Università degli Studi Roma Tre
Dipartimento di Ingegneria
Computer Networks Research Group

data centers'routing

Version	3.1
Author(s)	L. Ariemma, G. Di Battista, M. Patrignani, M. Scazzariello, T. Caiazzi
E-mail	contact@kathara.org
Web	http://www.kathara.org/
Description	Data Centers' Routing: Fat-Trees, BGP

copyright notice

- all the pages/slides in this presentation, including but not limited to, images, photos, animations, videos, sounds, music, and text (hereby referred to as "material") are protected by copyright
- this material, with the exception of some multimedia elements licensed by other organizations, is property of the authors and/or organizations appearing in the first slide
- this material, or its parts, can be reproduced and used for didactical purposes within universities and schools, provided that this happens for non-profit purposes
- any other use is prohibited, unless explicitly authorized by the authors on the basis of an explicit agreement
- this copyright notice must always be redistributed together with the material, or its portions

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

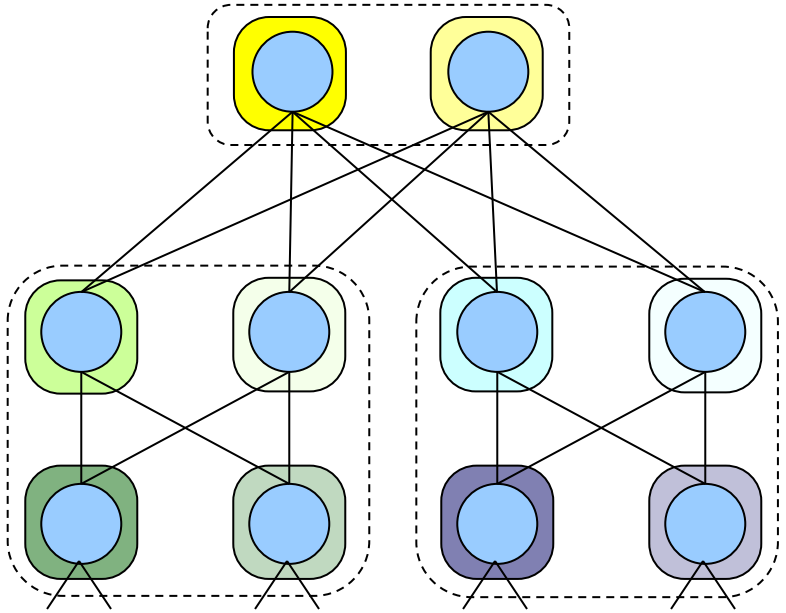
- BGP was primarily devised for inter-domain routing
  - default configurations are not suitable in a data center
- needs some tweaks described in RFC-7938
  - AS numbers assignment
  - ECMP *policy relax*
  - timer adjustment

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

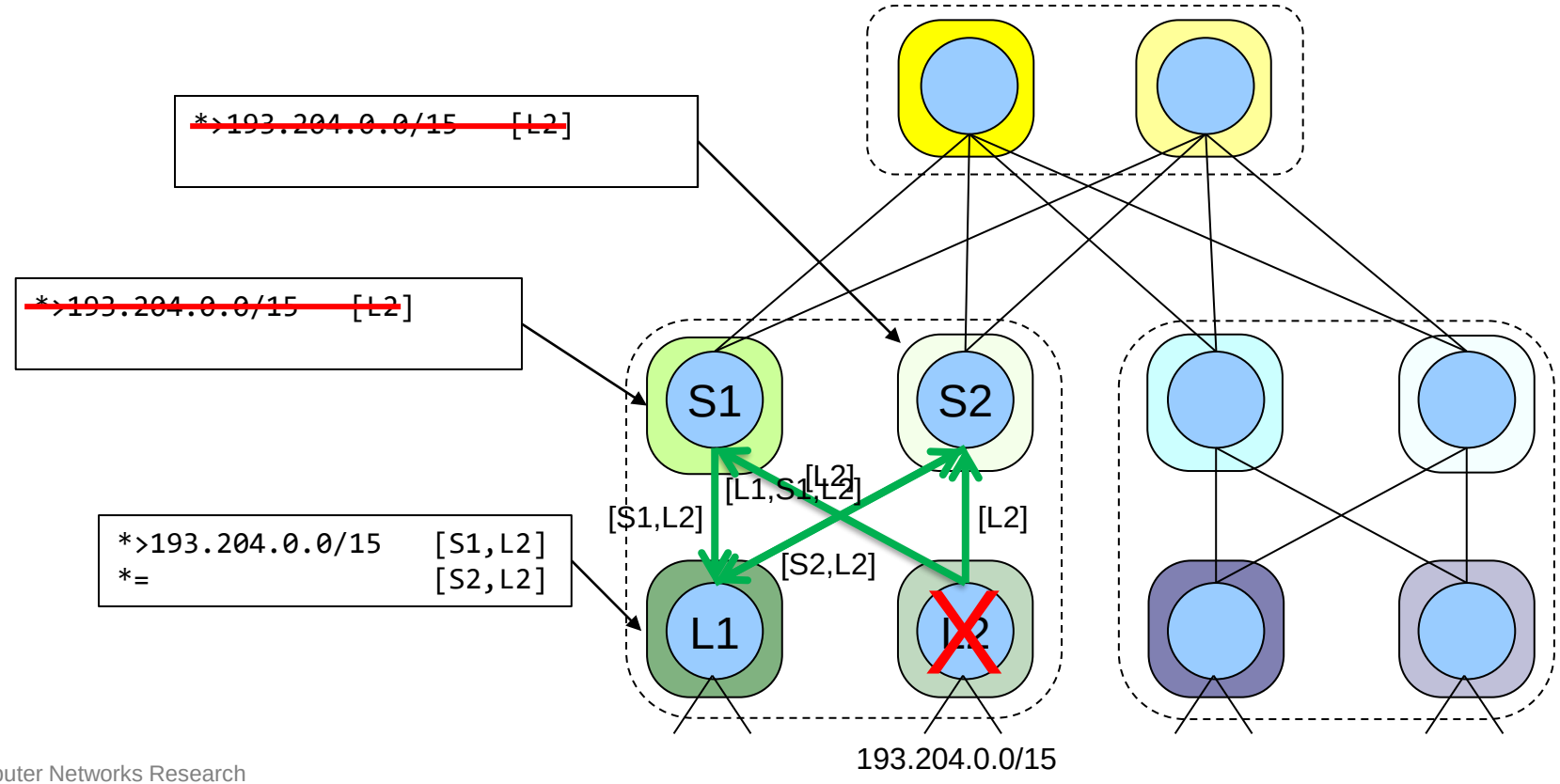


BGP path exploration

- 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

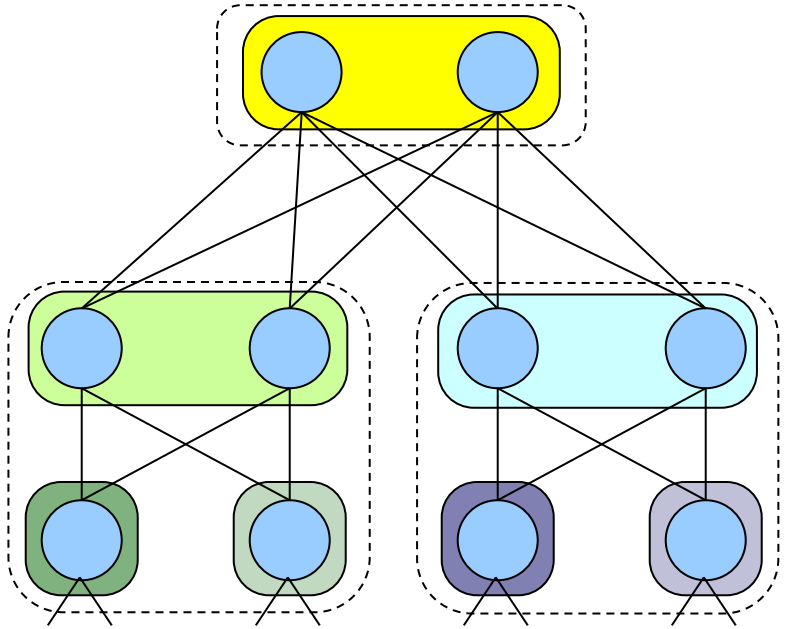
the problem of BGP path exploration

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



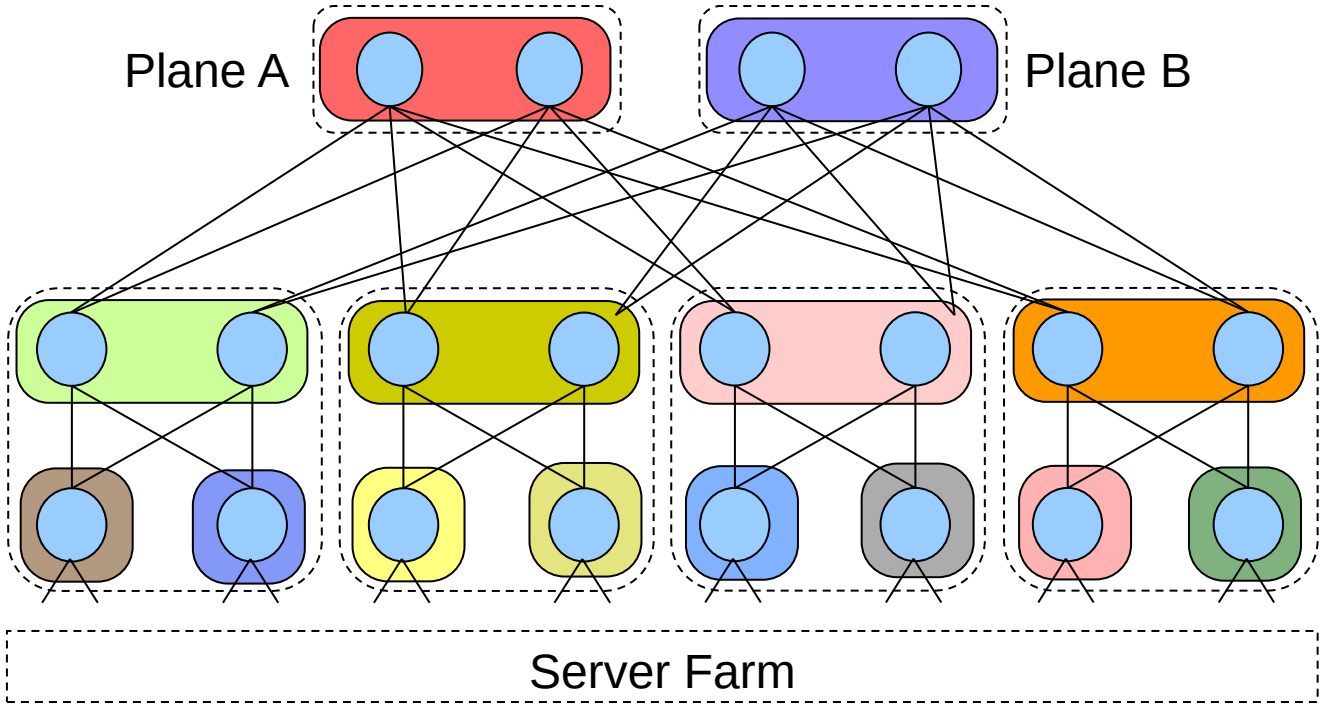
the ASes scheme of choice

- 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



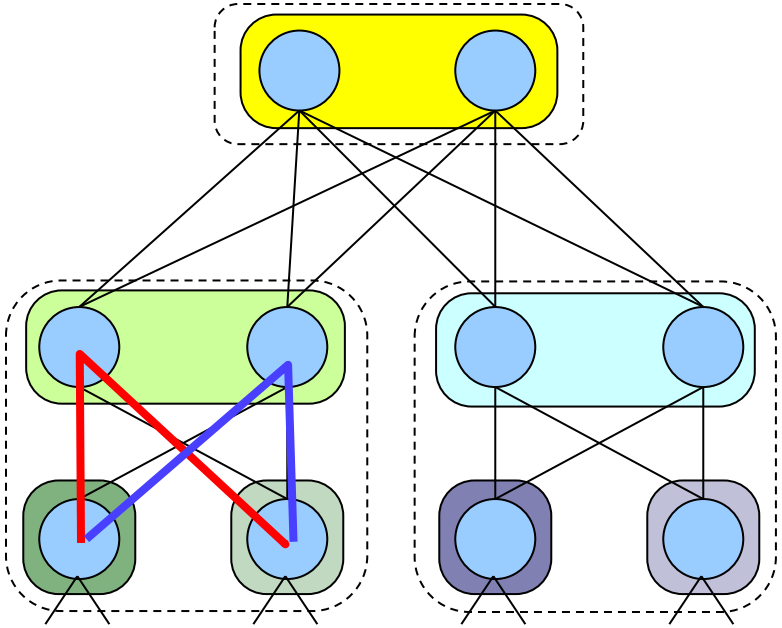
BEWARE: there are NO iBGP peerings

the ASes scheme of choice – multi-plane



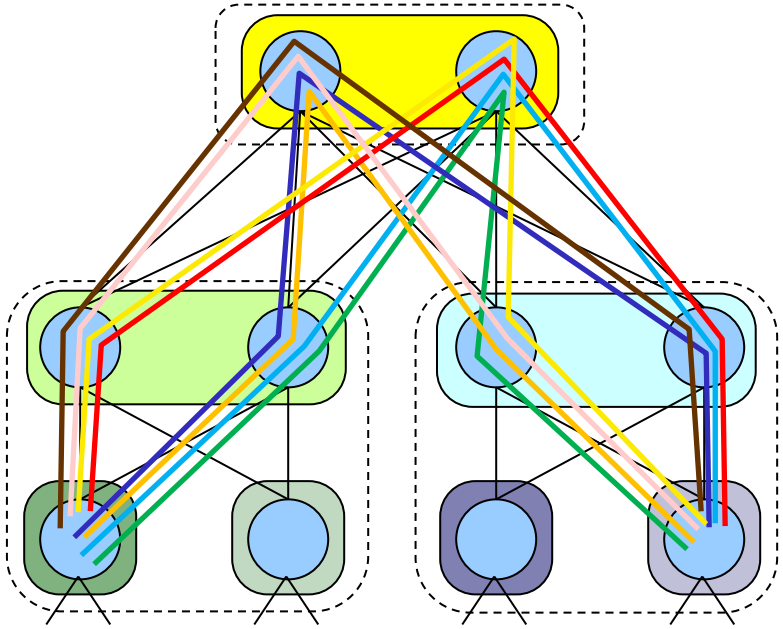
multiple paths between Leaves

- 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

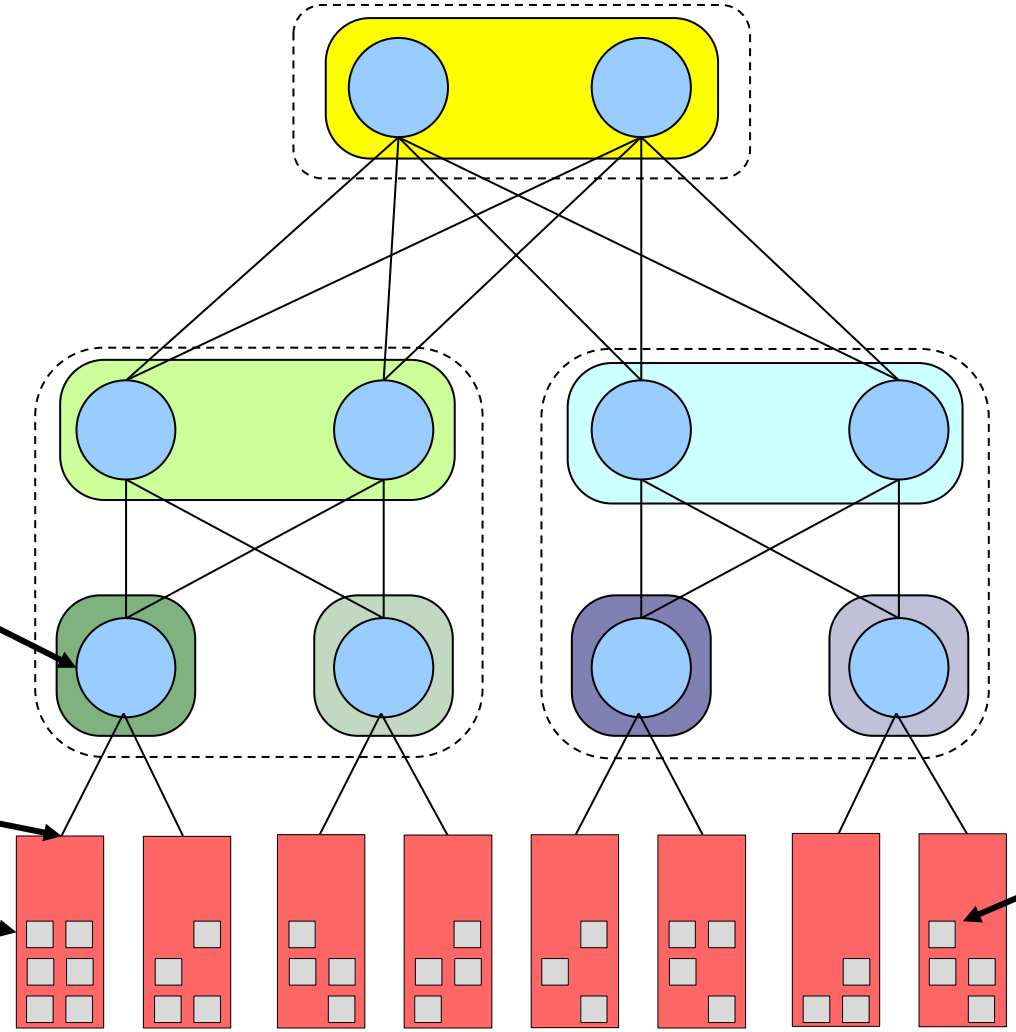
- unnumbered interfaces
  - used to establish peerings specifying the interface name rather than the IP address and the remote AS number
- peer groups
  - used to specify policies for groups of peers

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

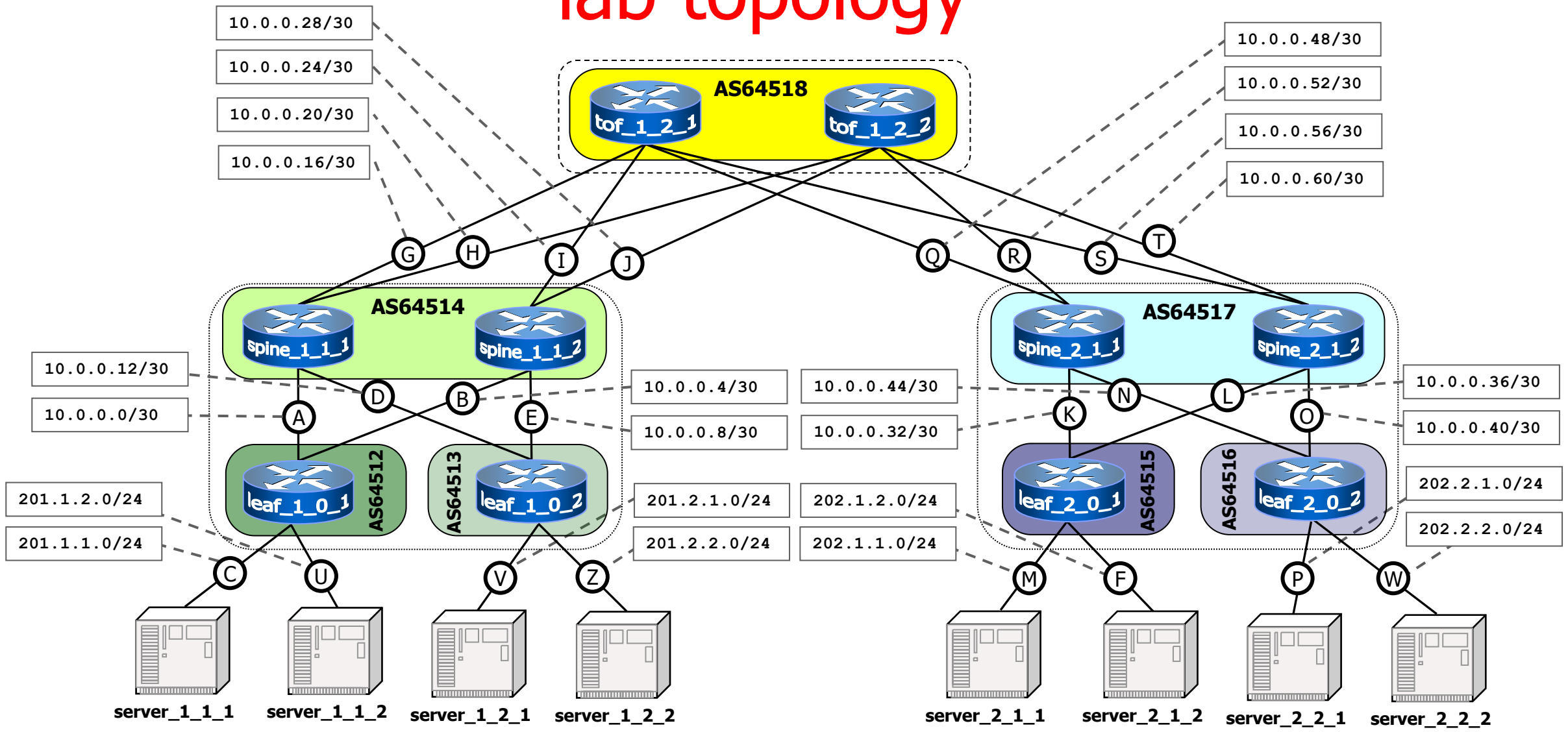
lab pre-conditions

- 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
```

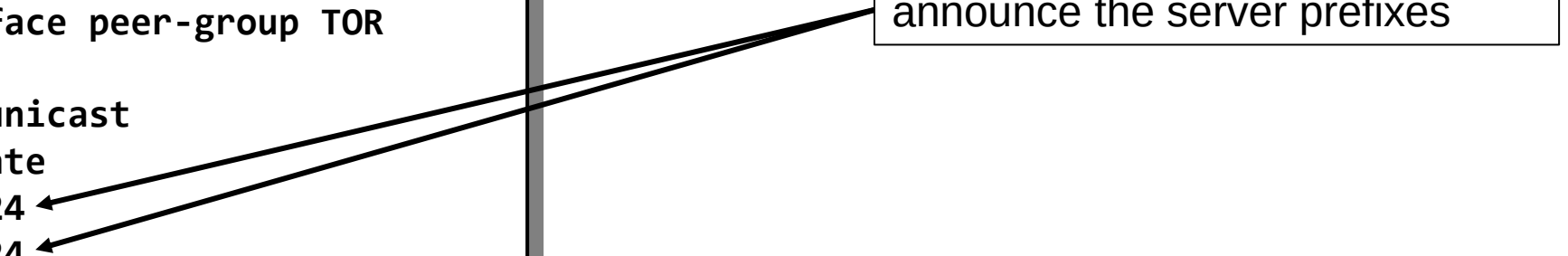
Leaf configuration example

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
```

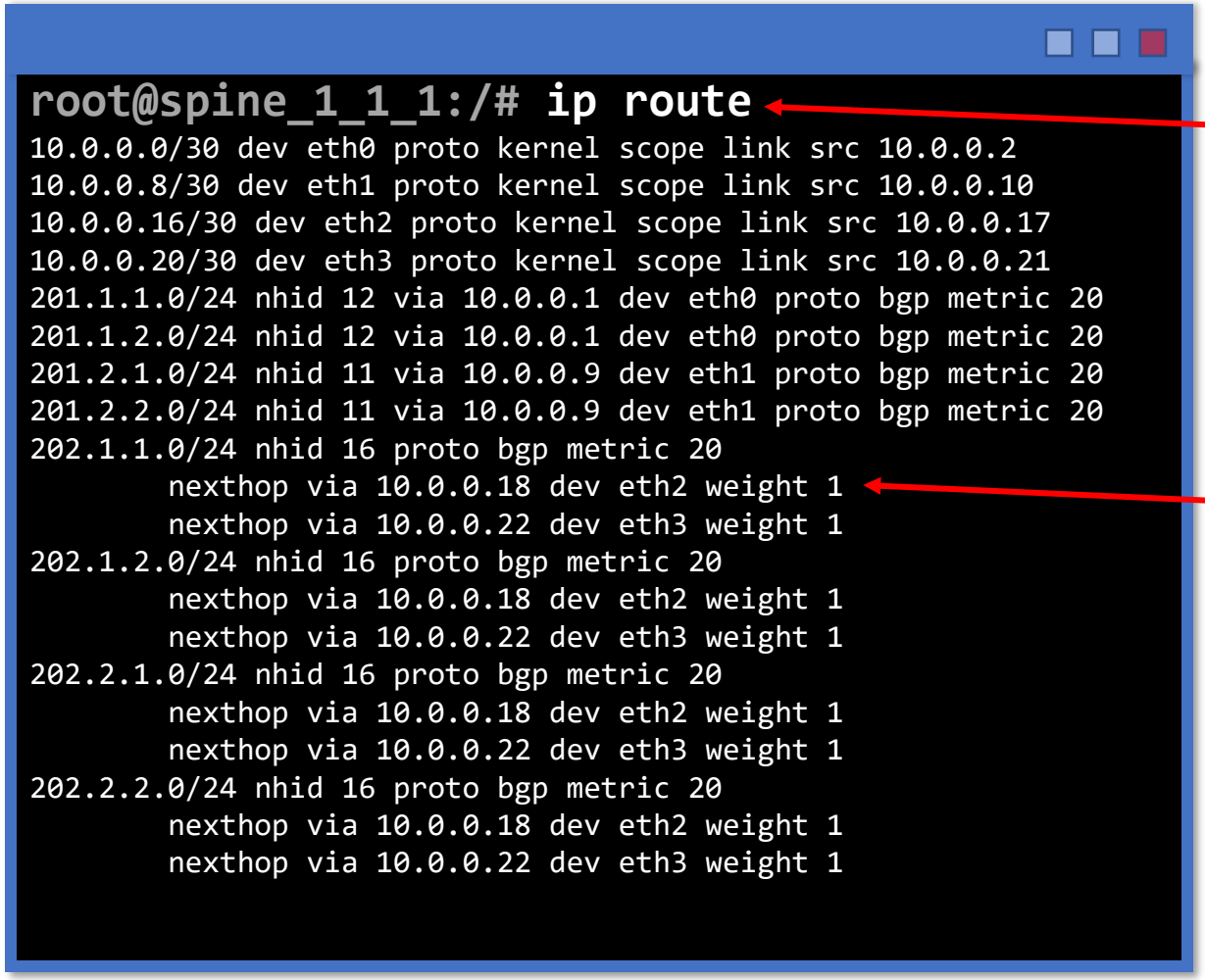


data plane

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
```

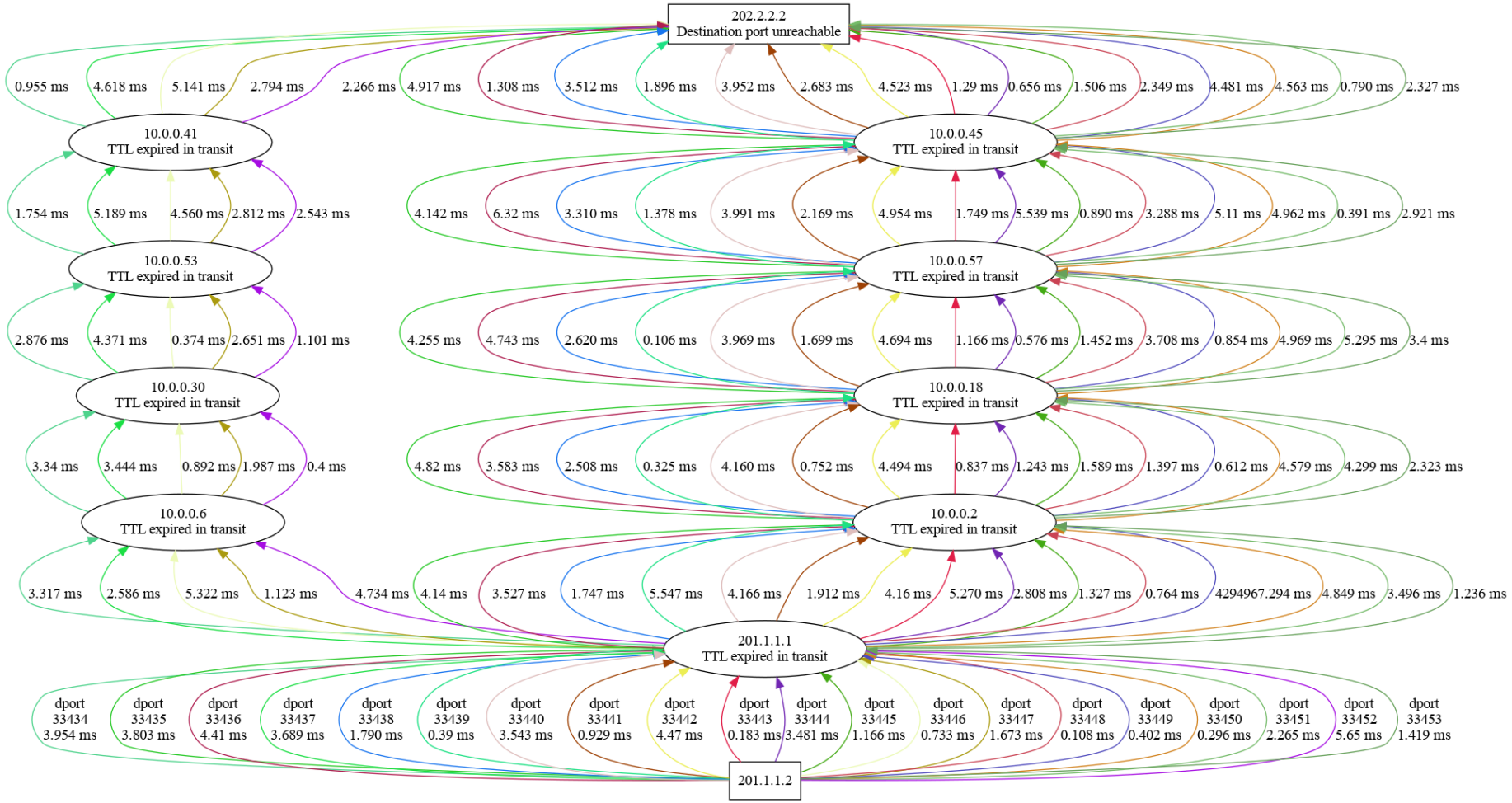
Multi-Path traceroute

- 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