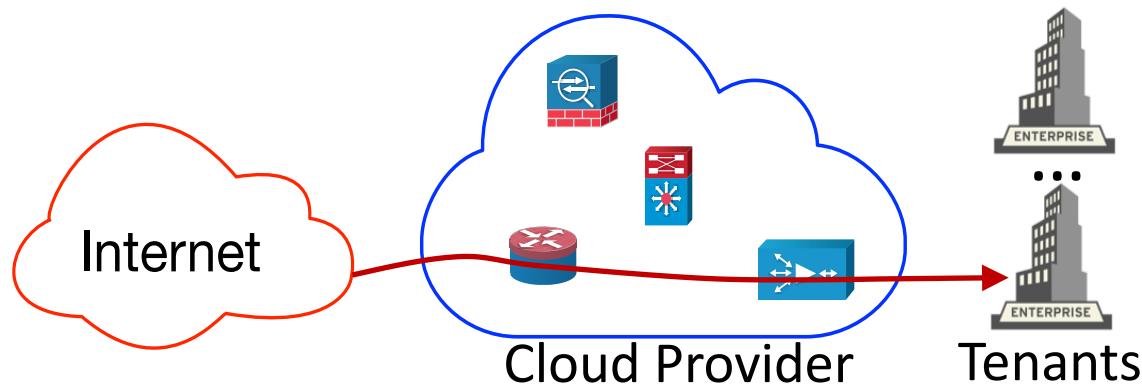


VNF Chain Allocation and Management at Data Center Scale



**Nodir Kodirov, Sam Bayless, Fabian Ruffy,
Ivan Beschastnikh, Holger Hoos, Alan Hu**



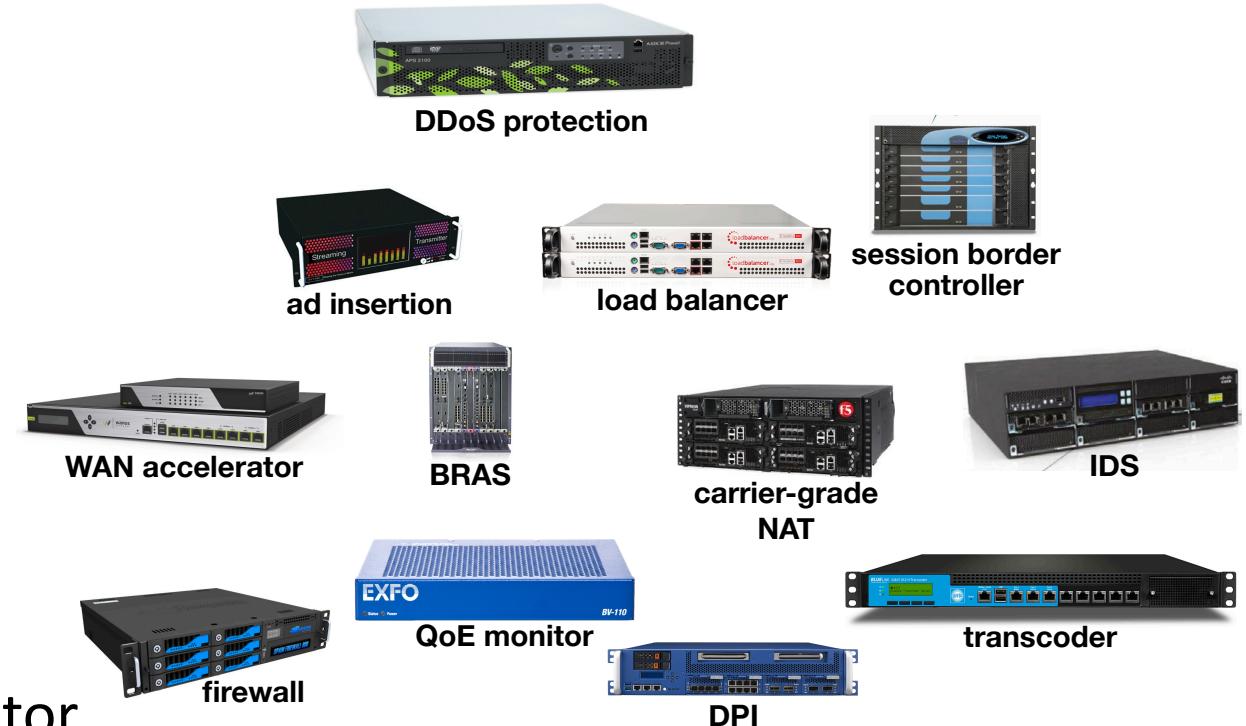
THE UNIVERSITY
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Universiteit
Leiden

Network Functions (NF) are useful and widespread

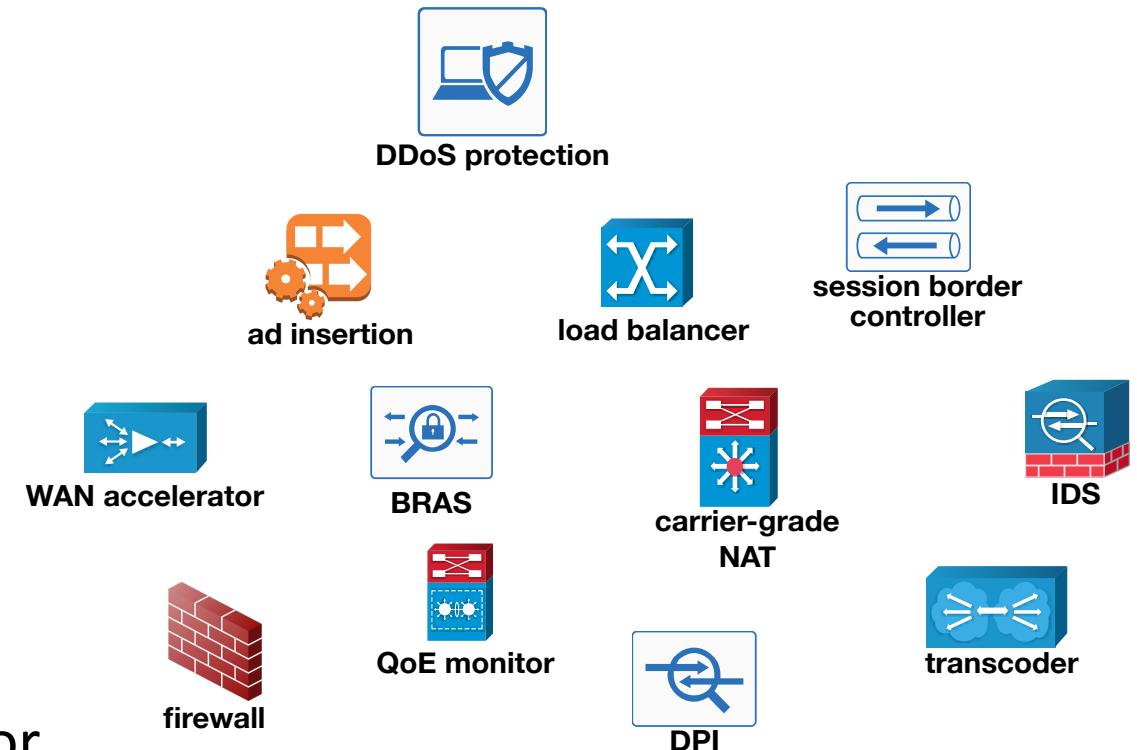
- Security
 - Firewall, DDoS protection, DPI
- Monitoring
 - QoE monitor, Network Stats
- Services
 - Ad insertion, Transcoder
- Network optimization
 - NAT, Load-balancer, WAN accelerator



Sherry et al. find # of middleboxes are \approx to # of L2/L3 devices in enterprise

Network Functions (NF) are useful and widespread

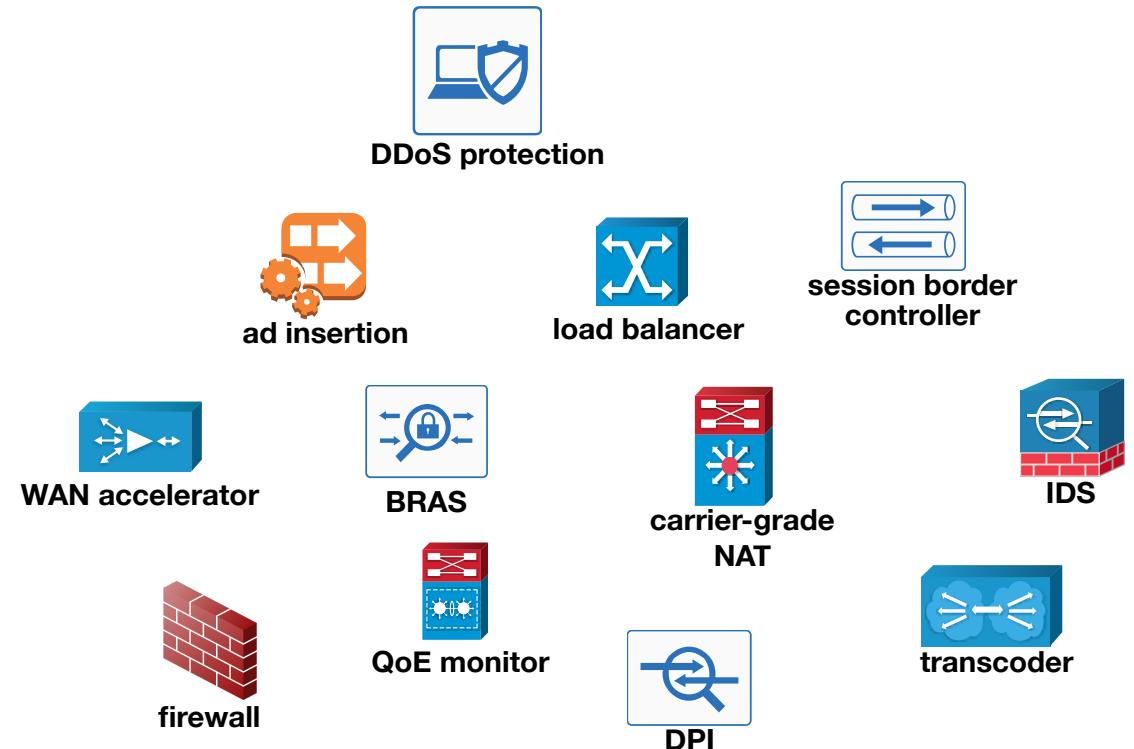
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Sherry et al. find # of middleboxes are \approx to # of L2/L3 devices in enterprise

Benefits of Virtualized Network Functions (VNF)

- **Elasticity**
 - Quick scale up and down NFs
- **Fast upgrades**
 - No need to wait for new hardware
- **Quick configuration, recovery**
 - Failover to the backup NF instance
- **Outsourcing**

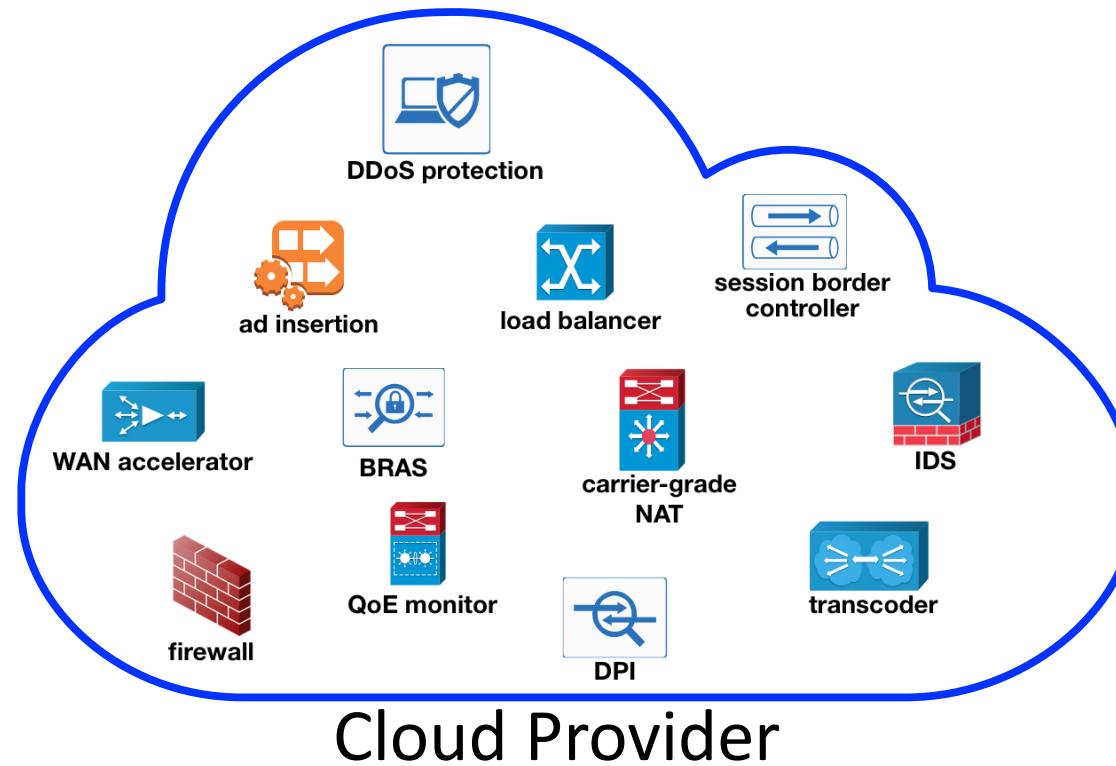


Sherry et al. Making Middleboxes Someone Else's Problem: Network Processing as a Cloud Service, SIGCOMM'12

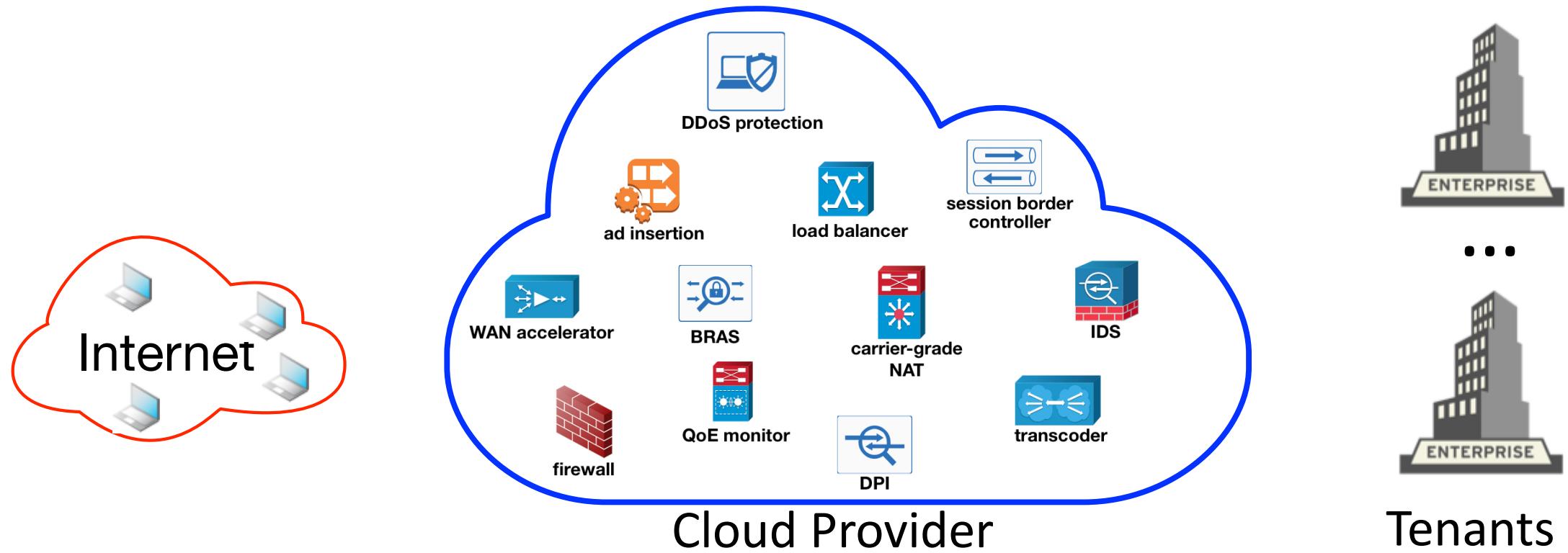
Rajagopalan et al., Split/Merge: System Support for Elastic Execution in Virtual Middleboxes, NSDI'13

Martins et al., ClickOS and the Art of Network Function Virtualization, NSDI'14

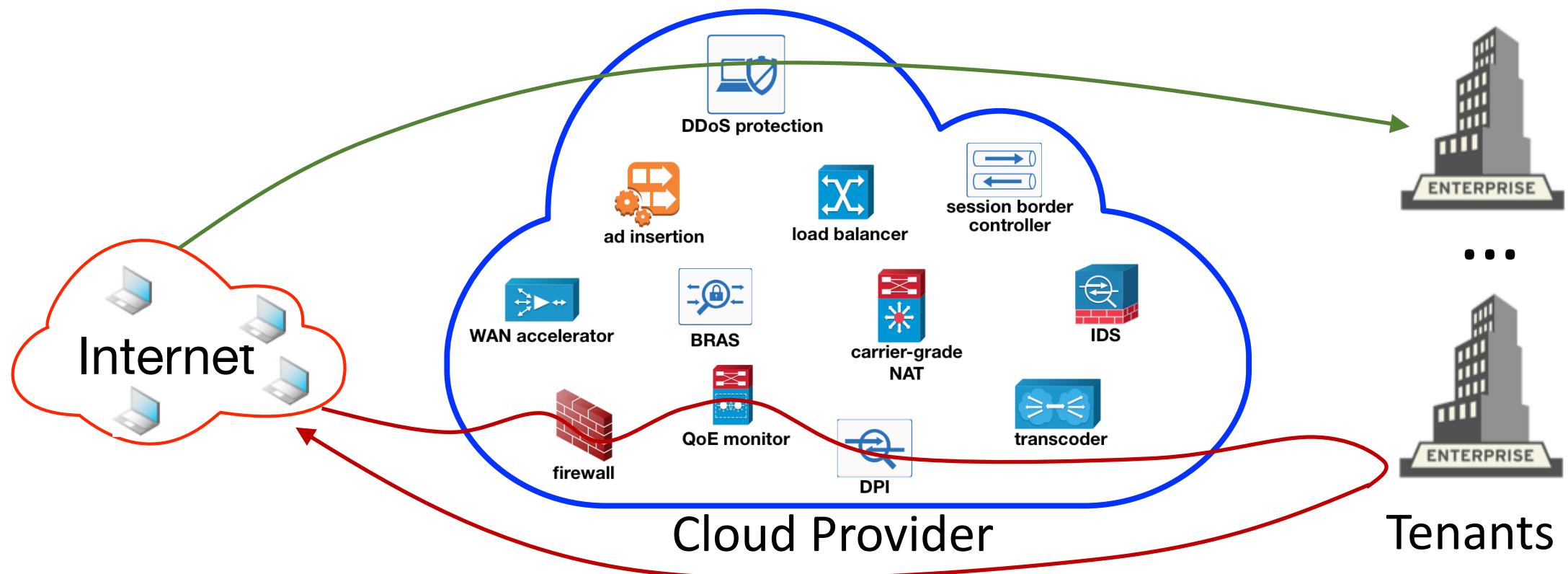
Outsourcing VNFs to the Cloud



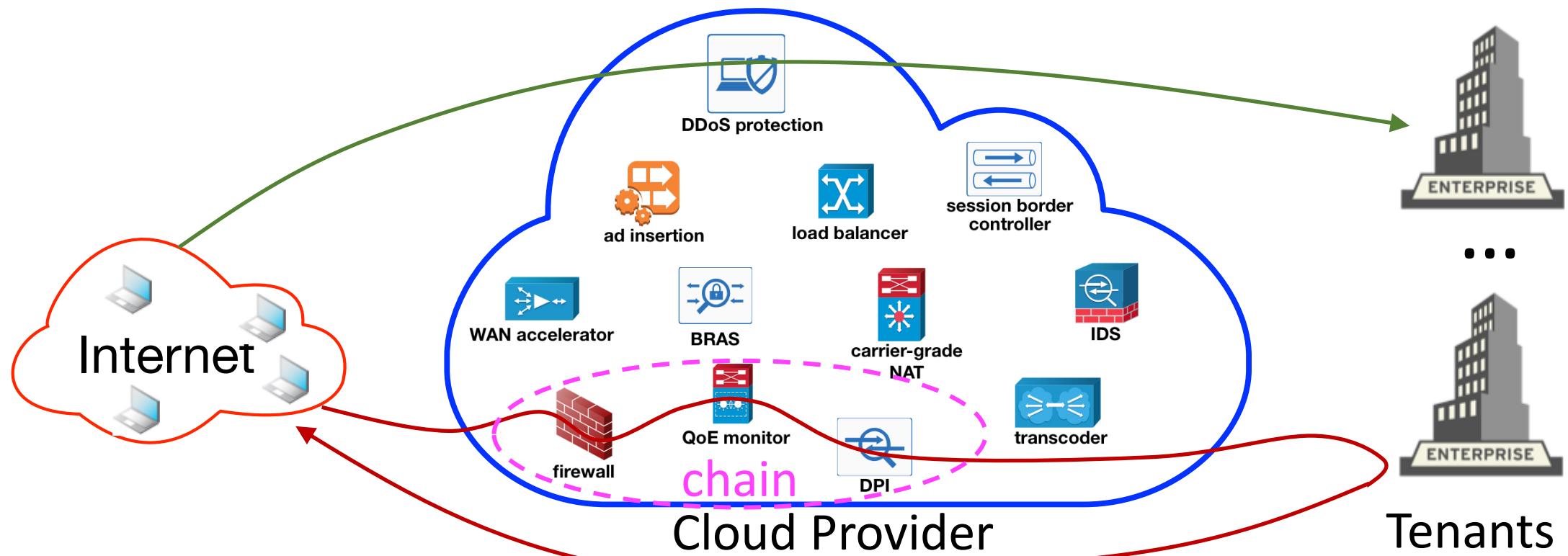
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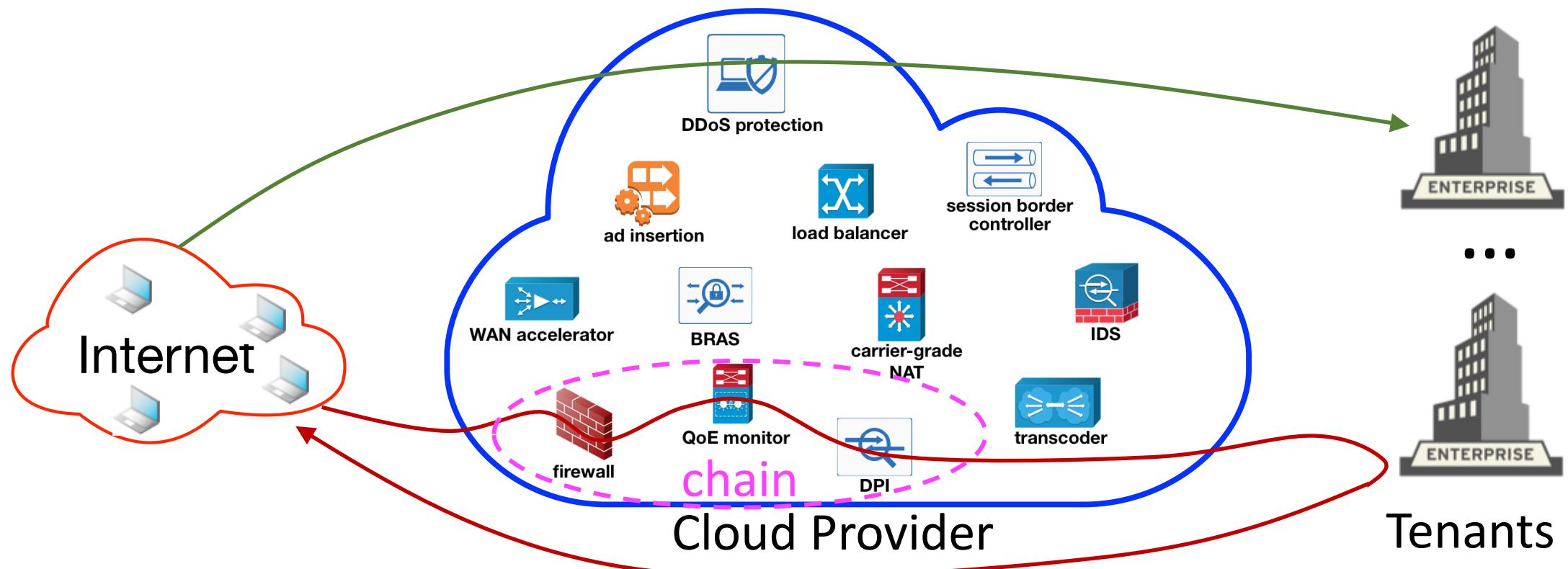
Outsourcing VNFs to the Cloud



Outsourcing VNF Chains to the Cloud



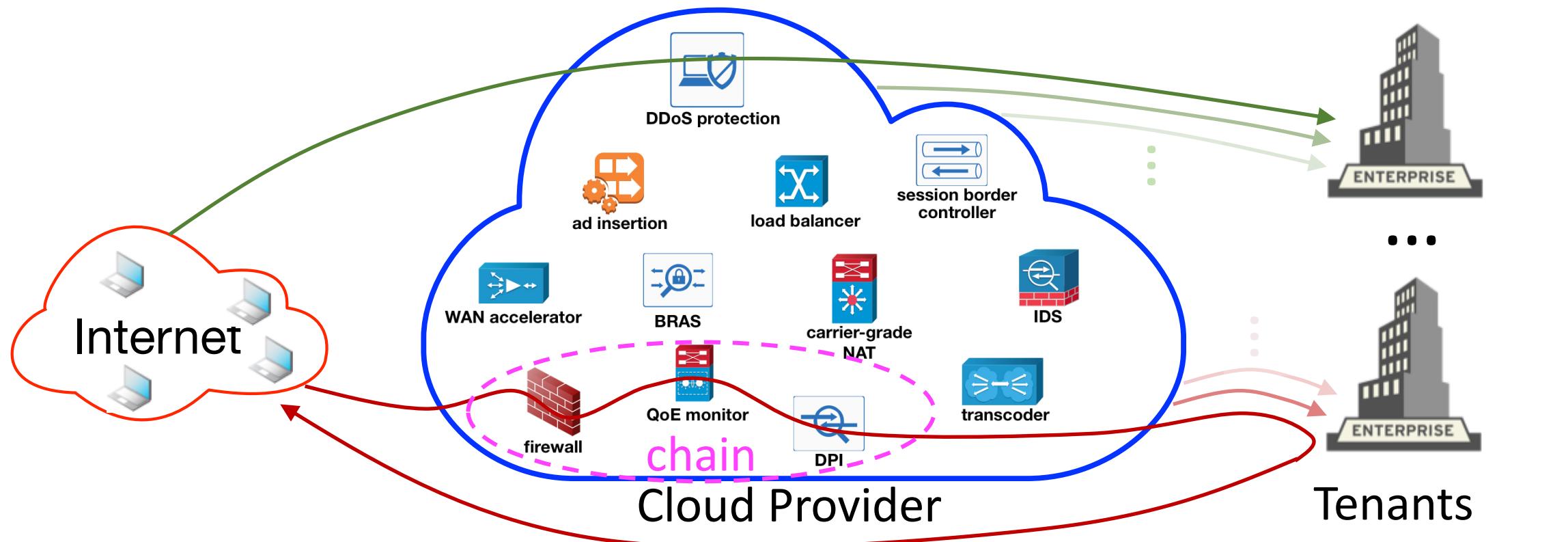
Outsourcing VNF Chains to the Cloud



Challenges of outsourcing VNF Chains

How can cloud providers achieve high **data center utilization**?

How can tenants **allocate and manage** their VNF chains?

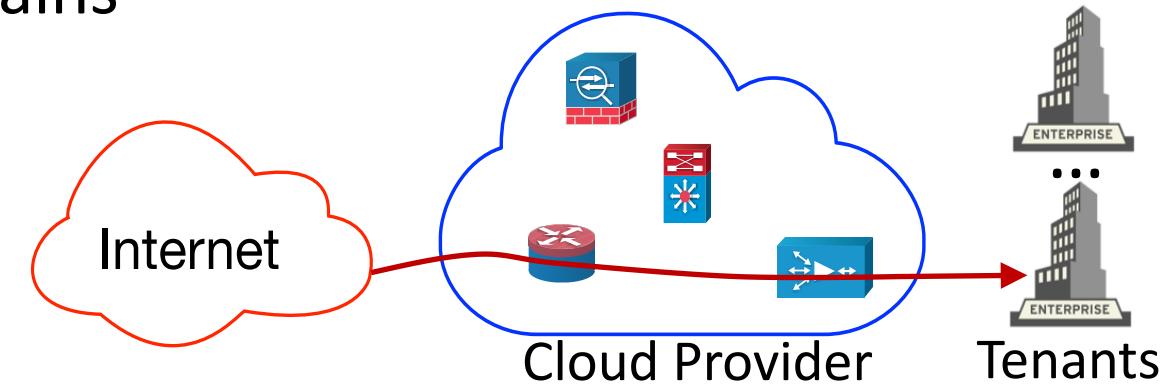


Our contributions: API and algorithm

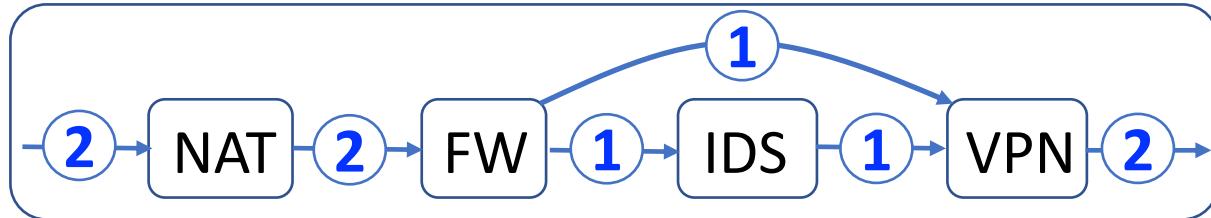
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 - **Daisy**: emulate chain management at rack-scale



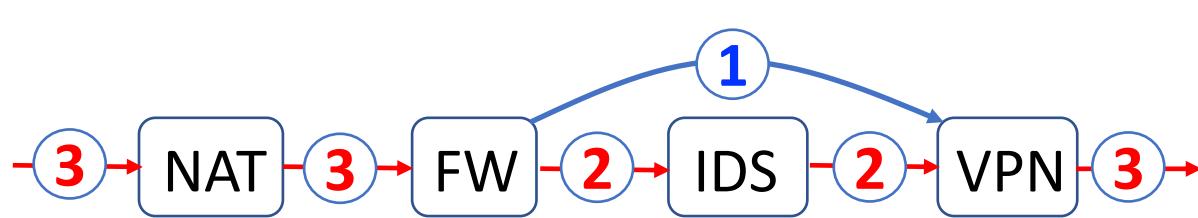
VNF Chain: six API with use-cases



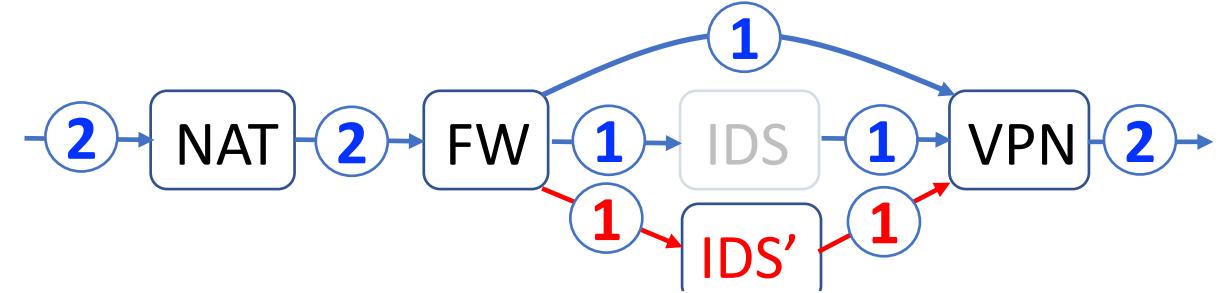
Initial chain

`cid ← allocate-chain(C, bw)`
`add-link-bandwidth(a, b, bw, cid)`
`add-node(f, cid)`

`remove-link-bandwidth(a, b, bw, cid)`
`remove-node(f, cid)`
`remove-e2e-bandwidth(cid, bw)`

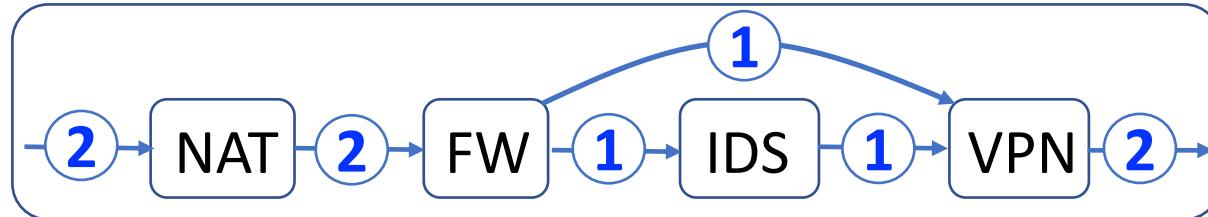


Chain scale-out



Element upgrade

VNF Chain: API is expressive



Initial chain

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`remove-e2e-bandwidth(cid, bw)`

A graph can be transformed arbitrarily by manipulating individual nodes and edges.

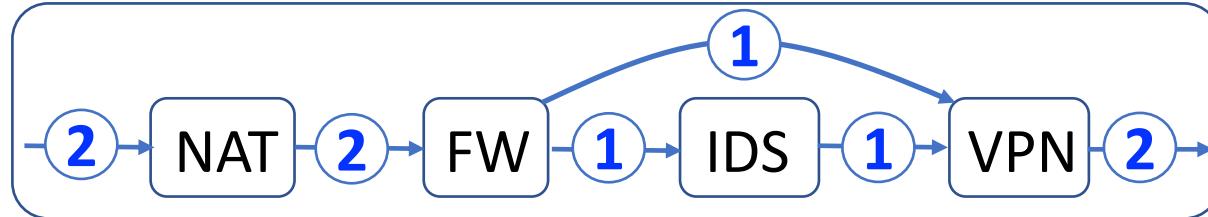
Chain scale-out

Element upgrade

Chain expand

...

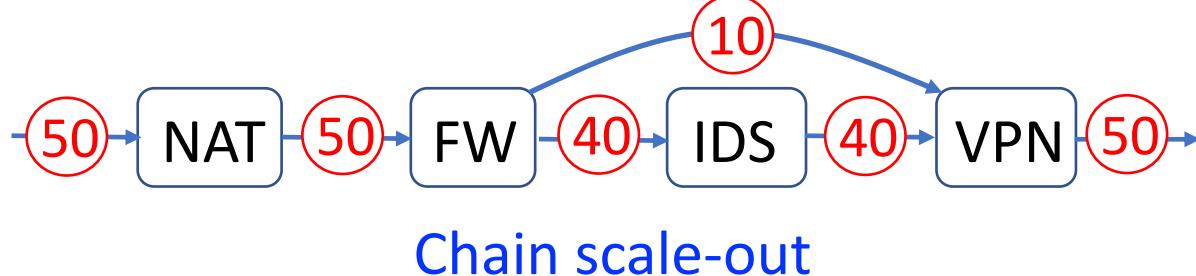
Scale-out beyond single physical resource capacity



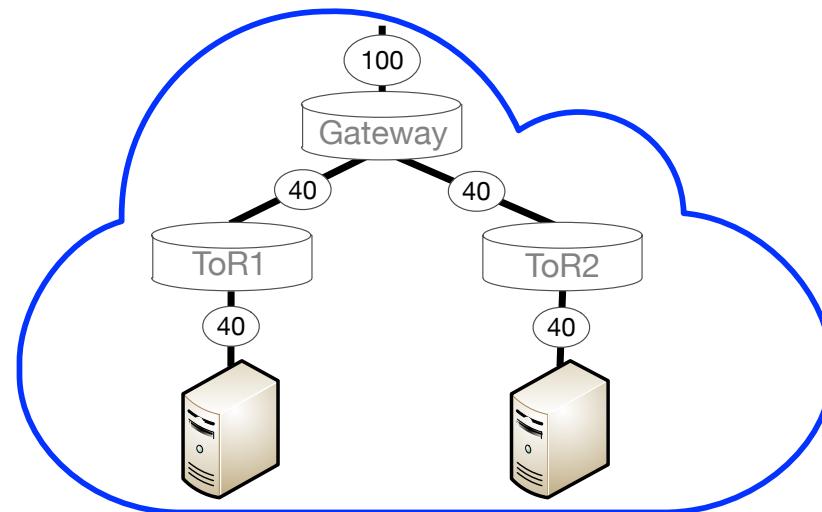
Initial chain

```
cid ← allocate-chain(C, bw)  
add-link-bandwidth(a, b, bw, cid)  
add-node(f, cid)
```

```
remove-link-bandwidth(a, b, bw, cid)  
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```

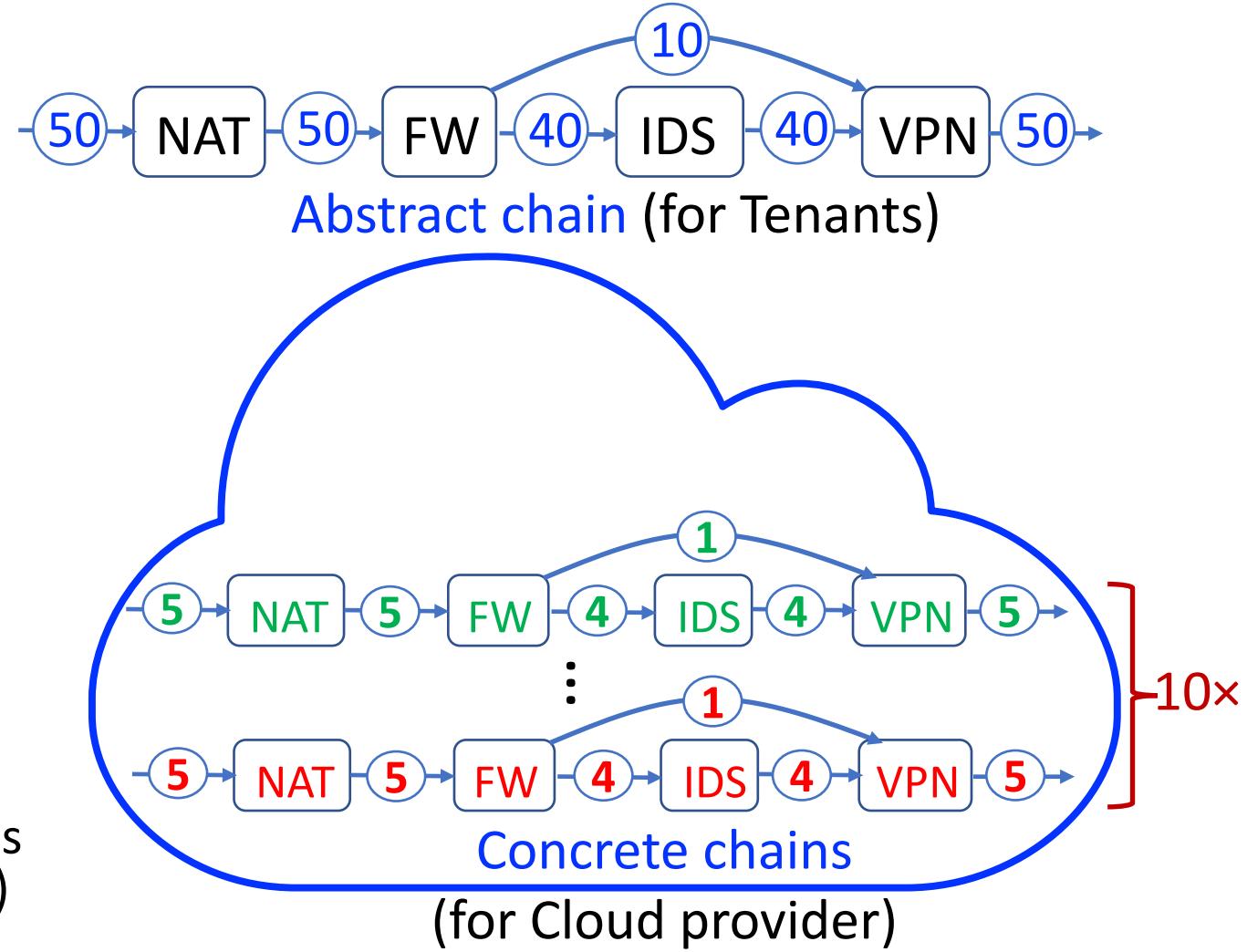


Chain scale-out



Chain Abstraction: Abstract-Concrete VNF Chains

- **Abstract VNF chain**
 - what tenant requires to allocate and operates on
- **Concrete VNF chain**
 - cloud provider's implementation of the abstract chain
- **Chains abstraction advantages**
 - facilitates high DC utilization
- **Challenges**
 - low-latency, packet loss, state synchronization, efficiency loss (see the paper and ANCS'18 poster)

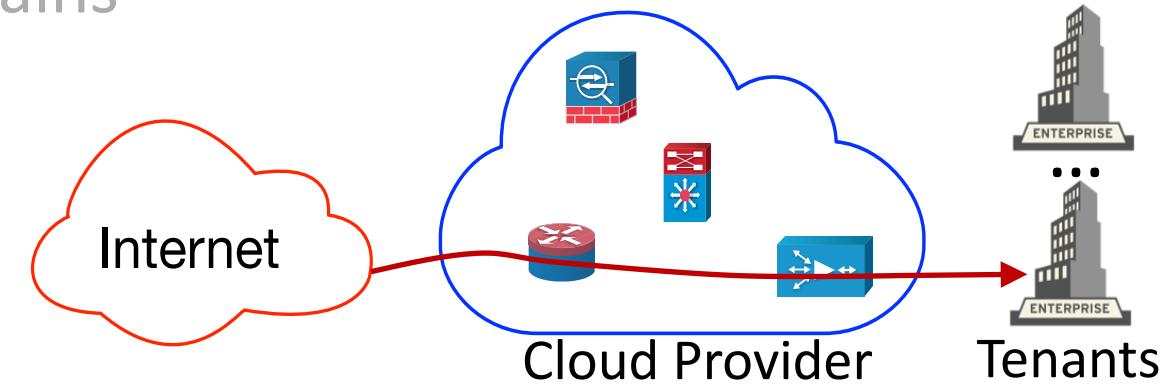


Our contributions: API and algorithm

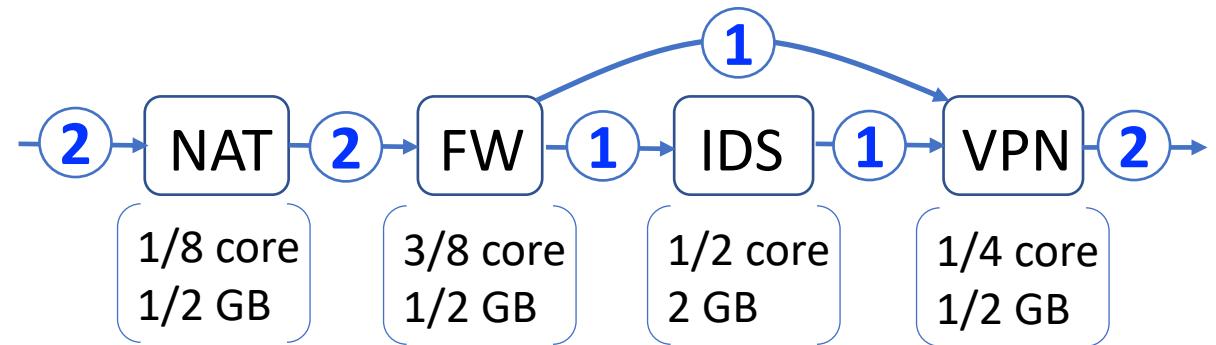
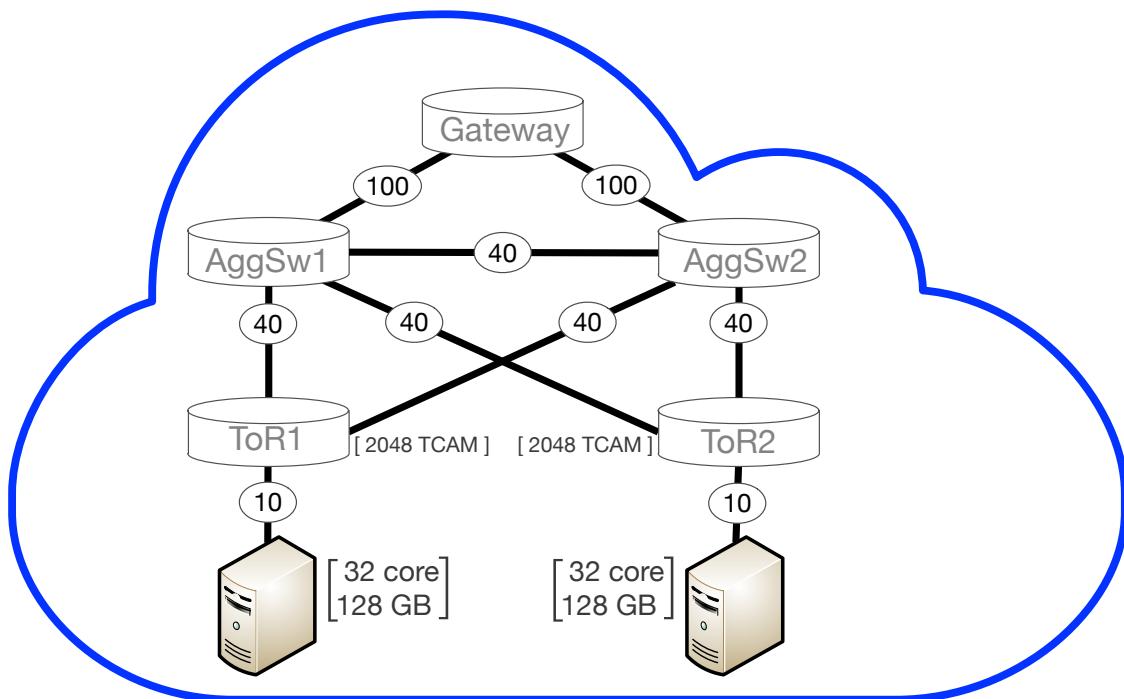
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Algorithm inputs: DC topology and chain



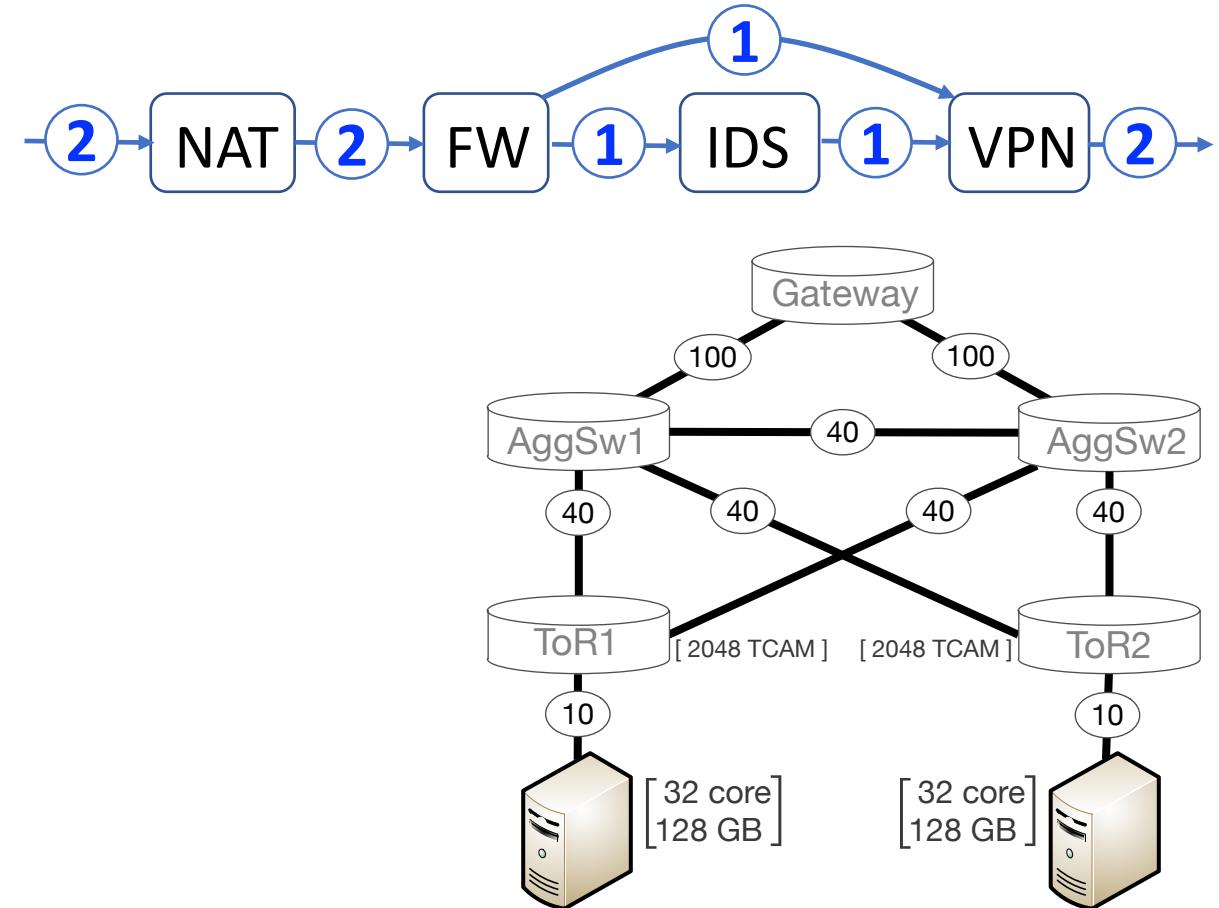
Expected resource consumption **per Gbps** of traffic
(see the paper for **VNF profile** generation)

Palkar et al., E2: A Framework for NFV Applications, SOSP'15

Naik et al., NFVPerf: Online performance monitoring and bottleneck detection for NFV, IEEE NFV-SDN 2016.

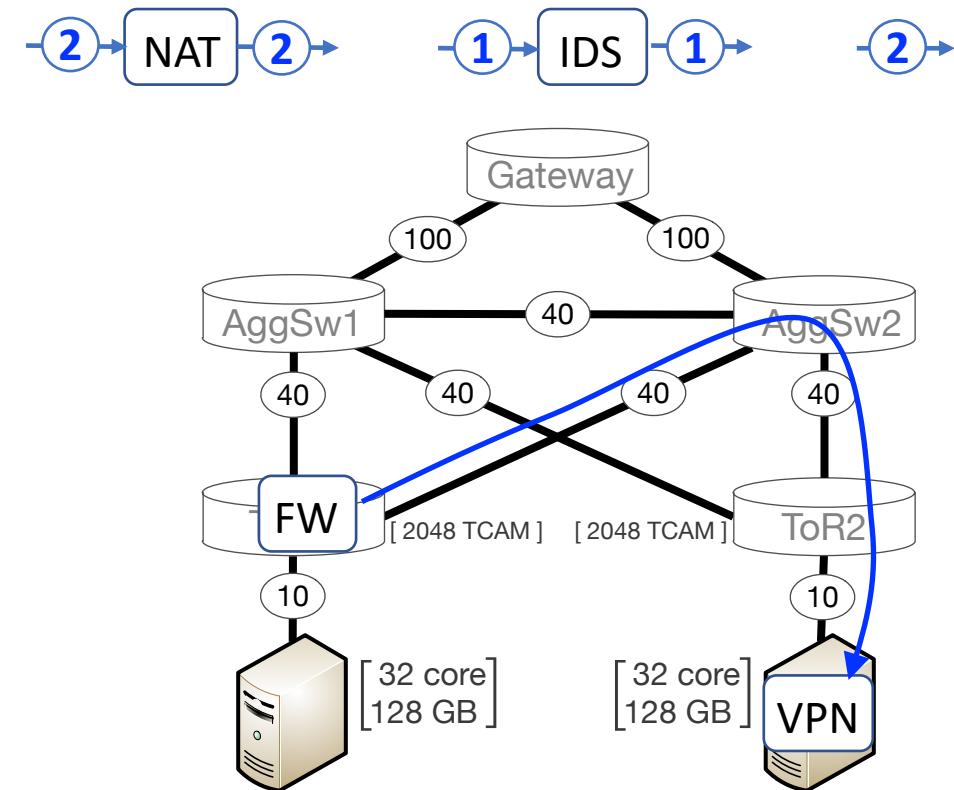
Nam et al., Probius: Automated Approach for VNF and Service Chain Analysis in Software-Defined NFV, SOSR'18

Algorithms for Chain Allocation and Management



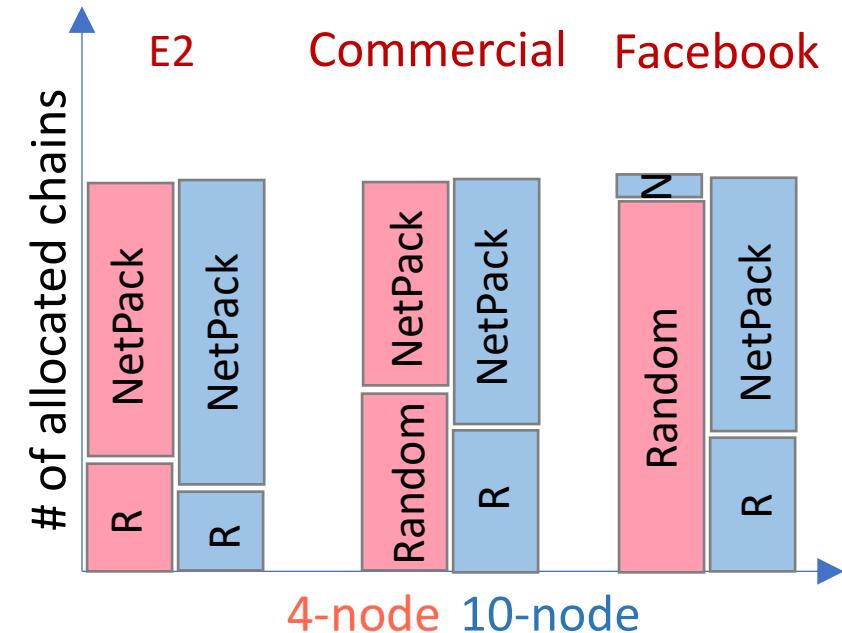
Algorithms for Chain Allocation and Management

- Random (baseline)
 - Consider NFs and servers/switches in **random order**
 - Attempt the above step ***n* times** (e.g., $n=100$)
 - Choose the **shortest path** between chain NFs



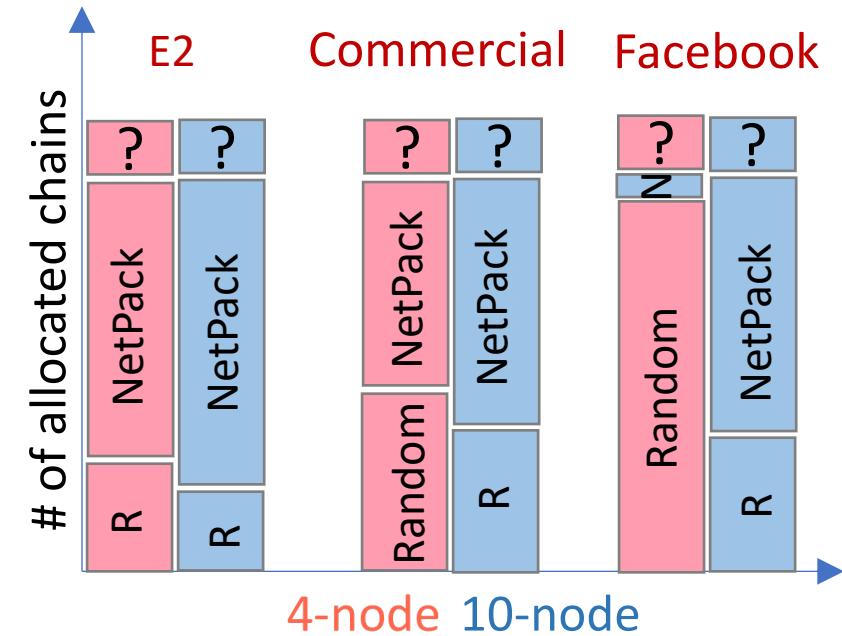
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- NetPack: Random + 3 simple heuristics
 - Consider the chain NFs in a **topological order**
 - **Re-use the same server** when allocating consecutive NFs
 - Gradually increase the **network scope**: rack, cluster, etc.



Algorithms for Chain Allocation and Management

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 - Gradually increase the **network scope**: rack, cluster, etc.
- VNFSolver: how optimal is NetPack?
 - **Constraint-solver based** chain allocation algorithm
 - Slow, but **complete**: finds a solution when one exists

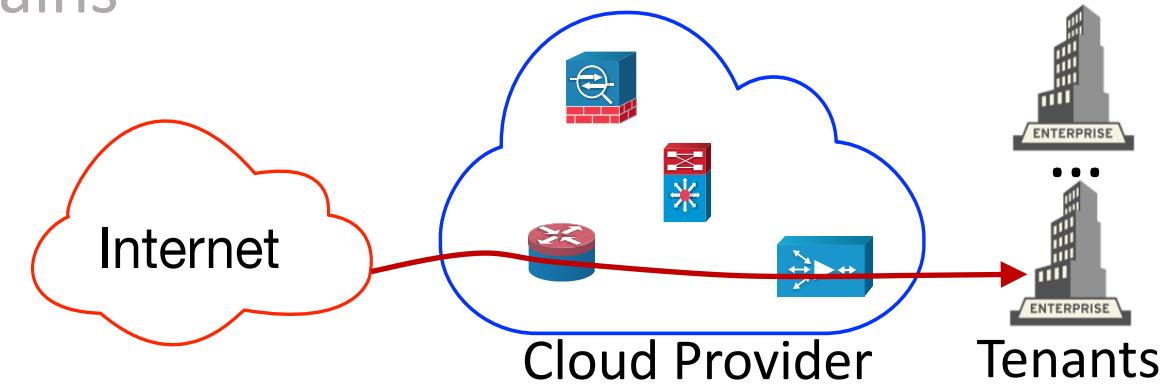


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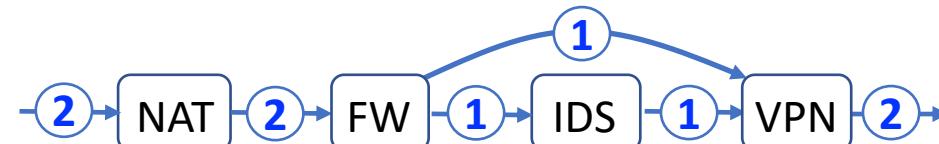
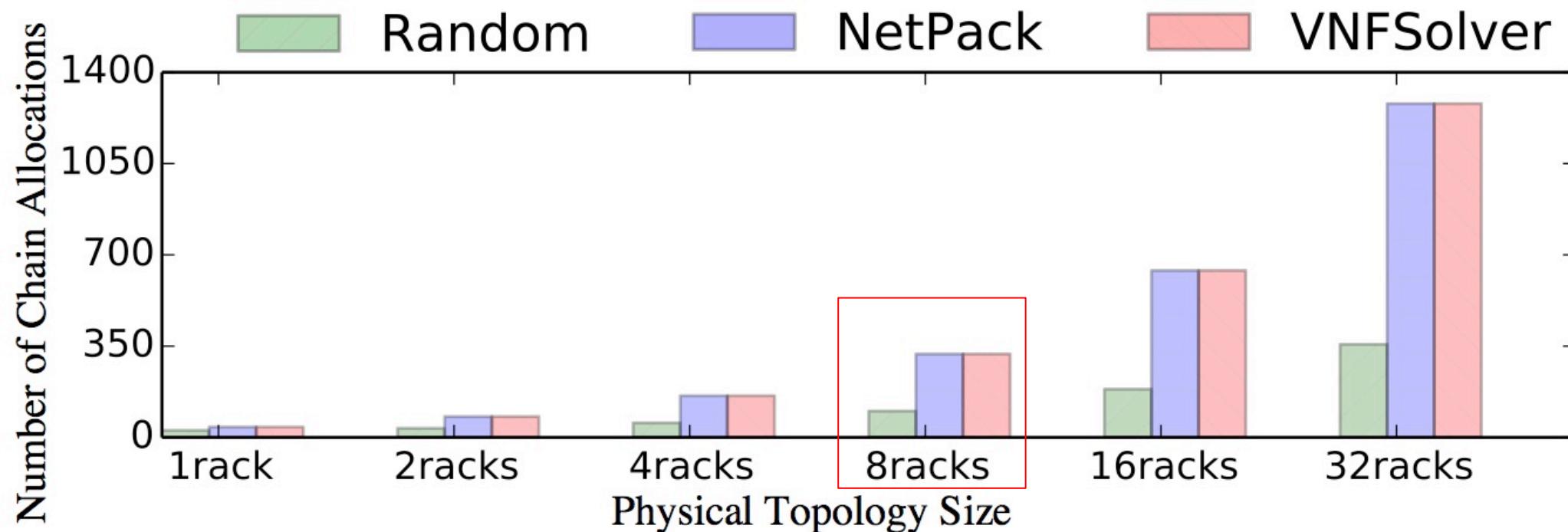
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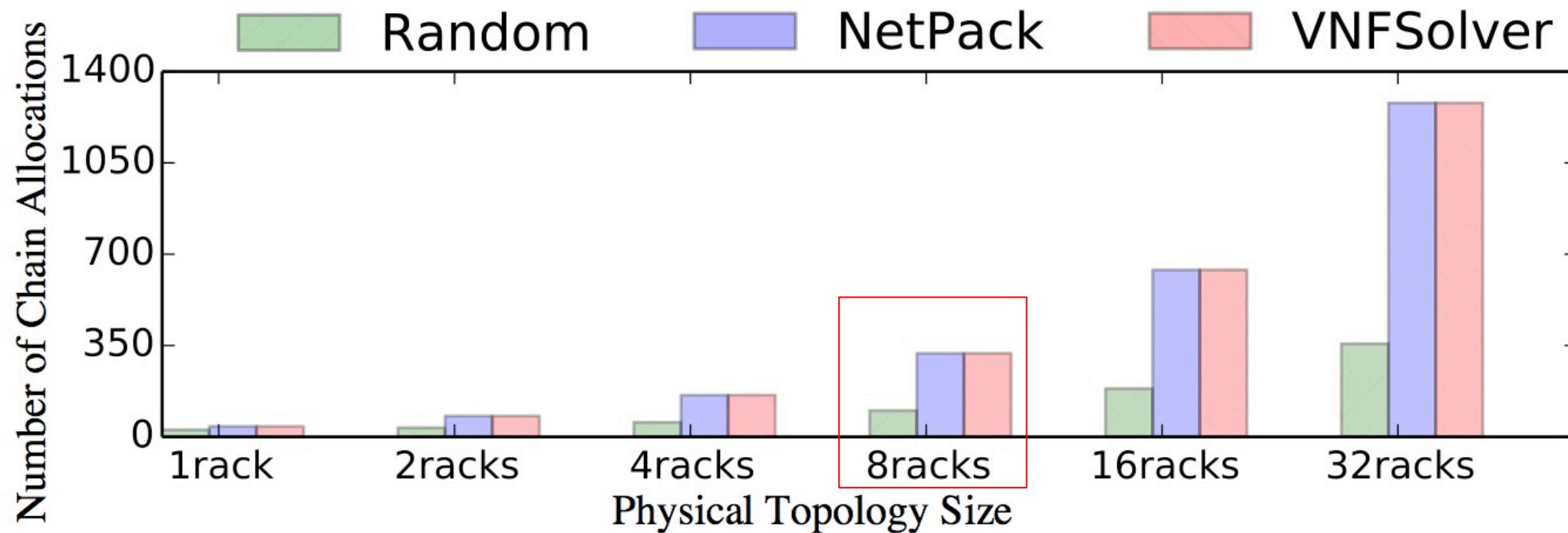
Evaluation: Objectives

- How good is the data center **utilization**?
 - Evaluate Random, NetPack, and VNFSolver
 - Consider three different data center topologies
 - Use five different VNF chains with varying length (2-10)
- How **fast** is chain allocation?
 - Measure time it takes to saturate the data center
- Does API **reliably implement** the use-cases?
 - Prototype scale-out and chain upgrade in Daisy
 - Use two different racks, two sources of packet traces

Data center utilization evaluation



Data center utilization evaluation



NetPack achieves **at least 96%** of VNFSolver allocations.

Chain allocation time: **Random \lesssim NetPack \ll VNFSolver**.

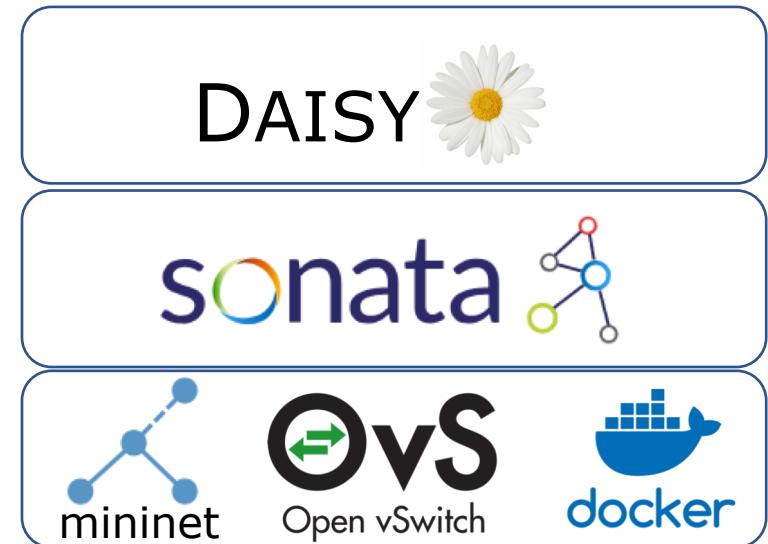
NetPack Utilization and Speed

NetPack achieves at least 96% of VNFSolver allocations while being 82x faster than VNFSolver (optimal) and only up to 54% slower (per chain) than Random (baseline) on average.

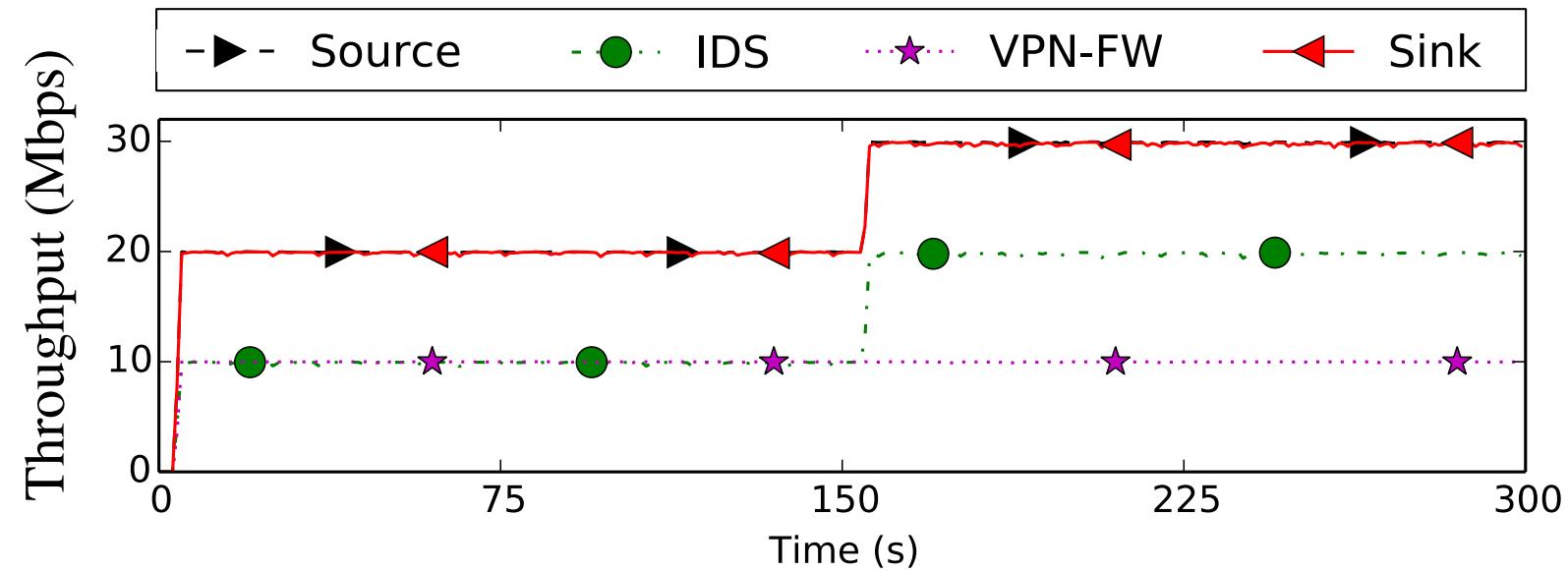
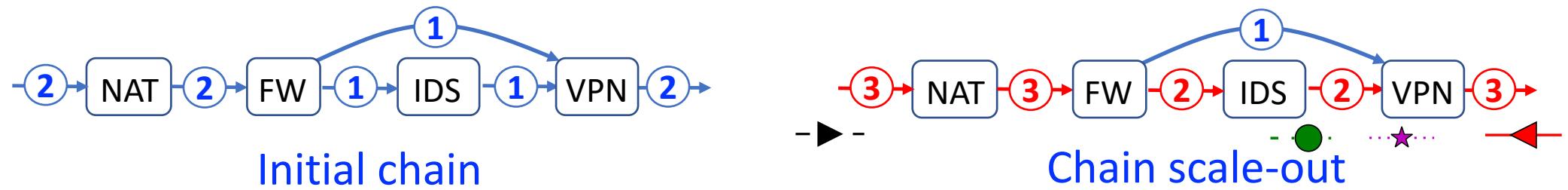
Qualitatively similar results with Facebook and Commercial DC topologies with chains of up to 10 nodes.
(see the paper for details)

Feasibility check: can API be implemented?

- Daisy builds on [Sonata framework](#)
 - Mininet to build DC topology
 - OVS for switches, and Dockers for NFs
- Runs on a single [Azure VM](#)
 - 64 cores, 432 GB RAM
- Emulates use-cases and chain arrivals
 - scale-out and upgrade use-cases
 - continuous arrival of tenant chains in rack-scale



VNF Chain use-cases are feasible with narrow API



Daisy implements scale-out with no packet drops.

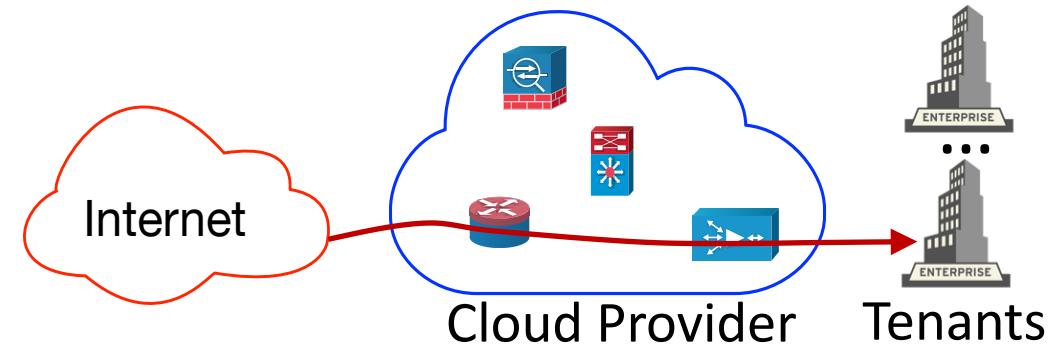
Daisy Contributions

Daisy implements scale-out with no packet drops and element upgrade with 1s packet drop at most.

We also emulated continuous chain arrival case where different tenants make chain allocation requests one-by-one.

Contributions

- API with **six primitives**
 - Implements wide-range of chain operations
 - Chain abstraction facilitates full DC utilization
- NetPack **algorithm**
 - Handles DC-scale allocation with **1000+ servers**
 - Achieves **at least 96%** allocations of VNFSolver (optimal) while being **82x faster** on average
- Daisy prototype
 - **Demonstrates feasibility** of API and algorithms



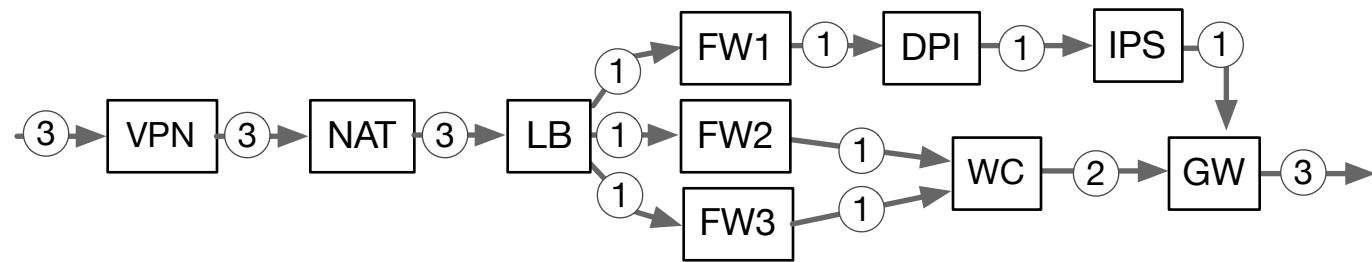
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Thank you!

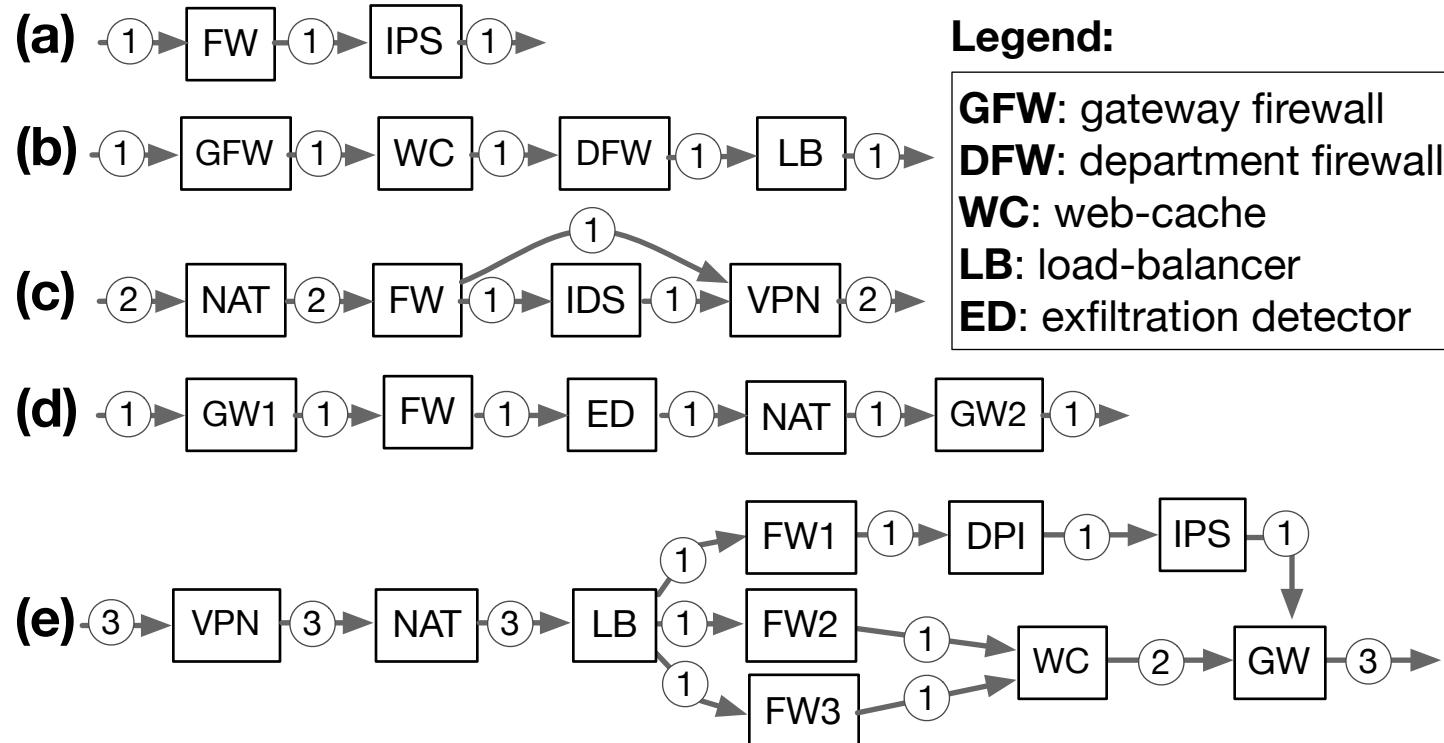
Backup Slides

Topological sort of VNF chain



An example using [Kahn's algorithm](#)
(VPN, NAT, LB, FW3, FW1, FW2, WC, DPI, IPS, GW)

VNF Chains we consider



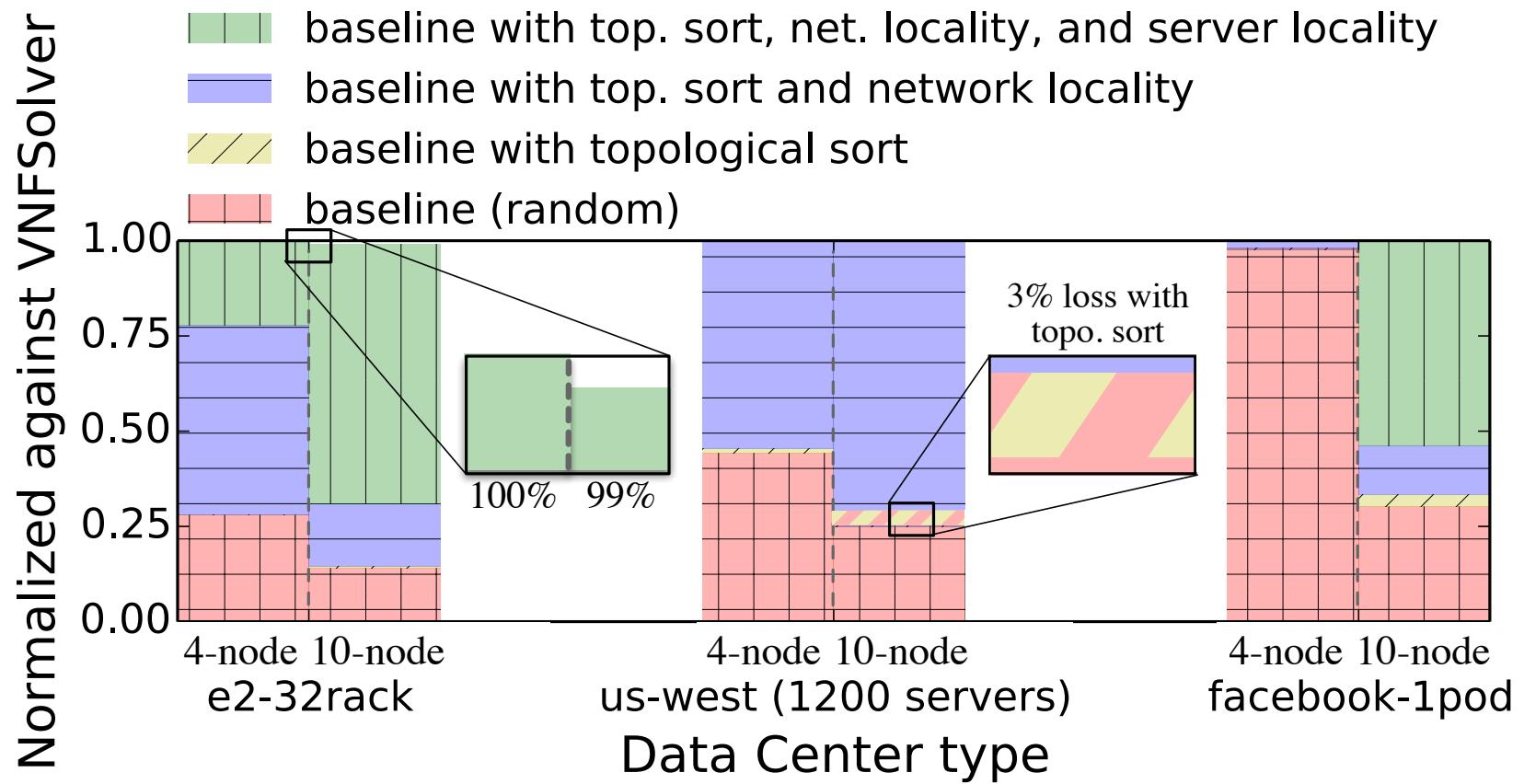
Chains (a) and (b) are from [OpenBox](#), (c) and (e)
are from [E2](#), and (d) is from [Embark](#).

Bremler-Barr et al., [OpenBox](#): A Software-Defined Framework for Developing, Deploying, and Managing Network Functions, SIGCOMM'16

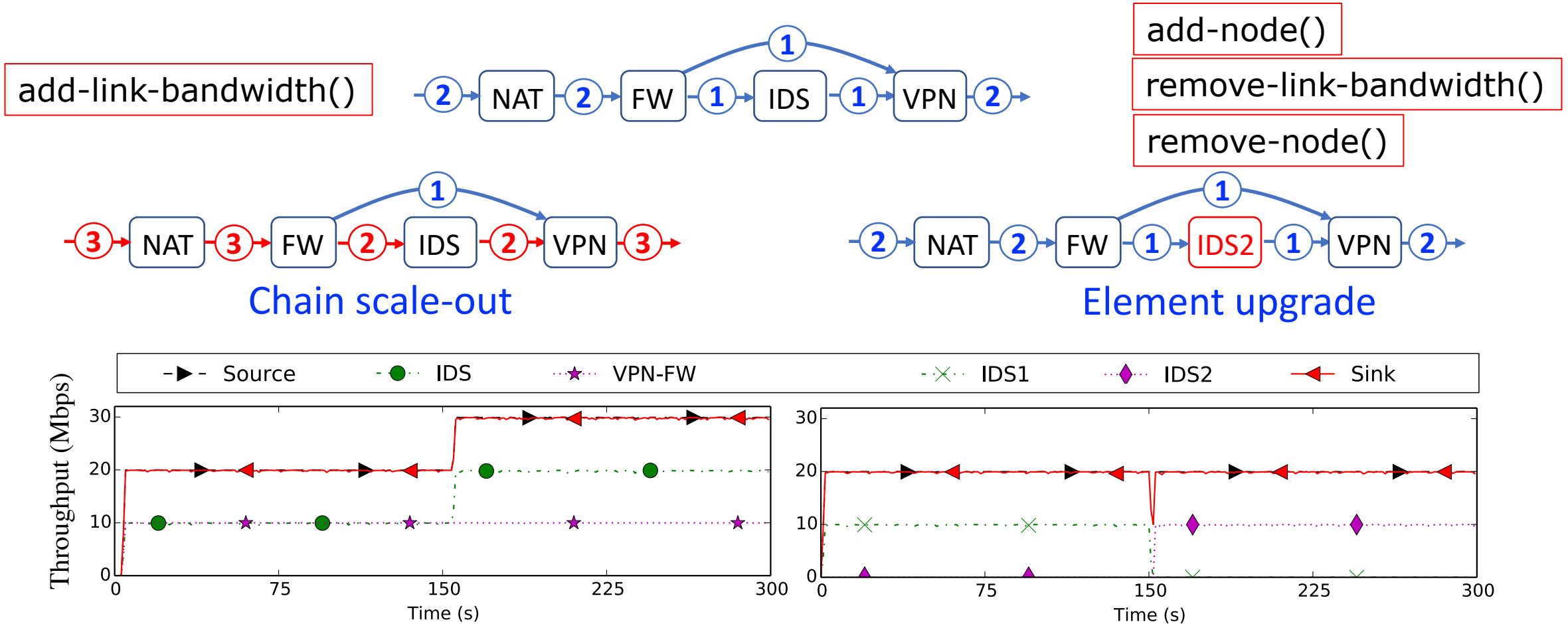
Palkar et al., [E2](#): A Framework for NFV Applications, SOSP'15

Chang et al., [Embark](#): Securely Outsourcing Middleboxes to the Cloud, NSDI'16

NetPack: Contribution of each Optimization

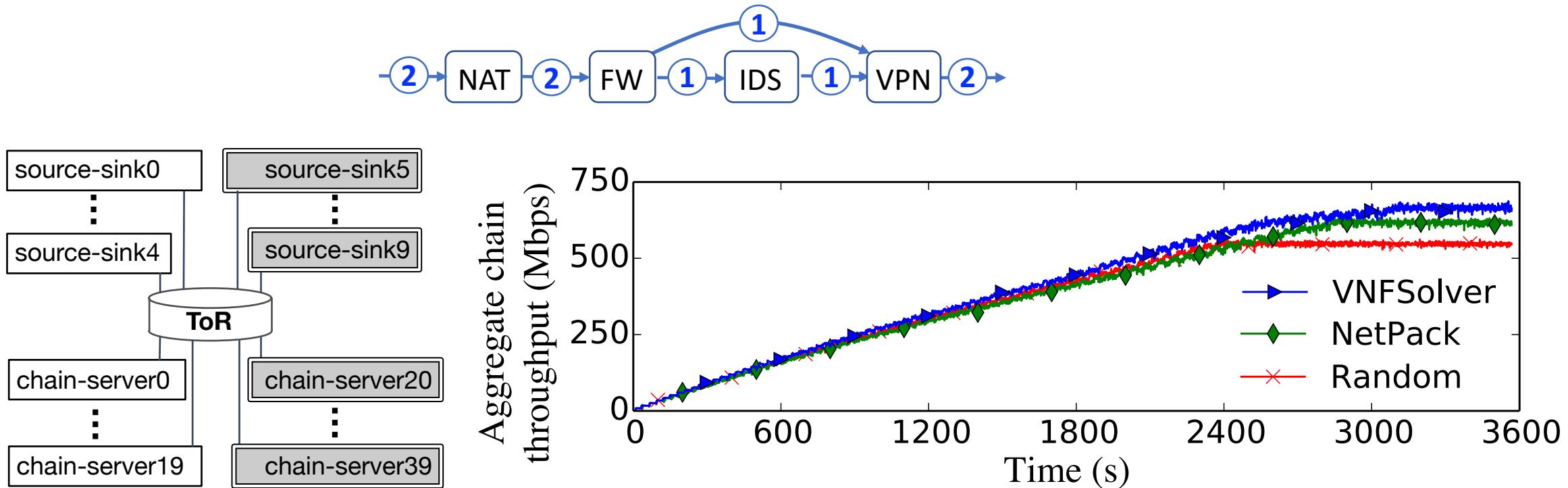


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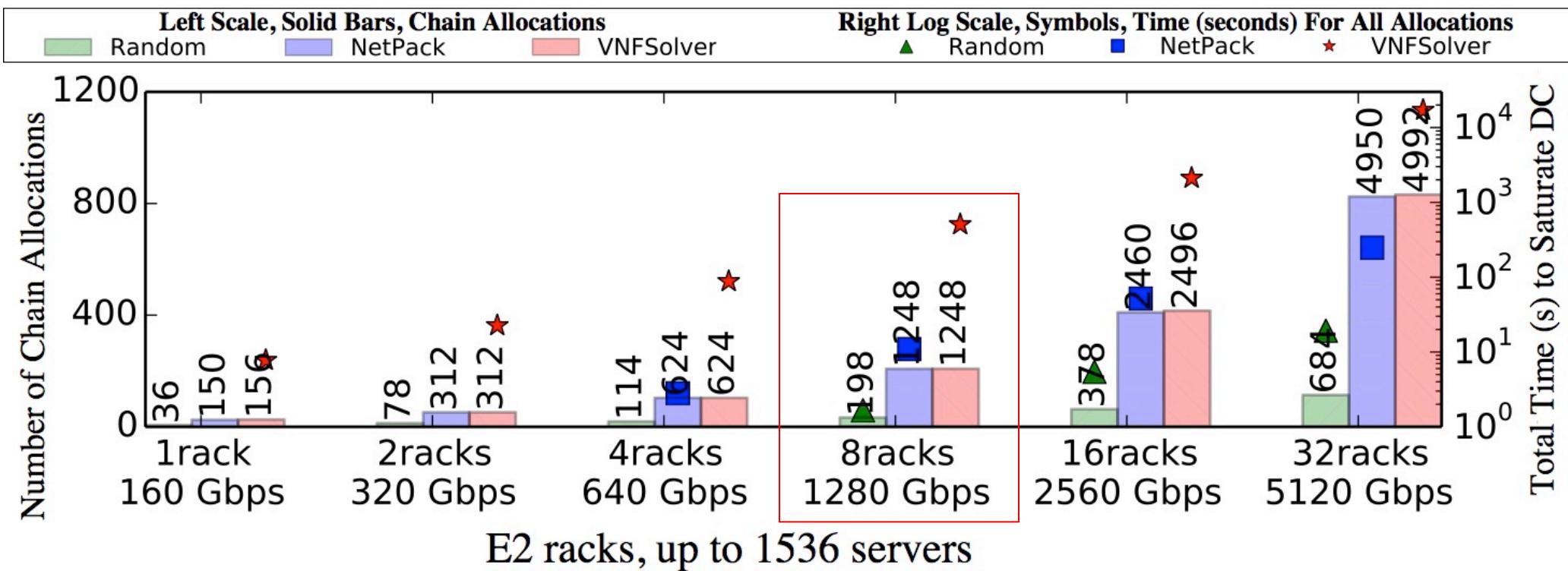
Daisy implements scale-out with no packet drops and element upgrade with 1s packet drop at most (not shown).

Daisy: continuous chain arrival



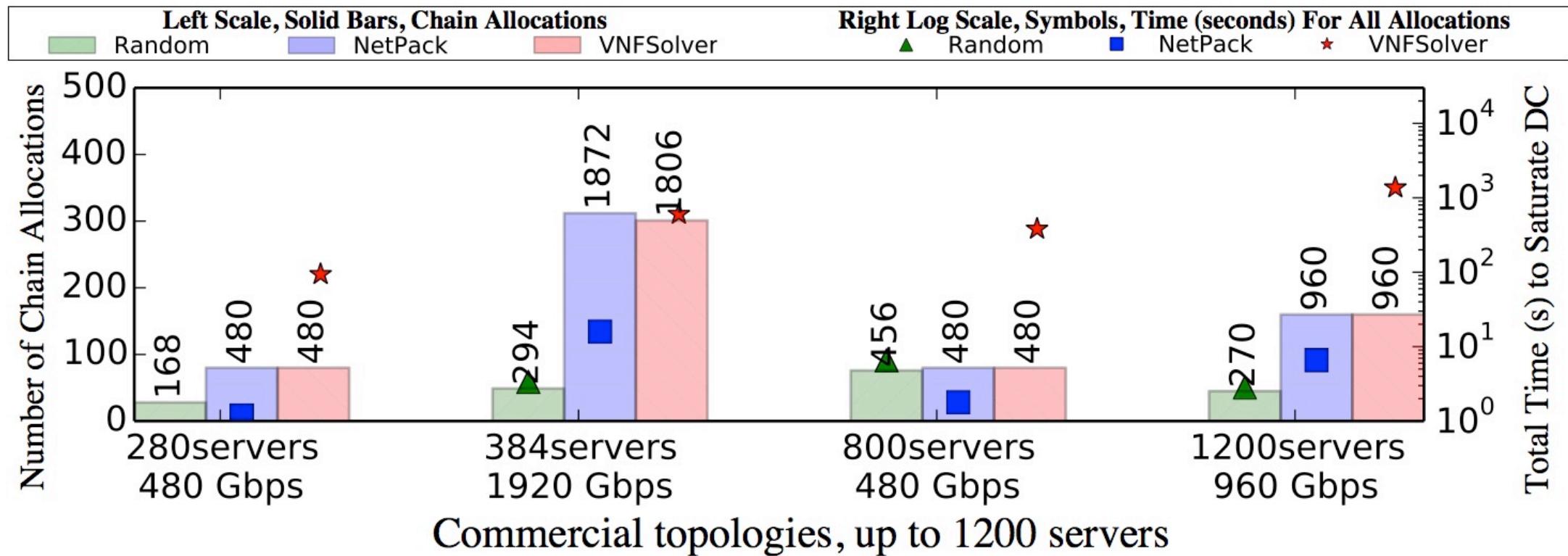
VNFSolver allocated 75 concrete chains (687 Mbps)
NetPack allocated 67 concrete chains (633 Mbps)
Random allocated 61 concrete chains (561 Mbps)
(throughput with iperf generated packets is precise)

Utilization and Speed on E2 racks



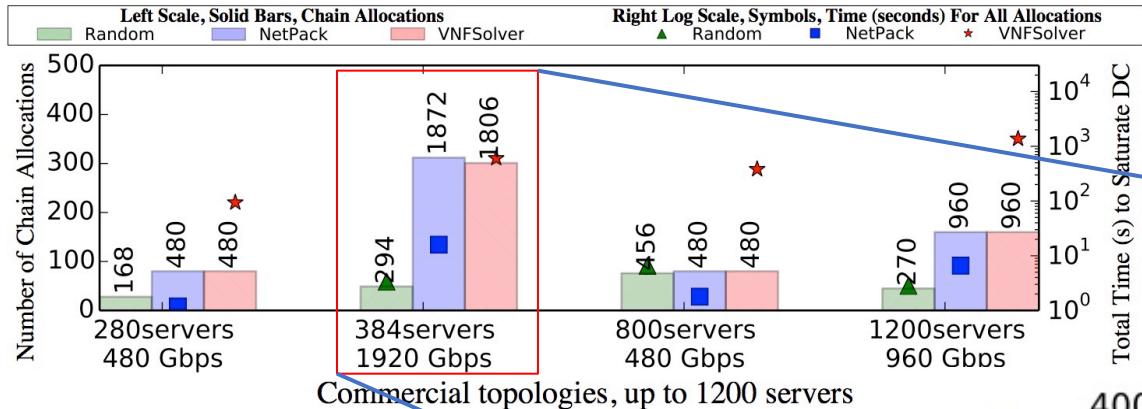
NetPack achieves **at least 96%** of VNFSolver allocations while being **82x faster** than VNFSolver on average.

Utilization and Speed on Commercial Topologies



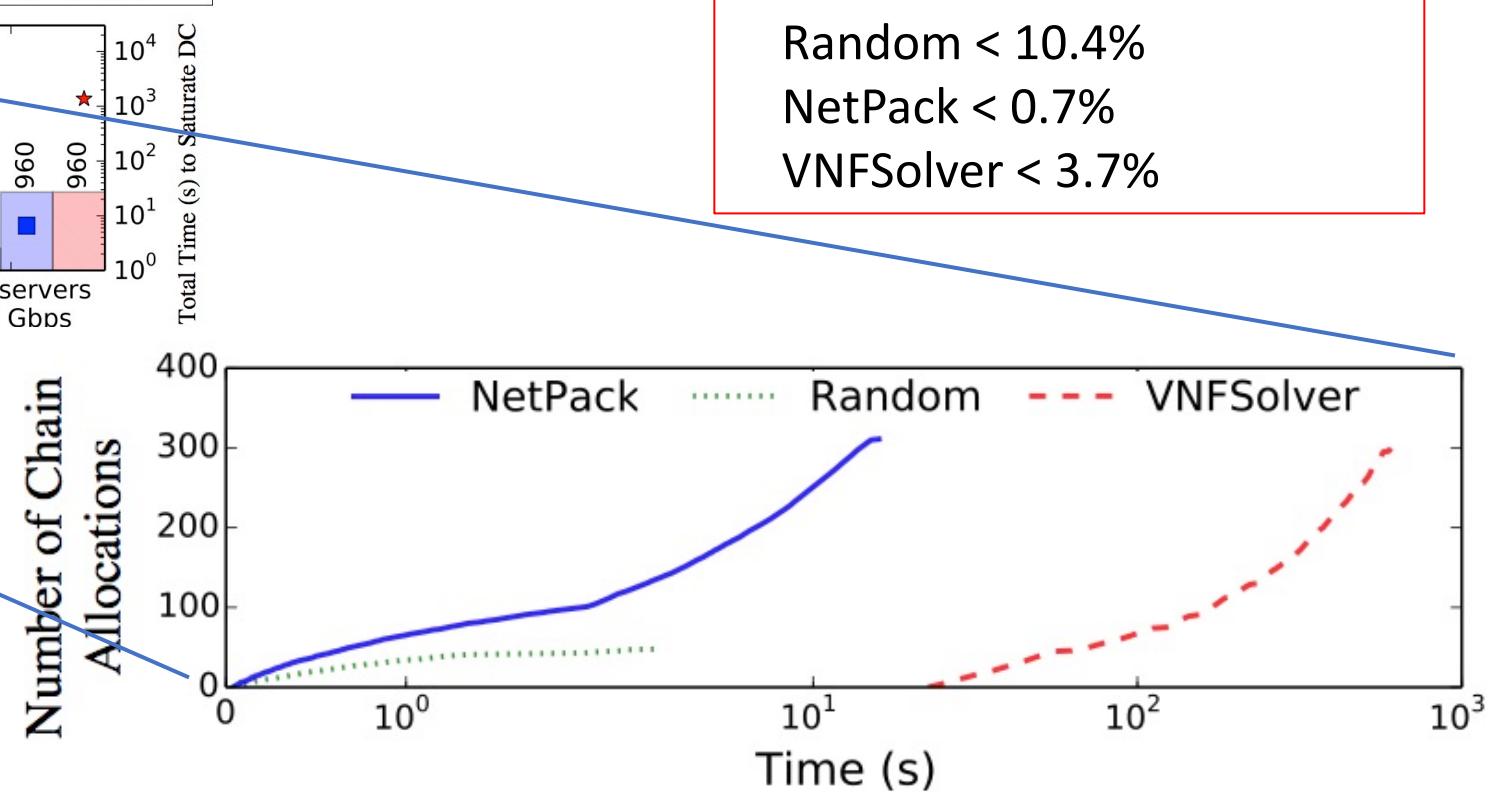
Gives qualitatively similar results, but also reveals a [corner case for VNF Solver](#) (-3.65%).

A corner case for VNFSolver



Variance across 10 runs:

- Random < 10.4%
- NetPack < 0.7%
- VNFSolver < 3.7%



Gives qualitatively similar results, but also reveals a corner case for VNFSolver (-3.65%).

