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data centers' architecture and routing

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Description	Basics of Data Centers' Routing

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Multi-Path

in a nutshell

Multi-Path

- data center architectures allow to establish several paths between pairs of nodes
- Multi-Path routing is used to
  - distribute and balance the traffic among different paths
  - increase the fault tolerance

Multi-Path

- allows to have more than one next-hop for the same prefix in the FIB (Forwarding Information Base)
- needs kernel support
  - the main OSes and routers support it
- different usage policies can be applied
- packets of the same *flow* should use the same path
  - reordering packets is computationally heavy

Equal-Cost Multi-Path (ECMP)

- a specific approach to Multi-Path
- exploits paths to the same destination that have the same "cost"
  - e.g., same IGP cost, same number of hops
- allows to choose among the available paths in a uniform way
- often used in Fat-Tree data centers
  - we'll get there in a couple of slides

how packets are forwarded

- for each packet, the kernel decides the FIB entry to be used
- different policies are allowed
  - hash-based policy
    - Layer-3 hash (src IP, dst IP)
    - Layer-4 hash (src IP, dst IP, src port, dst port, protocol)
  - round-robin

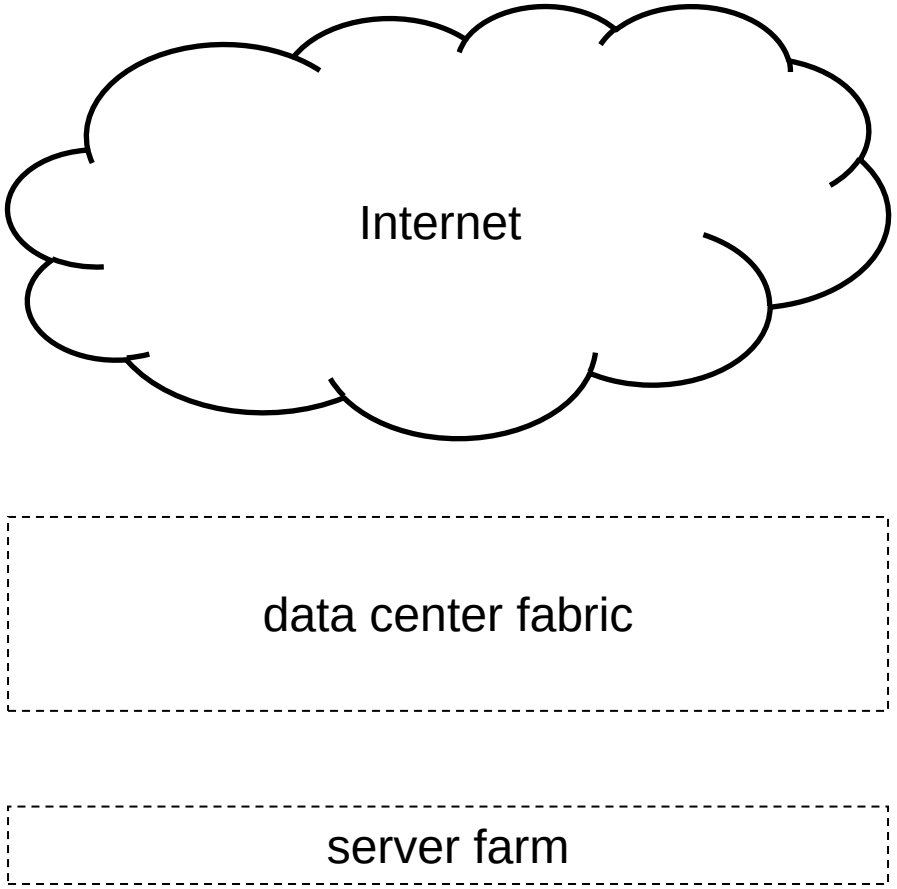
Hyper-scale Data Centers

main concepts

a high-level architecture

- Internet connections
  - multiple redundant high-speed fiber optic links
- fabric
  - infrastructure designed to transport packets between servers and between servers and Internet
- server farm
  - host applications and services

a high-level architecture



fabric architecture

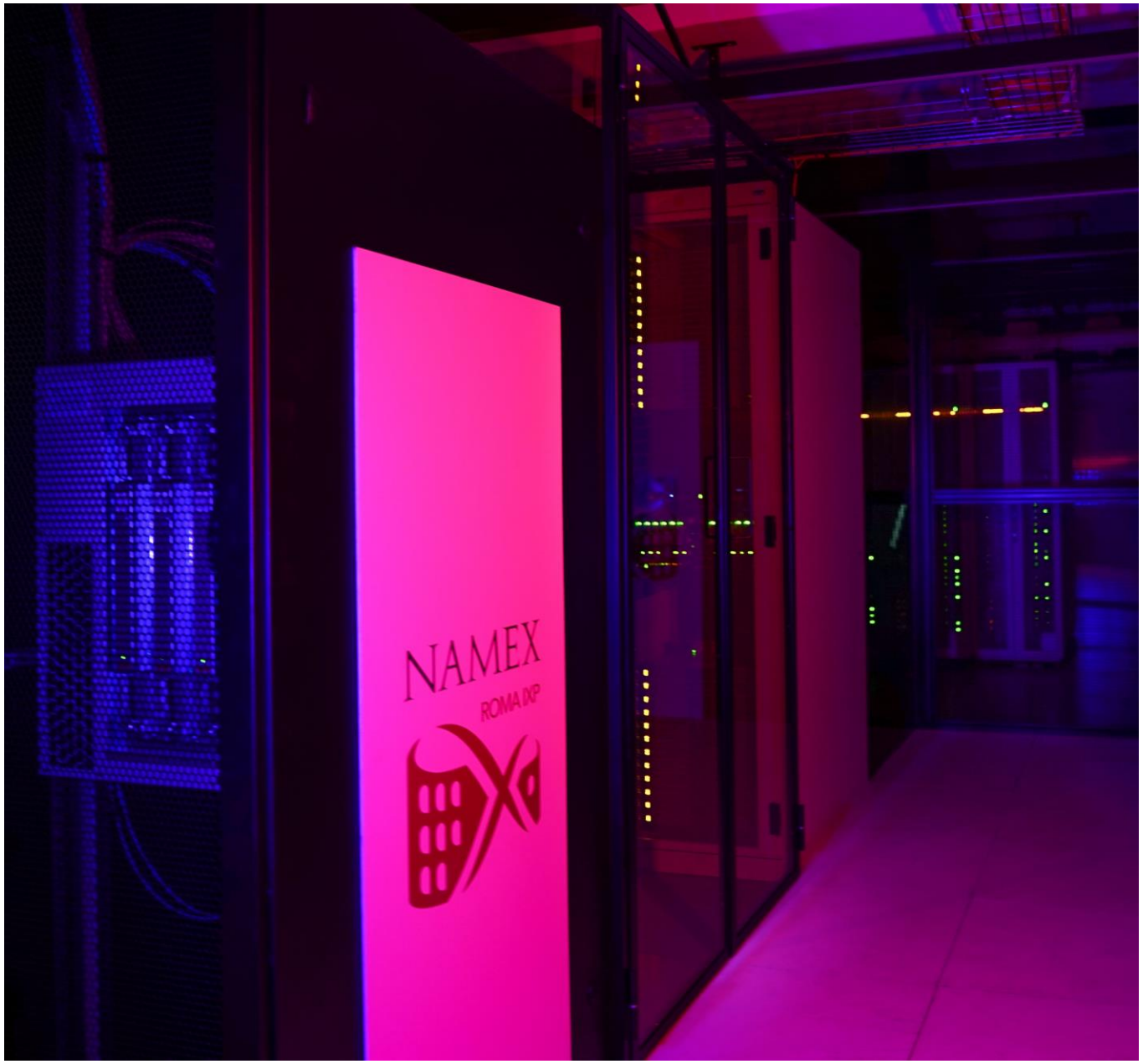
why Fat-Trees?

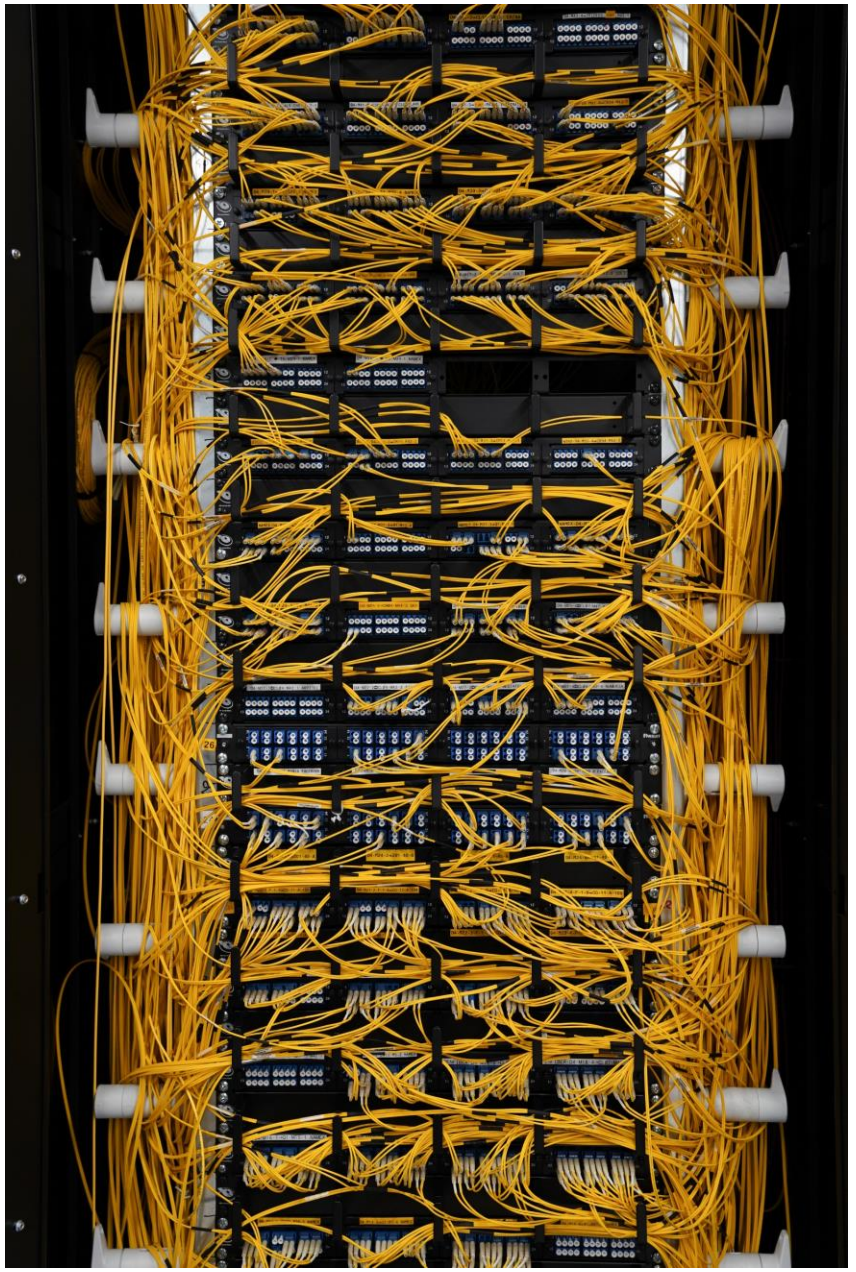
overview – fabric architecture

- real-life data centers
- service model
- data center network
  - traffic flow directions
  - requirements
  - components
  - topologies

real data center information – figures

- links are fiber optic links
- each link in the fabric is at least at 100Gb/s
- each switch is at least of 64 ports
- about 5,000 switches/routers
- about 60,000 servers





data center failures – yearly report

statistics by Google (2008) in a *portion* of data center composed of 1,800 servers:

- 1,000 individual machine (switch/router or server) failures
- thousands of hard drive failure
- 1 power distribution unit failure
  - down for 500/1000 machines for 6 hours
- 1 cluster complete rewire (not simultaneously)

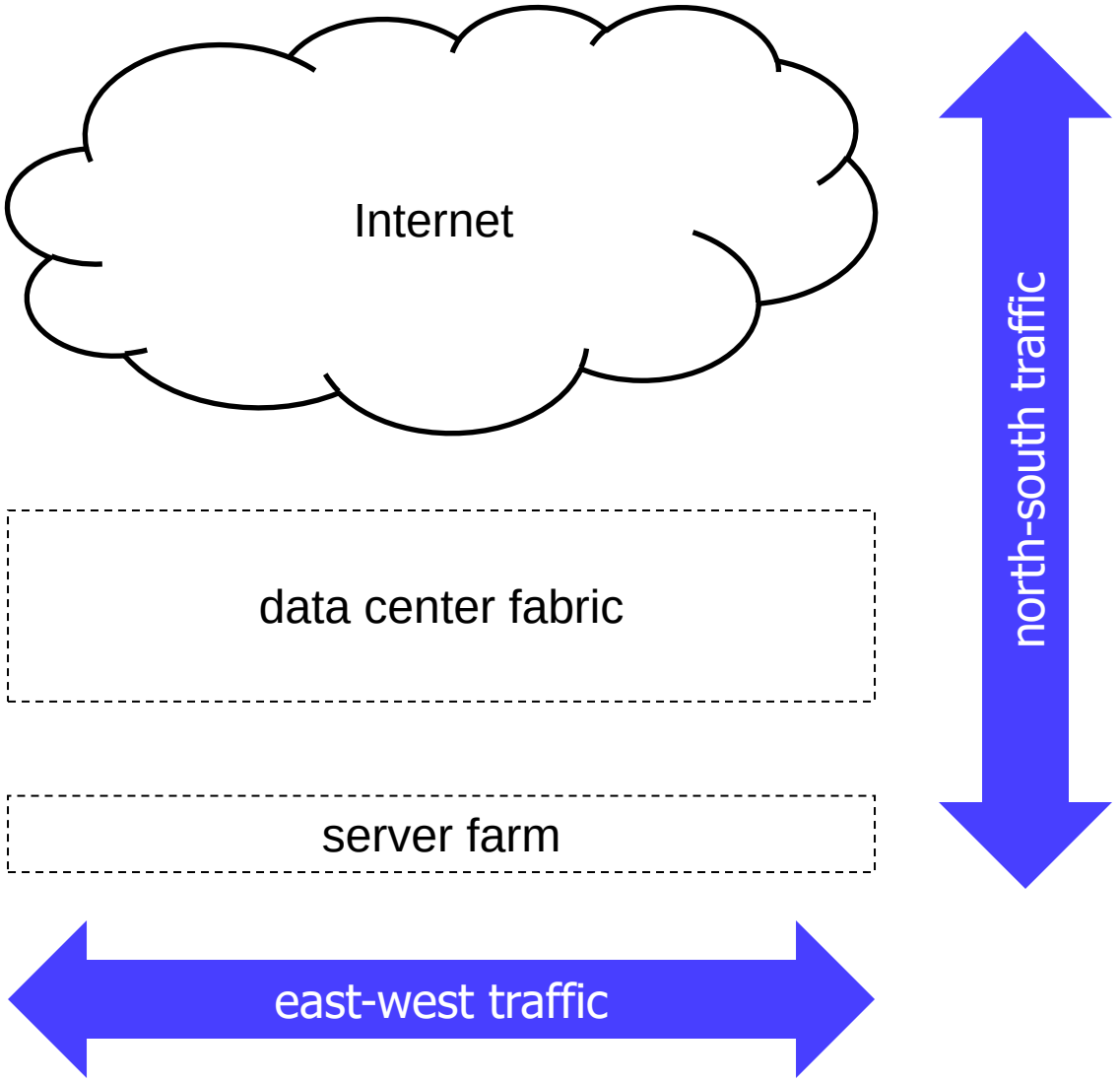
data center service models

- three different service models
  - on-premise data centers
    - built, owned and operated by a company
    - often housed in a building of the organization
  - colocation data centers
    - built and owned by a company that rents space within the data center to other companies
      - the hosting company manages the infrastructure (building, cooling, bandwidth, security etc.)
      - the hosted companies provides the components, including servers, storage, and firewalls
  - cloud data centers
    - applications and data are hosted by a cloud service provider such as Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform (GCP)

traffic flows inside a data center

- two types of flows can be identified
  - traffic exiting or entering the data center
    - also called “north-south traffic”
    - data sent/received via Internet
  - server-to-server communications
    - also called “east-west traffic”: in data center schemata servers are typically drawn side-by-side
    - primarily, supports micro-services and distributed architectures

traffic flows inside a data center



data center network requirements

- support high-bandwidth server-to-server communication
  - applications that rely on cluster computations, such as Hadoop or Spark, can involve hundreds or thousands of servers
  - customer's containers/virtual machines (VMs) are distributed across multiple servers but need to communicate seamlessly
  - microservice architectures heavily rely on server-to-server communication
- scale
  - data centers range from a few hundred to a hundred thousand servers in a single physical location
- resilience
  - data center applications are designed to work in presence of failures

data center network components

- data center nodes can be connected by using two network component types
  - specialized hardware
    - proprietary hardware that can scale to clusters of thousands of nodes with high bandwidth
      - e.g., Google Jupiter and InfiniBand switches
    - expensive option
  - commodity switches and routers
    - cheap option
    - widely adopted, this is the option we consider in the following

topology requirements

- scalability
  - it should be possible to expand the data center
  - in other words, it must be possible to buy and deploy hardware similar to the one already deployed
- bandwidth
  - hosts in the fabric should communicate with each other using the full bandwidth of their NICs

data center network topologies

- several topologies have been proposed
  - Clos
  - Fat-Tree
  - VL2
  - Jellyfish
  - Xpander
  - DCell
  - ...

Clos topology

- invented by Edson Erwin in 1938 to address scalability issues in telephone networking
  - formalized by Charles Clos in 1953
- the original problem was allowing N contemporary connections from N input lines to N output lines without using a single crossbar switch

Fat-Tree topology

- Fat-Trees were originally introduced by Charles Leiserson in 1985
- the Fat-Tree is a special case of a Clos
- typical Fat-Tree architectures today consist of three level of nodes (switches/routers)
- high redundancy
- constant *bisection* of the available bandwidth
- typically, nodes have the same characteristics
  - easier to stock spare equipments

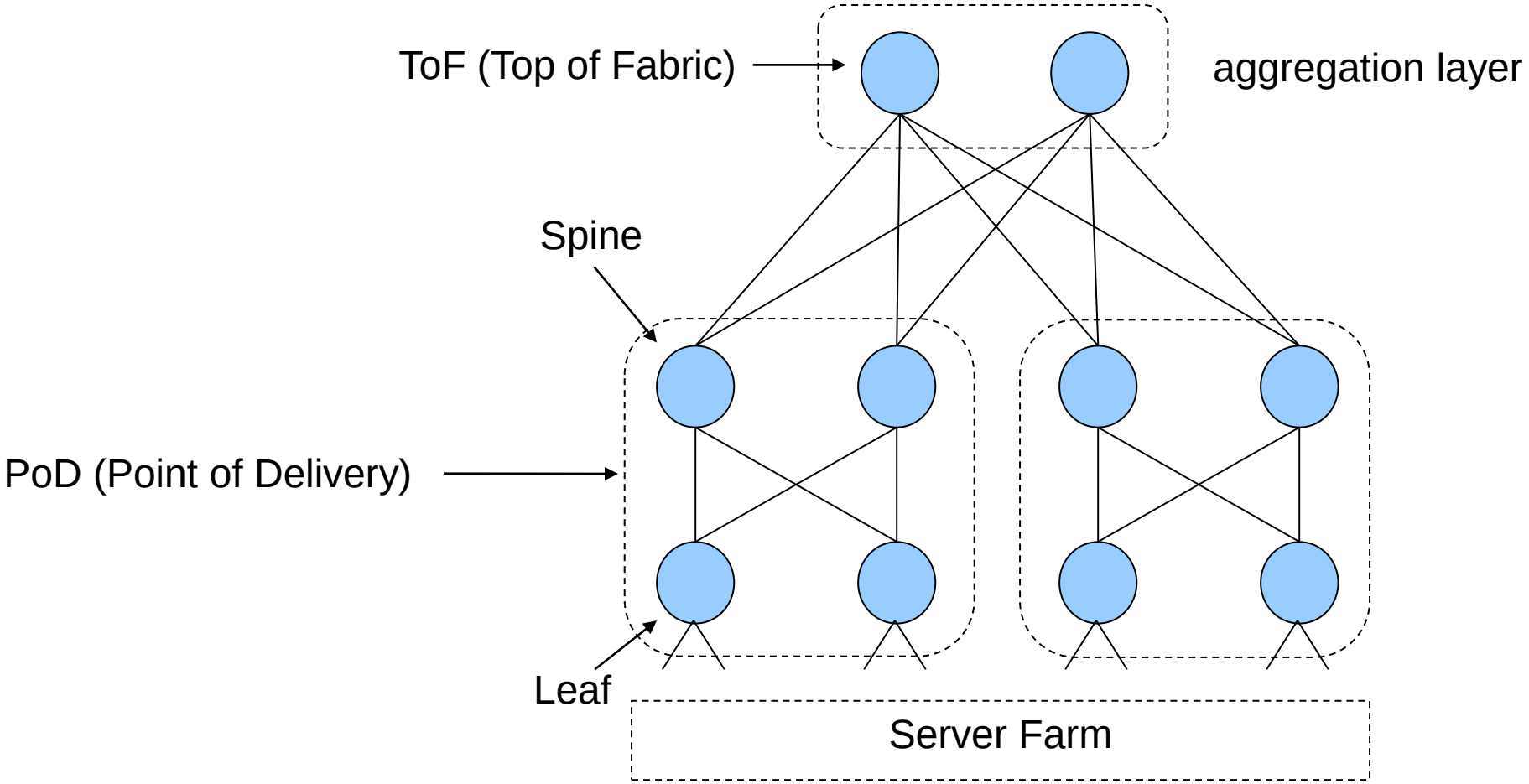
Fat-Tree parameters

- the Fat-Tree is a modular topology
- two parameters define a Fat-Tree
  - *radix* of the nodes (even number, denoted by 2K)
    - number of available ports
  - *redundancy factor* (denoted by R)
- usually, if the radix of a node is 2K it has K connections towards the north and K connections towards the south
  - different choices are possible, but not considered here

Fat-Tree nodes

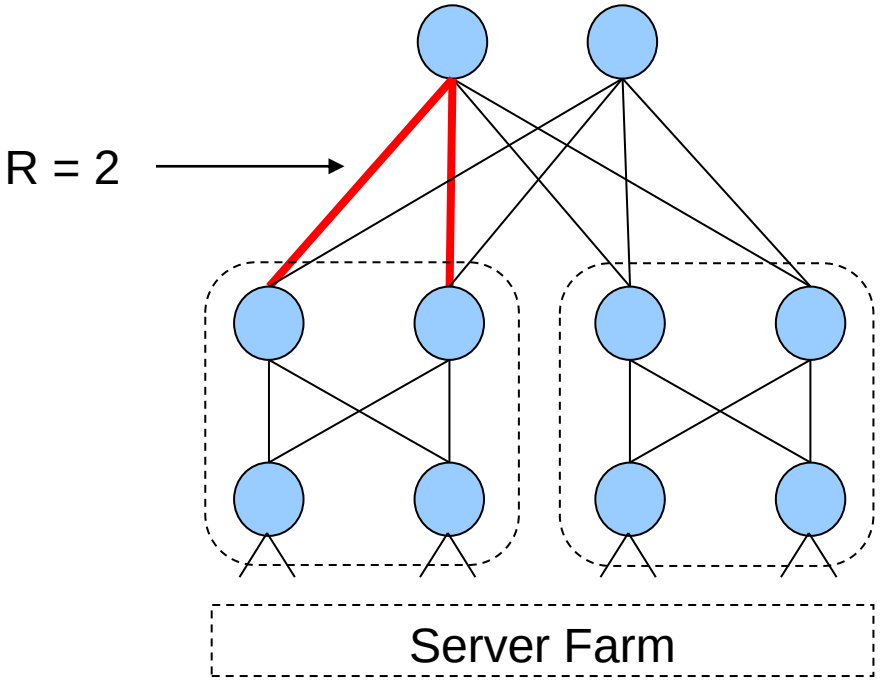
- Leaf
  - node connected to the server farm
- Spine
  - node north of Leaves and south of ToF nodes
- Point of Delivery (PoD)
  - set of fully interconnected Leaves and Spines
- Top of Fabric (ToF)
  - set of top nodes that provide inter-PoD communication

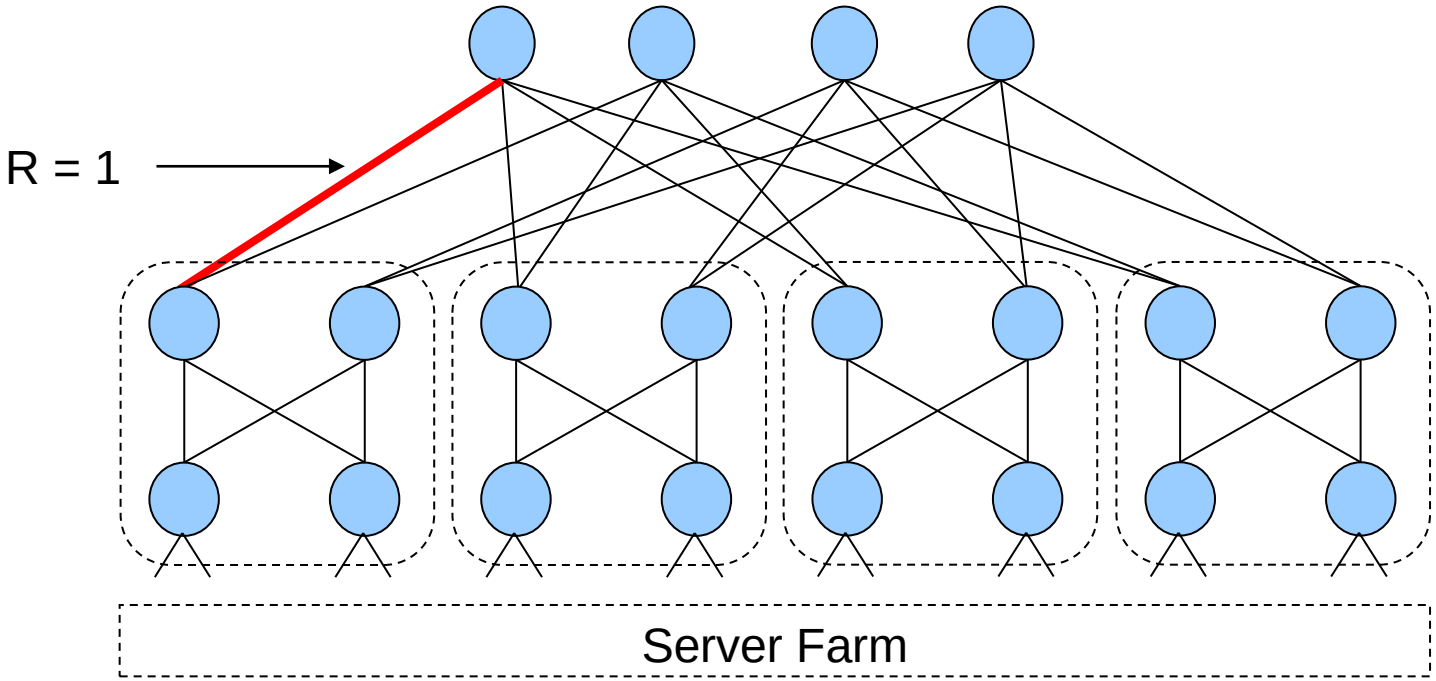
an example of Fat-Tree: FT(K=2,R=2)



redundancy factor (R)

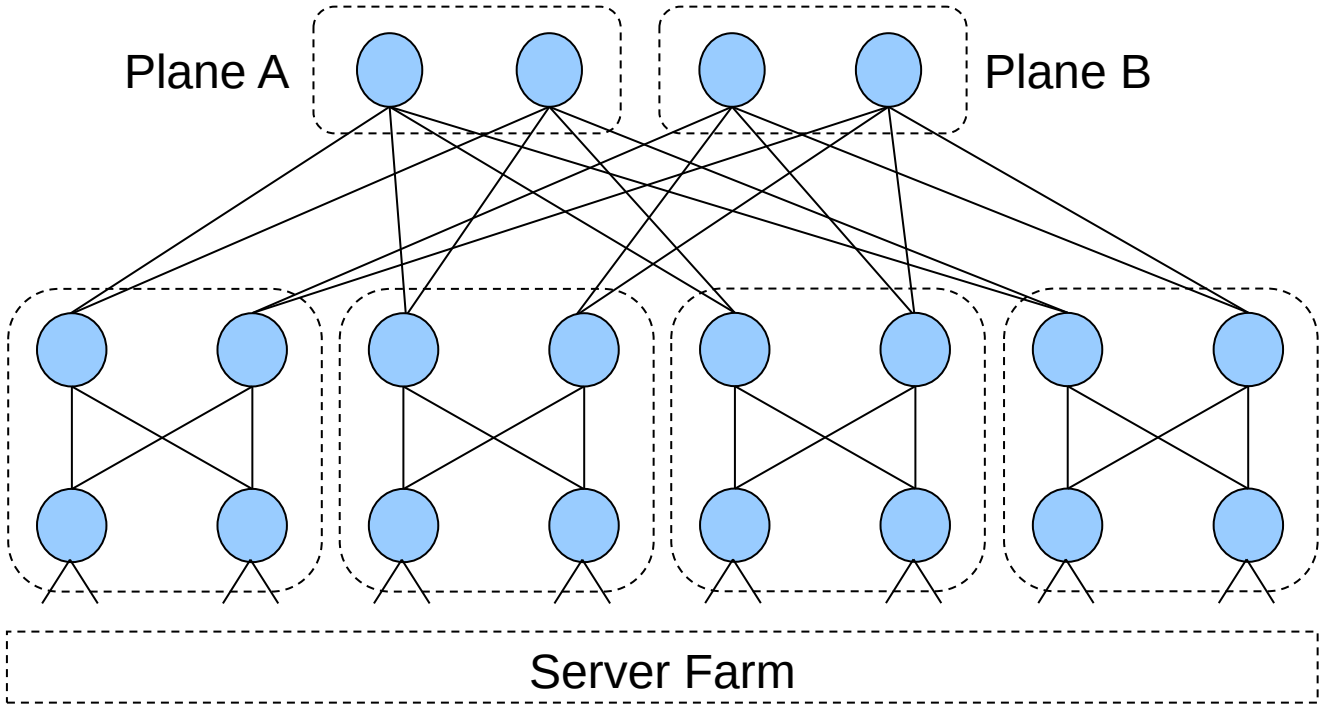
- number of links between a ToF node and a PoD
- allow to connect more PoDs reducing the redundancy





multi-plane Fat-Tree

- when K≠R the Fat-Tree is called *multi-plane*
- the ToF nodes are partitioned in sets called *planes*



example of a multi-plane Fat-Tree

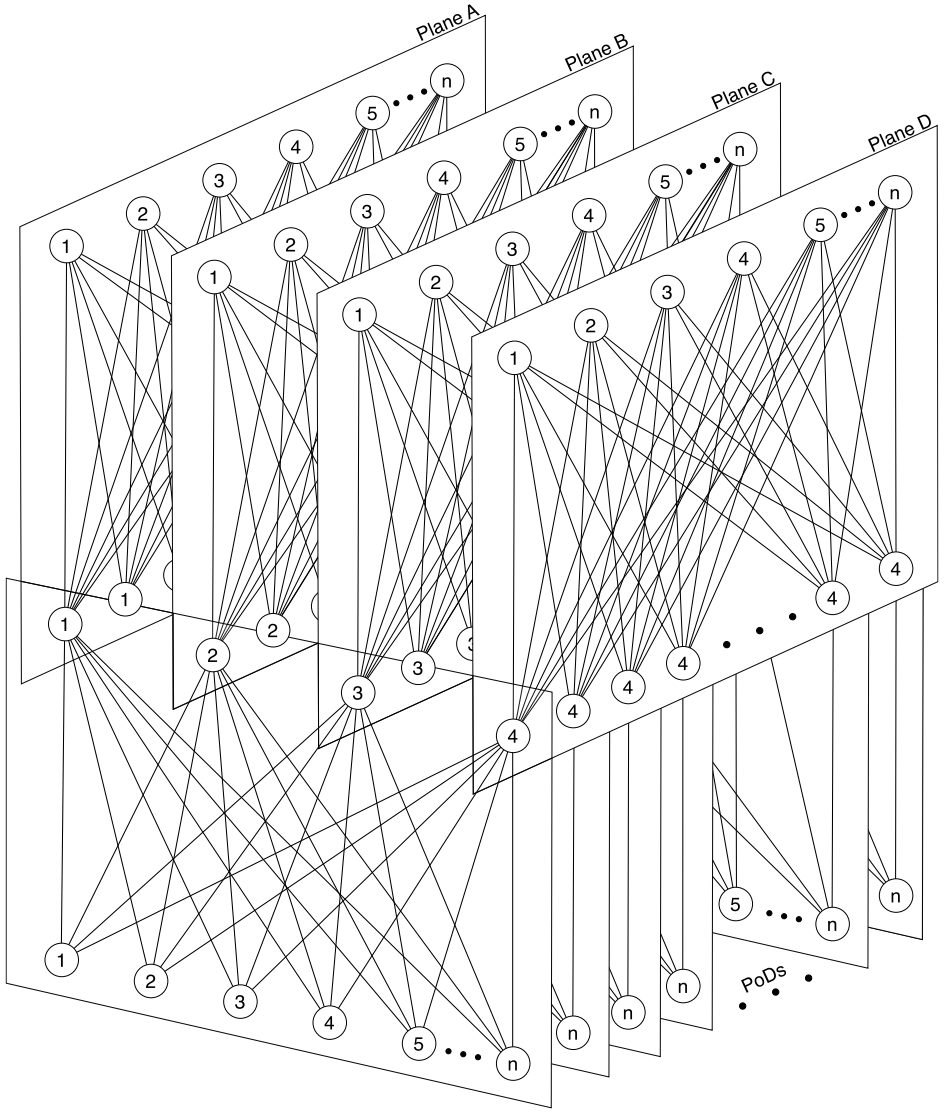
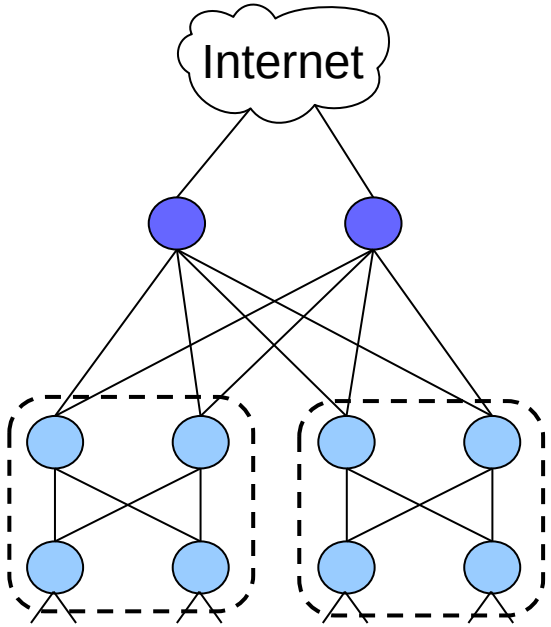
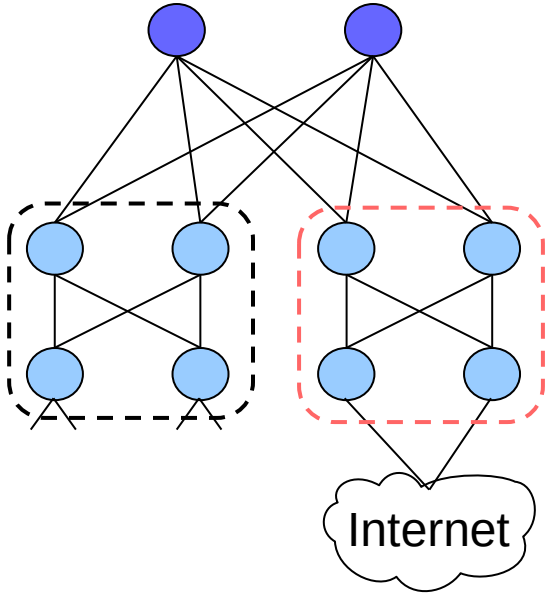


diagram from the
IETF RIFT Draft

connecting a Fat-Tree to the Internet

- two strategies
  - usage of a dedicated PoD
  - usage of ToFs





routing in Fat-Trees

why BGP?

overview – routing

- why routing and not switching?
- the choice of the routing protocols
- why using BGP in Fat-Tree data centers?
- inter-domain routing VS data center routing
- BGP in the data center

why routing and not switching?

	Pros	Cons
Switching (L2)	No configuration needed	• STP protocol has no multipath support • Using VLANs for load balancing is tricky • Broadcast traffic flooding the network
Routing (L3)	Multipath support	• Need of routing protocols • Complex configuration • Need of automating the configuration

choosing a routing protocol

- there are many possibilities, among them
  - a classical IGP protocol (e.g., OSPF, IS-IS)
  - BGP (most used in Hyperscale data centers)
  - RIFT (Routing In Fat-Trees)
    - Under standardization at IETF
    - Designed for Fat-Trees topologies
  - OpenFabric
    - IS-IS variant created for Clos topologies
  - SDN Protocols

why using BGP in Fat-Tree data centers?

- BGP has several stable and robust implementations, even open-source
  - e.g., FRRouting, Quagga
- BGP generates less flooding than common IGPs (IS-IS, OSPF, etc.)
  - if a received update does not change the best route, a BGP speaker does not propagate the update
- BGP natively supports ECMP (Equal-Cost Multi-Path)
  - Fat-Trees have many paths with the same length

why using eBGP? (and not iBGP)

- the most obvious choice would be to use iBGP since the data center networks is under the same administration
- however, eBGP is always used because
  - eBGP is easier to setup, no need for IGP
    - with iBGP, the IGP would compute routes
  - iBGP multipath support has some limitations
    - can be overcame, but it is complex

inter-domain routing VS DC routing

inter-domain routing	**data centers' routing**
the internet has relatively sparse connectivity	data centers' networks have very dense connectivity
stability is preferred over quick convergence	quick convergence is preferred over stability
the aim is computing a single best path for each destination	the aim is computing multiple paths to each destination

BGP in the data center

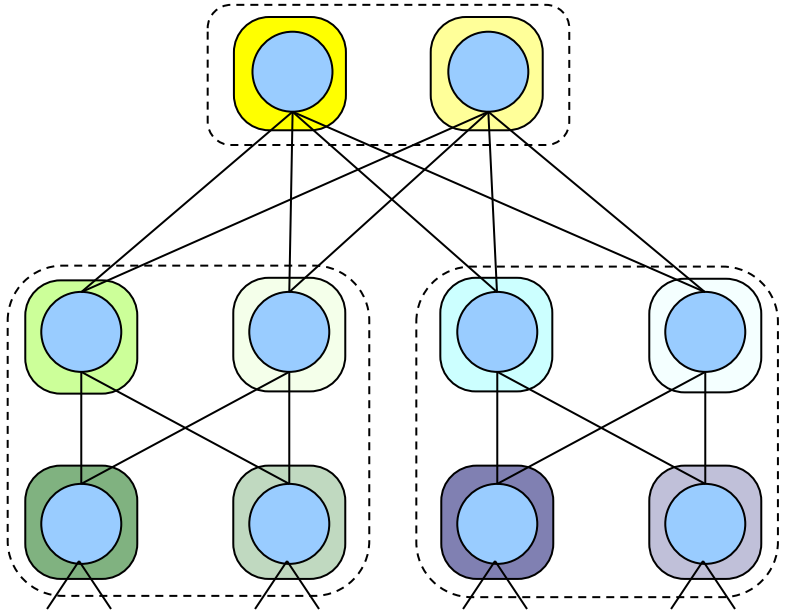
- BGP was primarily devised for inter-domain routing
  - default configurations are not suitable in a data center
- needs some tweaks described in RFC-7938
  - AS numbers assignment
  - ECMP *policy relax*
  - timer adjustment

AS numbers assignment

- global ASNs are not used in the data center
  - they can be misleading
    - because operators associate them with names
  - they are dangerous
    - an accidental leakage of the internal BGP notifications to the internet may be disruptive
- private ASNs are generally used
  - the 2-byte ASNs allow only 1,023 private ASes in the range 64512–65534
  - the 4-byte ASNs support almost 95 million private ASes in the range 4,200,000,000–4,294,967,294

ASes and routers

- the most obvious choice would be assigning a different ASN to each node
- however, this approach would lead to BGP *path exploration* issues

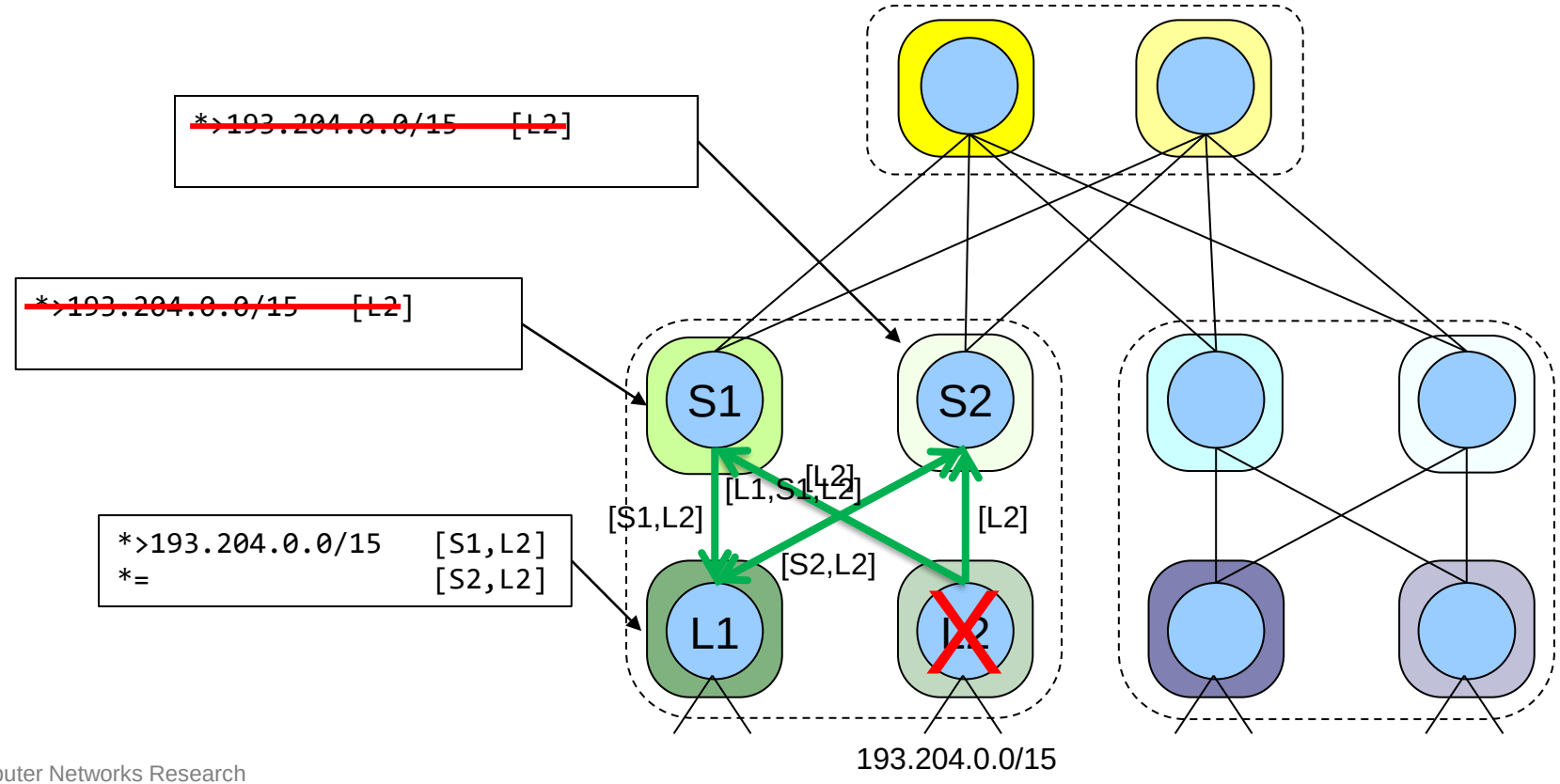


BGP path exploration

- immediately after a fault there is a transient period when inconsistent AS-paths are propagated in the network
  - routers have plenty of alternatives and jump from one to another before all alternatives are withdrawn
  - each best route change is propagated again by the routers
  - lots of useless BGP updates are transmitted
- since data centers' topologies are dense and hence have a lot of cycles this problem has to be addressed

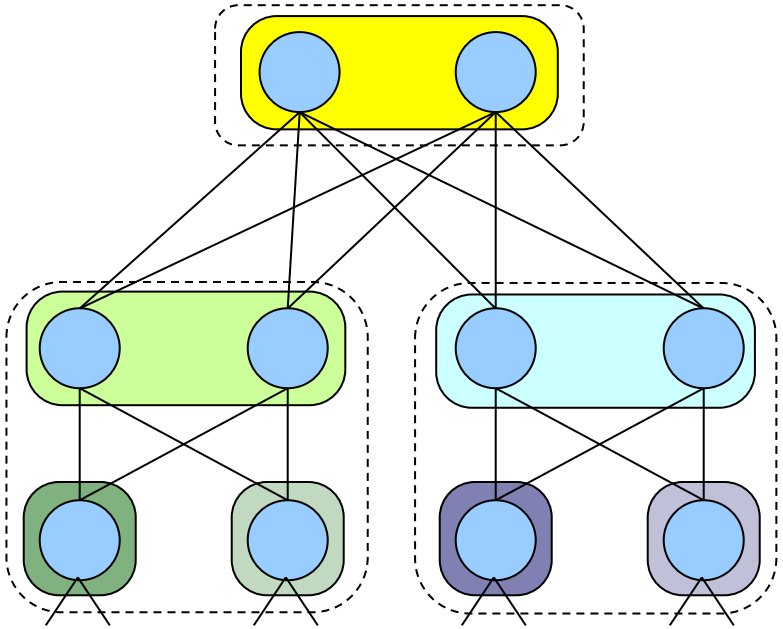
the problem of BGP path exploration

- because of the adopted AS scheme several fake routes could be possible during path exploration



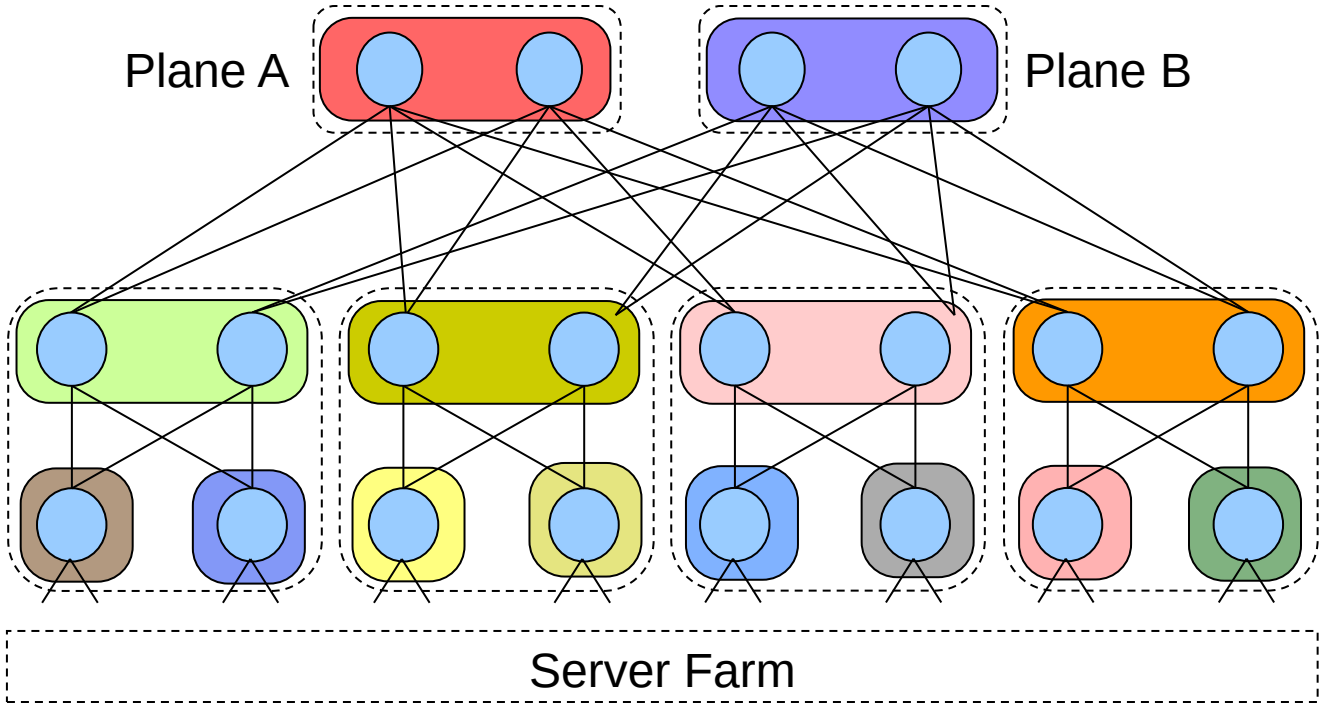
the ASes scheme of choice

- each Leaf is a different AS
- the Spine nodes of each PoD belong to the same AS
- the ToF nodes of the same plane belong to the same AS



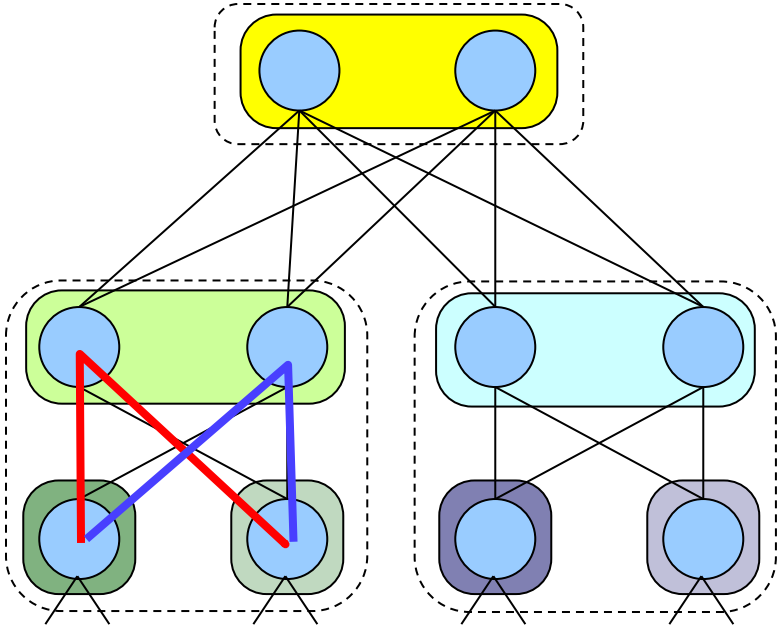
BEWARE: there are NO iBGP peerings

the ASes scheme of choice – multi-plane



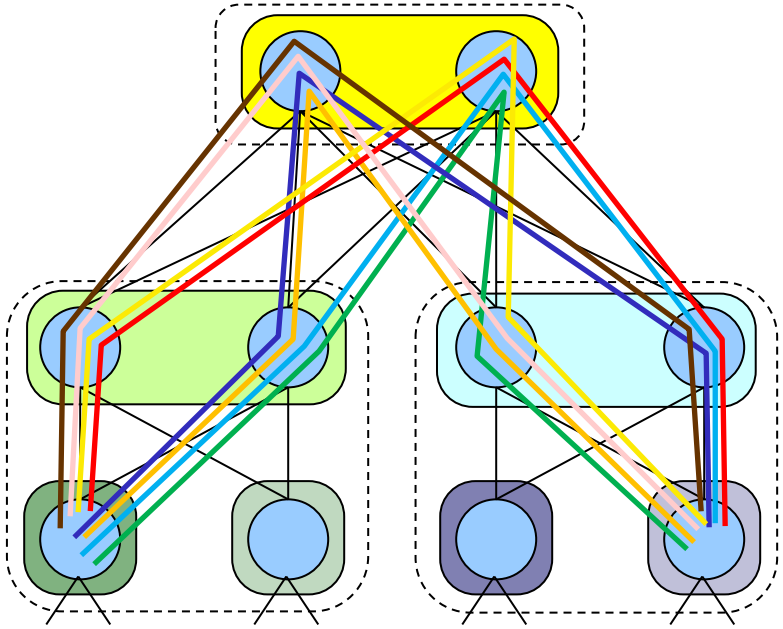
multiple paths between Leaves

- the adopted AS scheme allows for multiple paths between pairs of Leaves
  - in a FT(K=2,R=2) only two paths are possible between two Leaves of the same PoD
    - they don’t leave the PoD



multiple paths between Leaves

- the adopted AS scheme allows for multiple paths between pairs of Leaves
  - in a FT(K=2,R=2) eight paths are possible between two Leaves of different PoDs



BGP and ECMP

- BGP natively supports ECMP
- by default, BGP considers two announcement of the same prefix "equal" if they are equal in each best-path selection criterion except for the last one
  - lowest router-id of the announcing peer
- to enable multi-path, BGP requires that the AS-paths selected for multi-path match exactly
  - not just they have equal-length but equal AS numbers inside

BGP multi-path relax

- when the AS_PATH lengths of different announcements for the same prefix are the same, the best-path algorithm skips checking for exact match of the AS numbers
- this modification is often called “as-path multipath-relax”
  - different vendors may use different names
- really needed for using dual attached servers and multi-plane Fat-Trees

tuning BGP timers

- there are four main timers that are responsible for BGP behaviour
  - advertisement interval timer
  - keepalive timer
  - hold timer
  - connect timer

advertisement interval timer

- announcements that need to be sent to a neighbor are bunched together and sent together only when the interval expires
  - then the timer is reset for that neighbor
- the default value for eBGP is 30s
  - in interdomain routing this improves stability and reduces the number of multiple updates for the same prefix
- in data centers is set to 0s
  - it is required for fast convergence

keepalive and hold timers

- each BGP peer sends periodic keepalive messages to its neighbors according to the keepalive timer
- when a peer doesn’t receive a keepalive for a period greater than the hold timer
  - the connection is dropped
  - all the announcements received are considered invalid
  - the peer tries to re-establish the connection
- by default, the keepalive timer is 60s and the hold timer is 180s
- in data centers timers of 3s and 9s are used, respectively

connect timer

- when a connection to a peer fails, BGP waits for the connect timer expiration before attempting to reconnect
  - the connect timer by default is 60s
  - this can delay session re-establishment when a link recovers from a failure or a node powers up
- in data centers it is set to 10s

automating the configuration

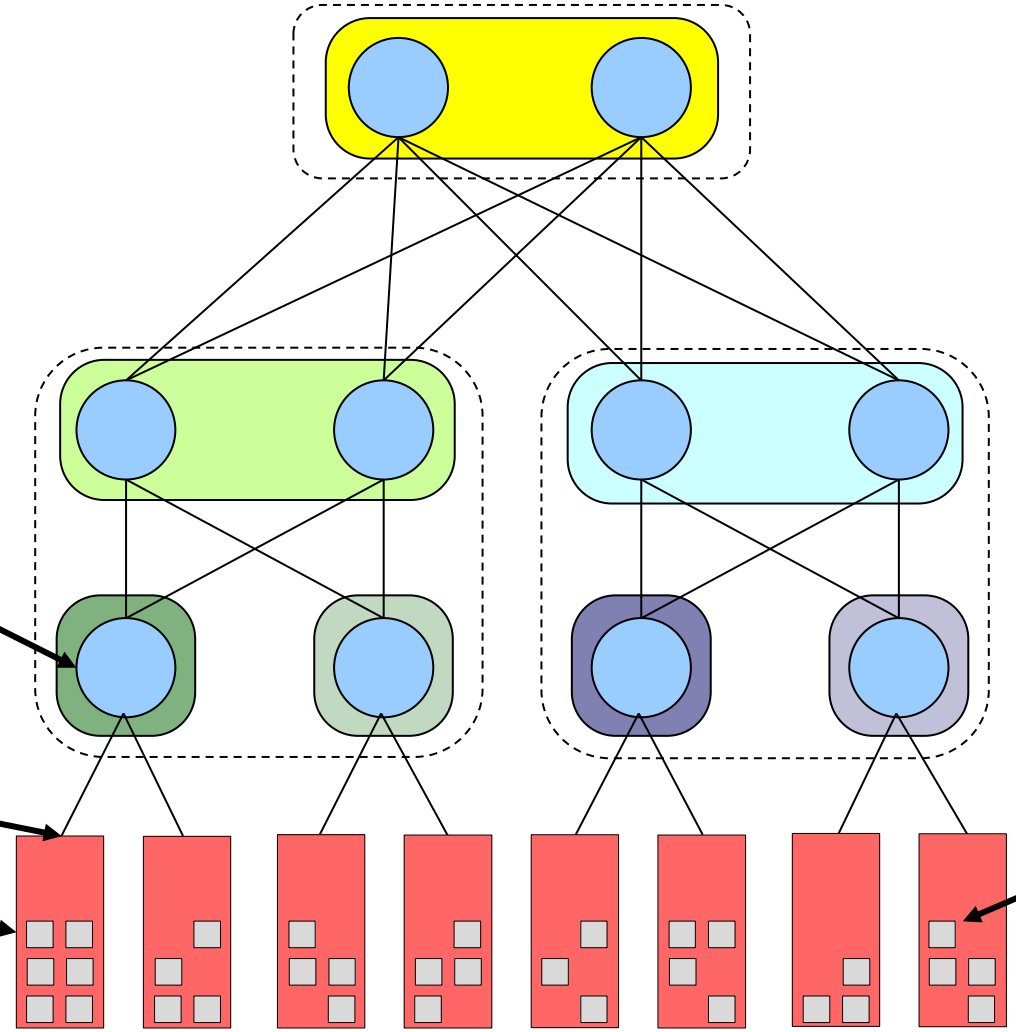
- unnumbered interfaces
  - used to establish peerings specifying the interface name rather than the IP address and the remote AS number
- peer groups
  - used to specify policies for groups of peers

connecting the servers

each Leaf announces its server's prefix

IPs are assigned directly to the servers

Servers



Containers or VMs

disadvantages

- containers/VMs share the same IP prefix of the server
  - no possibility to move containers between servers without IP remapping
- tenants must follow the IP plan of the data center
  - cannot expose containers with custom IPs
- there is no isolation between
  - the data center traffic and the tenants traffic
  - different tenants

basic Fat-Tree lab

hands on Kathará

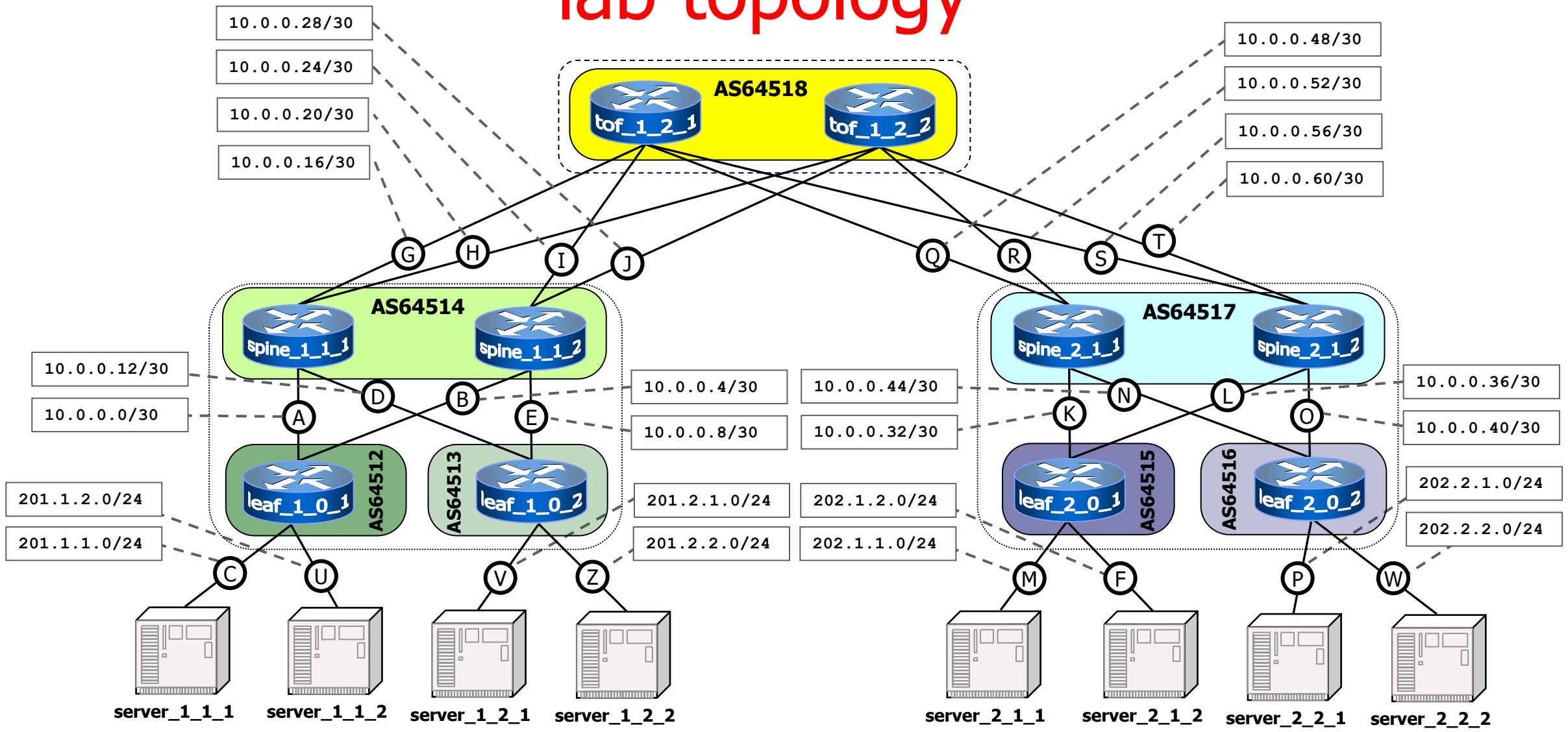
lab pre-conditions

- Linux and macOS
  - no specific requirement
- Windows
  - WSL 2 does not support Multi-Path
  - need to fallback to Hyper-V Docker backend
    - open Docker Desktop and go to Settings (cog in the top-right corner)
    - unselect the “Use the WSL 2 based engine” checkbox
    - click “Apply & restart”
  - or create a VM with a Linux distribution

naming convention

- tof_x_y_z
  - x: plane number
  - y: level, always 2
  - z: ToF number
- spine_x_y_z
  - x: PoD number
  - y: level, always 1
  - z: Spine number
- leaf_x_y_z
  - x: PoD number
  - y: level, always 0
  - z: Leaf number
- server_x_y_z
  - x: PoD number
  - y: corresponding Leaf number
  - z: server number

lab topology



ToF configuration example

bgpd.conf

```
router bgp 64518
 timers bgp 3 9
 bgp router-id 192.168.0.14
 no bgp ebgp-requires-policy
 bgp bestpath as-path multipath-relax

neighbor fabric peer-group
 neighbor fabric remote-as external
 neighbor fabric advertisement-interval 0
 neighbor fabric timers connect 10
 neighbor eth0 interface peer-group fabric
 neighbor eth1 interface peer-group fabric
 neighbor eth2 interface peer-group fabric
 neighbor eth3 interface peer-group fabric

address-family ipv4 unicast
  neighbor fabric activate
  maximum-paths 64
exit-address-family
```

- set keepalive and hold timers
- BGP multi-path relax
- create a peer-group
- all peers of the group are eBGP. The remote ASN is inferred
- set advertisement interval timer
- set connect timer
- add interfaces to peer-group for unnumbered peering
- enable A.F. to peer-group
- maximum Multi-Path possibilities

Spine configuration example

bgpd.conf – part 1

```
router bgp 64514
 timers bgp 3 9
 bgp router-id 192.168.0.5
 no bgp ebgp-requires-policy
 bgp bestpath as-path multipath-relax

neighbor TOR peer-group
 neighbor TOR remote-as external
 neighbor TOR advertisement-interval 0
 neighbor TOR timers connect 10
 neighbor eth0 interface peer-group TOR
 neighbor eth1 interface peer-group TOR

neighbor fabric peer-group
 neighbor fabric remote-as external
 neighbor fabric advertisement-interval 0
 neighbor fabric timers connect 10
 neighbor eth2 interface peer-group fabric
 neighbor eth3 interface peer-group fabric
```

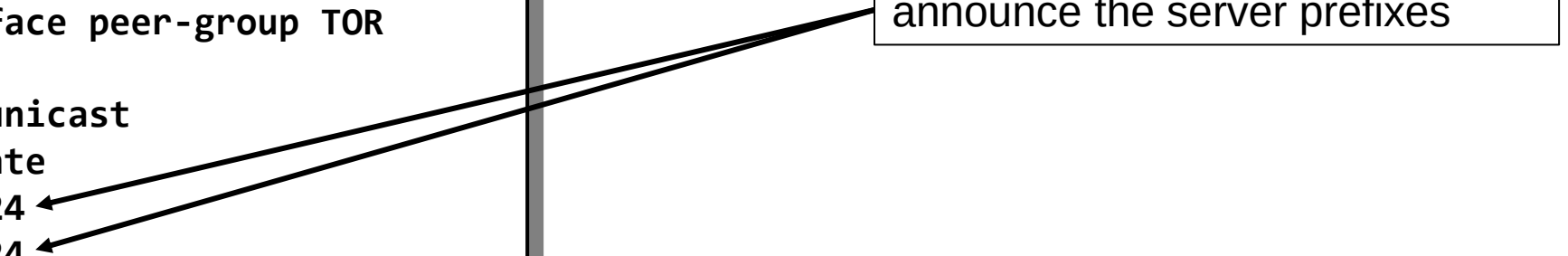
bgpd.conf – part 2

```
address-family ipv4 unicast
  neighbor fabric activate
  neighbor TOR activate
  maximum-paths 64
exit-address-family
```

Leaf configuration example

bgpd.conf

```
router bgp 64512
 timers bgp 3 9
 bgp router-id 192.168.0.1
 no bgp ebgp-requires-policy
 bgp bestpath as-path multipath-relax

neighbor TOR peer-group
 neighbor TOR remote-as external
 neighbor TOR advertisement-interval 0
 neighbor TOR timers connect 10
 neighbor eth0 interface peer-group TOR
 neighbor eth1 interface peer-group TOR

address-family ipv4 unicast
  neighbor TOR activate
  network 201.1.1.0/24
  network 201.1.2.0/24
  maximum-paths 64
exit-address-family
```

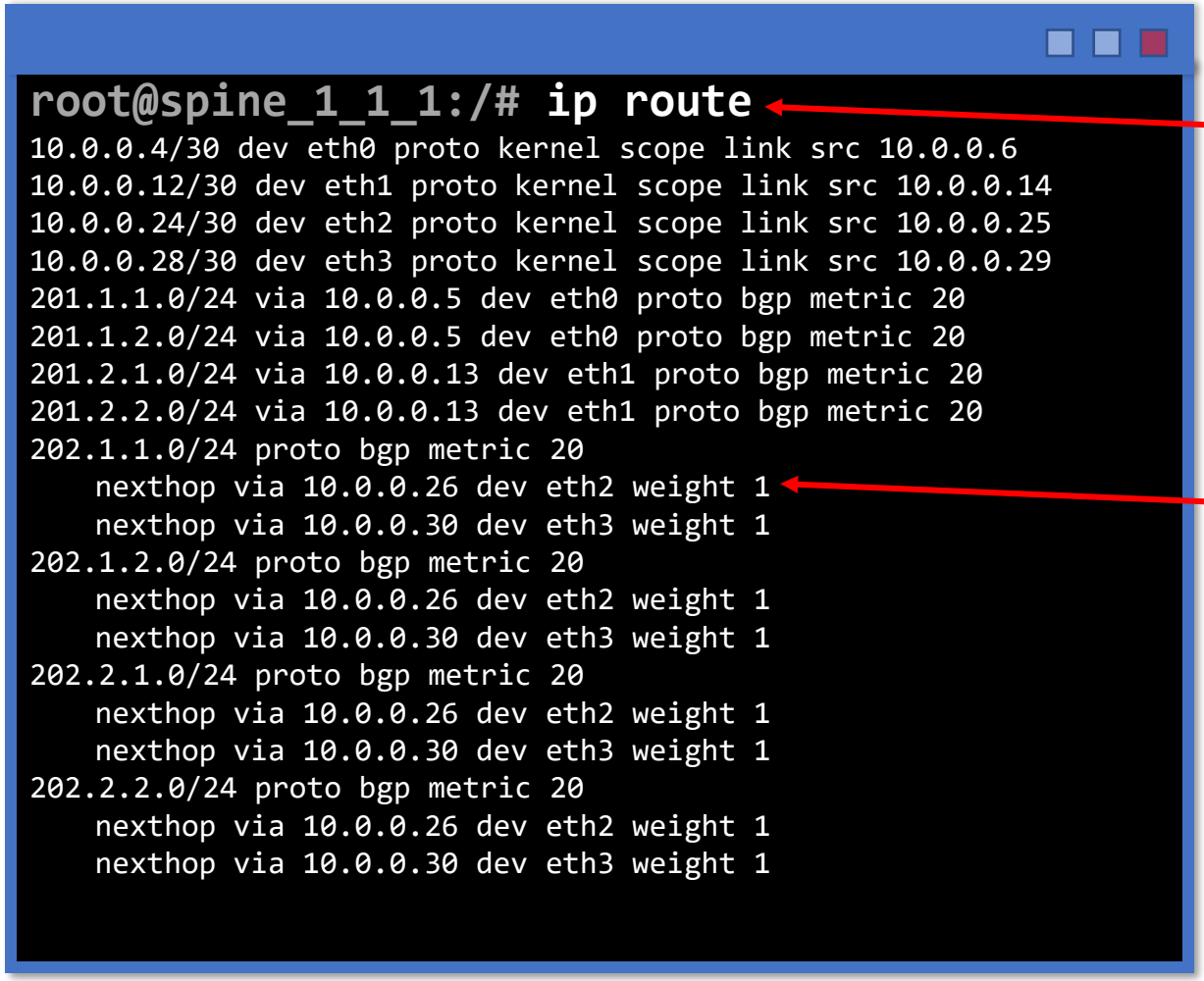


data plane

unable to view multi-path routes

```
root@spine_1_1_1:/# route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
10.0.0.4        0.0.0.0         255.255.255.252 U     0      0        0 eth0
10.0.0.12       0.0.0.0         255.255.255.252 U     0      0        0 eth1
10.0.0.24       0.0.0.0         255.255.255.252 U     0      0        0 eth2
10.0.0.28       0.0.0.0         255.255.255.252 U     0      0        0 eth3
201.1.1.0       10.0.0.5        255.255.255.0   UG    20     0        0 eth0
201.1.2.0       10.0.0.5        255.255.255.0   UG    20     0        0 eth0
201.2.1.0       10.0.0.13       255.255.255.0   UG    20     0        0 eth1
201.2.2.0       10.0.0.13       255.255.255.0   UG    20     0        0 eth1
202.1.1.0       10.0.0.26       255.255.255.0   UG    20     0        0 eth2
202.1.2.0       10.0.0.26       255.255.255.0   UG    20     0        0 eth2
202.2.1.0       10.0.0.26       255.255.255.0   UG    20     0        0 eth2
202.2.2.0       10.0.0.26       255.255.255.0   UG    20     0        0 eth2
```

data plane



command to manage routing tables

multiple next-hop for the same prefix

control plane

```
spine_1_1_1# show ip bgp
BGP table version is 8, local router ID is 192.168.0.6, vrf id 0
Default local pref 100, local AS 64514
Status codes:  s suppressed, d damped, h history, * valid, > best, = multipath,
               i internal, r RIB-failure, S Stale, R Removed
Nexthop codes: @NNN nexthop's vrf id, < announce-nh-self
Origin codes:  i - IGP, e - EGP, ? - incomplete

   Network          Next Hop            Metric LocPrf Weight Path
*> 201.1.1.0/24     10.0.0.5                 0             0 64512 i
*> 201.1.2.0/24     10.0.0.5                 0             0 64512 i
*> 201.2.1.0/24     10.0.0.13                0             0 64513 i
*> 201.2.2.0/24     10.0.0.13                0             0 64513 i
*> 202.1.1.0/24     10.0.0.26                              0 64518 64517 64515 i
*=                  10.0.0.30                              0 64518 64517 64515 i
*> 202.1.2.0/24     10.0.0.26                              0 64518 64517 64515 i
*=                  10.0.0.30                              0 64518 64517 64515 i
*> 202.2.1.0/24     10.0.0.26                              0 64518 64517 64516 i
*=                  10.0.0.30                              0 64518 64517 64516 i
*> 202.2.2.0/24     10.0.0.26                              0 64518 64517 64516 i
*=                  10.0.0.30                              0 64518 64517 64516 i

Displayed  8 routes and 12 total paths
```

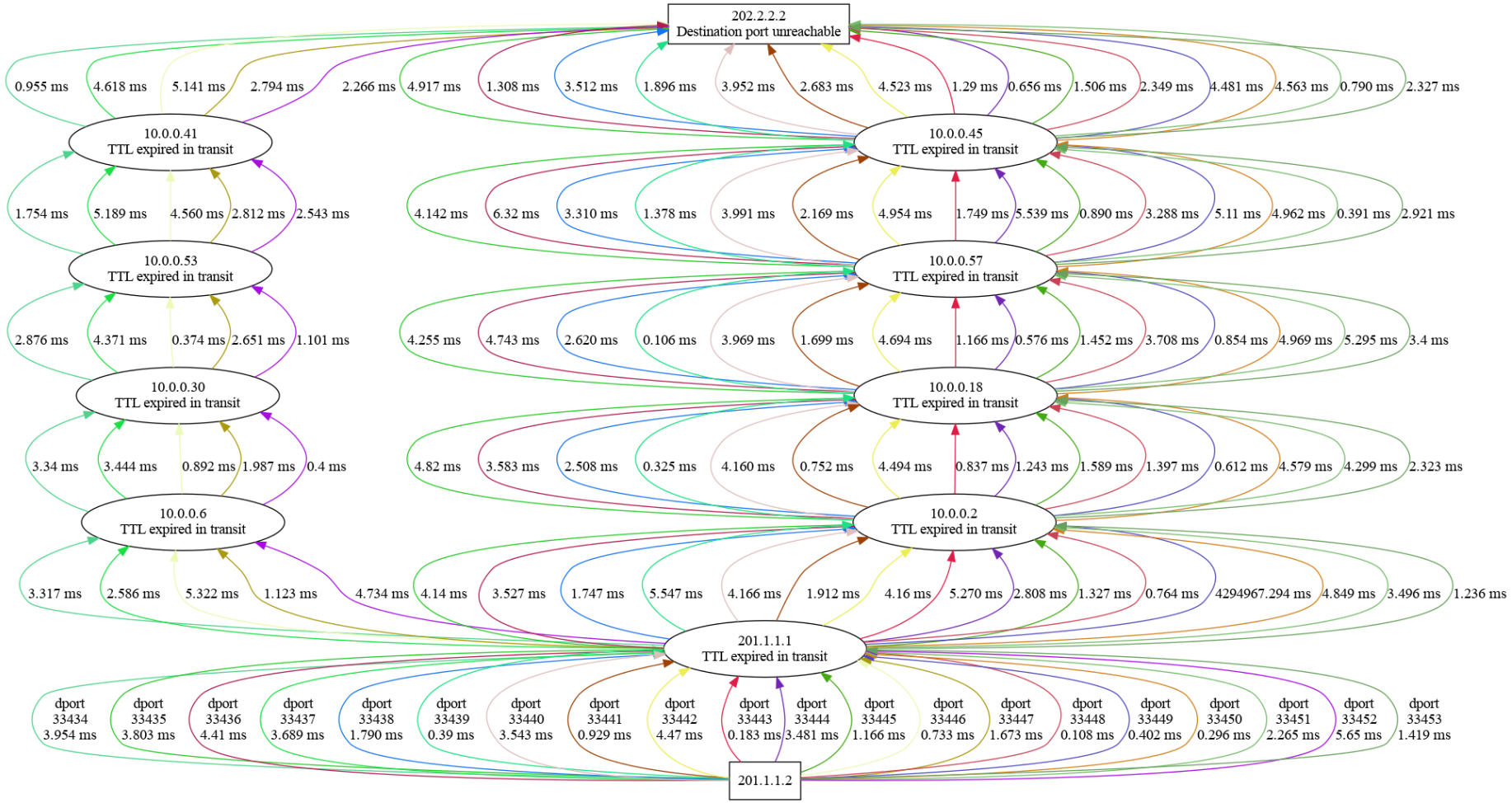
Multi-Path traceroute

- traditional traceroute may provide hard-to-interpret or even misleading results when used in presence of ECMP
- Multi-Path traceroute tools generate packet header contents to obtain a more precise picture of the actual routes of packets
  - allow all probes towards a destination to follow the same path in the presence of per-flow load balancing
  - allow a user to distinguish between the presence of per-flow load balancing and per-packet load balancing

Multi-Path traceroute

- two different tools:
  - `paris-traceroute`
    - traceroute designed to work in presence of Multi-Path and load balancers
  - `dublin-traceroute`
    - based on the `paris-traceroute`
    - adds a NAT detection technique
    - introduces visualization and analysis tools

dublin-traceroute example output



bibliography and further readings

- [Caiazzi ‘22] Caiazzi, Scazzariello, Alberro, Ariemma, Castro, Grampin, Di Battista, “Sibyl: a Framework for Evaluating the Implementation of Routing Protocols in Fat-Trees“, NOMS 2022
- [Caiazzi ‘21] Caiazzi, Scazzariello, Ariemma, “VFTGen: a Tool to Perform Experiments in Virtual Fat Tree Topologies“, IM 2021
- [Caiazzi ‘19] Caiazzi, “Software Defined Data Centers: methods and tools for routing protocol verification and comparison”, Ms. Thesis, Roma Tre University, 2019
- [Dutt ‘17] Dutt, “BGP in the Data Center”, O’Reilly, 2017
- [RFC-7938] Lapukhov, Premji, “Use of BGP for Routing in Large-Scale Data Centers” Internet Engineering Task Force (IETF) Request for Comments: 7938

how to handle multiple tenants?

again, why BGP?

overview – multiple tenants

- requirements
  - servers' architecture requirements
  - orchestration requirements
  - tenant requirements
- tunneling protocols
- VXLAN
- EVPN-BGP

servers' architecture requirements

- having services directly on bare metal is not used
  - too many physical servers needed
  - no way to scale if more resources are requested
  - no isolation between different services on the same server
- support a virtual layer of containers or VMs
  - high-availability guaranteed via orchestration
  - useful for resource-slicing
  - complete isolation between different containers or VMs on the same server
    - possibility to assign containers or VMs to different tenants

orchestration requirements

- an orchestrator is a software that manages the lifecycle of containers/VMs
  - creates, moves, and destroys containers/VMs
- needed for
  - optimal resource allocation, handling failures, management
- when moving a container/VM
  - possibility to keep network configurations (MAC/IP)
  - minimal downtime

tenant requirements

- each tenant wants to independently manage its own private IP address space
  - containers/VMs traffic must be segregated between tenants and between the data center traffic

consequence of requirements

- server, orchestration, and tenant requirements have a consequence
  - usage of tunnels

tunneling protocol requirements

- minimal configuration
- encapsulate the traffic of each tenant
  - an identifier of the tenant is needed
- encapsulation in Layer-4
  - to fully exploit IP Multi-Path
  - to traverse routers
    - data center fabric is Layer-3
  - to traverse Internet
    - different data centers must interconnect via Internet transparently (to create the so called *regions*)

possible choices for tunneling

- VLAN
  - can be used only in L2, the data center is L3
- MPLS
  - each router must be configured for each new tenant
  - traversing Internet requires ISP to configure intermediate routers
- VXLAN
  - created ad-hoc ☺

VXLAN

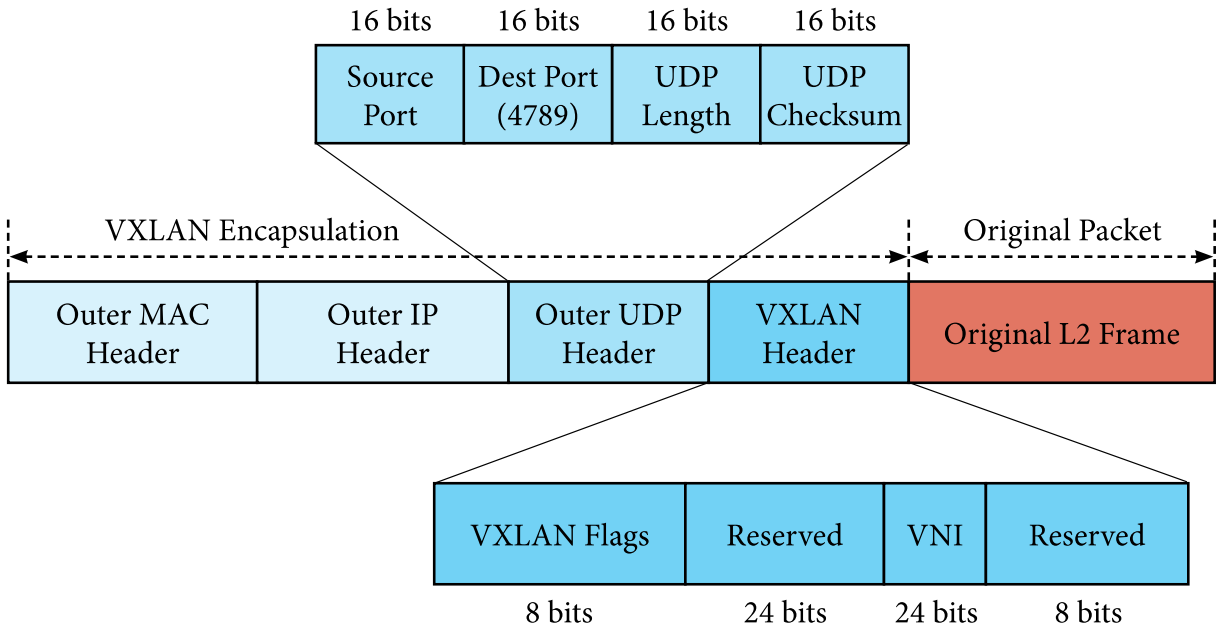
- Virtual eXtensible Local Area Network (RFC-7348)
- designed to address the need for overlay networks within virtualized data centers accommodating multiple tenants
- encapsulates Layer-2 frames into UDP packets

VXLAN terminology

- VNI: VXLAN Network Identifier
  - identifier of a specific VXLAN tunnel
  - similar to the VLAN ID
  - 24 bit address space, more than 16M possible VNIs
- VTEP: VXLAN Tunnel End Point
  - device that encapsulates and decapsulates VXLAN packets

VXLAN encapsulation

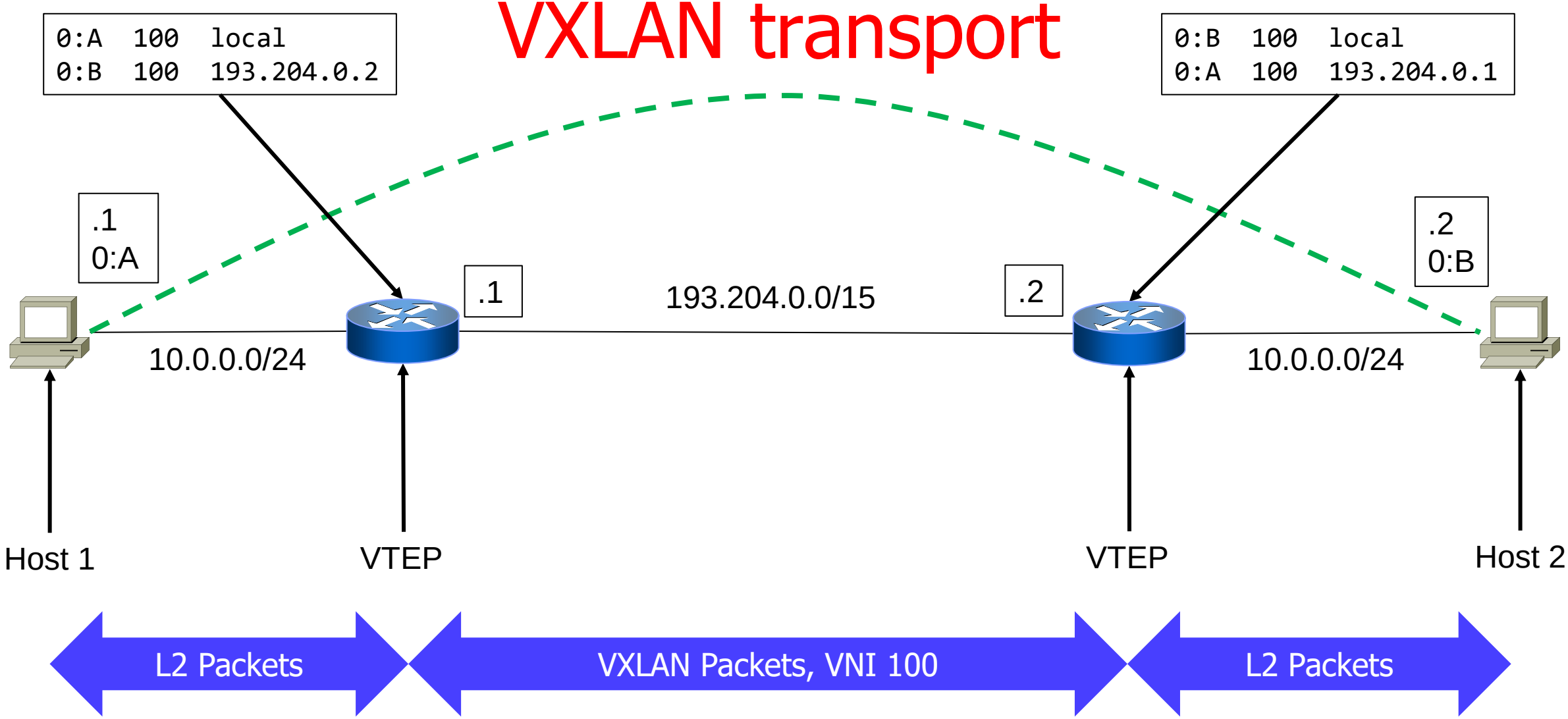
- overhead of 50 bytes
- random Source Port to fully exploit Multi-Path



MAC-to-VTEP Table

- hosted in each VTEP
- similar to the switch forwarding table
- for each VNI the VTEP keeps a table of pairs $<mac, ip>$, that associates MAC Addresses and destination VTEP IPs
- when a device sends a frame to a MAC Address m, the VTEP checks for the existence of a VNI containing a pair $<m, i>$ containing m; if yes, the VTEP encapsulates the frame, and sends the encapsulated packet to the destination VTEP IP i

VXLAN transport



how to fill the MAC-to-VTEP table?

- IP multicast groups are used by default
- each VNI is assigned to an IP multicast group and each VTEP subscribes itself to each group of its VNIs
- the multicast group is used to send the broadcast traffic
  - e.g., ARP traffic
- the MAC-to-VTEP table is populated accordingly

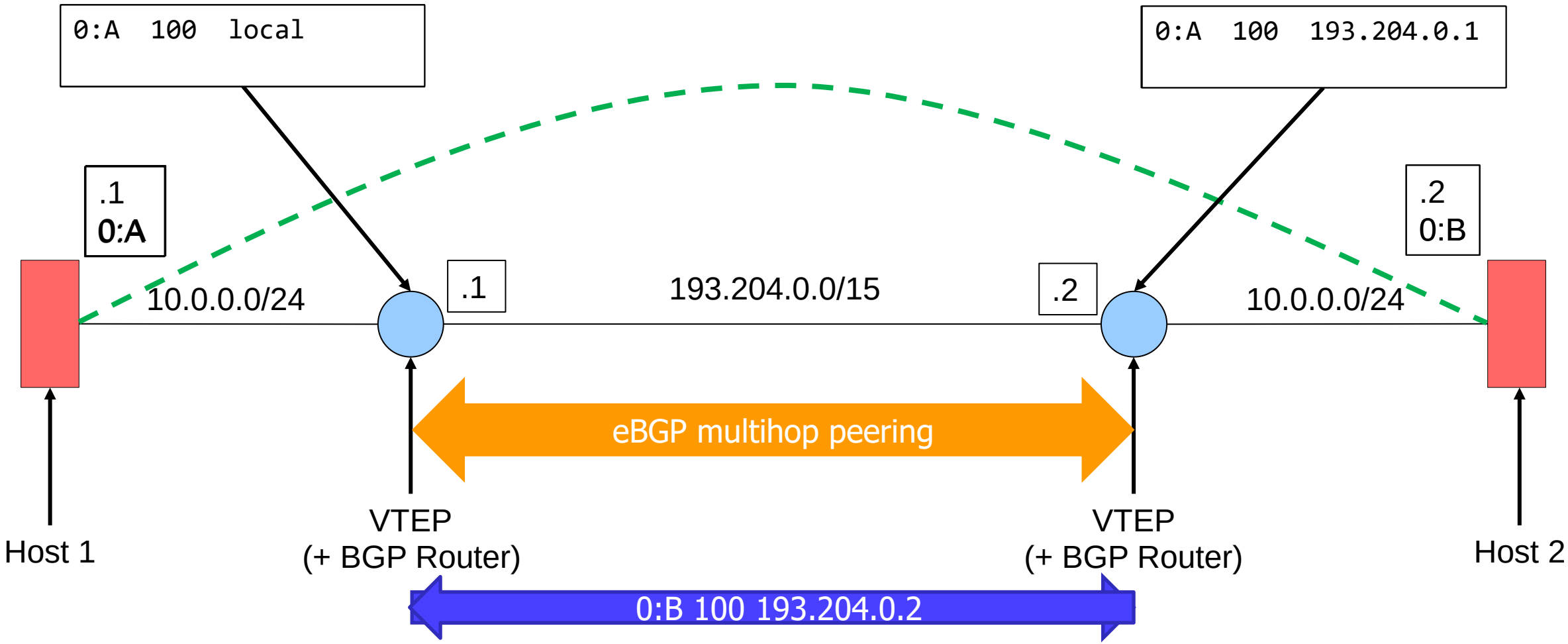
disadvantages of mcast MAC-to-VTEP table

- multicast must be enabled in the fabric
  - it may require to deploy several protocols
    - e.g., IGMP, IGMP Snooping, PIM, MSDP
  - complex configuration
- host discovery is achieved sending packets to all devices on the same VNI
  - VTEP populates the table similar to L2 learning
  - example of host discovery protocols are ARP, NDP
  - many useless packets traversing the fabric

EVPN-BGP

- Ethernet VPN (RFC-7432 and RFC-8365)
- uses MP-BGP with specific AFI/SAFI
  - AFI=25 (L2VPN) – SAFI=70 (EVPN)
- transports MAC Addresses into BGP updates
- VTEP automatically learns local MAC Addresses and sends them to all other VTEPs (of the same VNI)
  - subscribes to the updates of the local switch forwarding table
- VTEP proxies ARP requests to avoid broadcast traffic

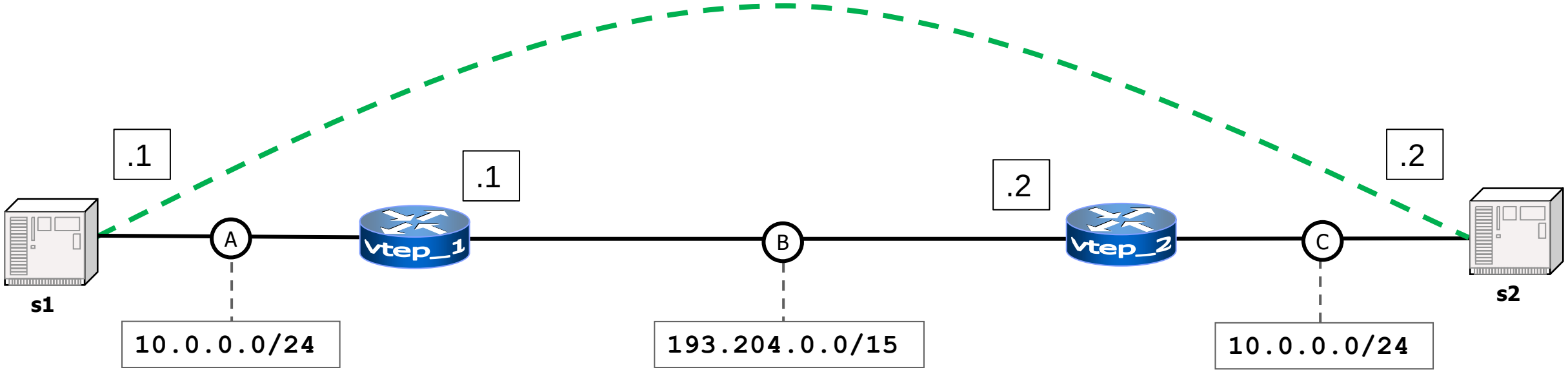
VXLAN and EVPN-BGP transport



VXLAN and EVPN-BGP Lab

time to use Kathará

topology



lab base config

lab.conf

```
s1[0]=A

vtep1[0]=A
vtep1[1]=B

vtep2[0]=C
vtep2[1]=B

s2[0]=C
```

s1.startup

```
ifconfig eth0 10.0.0.1/24 up
ip link set dev eth0 mtu 1450
/etc/init.d/apache2 start
```

s2.startup

```
ifconfig eth0 10.0.0.2/24 up
ip link set dev eth0 mtu 1450
/etc/init.d/apache2 start
```

vtep1.startup

```
ifconfig eth1 193.204.0.1/30 up
```

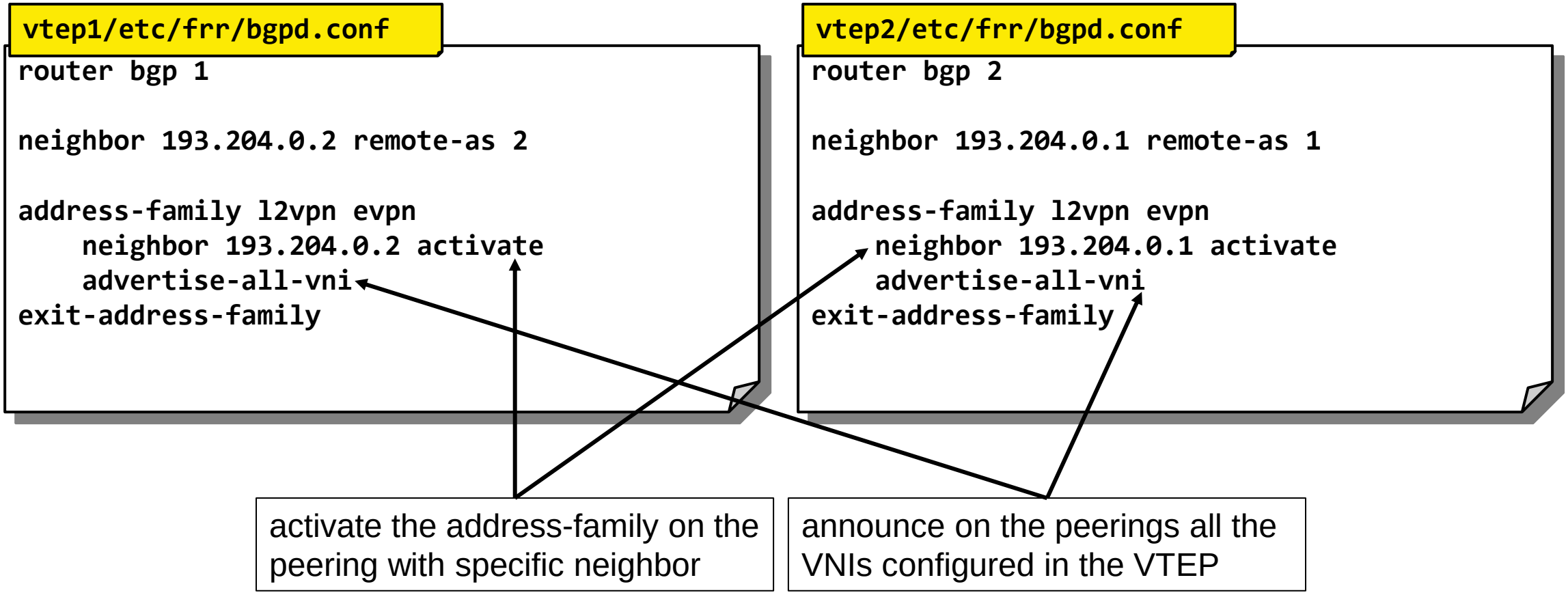
vtep2.startup

```
ifconfig eth1 193.204.0.2/30 up
```

vtep frr config

- configure the base BGP peering
- enable the AFI/SAFI of EVPN
- decapsulate VXLAN
  - create the companion bridge for the VNI
  - attach the server collision domain to the companion bridge

vtep bgp configuration



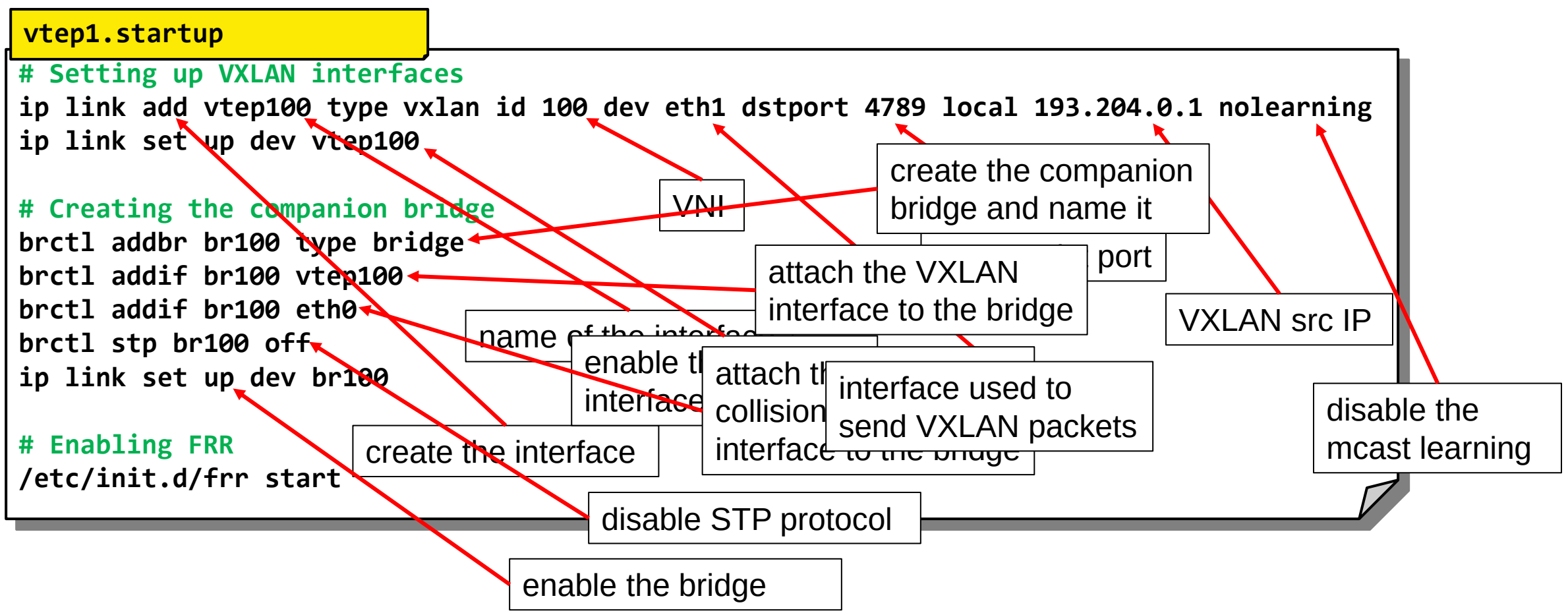
the companion bridge

- the bridge connected to the VTEP interface
- used by the VTEP to perform source address learning of local interfaces
- when in combination with EVPN-BGP
  - its forwarding table is populated via updates received from BGP
  - the FRR control plane subscribes to updates of its forwarding table to send updates via BGP

vtep1 bridge configuration

vtep1.startup

```
# Setting up VXLAN interfaces
ip link add vtep100 type vxlan id 100 dev eth1 dstport 4789 local 193.204.0.1 nolearning
ip link set up dev vtep100

# Creating the companion bridge
brctl addbr br100 type bridge
brctl addif br100 vtep100
brctl addif br100 eth0
brctl stp br100 off
ip link set up dev br100

# Enabling FRR
/etc/init.d/frr start
```



vtep2 bridge configuration

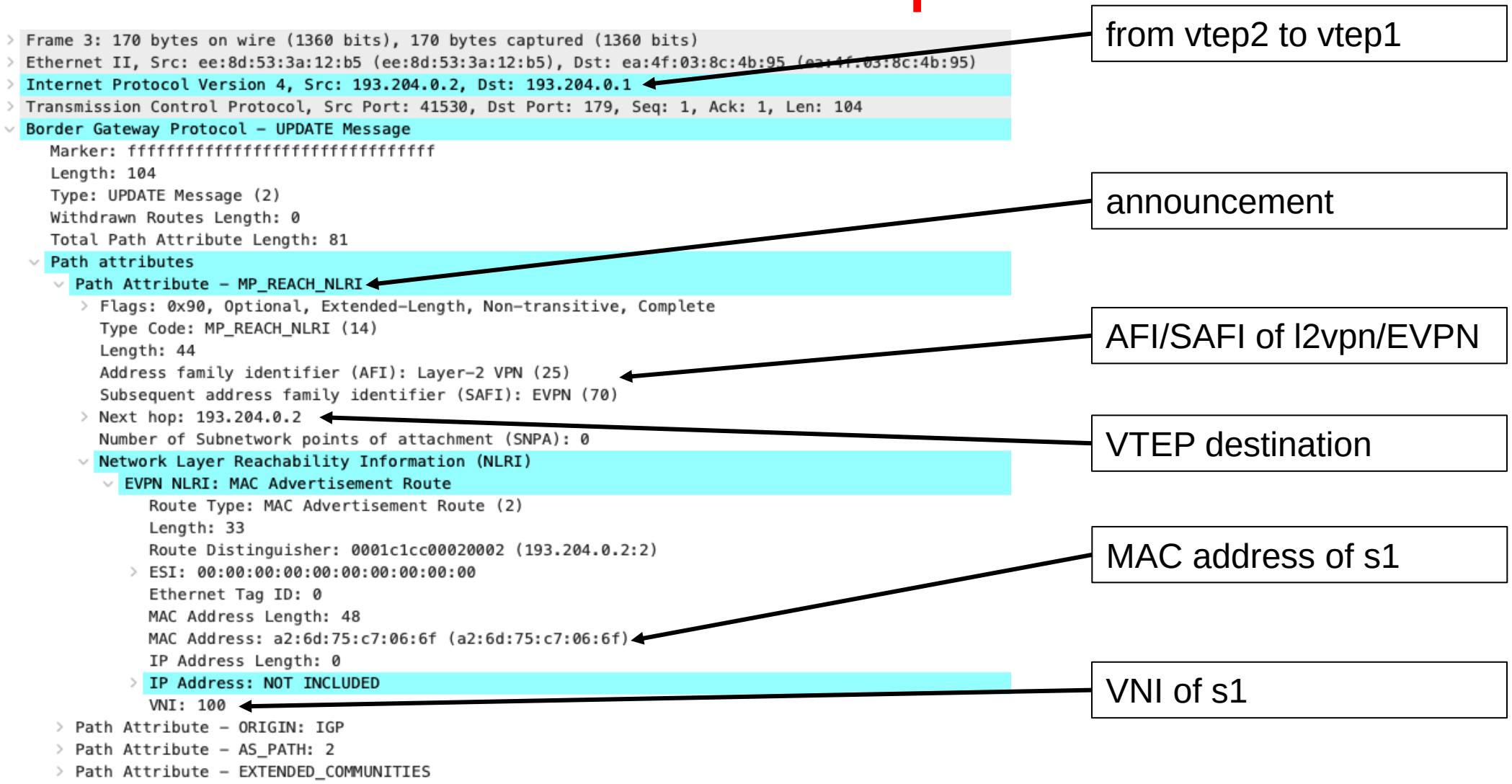
vtep2.startup

```
# Setting up VXLAN interfaces
ip link add vtep100 type vxlan id 100 dev eth1 dstport 4789 local 193.204.0.2 nolearning
ip link set up dev vtep100

# Creating the companion bridge
brctl addbr br100 type bridge
brctl addif br100 vtep100
brctl addif br100 eth0
brctl stp br100 off
ip link set up dev br100

# Enabling FRR
/etc/init.d/frr start
```

the EVPN-BGP control-plane

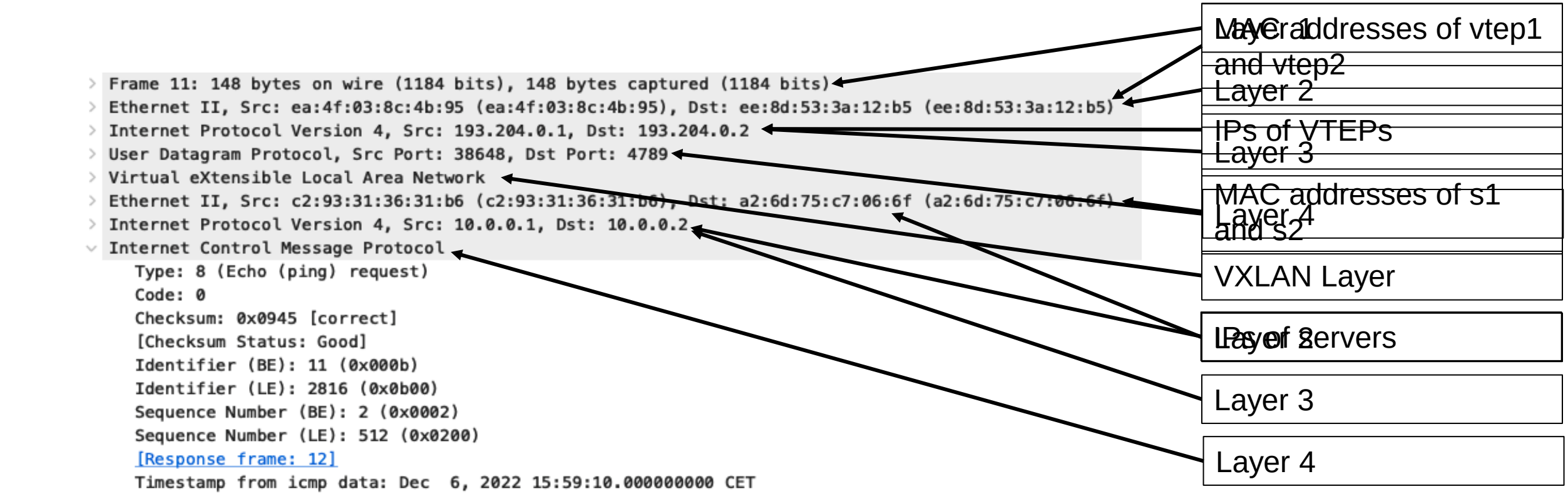
```
vtep1# show evpn mac vni all

VNI 100 #MACs (local and remote) 2

Flags: N=sync-neighs, I=local-inactive, P=peer-active, X=peer-proxy
MAC               Type   Flags Intf/Remote ES/VTEP            VLAN  Seq #'s
a2:6d:75:c7:06:6f remote       193.204.0.2                           0/0
c2:93:31:36:31:b6 local        eth0                                  0/0
```

the BGP update



packet encapsulation

```
> Frame 11: 148 bytes on wire (1184 bits), 148 bytes captured (1184 bits)
> Ethernet II, Src: ea:4f:03:8c:4b:95 (ea:4f:03:8c:4b:95), Dst: ee:8d:53:3a:12:b5 (ee:8d:53:3a:12:b5)
> Internet Protocol Version 4, Src: 193.204.0.1, Dst: 193.204.0.2
> User Datagram Protocol, Src Port: 38648, Dst Port: 4789
> Virtual eXtensible Local Area Network
> Ethernet II, Src: c2:93:31:36:31:b6 (c2:93:31:36:31:b6), Dst: a2:6d:75:c7:06:6f (a2:6d:75:c7:06:6f)
> Internet Protocol Version 4, Src: 10.0.0.1, Dst: 10.0.0.2
v Internet Control Message Protocol
    Type: 8 (Echo (ping) request)
    Code: 0
    Checksum: 0x0945 [correct]
    [Checksum Status: Good]
    Identifier (BE): 11 (0x000b)
    Identifier (LE): 2816 (0x0b00)
    Sequence Number (BE): 2 (0x0002)
    Sequence Number (LE): 512 (0x0200)
    [Response frame: 12]
    Timestamp from icmp data: Dec  6, 2022 15:59:10.000000000 CET
    [Timestamp from icmp data (relative): 0.401357000 seconds]
  > Data (48 bytes)
```



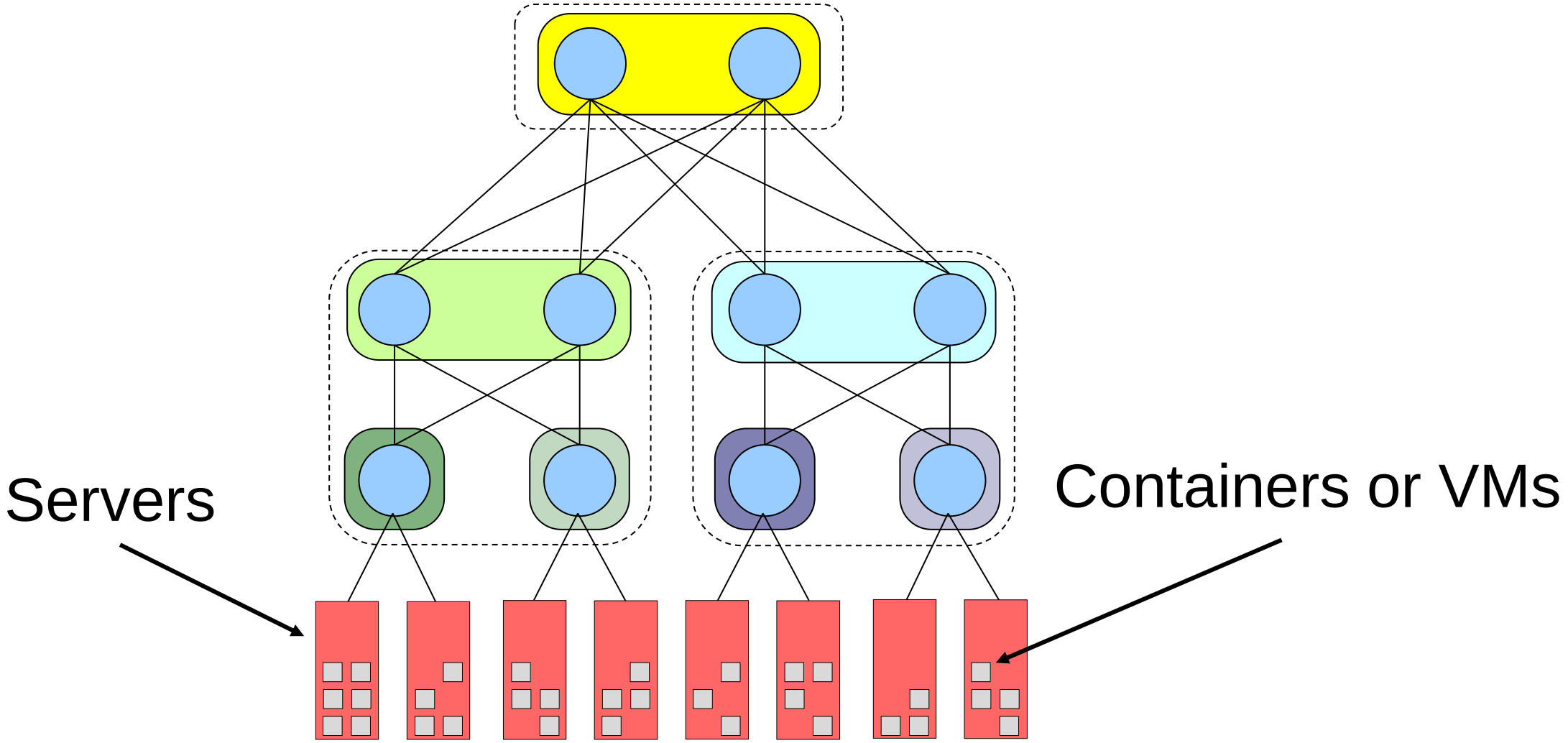
connecting all together

(EVPN-)BGP ☺

overview

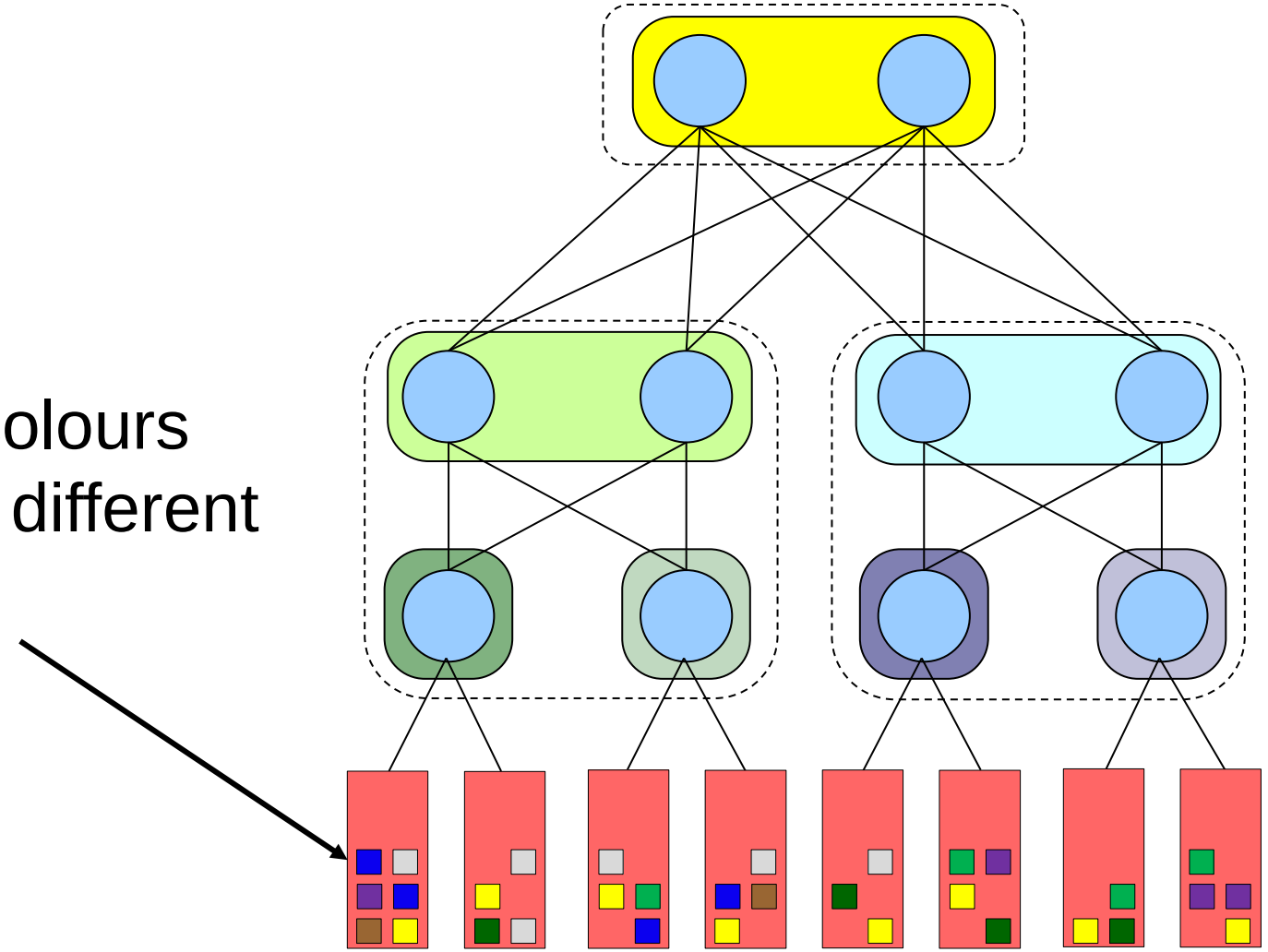
- containers or VMs of different tenants
- where is the VTEP?
- the Leaf-server links
- inside the servers
- dual attached servers
- one week later

servers in the fabric – recap



containers or VMs of different tenants

different colours represent different tenants



EVPN-BGP – where is the VTEP?

- containers must be unaware of the tunneling
- different choices for the positioning of the VTEP
  - in each server
    - the server should have a BGP peering for enabling EVPN-BGP
    - the server CPU would be used to route packets
  - in each Leaf
    - the Leaf already has a BGP peering
    - the Leaf is a router, so it has dedicated routing hardware
    - additional encapsulation is required between Leaves and servers

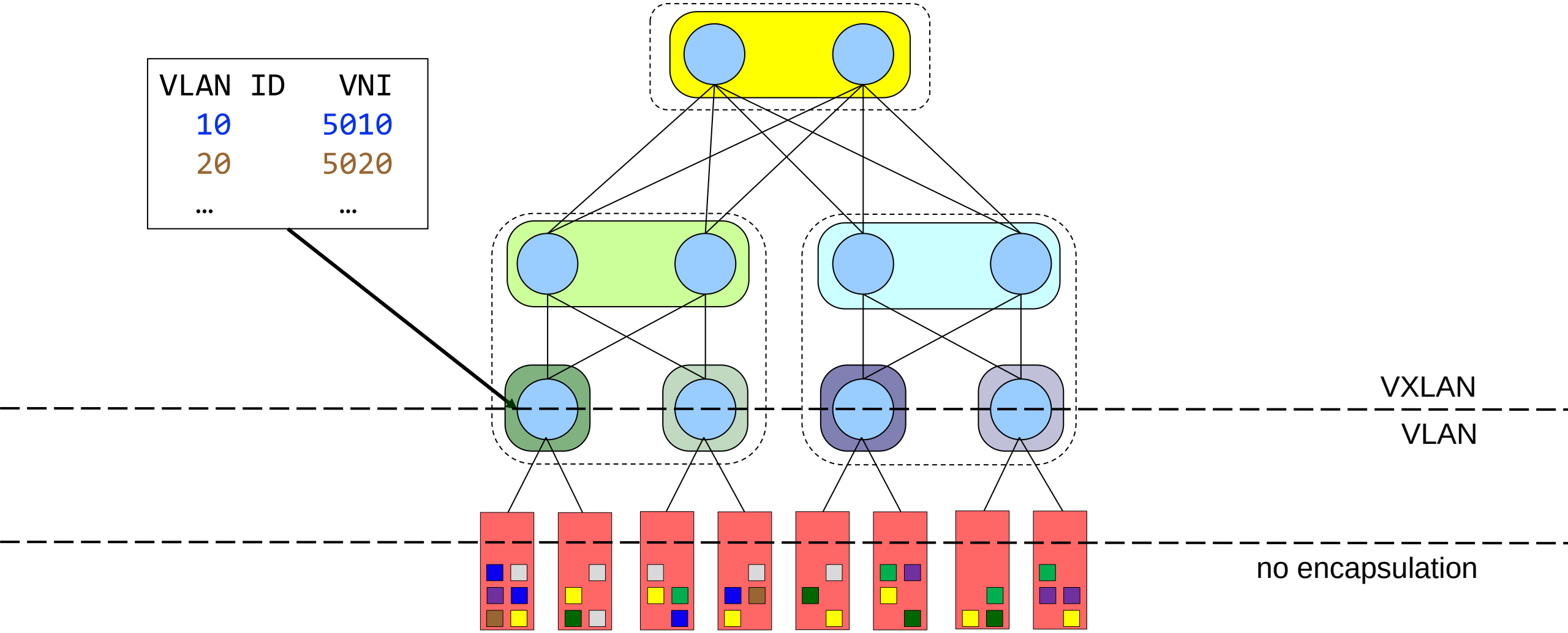
inside the Leaves

- VLAN is used
- mapping between VNIs and VLAN IDs
  - tenants are unaware of the mapping
- Leaves decapsulate VXLAN packets and encapsulate them into VLAN frames, according to the mapping

inside the servers

- the server uses the VLAN IDs to forward packets to the correct containers/VMs
- the server untags the packets so that the containers/VMs are unaware of the VLANs
  - containers/VMs of the same tenant shares the same virtual Layer-2 network

deploying VXLAN



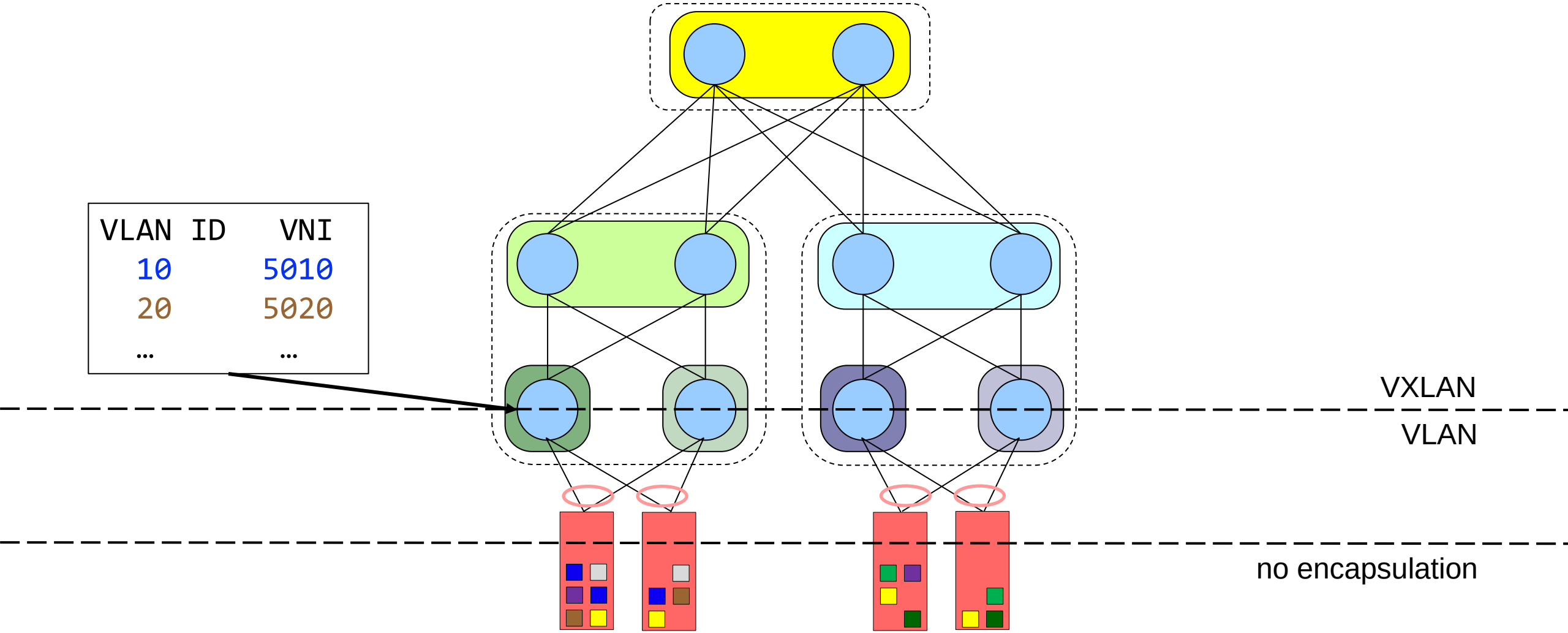
the last problem to overcome

- if a Leaf-server link breaks down, the server is severed off the data center
- if a Leaf breaks, all the servers connected to that Leaf are severed off the data center
- if a maintenance needs to be done on a Leaf, all the servers connected to that Leaf are temporarily severed off the data center

dual attached servers – bonding

- aggregates multiple NICs into a single virtual interface
- Layer-2 technology
- different policies are possible
  - active-backup
  - active-active
    - round-robin
    - broadcase
    - balance-xor
    - and more…

one week later



bibliography and further readings

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- [Bernat '17] Bernat, "VXLAN & Linux", https://vincent.bernat.ch/en/blog/2017-vxlan-linux
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- [RFC-8365] Sajassi, Drake, Bitar, Shekhar, Uttaro, Henderickx, "A Network Virtualization Overlay Solution Using Ethernet VPN (EVPN)" Internet Engineering Task Force (IETF) Request for Comments: 8365