Advanced Computer Networks

Load Balancing in Data Center Networks (II)

https://pages.cs.wisc.edu/~mgliu/CS740/F25/index.html

Ming Liu
mgliu@cs.wisc.edu

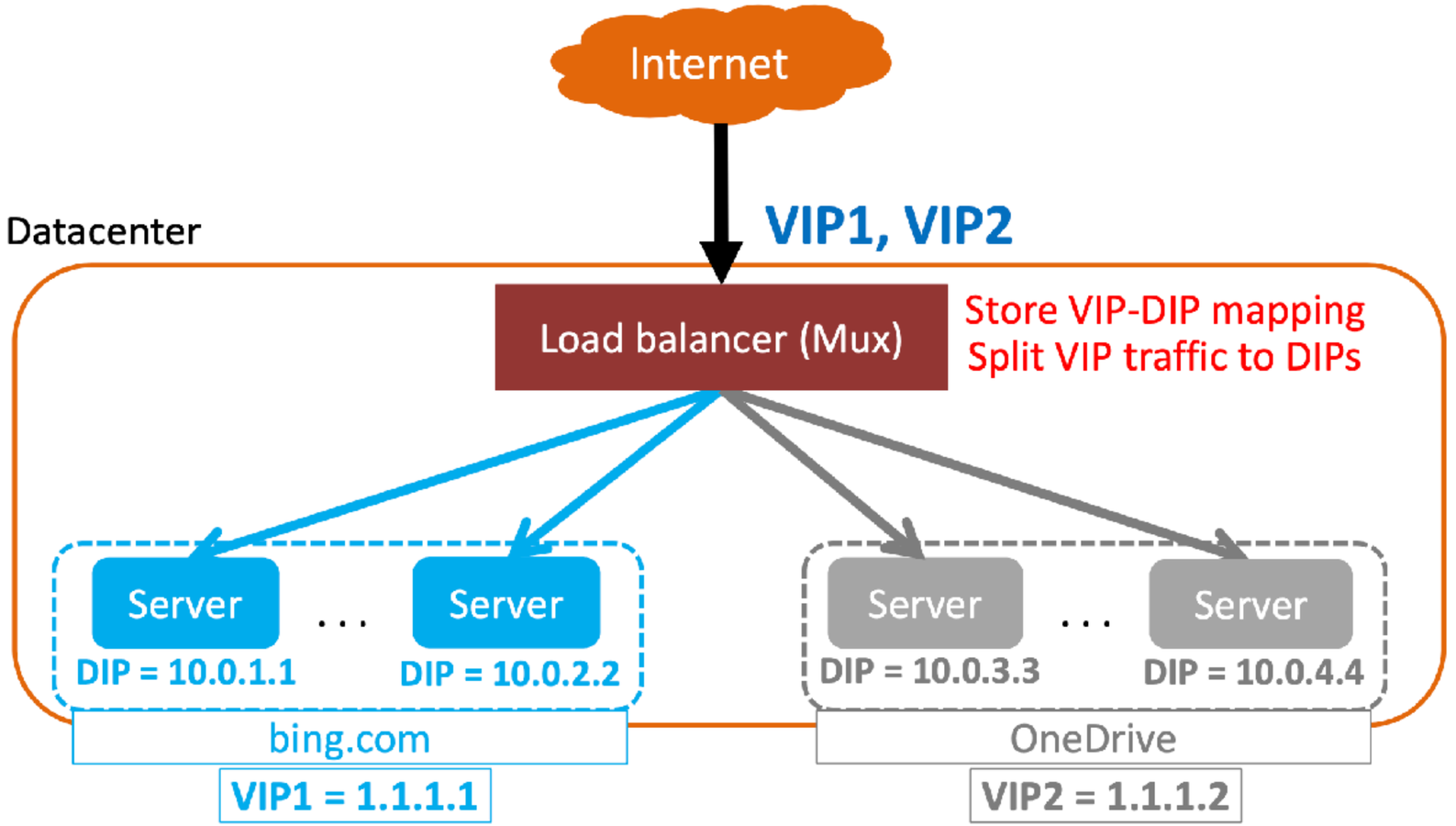
Outline

- Last lecture
  - Load balancing in data center networks (I)
- Today
  - Load balancing in data center networks (II)
- Announcements
  - Lab1 due 10/08/2025 11:59 PM

Design requirements of a load balancer

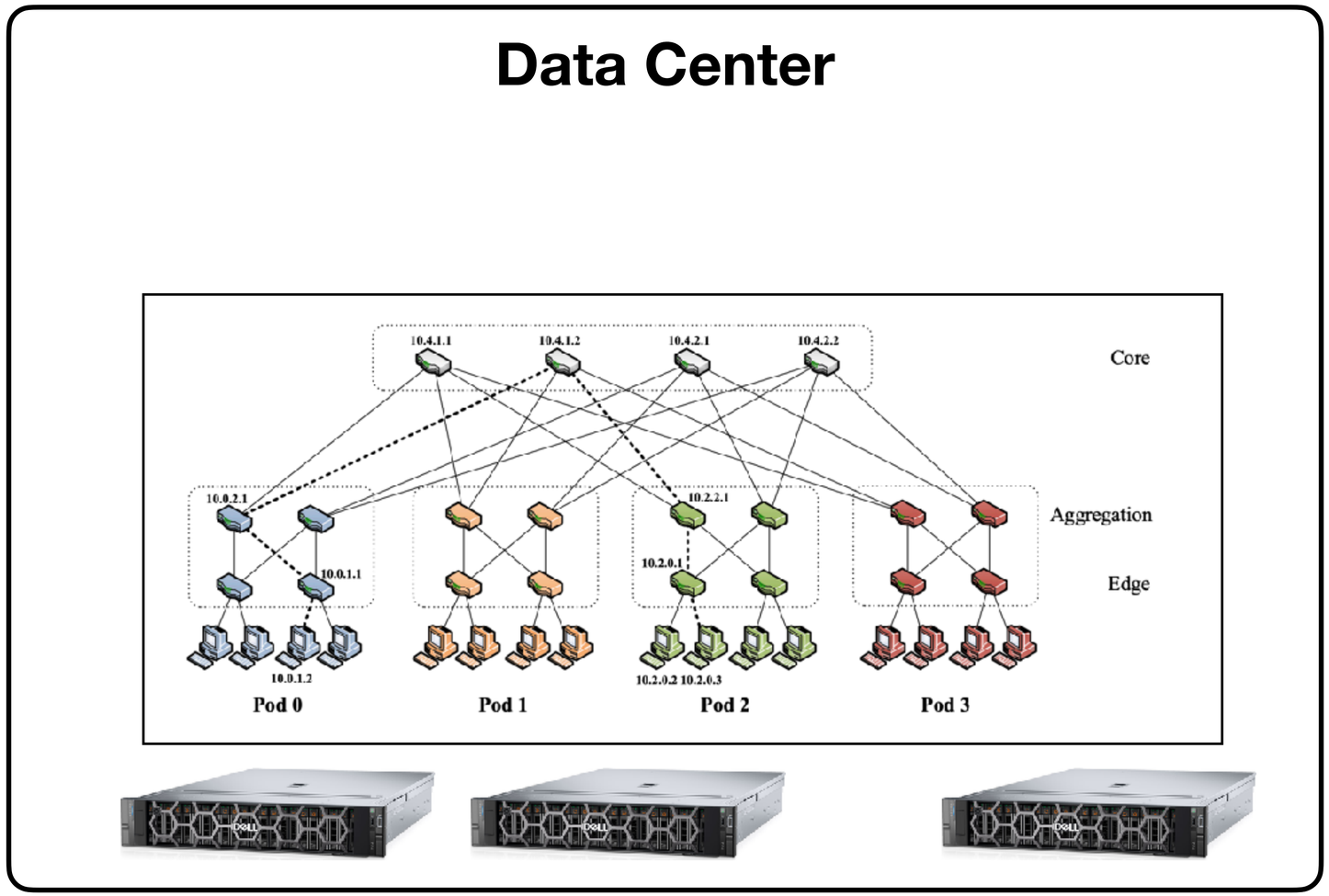
- Multiple NIC interfaces
- Fast memory
- Line-rate processing
- Maintain a load-balancing table
- Perform hashing and lookup
- Maintain a connection tracking table

Microsoft Azure Example



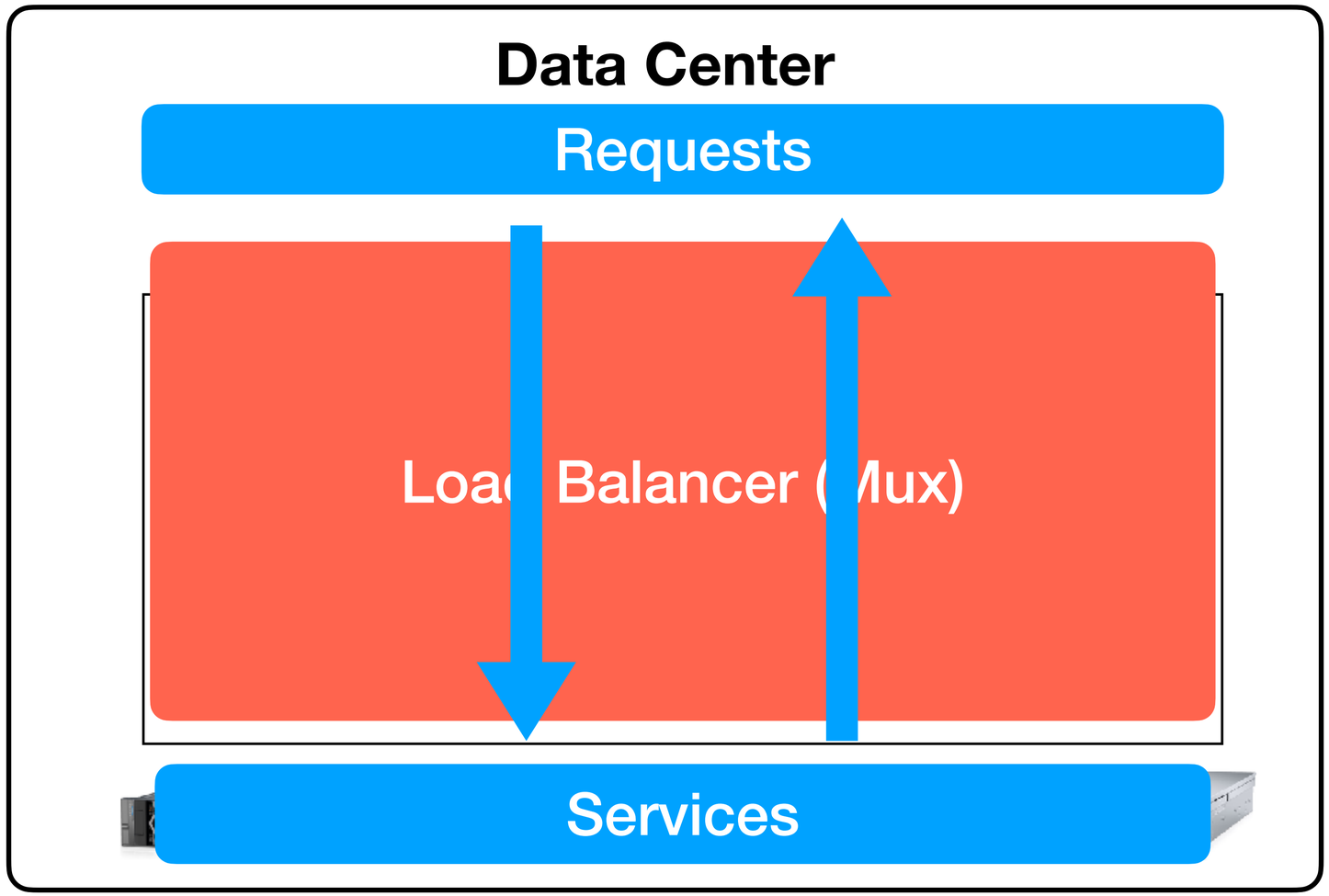
Load balancer overview

- Like what we discussed in the last lecture



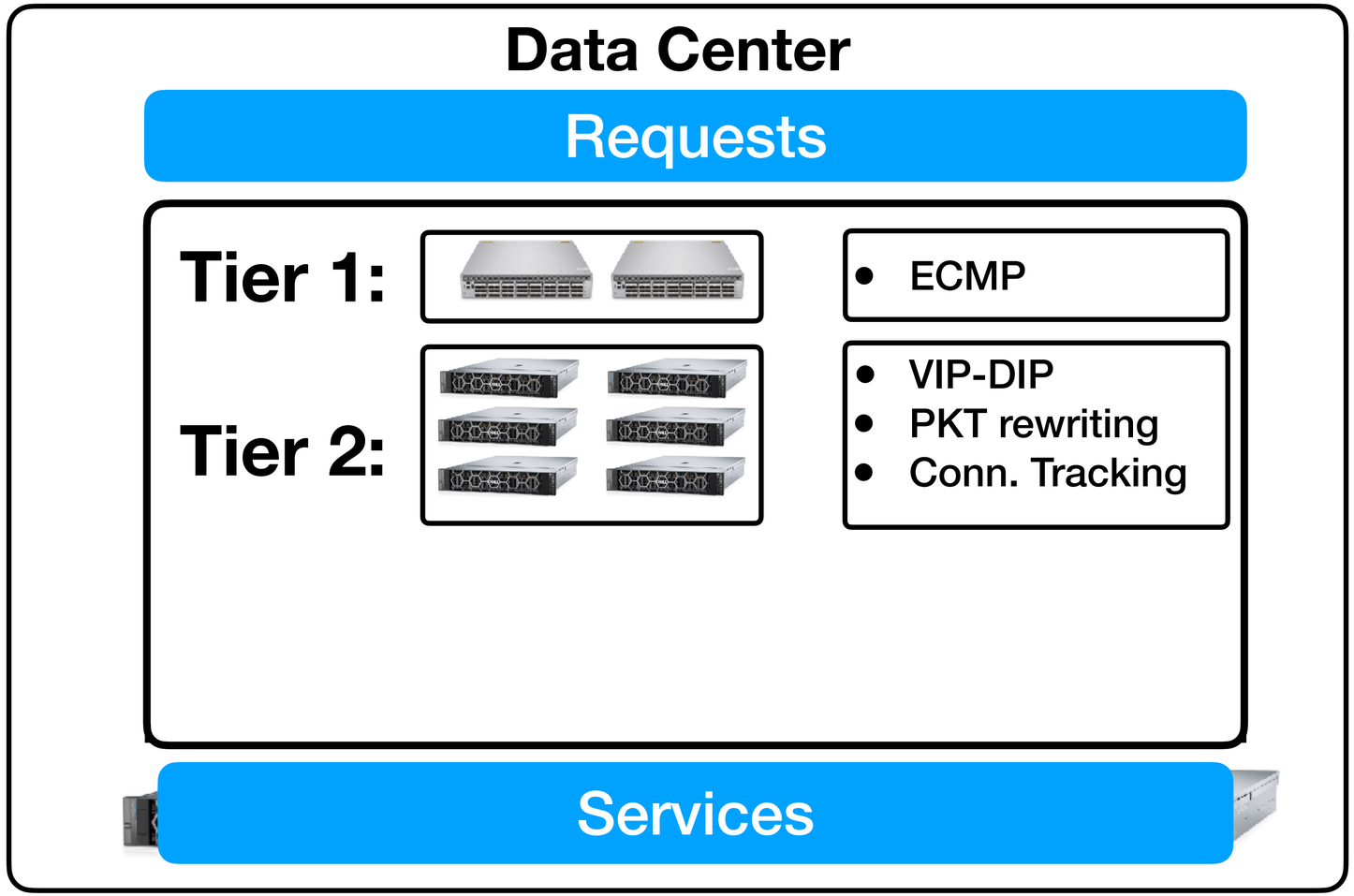
Load balancer overview

- Like what we discussed in the last lecture



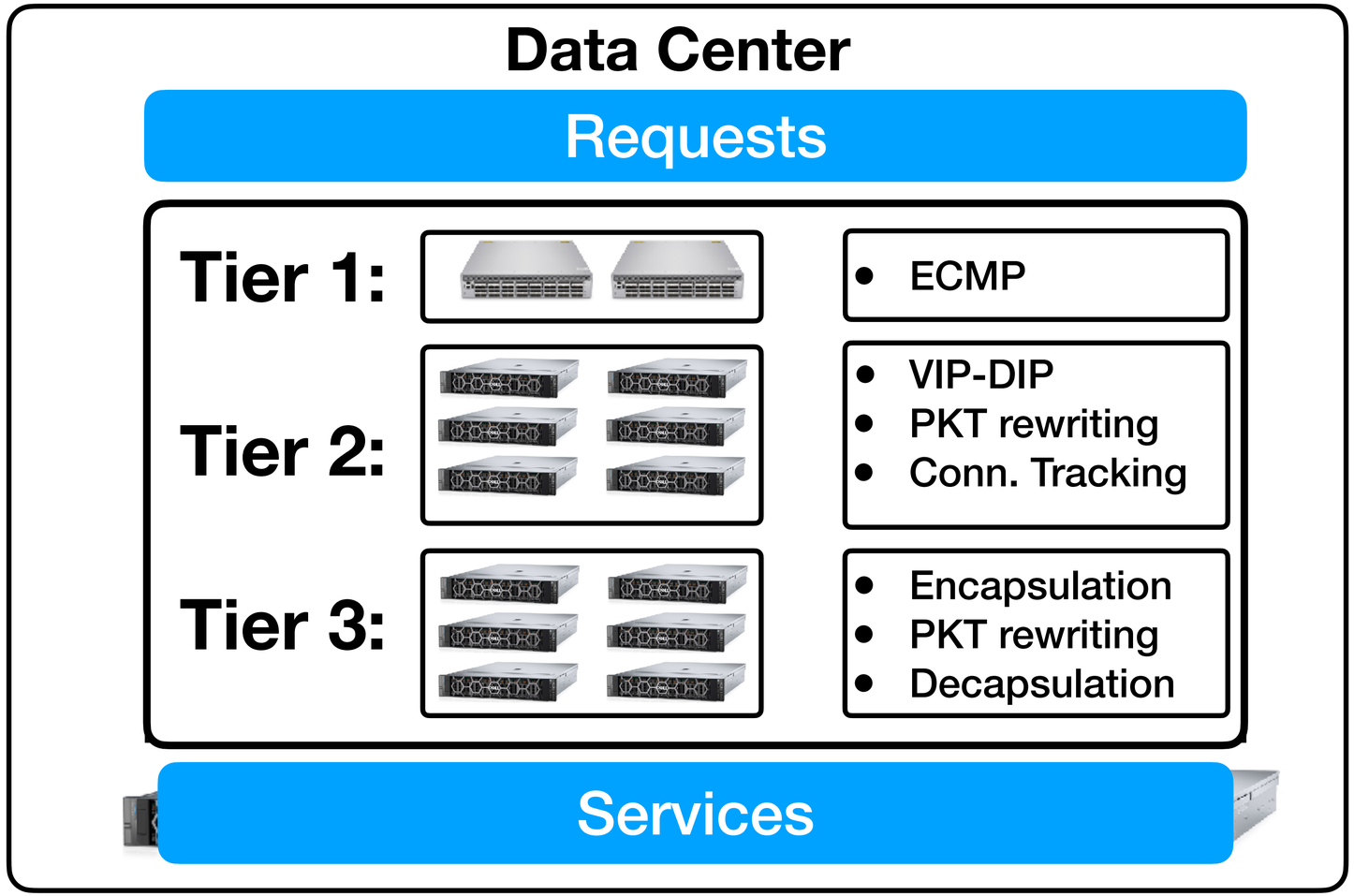
System Architecture of a SW load balancer

- Distributed systems



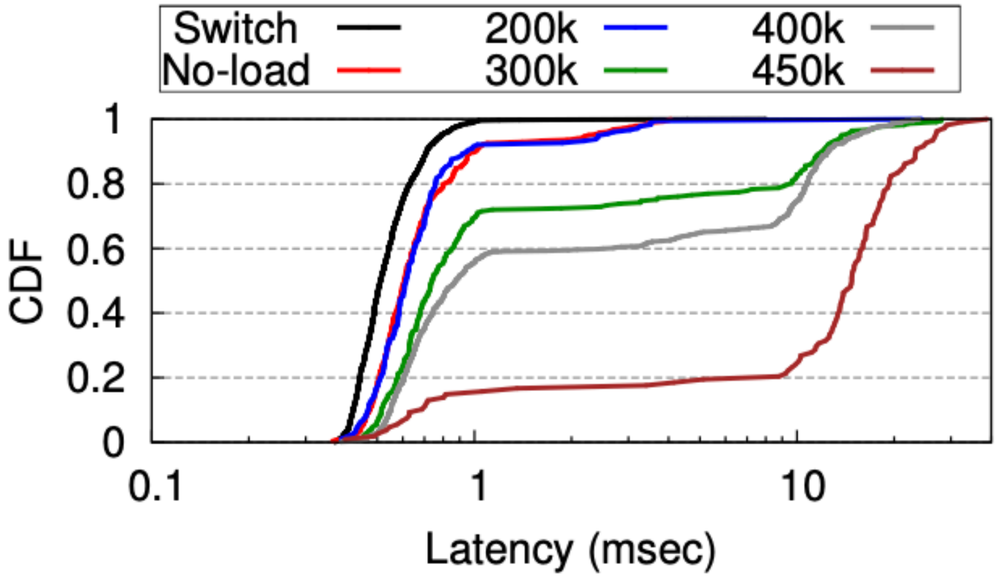
System Architecture of a SW load balancer

- Distributed systems
- Tunneling adds more complexity



What are the limitations of a software load balancer?

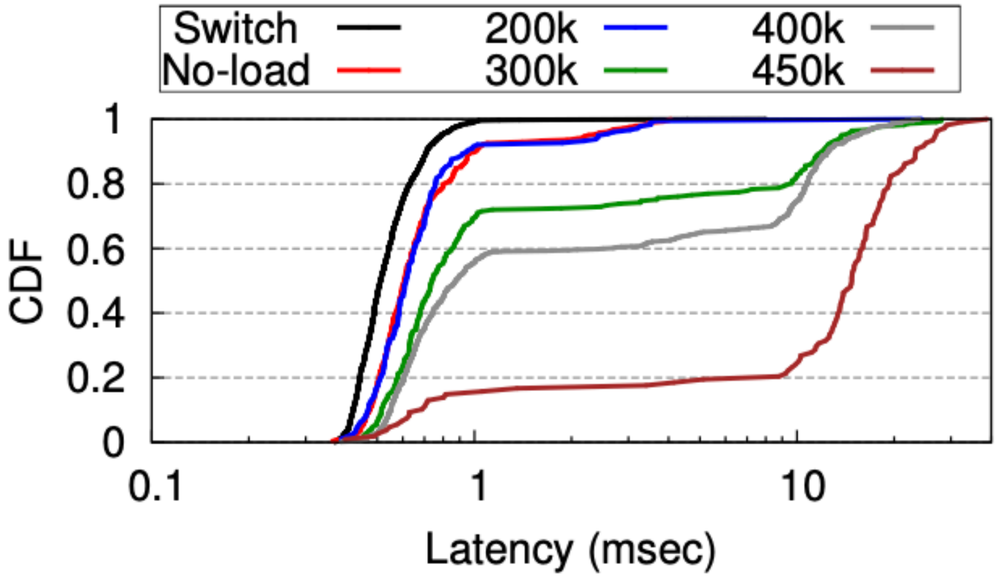
Limitations of the software load balancer

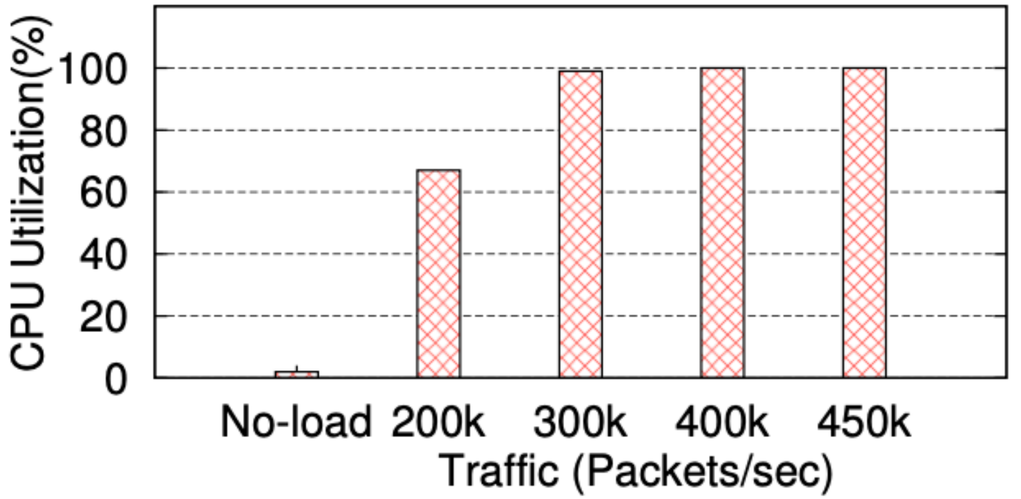


#1: Slow

- SMux adds a media latency of 196us
- High latency variance

Limitations of the software load balancer





#1: Slow

- SMux adds a media latency of 196us
- High latency variance

#2: Costly

- Up to 300K pkts/s per server => 3.6Gbps
- 15Tbps => 5K servers

How does Duet solve it?

How does Duet solve it?
Hardware-software co-design

How does Duet solve it?
Hardware-software co-design

But, why can we co-design the hardware and software?

Key Observation: Commodity switches transit to a gray box. They provide APIs for fine-grained control over ECMP and tunneling functionality.

Key ideas:

- #1: Use commodity switches as hardware Muxes
- #2: Use software Muxes as a backstop

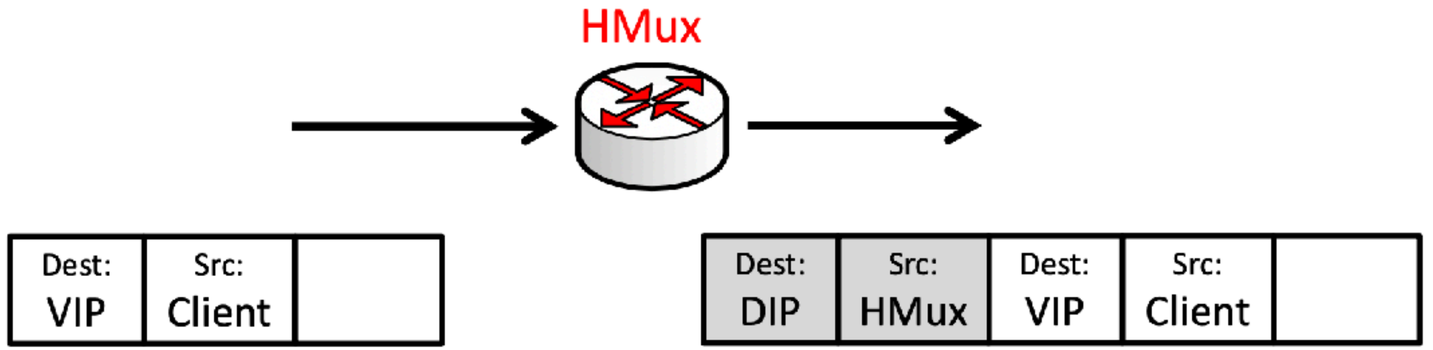
HW Mux Design

- Technique #1: chained table execution

HW Mux Design

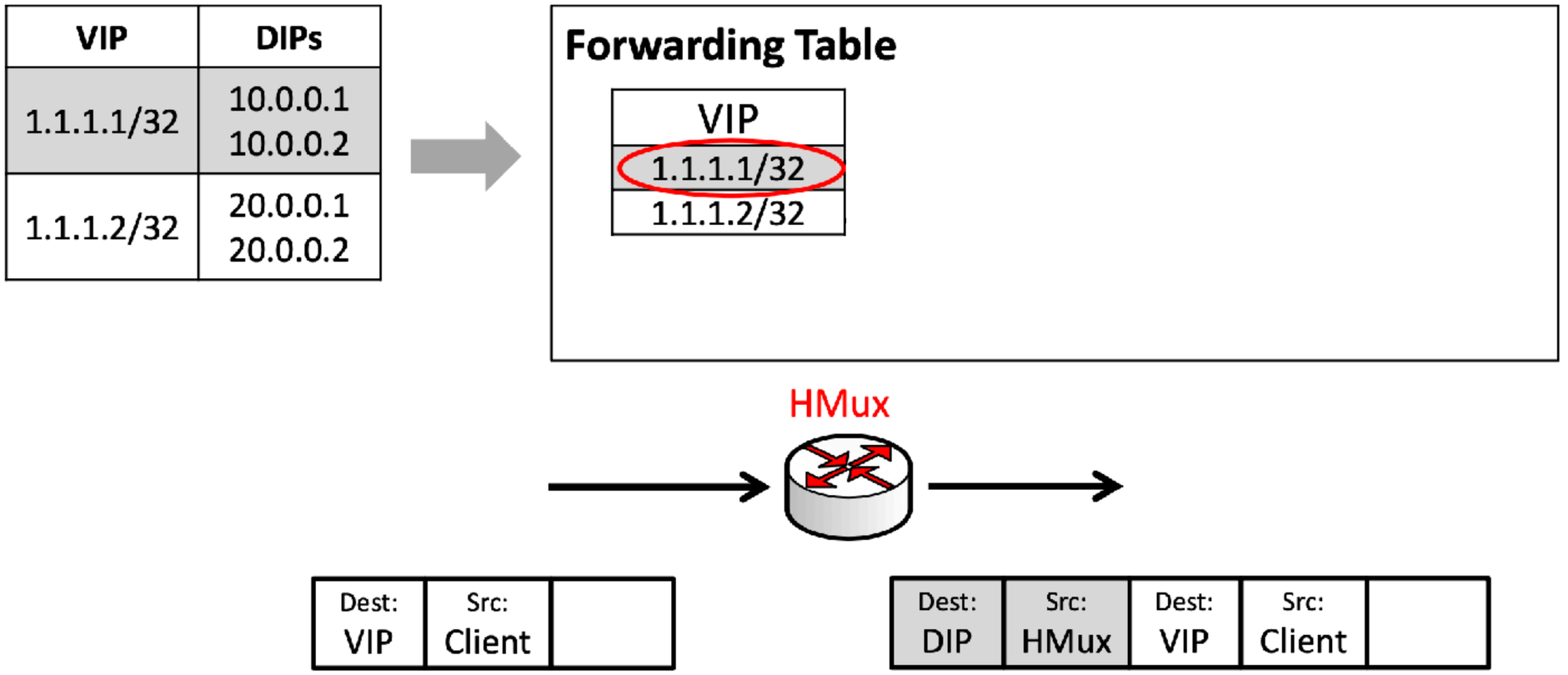
- Technique #1: chained table execution

VIP	DIPs
1.1.1.1/32	10.0.0.1 10.0.0.2
1.1.1.2/32	20.0.0.1 20.0.0.2



HW Mux Design

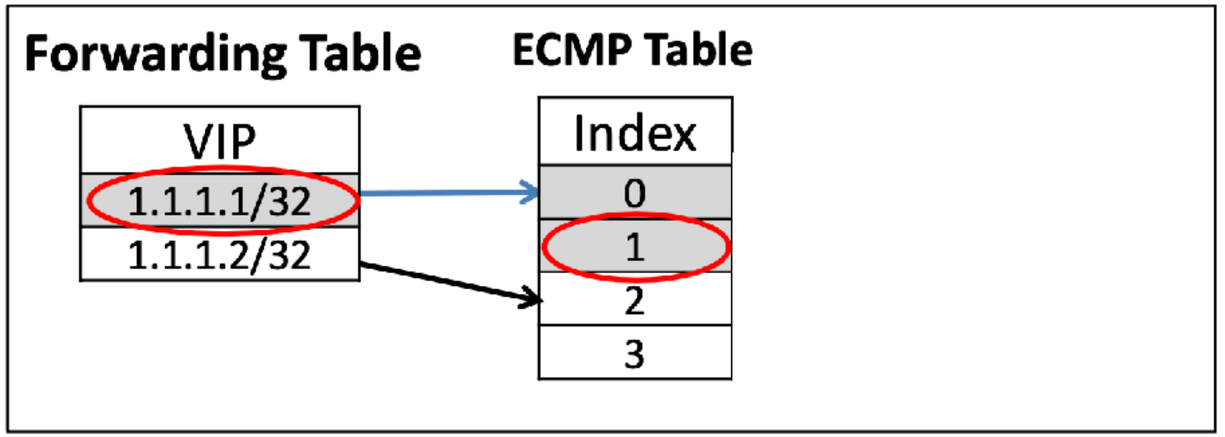
- Technique #1: chained table execution

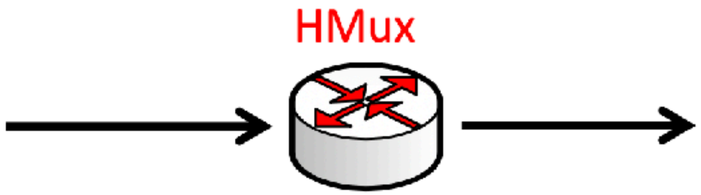


HW Mux Design

- Technique #1: chained table execution

VIP	DIPs
1.1.1.1/32	10.0.0.1 10.0.0.2
1.1.1.2/32	20.0.0.1 20.0.0.2

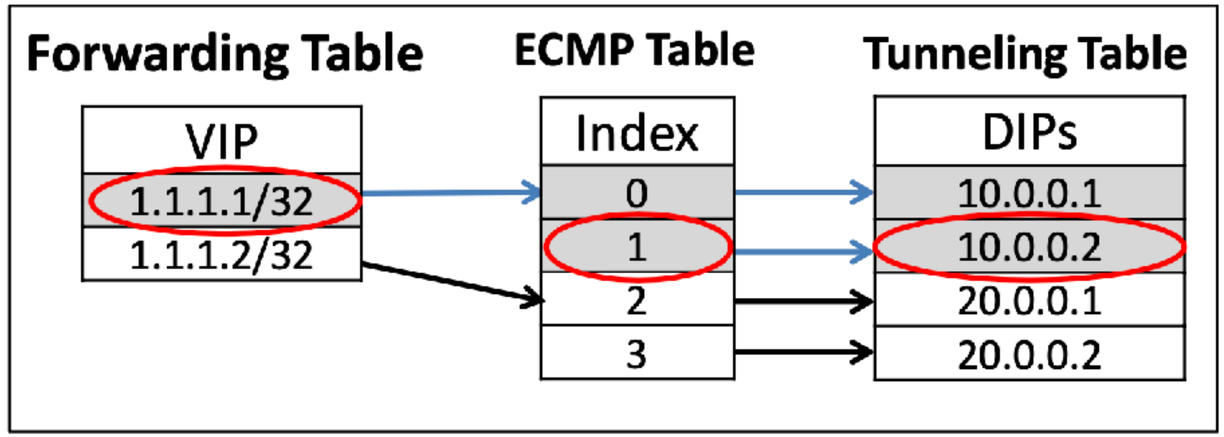




HW Mux Design

- Technique #1: chained table execution

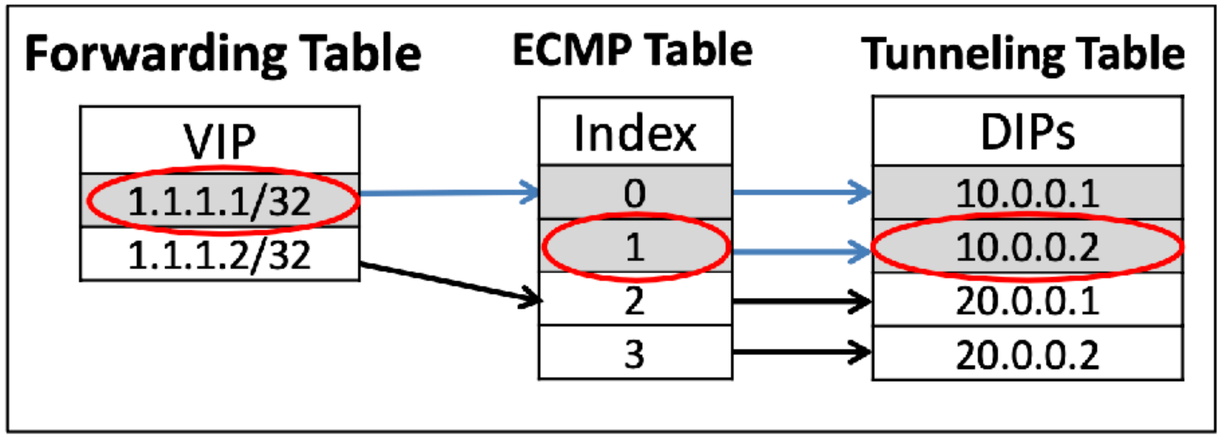
VIP	DIPs
1.1.1.1/32	10.0.0.1 10.0.0.2
1.1.1.2/32	20.0.0.1 20.0.0.2



HW Mux Design

- Technique #1: chained table execution

VIP	DIPs
1.1.1.1/32	10.0.0.1 10.0.0.2
1.1.1.2/32	20.0.0.1 20.0.0.2



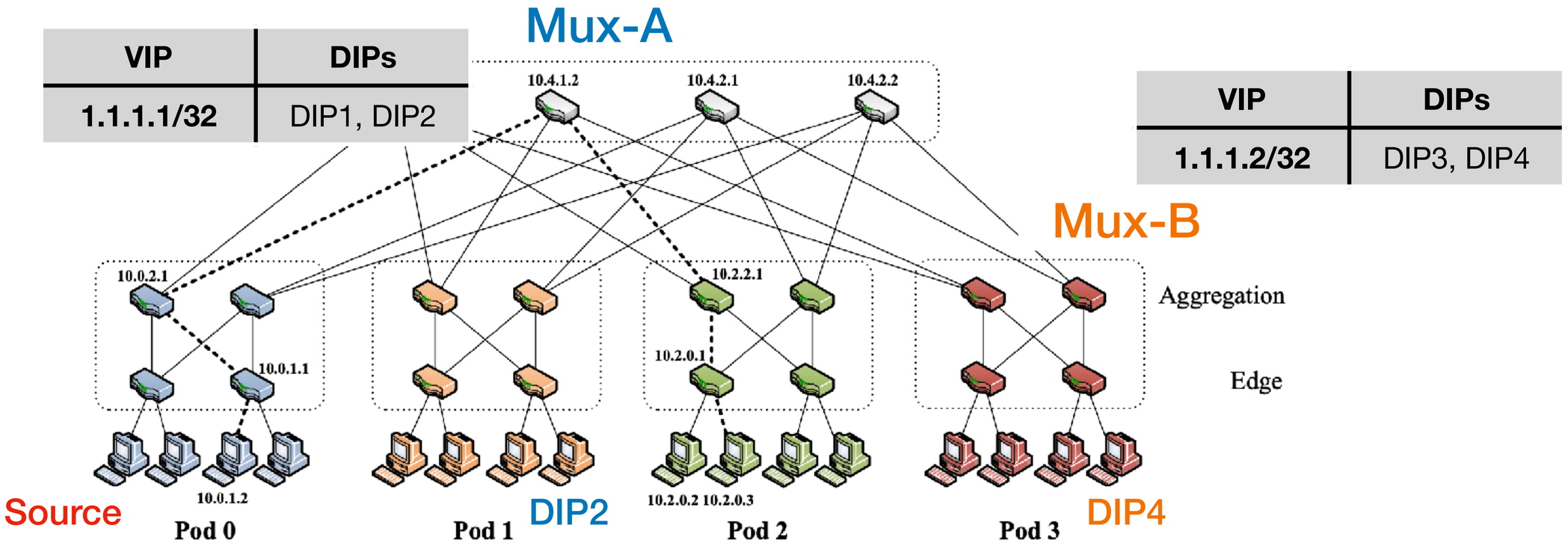
But a switch has limited table entries!

- **16K in the forwarding table**
- **512 in the tunneling table**

How can we solve it?

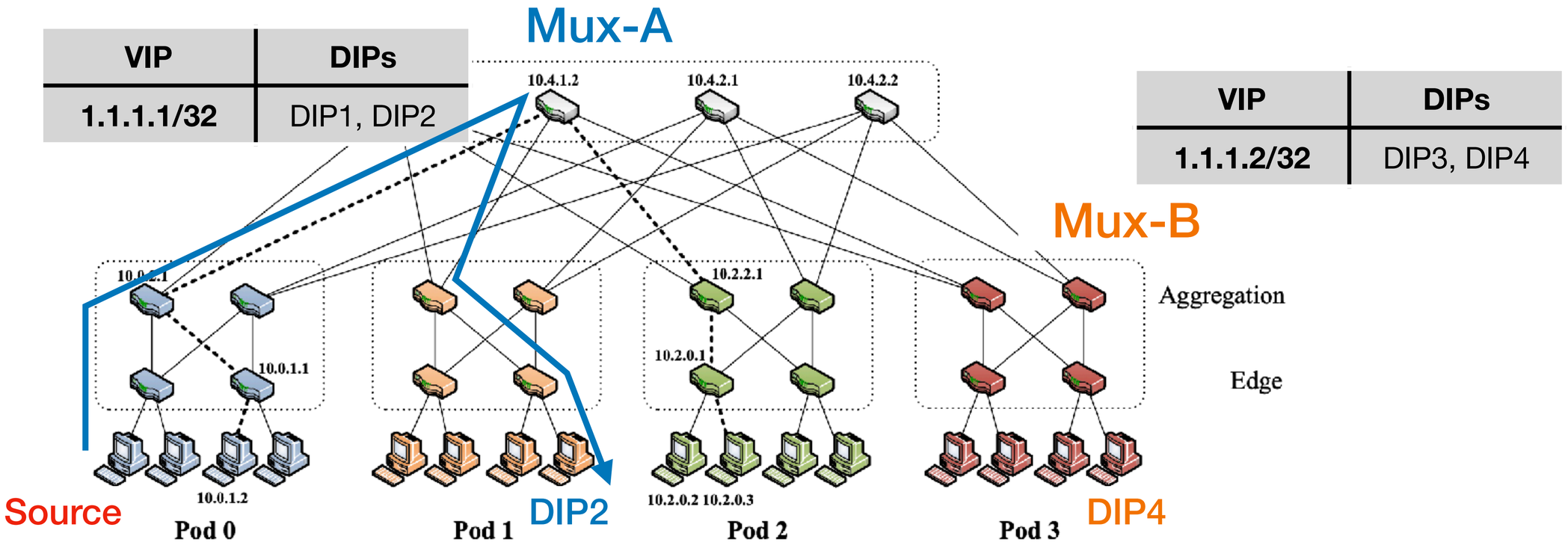
Technique #2: VIP Partition

- Divide VIP-to-DIP mapping across multiple switches



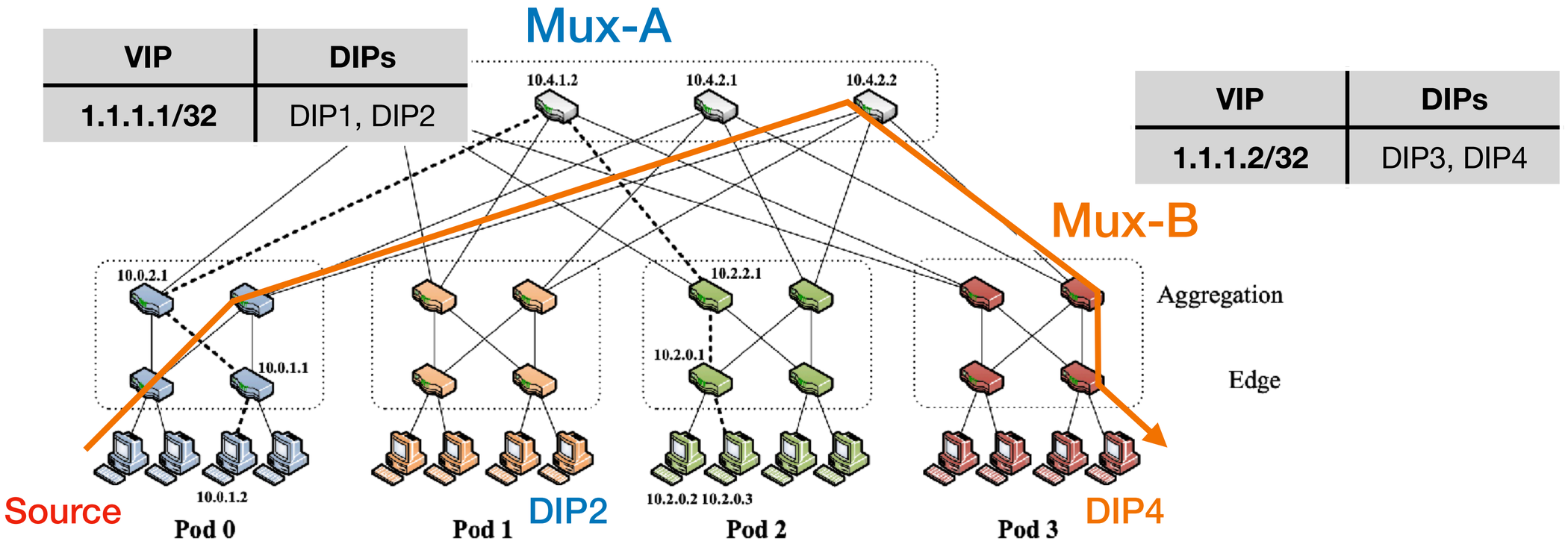
Technique #2: VIP Partition

- Divide VIP-to-DIP mapping across multiple switches



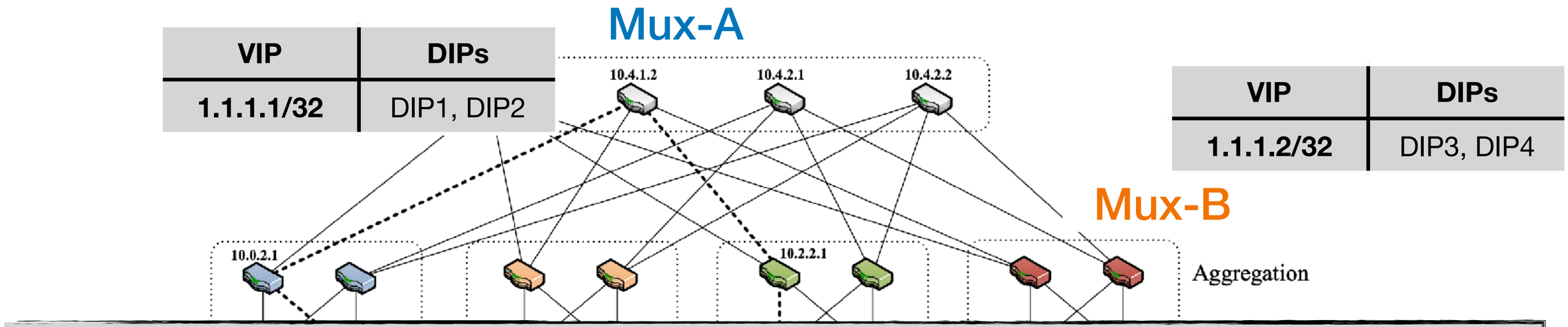
Technique #2: VIP Partition

- Divide VIP-to-DIP mapping across multiple switches



Technique #2: VIP Partition

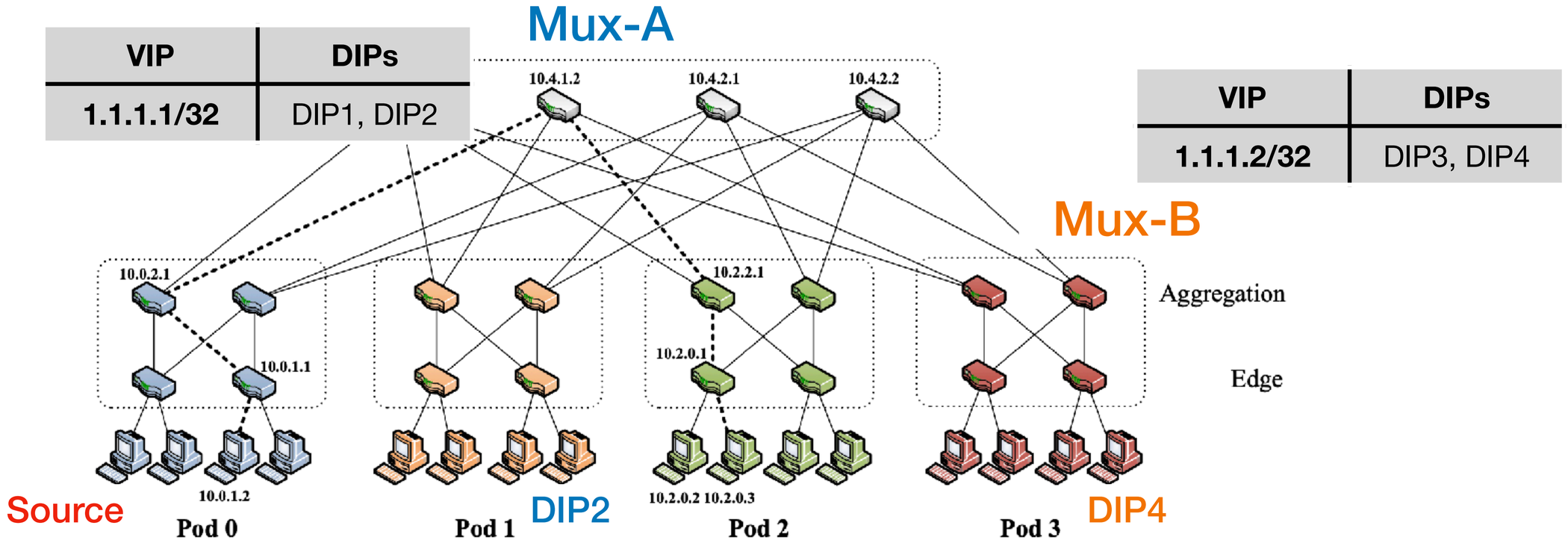
- Divide VIP-to-DIP mapping across multiple switches



But what happens if none of the on-path switches have this table entry?

Technique #2: VIP Partition

- Divide VIP-to-DIP mapping across multiple switches
- BGP announcement

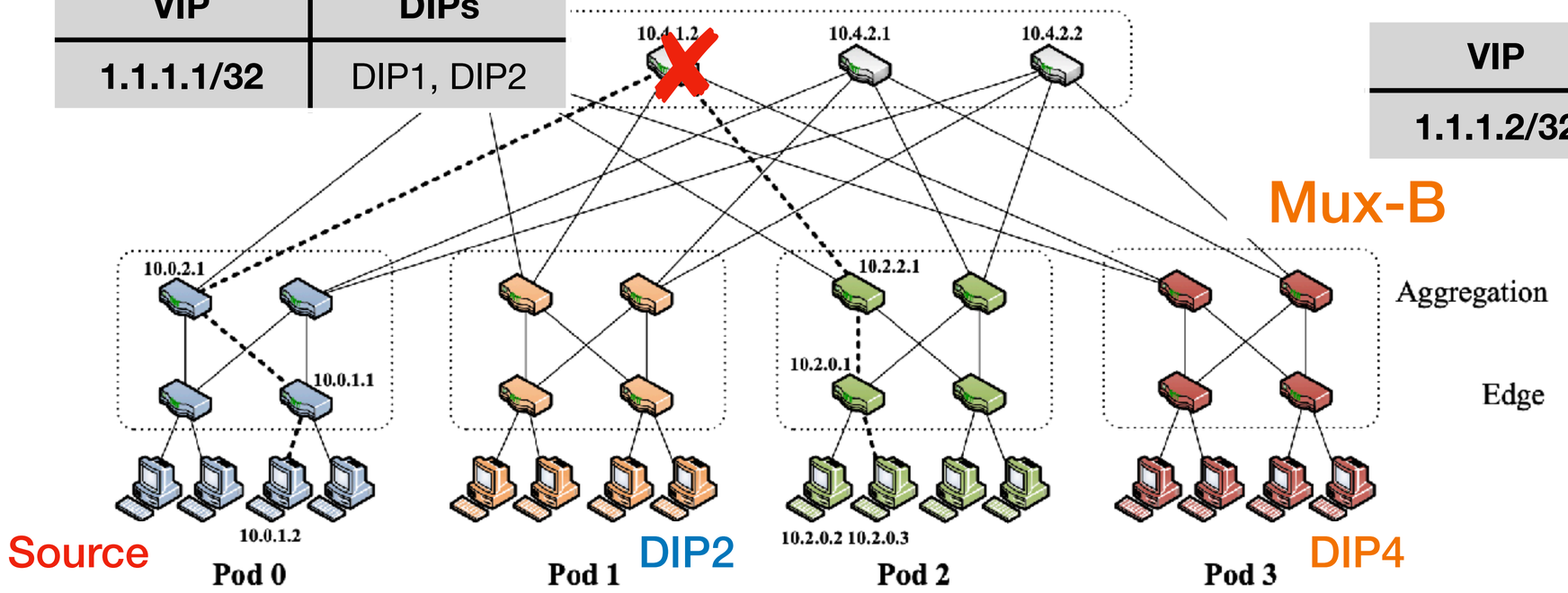


Seems problem solved?

What happens if Mux-A fails

VIP	DIPs
1.1.1.1/32	DIP1, DIP2

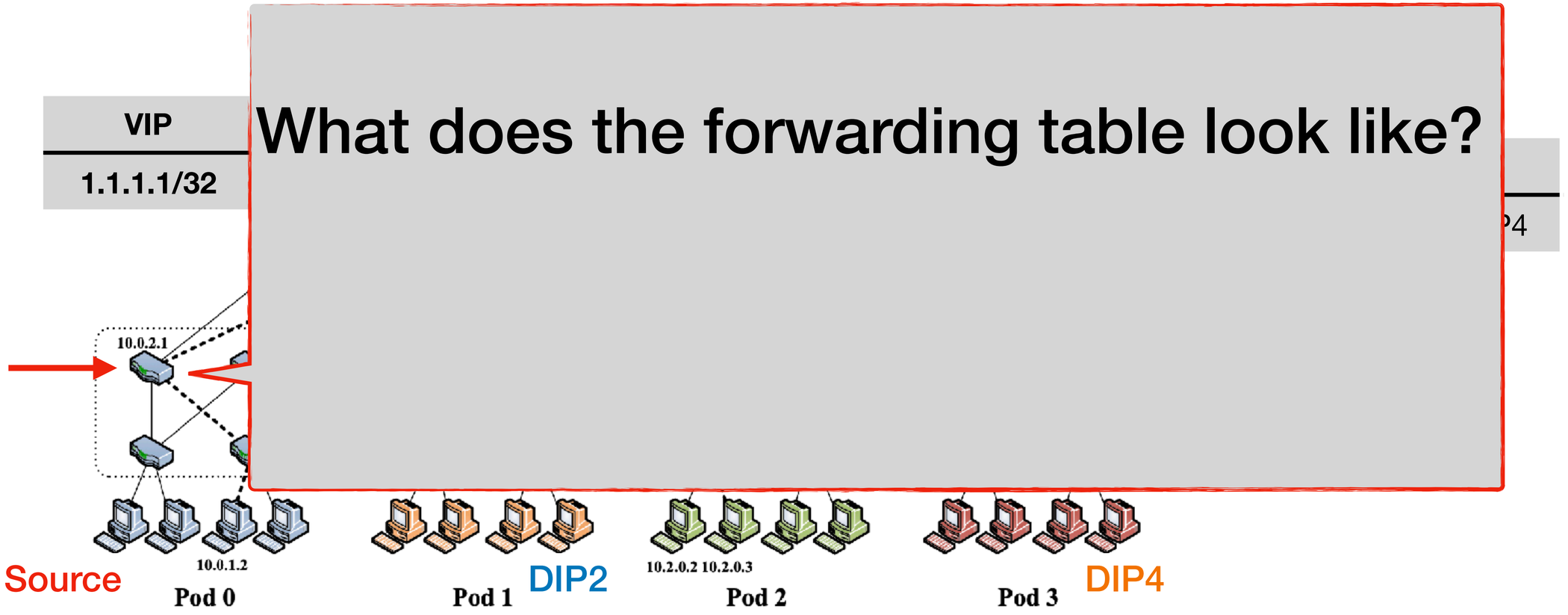
Mux-A



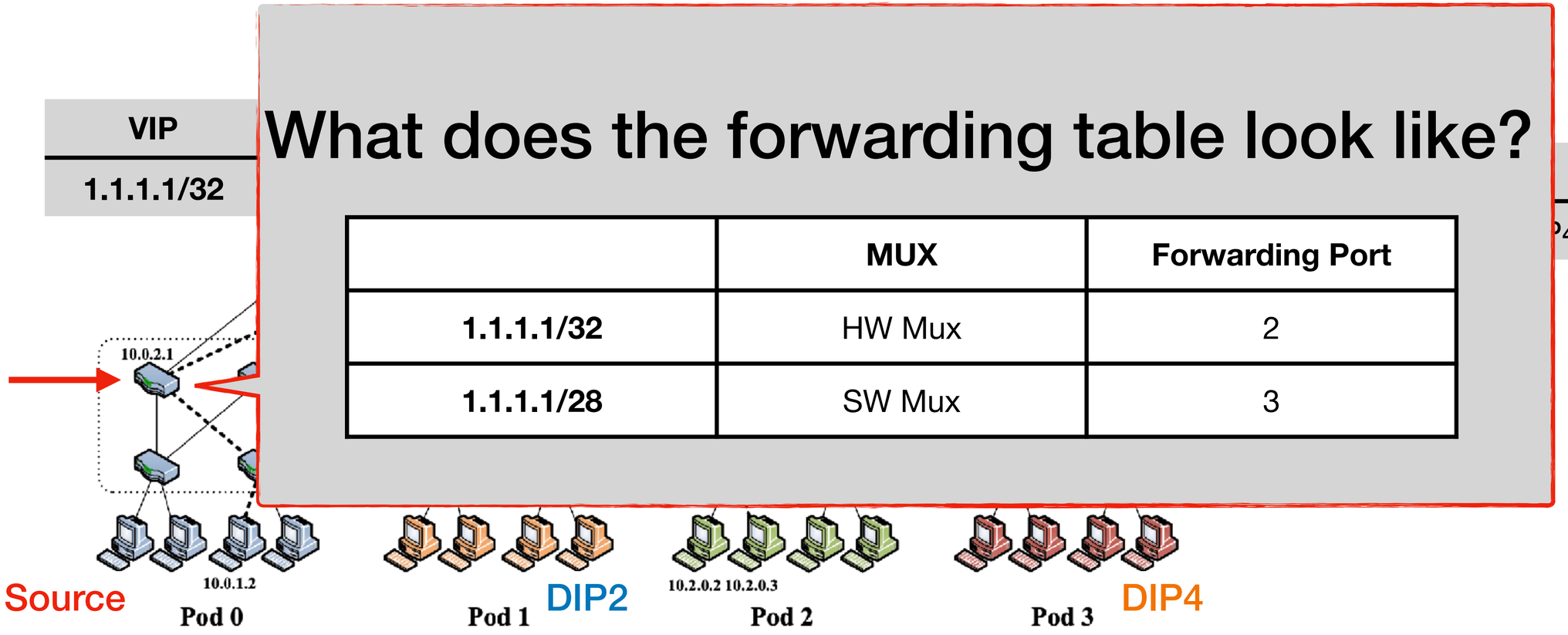
VIP	DIPs
1.1.1.2/32	DIP3, DIP4

Mux-B

What happens if Mux-A fails

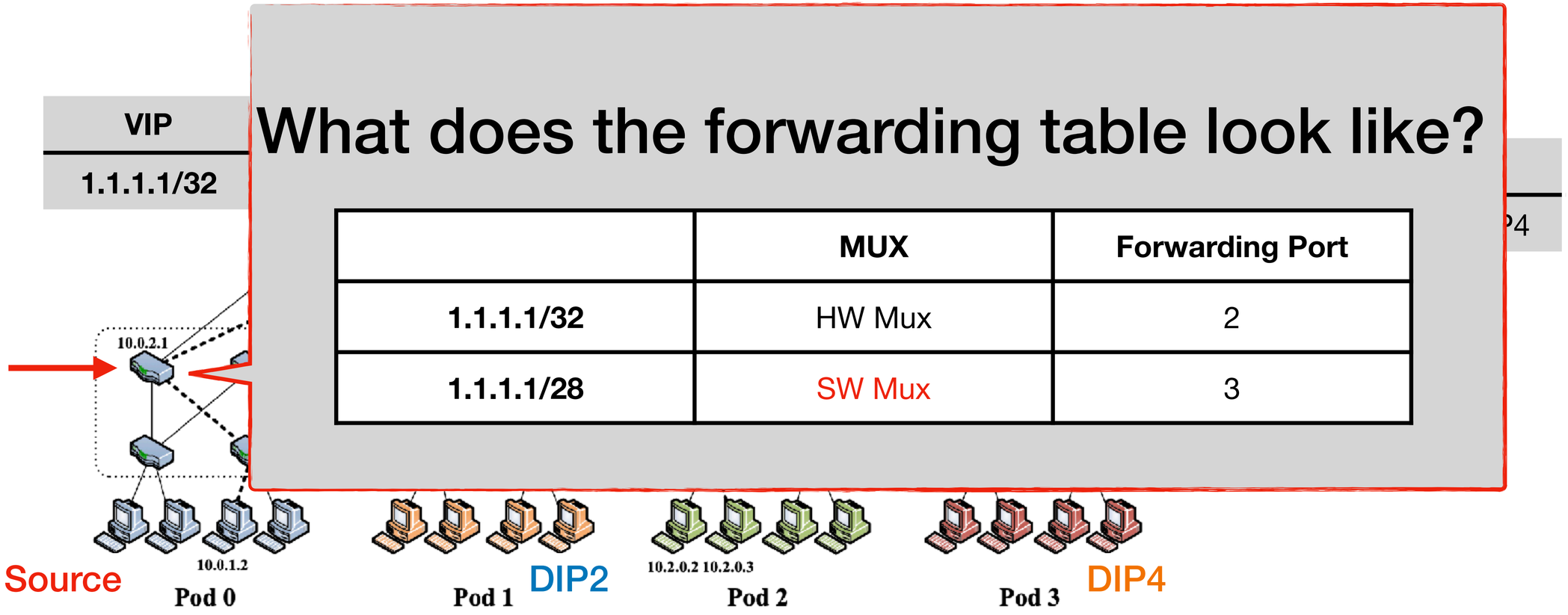


What happens if Mux-A fails



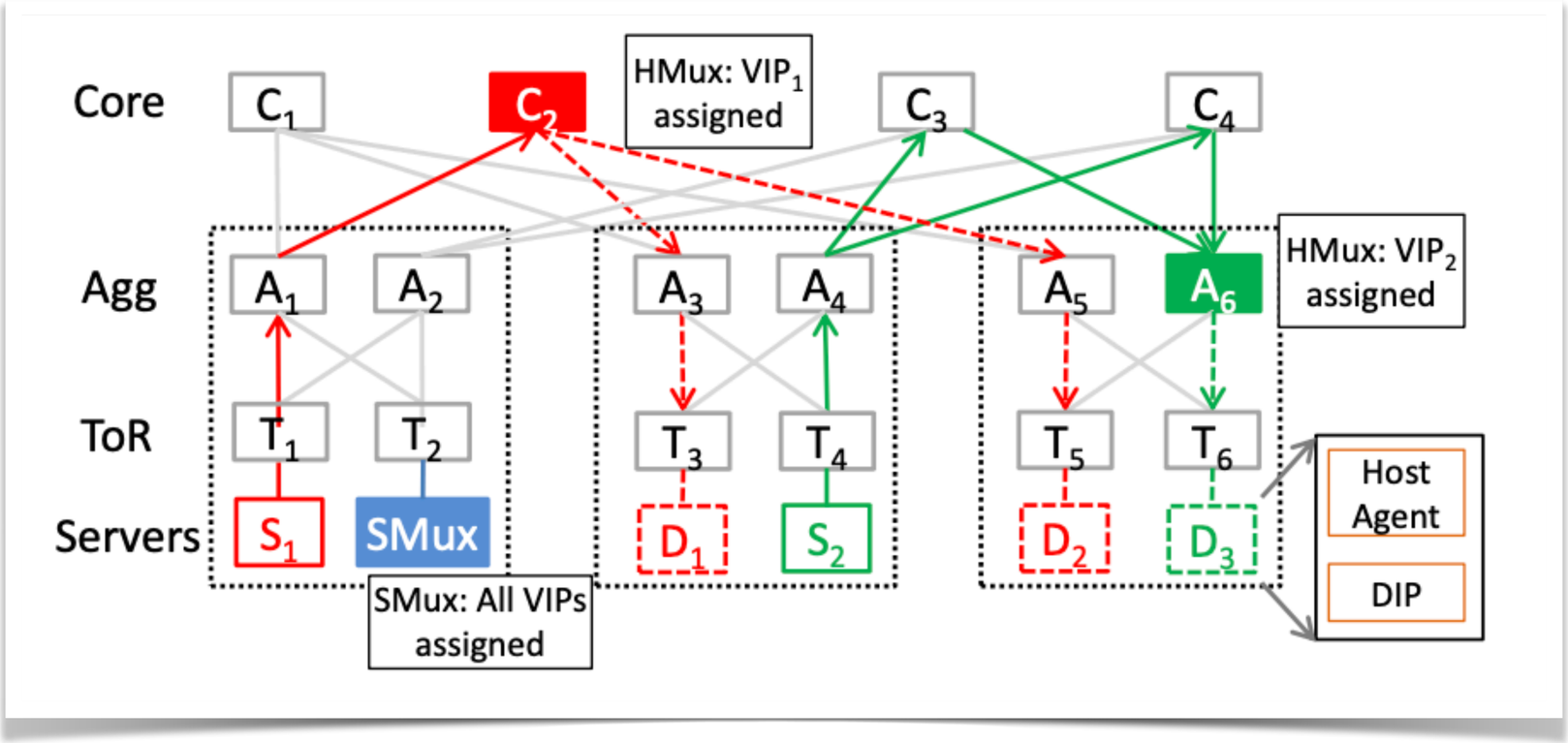
What happens if Mux-A fails

- Use LPM to make the decision



Duet: HW Mux + SW Mux (Technique #3)

- HW: commodity switch => Primary
- SW: x86 server box => Secondary



Are we done?

What is Duet fundamentally?

What is Duet fundamentally?

Load balancer!

What is Duet fundamentally?

Load balancer!

How does Duet balance the traffic load?

What is Duet fundamentally?

Load balancer!

How does Duet balance the traffic load?

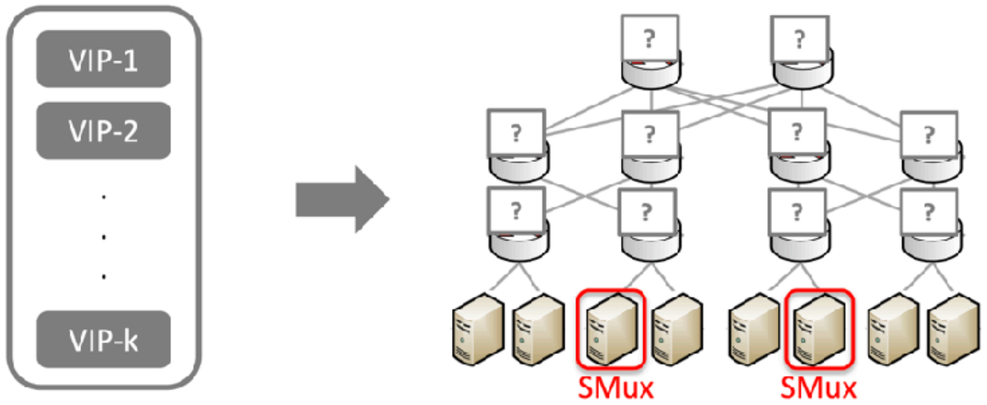
Technique #4: A Greedy VIP Assignment Algorithm

- Problem formulation: multi-dimensional bin-packing problem
  - Resources: switch memory and link bandwidth
  - Objects: VIPs
- Goal: find the VIP-switch assignment maximizing VIP traffic load
  - Maximum resource utilization (MRU)
- Constraints
  - Any VIP-switch assignment should not exceed the capacity of a link
  - Any VIP-switch assignment should not exceed the switch memory size

Algorithm Details

- Sketch: walk through VIPs and maximize MRU
  - MRU can be accumulated

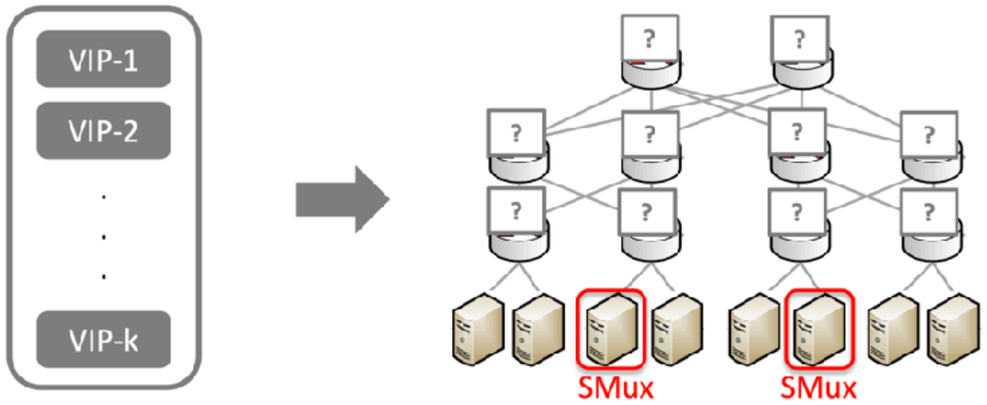
Notation	Explanation
V	Set of VIPs
d_v	Set of DIPs for the v-th VIP
S, E	Set of switches and links respectively
R	Set of resources (switches and links)
C_i	Capacity of i-th resource
$t_{i,s,v}$	v-th VIP's traffic on i-th link, when it is assigned to s-th switch
$L_{i,s,v}$	load (additional utilization) on i-th resource if v-th VIP is assigned to s-th switch
$U_{i,s,v}$	Cumulative utilization of i-th resource if v-th VIP is assigned to s-th switch
$U_{i,v}$	Cumulative utilization of i-th resource after v VIPs have been assigned
$MRU_{s,v}$	Max. Resource Utilization (MRU) after v-th VIP is assigned to s-th switch



Algorithm Details

- Sketch: walk through VIPs and maximize MRU
  - MRU can be accumulated

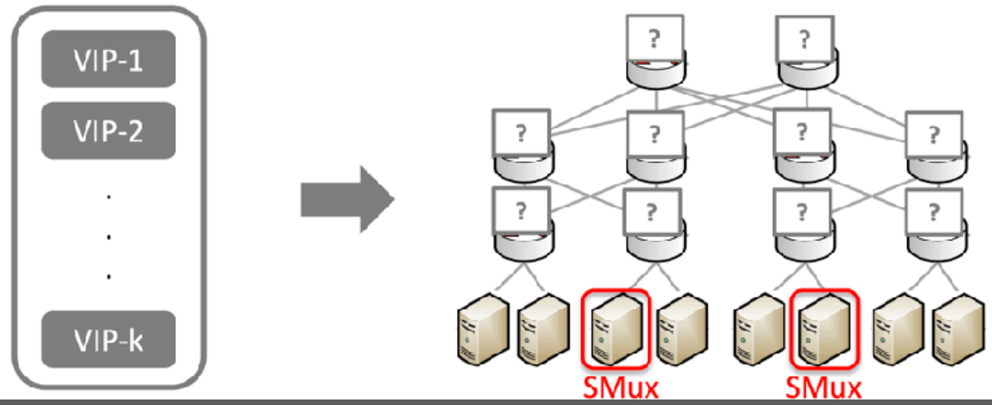
Notation	Explanation
V	Set of VIPs
d_v	Set of DIPs for the v-th VIP
S, E	Set of switches and links respectively
R	Set of resources (switches and links)
C_i	Capacity of i-th resource
$t_{i,s,v}$	v-th VIP's traffic on i-th link, when it is assigned to s-th switch
$L_{i,s,v}$	load (additional utilization) on i-th resource if v-th VIP is assigned to s-th switch
$U_{i,s,v}$	Cumulative utilization of i-th resource if v-th VIP is assigned to s-th switch
$U_{i,v}$	Cumulative utilization of i-th resource after v VIPs have been assigned
$MRU_{s,v}$	Max. Resource Utilization (MRU) after v-th VIP is assigned to s-th switch



Algorithm Details

- Sketch: walk through VIPs and maximize MRU
  - MRU can be accumulated

Notation	Explanation
V	Set of VIPs
d_v	Set of DIPs for the v-th VIP
S, E	Set of switches and links respectively
R	Set of resources (switches and links)
C_i	Capacity of i-th resource
$t_{i,s,v}$	v-th VIP's traffic on i-th link, when it is assigned to s-th switch
$L_{i,s,v}$	load (additional utilization) on i-th resource if v-th VIP is assigned to s-th switch
$U_{i,s,v}$	Cumulative utilization of i-th resource if v-th VIP is assigned to s-th switch
$U_{i,v}$	Cumulative utilization of i-th resource



How do we know this?

Technique #5:

- Rerun the algorithm periodically
  - Perform VIP-DIP migraiton

Technique #5: VIP Migration

- Rerun the algorithm periodically
  - Perform VIP-DIP migraiton

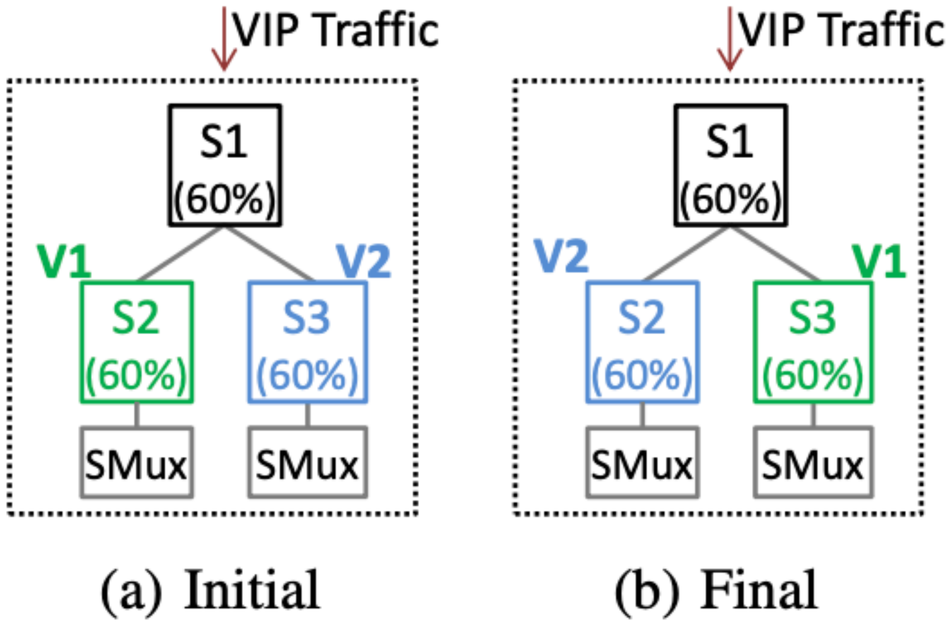
- How to minimize VM reshuffling?
- How to ensure correctness after migration?

Technique #5: VIP Migration

- Rerun the algorithm periodically
  - Perform VIP-DIP migraiton
- Non-sticky; make-before-break
  - Announce the VIP assignment before withdrawing from the old one

Technique #5: VIP Migration

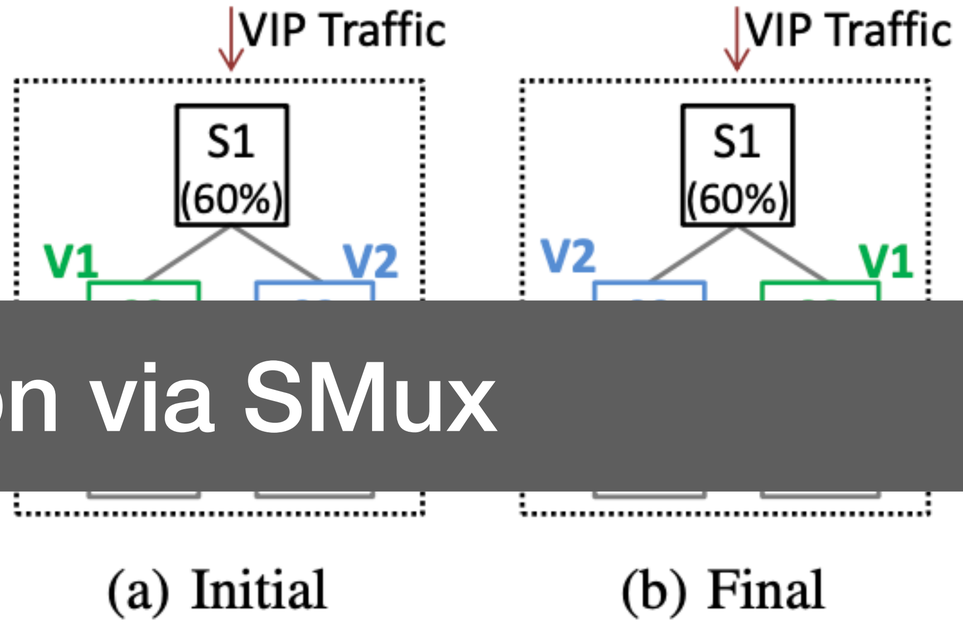
- Rerun the algorithm periodically
  - Perform VIP-DIP migraiton
- Non-sticky; make-before-break
  - Announce the VIP assignment before withdrawing from the old one
- Issues:
  - Memory deadlock
  - Reshuffling is heavy



(a) Initial (b) Final

Technique #5: VIP Migration

- Rerun the algorithm periodically
  - Perform VIP-DIP migraiton
- Non-sticky; make-before-break
  - Announce the VIP assignment before withdrawing from the old one
- Issues:
  - Memory deadlock
  - Reshuffling is heavy

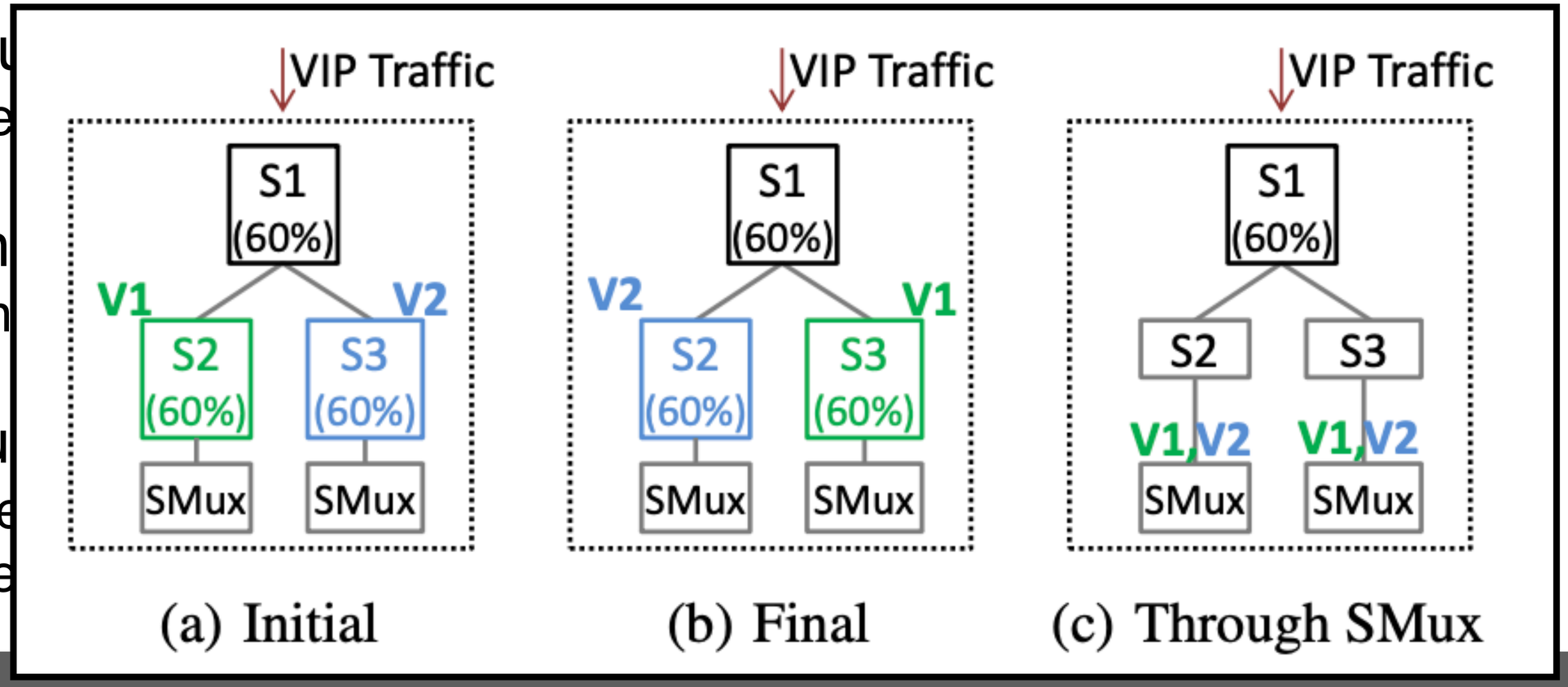


(a) Initial (b) Final

Migration via SMux

Technique #5: VIP Migration

- Reru
  - Pe
- Non
  - An
- Issu
  - Me
  - Re



Migration via SMux

(a) Initial (b) Final

Combine Everything Together

- Technique #1: chained table execution in HMux
- Technique #2: VIP partition over multiple HMuxes
- Technique #3: SMux as a backup
- Technique #4: Greedy VIP assignment
- Technique #5: VIP migration

Summary

- Today
  - Load balancing in data center networks (II)

- Next week: host network virtualization
  - Andromeda (NSDI'18)
  - PicNIC (SIGCOMM'19)