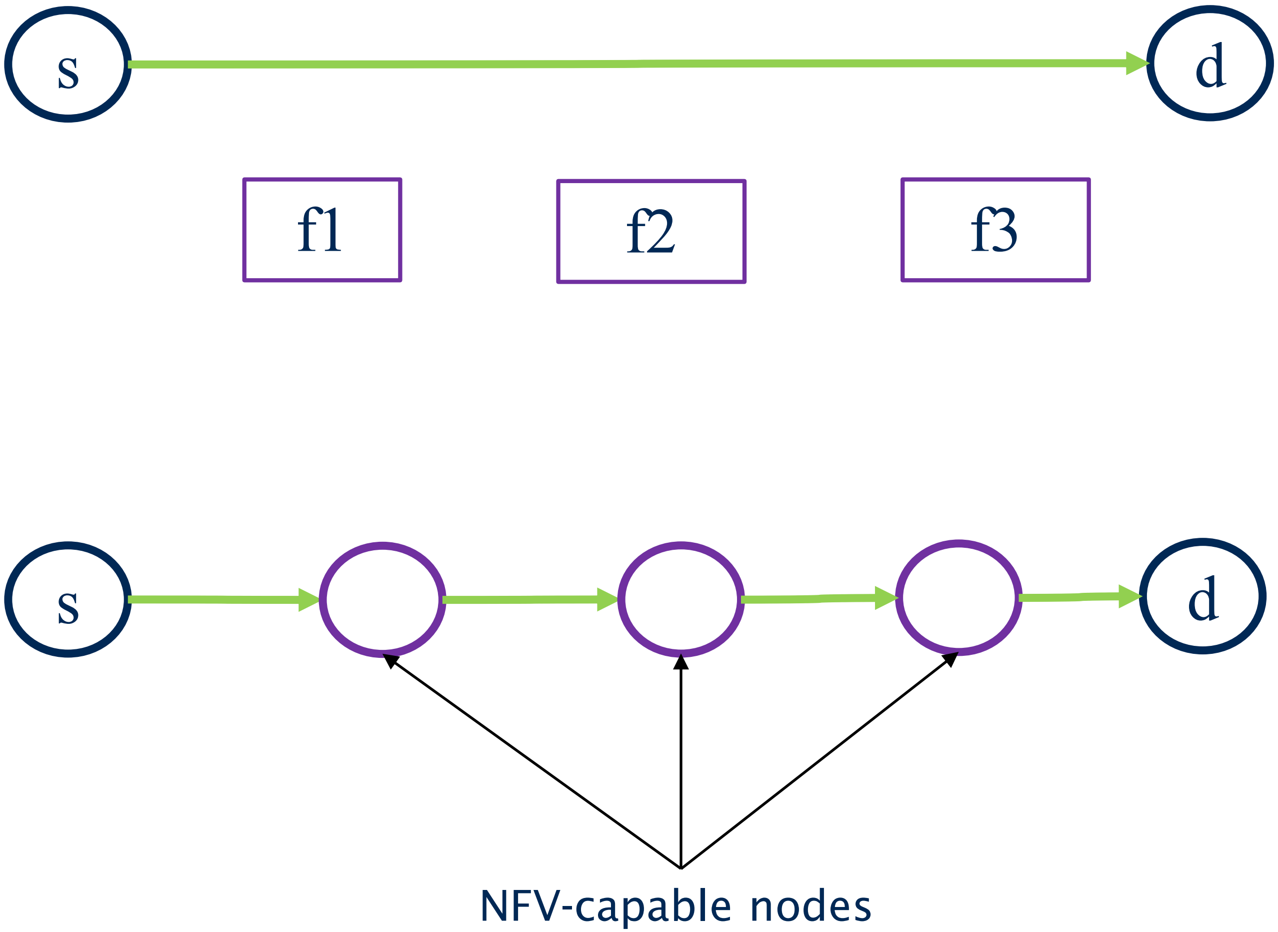
[4]A. Gupta et al., "Joint Virtual Network Function Placement and Routing of Traffic in Operator Networks," *Technical Report, UC Davis*

CPU-core-to-throughput relationship of a VNF

Applications	Throughput		
	1 Gbps	5 Gbps	10 Gbps
NAT	1 CPU	1 CPU	2 CPUs
IPsec VPN	1 CPU	2 CPUs	4 CPUs
Traffic Shaper	1 CPU	8 CPUs	16 CPUs

[3]Cisco, "Cisco Cloud Services Router 1000V 3.14 Series Data Sheet,"2015.

VNF placement (on throughput and CPU cores)

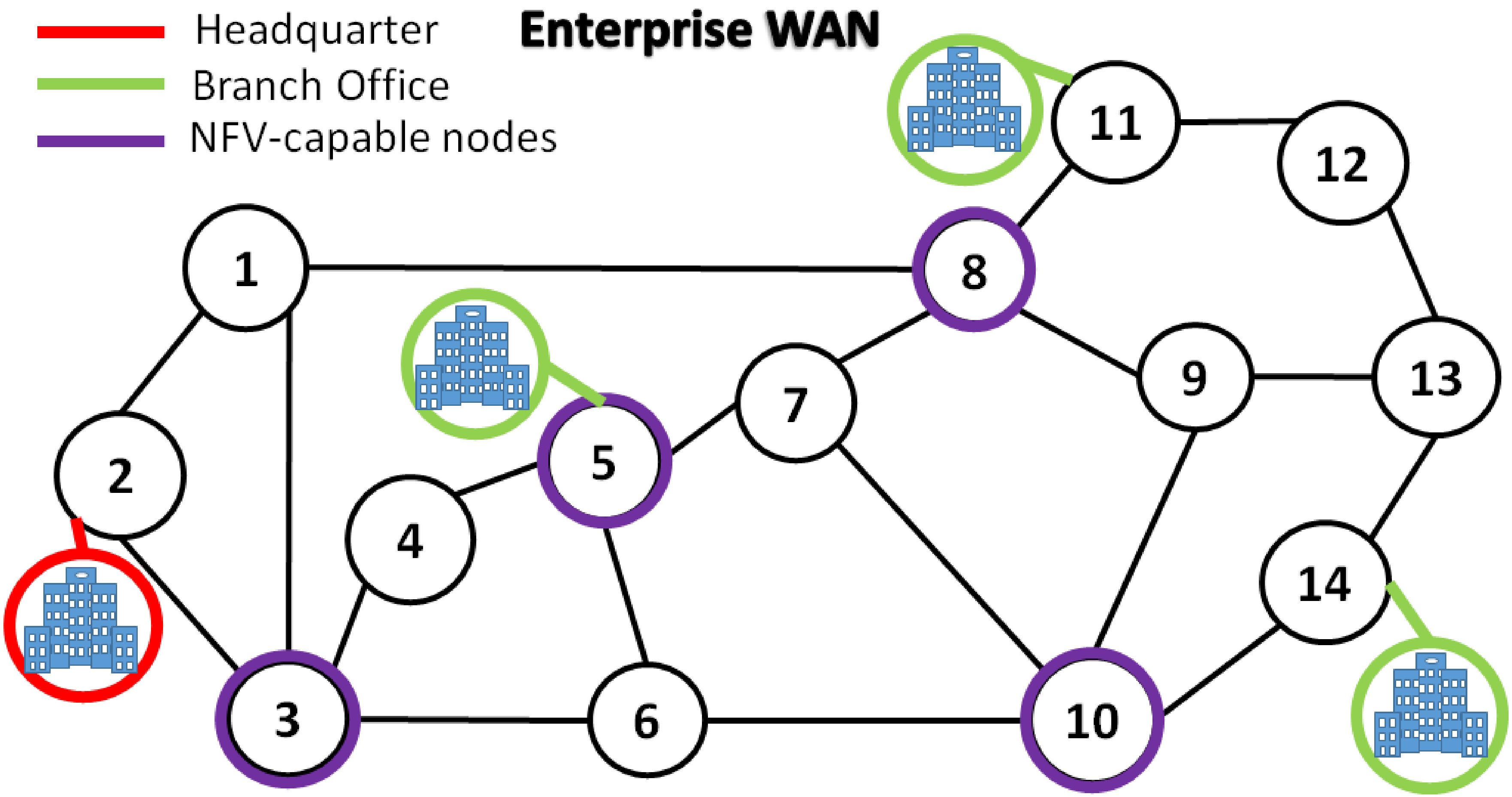


[4]A. Gupta et al., "Joint Virtual Network Function Placement and Routing of Traffic in Operator Networks," *Technical Report, UC Davis*

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



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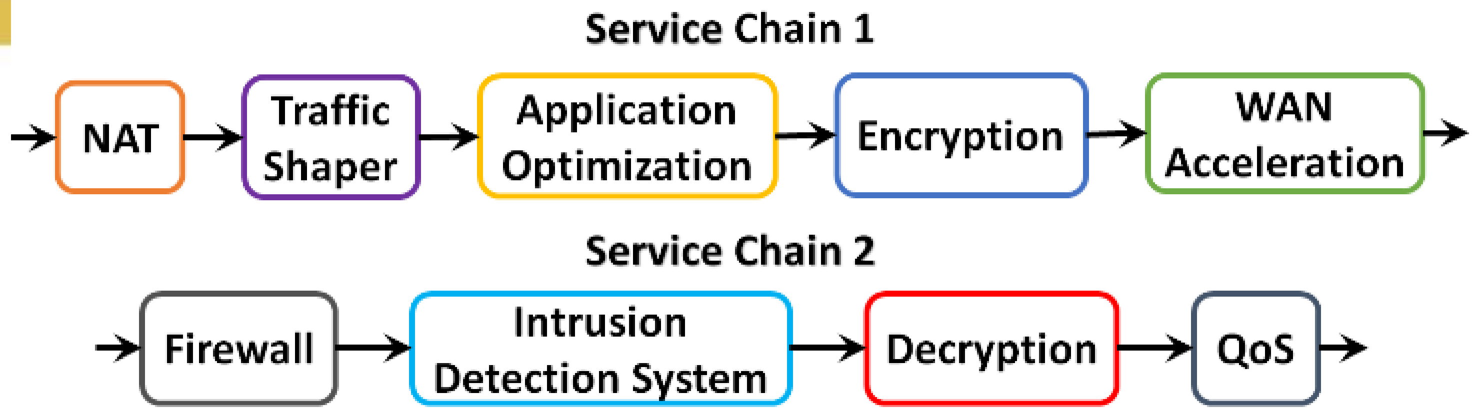
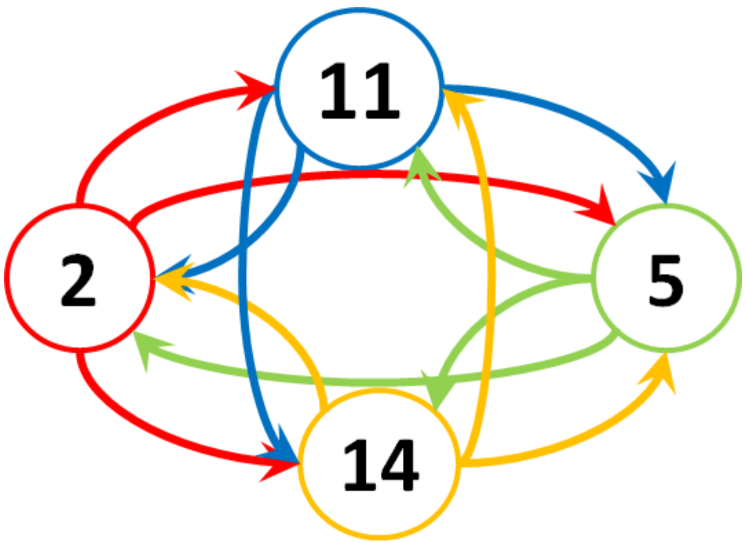
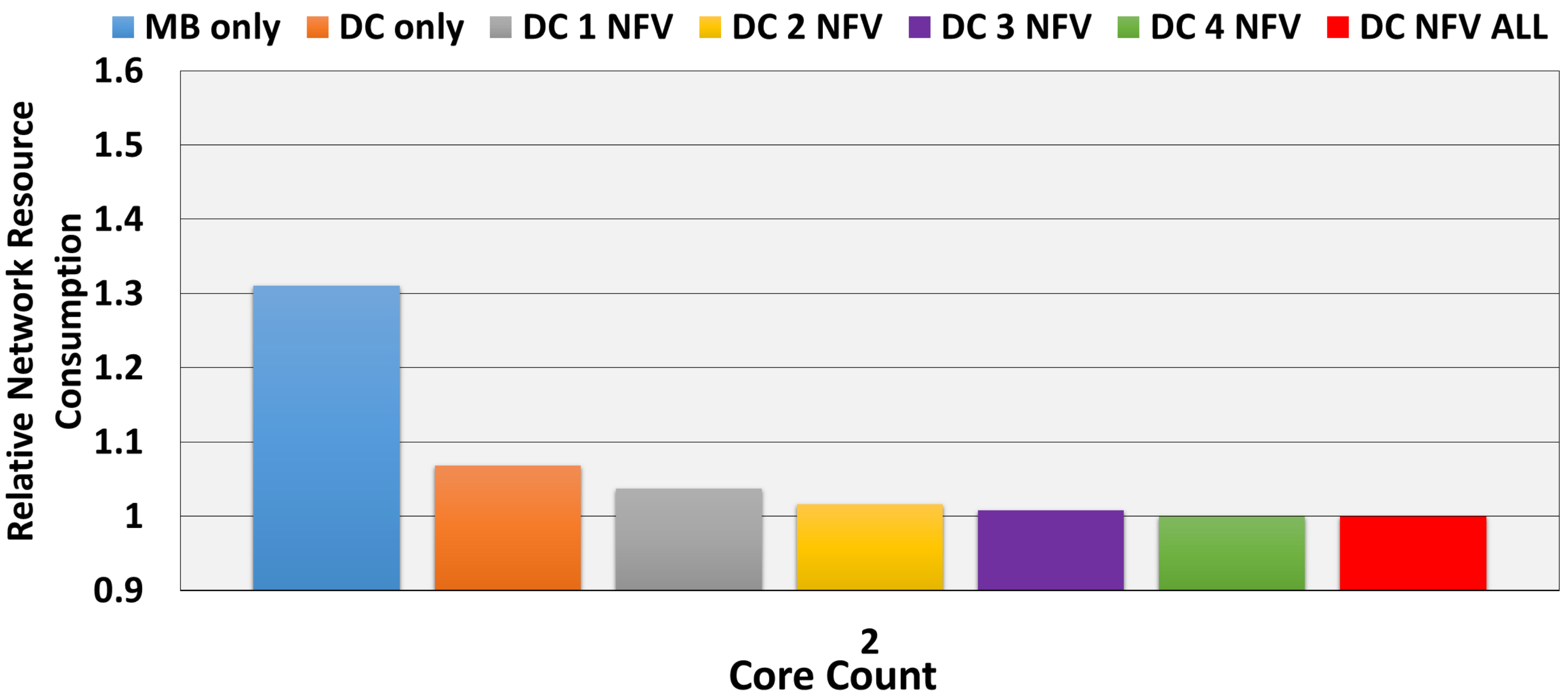




Traffic Flows

1 Gbps traffic



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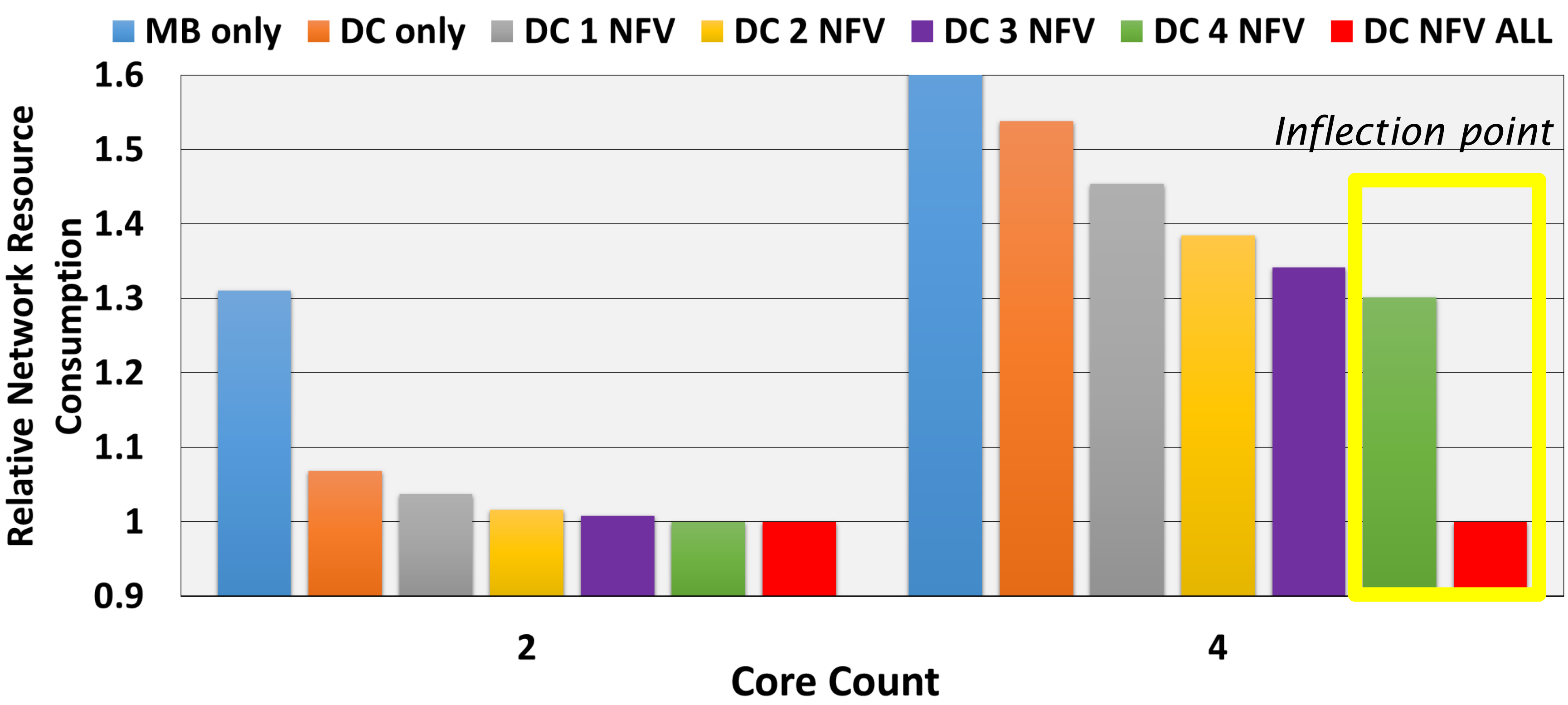
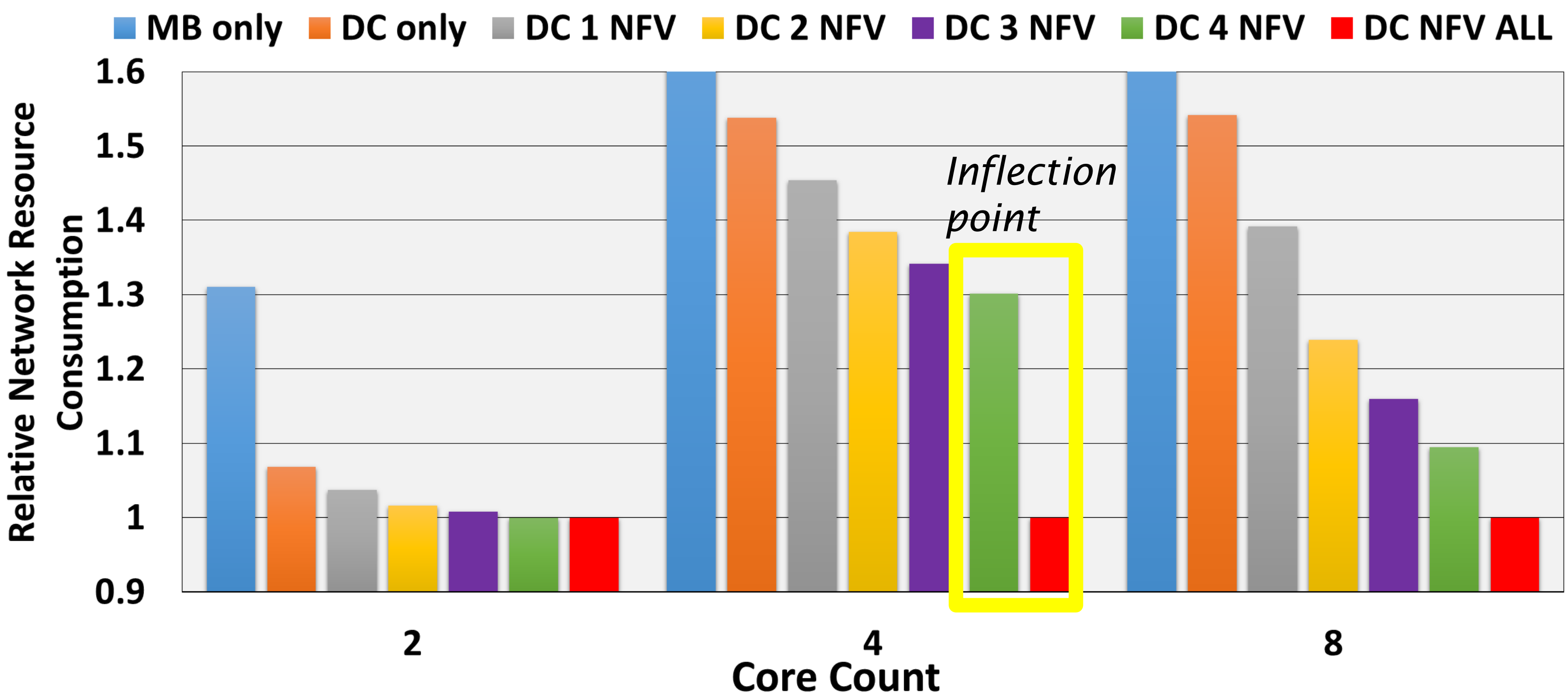

MB only
DC only
DC 1 NFV
DC 2 NFV
DC 3 NFV
DC 4 NFV
DC NFV ALL
Relative Network Resource Consumption
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
Inflection point
2
4
Core Count

Continued…



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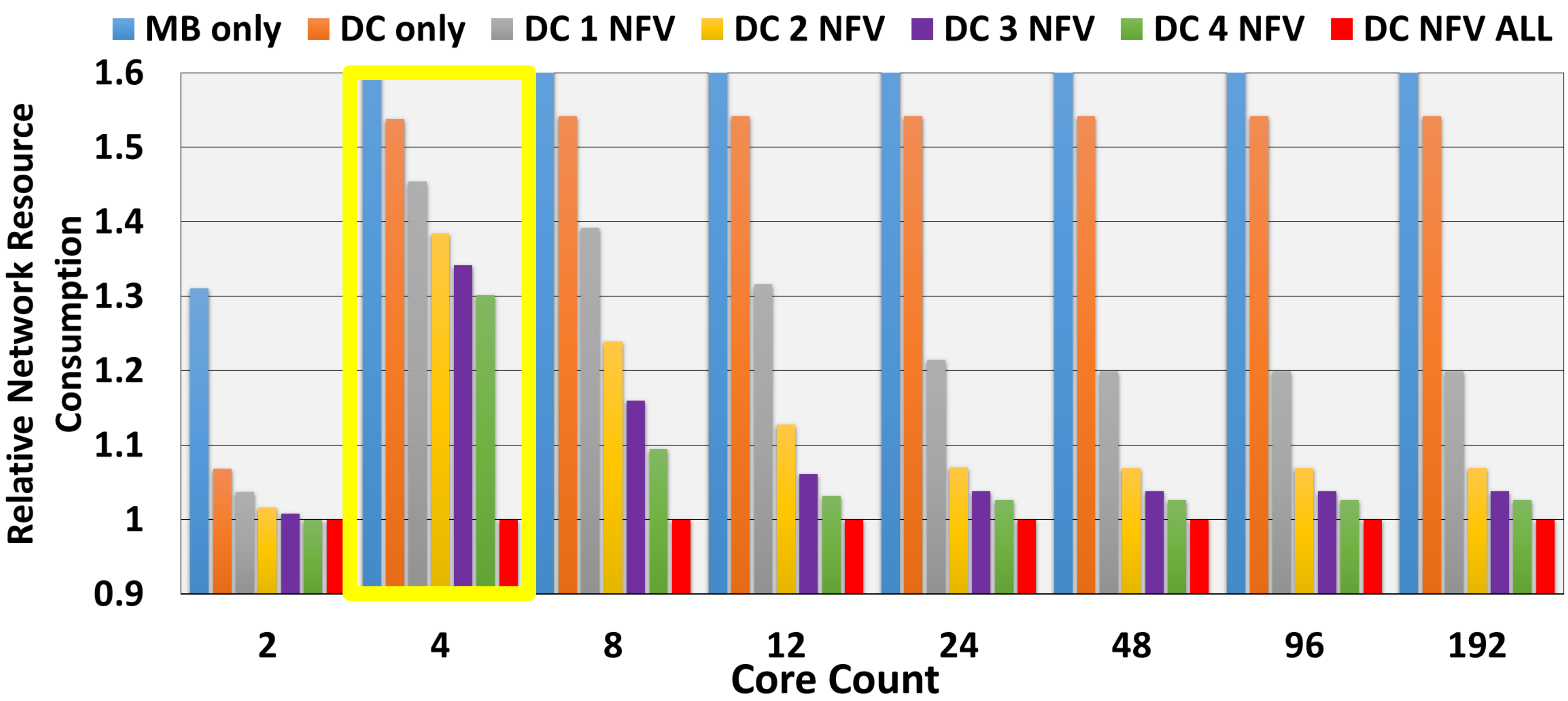
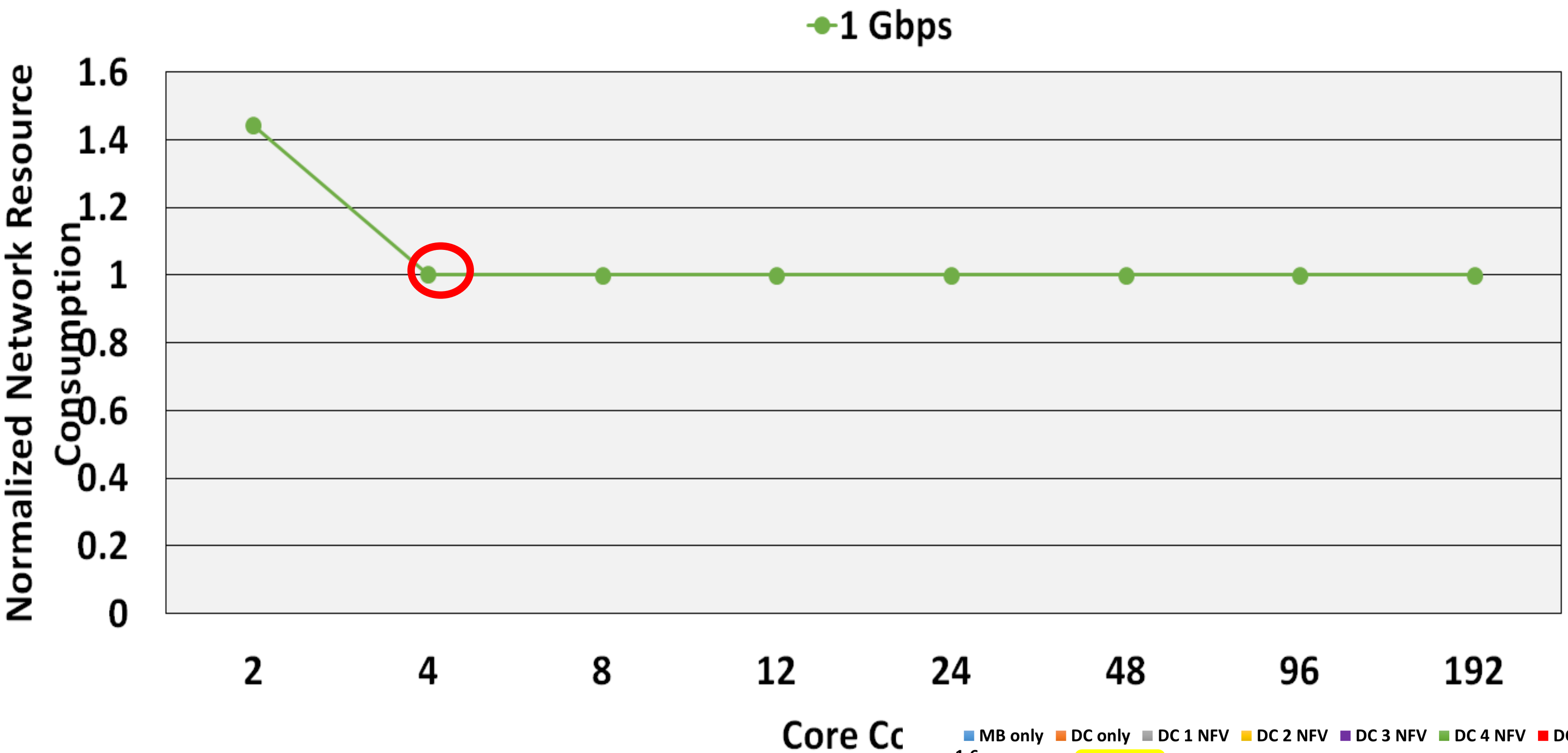
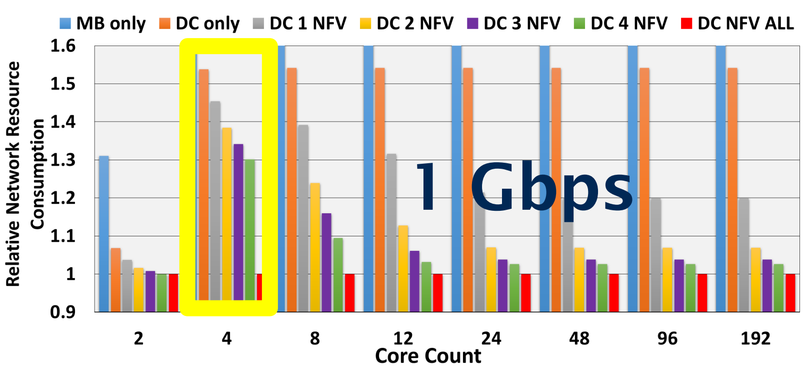


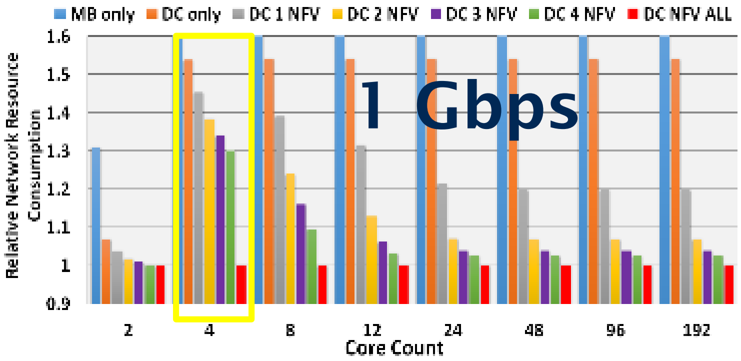
MB only
DC only
DC 1 NFV
DC 2 NFV
DC 3 NFV
DC 4 NFV
DC NFV ALL
Relative Network Resource Consumption
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
2
4
8
12
24
48
96
192
Core Count

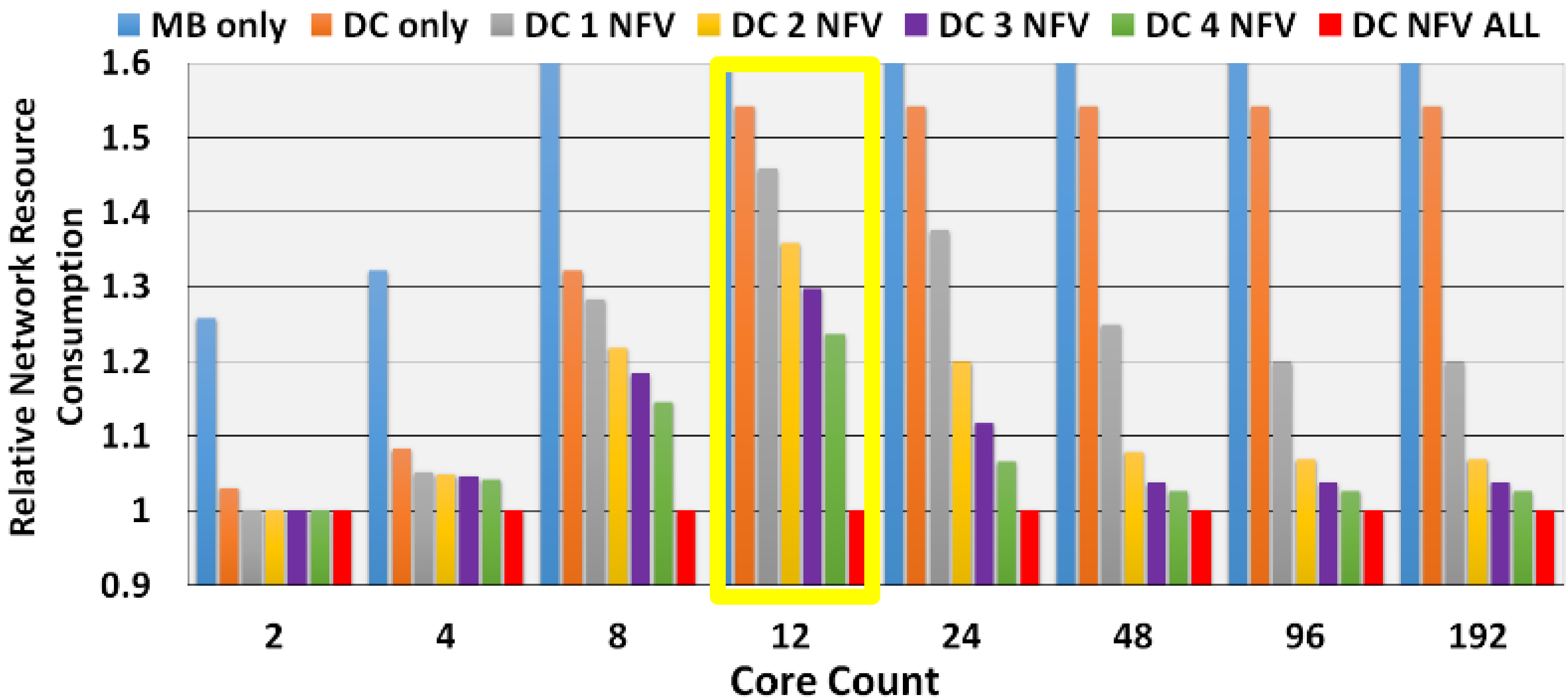
Inflection Point (DC NFV ALL)





2.5 Gbps traffic





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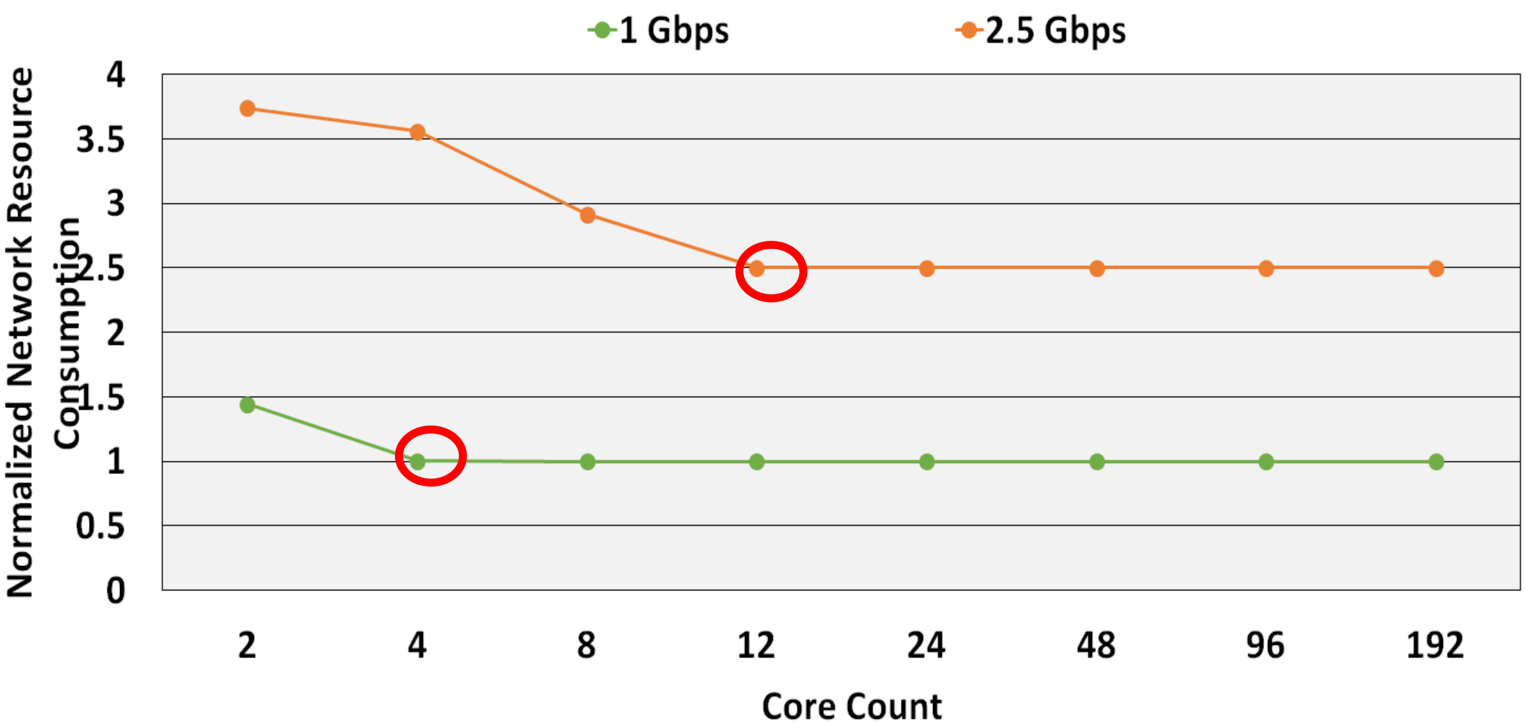
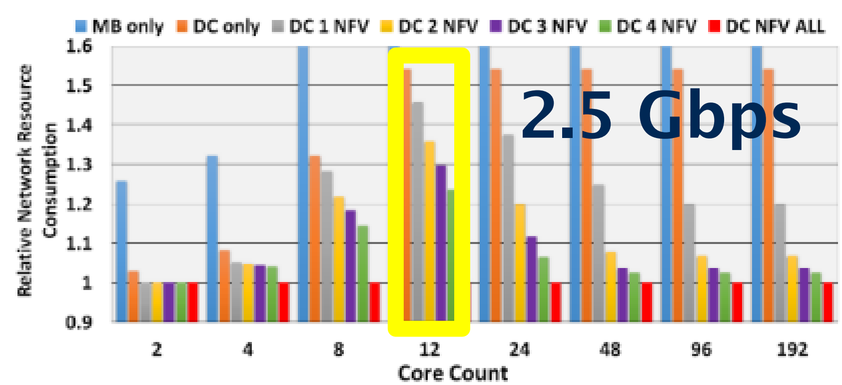
Inflection Point (DC NFV ALL)





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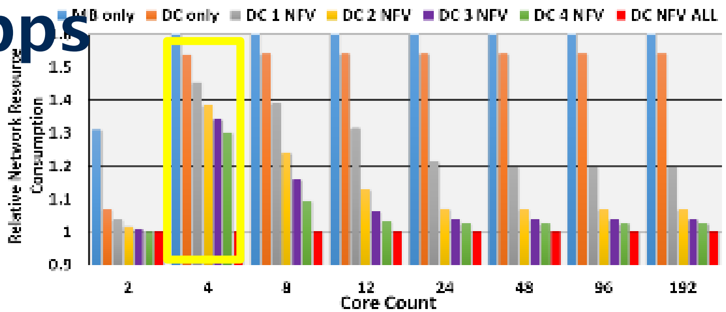
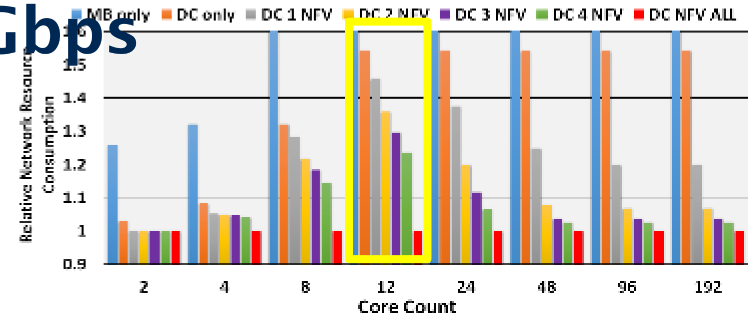
Results

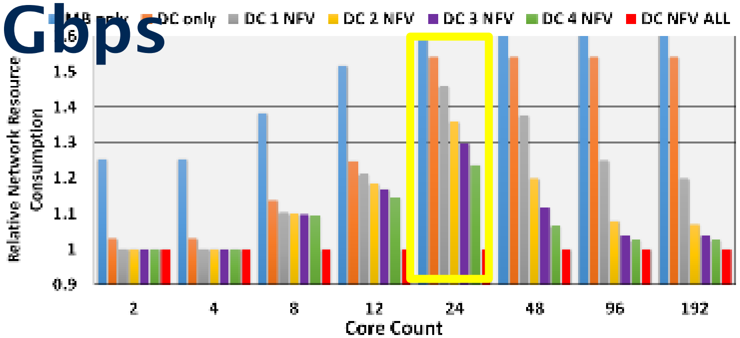
1 Gbps



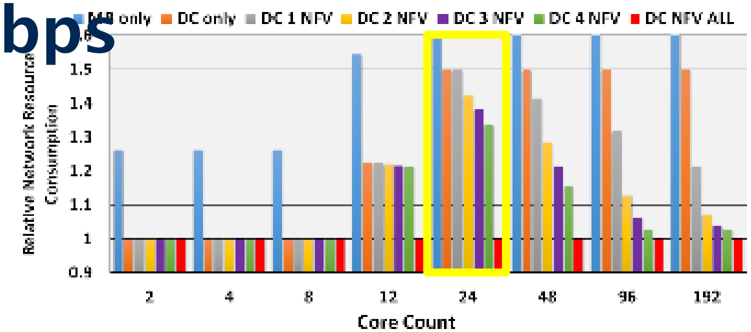
2.5 Gbps



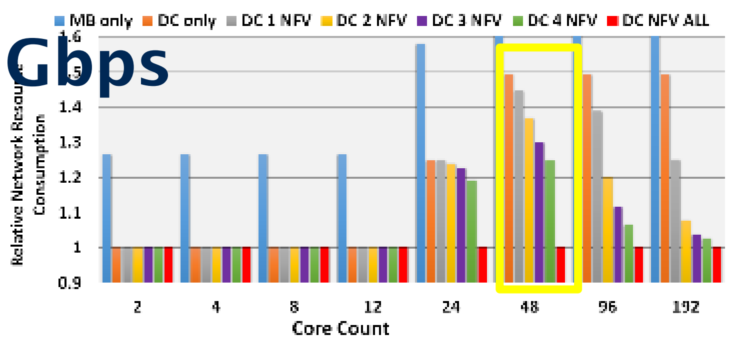
7.5 Gbps



5 Gbps



10 Gbps



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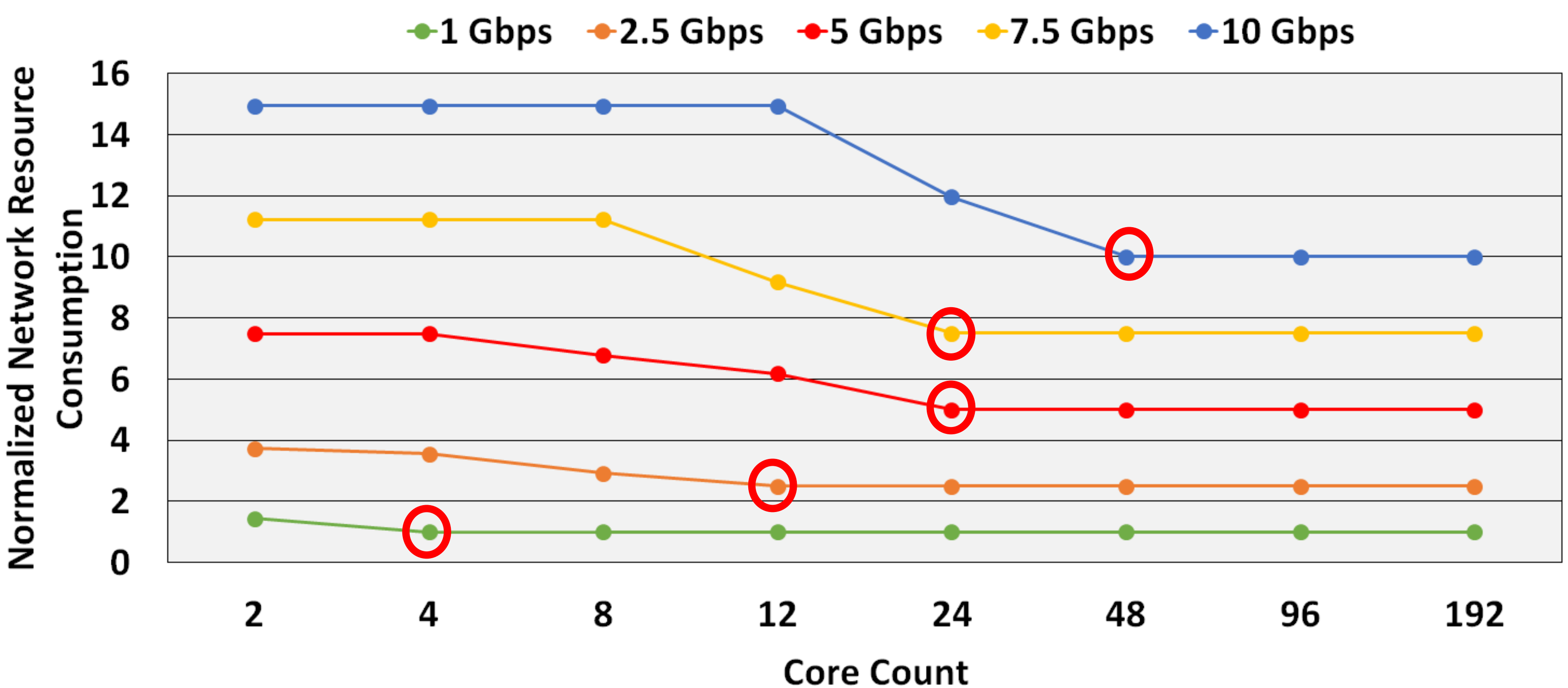
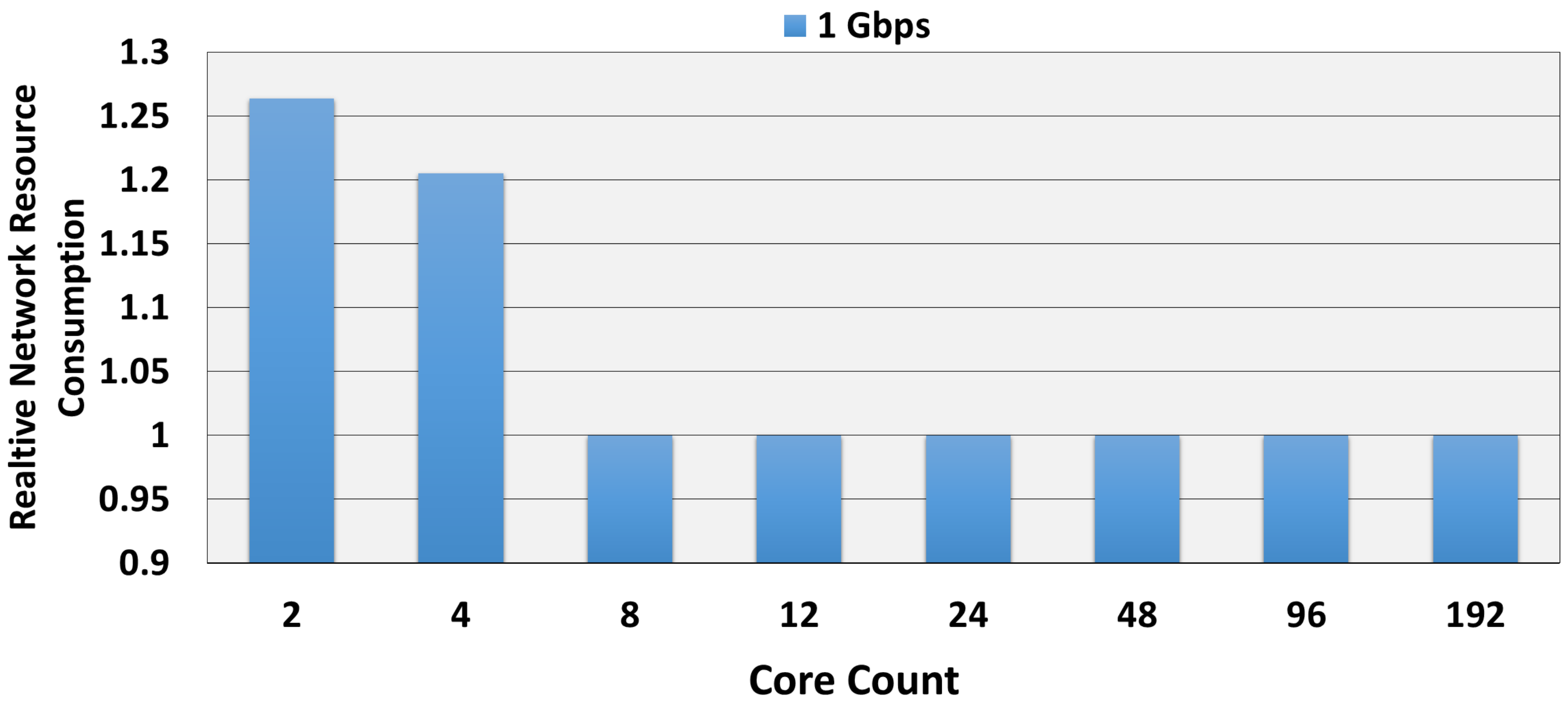
Inflection points (DC NFV ALL)



ALL NFV (Completely-Distributed) vs DC NFV ALL



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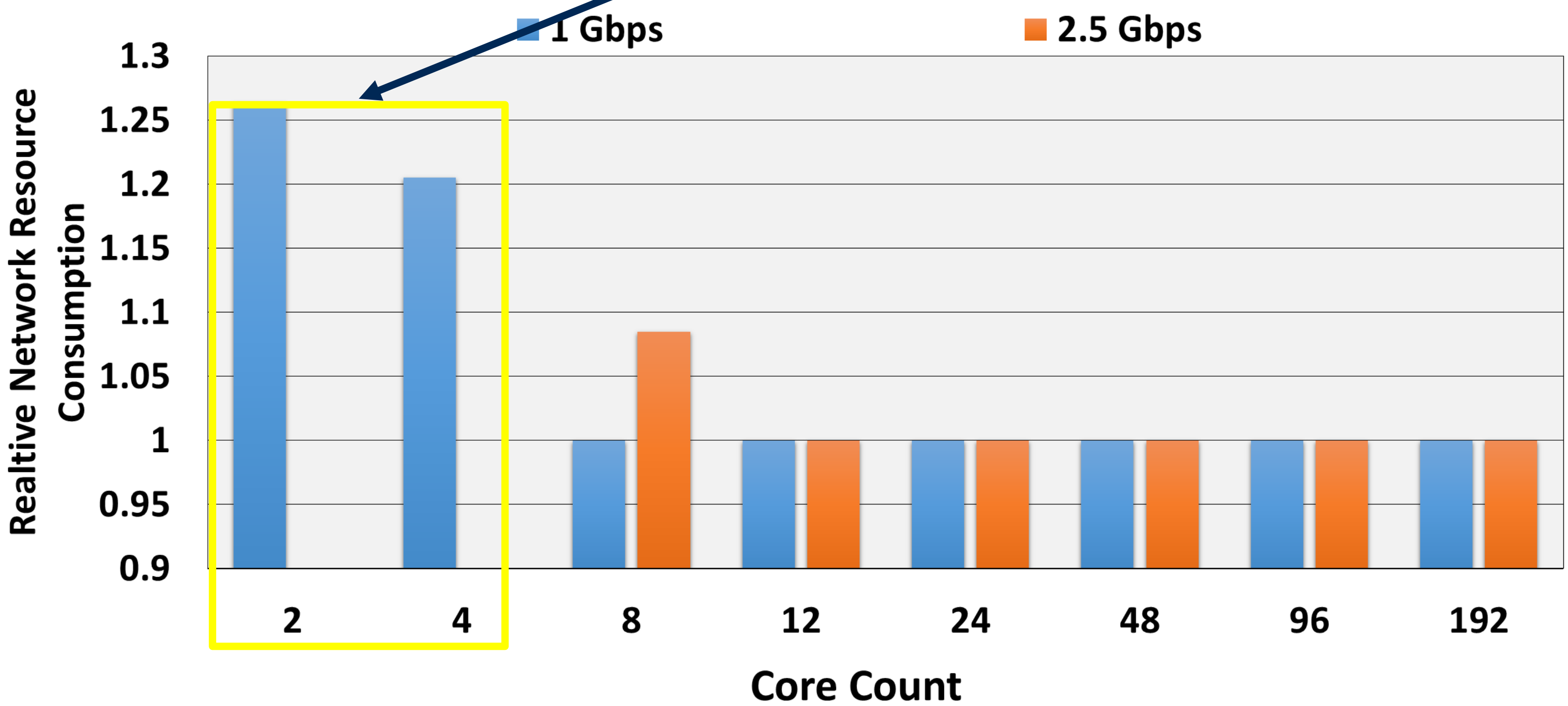
ALL NFV infeasible for these CPU core counts at 2.5 Gbps



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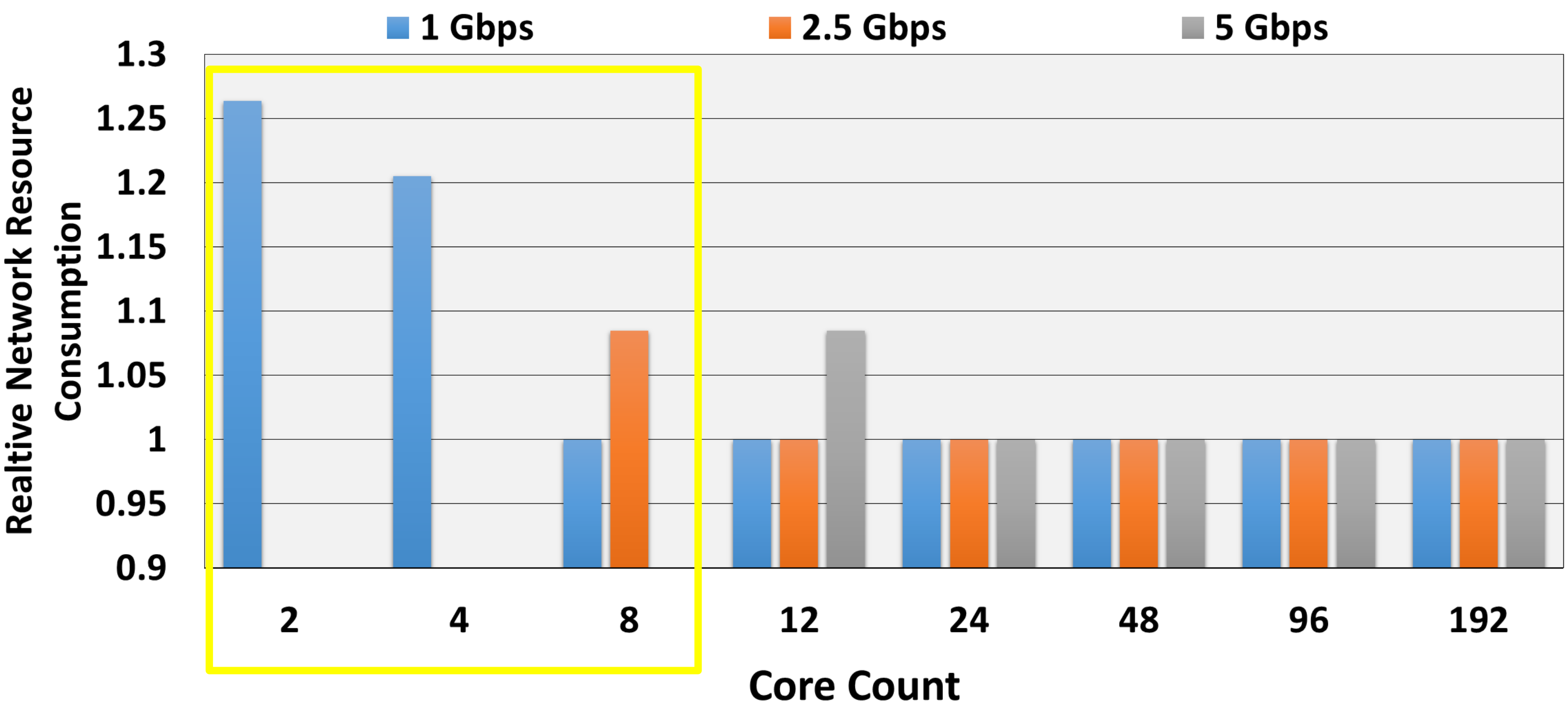
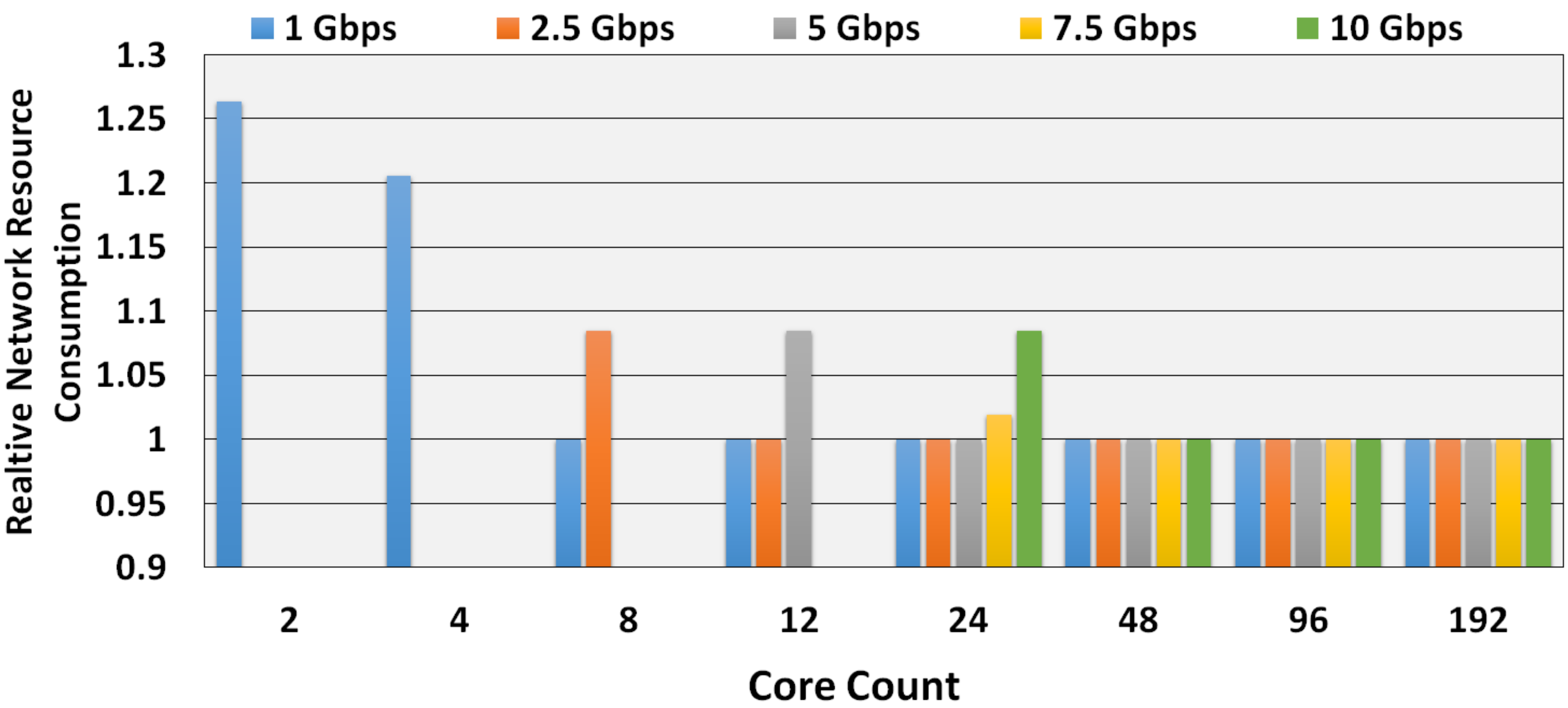

1 Gbps
2.5 Gbps
5 Gbps
Realtive Network Resource Consumption
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
2
4
8
12
24
48
96
192
Core Count

Continued…



1 Gbps
2.5 Gbps
5 Gbps
7.5 Gbps
10 Gbps
Realtive Network Resource Consumption
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
2
4
8
12
24
48
96
192
Core Count

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%.

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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**

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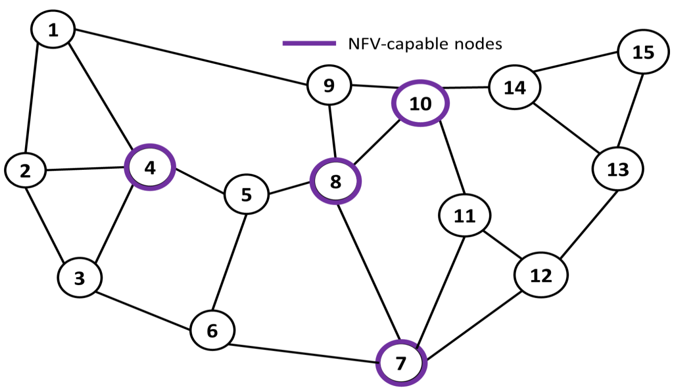
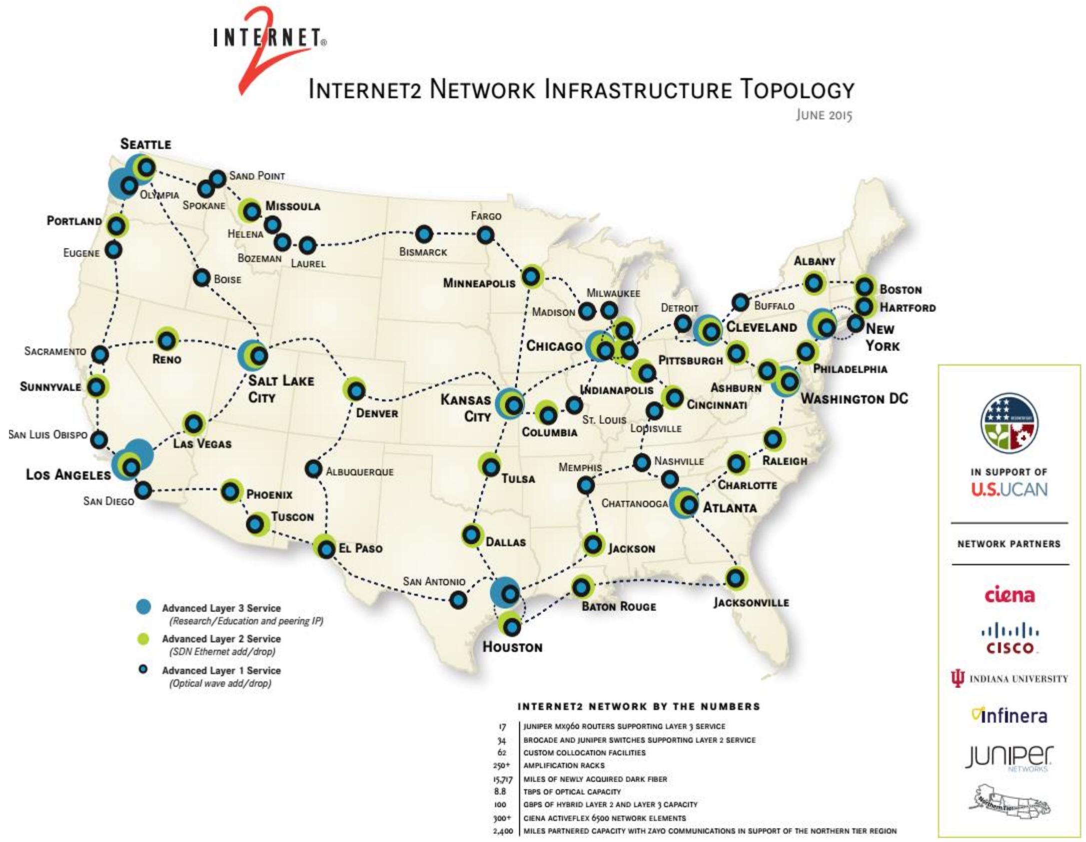
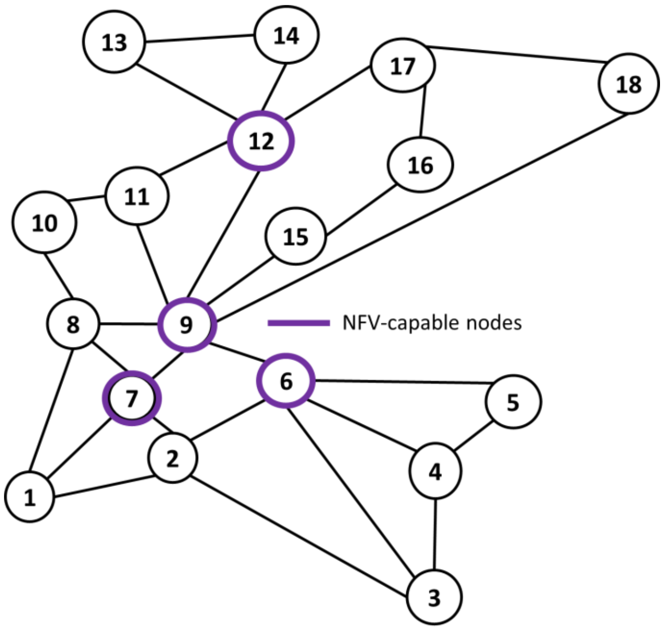
Network Topology (Internet2)

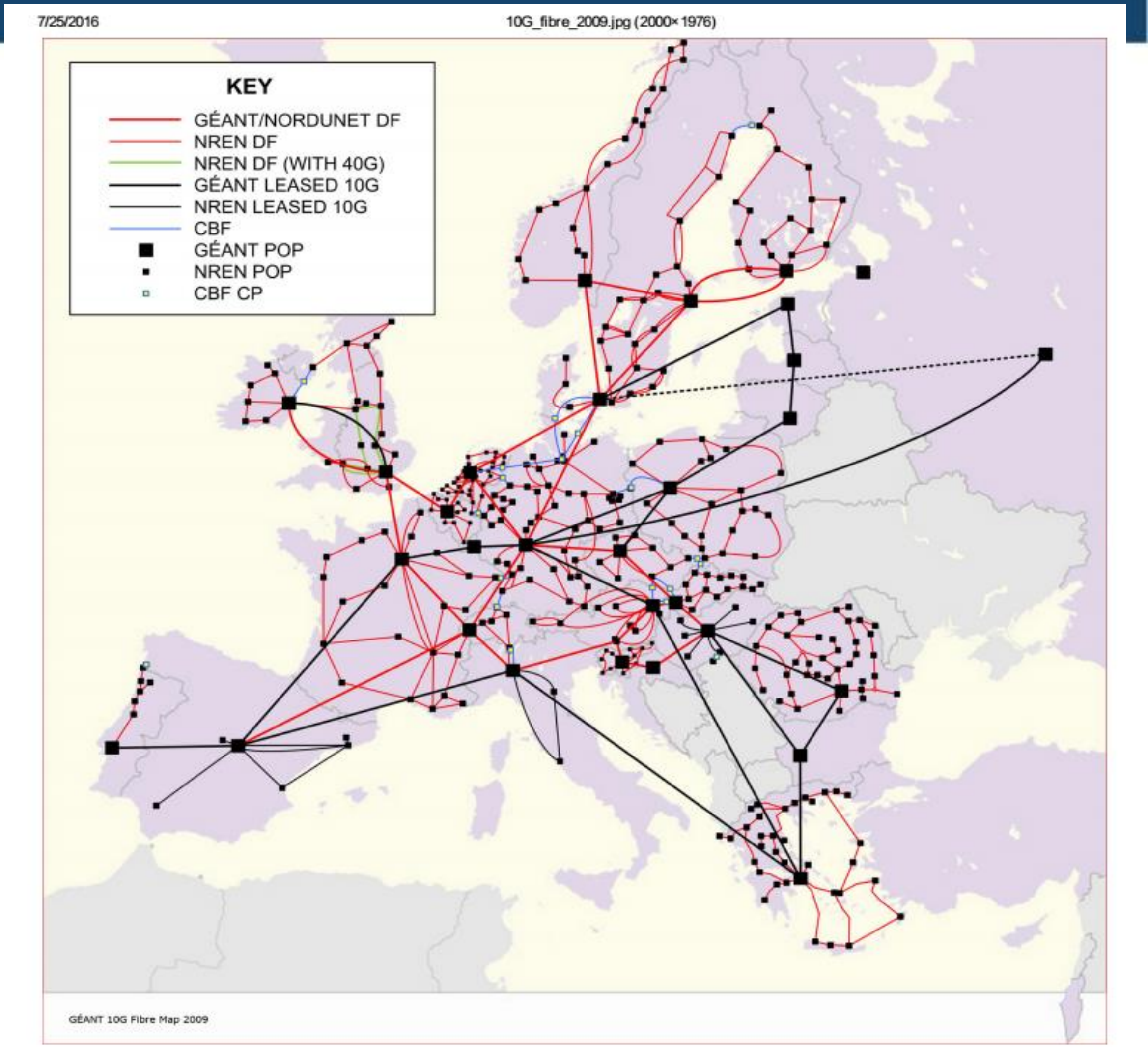




[5] https://www.internet2.edu/media/medialibrary/2015/08/04/NetworkMap_all.pdf

Network Topology (Geant)





[6] http://geant3plus.archive.geant.net/Resources/Media_Library/PublishingImages/maps/10G_fibre_2009.jpg

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

Traffic	Nodes
1 Gbps	None
2.5 Gbps	1,2
5 Gbps	4,5,6,7
7.5 Gbps	11,12,13 ,14
10 Gbps	3,8,10

For each of the Internet2, Geant

Traffic	Infeasible DC Nodes		
	TM1	TM2	TM3
1 Gbps	None		
2.5 Gbps	1,2		
5 Gbps	4,5,6,7		
7.5 Gbps	11,12,13,14		
10 Gbps	3,8,10		

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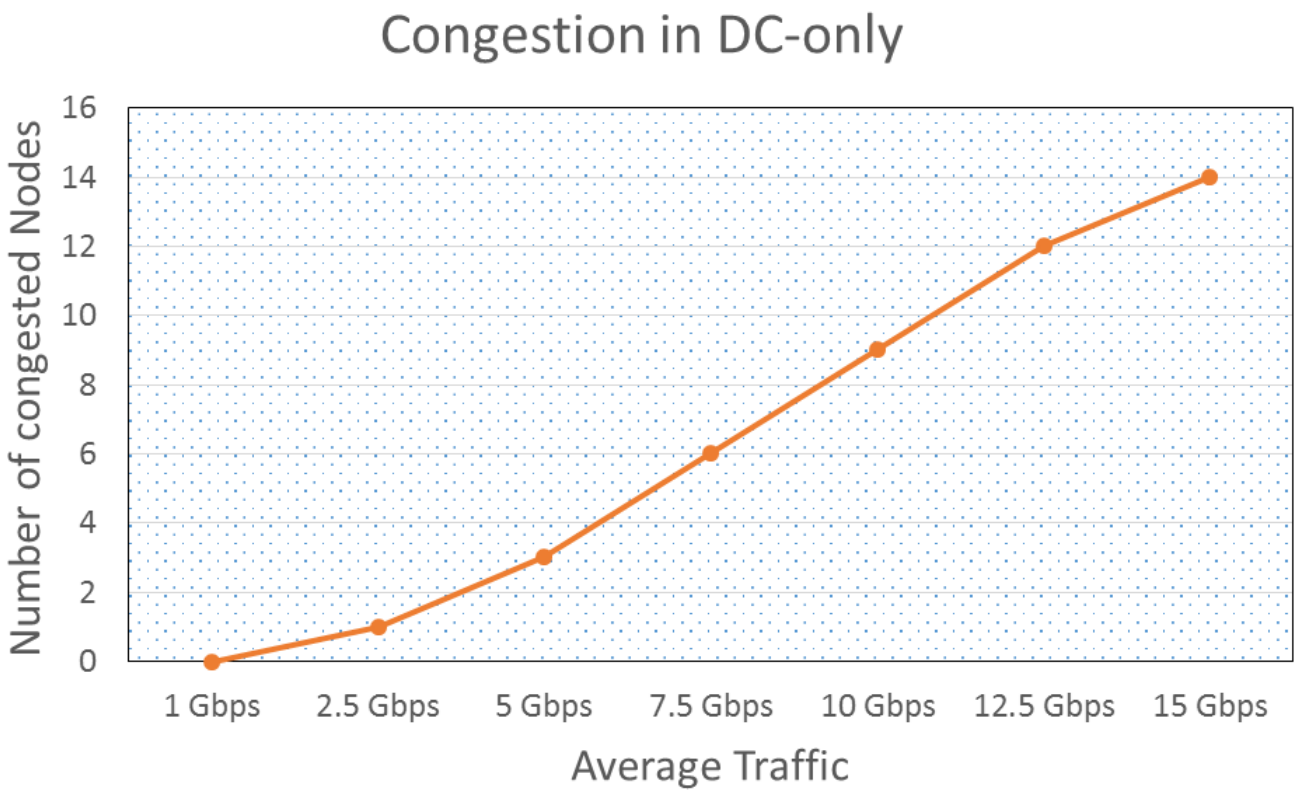

Congestion in DC-only
Number of congested Nodes
0
2
4
6
8
10
12
14
16
1 Gbps
2.5 Gbps
5 Gbps
7.5 Gbps
10 Gbps
12.5 Gbps
15 Gbps
Average Traffic

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.**

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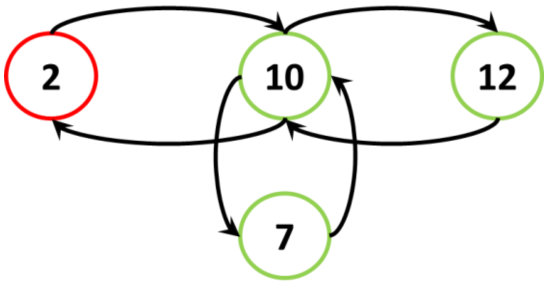
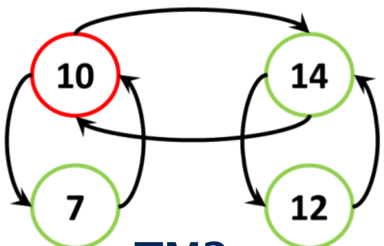
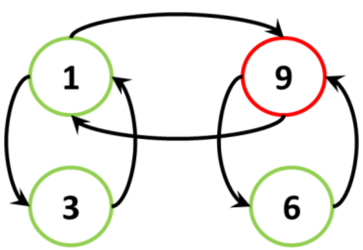
TM's for Internet 2



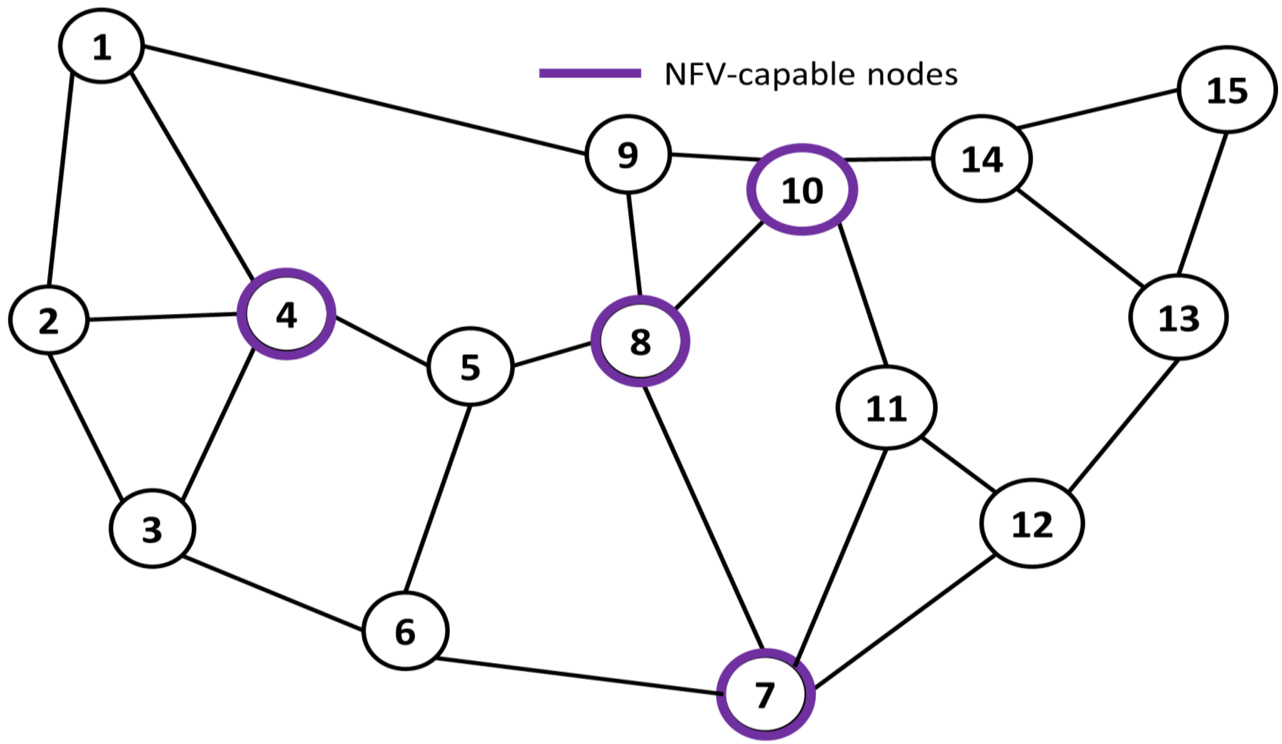
TM1



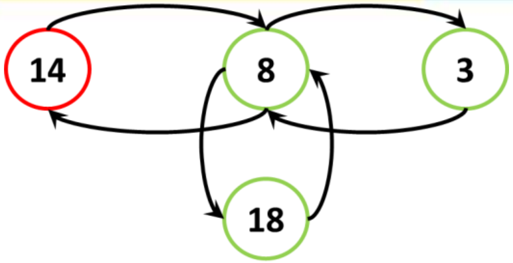
TM2



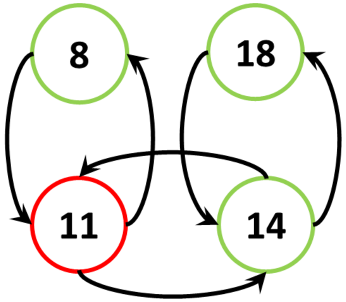
TM3



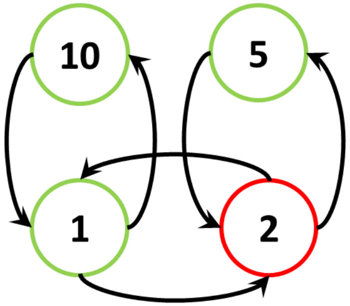
TM's for Geant



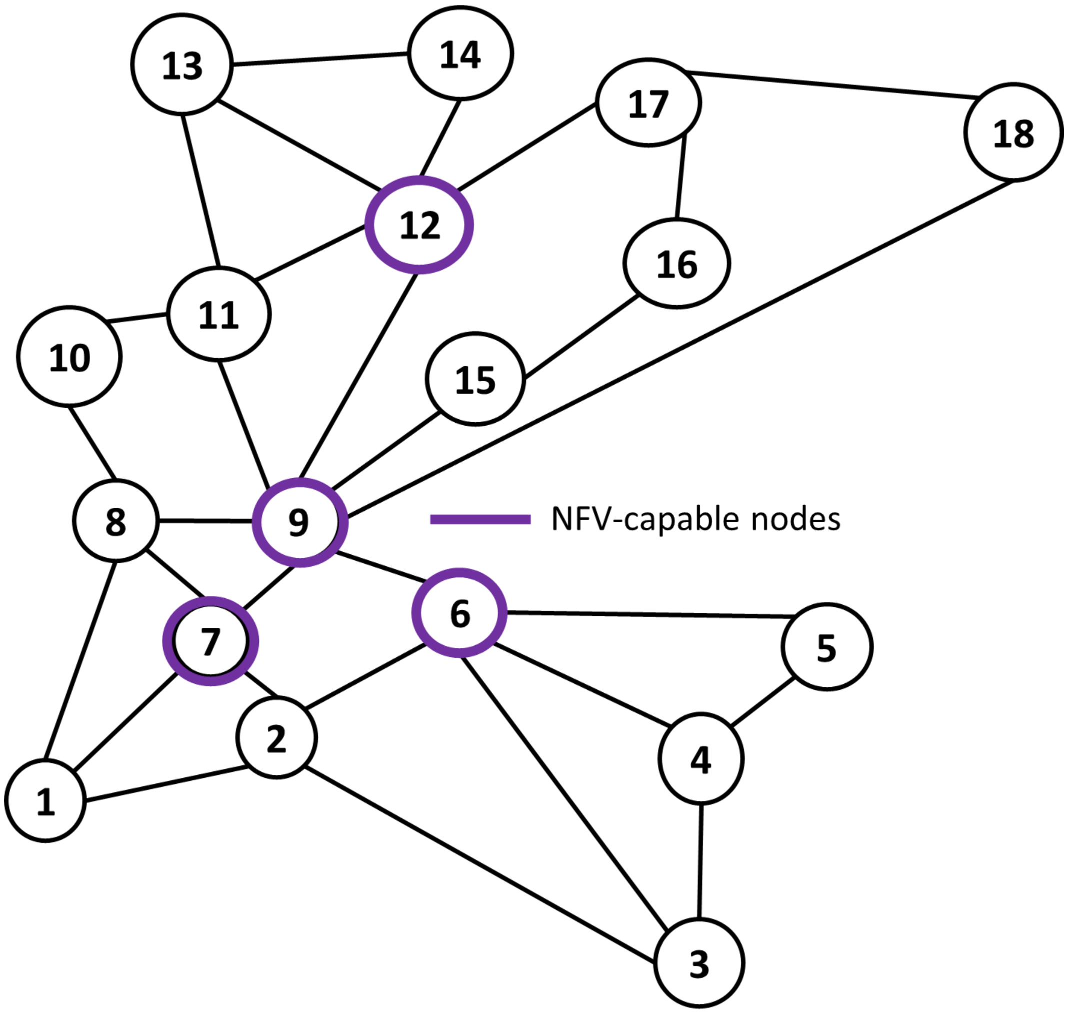
TM1



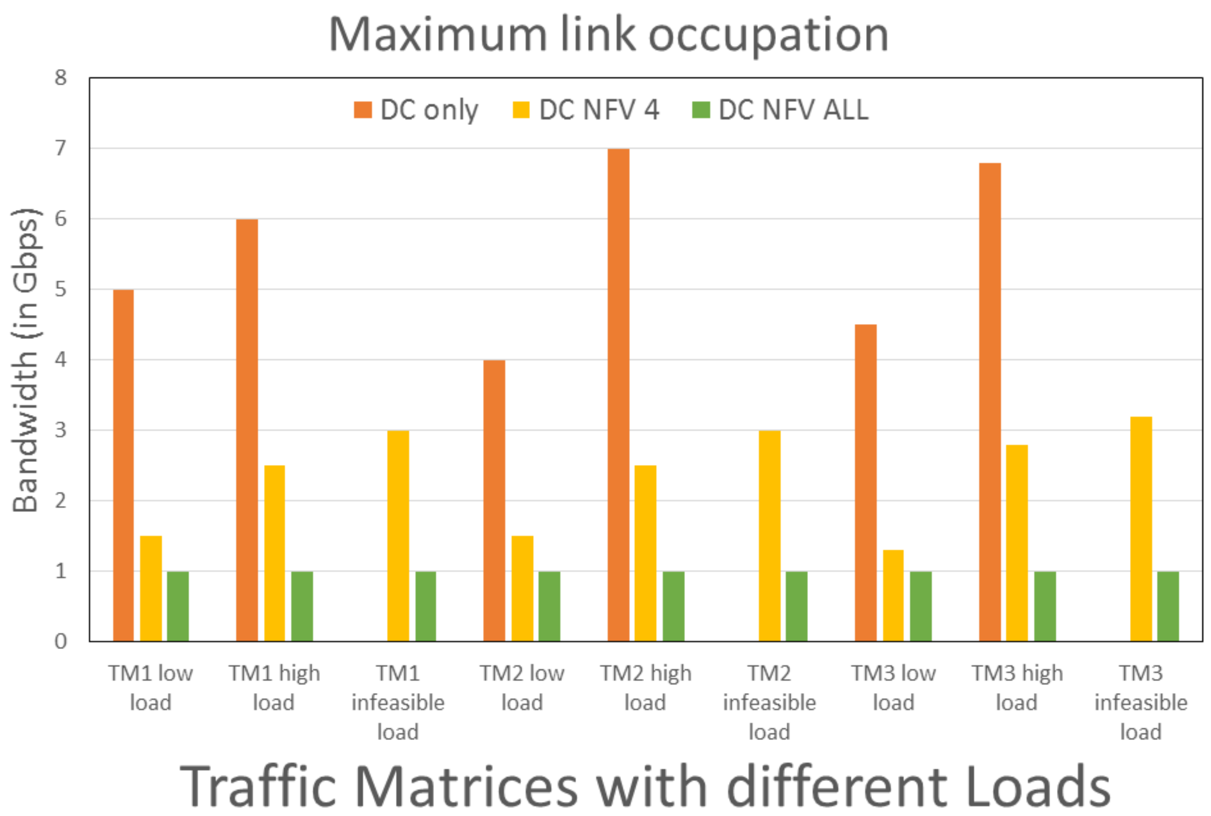
TM2



TM3



Load balancing aspect of an NeC



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

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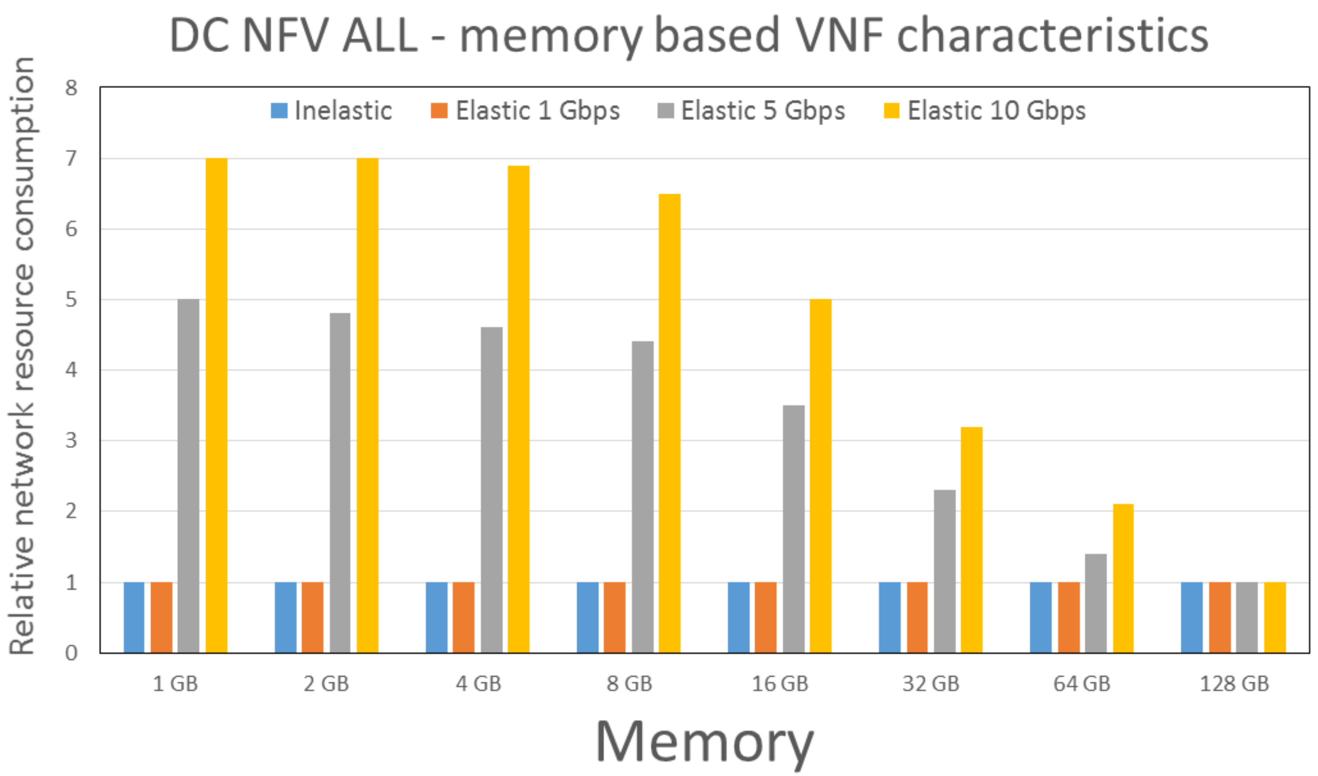

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Thank You

Related Work

- **[7]**S. Mehraghdam et al., **“Specifying and Placing Chains of Virtual Network Functions,”***arXiv preprint arXiv:1406.1058, 2014*
- **[8]**A. Mohammadkhan et al., **“Virtual Function Placement and Traffic Steering in Flexible and Dynamic Software Defined Networks,”** *IEEE Workshop on Local and Metropolitan Area Networks (LANMAN 15), April 2015*
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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)

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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**

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