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

By

Abhishek Gupta

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Dissertation Committee:

Prof. Biswanath Mukherjee (Advisor)

Prof. Massimo Tornatore (Co-advisor)

Prof. S. Felix Wu

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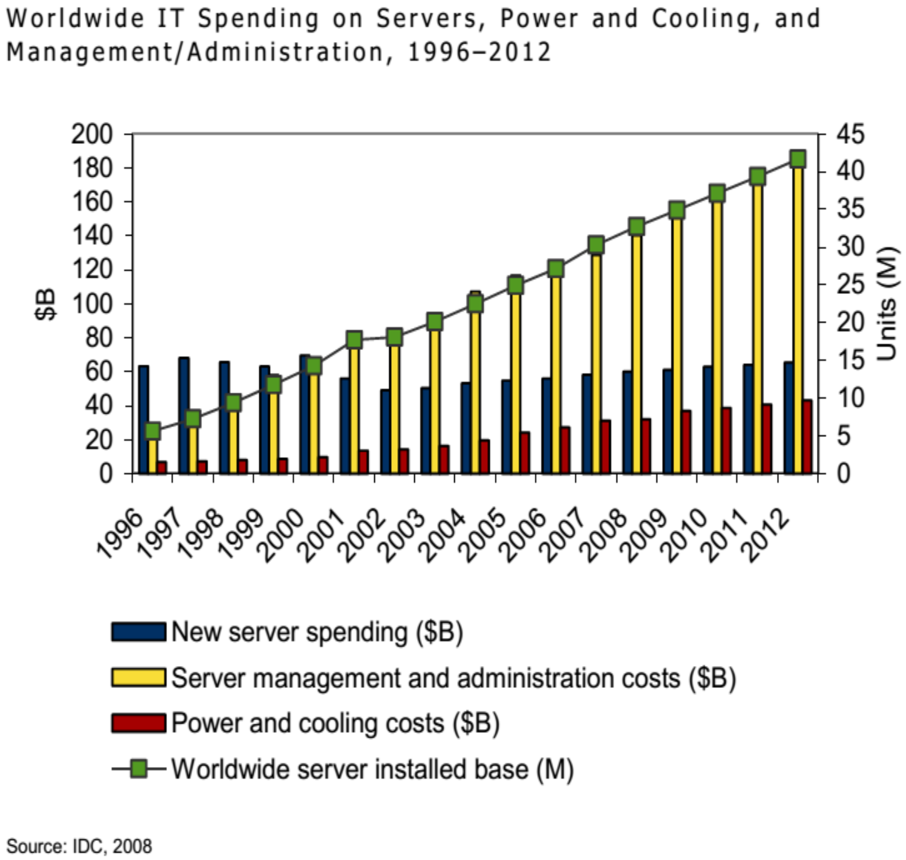
UNIVERSITY OF CALIFORNIA

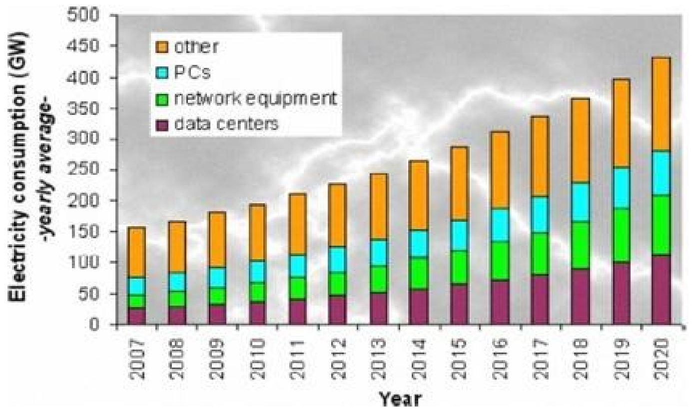
Outline

1. Cost-Efficient Live VM Migration based on Varying Electricity Cost in Optical Networks
2. How to Reduce Operating Costs of Communication Networks? – Network Function Virtualization (NFV)
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





[1] http://www.wica.intec.ugent.be/research/green-ict

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

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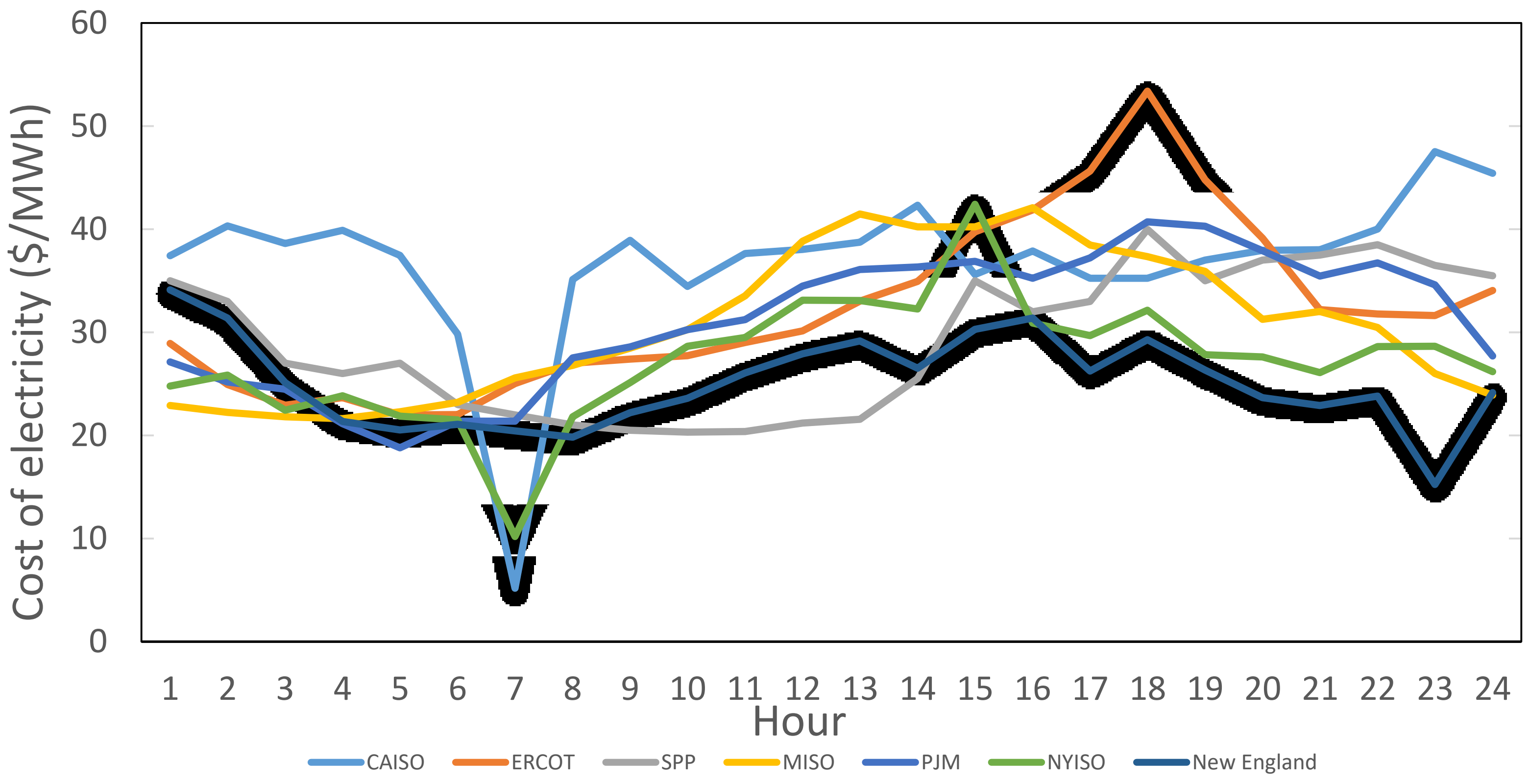
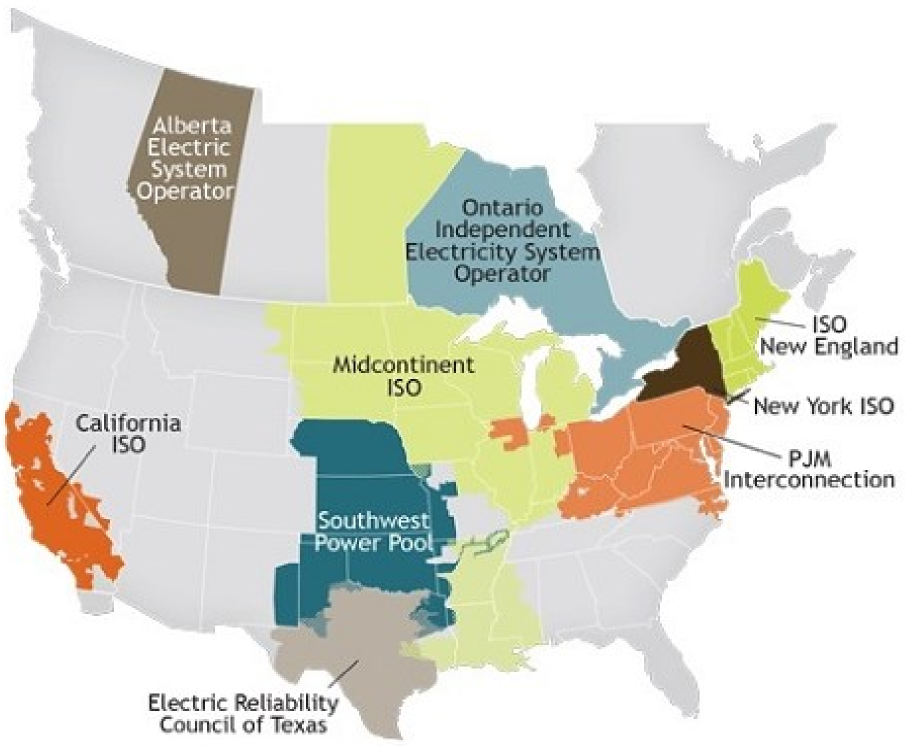
Dynamic Electricity Pricing in Independent System Operator (ISO) / Regional Transmission Organization (RTO)





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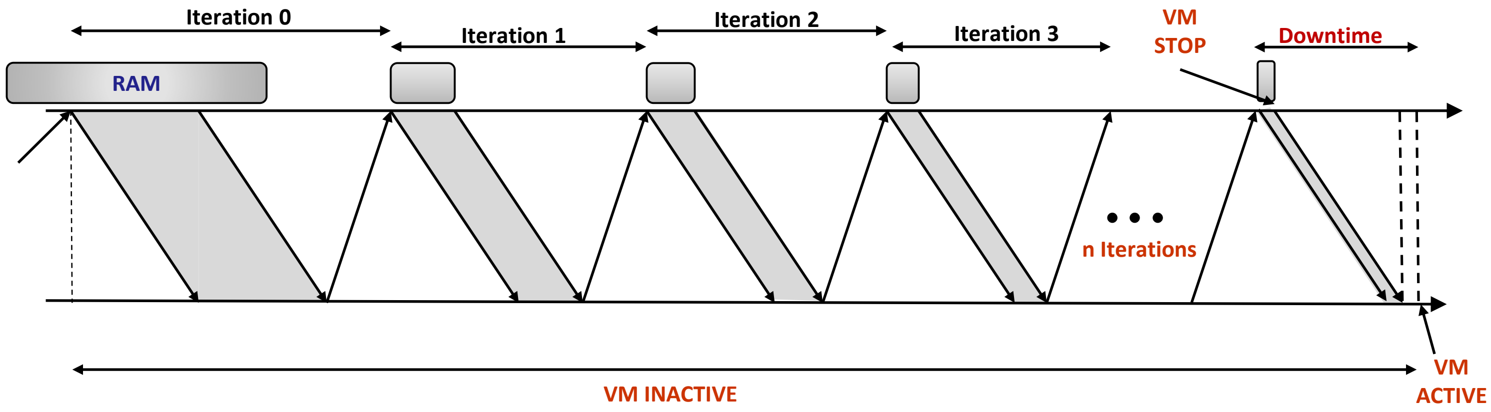
[2] www.isorto.org; data points for July 17, 2014

Live VM Migration



[3] H. Liu et al. “Performance and energy modeling for live migration of virtual machines”, Cluster Computing (2013)

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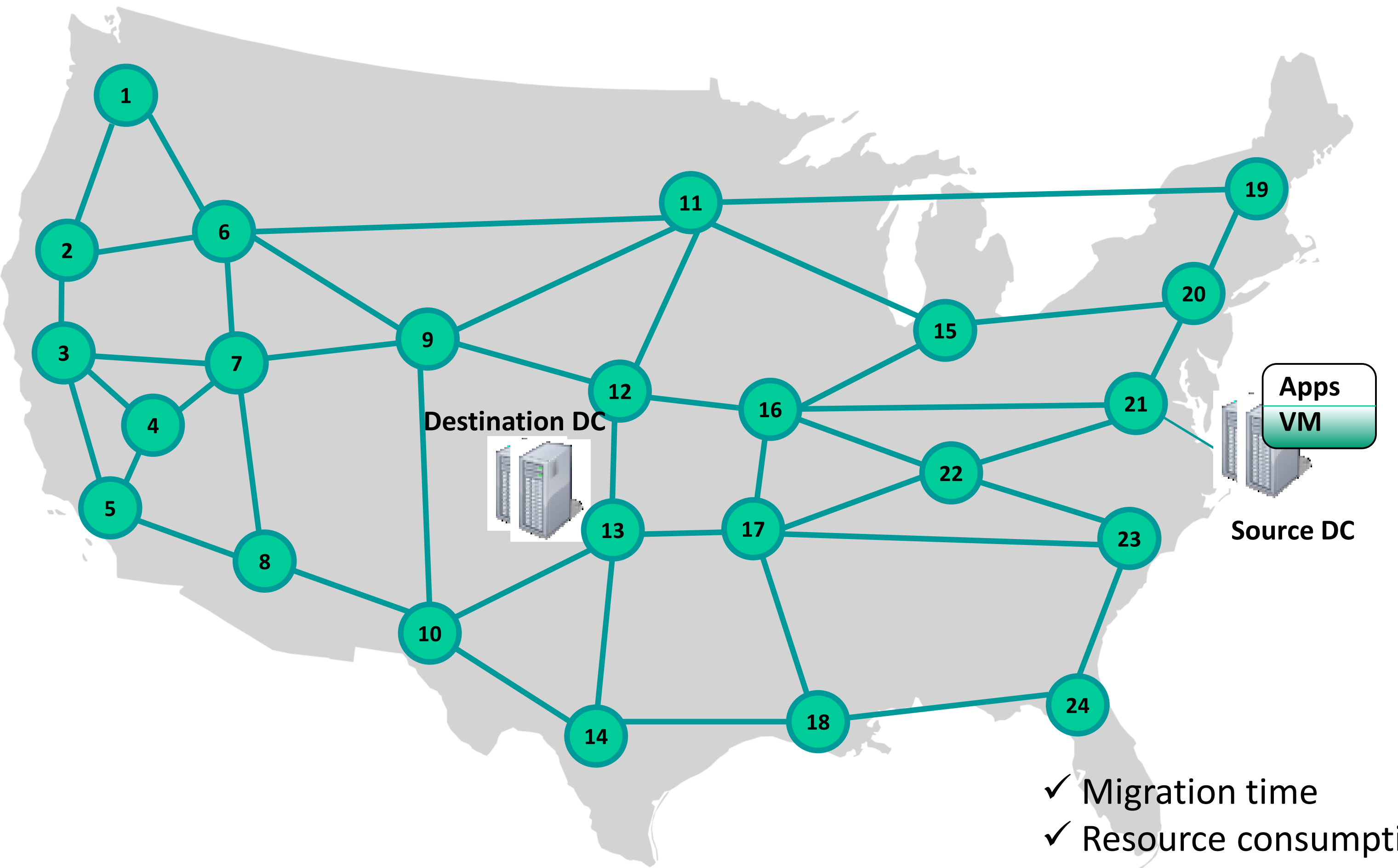
Using VM migration to exploit variation in electricity prices



- ✓ Migration time
- ✓ Resource consumption
- ✓ VM Downtime

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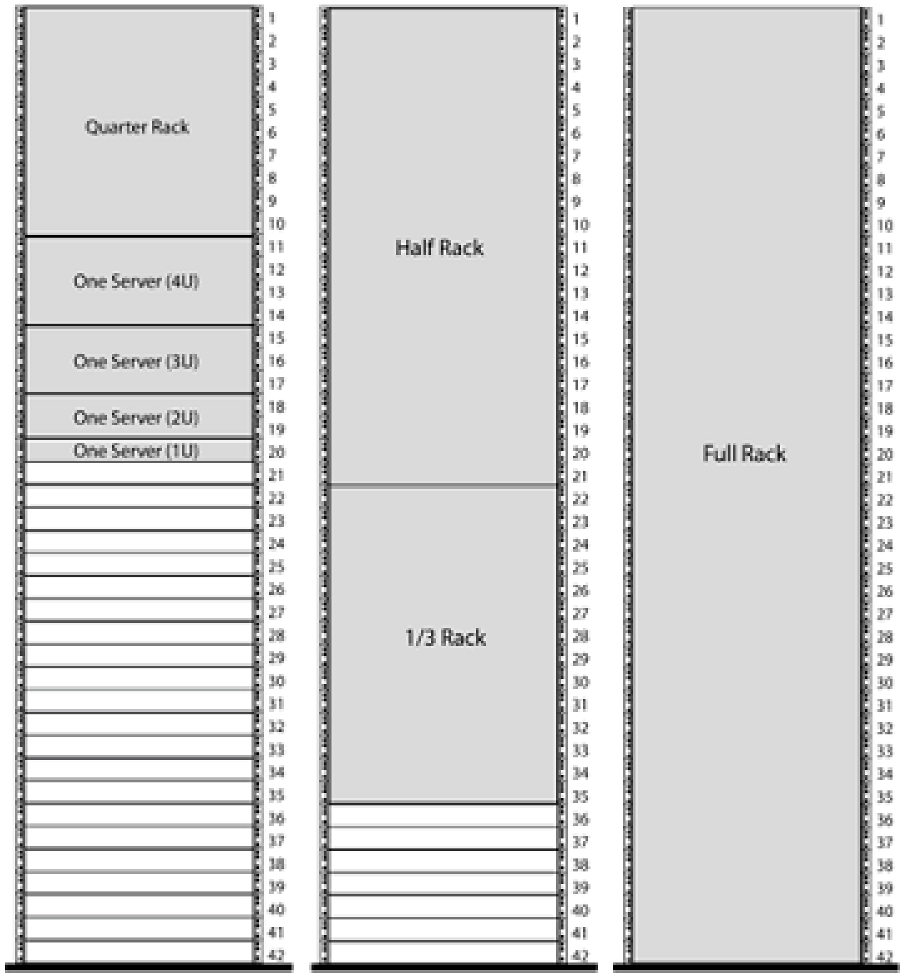
Power Model

- Pack servers and racks (VM consolidation).
- Switching off racks and servers at source DC.
- Switching on racks and servers at destination DC.



[4] www.ksc.net

Research Contributions

- We propose using dynamic electricity pricing and Live VM migration to reduce **VM operating cost**

- We have presented an **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

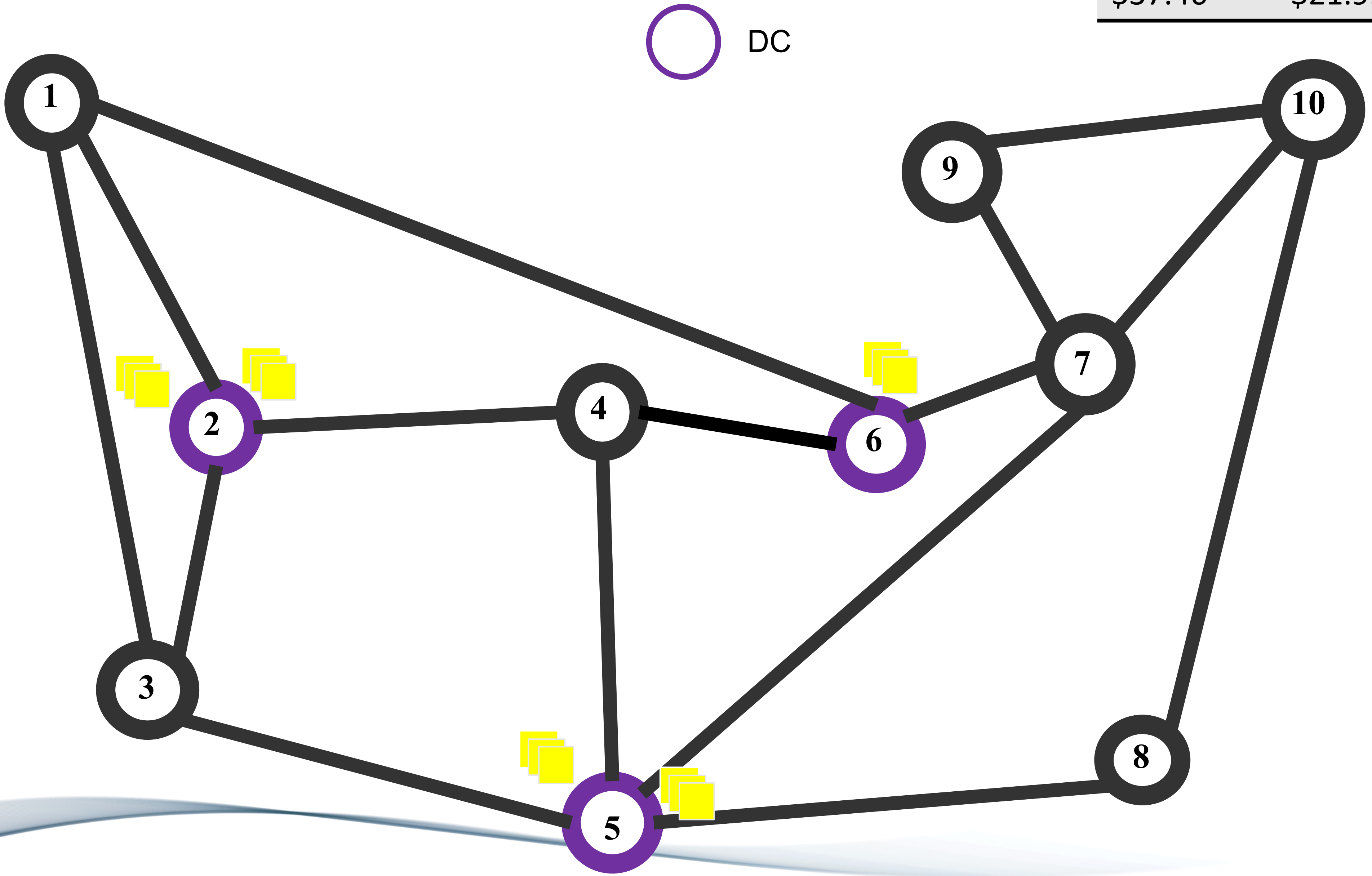
- Hourly price of electricity across the DC nodes.
- Prices have been synchronized with Eastern Standard Time(EST).

Prices in $/MWh

Hour	DC node 2	DC node 5	DC node 6
0400	$37.46	$21.99	$18.79
0500	$29.82	$22.01	$21.37
0600	$5.17	$25.01	$21.37
0700	$35.12	$27.01	$27.51

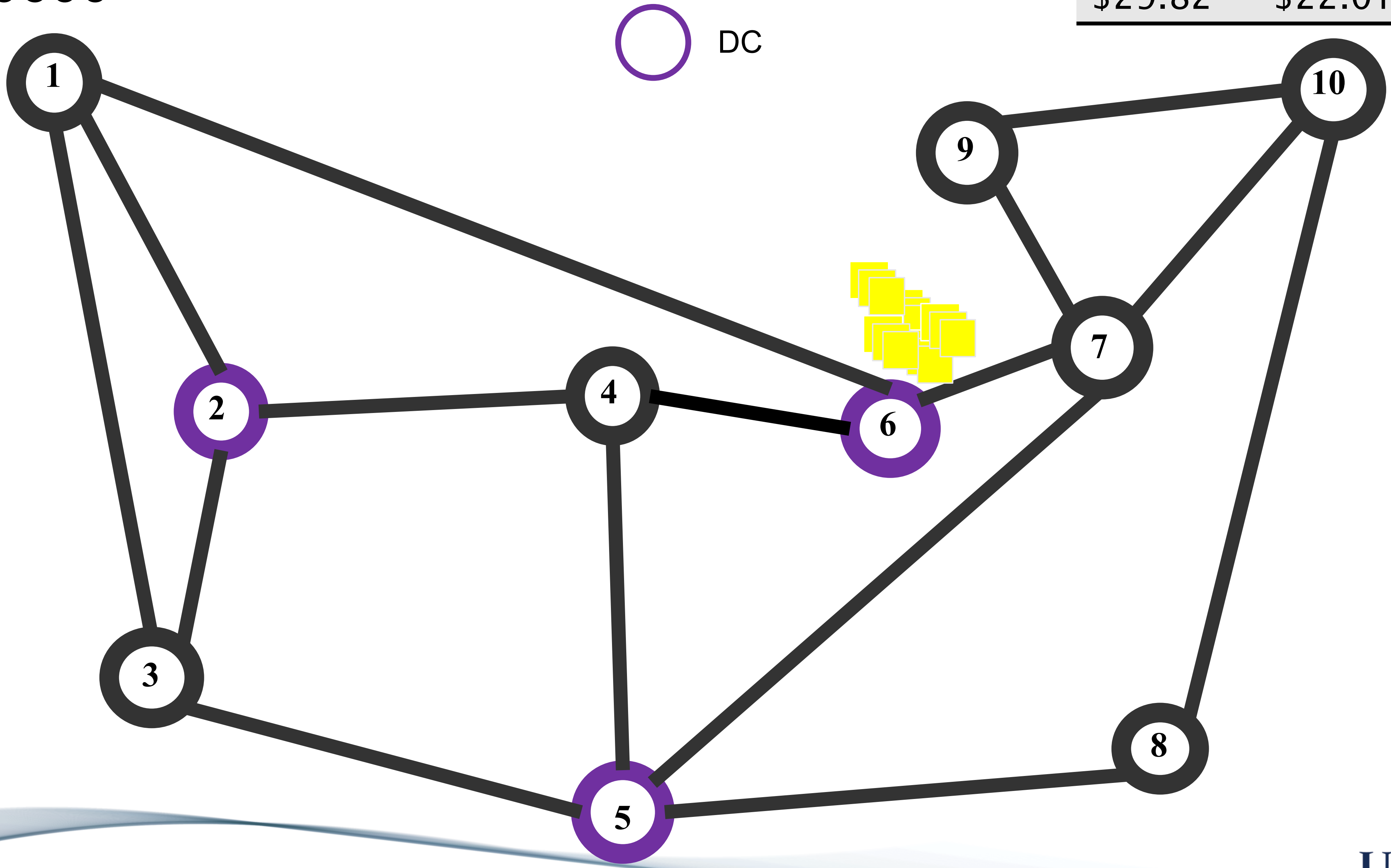
Simulation (0400 - 0500)

Node 2	Node 5	Node 6
$37.46	$21.99	$18.97



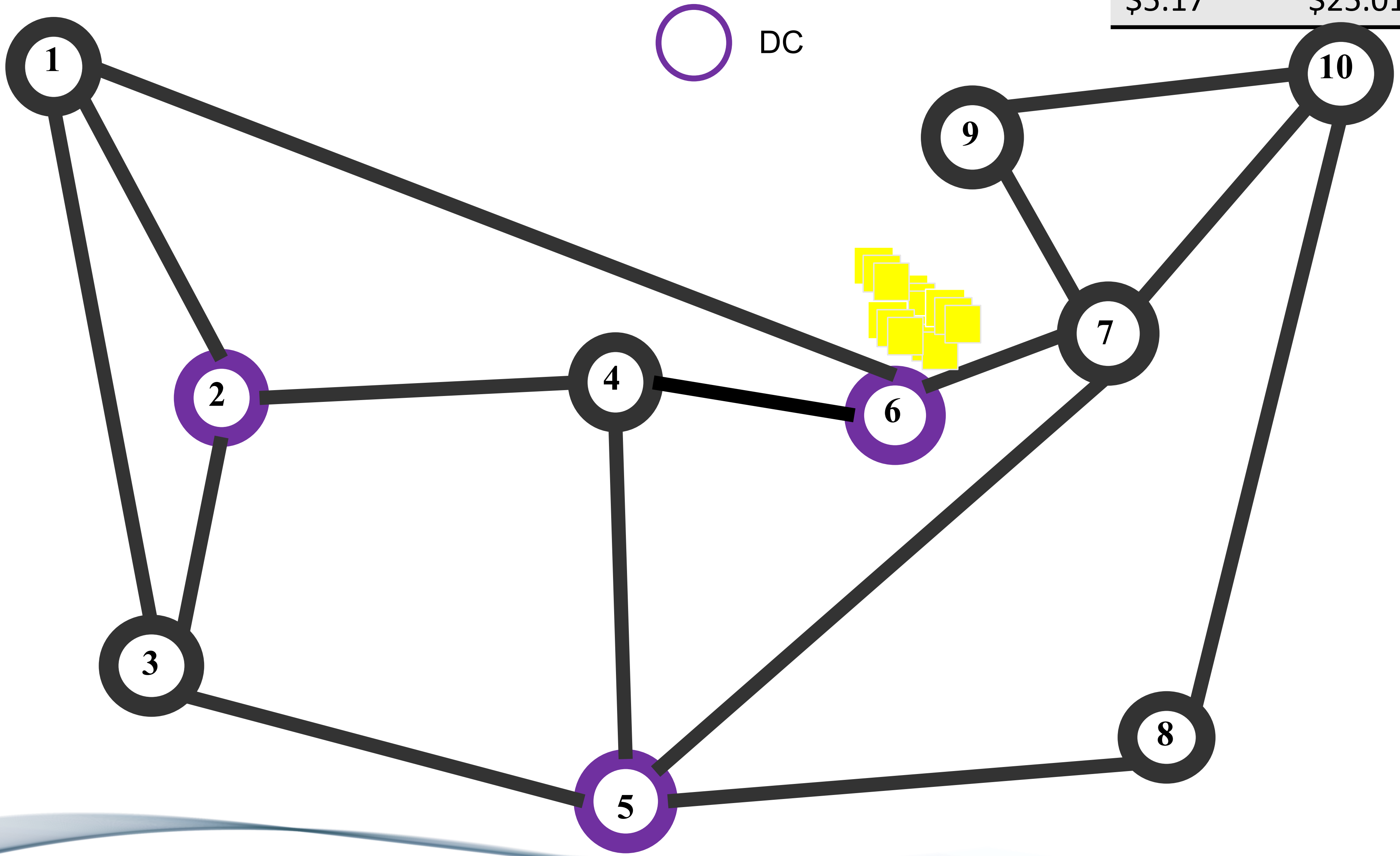
0500 - 0600

Node 2	Node 5	Node 6
$29.82	$22.01	$21.37



0600 - 0700

Node 2	Node 5	Node 6
$5.17	$25.014	$21.37



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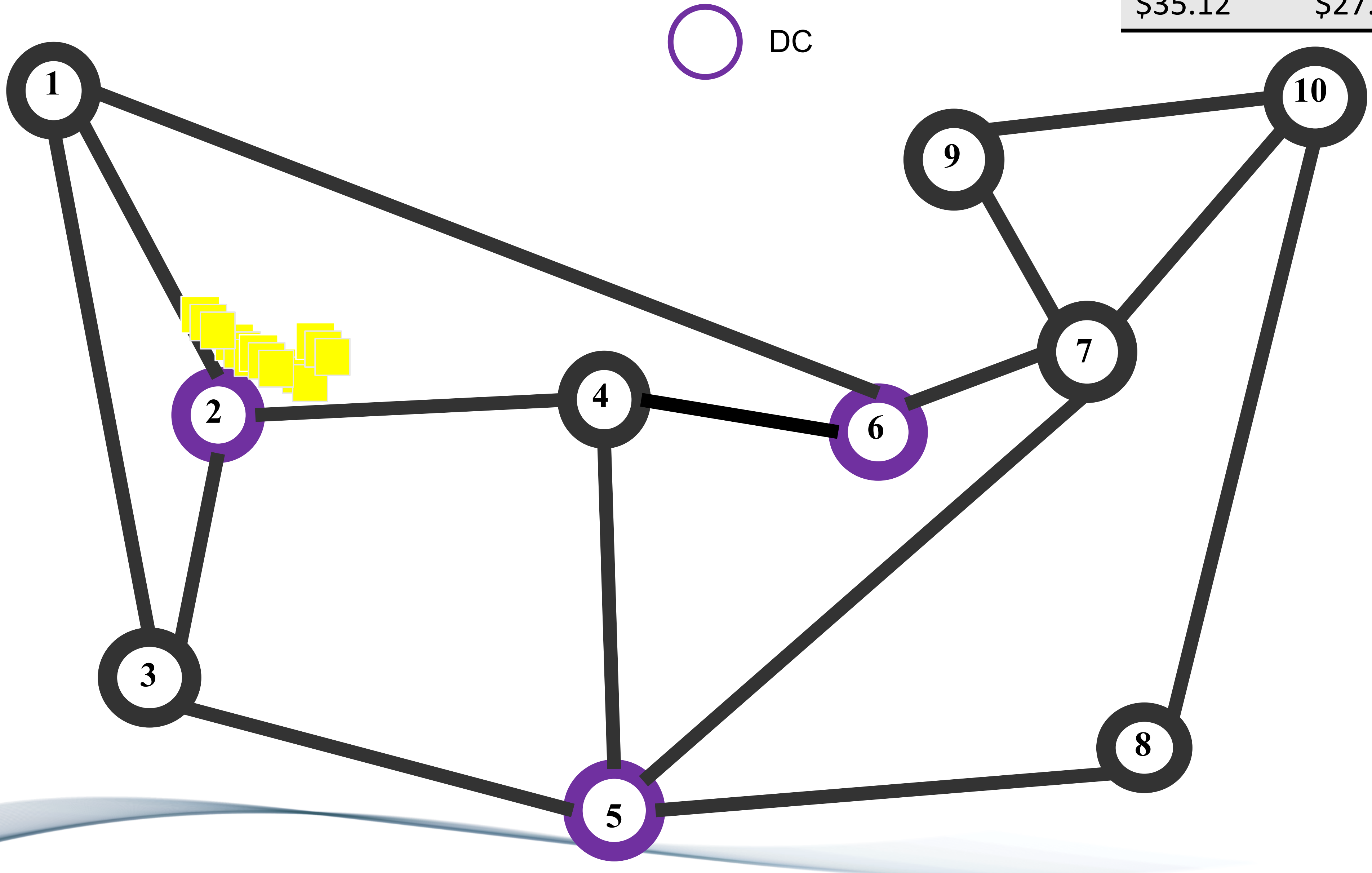
0700 - 0800

Node 2	Node 5	Node 6
$35.12	$27.01	$27.51



Publications

- [5] A. Gupta, U. Mandal, P. Chowdhury, M. Tornatore, and B. Mukherjee, “Cost-efficient live VM migration based on varying electricity cost in optical cloud networks," in *IEEE International Conference on Advanced Networks and Telecommuncations Systems (ANTS)*, 2014, pp. 1-3 (**Best Short Paper Award**)
- [6] A. Gupta, U. Mandal, P. Chowdhury, M. Tornatore, and B. Mukherjee, “Cost-efficient live VM migration based on varying electricity cost in optical cloud networks," *Photonic Network Communications*, vol. 30, no. 3, pp. 376-386, 2015
- [7] S. Rahman, A. Gupta, M. Tomatore and B. Mukherjee, "Dynamic workload migration over optical backbone network to minimize data center electricity cost," *2017 IEEE International Conference on Communications (ICC)*, Paris, 2017, pp. 1-5
- [8] S. Rahman, A. Gupta, M. Tornatore, and B. Mukherjee, “Dynamic workload migration over backbone network to minimize data center electricity cost," *IEEE Transactions on Green Communications and Networking*, pp. 1-1, 2017

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

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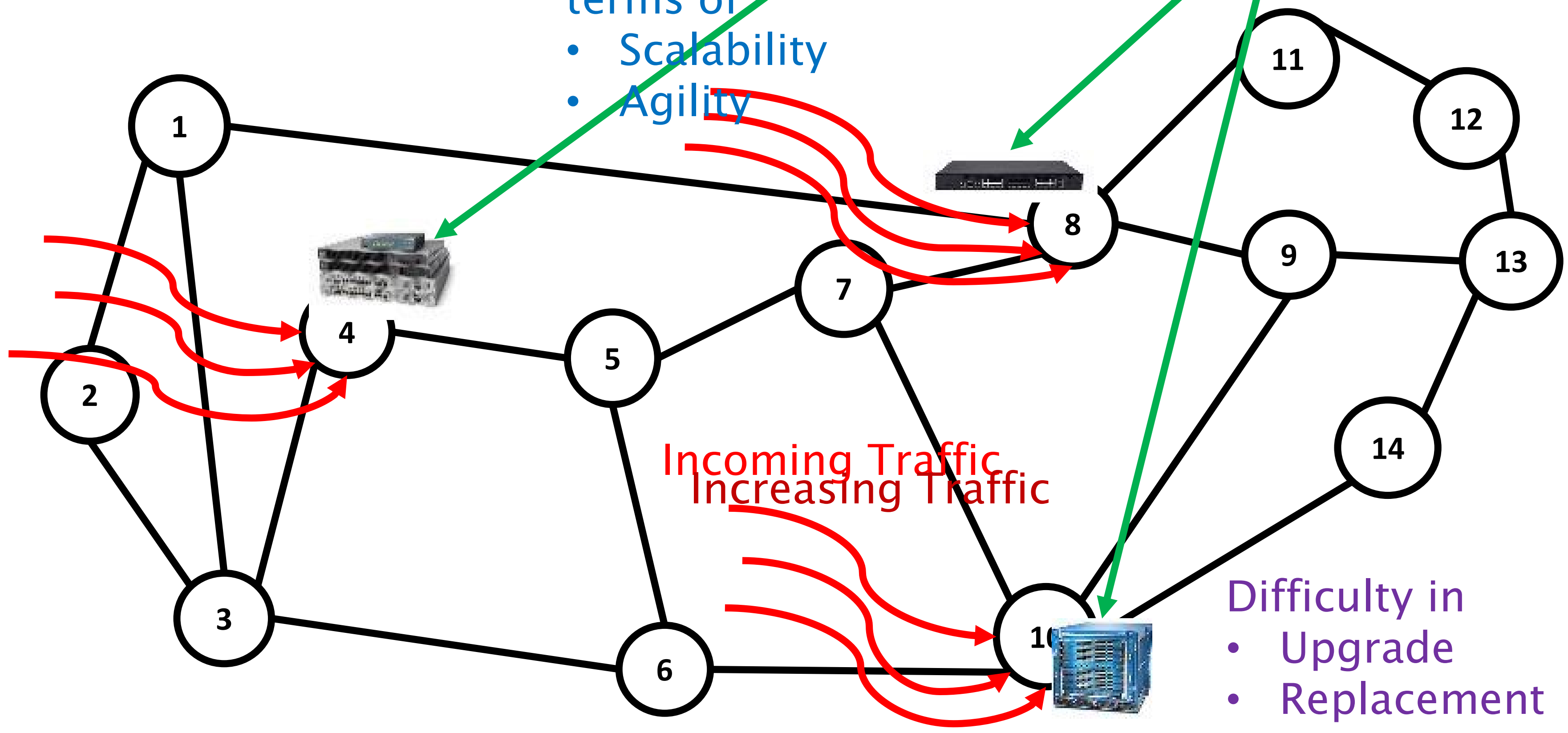
Motivation

Operator Network (AT&T, Verizon …)

Proprietary Network Appliances

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



Difficulty in
- Upgrade
- Replacement
- Maintenance

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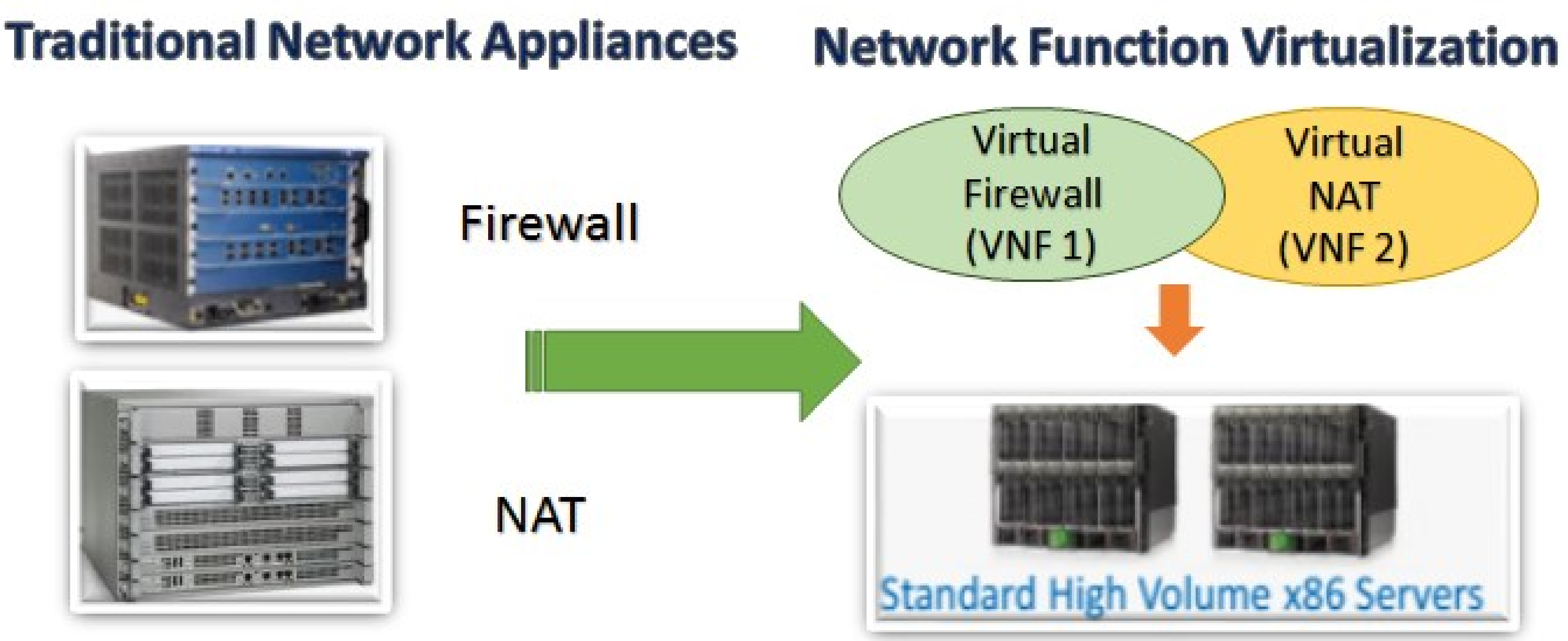
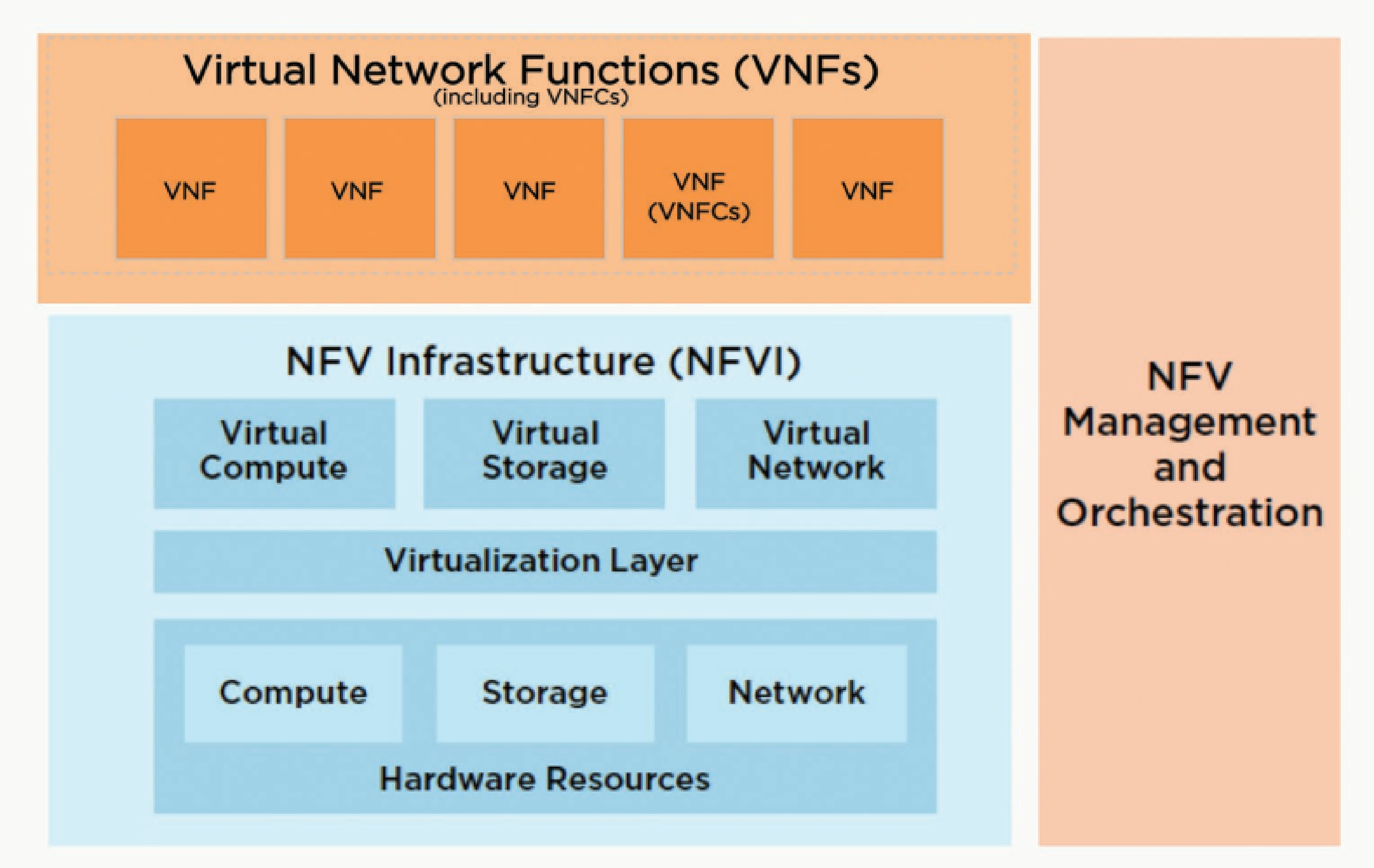

Traditional Network Appliances
Network Function Virtualization
Virtual Firewall (VNF 1)
Virtual NAT (VNF 2)
Firewall
NAT
Standard High Volume x86 Servers

NFV framework and role of VNFs



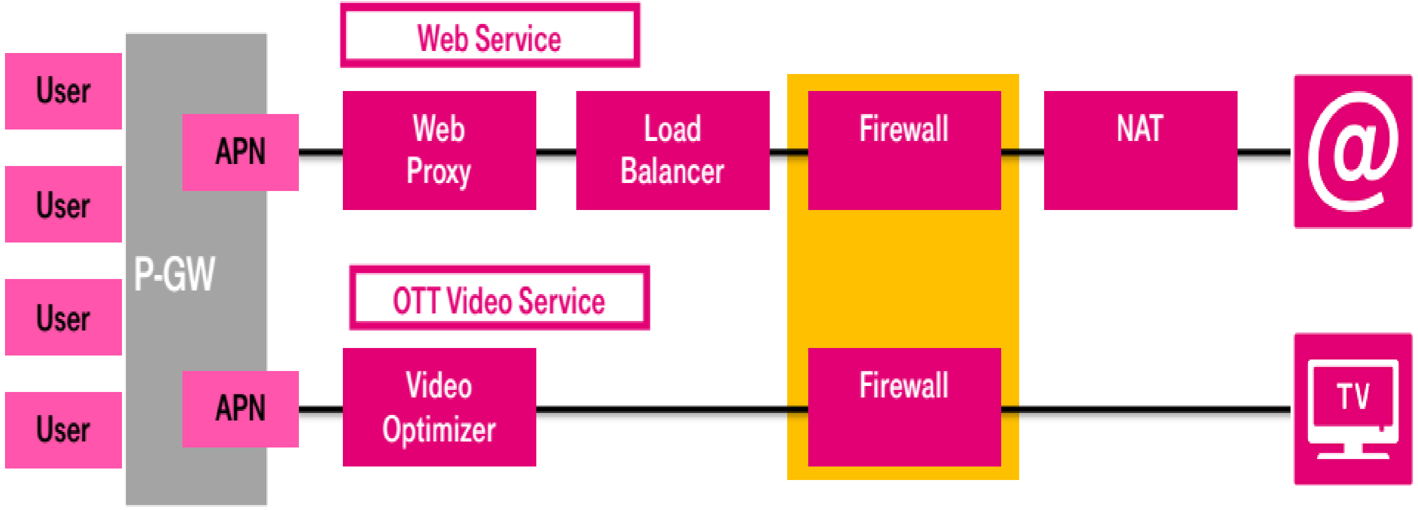
[9]"Powering NFV – Virtual Network Functions (VNFs)" – SDxCentral – 2017 NFV Report Series Part 3: Virtual Network Functions (VNFs)

Service Chain (SC)

- "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



[10] IETF, "Network service chaining problem statement," https://tools.ietf.org/html/draft-quinn-nsc-problem-statement-00, 2013

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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

[11] W. John *et al.*, "Research Directions in Network Service Chaining," *2013 IEEE SDN for Future Networks and Services (SDN4FNS)*

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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

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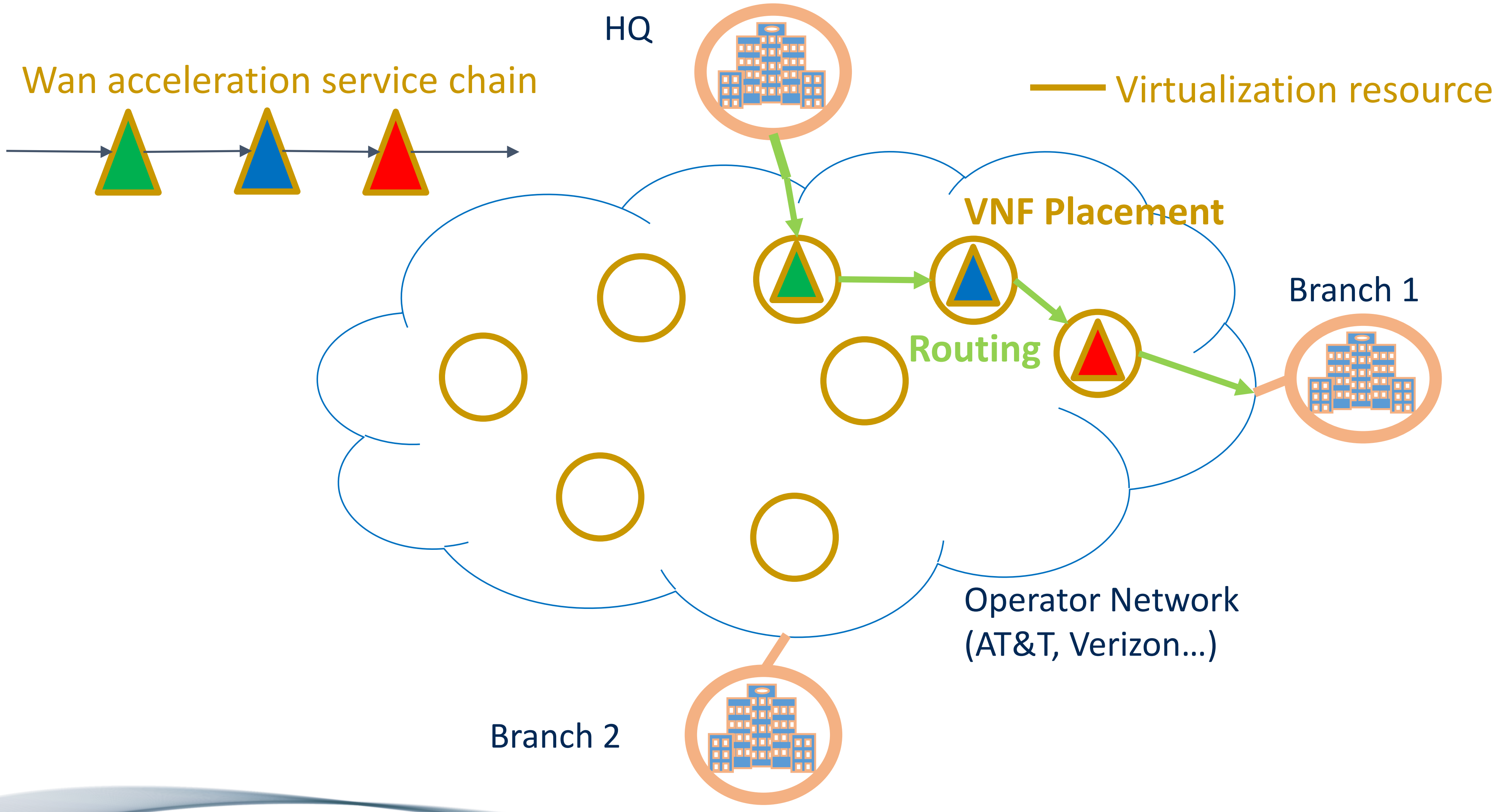
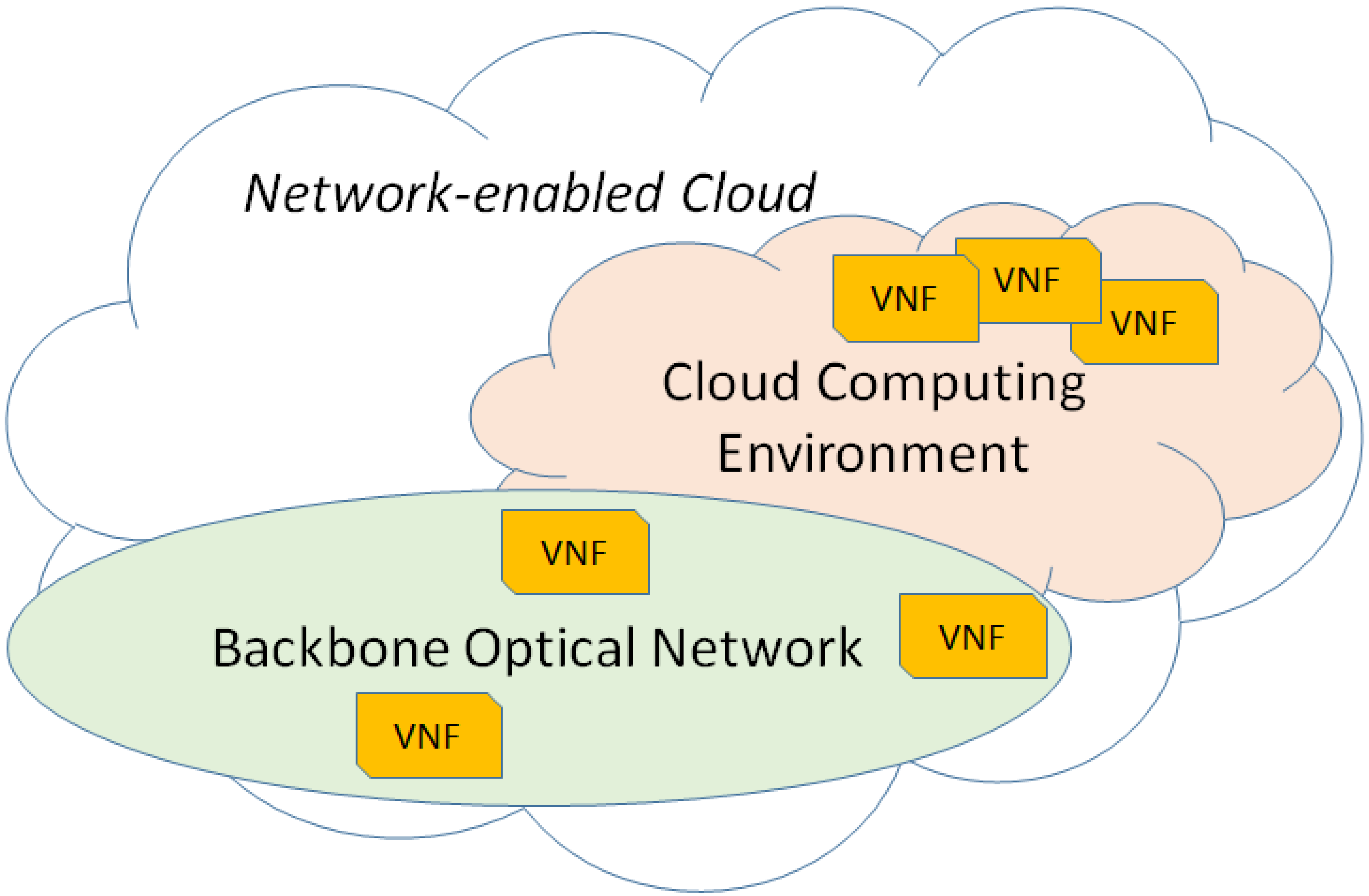
Service Chain Placement and Routing

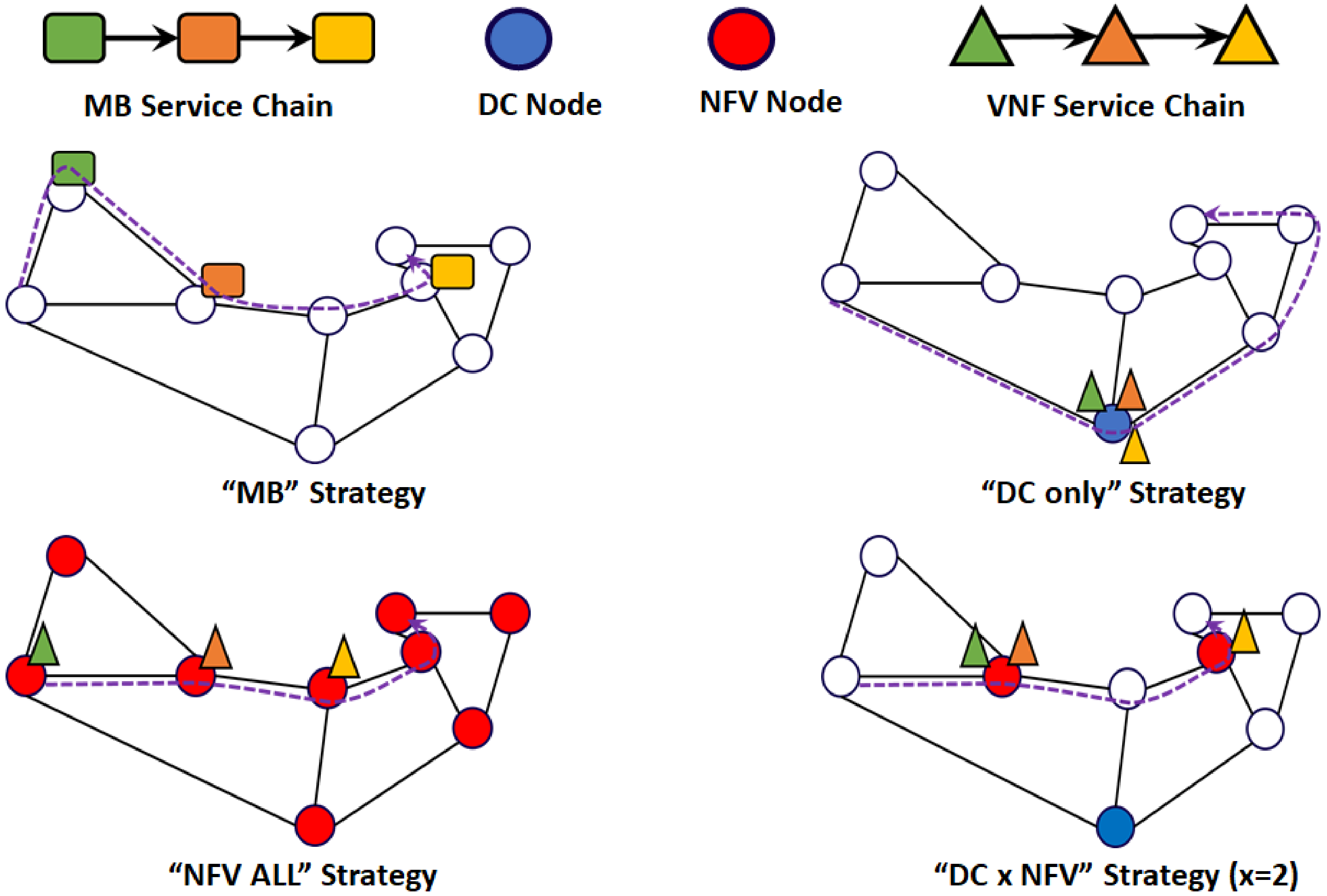


Network-enabled Cloud



[12] Ericsson, “The real-time cloud combining cloud, NFV and service provider SDN,” 2014

Service Chaining Strategies



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

[13] Cisco, “Cisco Cloud Services Router 1000V 3.14 Series Data Sheet,”2015

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

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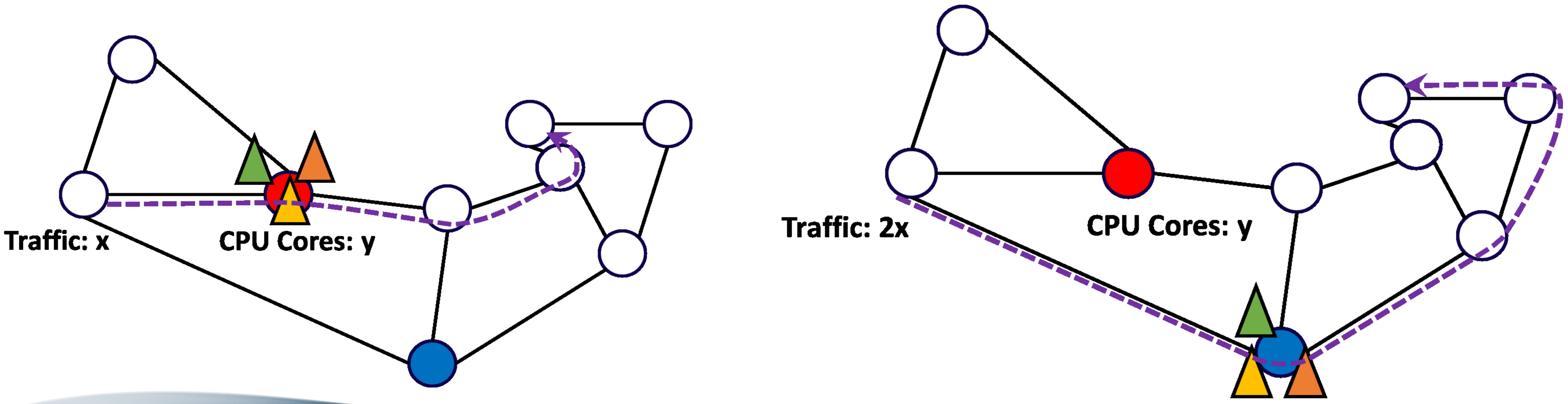
Tradeoffs

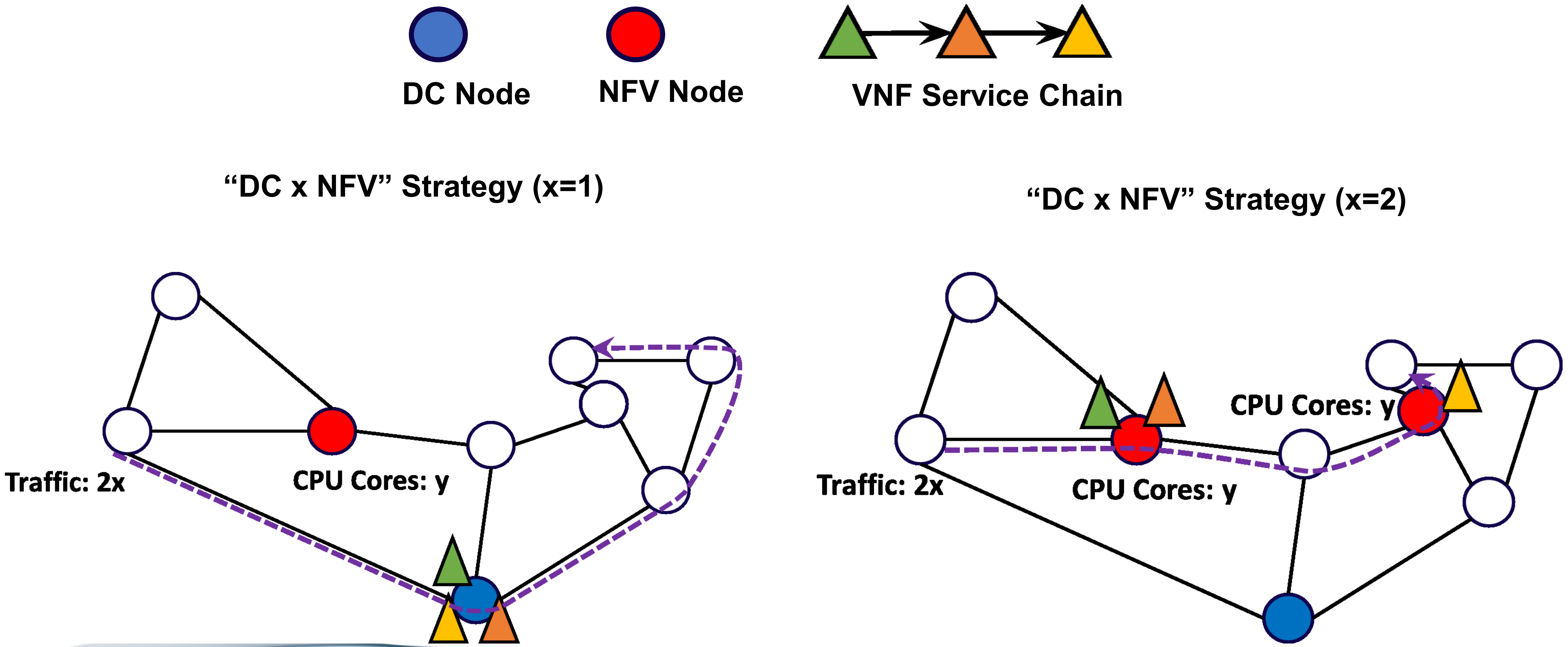
- CPU cores per NFV node
- Number of NFV nodes
- Location of NFV nodes

Bandwidth vs CPU cores per node

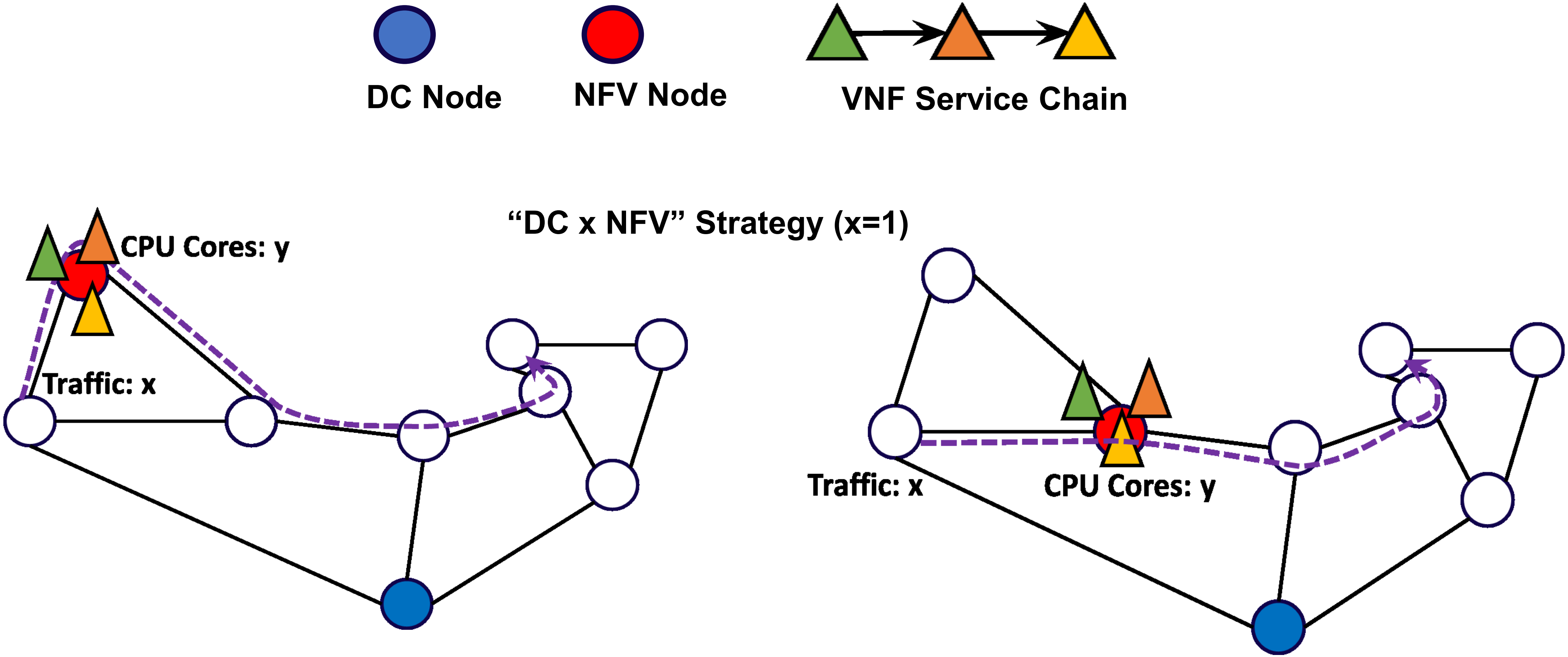
"DC x NFV" Strategy (x=1)



Bandwidth Vs Number of NFV nodes

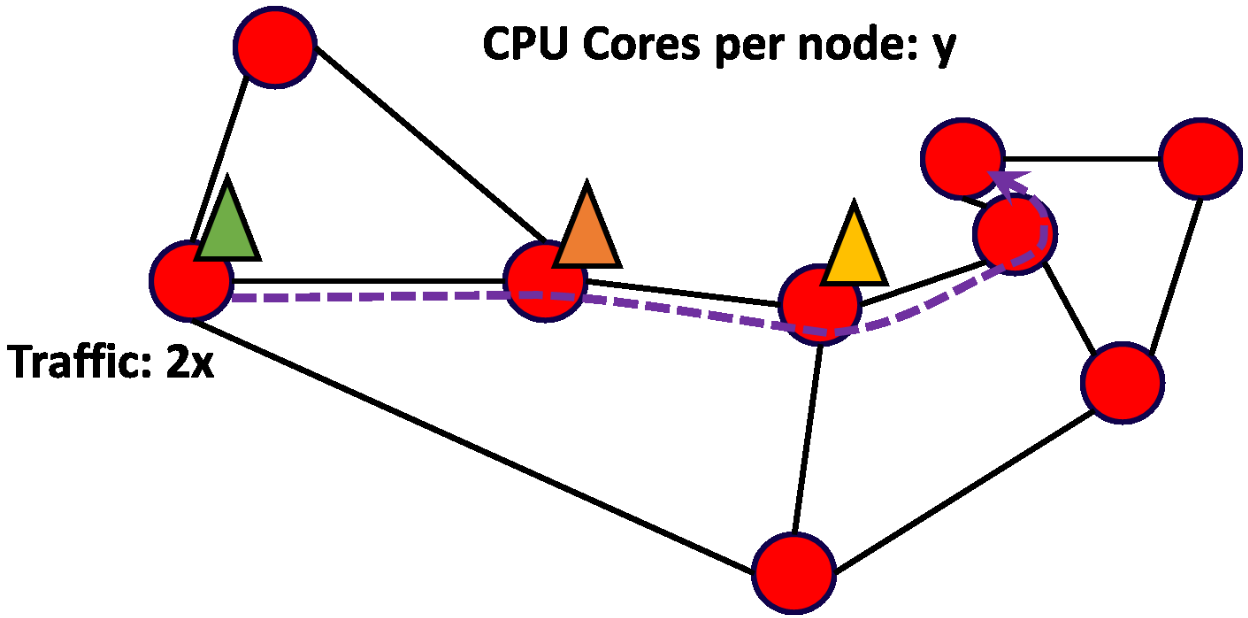


Bandwidth Vs Location of NFV nodes

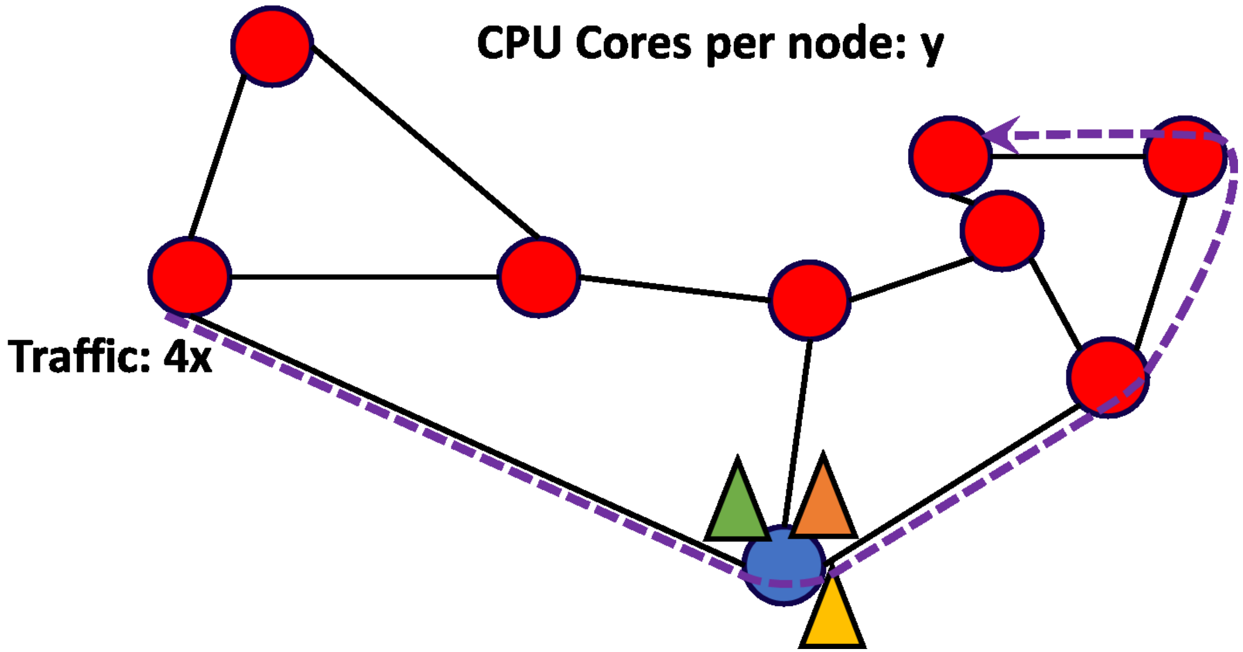


No DC Vs DC

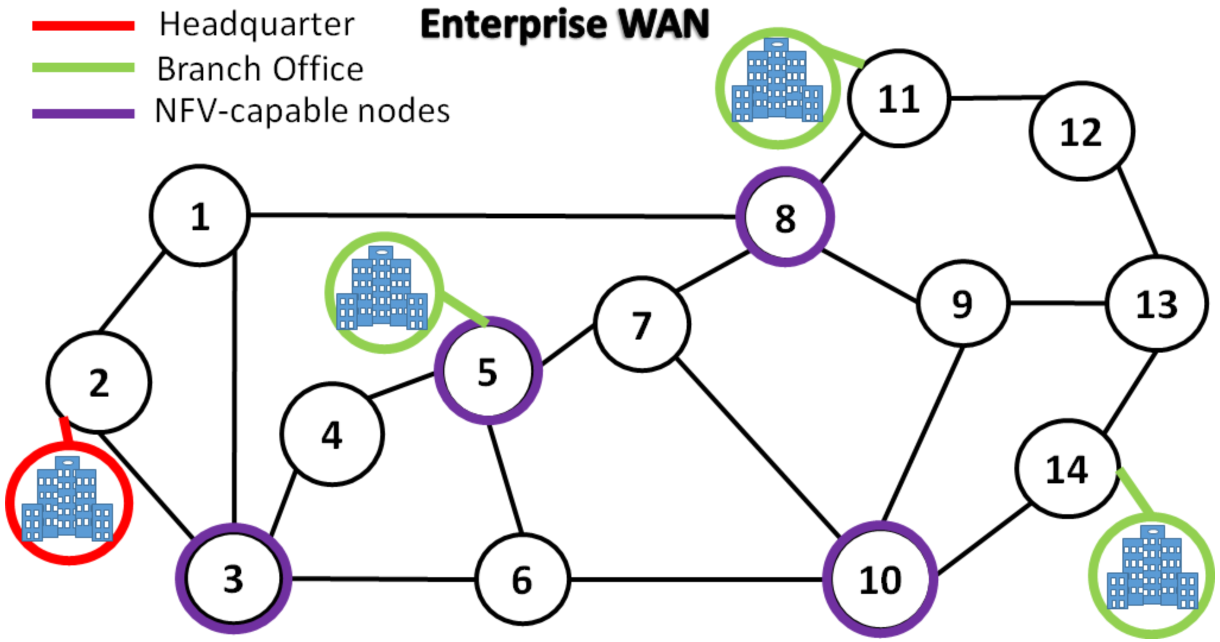
"NFV ALL" Strategy

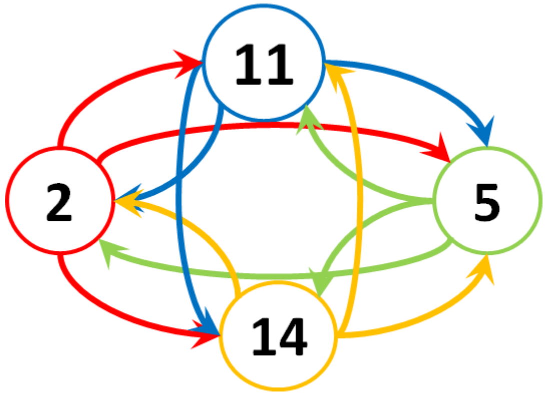


"DC NFV ALL" Strategy

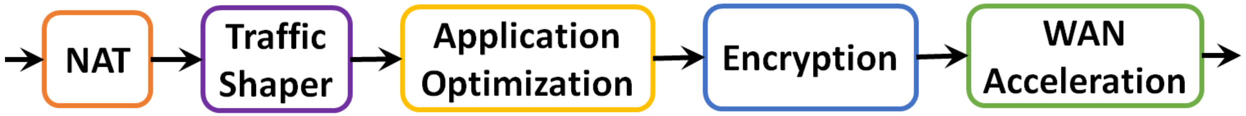


Simulation Scenario 1



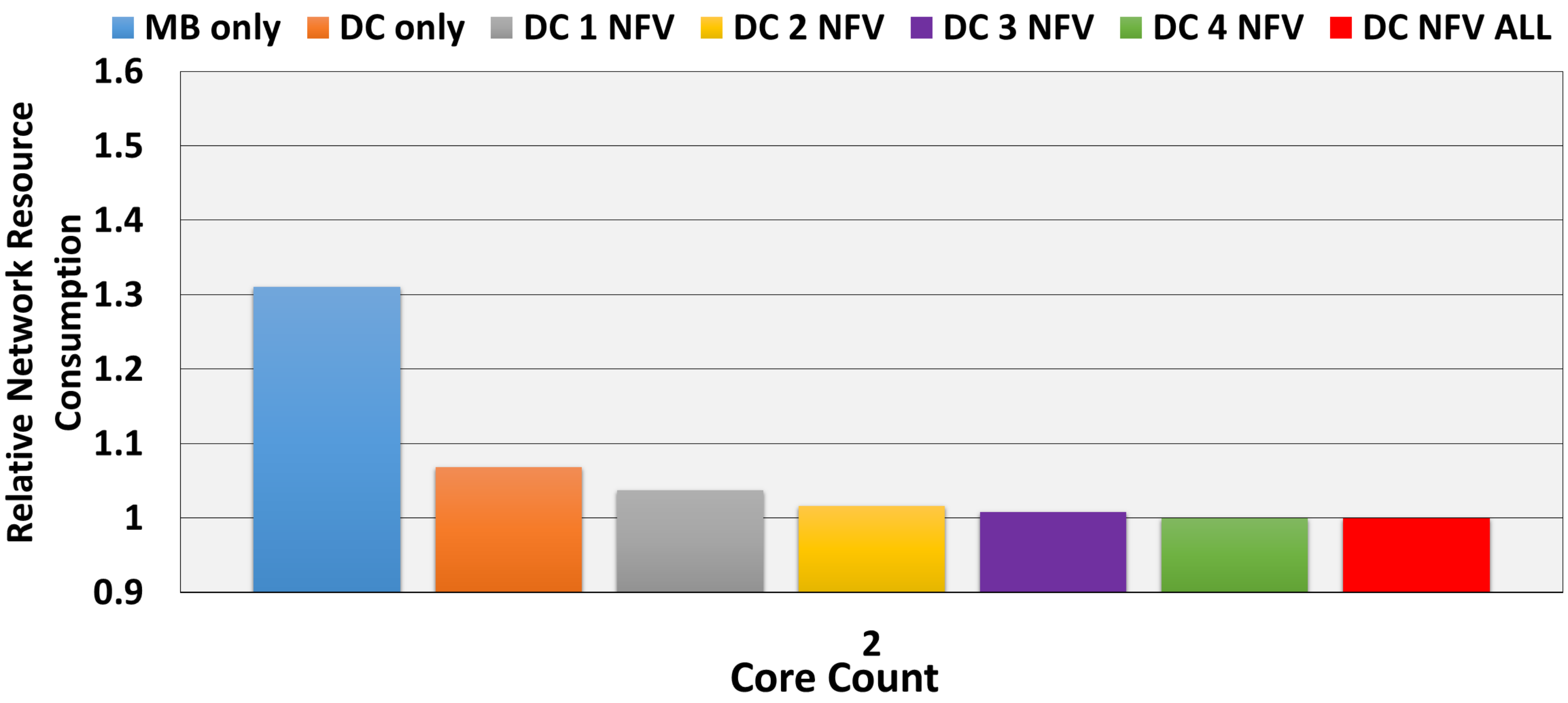


Service Chain 1



Service Chain 2

Scenario 1 – 1 Gbps traffic



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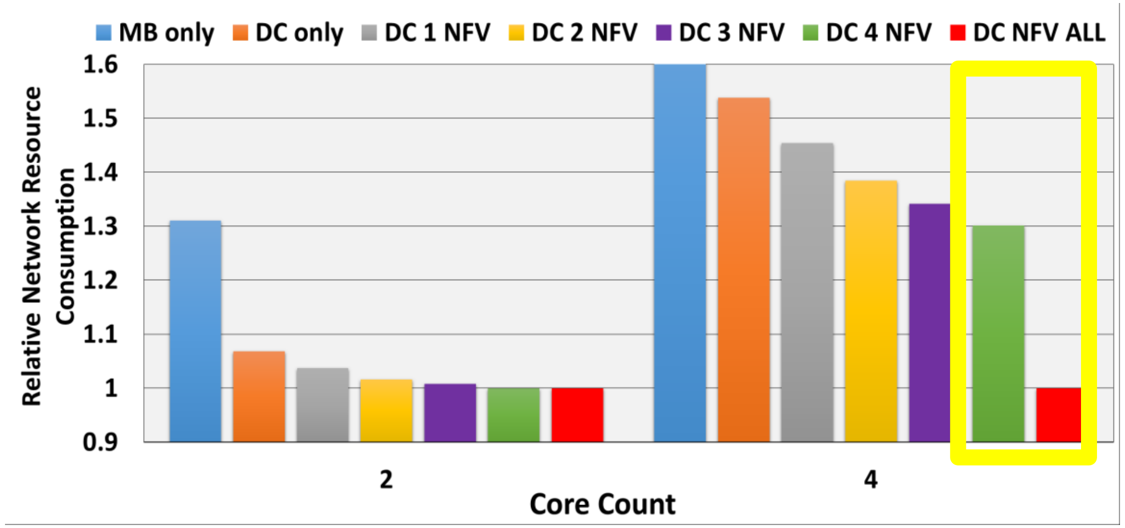

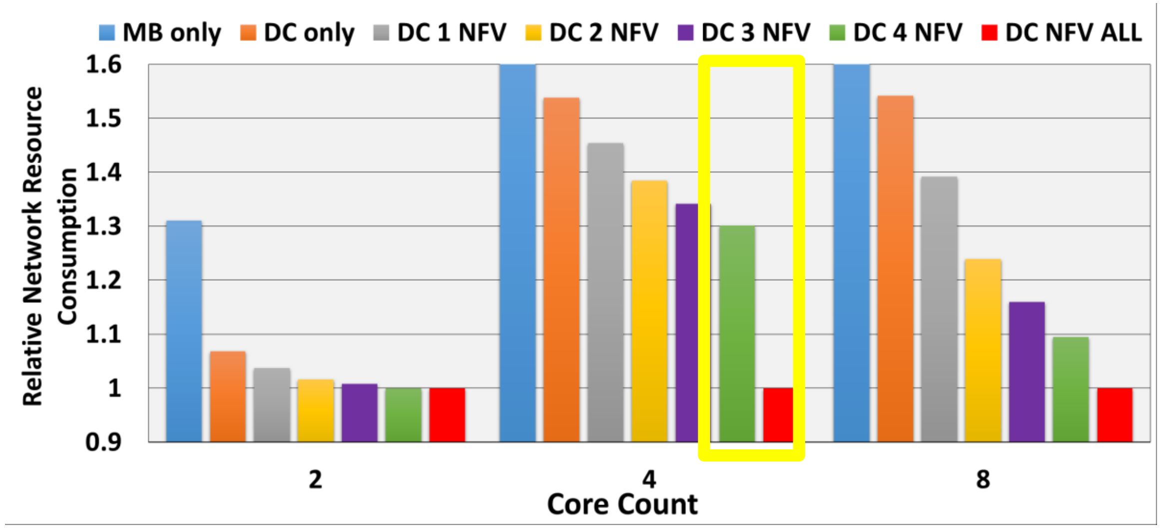

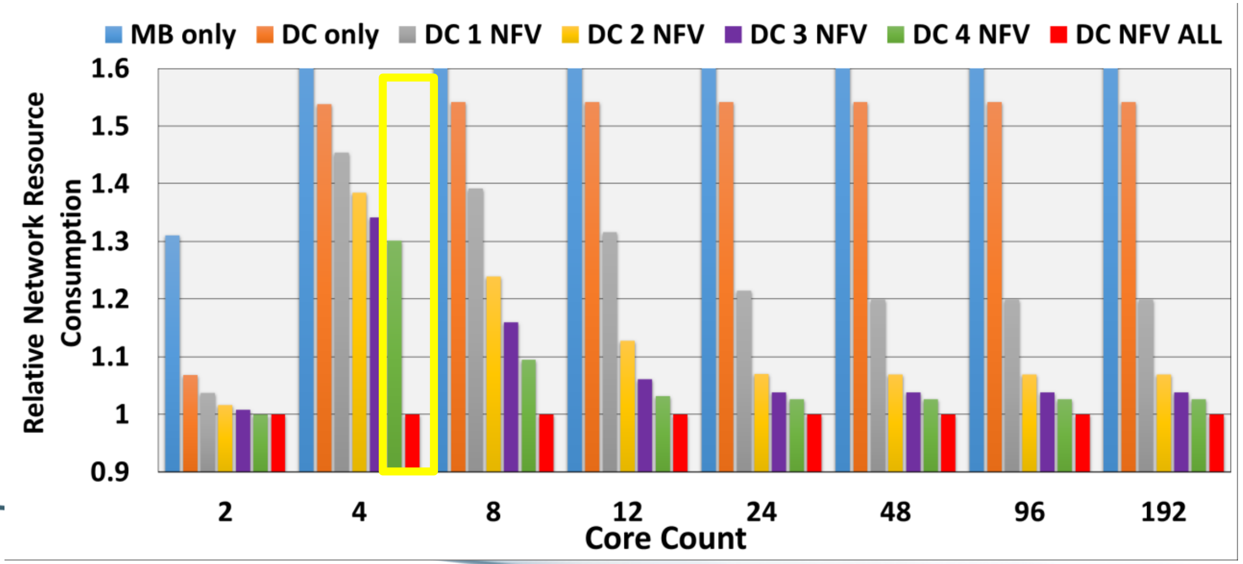

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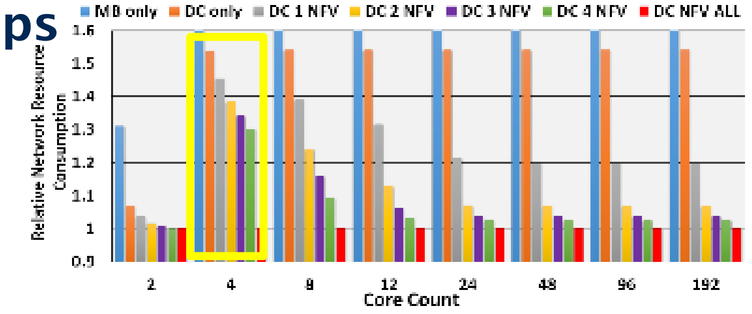
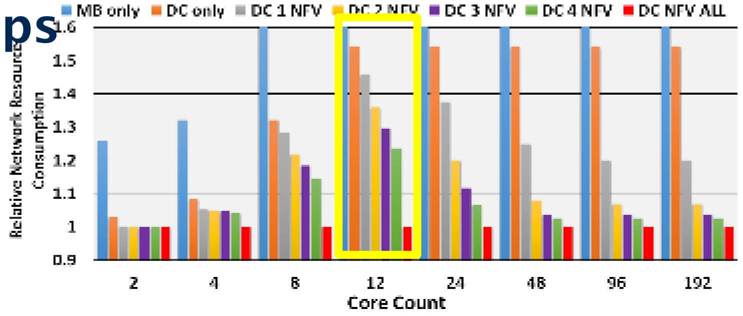
Scenario 1 - Results

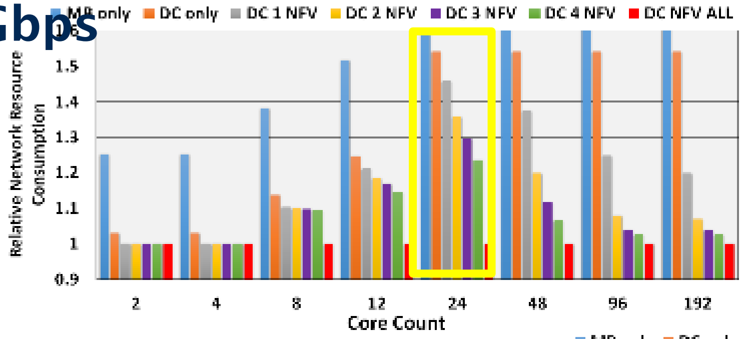
1 Gbps



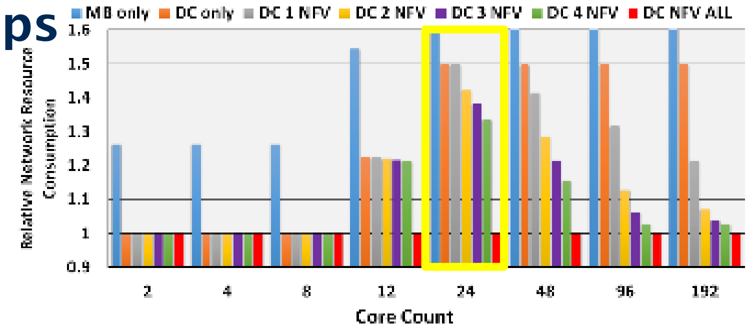
2.5 Gbps



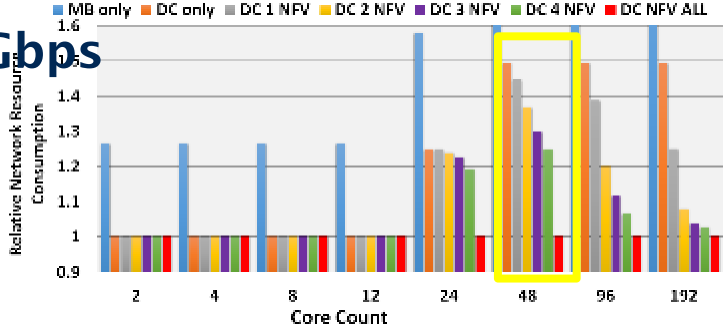
7.5 Gbps



5 Gbps



10 Gbps



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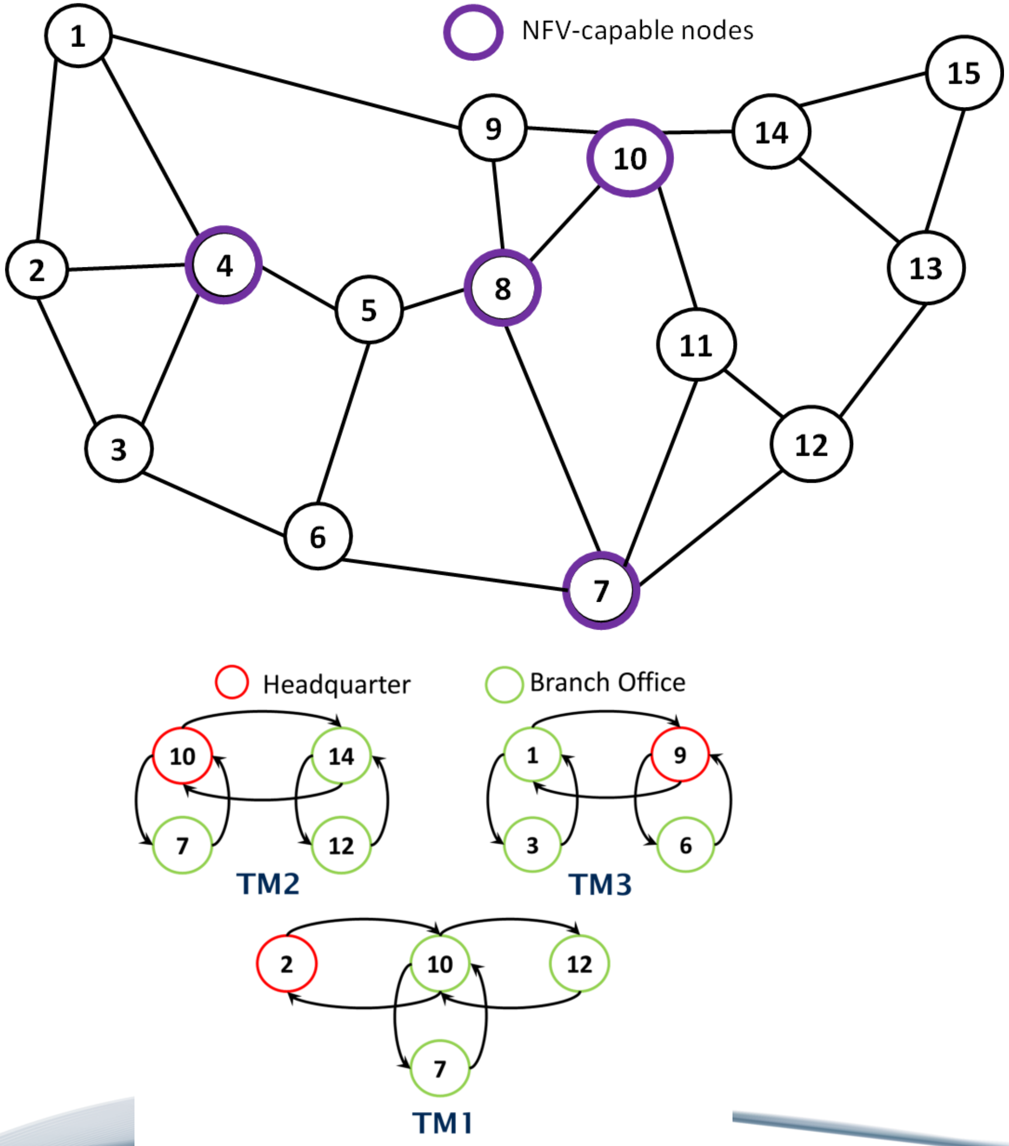
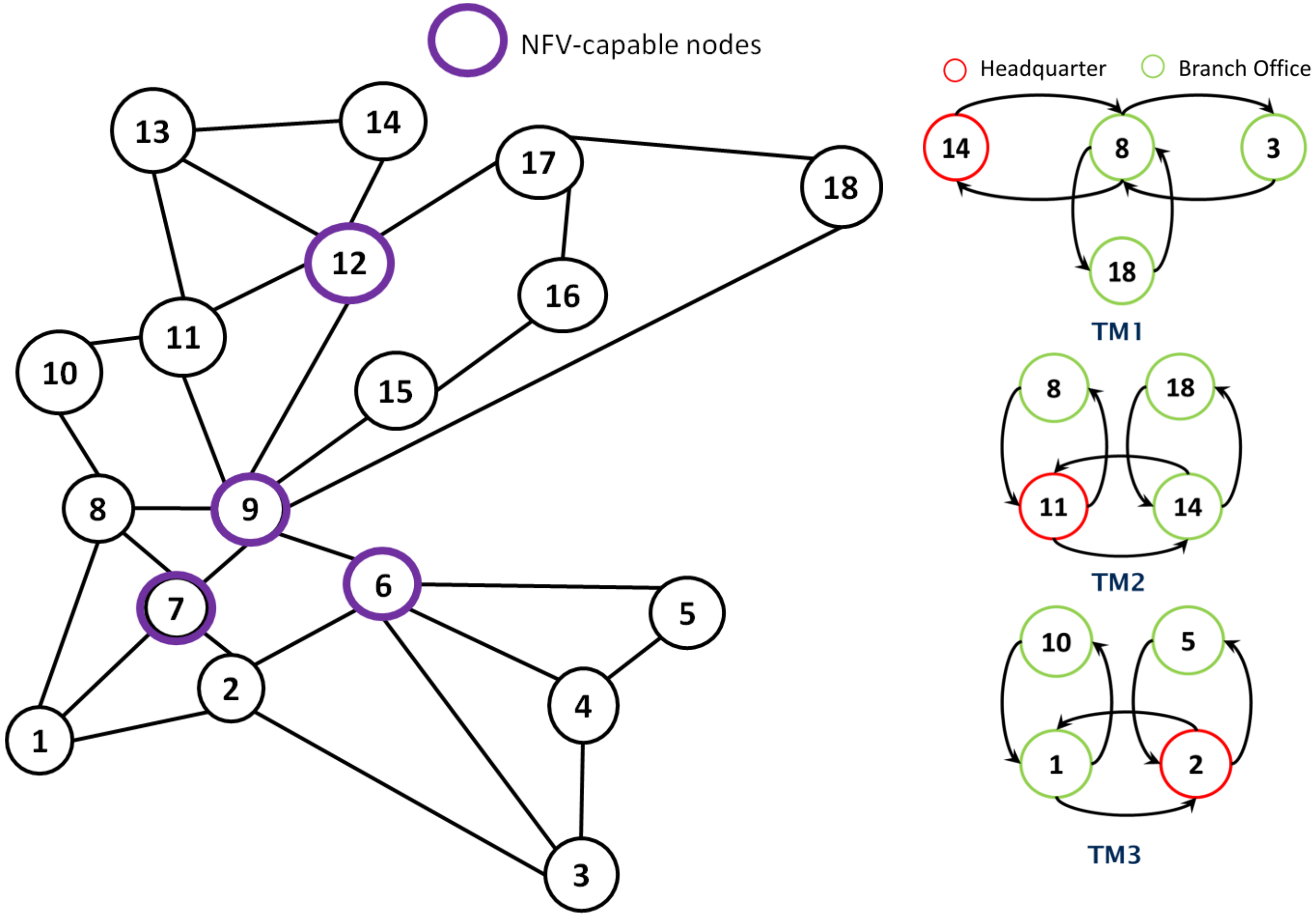
Other Scenarios





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

Publications

- [14] A. Gupta, M. F. Habib, P. Chowdhury, M. Tornatore, and B. Mukherjee,“On service chaining using Virtual Network Functions in Network-enabled Cloud systems,“ in *IEEE International Conference on Advanced Networks and Telecommuncations Systems (ANTS)*, 2015, pp. 1-3 (**Honorable Mention in Short Paper Category**)
- [15] A. Gupta, B. Jaumard, M. Tornatore, and B. Mukherjee,”Multiple Service Chain Placement and Routing in a Network-enabled Cloud," in *IEEE International Conference on Advanced Networks and Telecommuncations Systems (ANTS)*, 2017
- [16] A. Gupta, M. F. Habib, U. Mandal, P. Chowdhury, M. Tornatore, and B. Mukherjee,”On service-chaining strategies using Virtual Network Functions in operator networks," *Computer Networks*, vol. 133, pp. 1-16, 2018

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

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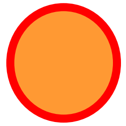
Single Instance per Service Chain (SC)



2 Demand Requests SC1

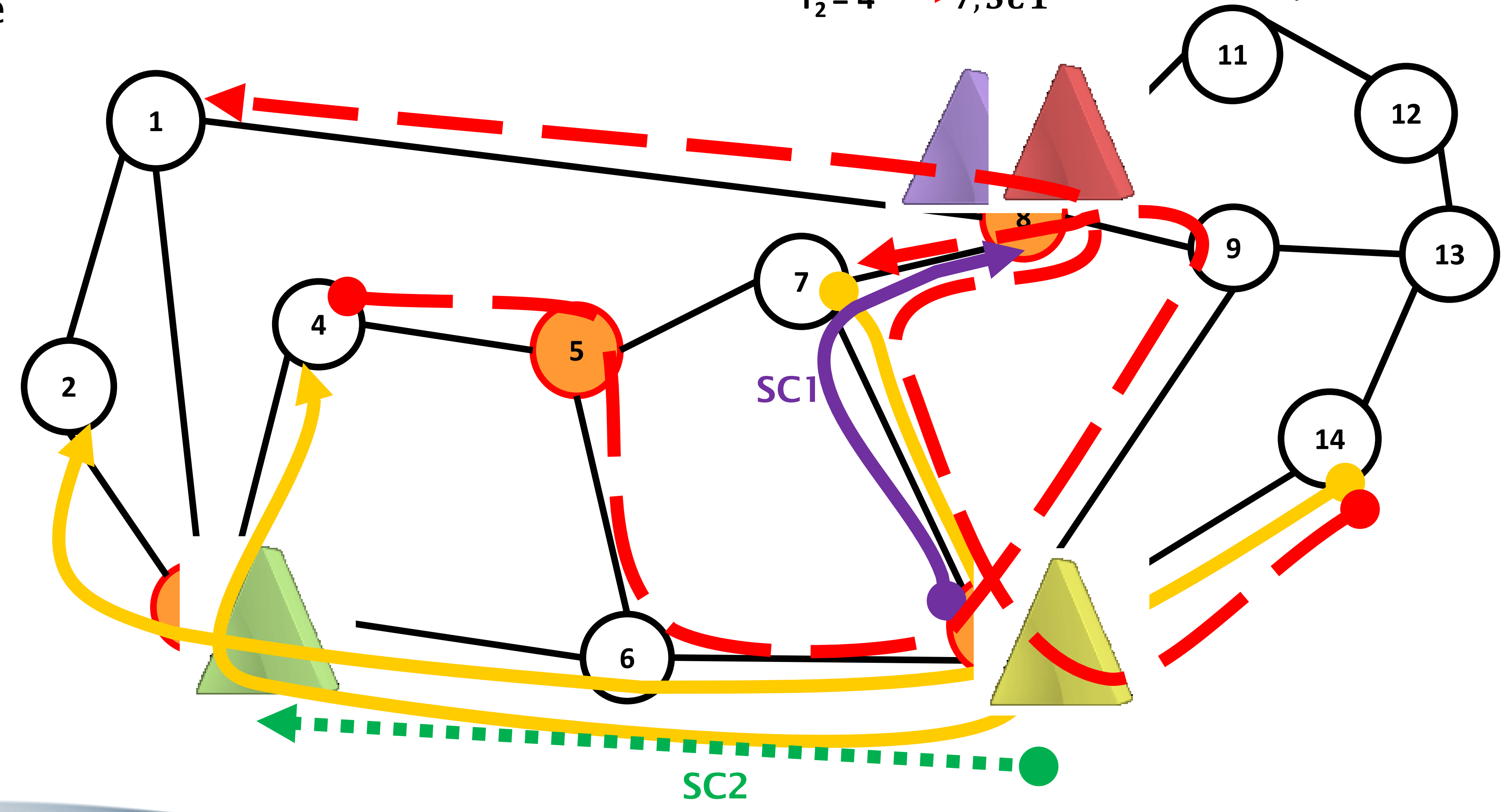
$r_1 = 14 \rightarrow 1, SC1$

$r_2 = 4 \rightarrow 7, SC1$

2 Demand Requests SC2

$r_3 = 14 \rightarrow 2, SC2$

$r_4 = 7 \rightarrow 4, SC2$



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Multiple Instances per SC

2 Demand Requests SC1

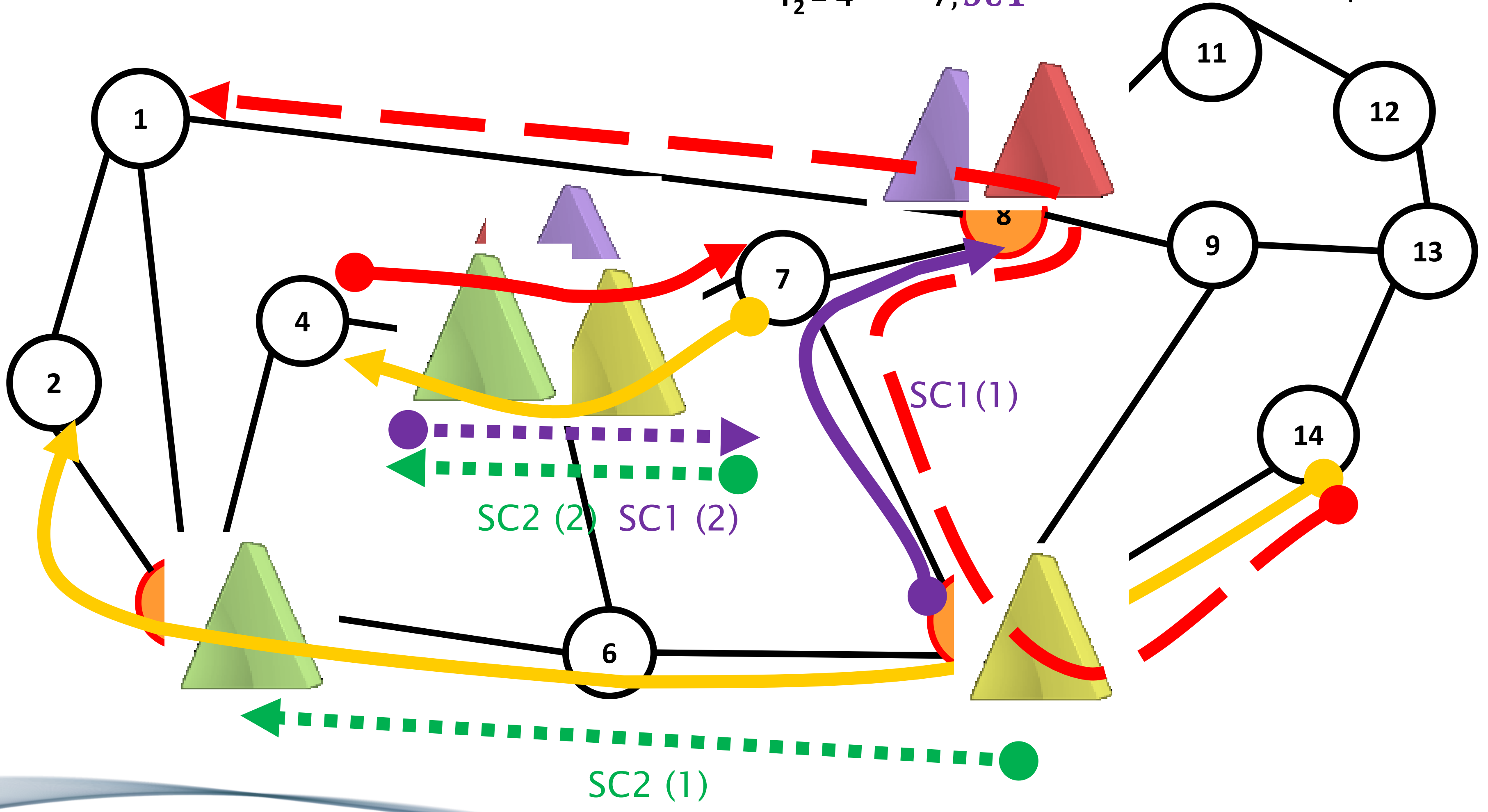
r_1 = 14 → 1, *SC1*

r_2 = 4 → 7, *SC1*

2 Demand Requests SC2

r_3 = 14 → 2, *SC2*

r_4 = 7 → 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

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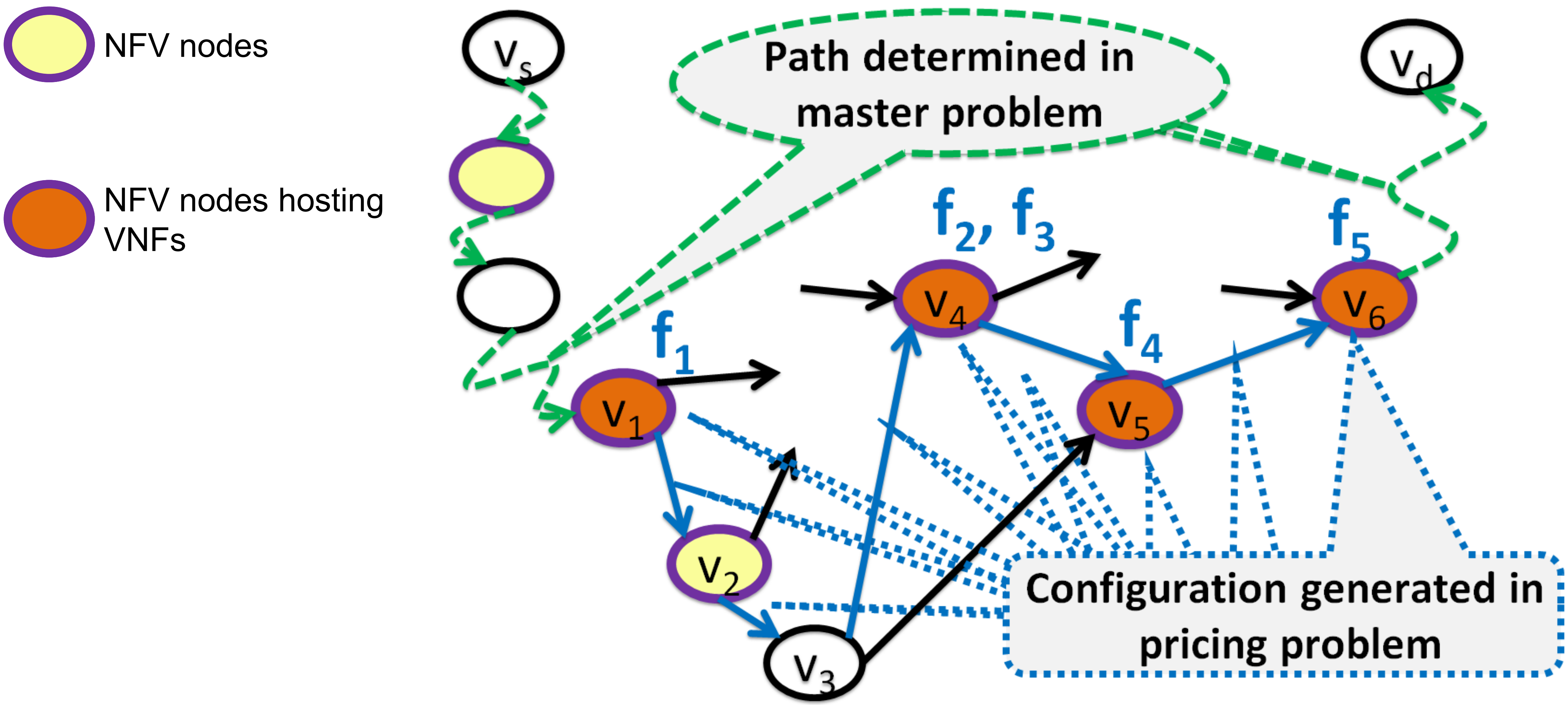

NFV nodes
NFV nodes hosting VNFs
Path determined in master problem
Configuration generated in pricing problem
v_s
v_d
v_1
v_2
v_3
v_4
v_5
v_6
f_1
f_2, f_3
f_4
f_5

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

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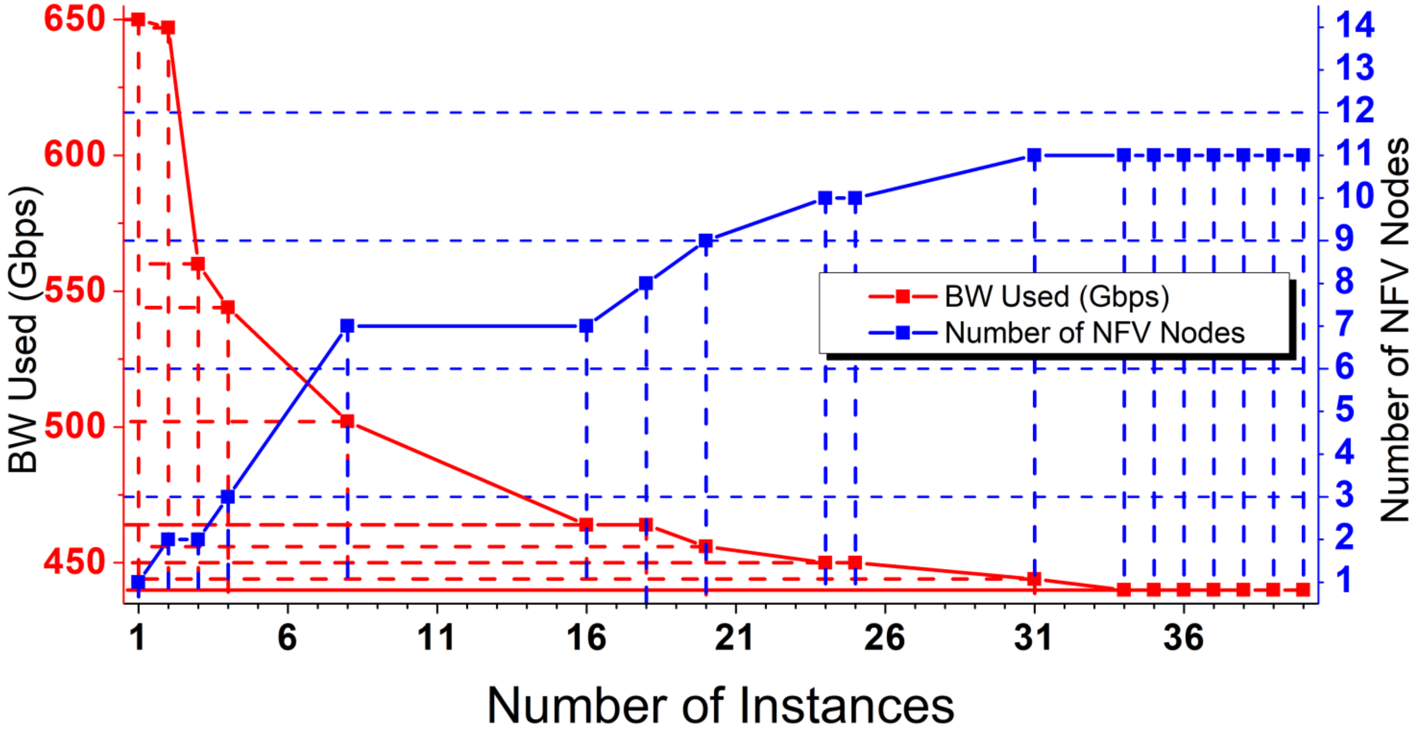
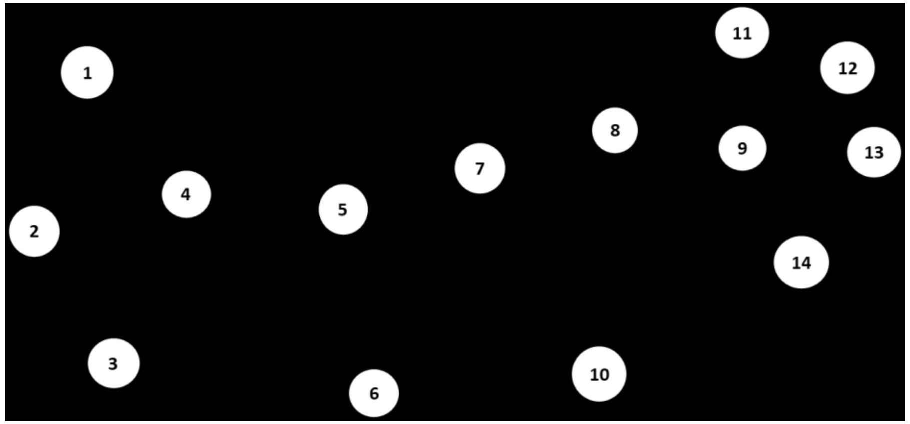
Tradeoffs

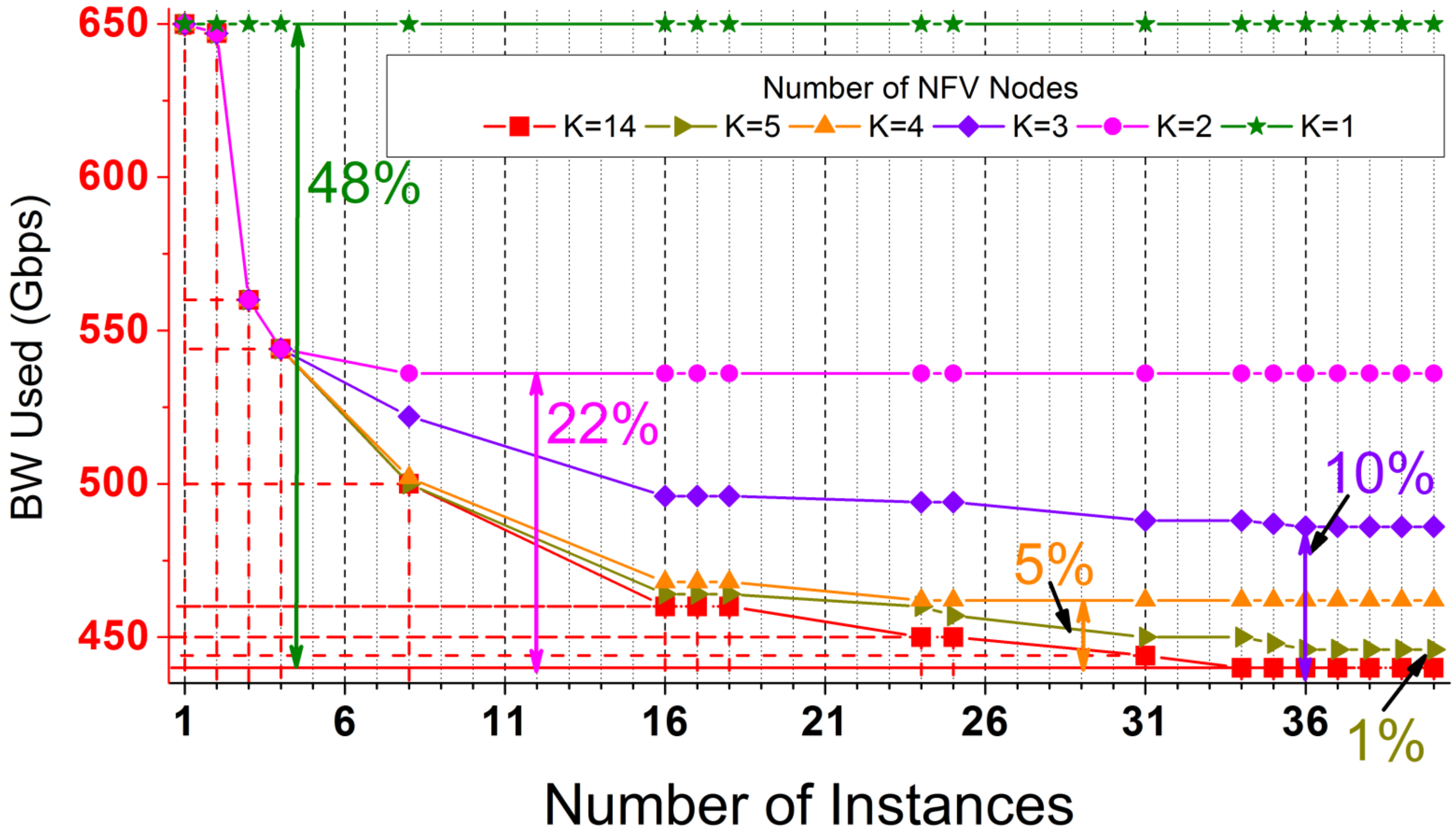
- Bandwidth Vs Number of SC instances deployed
- Bandwidth Vs Number of NFV nodes allowed

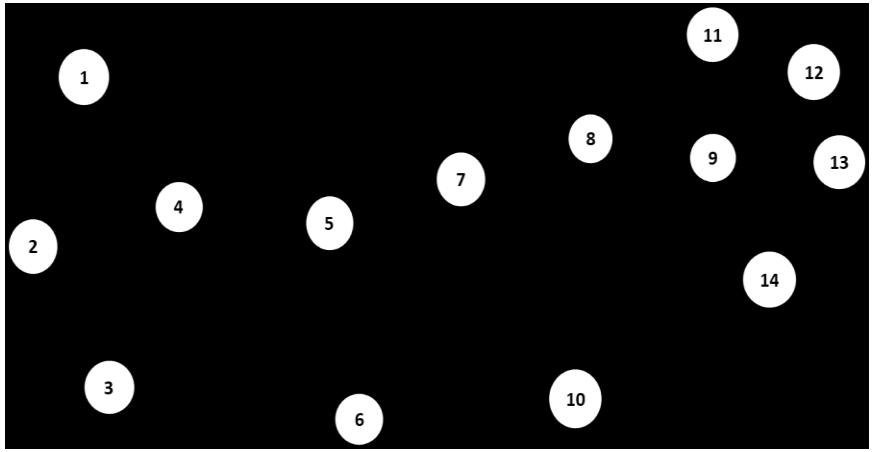
Results – NSFNet (BW vs. Instances)





NSFNet (BW vs Instances vs NFV nodes allowed)





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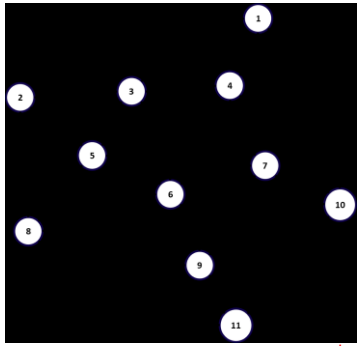

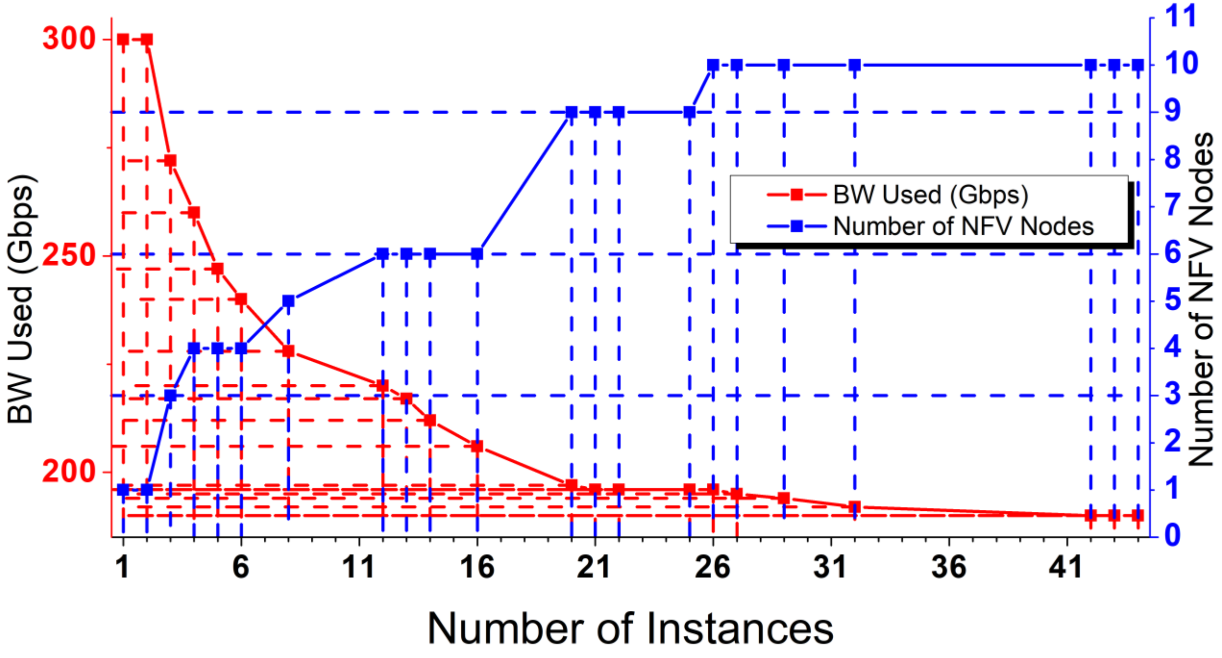

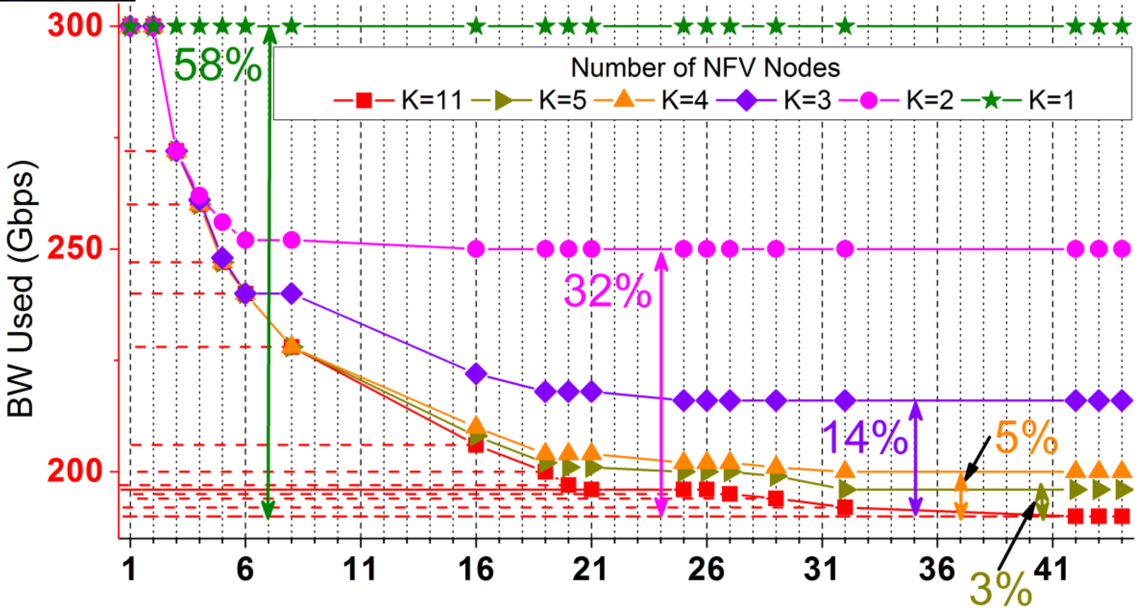

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Conclusion

- Near optimal bandwidth consumption achieved by using relatively small number of SC instances and NFV Nodes

Publications

- [17] A. Gupta, B. Jaumard, M. Tornatore, and B. Mukherjee,"Service Chain (SC) Mapping with Multiple SC Instances in a Wide Area Network," in *IEEE GLOBECOM*, 2017, pp. 1-6
- [18] A. Gupta, B. Jaumard, M. Tornatore and B. Mukherjee, "A Scalable Approach for Service Chain Mapping With Multiple SC Instances in a Wide-Area Network," in *IEEE Journal on Selected Areas in Communications*, vol. 36, no. 3, pp. 529-541, March 2018

Outline

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

2. How to Reduce Operating Costs of Communication Networks? – Network Function Virtualization (NFV)

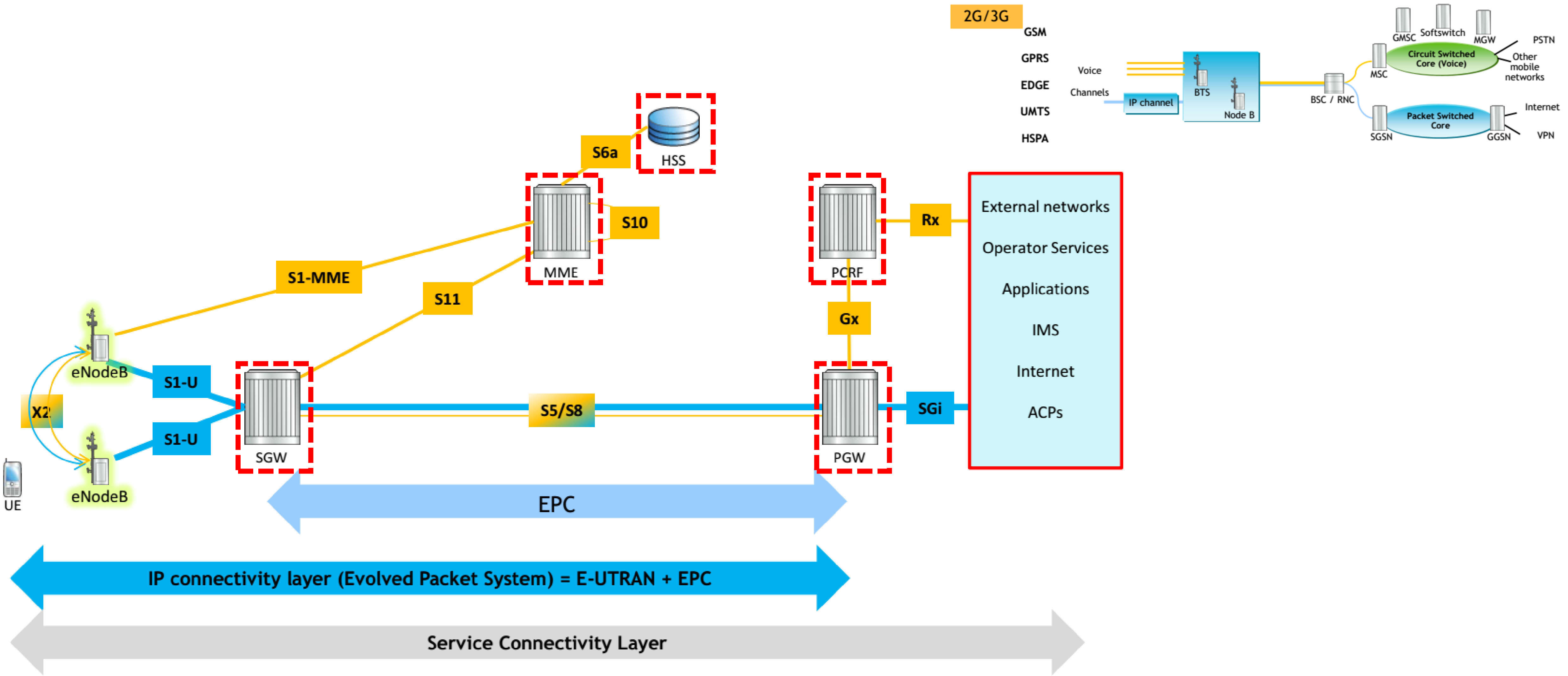
3. On Service-Chaining Strategies using Virtual Network Functions in Operator Networks

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

Virtual-Mobile-Core Placement for Metro Network

Mobile Core Architecture (Evolved Packet Core (EPC))

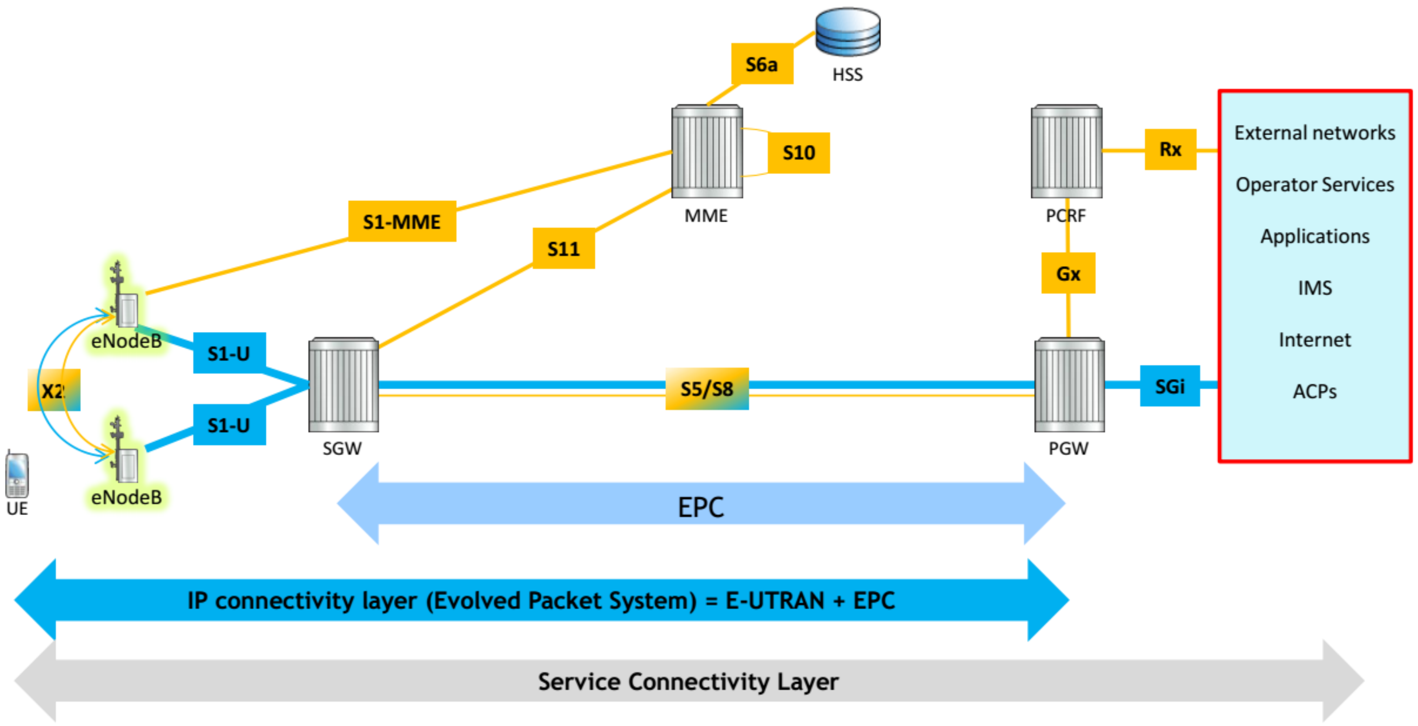


[19] Introduction to Evolved Packet Core (EPC) – EPC elements, protocols and procedures – Alcatel Lucent

Control and Data Plane Elements of EPC

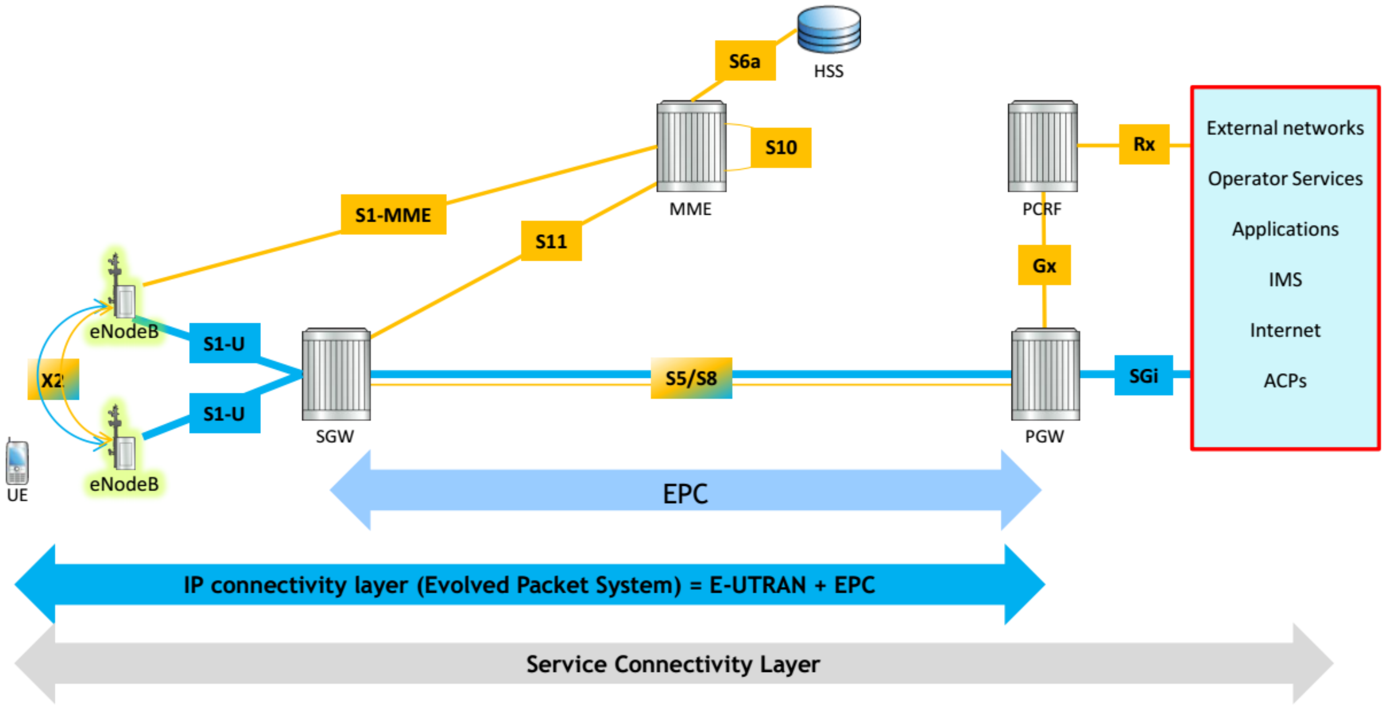
- Exclusively Control Plane Elements
  - Mobility Management Element (MME)
  - Policy and Charging Rules Function (PCRF)
  - Home Subscriber Server (HSS)

- 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

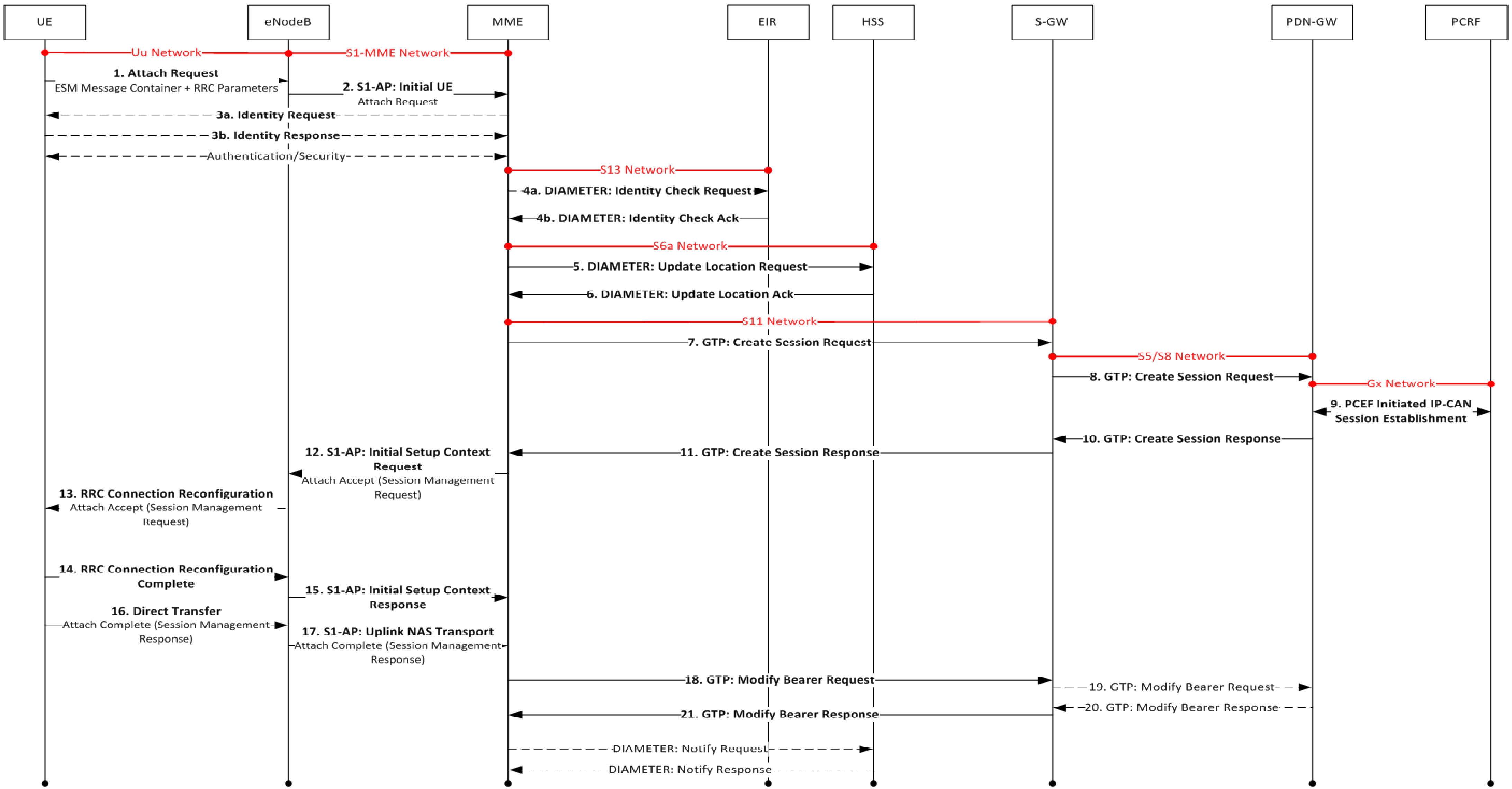
EPC Non-Access Stratum (NAS) Procedures Summary

Event Type	MME	HSS	S-GW	P-GW	PCRF
Attaches	10	2	3	2	1
Additional Default Bearer Setups	4	0	3	2	1
Dedicated Bearer Setups	2	0	2	2	1
Idle-to-Connected Transitions	3	0	1	0	0
Conntected-to-Idle	3	0	1	0	0
X2-based Handovers	2	0	1	0	0
S1-based Handovers	8	0	3	0	0
Tracking Area Updates	2	0	0	0	0
Total	34	2	14	6	3

TABLE I. TRANSACTION PER NAS EVENT BY EPC ELEMENT

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

NAS Attach Procedure



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

Control- and Data-plane interactions as Service Chains (SCs)

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

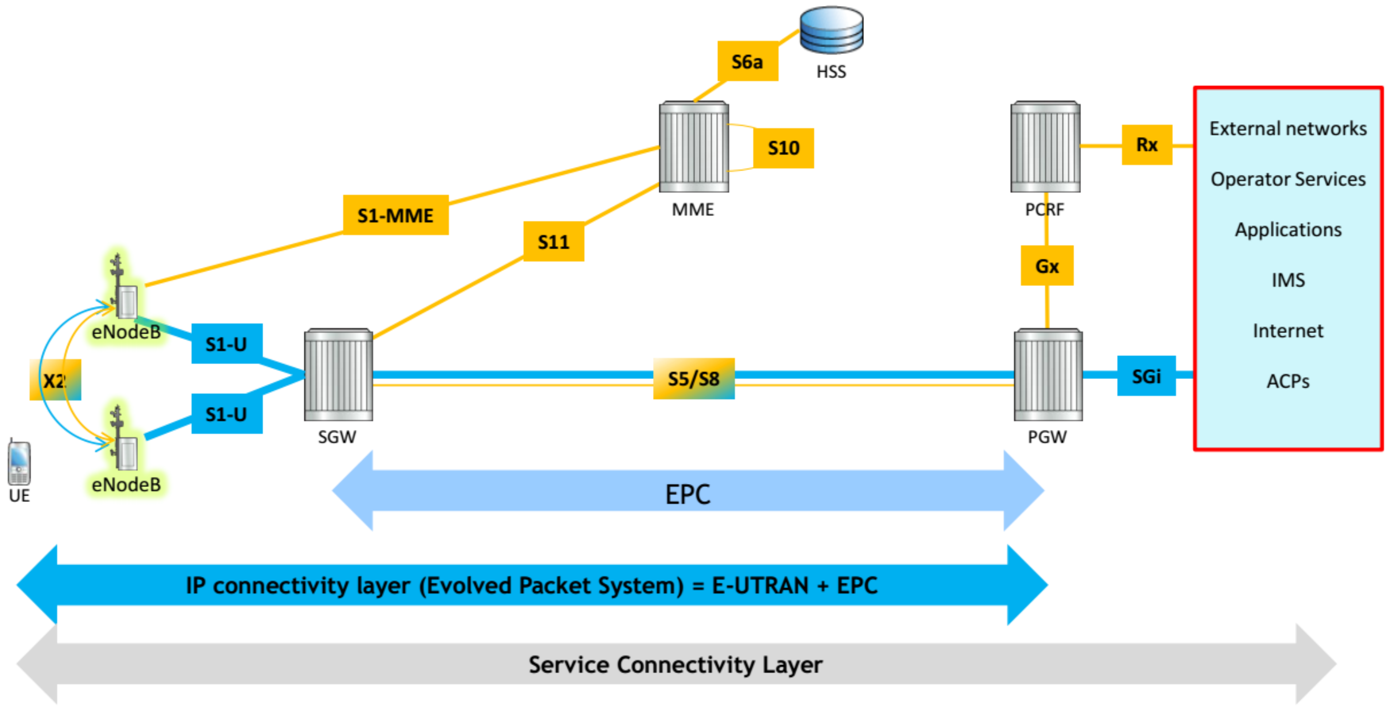
MME → HSS → MME → PGW → MME → SGW → MME

Data Plane - Download

PGW → SGW

Data Plane - Upload

SGW → PGW



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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

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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

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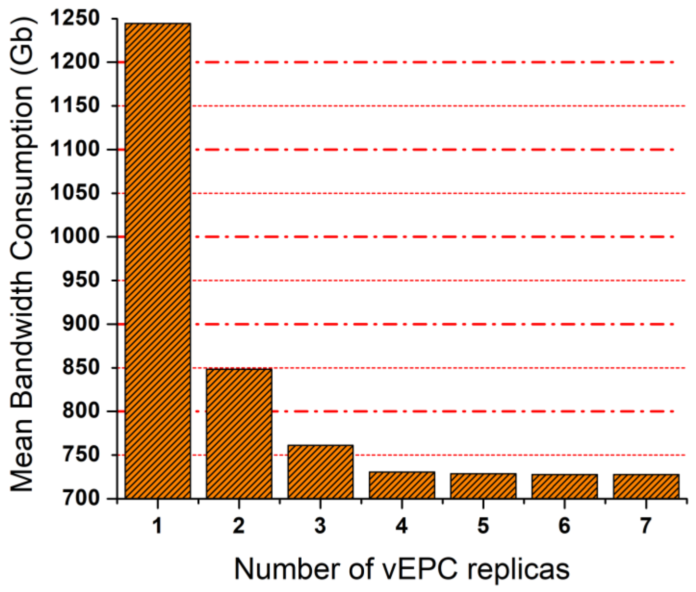
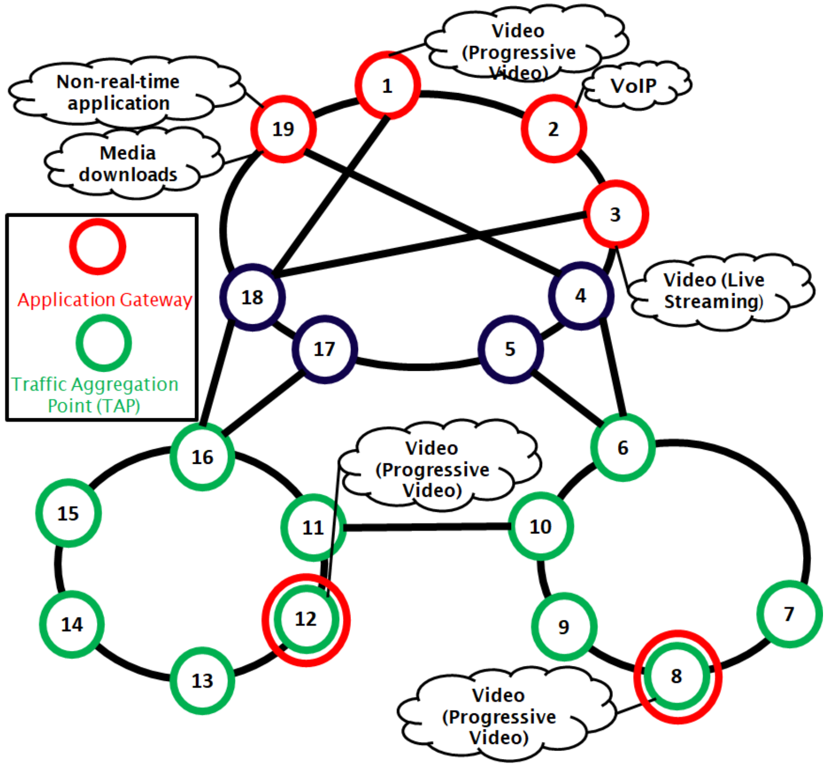
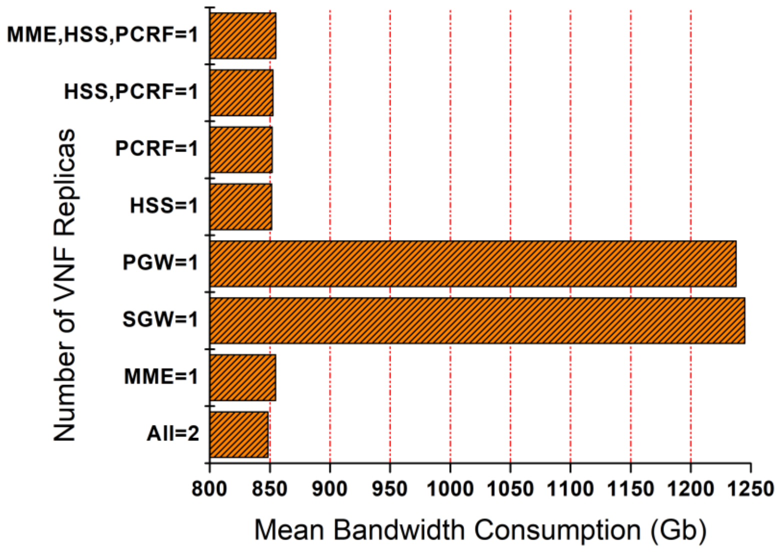
Results



Mean Bandwidth Consumption (Gb)
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
1
2
3
4
5
6
7
Number of vEPC replicas



Non-real-time application
Media downloads
Video (Progressive Video)
VoIP
Video (Live Streaming)
Application Gateway
Traffic Aggregation Point (TAP)
Video (Progressive Video)
Video (Progressive Video)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19



Number of VNF Replicas
MME,HSS,PCRF=1
HSS,PCRF=1
PCRF=1
HSS=1
PGW=1
SGW=1
MME=1
All=2
800
850
900
950
1000
1050
1100
1150
1200
1250
Mean Bandwidth Consumption (Gb)

Conclusion

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

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- [4] www.ksc.net
- [5] A. Gupta, U. Mandal, P. Chowdhury, M. Tornatore, and B. Mukherjee, “Cost-efficient live VM migration based on varying electricity cost in optical cloud networks," in *IEEE International Conference on Advanced Networks and Telecommuncations Systems (ANTS)*, 2014, pp. 1-3 (**Best Short Paper Award**)
- [6] A. Gupta, U. Mandal, P. Chowdhury, M. Tornatore, and B. Mukherjee, “Cost-efficient live VM migration based on varying electricity cost in optical cloud networks," *Photonic Network Communications*, vol. 30, no. 3, pp. 376-386, 2015
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- [9]”Powering NFV – Virtual Network Functions (VNFs)” – SDxCentral – 2017 NFV Report Series Part 3: Virtual Network Functions (VNFs)
- [10] IETF, “Network service chaining problem statement,” https://tools.ietf.org/html/draft-quinn-nsc-problem-statement-00, 2013
- [11] W. John *et al*., "Research Directions in Network Service Chaining," *2013 IEEE SDN for Future Networks and Services (SDN4FNS)*
- [12] Ericsson, “The real-time cloud combining cloud, NFV and service provider SDN,” 2014
- [13] Cisco, “Cisco Cloud Services Router 1000V 3.14 Series Data Sheet,”2015
- [14] A. Gupta, M. F. Habib, P. Chowdhury, M. Tornatore, and B. Mukherjee,“On service chaining using Virtual Network Functions in Network-enabled Cloud systems,“ in *IEEE International Conference on Advanced Networks and Telecommuncations Systems (ANTS)*, 2015, pp. 1-3 (**Honorable Mention in Short Paper Category**)
- [15] A. Gupta, B. Jaumard, M. Tornatore, and B. Mukherjee,”Multiple Service Chain Placement and Routing in a Network-enabled Cloud," in *IEEE International Conference on Advanced Networks and Telecommuncations Systems (ANTS)*, 2017
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- [20] Understanding the bottlenecks in Virtualizing Cellular Core Network Functions – Intel Labs, Connectem, AT&T Labs
- [21] https://sites.google.com/site/amitsciscozone/home/lte-notes/default-bearer-setup