Balancing on the edge

Transport affinity without network state

NSDI 2018 | João Taveira Araújo, Lorenzo Saino, Raul Landa and Lennert Buytenhek

fastly®

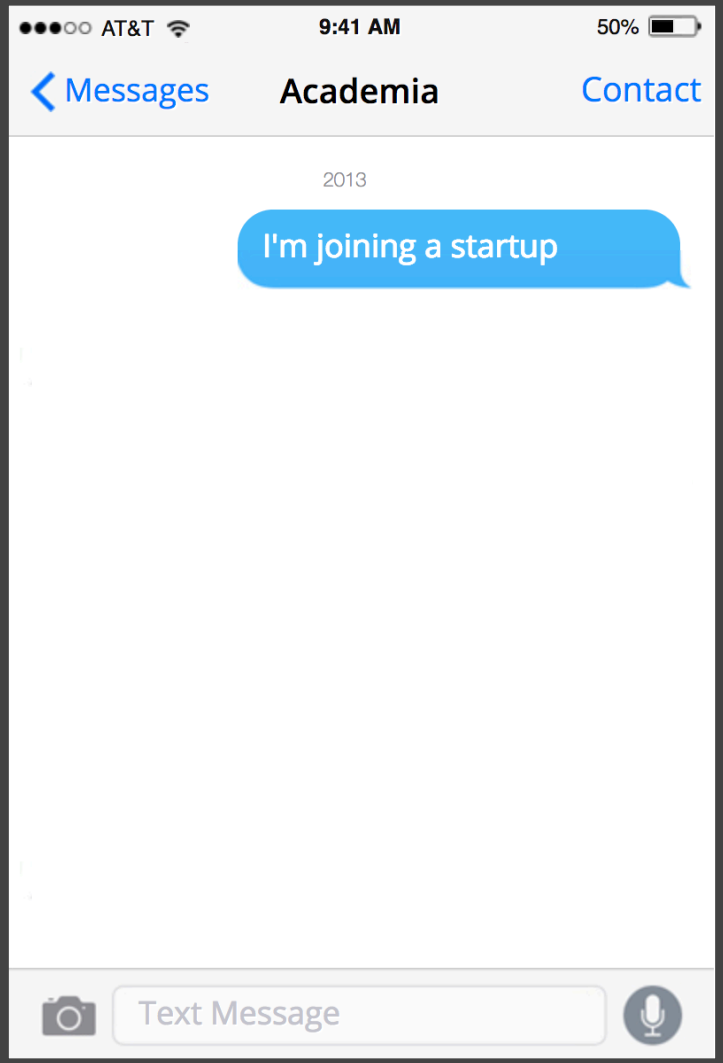
this is the last slide (sort of)

Faild decomposes load balancing as a division of labour

- leverage hardware wherever possible - **no latency cost in expected case**
- push functions requiring state towards hosts - **low latency overhead in worst case**
- efficient, stateless, while ensuring graceful completion of flows
- in production at Fastly since 2013

Read paper if you have an interest in transport protocols, Internet architecture

the problem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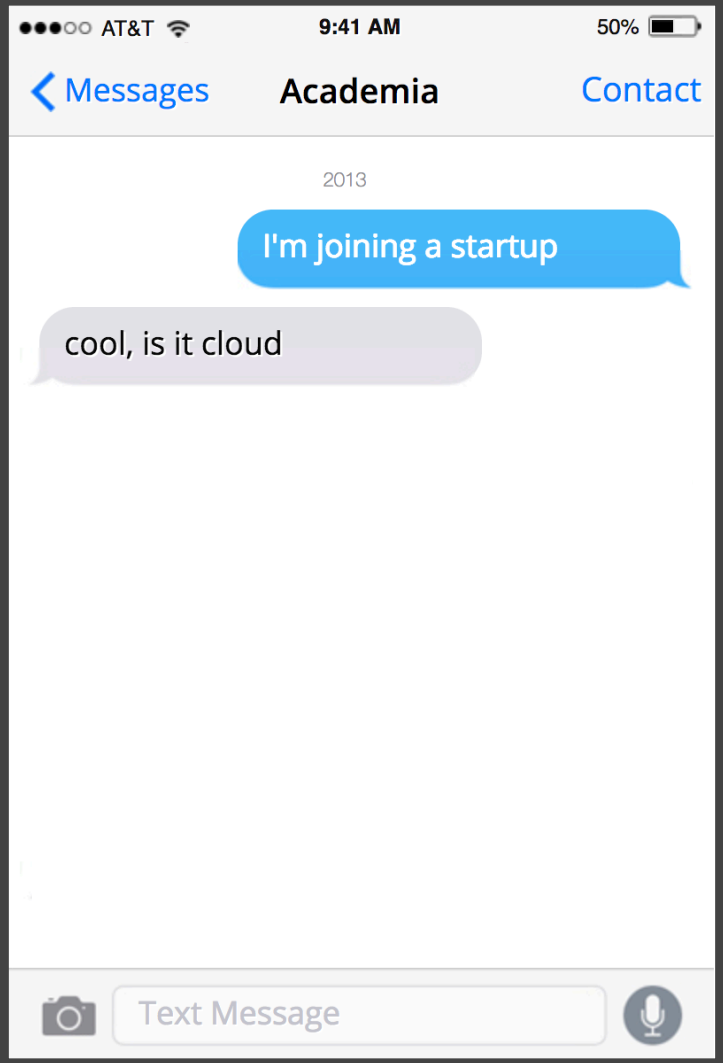
Messages
Academia
Contact
2013
I'm joining a startup
Text Message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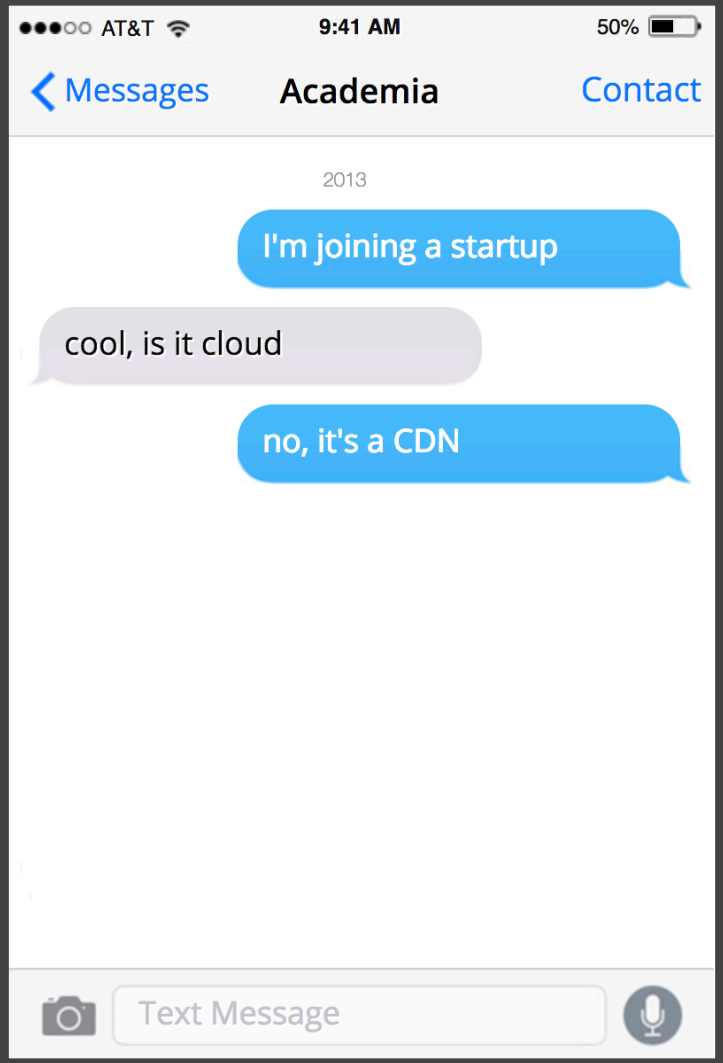
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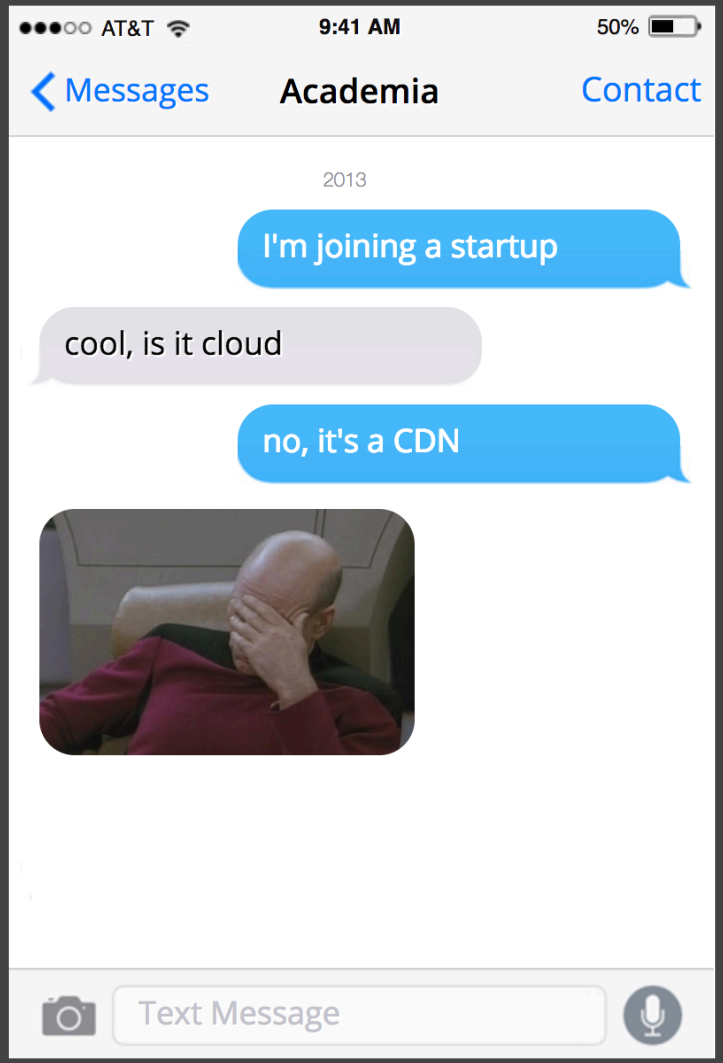
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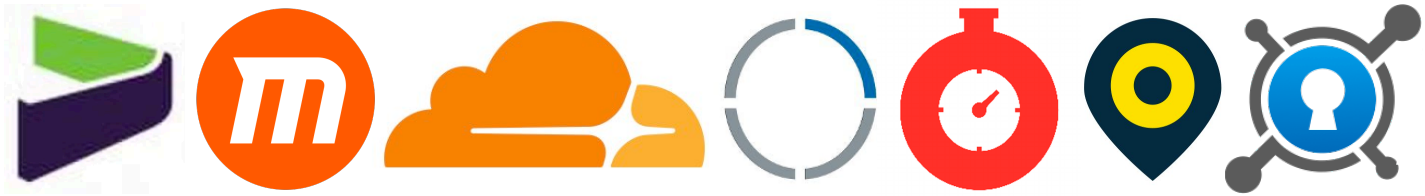
CDN is a solved problem, vendor X already exists
Text Message

2009 ~ 2012



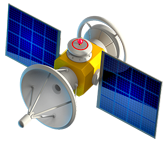
market

- incumbents addressed shrinking use case: large static assets
- a lot of suppressed demand

cost of entry

- maturity of open source reverse proxies (nginx, varnish)
- network topology flattened and bandwidth costs dropped

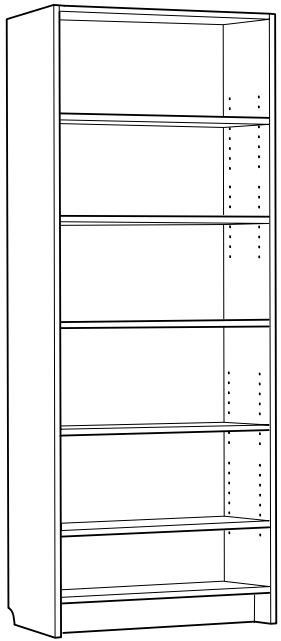
technology



- SSD, multicore, 10Gbps NICs
- network programmability

start over

PÖP *(point of presence)*



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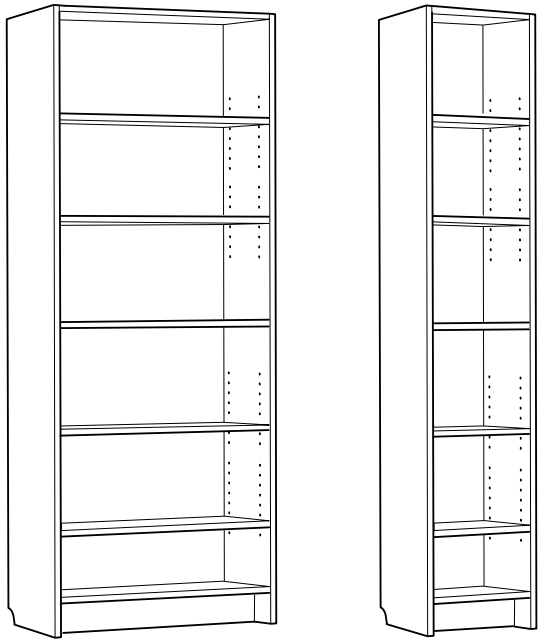

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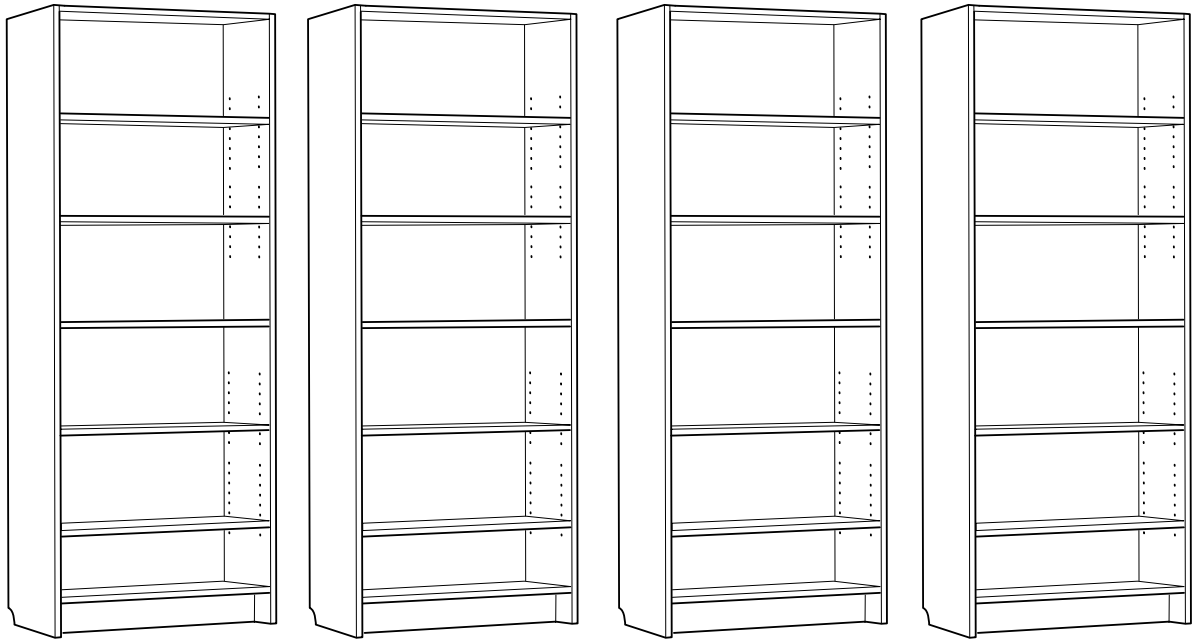

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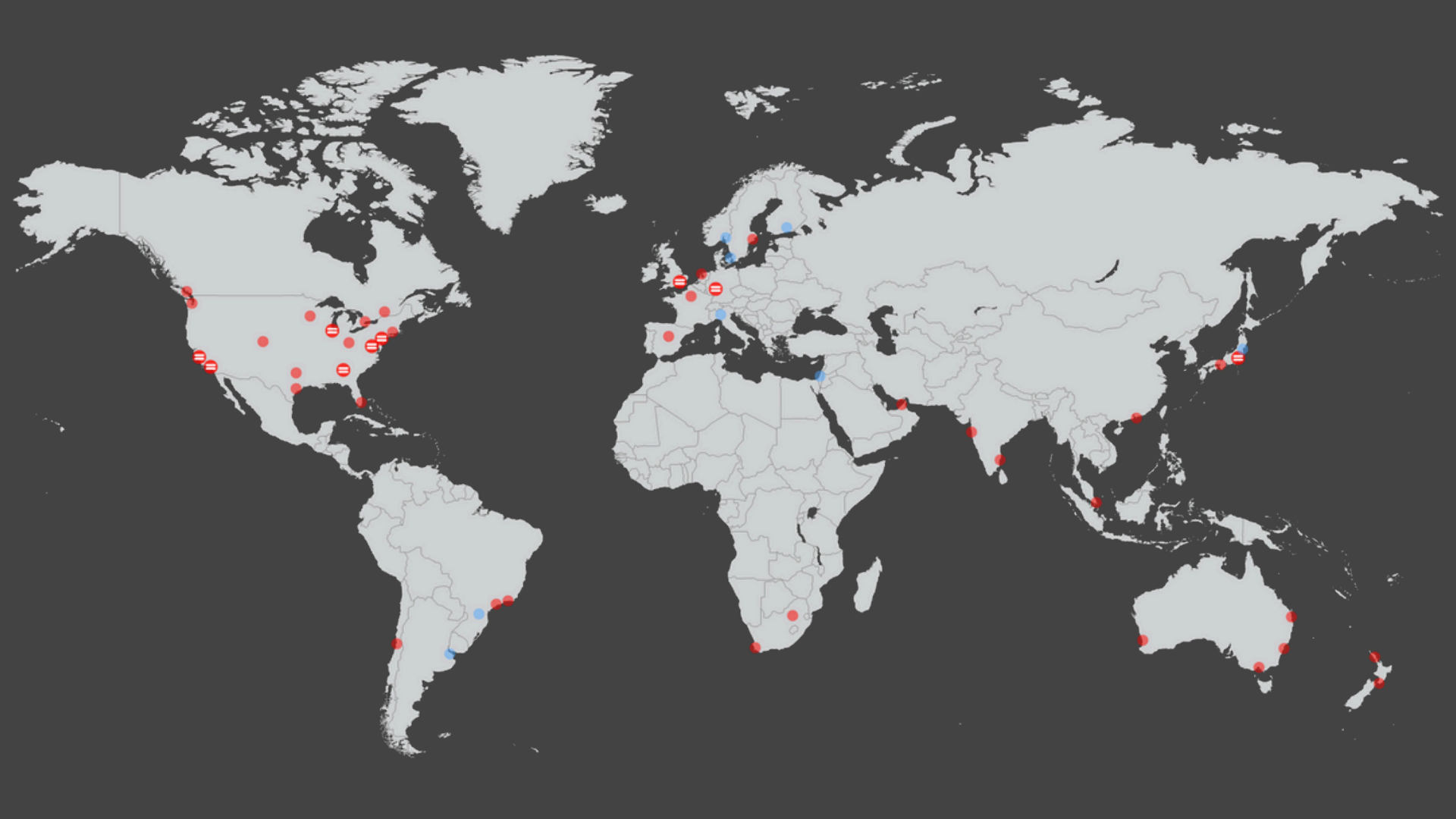
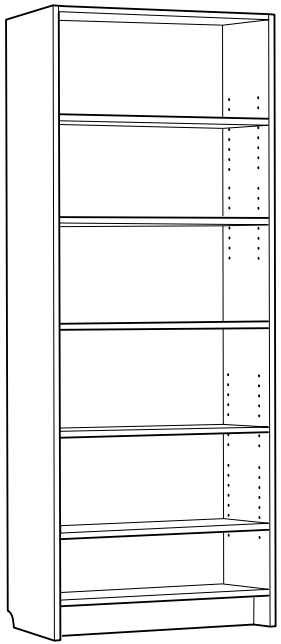
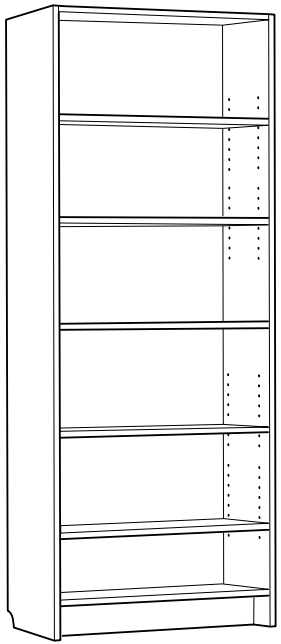




RÅCK



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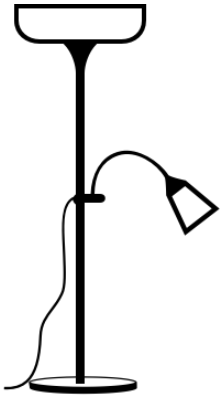
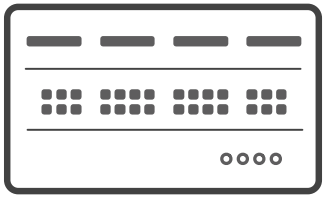
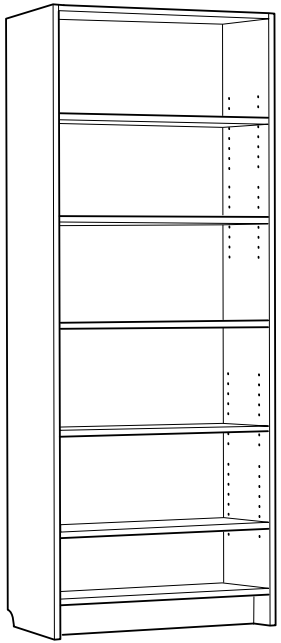




Requirements



- maximize RPS
- low latency
- absorb DDOS attacks
- no single points of failure
- no service disruption on maintenance

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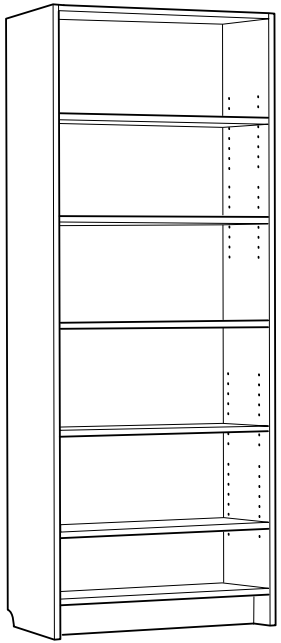

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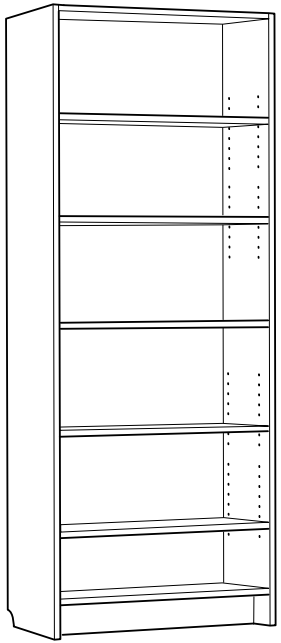

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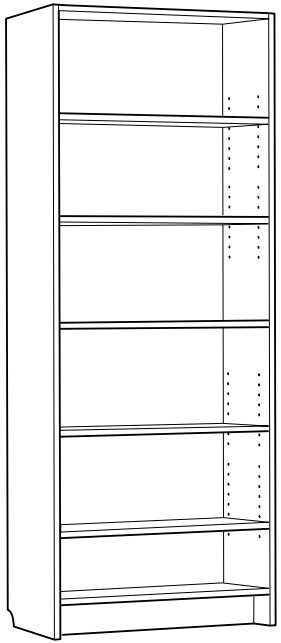
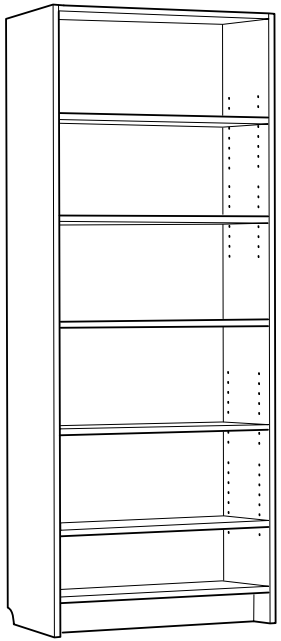
Problem statement



Given fixed physical footprint, how do you design a load balancing architecture which is **efficient**, **resilient** and **graceful**?

the topology

Guidelines



maximize number of hosts

need switches for connecting to upstreams

avoid dedicated network hardware:

- unneeded features (routers)
- load balancer appliances
- multiple switch tiers

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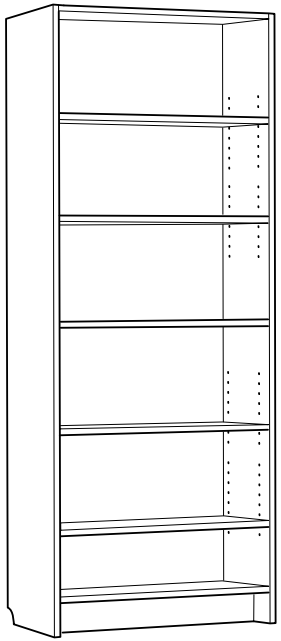

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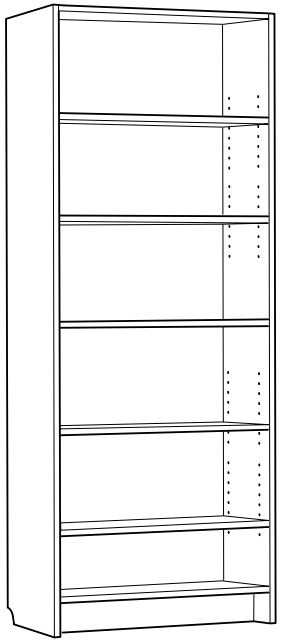

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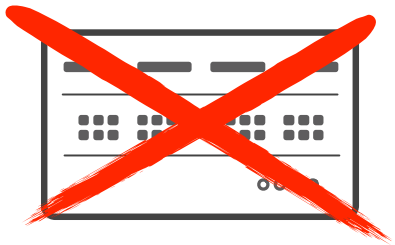

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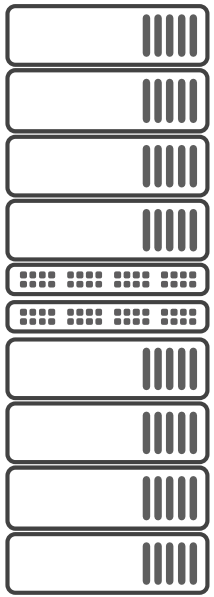
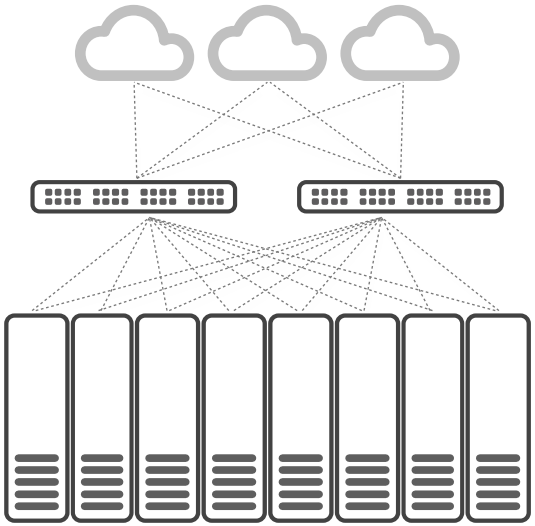
POP topology



POP topology



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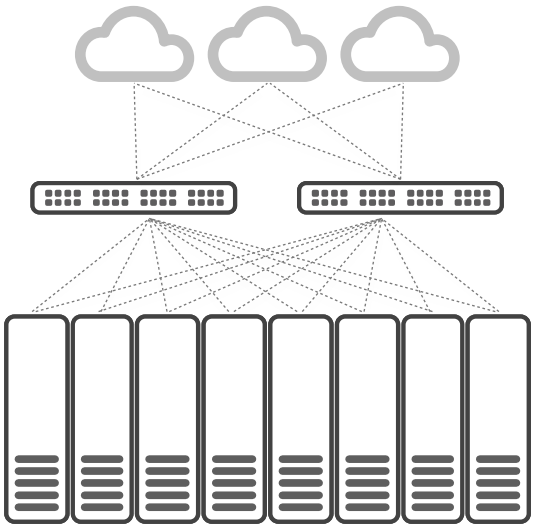
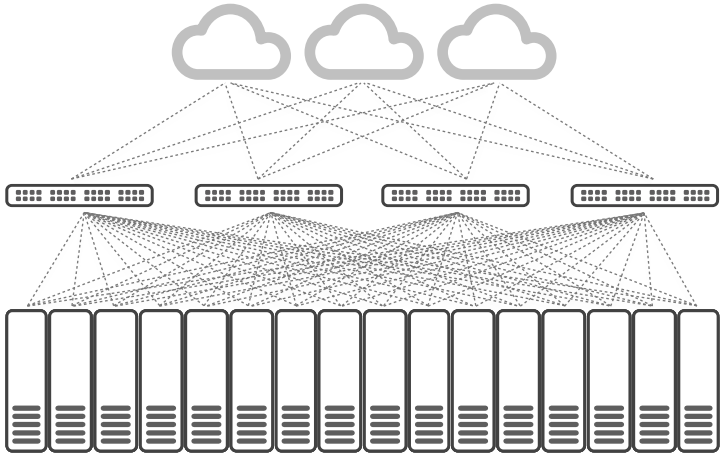


Hosts	Racks	Bandwidth* (Gbps)	RPS (millions)	Storage (TB)
8	0.5	200	0.32	768

***** notional host bandwidth on fabric accounting for loss of one switch

POP topology



Hosts	Racks	Bandwidth* (Gbps)	RPS (millions)	Storage (TB)
8	0.5	200	0.32	768
16	1	1200	0.64	1536

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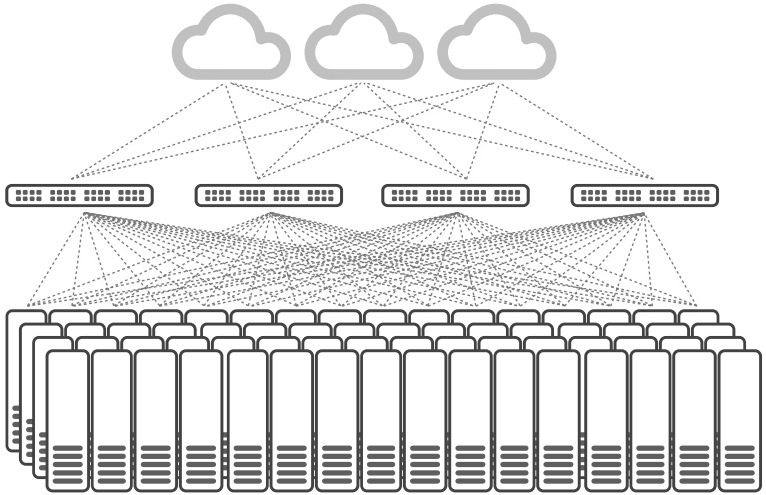
POP topology



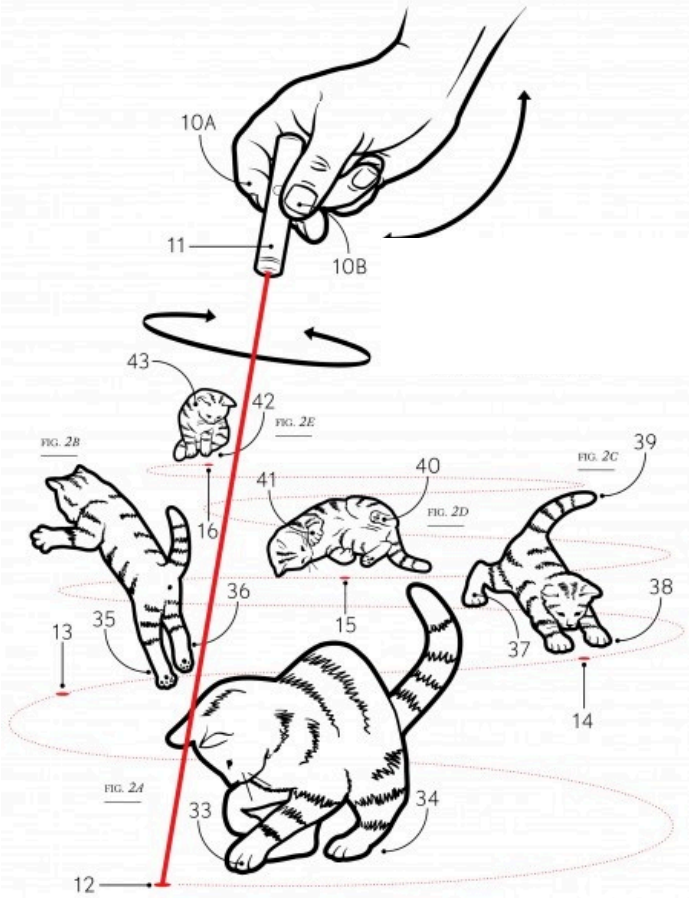
Hosts	Racks	Bandwidth* (Gbps)	RPS (millions)	Storage (TB)
8	0.5	200	0.32	768
16	1	1200	0.64	1536
32	2	2400	1.28	3072
64	4	4800	2.56	6144

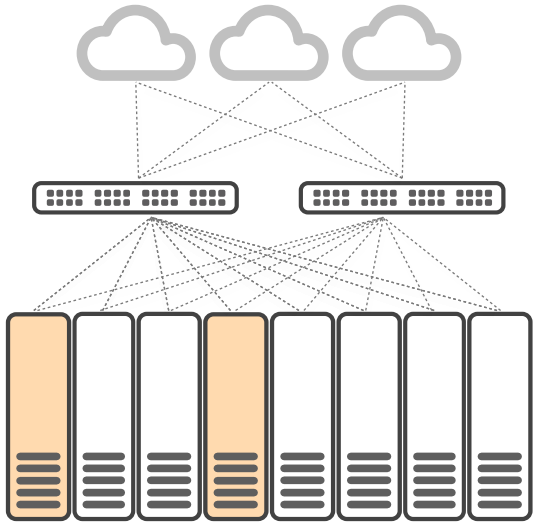
***** notional host bandwidth on fabric accounting for loss of one switch

load balancing

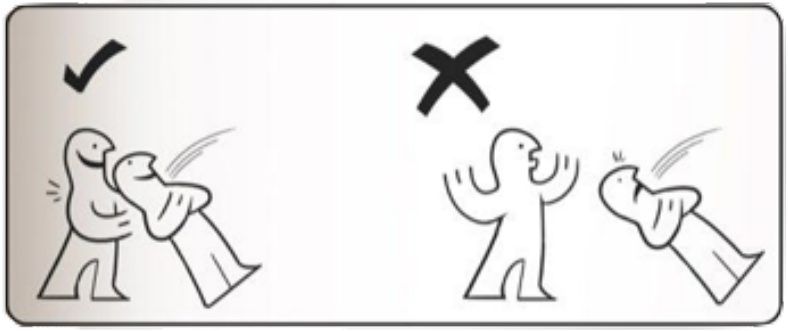
anything that maintains state is easy to DDOS

- load balancer appliances
- Ananta [SIGCOMM'13]
- Duet [SIGCOMM'14]
- MagLev [NSDI'16]
- SilkRoad [SIGCOMM'17]





software-only load balancers can’t make use of full bisection bandwidth

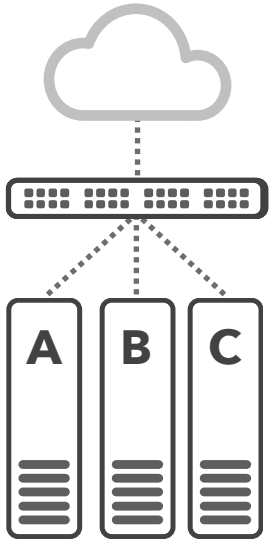


stateless solutions are not graceful

- many switch ECMP implementations result in rehashing
- even ones that don’t will break ongoing connections

faild

Faild



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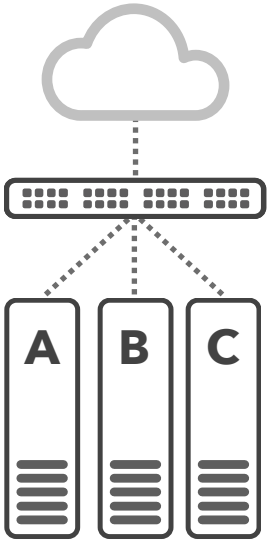
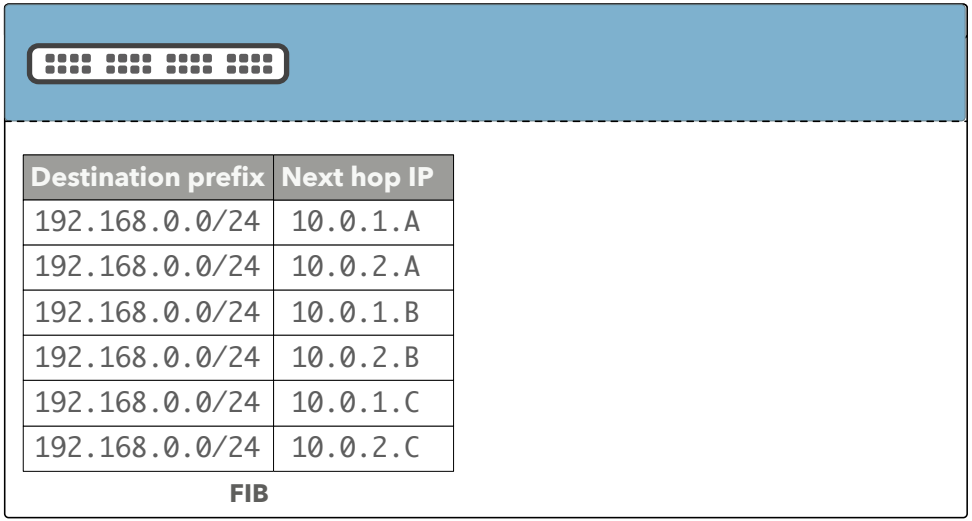




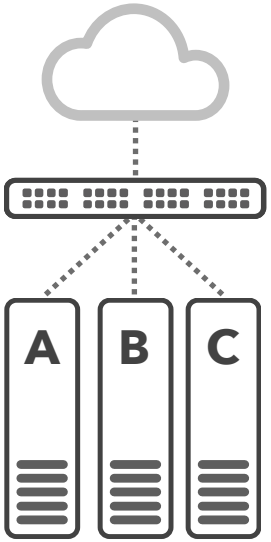
Destination prefix	Next hop IP
192.168.0.0/24	10.0.1.A
192.168.0.0/24	10.0.2.A
192.168.0.0/24	10.0.1.B
192.168.0.0/24	10.0.2.B
192.168.0.0/24	10.0.1.C
192.168.0.0/24	10.0.2.C

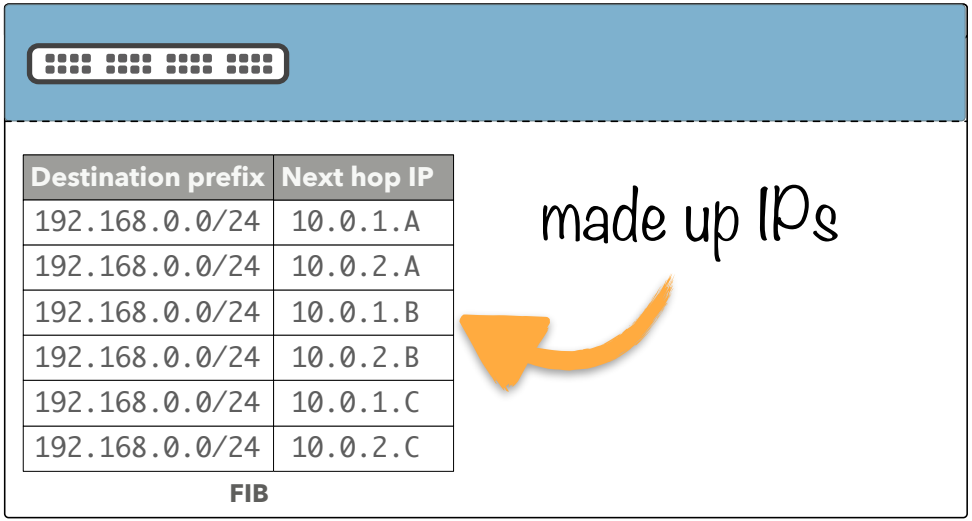
FIB

on switch, map VIP to static set of virtual next hops

- using static set avoids rehashing
- ECMP width determines granularity with which we load balance

Faild





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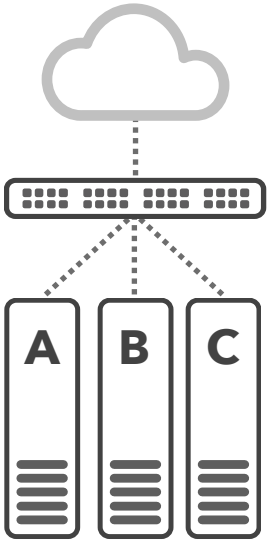

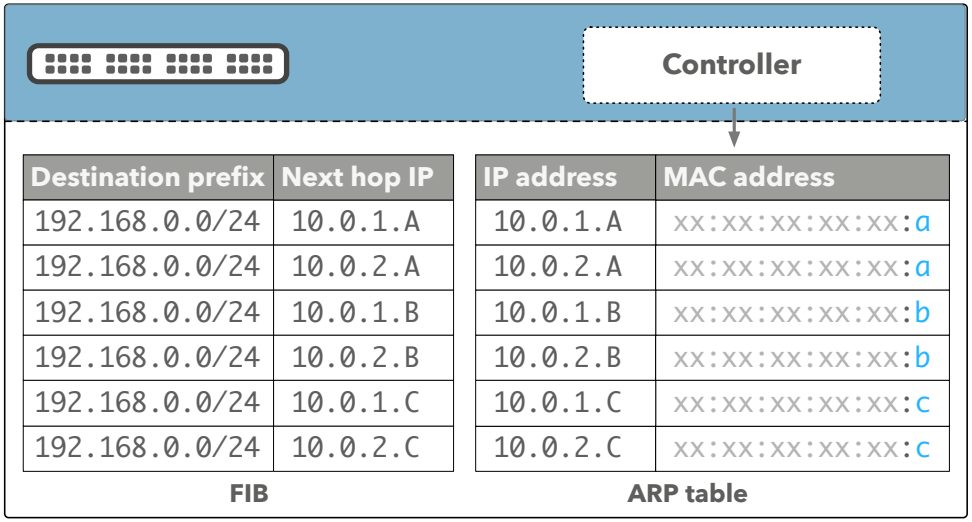

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192.168.0.0/24	10.0.2.A
192.168.0.0/24	10.0.1.B
192.168.0.0/24	10.0.2.B
192.168.0.0/24	10.0.1.C
192.168.0.0/24	10.0.2.C

FIB

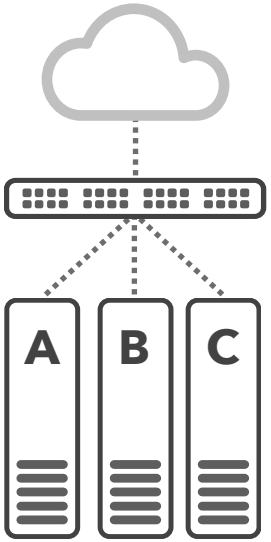
IP address	MAC address
10.0.1.A	xx:xx:xx:xx:xx:a
10.0.2.A	xx:xx:xx:xx:xx:a
10.0.1.B	xx:xx:xx:xx:xx:b
10.0.2.B	xx:xx:xx:xx:xx:b
10.0.1.C	xx:xx:xx:xx:xx:c
10.0.2.C	xx:xx:xx:xx:xx:c

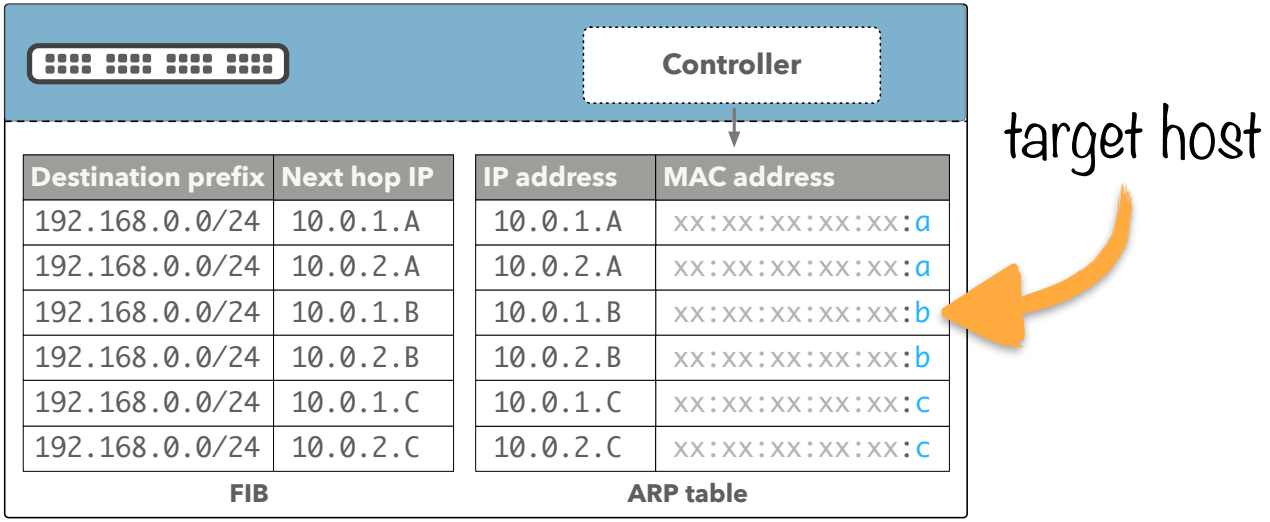
ARP table

on switch, control forwarding by manipulating ARP entry

- controller maps virtual next hop to virtual MAC address
- encode information about current host in virtual MAC address
- bridging table configured to map virtual MAC to egress port

Faild





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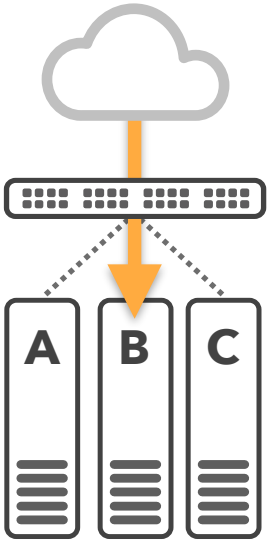

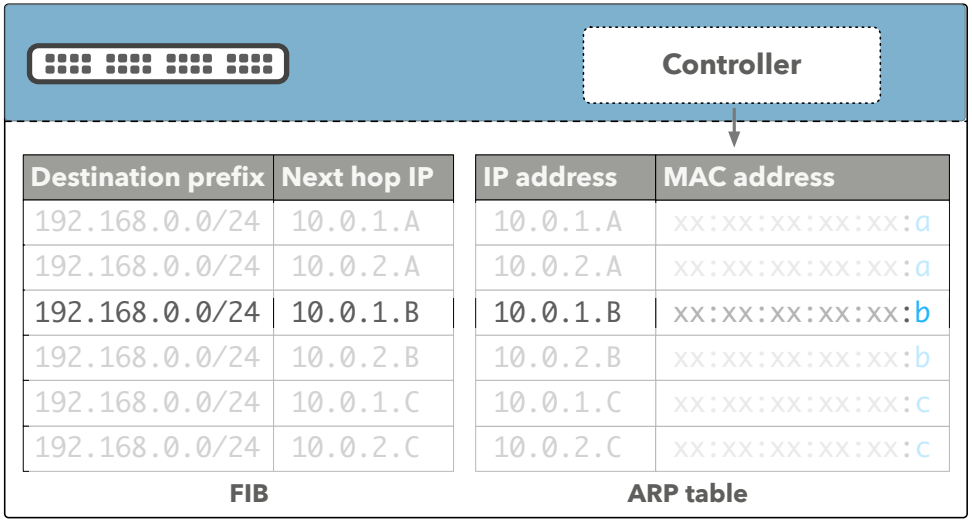

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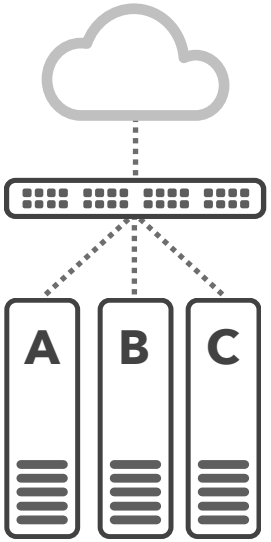

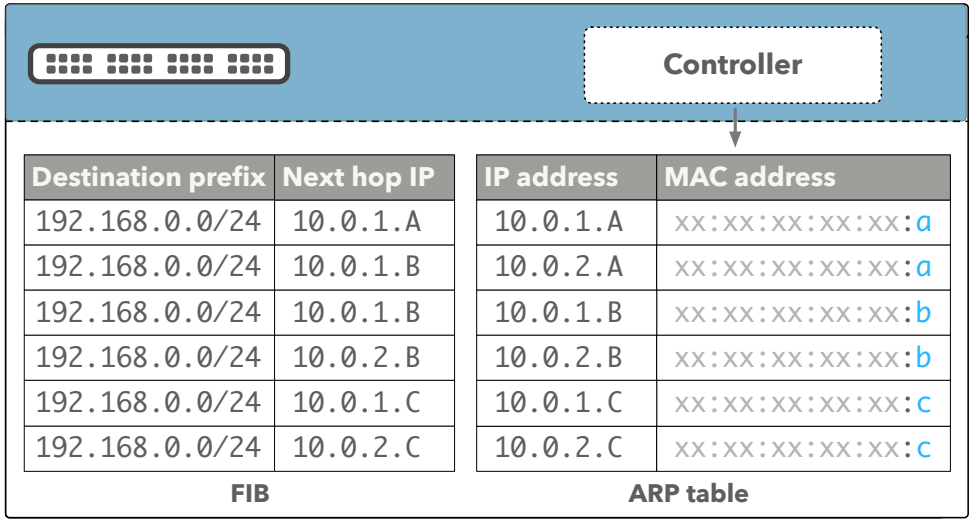

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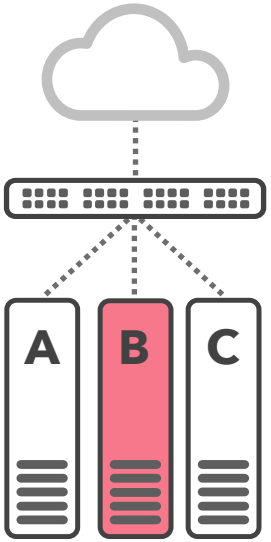
10.0.1.C	xx:xx:xx:xx:xx:c
10.0.2.C	xx:xx:xx:xx:xx:c

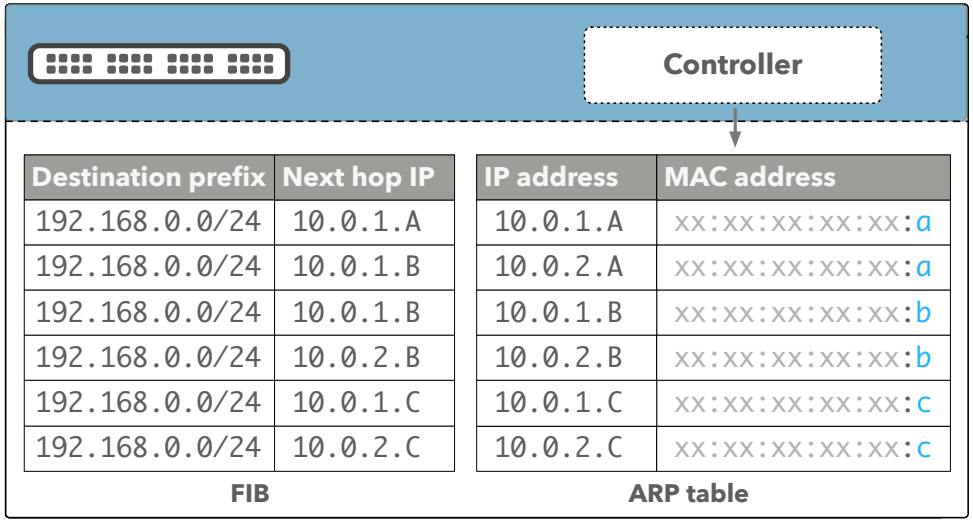
ARP table

hosts send health status to controller

- on drain, update ARP entry
- balance virtual next hops across available servers

Faild





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192.168.0.0/24	10.0.1.C
192.168.0.0/24	10.0.2.C

FIB

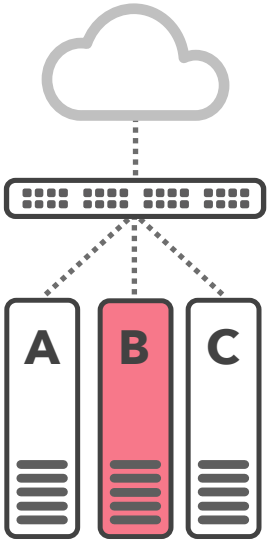
IP address	MAC address
10.0.1.A	xx:xx:xx:xx:xx:a
10.0.2.A	xx:xx:xx:xx:xx:a
10.0.1.B	xx:xx:xx:xx:xx:b
10.0.2.B	xx:xx:xx:xx:xx:b
10.0.1.C	xx:xx:xx:xx:xx:c
10.0.2.C	xx:xx:xx:xx:xx:c

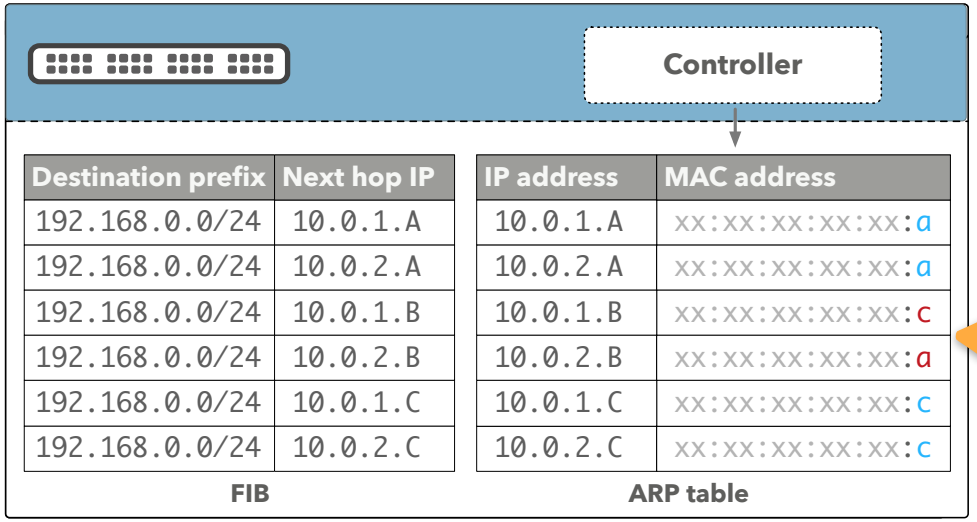
ARP table

hosts send health status to controller

- on drain, update ARP entry
- balance virtual next hops across available servers

Faild



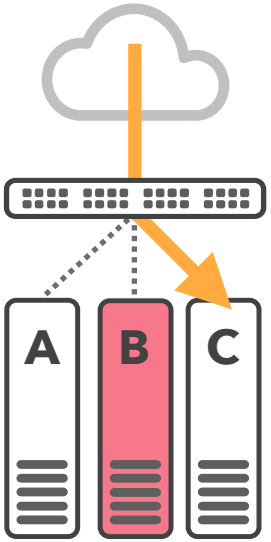


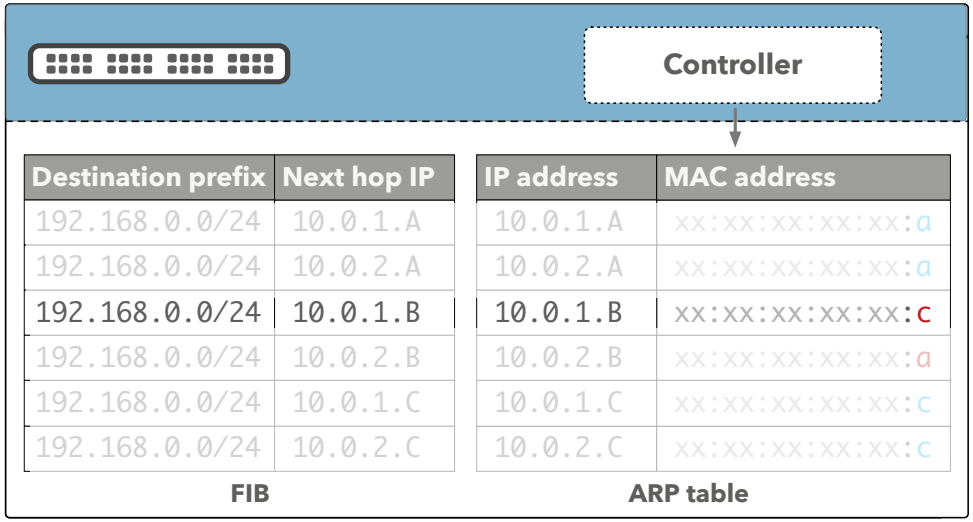
remap entries

hosts send health status to controller

- on drain, update ARP entry
- balance virtual next hops across available servers

Faild





hosts send health status to controller

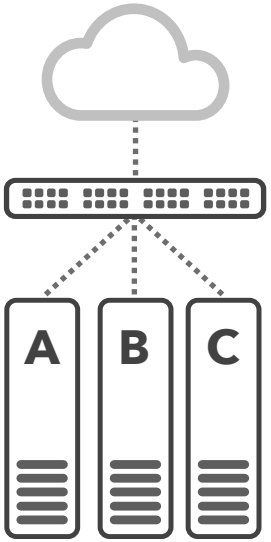
- on drain, update ARP entry
- balance virtual next hops across available servers

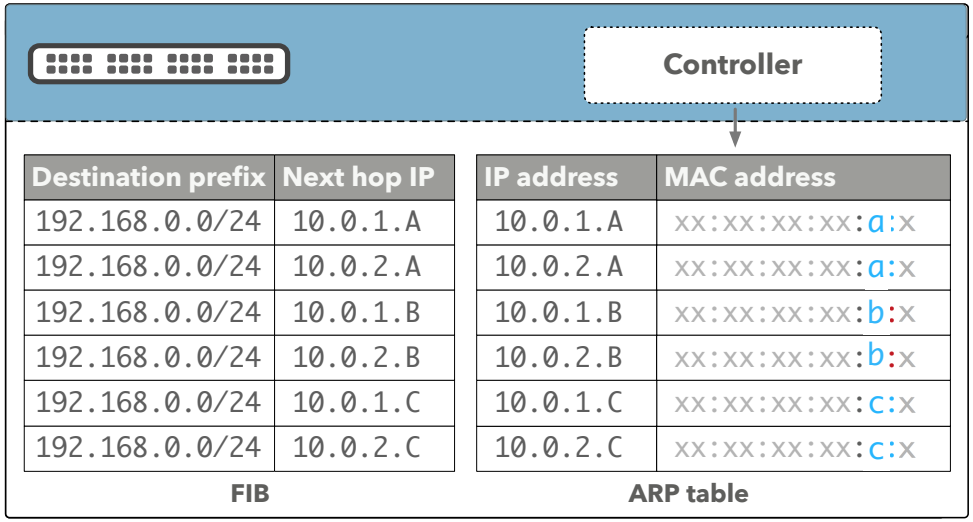
isn’t this just consistent hashing?

isn’t this just consistent hashing?

yes, but we can extend mechanism and avoid resets entirely

Faild





Destination prefix	Next hop IP
192.168.0.0/24	10.0.1.A
192.168.0.0/24	10.0.2.A
192.168.0.0/24	10.0.1.B
192.168.0.0/24	10.0.2.B
192.168.0.0/24	10.0.1.C
192.168.0.0/24	10.0.2.C

FIB

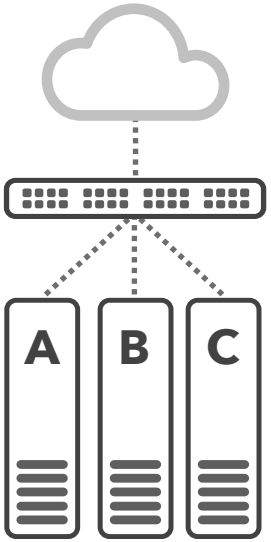
IP address	MAC address
10.0.1.A	xx:xx:xx:xx:a:x
10.0.2.A	xx:xx:xx:xx:a:x
10.0.1.B	xx:xx:xx:xx:b:x
10.0.2.B	xx:xx:xx:xx:b:x
10.0.1.C	xx:xx:xx:xx:c:x
10.0.2.C	xx:xx:xx:xx:c:x

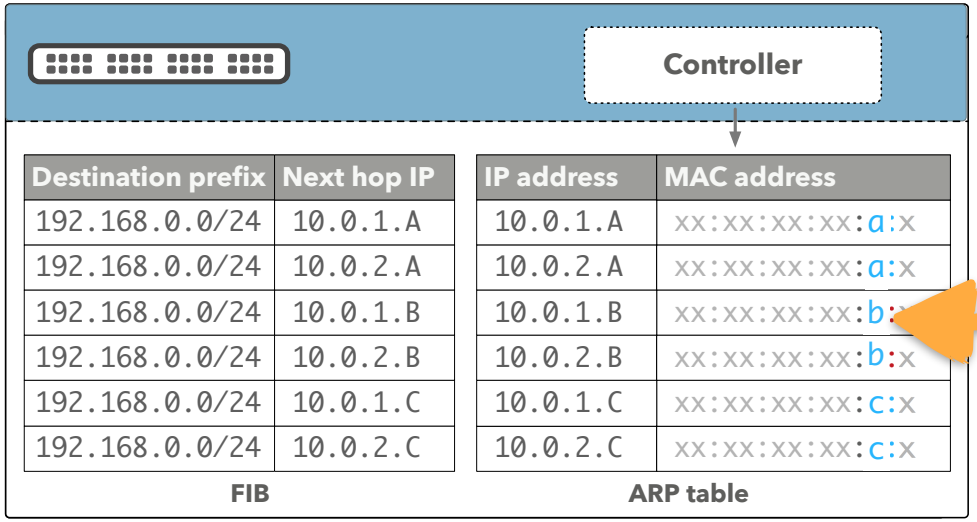
ARP table

embed mapping history in MAC address

- append previous target as part of MAC address
- still results in resets, but…
- …conveys necessary information down to the host

Faild



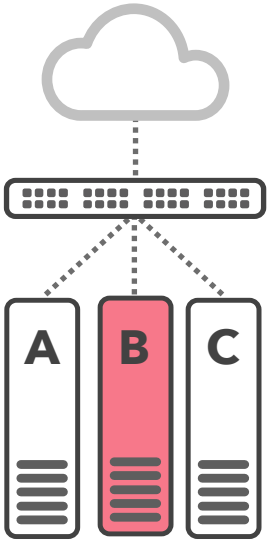


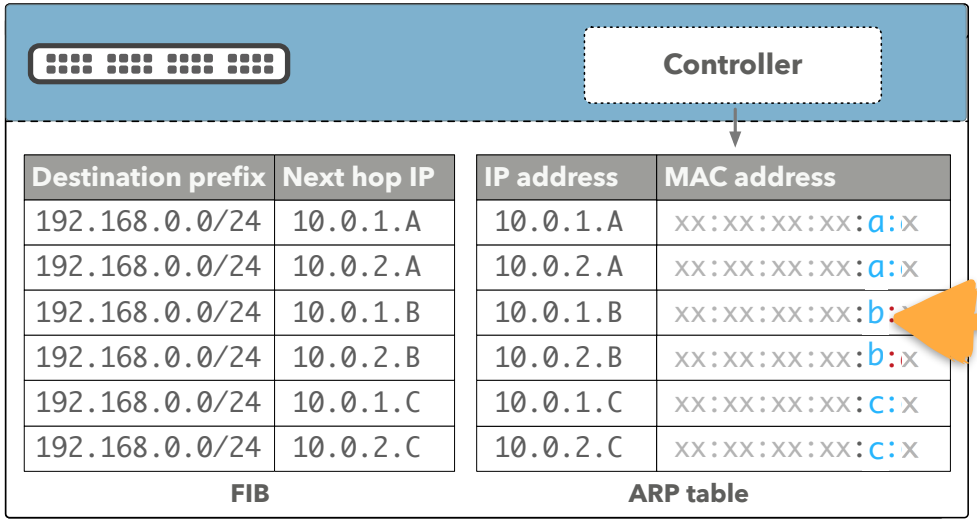
current host

embed mapping history in MAC address

- append previous target as part of MAC address
- still results in resets, but…
- …conveys necessary information down to the host

Faild





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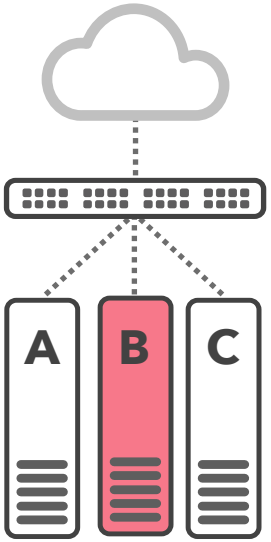

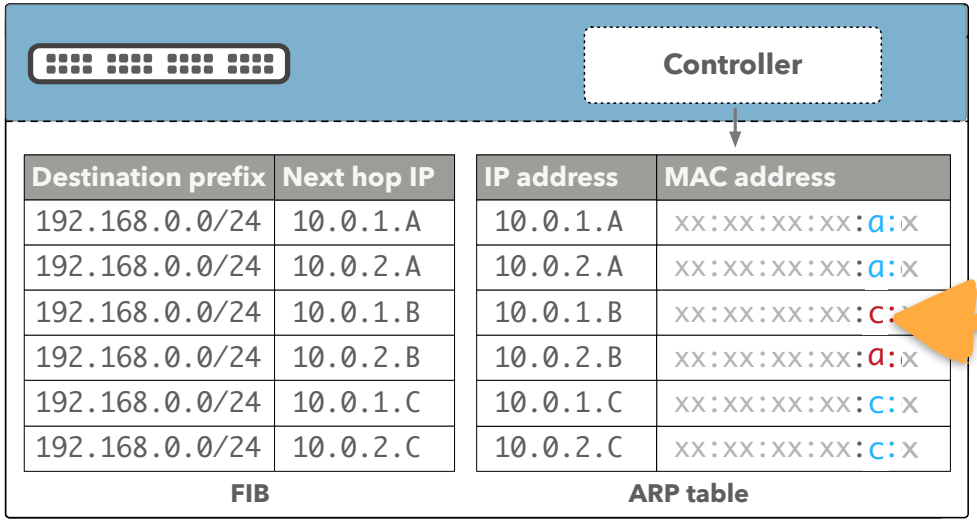

current host

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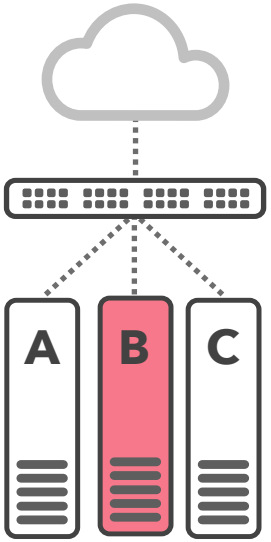
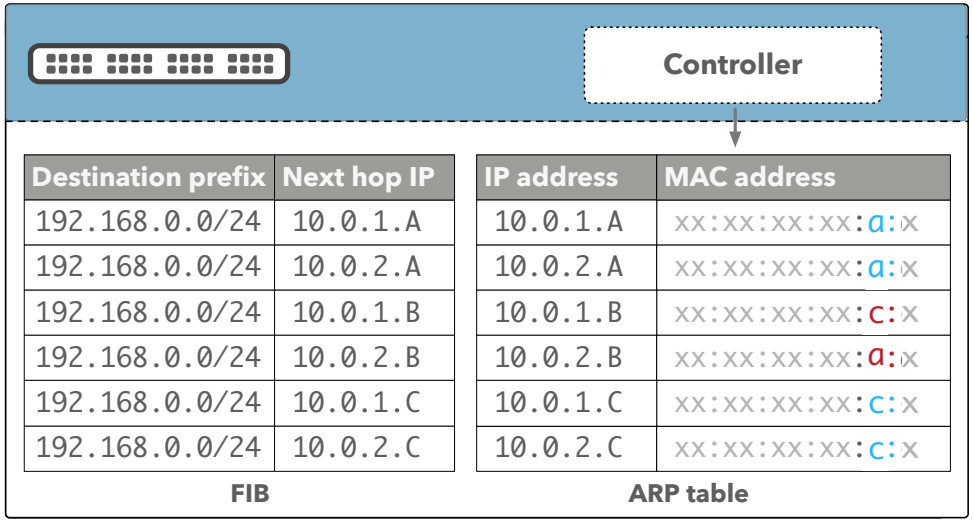




Destination prefix	Next hop IP
192.168.0.0/24	10.0.1.A
192.168.0.0/24	10.0.2.A
192.168.0.0/24	10.0.1.B
192.168.0.0/24	10.0.2.B
192.168.0.0/24	10.0.1.C
192.168.0.0/24	10.0.2.C

FIB

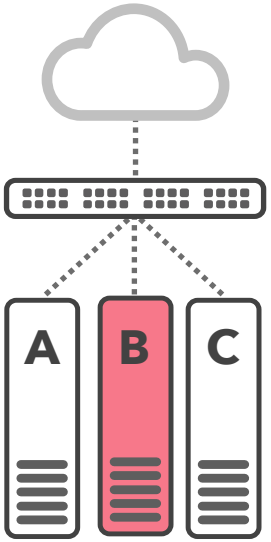
IP address	MAC address
10.0.1.A	xx:xx:xx:xx:a:x
10.0.2.A	xx:xx:xx:xx:a:x
10.0.1.B	xx:xx:xx:xx:c:x
10.0.2.B	xx:xx:xx:xx:a:x
10.0.1.C	xx:xx:xx:xx:c:x
10.0.2.C	xx:xx:xx:xx:c:x

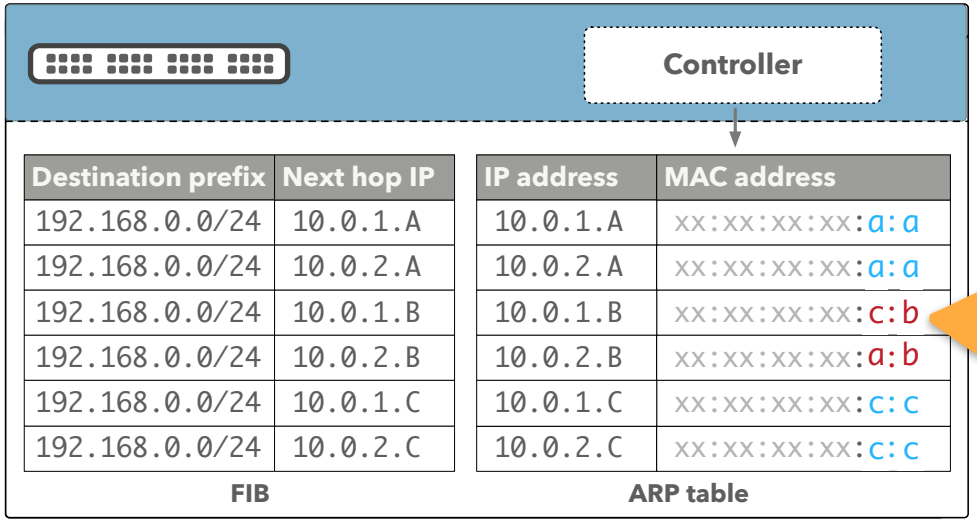
ARP table

embed mapping history in MAC address

- append previous target as part of MAC address
- still results in resets, but…
- …conveys necessary information down to the host

Faild



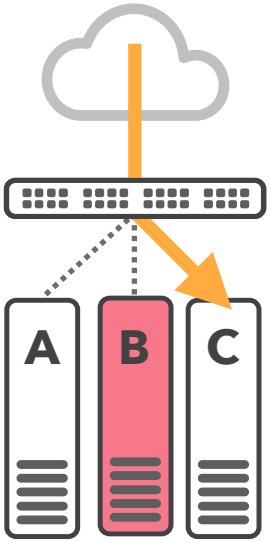


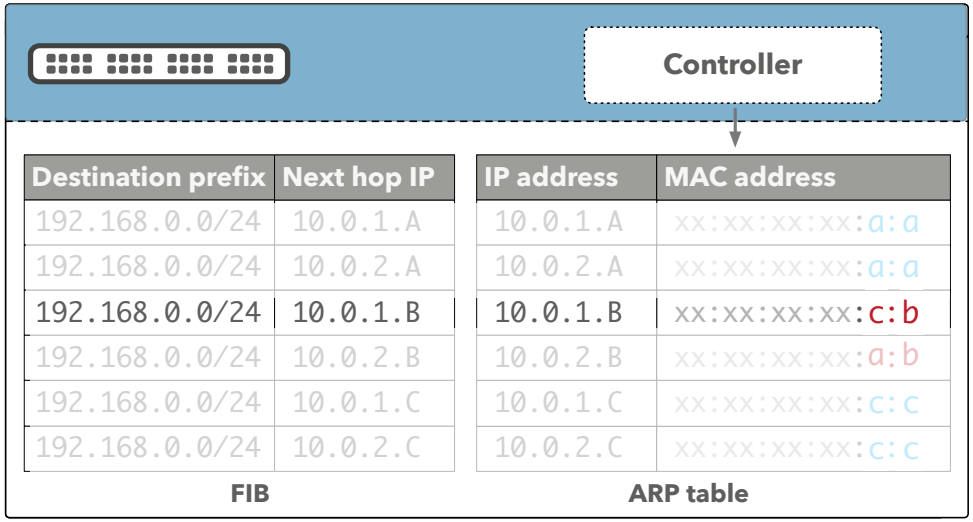
previous host

embed mapping history in MAC address

- append previous target as part of MAC address
- still results in resets, but…
- …conveys necessary information down to the host

Faild





embed mapping history in MAC address

- append previous target as part of MAC address
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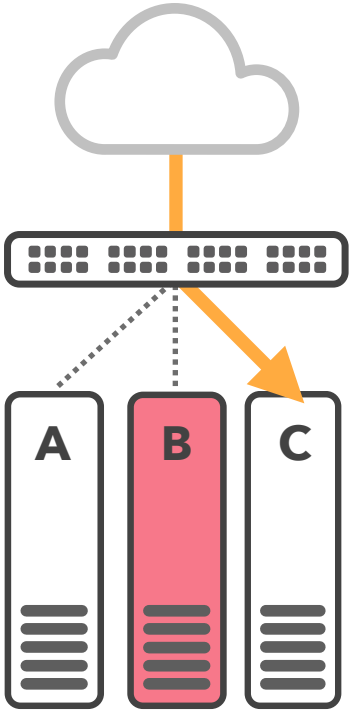
Host processing

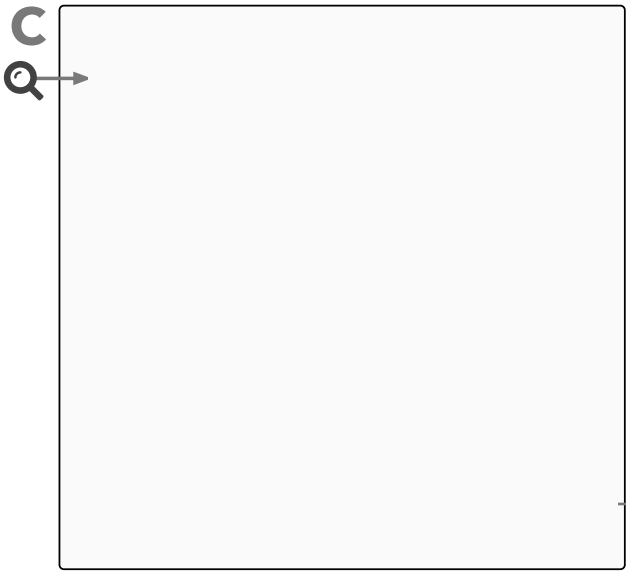


Destination MAC address

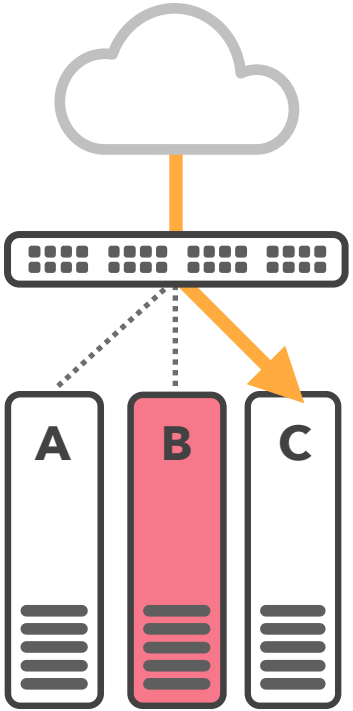
xx:xx:xx:xx:c:b

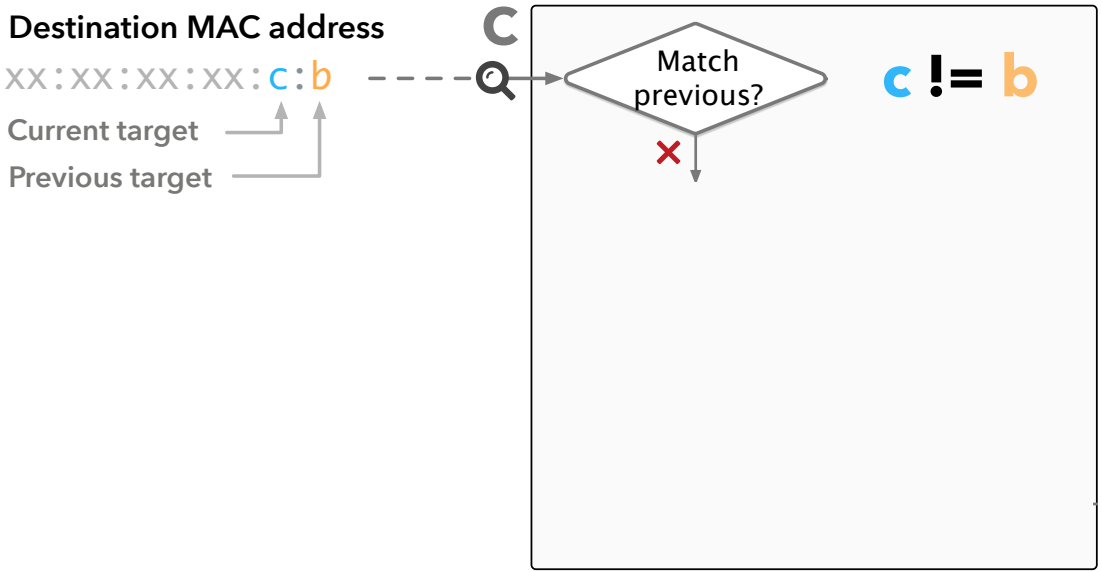
Current target

Previous target

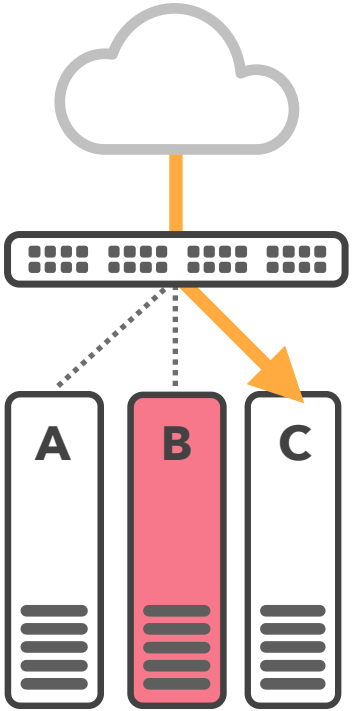


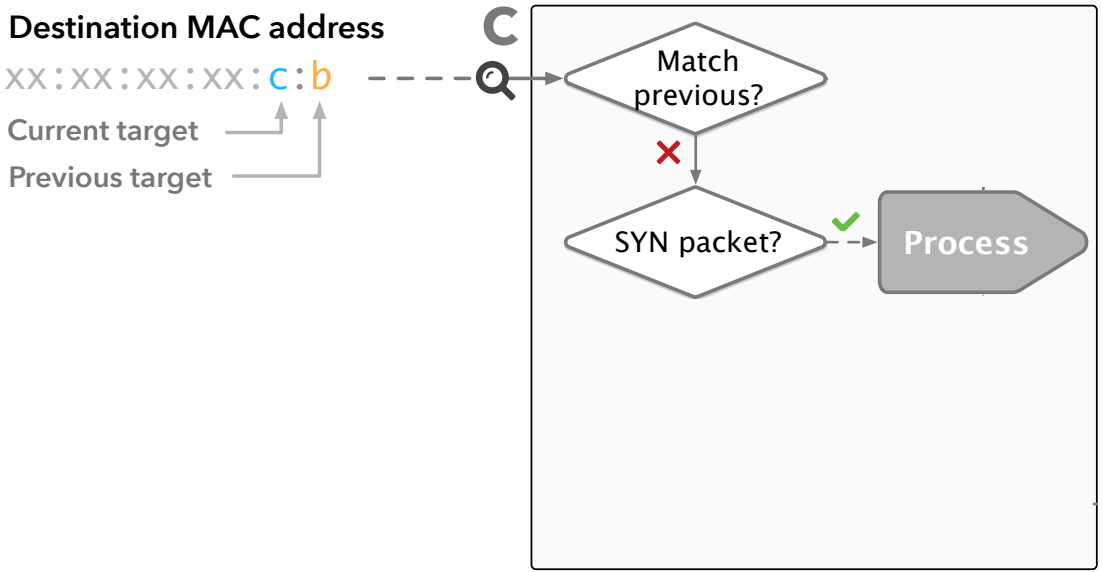
Host processing



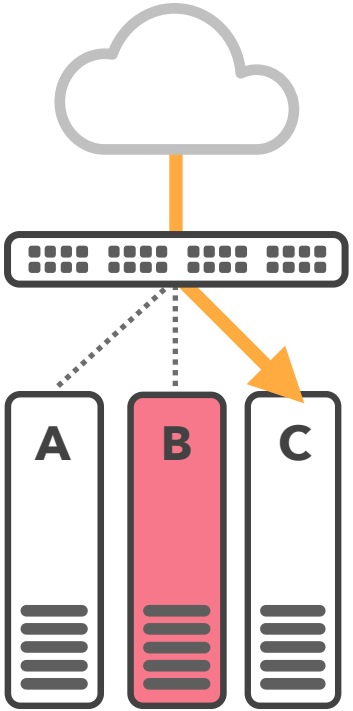


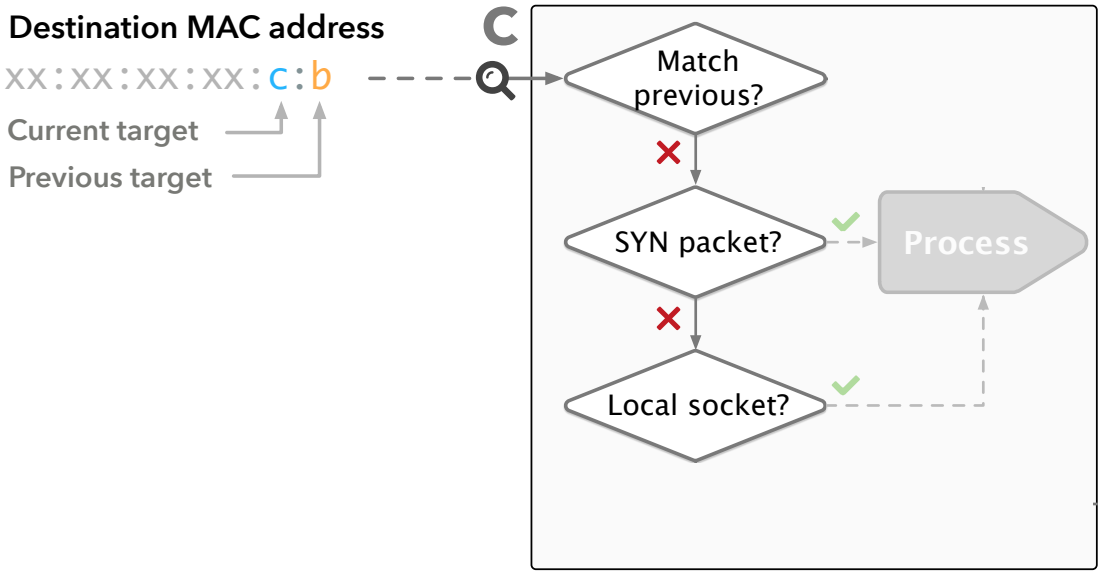
Host processing



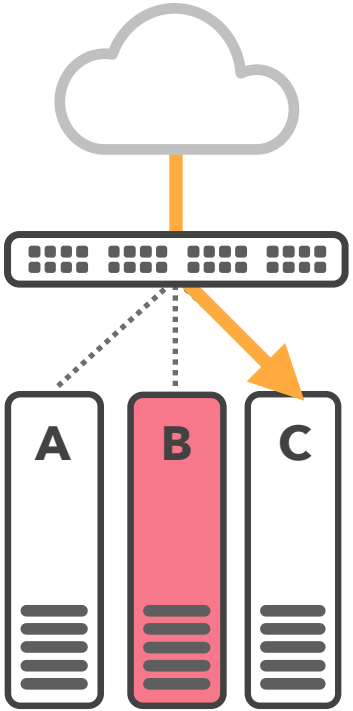


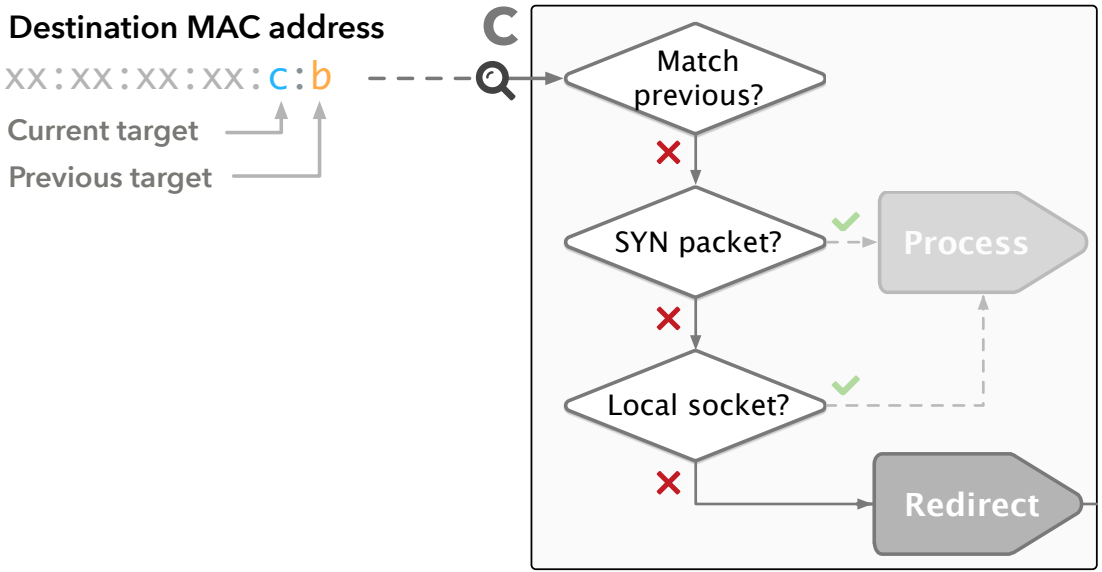
Host processing



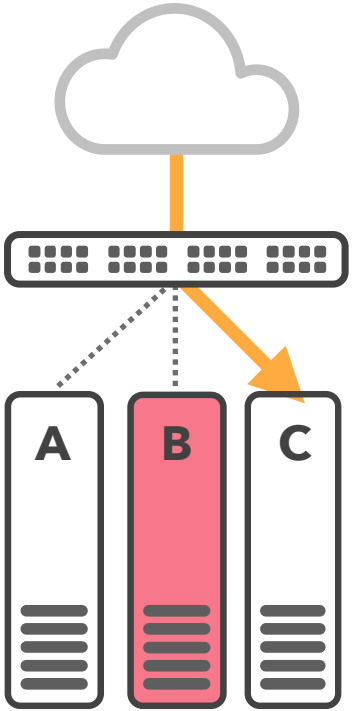


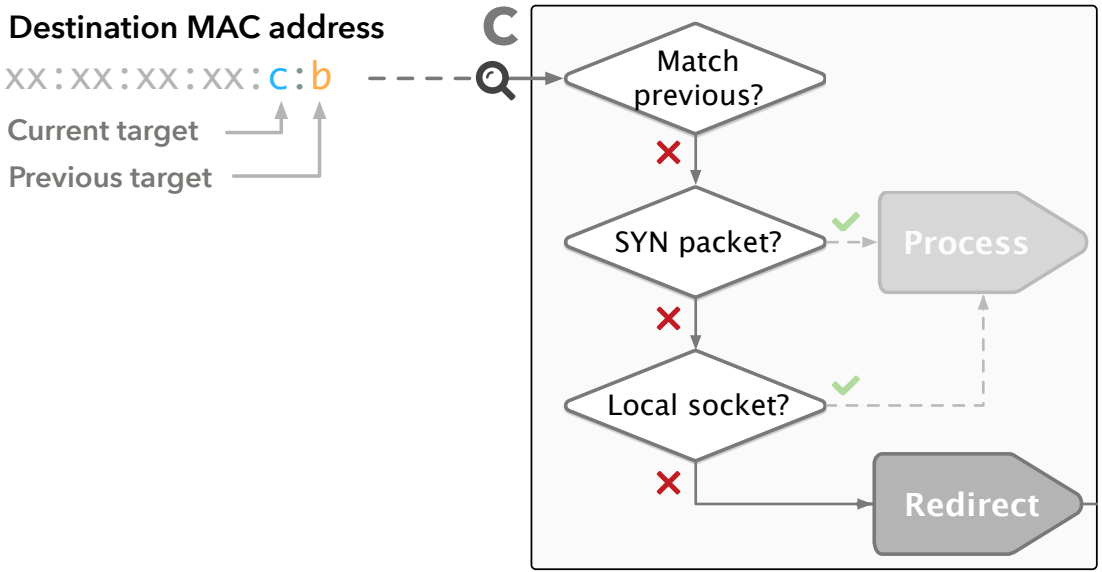
Host processing



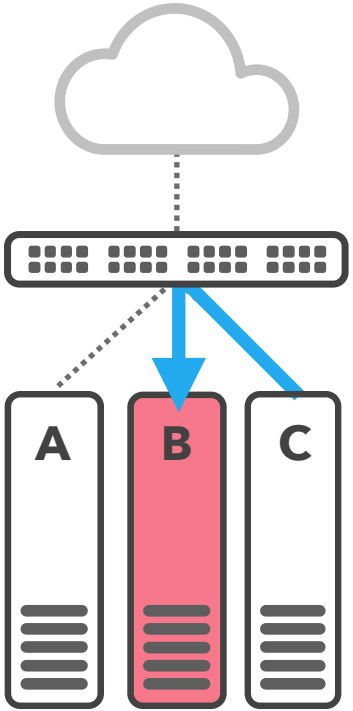


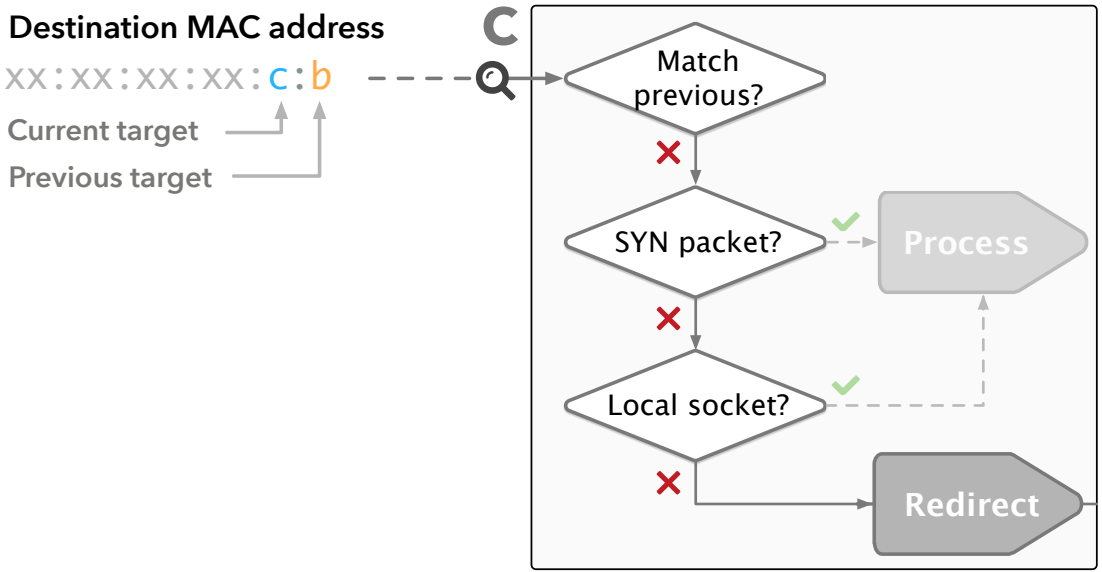
Host processing



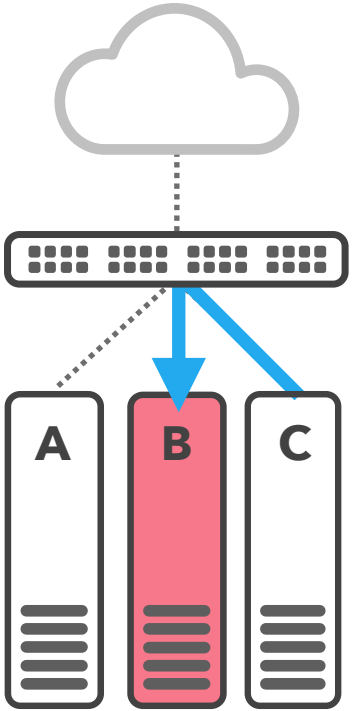


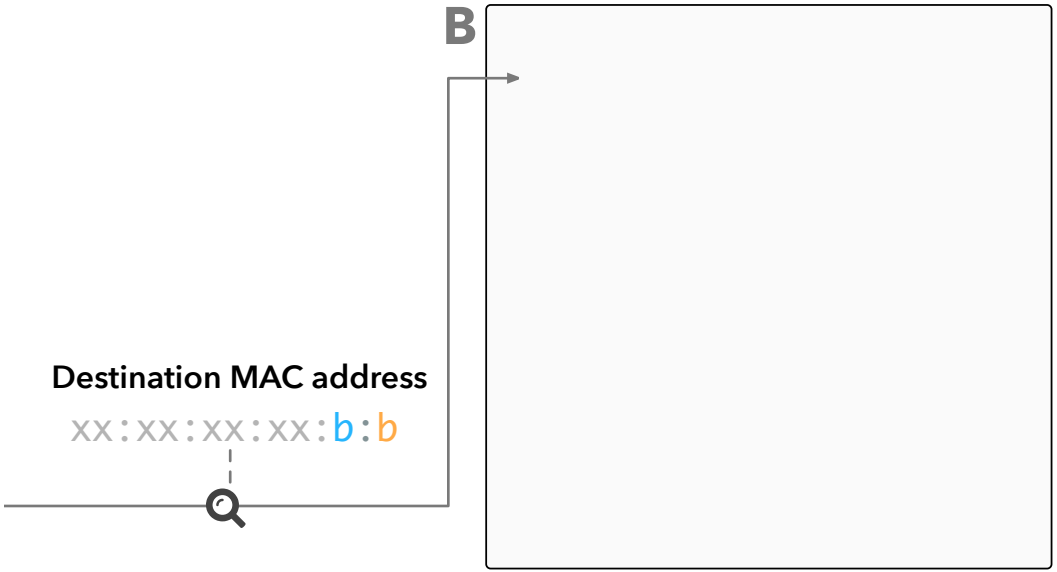
Host processing



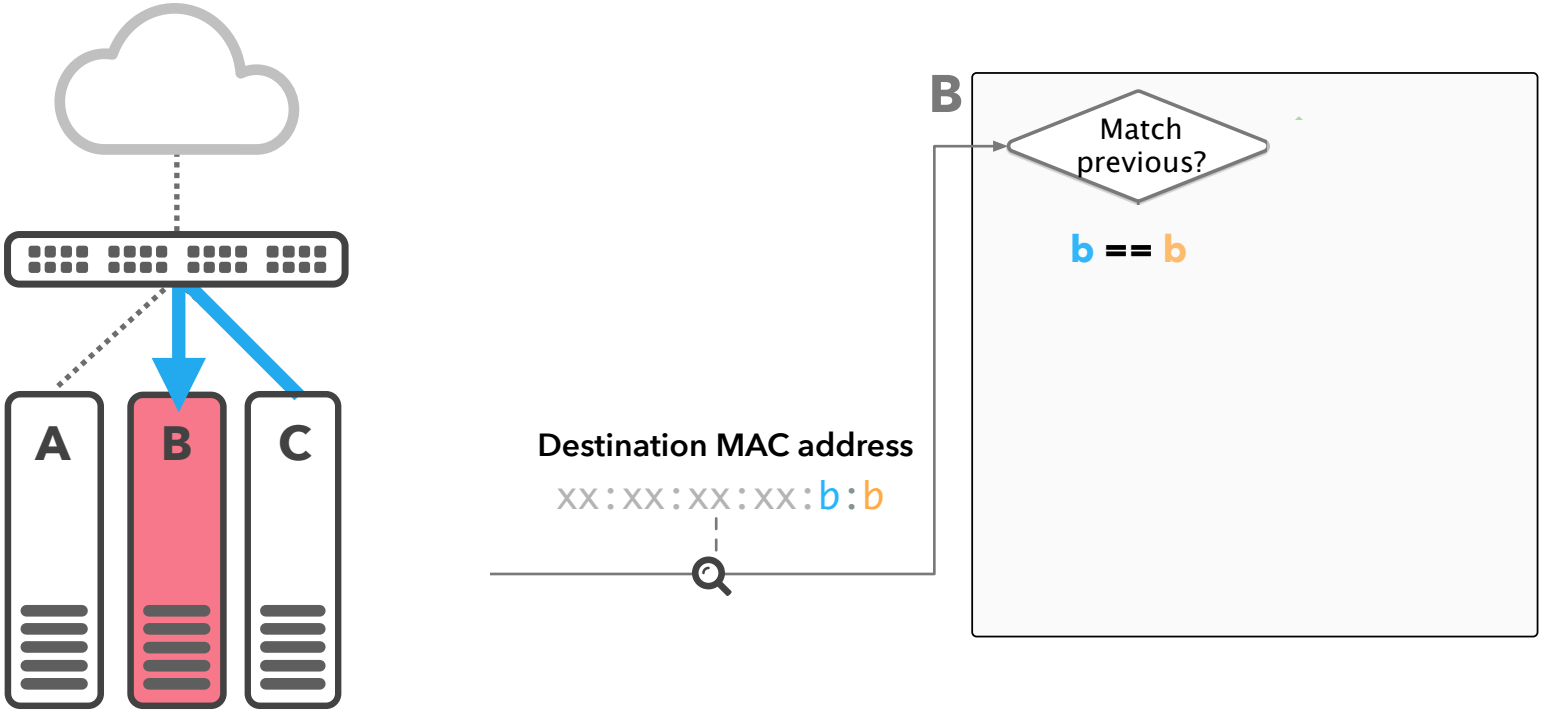


Host processing

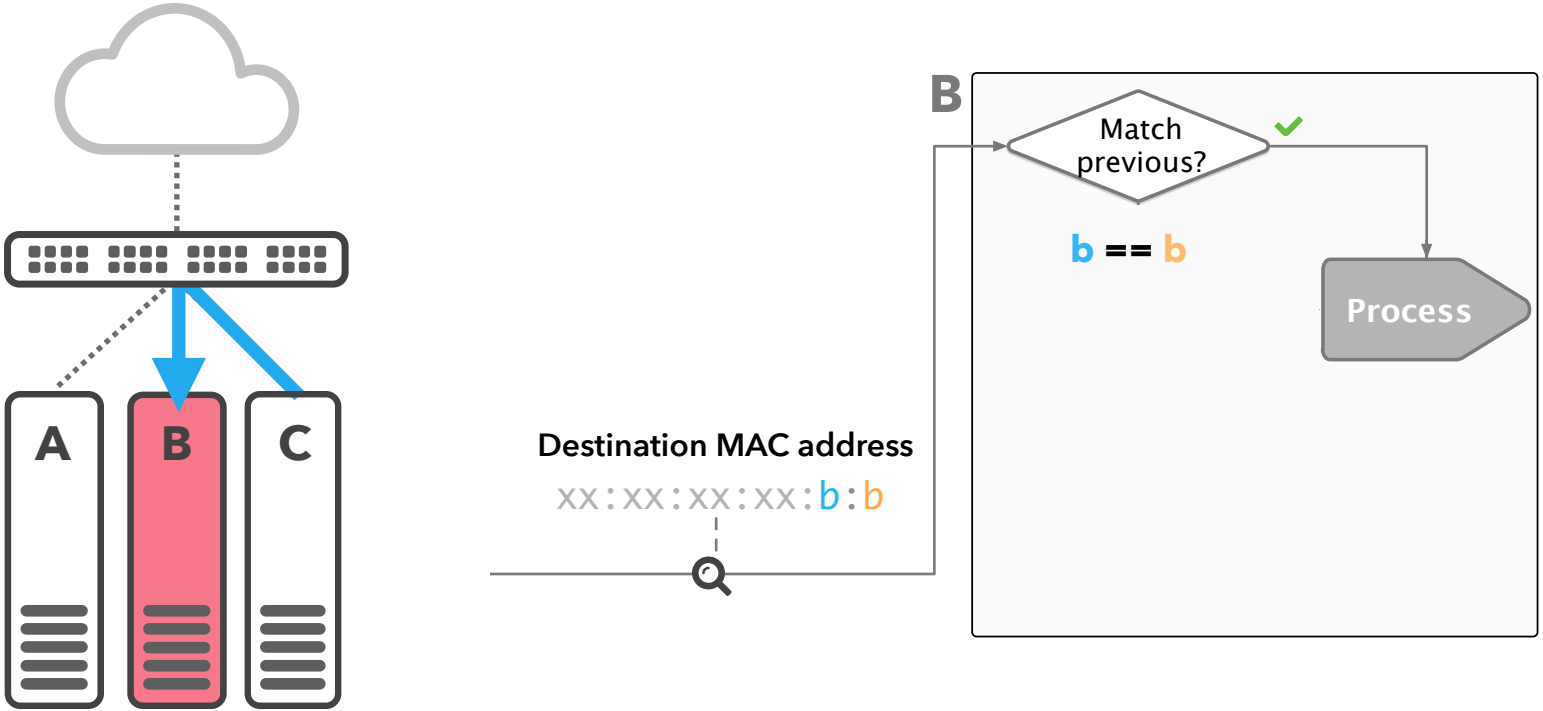




Host processing



Host processing



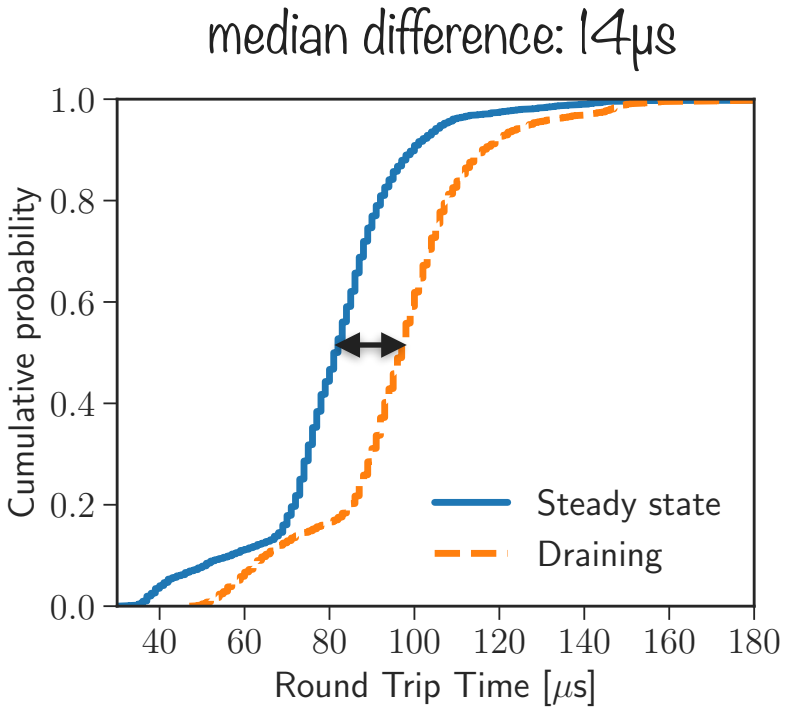
Host processing

Low latency

- expected case: switches do all heavy lifting
- worst case: detour routing costs 14µs

Negligible impact on CPU utilization

- impact only when refilling
- peak CPU utilization below 0.3%



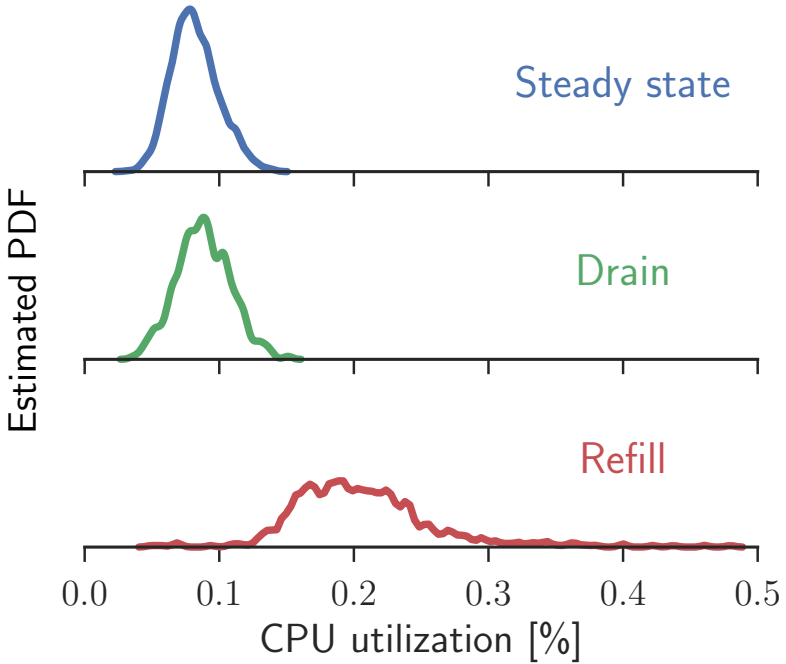
Host processing

Low latency

- expected case: switches do all heavy lifting
- worst case: detour routing costs 20µs

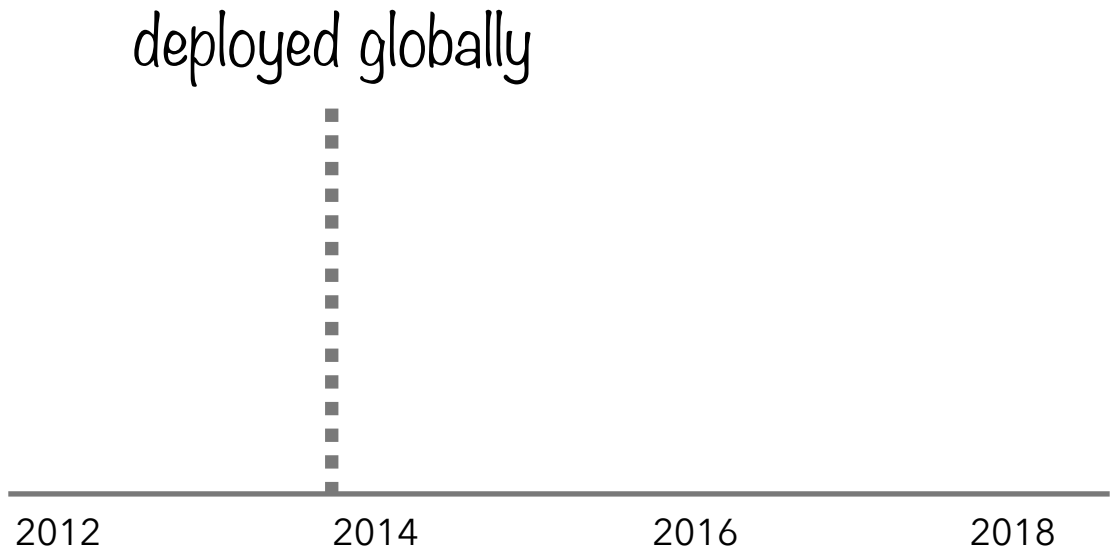
Negligible impact on CPU utilization

- impact only when refilling (transient)
- peak CPU utilization below 0.3%

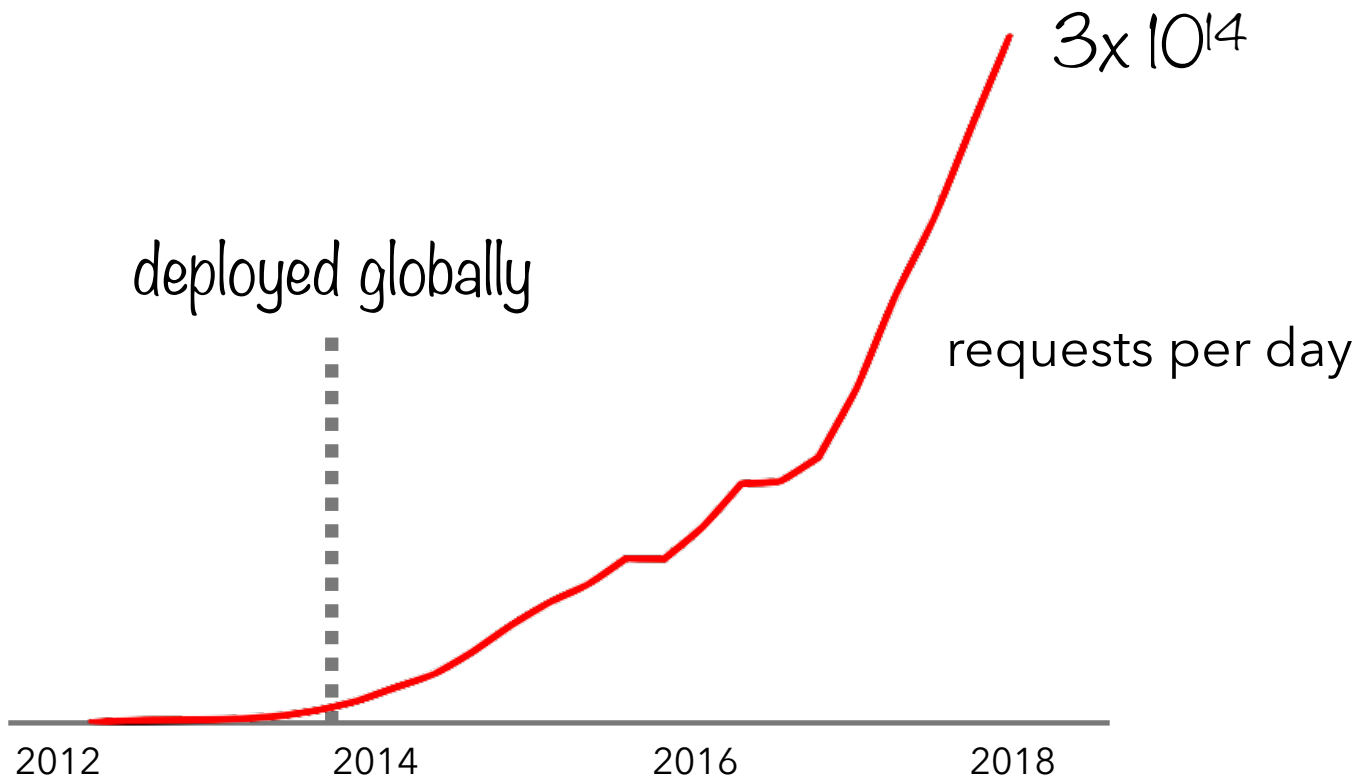


Timeline

Timeline



Timeline

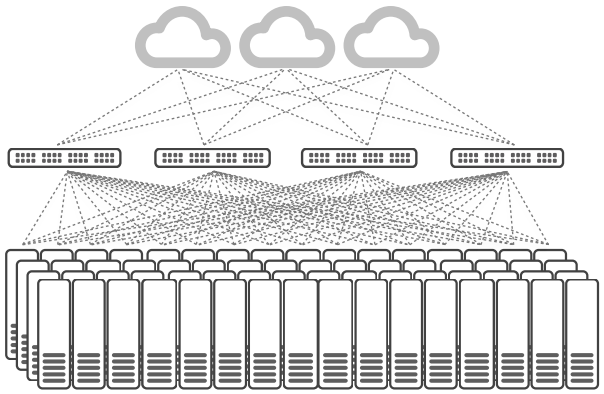

3x 10^14
deployed globally
requests per day
2012
2014
2016
2018

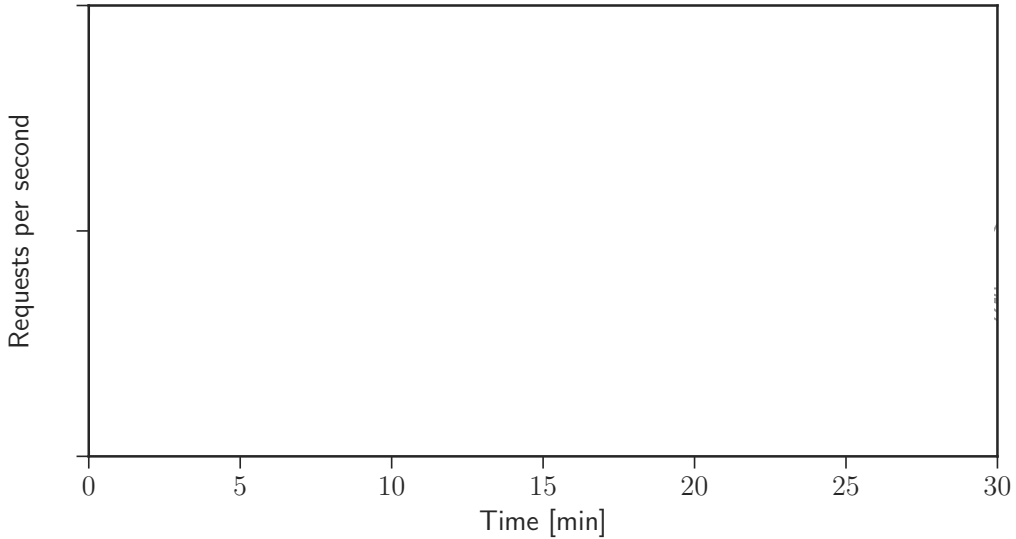
we suspect it works

Assumption #1

hash buckets are equally loaded

Hashing

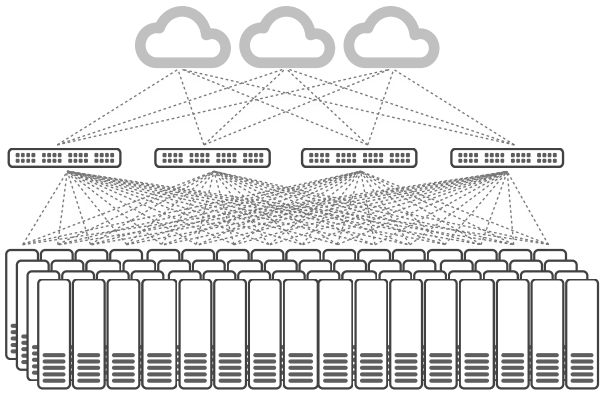


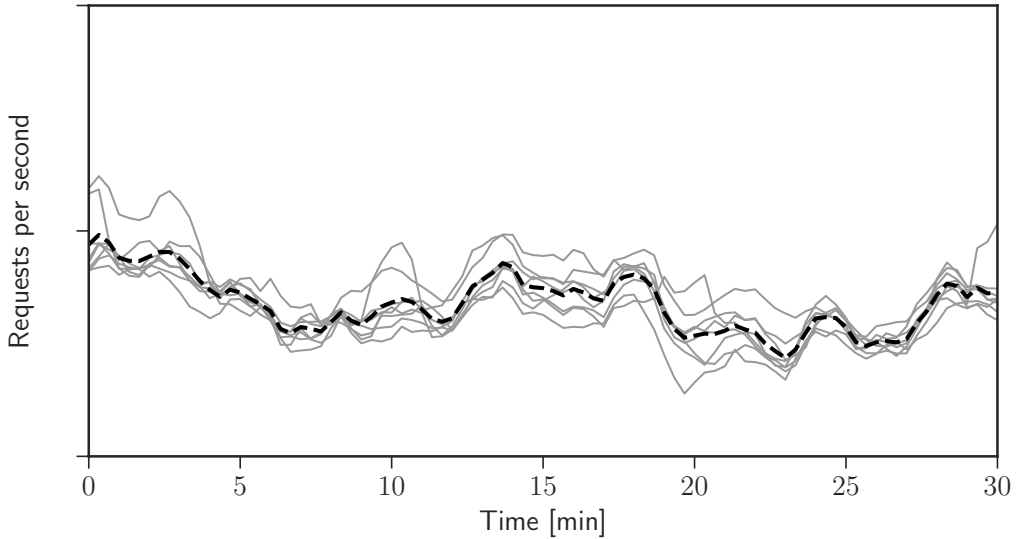


Implications for capacity planning

- you are bound by most loaded host in a cluster

Hashing

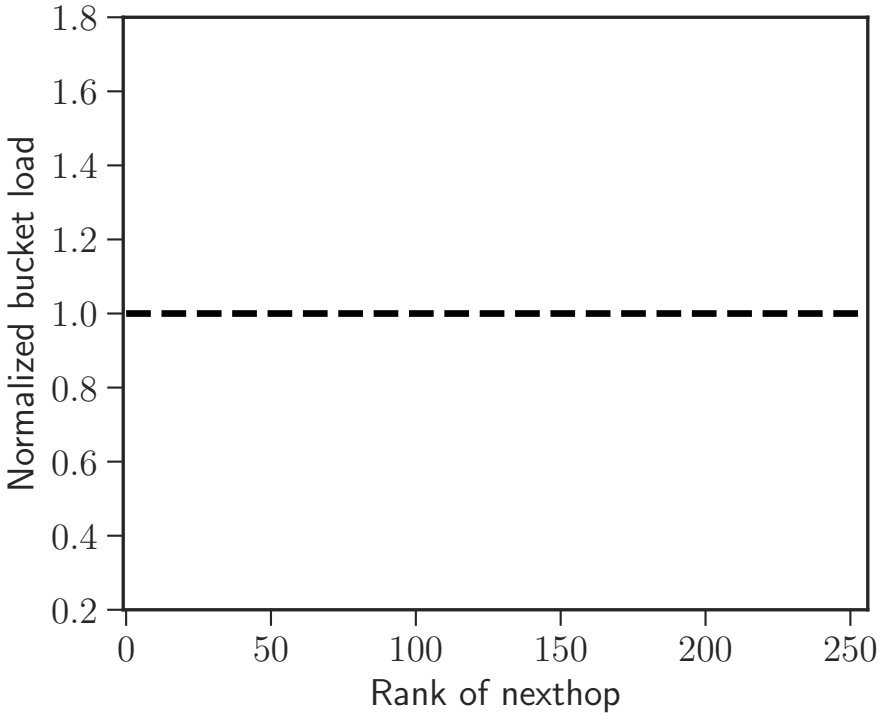




Implications for capacity planning

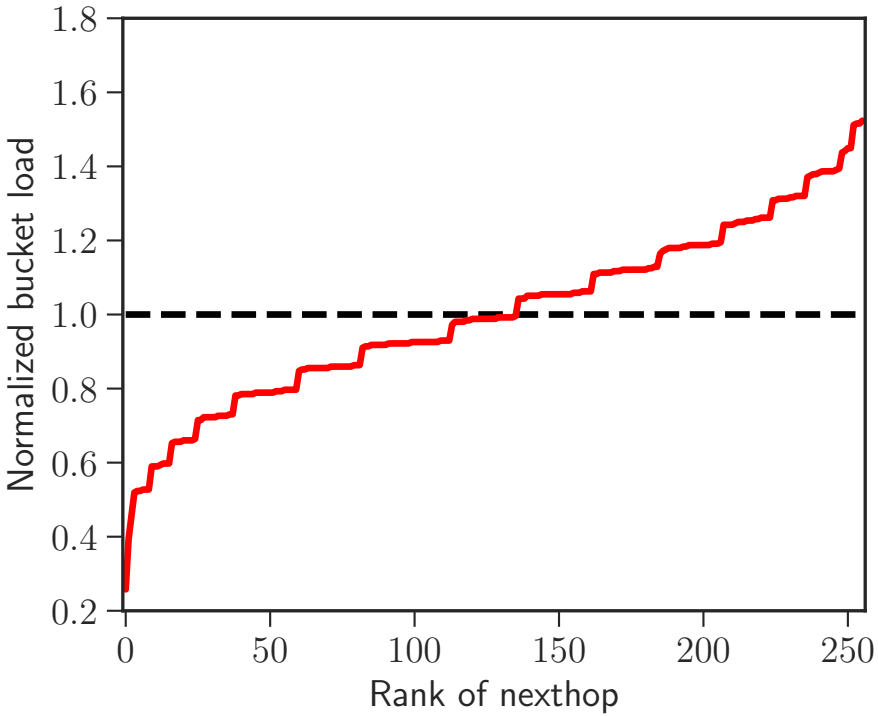
- you are bound by most loaded host in a cluster

Uneven hashing



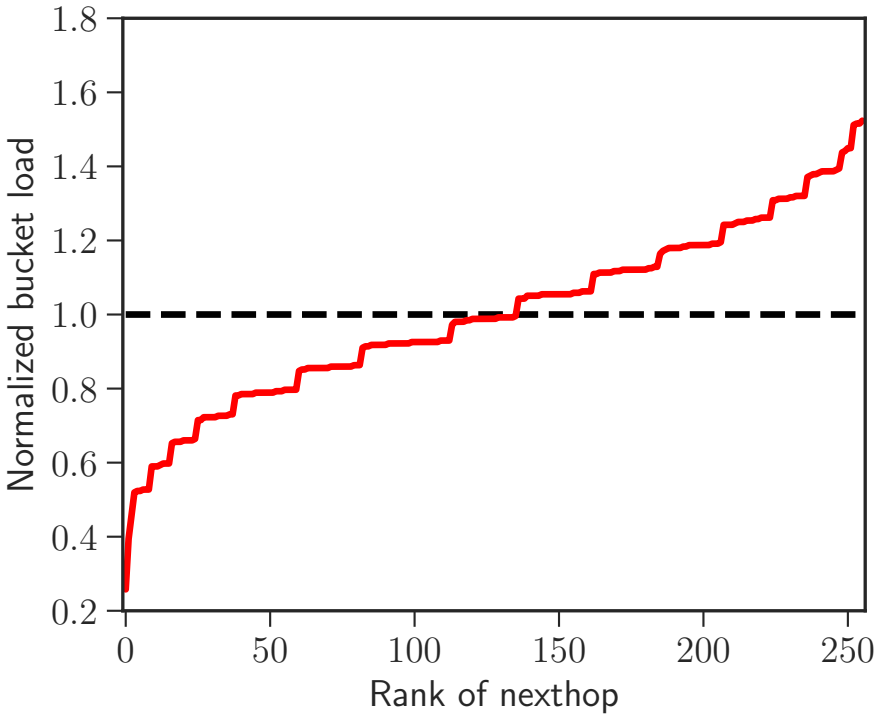
Inject synthetic, equally distributed traffic

Uneven hashing



Inject synthetic, equally distributed traffic

Uneven hashing

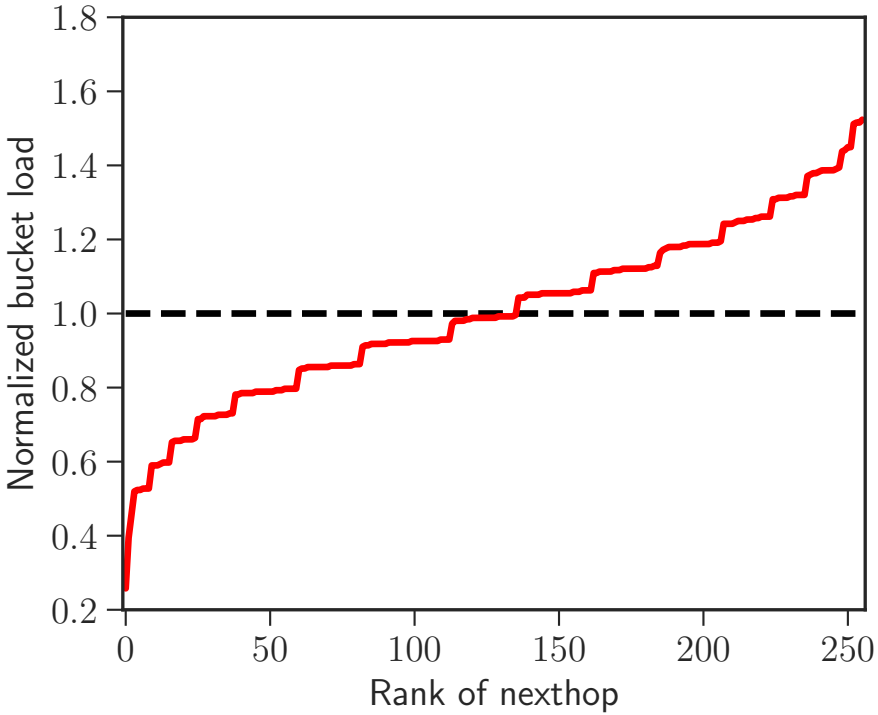


Inject synthetic, equally distributed traffic

Significant skew

- most loaded bucket 6 times more loaded than the least loaded

Uneven hashing



Inject synthetic, equally distributed traffic

Significant skew

- most loaded bucket 6 times more loaded than the least loaded

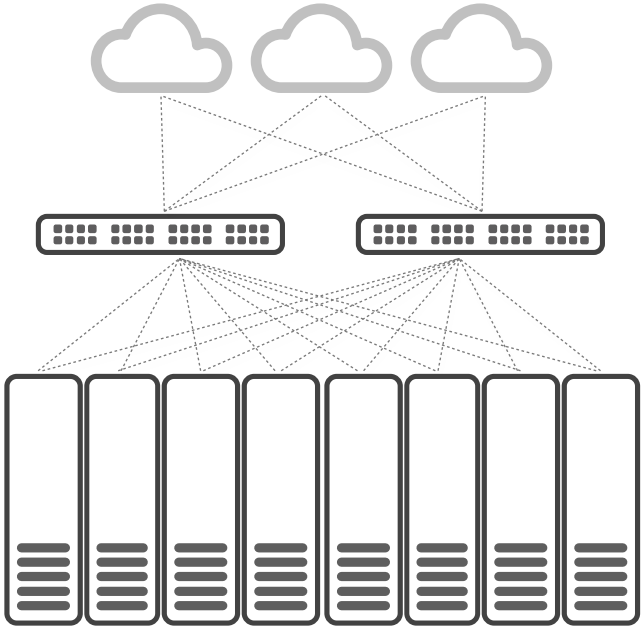
Behaviour can depend on number of nexthops

- some buckets received **no** traffic for specific number of configured nexthops

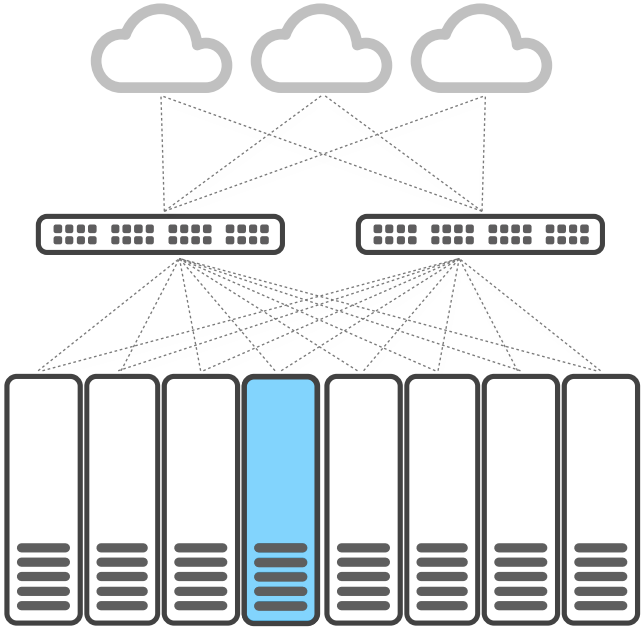
Assumption #2

switches hash identically

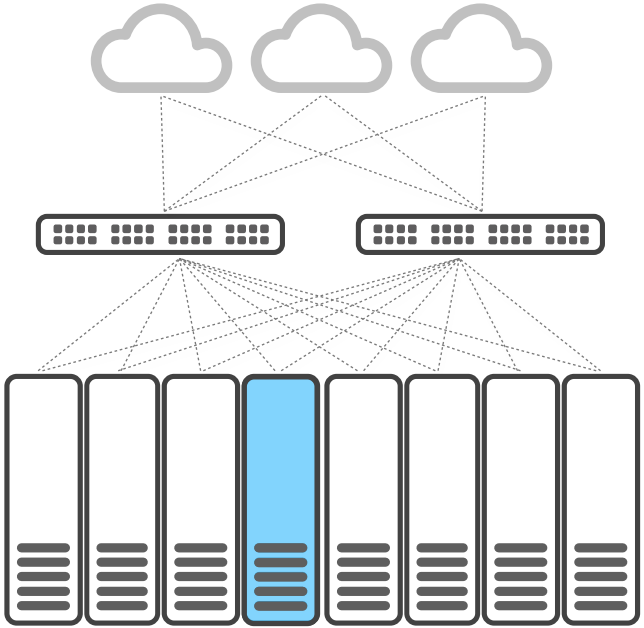
Hash polarization



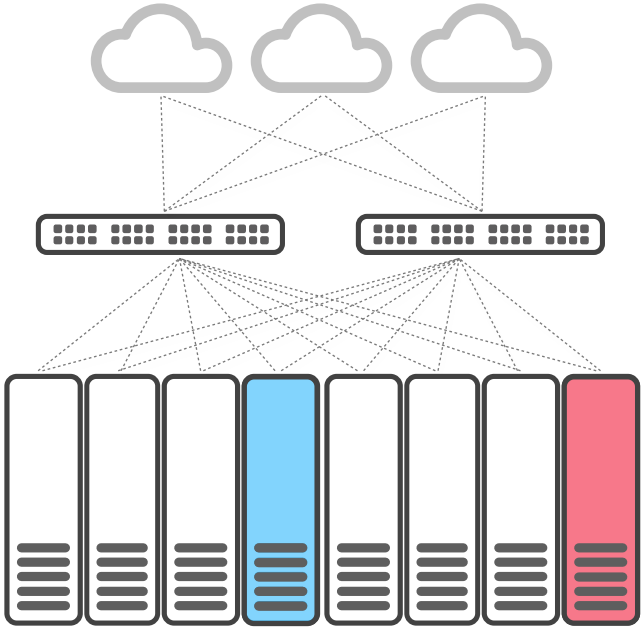
Hash polarization



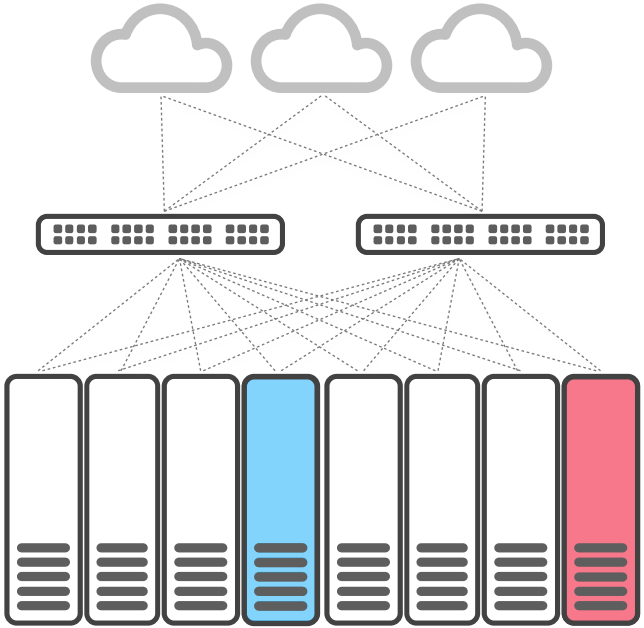
Hash polarization



Hash polarization



Hash polarization



Vendors were told hash polarization was bad

- in many cases you can't configure seed
- in one case, you can configure the seed, but vendor additionally uses boot order of linecards to add entropy

Assumption #3

packets in a flow use same network path

Nope, things break

Fragmentation

- returning ICMP packets hash on outer header
- took draft to IETF in 2014

ECN

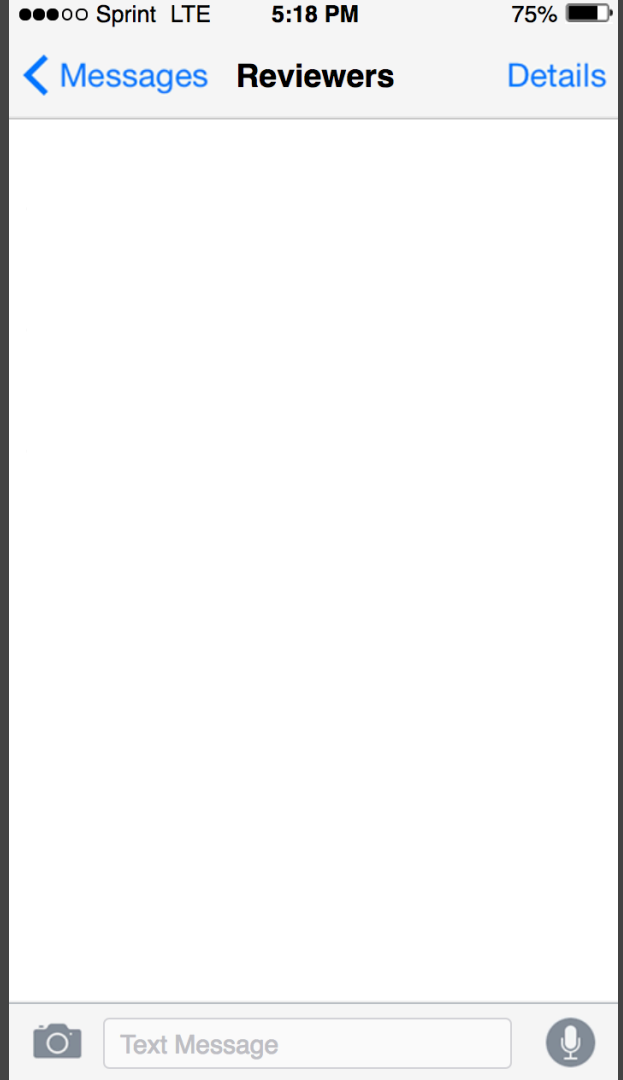
- some middleboxes hash on TOS field
- ended up turning ECN negotation off, breaks anycast too
- still looking for vendor(s) behind this, affected multiple ISPs

SYN proxies

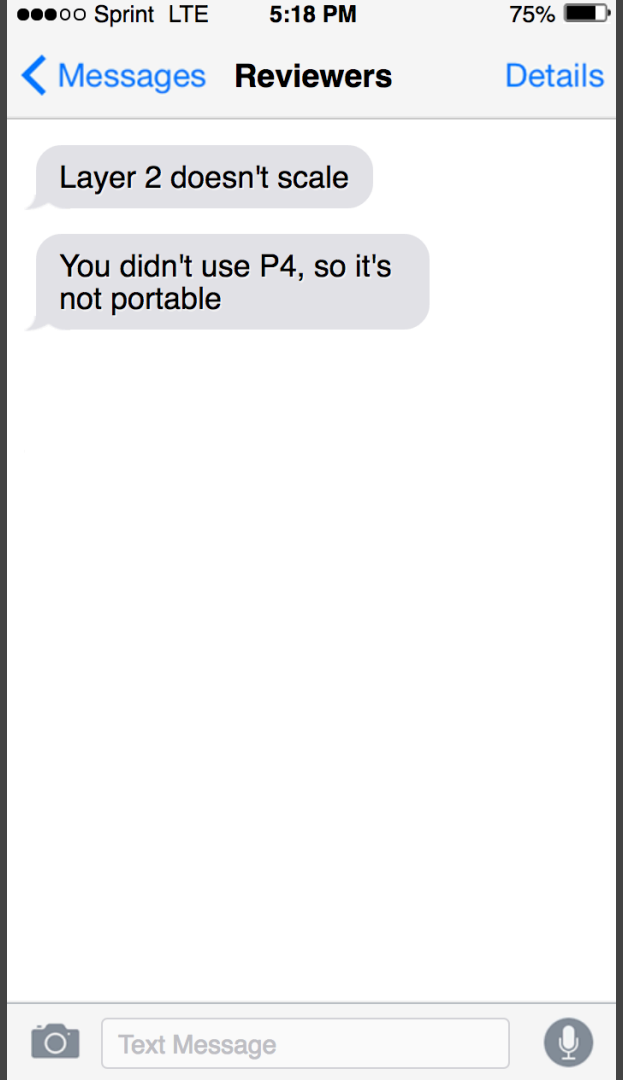
- recent trend in enterprise appliances
- route lookup after connection handoff results in new path
- one vendor fixed implementation

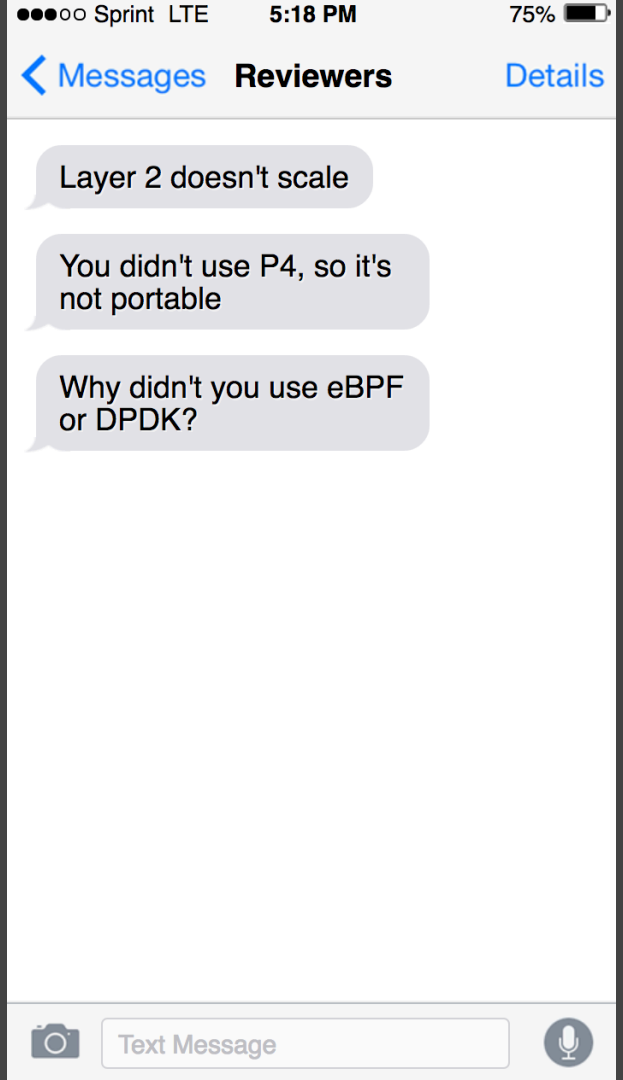
paper has lots more stuff

- SYN cookie handling
- ARP reconfiguration measurements
- evaluation of switch and host draining
- switch controller details
- host-side implementation quirks
- ECMP skew results
- switch memory
- real flow measurements
- vendors that don’t test their products
- …


●●●○○ Sprint LTE
5:18 PM
75%
Messages
Reviewers
Details
Text Message

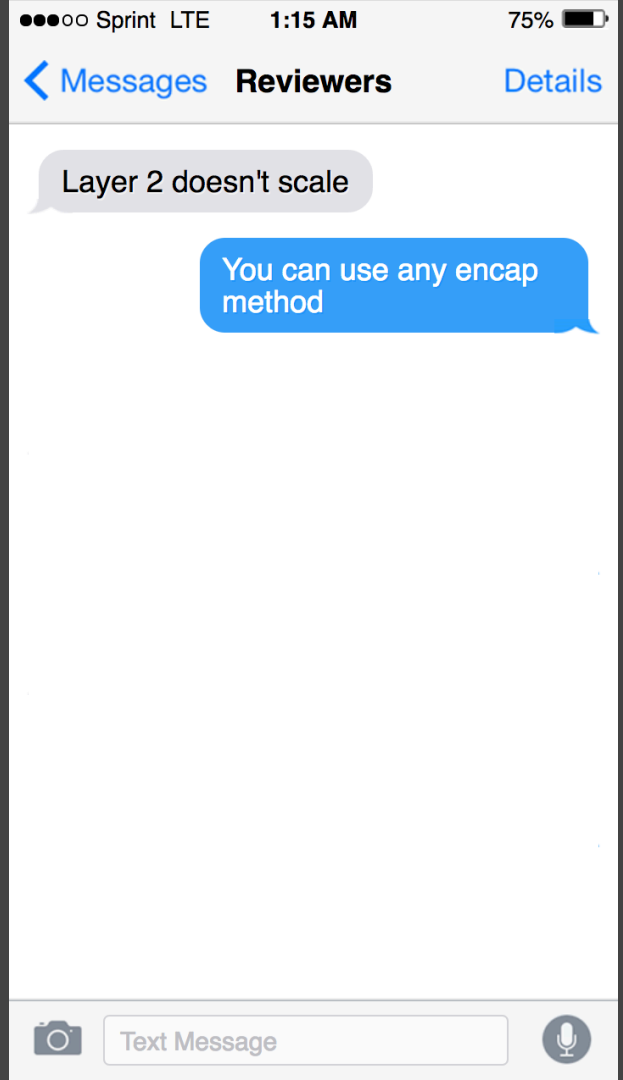

●●●○○ Sprint LTE
5:18 PM
75%
Messages
Reviewers
Details
Layer 2 doesn't scale
Text Message

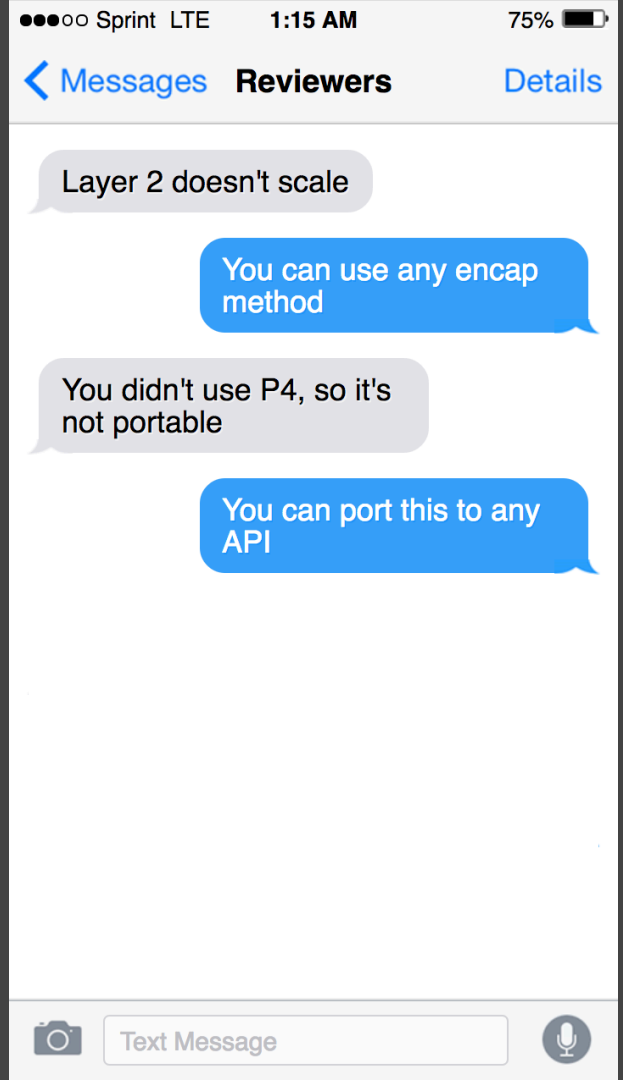

Sprint LTE
5:18 PM
75%
Messages
Reviewers
Details
Layer 2 doesn't scale
You didn't use P4, so it's not portable
Text Message

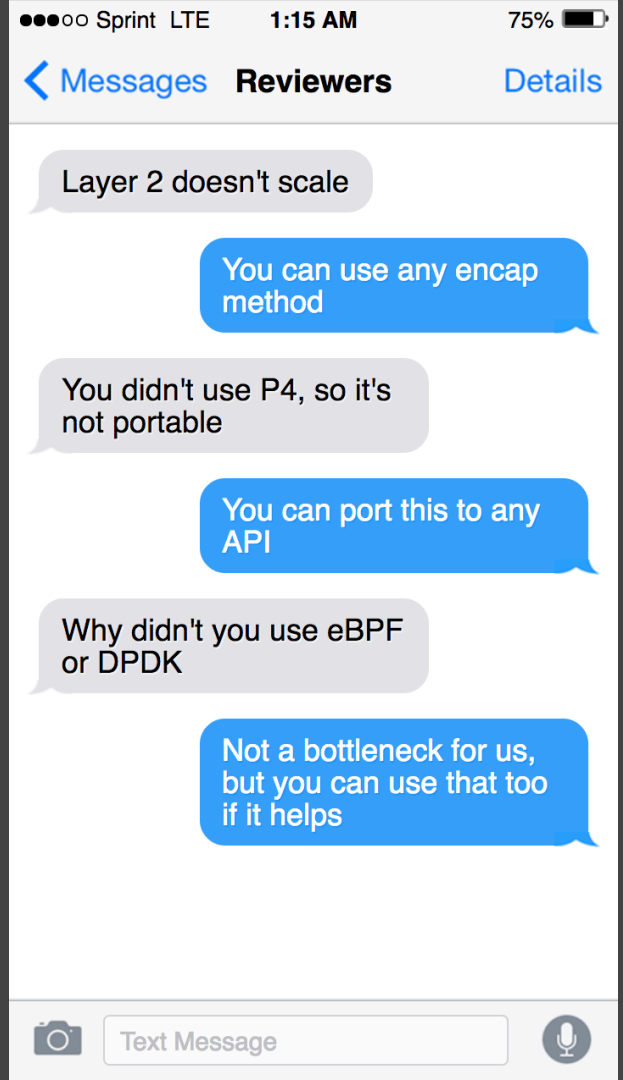

Sprint LTE
5:18 PM
75%
Messages
Reviewers
Details
Layer 2 doesn't scale
You didn't use P4, so it's not portable
Why didn't you use eBPF or DPDK?
Text Message

NSDI

the value is not in the implementation


●●●○○ Sprint LTE
1:15 AM
75%
Messages
Reviewers
Details
Layer 2 doesn't scale
You can use any encap method
Text Message


●●●○○ Sprint LTE
1:15 AM
75%
Messages
Reviewers
Details
Layer 2 doesn't scale
You can use any encap method
You didn't use P4, so it's not portable
You can port this to any API
Text Message


Sprint LTE
1:15 AM
75%
Messages
Reviewers
Details
Layer 2 doesn't scale
You can use any encap method
You didn't use P4, so it's not portable
You can port this to any API
Why didn't you use eBPF or DPDK
Not a bottleneck for us, but you can use that too if it helps
Text Message

NSDI

the value is in the design

NSDI

the value is in the design

Faild decomposes load balancing as a division of labour

- leverage hardware wherever possible - **no latency cost in expected case**
- push functions requiring state towards hosts - **low latency overhead in worst case**
- result is **efficient**, **resilient** and **graceful**
- many of the design patterns applicable to other networking environments

NSDI

…the design is now part of the architecture

Faild part of shift in economics of edge delivery, has since percolated through industry

Five years of dealing with the consequences of changing a fraction of the Internet:

- PMTUD in ECMP networks
- talking to vendors about broken hashing implementations and middleboxes
- raising awareness within transport community and academia

If you propose protocol changes, please take this paper into account

Additional materials

2015

- Networking @Scale presentation
- SREcon presentation

2016

- RFC7690 workarounds for PMTUD in ECMP
- blogpost covering Faild design

2017

- NANOG 70 presentation on broken hashing

fastly