Effective Resource Provisioning for QoS-aware Virtual Networks in SDN

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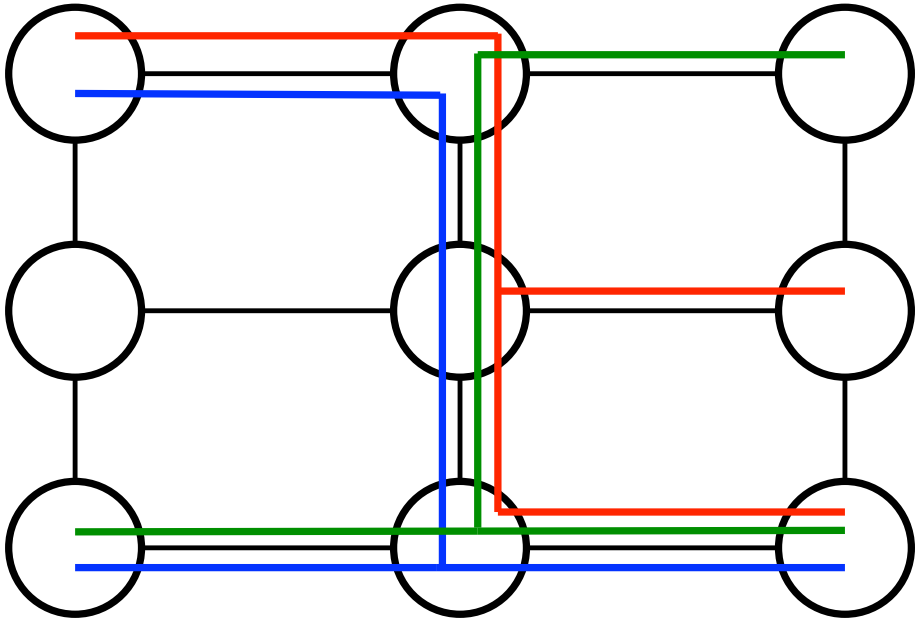
Background: Network Virtualization

- Examples
  - VLAN, VXLAN, Network Slicing
  - LAN Emulation, Broadcast Emulation
  - Tunneling, VPN, Link Aggregation
  - NFV, Virtual Switches / Routers

- Major Challenges
  - Resource Provisioning
    - Growing Demand over Limited Resource
  - QoS-awareness
    - Increasing Constraint to Virtual Networks

Problem on Resource Provisioning for QoS-aware Virtual Networks

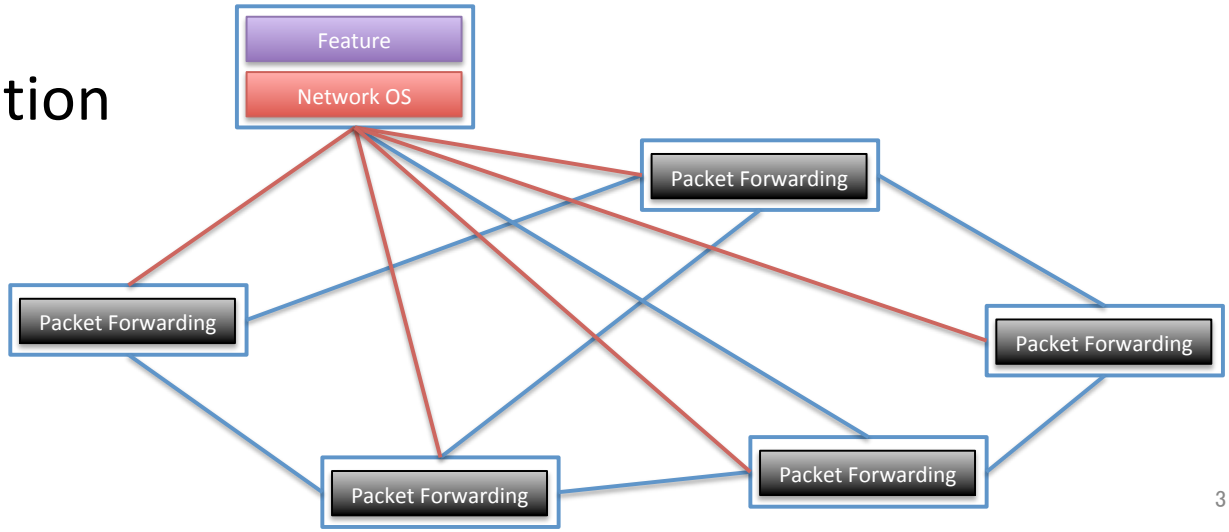
- Lack of load balancing
- Over-provisioning of network resources
- Degradation of acceptance ratio of the provision requests



Software-Defined Networking (SDN) for Network Virtualization

- Programmability and Global View of Network
  - Knowing the network state (Topology, Delay, Bandwidth)
  - Awareness of QoS (Demand) and resource (Supply)
  - Flexibility on stretching a virtual network

- SDN-oriented Problems
  - Size of flow table
  - Intensive computation



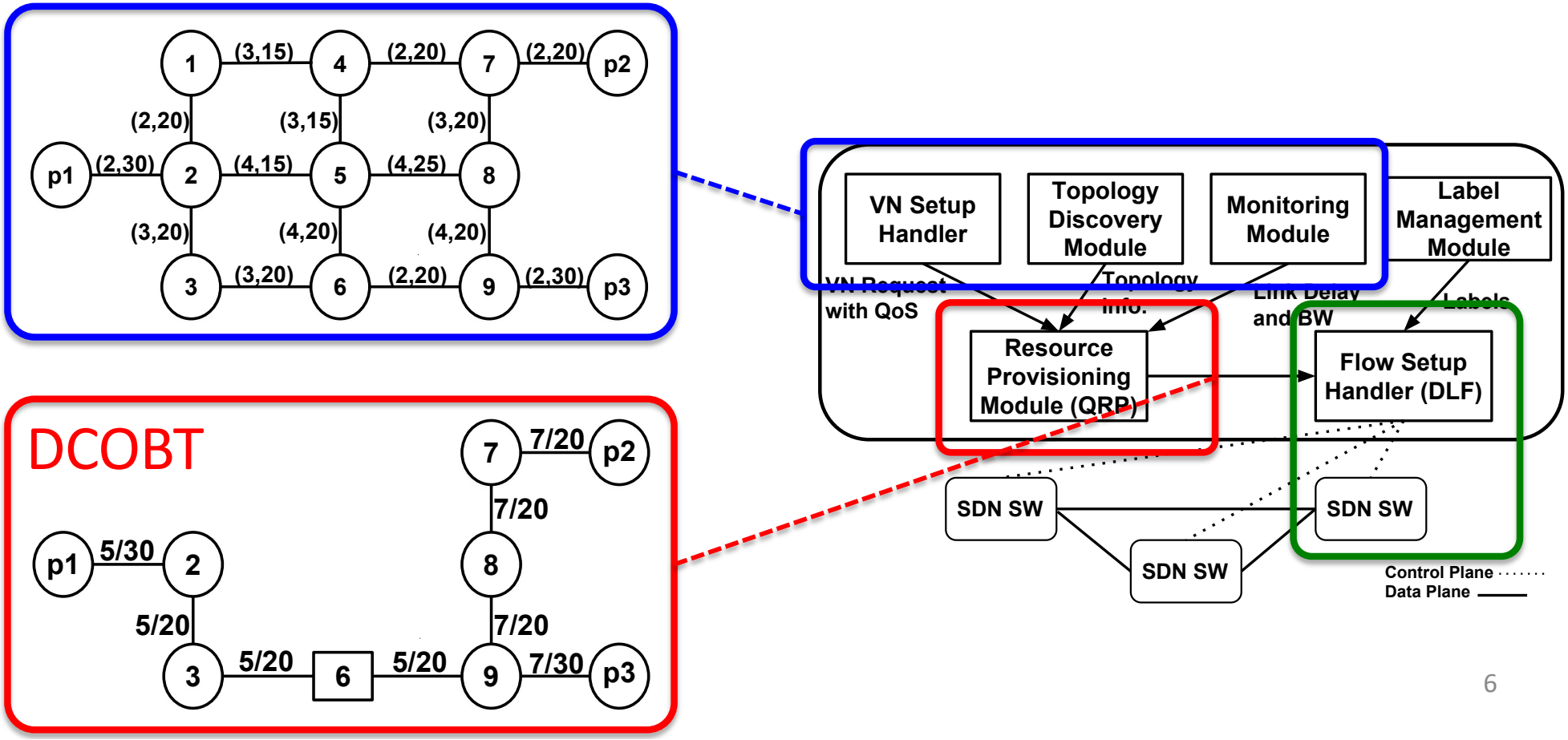
Solution: Provisioning Virtual Networks using Tree

- Delay Constraint Optimum Bandwidth Tree (DCOBT)
  - A tree-based approach to provision as many VN requests as possible with QoS constraints
  - QoS-aware Resource Provisioning (QRP) algorithm for determining DCOBT
- Destination Label-based Forwarding (DLF)
  - A mechanism to reduce the number of flow rules

- Benefits Offered
  - General benefits of tree, and
  - Load-balancing
  - Reducing the overall bandwidth consumption
  - Reducing the number of flow rules to install

System Overview

- Input: network topology / state and VN requests
- Output: DCOBT and implementation on SDN switches



System Overview

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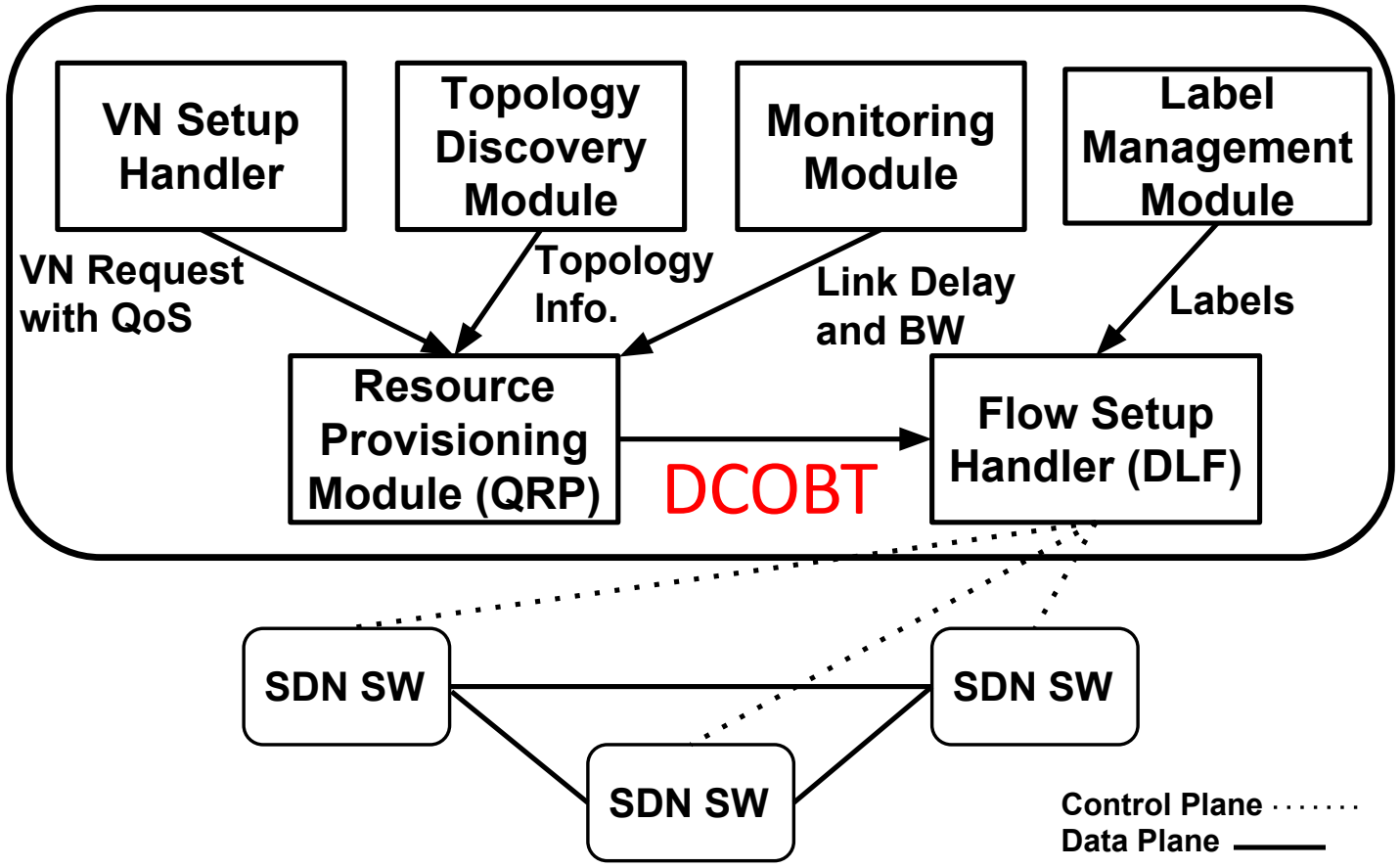
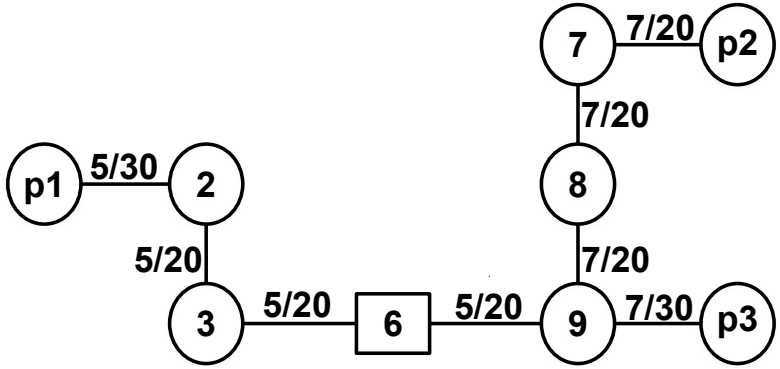


Delay Constraint Optimum Bandwidth Tree (DCOBT)

- A tree
  - Consumes low overall bandwidth
  - Satisfiyies the delay as well as bandwidth requirement for a VN
  - Uses less-utilized links as far as VN requirement is satisfied

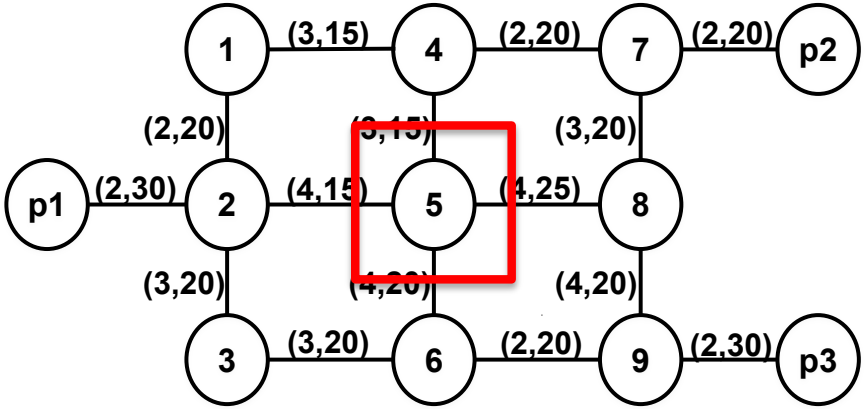
$$\begin{cases} C_T = \sum_{(i,j)\in T} \frac{C_{ij}}{r_{ij}} \ is\ minimum,\ and \\ \\ Max(\forall (u,v) \in P,\ (d_{u,v})) \leq D_{req} \end{cases}$$

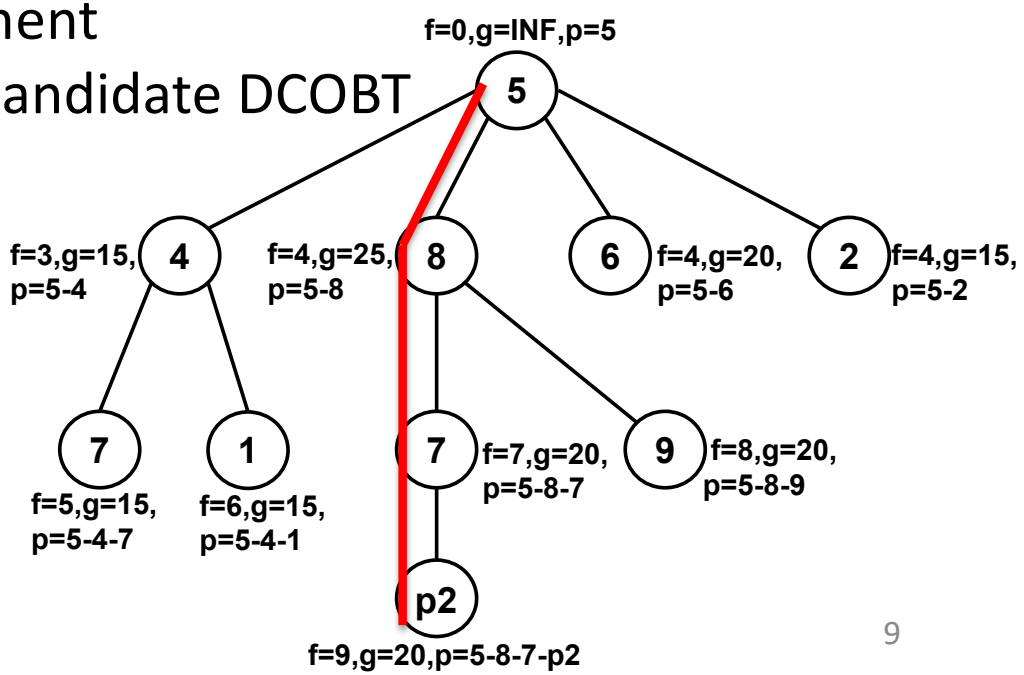


- Where…
  - P: Set of end points in a VN
  - C_T: Sum of bandwidth reserved on all links
  - D_{req}: the delay requirement
  - d(u,v): Delay between path between end points u,v, in T
  - $r_{i,j}$: Minimum bandwidth available in both directions of (i,j)
- NP-Hard Problem

QoS-aware Resource Provisioning (QRP) Algorithm for Finding DCOBT (1/2)

- Step 1: Finding the center of graph
  - Uses Radius Constrained (RC) heuristic to find the center of graph to be a root of DCOBT
  - Delay shall be minimum from the center to the endpoints
- Step 2: Finding the DCOB Path
  - Has maximum residual bandwidth (resource)
  - Satisfies bandwidth requirement
  - A group of DCOBPs forms a candidate DCOBT

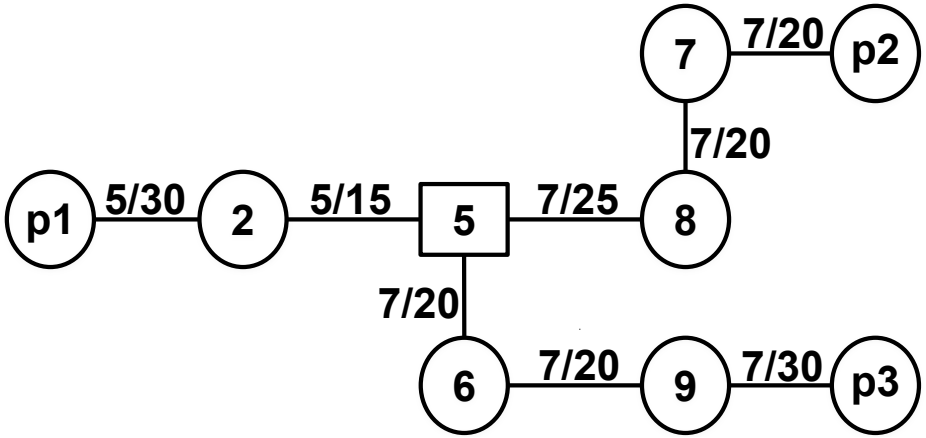




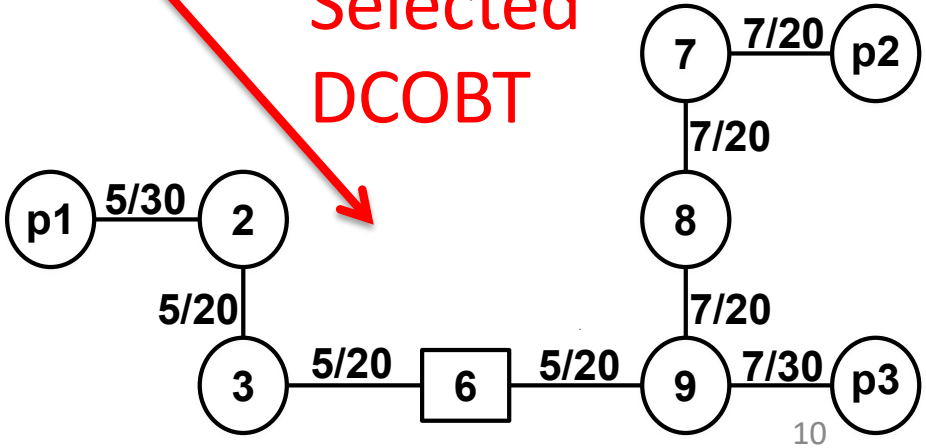
QoS-aware Resource Provisioning (QRP) Algorithm for Finding DCOBT (2/2)

- Step 3: Comparing the candidate DCOBTs and selecting the better one
  - DCOBT that consumes less bandwidth is better

$$\begin{cases} C_T = \sum_{(i,j)\in T} \frac{C_{ij}}{r_{ij}} \ is\ minimum, \ and \\ Max(\forall (u,v) \in P,\ (d_{u,v})) \le D_{req} \end{cases}$$

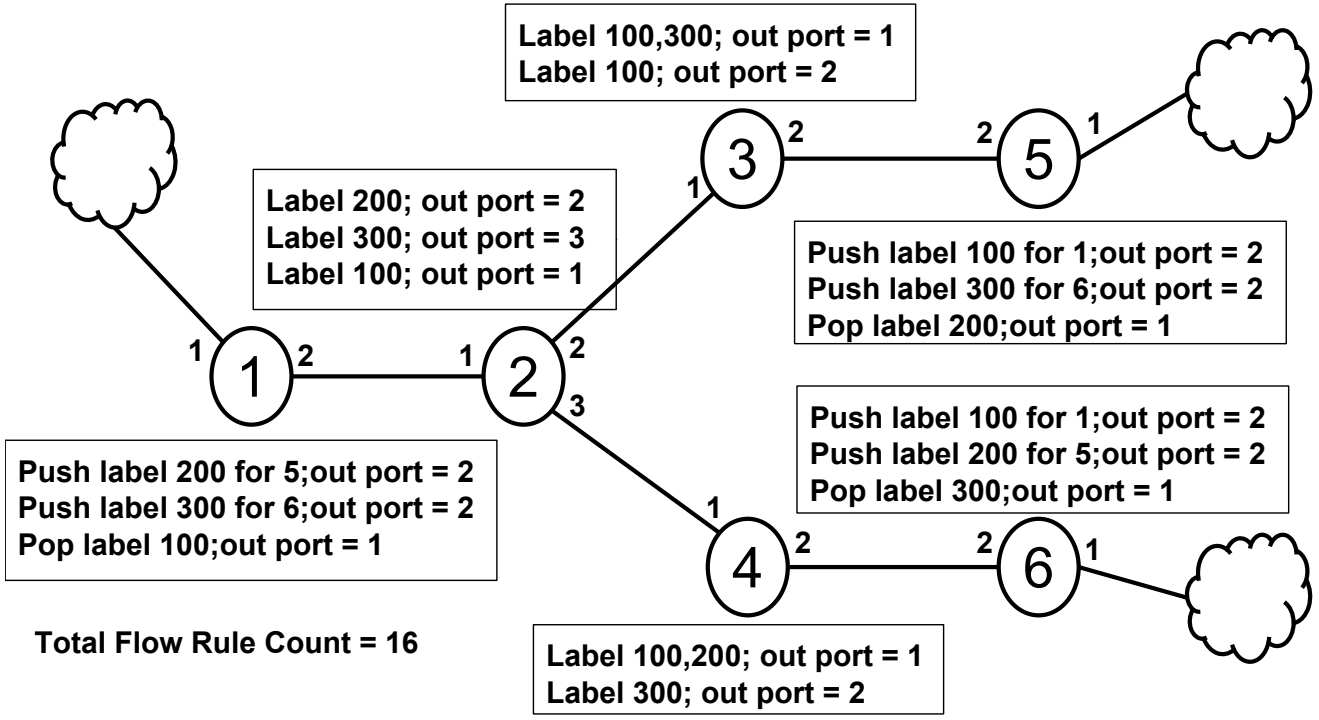


Selected DCOBT



Destination Label based Forwarding (DLF)

- 1 label per endpoint, VN involves a set of labels
  - {Push/Pop and forward} operation at ingress and egress switches
  - Intermediate switches forwards the packet based on the label
- Aggregating the flow rule having the common “out port” across labels
  - Ingress / egress switches needs n-1 flow rules
  - The number of “DLF-related” flow rules will be same that of outgoing ports



Proof of Concept Implementation

- Setup
  - SDN Controller: Ryu 4.2
  - SDN Switch: Open vSwitch 2.5.2
  - Open Flow Version: 1.3
  - Network Emulator: Mininet 2.2

- Flow Rule Aggregation of DLF
  - Using Group_Indirect feature of openflow for implementing flows that has a common action in intermediate switches
  - Created a indirect group type for every intermediate switch and made to point all flows with different labels to the corresponding group

Evaluation Setup

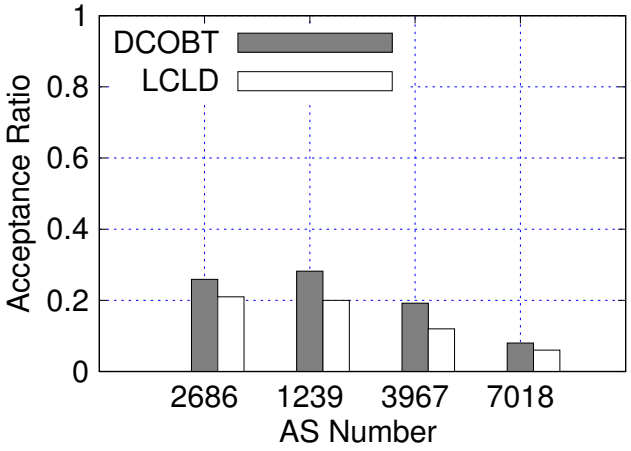
- Sparse and Dense ASes
- Pseudo Internet
  - Random network using Waxman model
  - Network Size: 40, 60, 80 and 100 nodes
- Evaluation Metrics and Approach
  - Acceptance Ratio of VNs, Link Utilization, Provisioning Cost, Time Requirement, and Number of Flow Rules
  - Comparison with LCLD as Benchmark

TABLE II: RocketFuel Dataset [27]

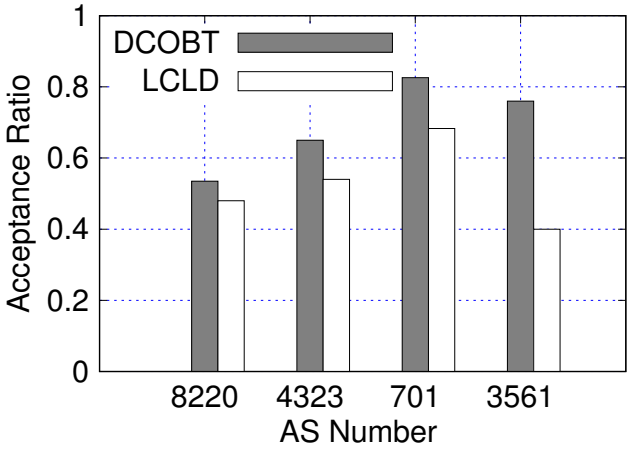
	AS Number	# of Nodes	# of Edges	Average node degree
Sparse Topologies	2686	25	35	3
	1239	52	84	3
	3967	79	147	3
	7018	115	148	3
Dense Topologies	8220	25	64	6
	4323	51	161	7
	701	83	219	6
	3561	92	329	8

Acceptance Ratio of VN Requests (with different size of networks)

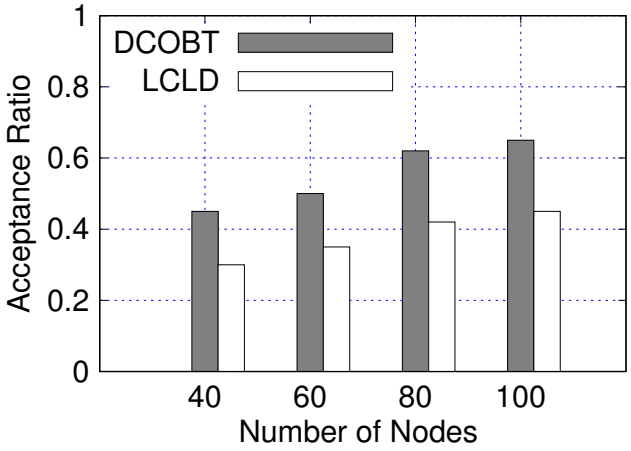
- DCOBT outperformed LCLD in sparse / dense networks as well as Pseudo Internet
- Higher acceptance ratio was observed in dense networks
  - More availability of alternative paths
  - Better load balancing



Sparse Network



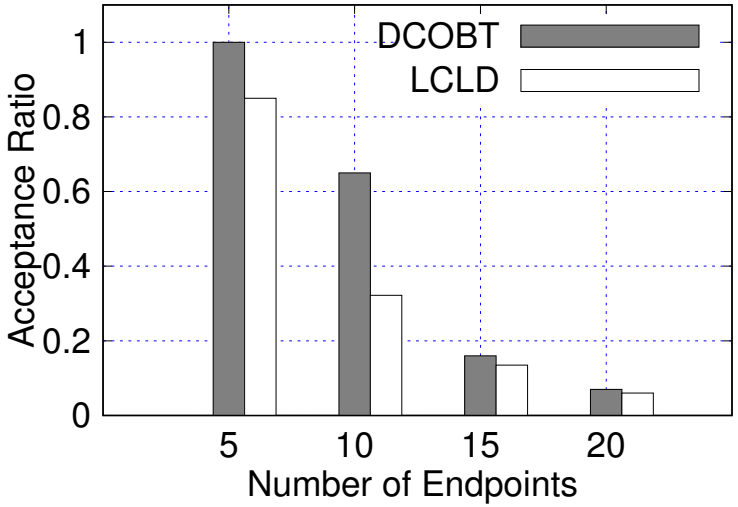
Dense Network



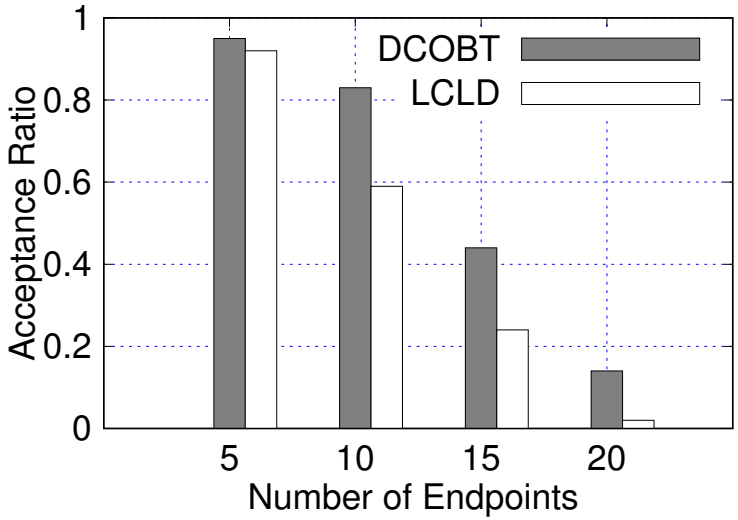
Pseud-Internet

Acceptance Ratio of VN Requests (with increasing number of end points)

- Acceptance Ratio decreases in both approaches due to the increasing provisioning cost
- DCOBT can still accept more VN requests by aggressively utilizing the alternate paths that have high residual bandwidth in a VN tree



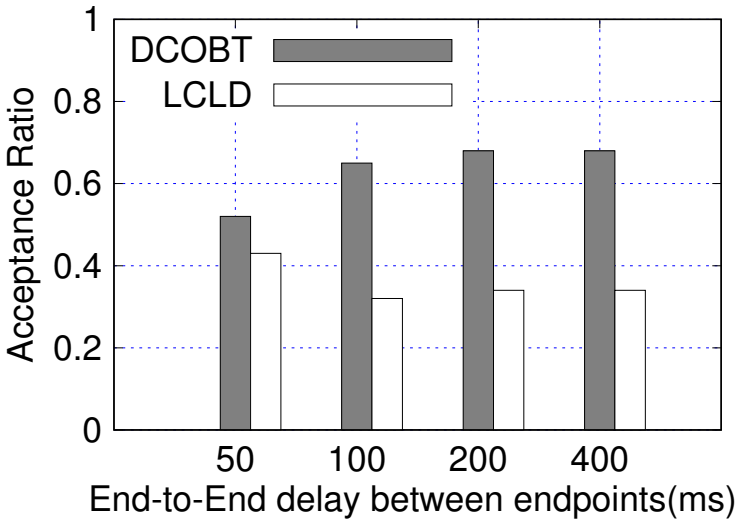
AS3561 (Dense, 92 nodes)



Pseud-Internet (100 nodes)

Acceptance Ratio of VN Requests (with relaxation of Delay Constraint)

- Relaxation of delay constraint gives chance to consider more alternative path in the process of finding DCOBPs



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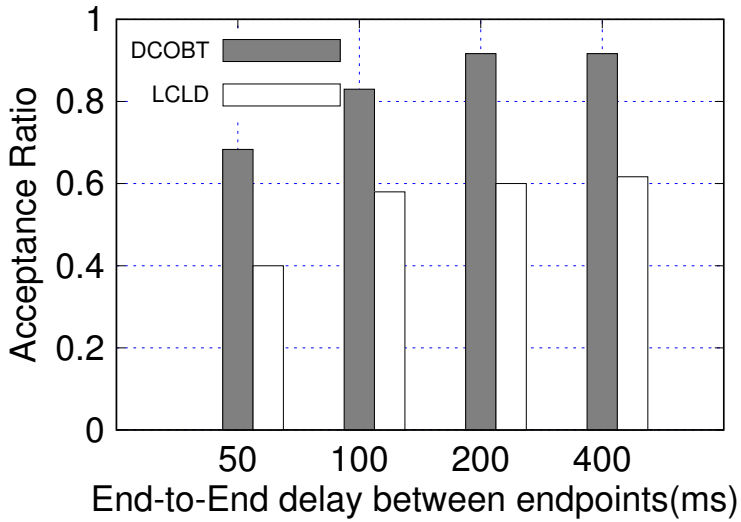
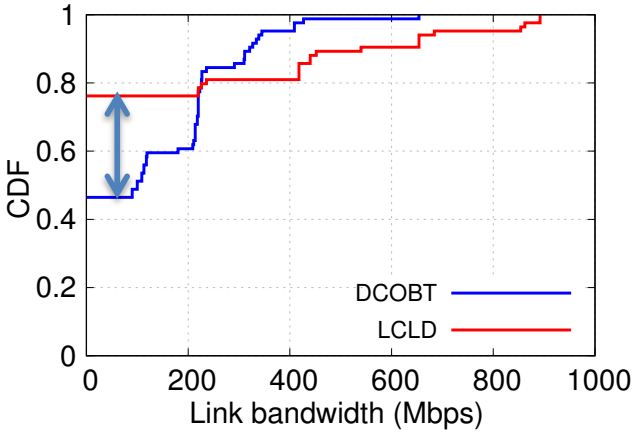


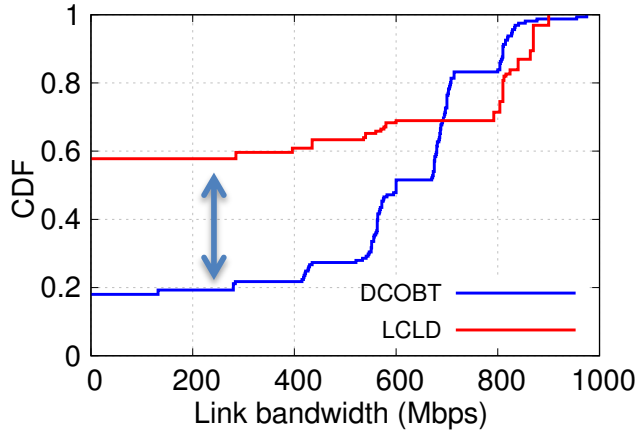
Pseud-Internet (100 nodes)

Link Utilization (Load Balancing)

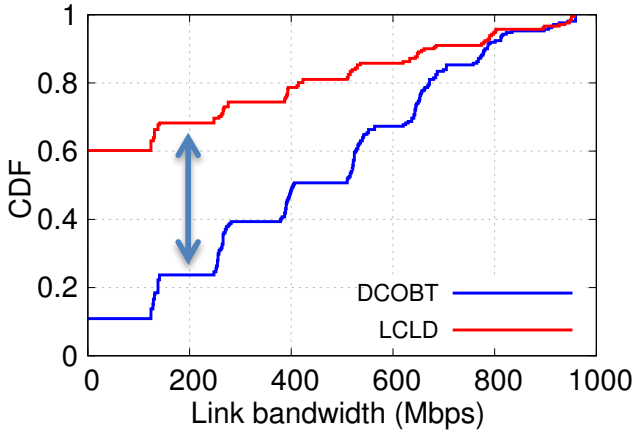
- DCOBT uses more links, i.e. reduces unused links



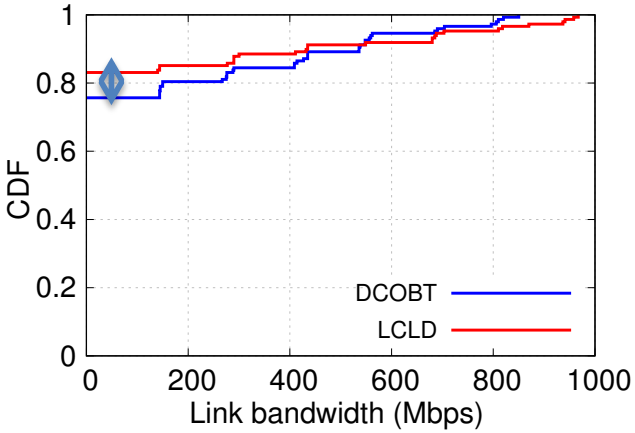
AS1329 (Sparse, 52 nodes)



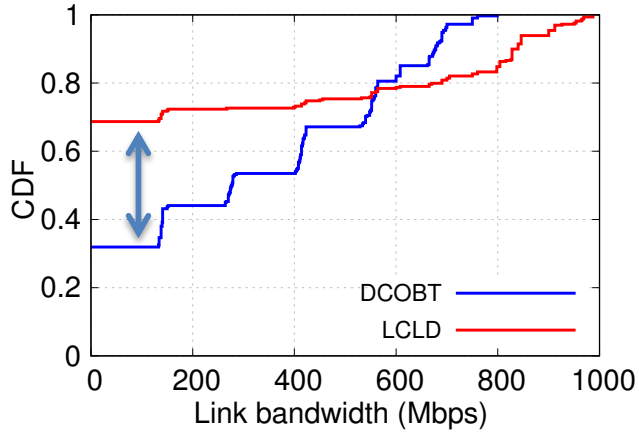
AS4323 (Dense, 51 nodes)



Pseudo Internet (60 nodes)



AS7018 (Sparse, 115 nodes)



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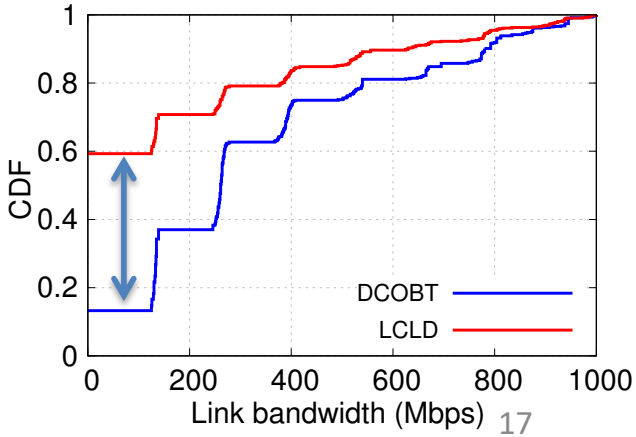
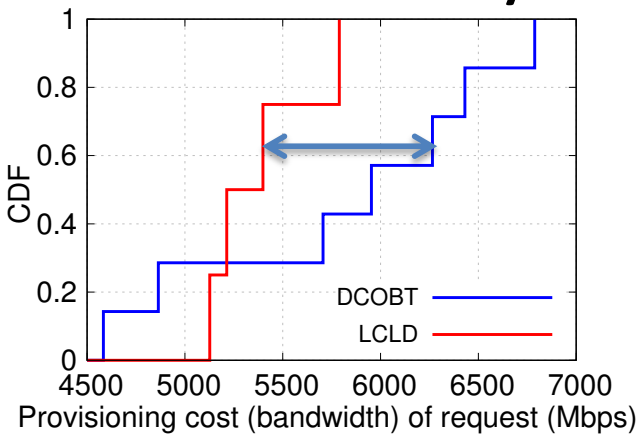


Pseudo Internet (100 nodes)

Provisioning Cost

- DCOBT utilizes bandwidth resource more effectively and keeps the acceptance ratio higher



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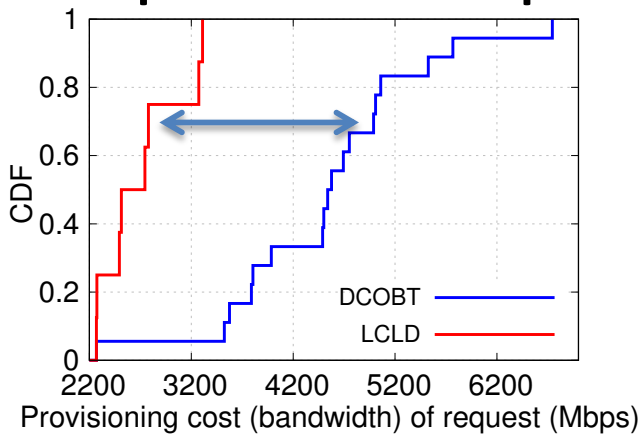

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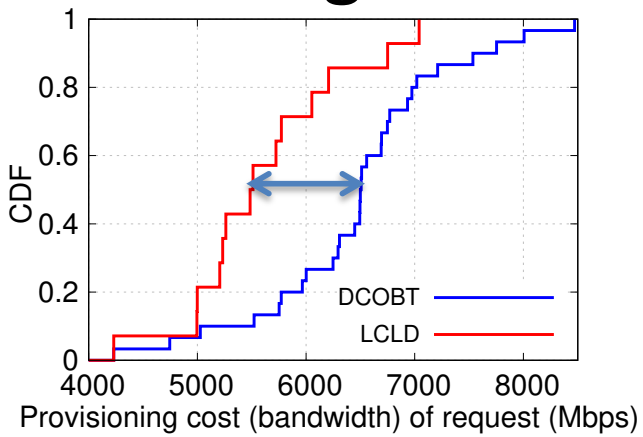

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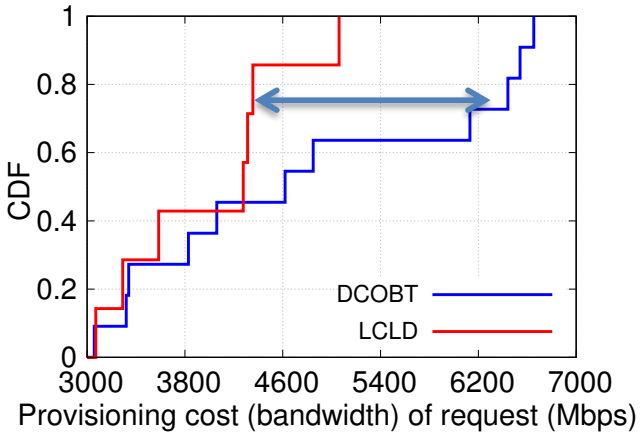

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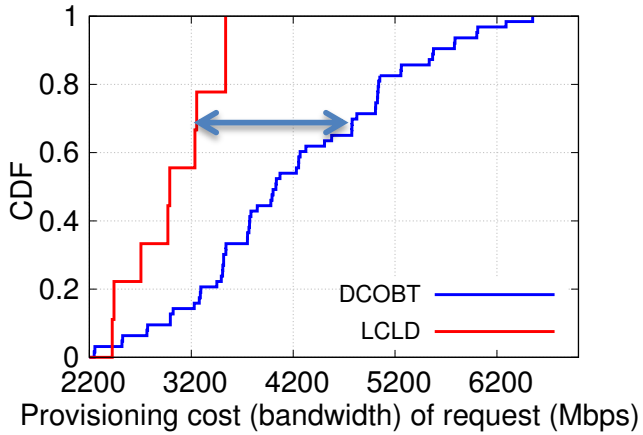

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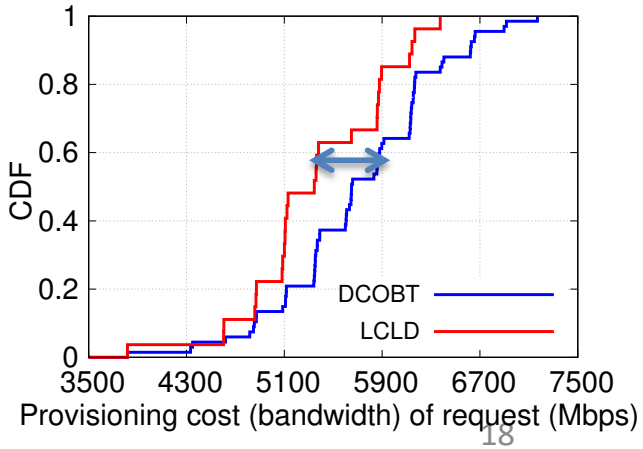
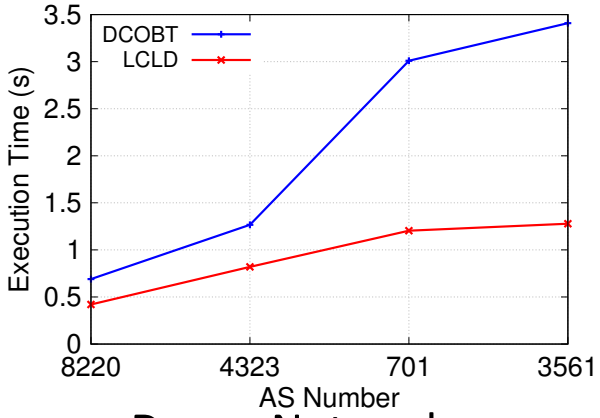


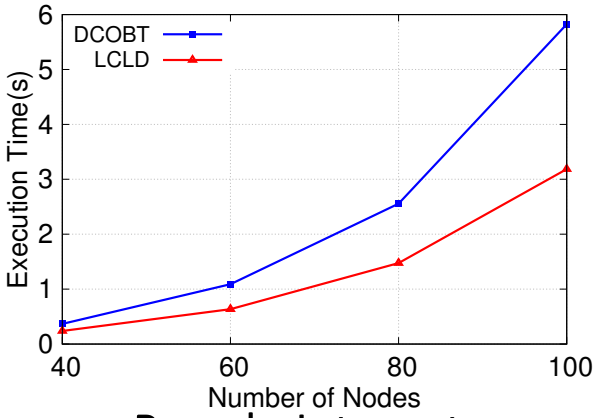
Pseudo Internet (100 nodes)

Time required for Provisioning VNs

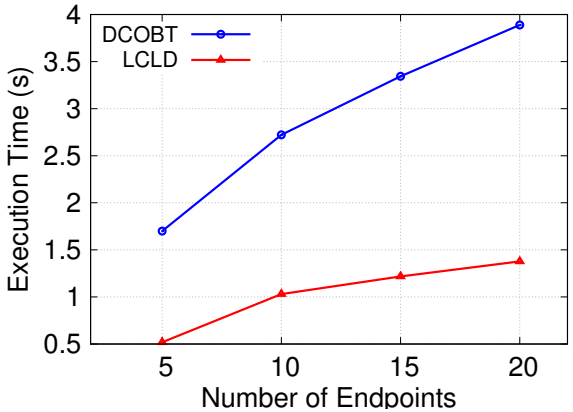
- Provisioning time is proportional to the size of network as well as the number of endpoints (but is affordable!!)
- LCLD performs better in terms of Provisioning Time
- Complexity of QRP
  - $O(n*l*|V|^2)$
  - n: # of endpoints
  - l: # of "centers" to search
  - V: size of network



Dense Networks



Pseudo Internet



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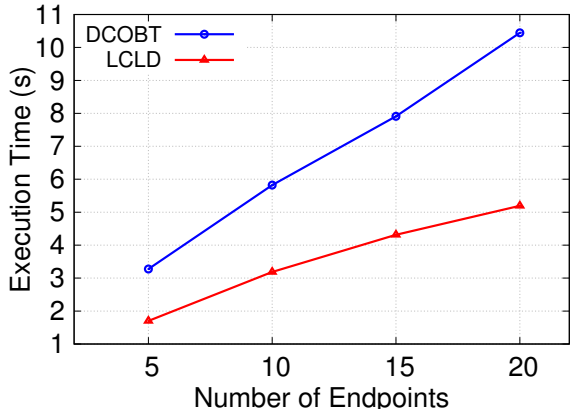
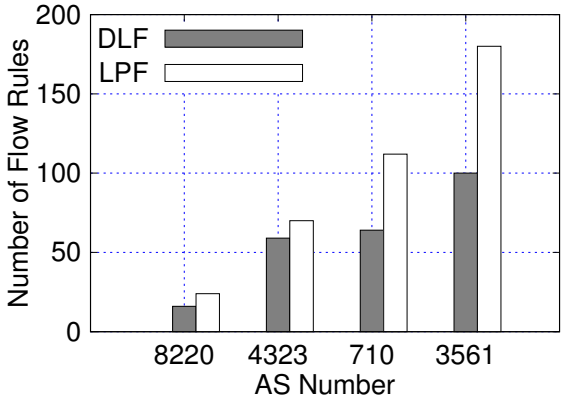
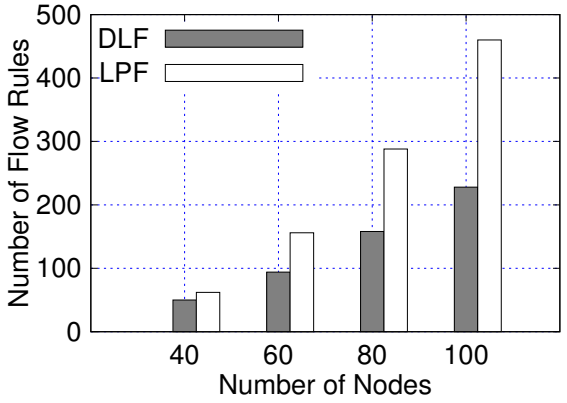


Pseudo Internet (100 nodes)

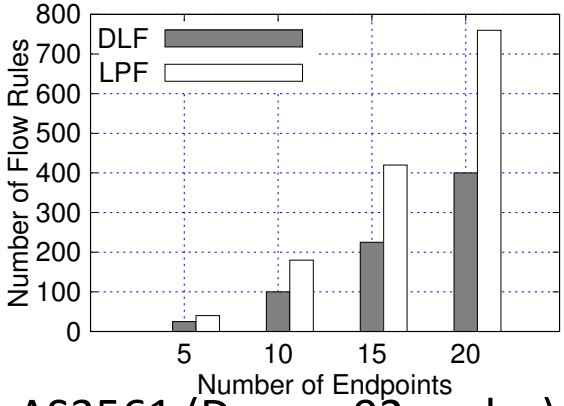
Reduction of Flow Rules

- The number of flow rules are proportional to the size of network and end points





- DLF of DCOBT inserts less flow rules than conventional Label Path Forwarding (LPF)



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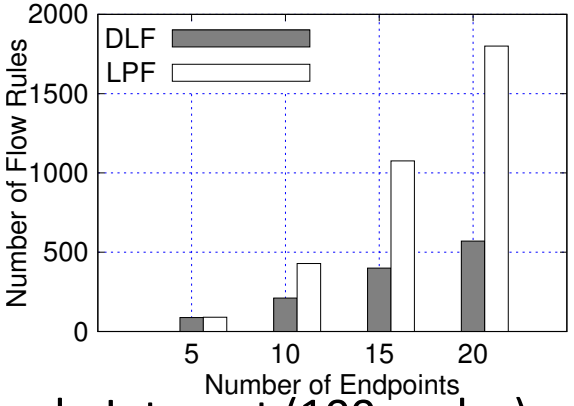

Pseudo Internet (100 nodes)

Discussions

- What happens if the “center” can’t be found?
  - The system can fall back to point-to-point (non-Tree) approach.
  - The algorithm for computing DCOBP can help to find high residual paths with delay bound between a pair of end points.
- Can the Provisioning Time be shorter?
  - Quick way is to reduce the number of center to examine for determining DCOBT.
  - Caching candidate DCOBT in SDN controller can also help.
- Does DCOBT help Data Center Networks?
  - Not much. Load balancing can be done, but no significant improvement on acceptance ratio of VNs.
  - This is due to short and small number of paths between centers and hosts.

Conclusion and Future Work

- Conclusion: This paper
  - Addressed the problems on QoS-aware Network Virtualization
  - Proposed Delay Constraint Optimum Bandwidth Tree (DCOBT)
    - QoS-aware Resource Provisioning (QRP) algorithm
    - Destination Label Forwarding (DLF)
  - Proved that DCOBT approach can introduce
    - Better load balancing
    - Higher resource utilization
    - Improved acceptance ratio
    - Reduction of Flow Rules
    - Slightly longer, but affordable provisioning time as trade-off

- Future Work
  - Further optimization of resource usage
  - Comparison with the link-mapping phase of VNE

Thank you. Q&A?