Lab 5

Network Function Virtualization:
Software Router and Containerization

Deadline: 2024/11/27 (WED) 23:59

Outline

- Introduction
- Docker Installation
- Docker Usage
- Example Scenario Setup
- Introduction to Docker Compose
- Lab 5 Overview
- Submission & Scoring Criteria
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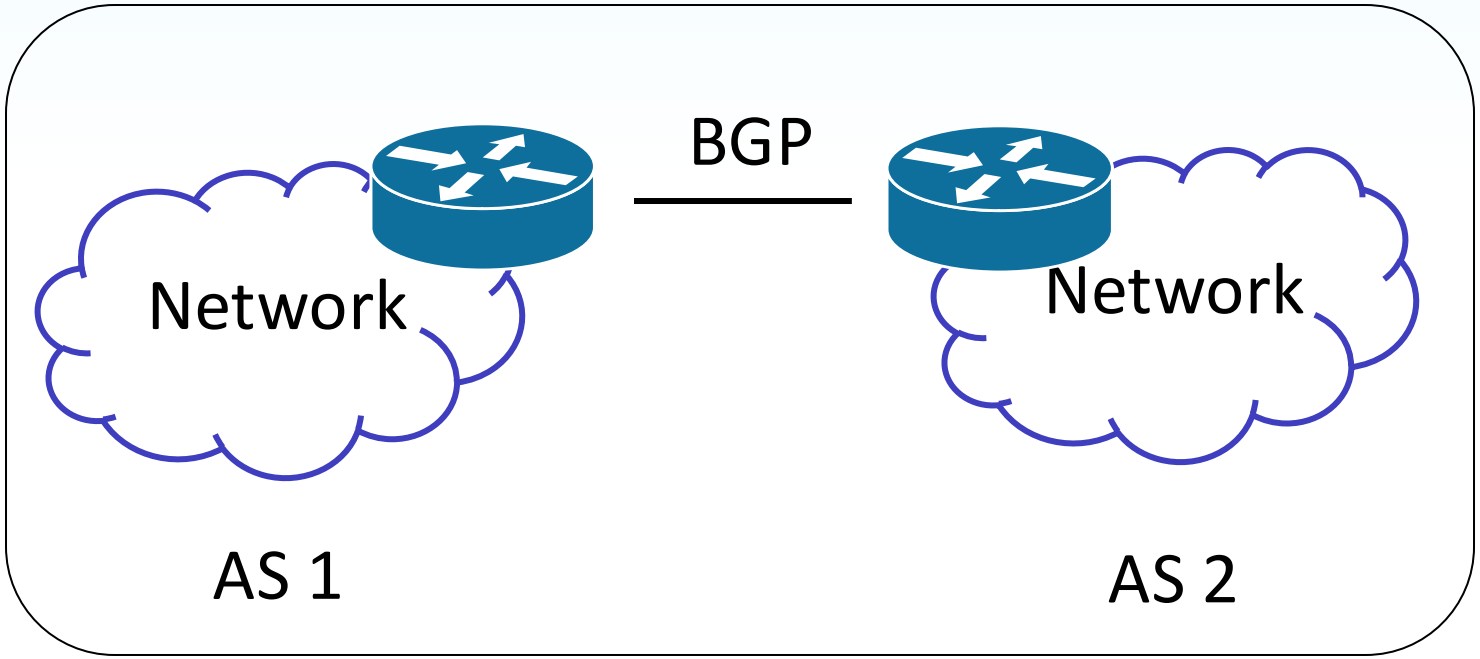
Example Scenario

- Interconnection of two networks



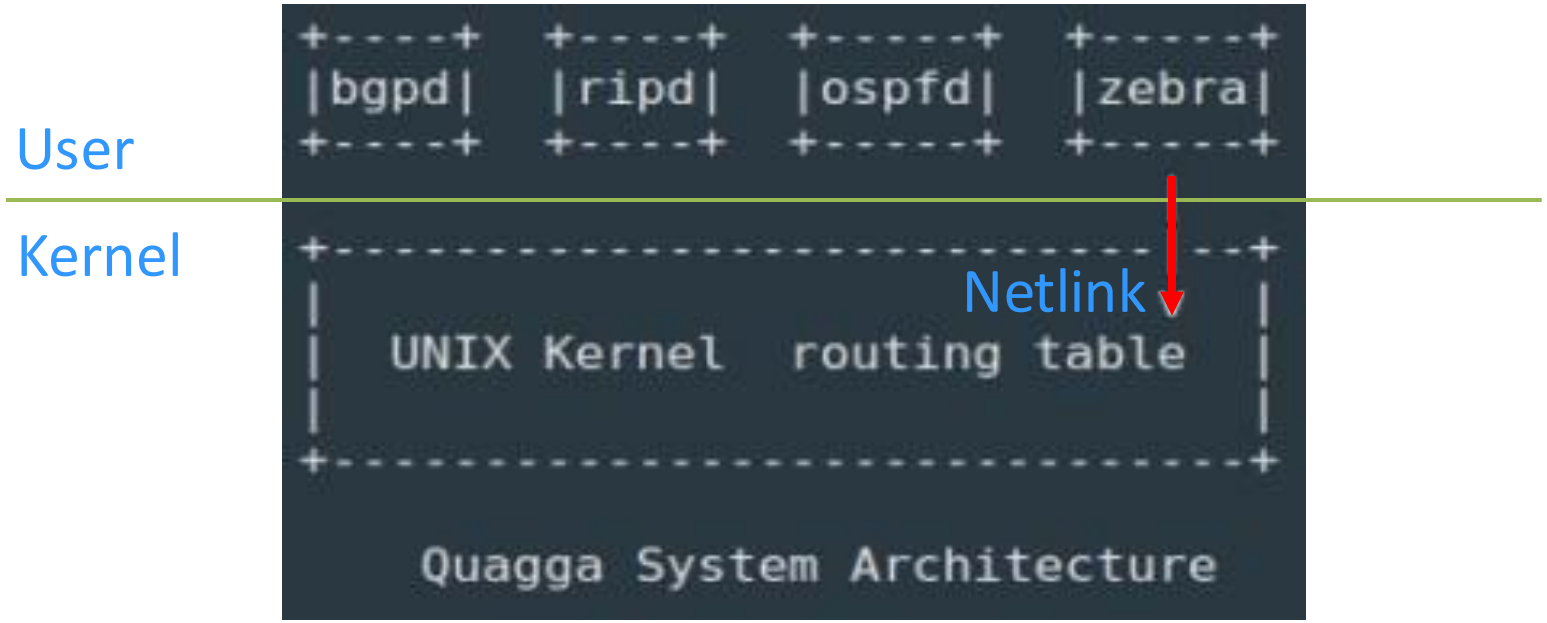
- **BGP**: Border Gateway Protocol
- **AS**: Autonomous System

Introduction to FRRouting

FRRouting is an open-source software that **provides routing services**

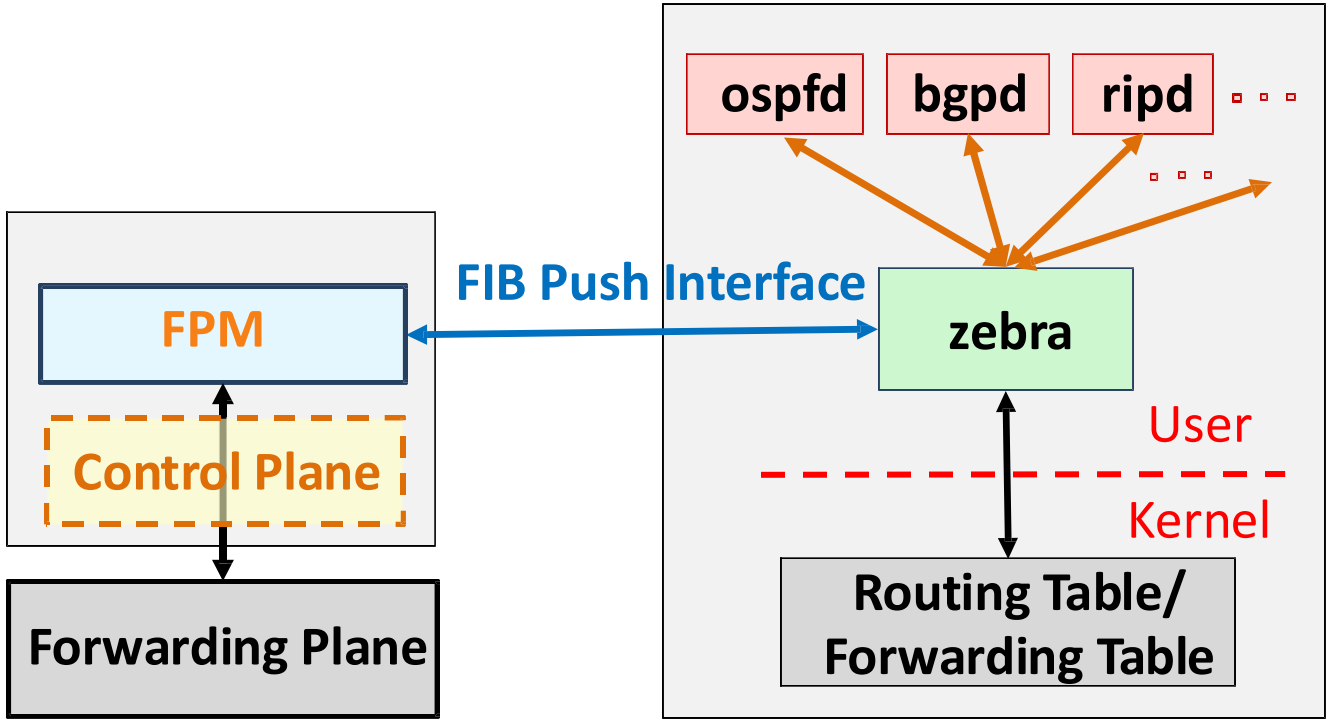
- Supports common routing protocols: BGP, OSPF, RIP, and IS-IS
- Consists of a **core daemon Zebra** and separate **routing protocol** daemons

- Routing Protocols (daemons) communicate their best routes to Zebra
- Zebra computes best routes and modifies **kernel routing table** through netlink



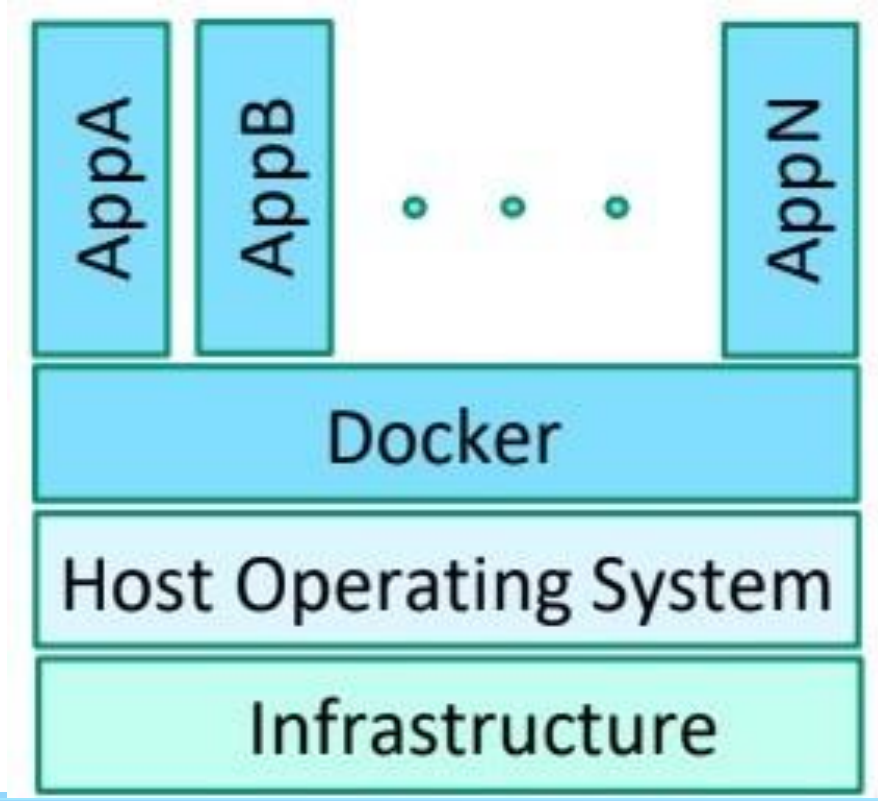
Introduction to FIB Pushing

- Zebra supports a FIB Push Interface (FPI)
  - FPI allows an **external component** to **learn** the forwarding information
- Forwarding Plane Manager (FPM):
  - Receives FIB
  - Decode FIB into routes
  - Programs forwarding plane
- FIB Pushing:
  - FPM establishes a TCP connection with zebra
  - Zebra pushes FIB to FPM



Introduction to Docker

- Docker is a software platform that allows you to build, test, and deploy applications quickly in packages called containers
- Typical steps for creating Docker containers:
  1. **Build Docker images** of the desired OS distribution and applications
  2. Store the images in a Docker Registry
     - Public (Docker Hub)
     - Private
  3. **Run Docker to build containers** of images



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Installation of Docker

- Update apt (confirm to install the latest package)

```
$ sudo apt-get update
```

- Install curl for data transfer

```
$ sudo apt-get install -y curl
```

- Retrieve Docker installation script and install Docker

```
$ sudo curl -ssl https://get.docker.com | sh
```

- Manage Docker as a non-root user

```
$ sudo groupadd docker
$ sudo usermod -aG docker $USER
$ newgrp docker
```

Other Methods: https://docs.docker.com/engine/install/ubuntu/

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Pull Image

- Usage

```
$ docker pull <name>:<tag>
```

- E.g., Pull ubuntu:22.04 image from Docker hub registry

```
$ docker pull ubuntu:22.04
```

- List images

```
$ docker images
```

```
cu@SDN-NFV:~$ docker images
REPOSITORY   TAG       IMAGE ID       CREATED        SIZE
ubuntu       22.04     e4c58958181a   2 weeks ago    77.8MB
```

Docker run (1/2)

- Run a command in a new container
  - Create and run a container
  - Execute a command in the container
- Usage

```
$ docker run <options> <image>:<tag> <command><arg..>
```

Create and Run a container Execute a command in the container

- E.g., Create and Run a container “test”

```
$ docker run -d -it --name test ubuntu:22.04
```

  - -d: Detached (like a daemon in background)
  - -it: Interactive processes (like a shell)
  - --name: Assign a name to the container

Docker run (2/2)

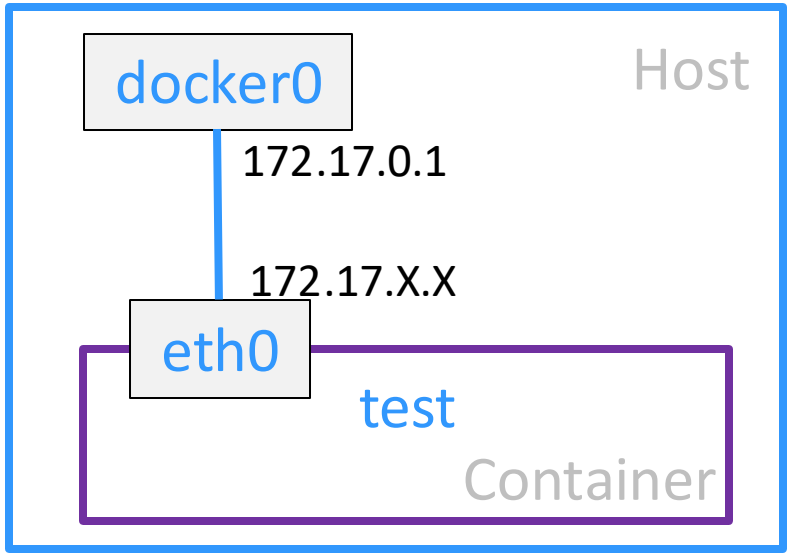
- List containers

```
$ docker ps -a
```

  - “--all”, “-a”: Show all containers

```
cu@SDN-NFV:~$ docker ps -a
CONTAINER ID   IMAGE          COMMAND       CREATED          STATUS          PORTS     NAMES
23497ece301e   ubuntu:22.04   "/bin/bash"   4 seconds ago    Up 3 seconds              test
```

- Container is connected to docker0 bridge by default
- Default IP for docker0 bridge is 172.17.0.1/16
- Docker will assign an IP for the container



Docker exec

- Execute a command in a running container
- Usage

```
$ docker exec <options> <container> <command>
```

- E.g., Exec *bash* command in a **running** container “test”

```
$ docker exec -it test bash
```

```
cu@SDN-NFV:~$ docker exec -it test bash
root@23497ece301e:/#
```

Docker network - Create

- Create a bridge network
- Usage

```
$ docker network create <bridge>
```

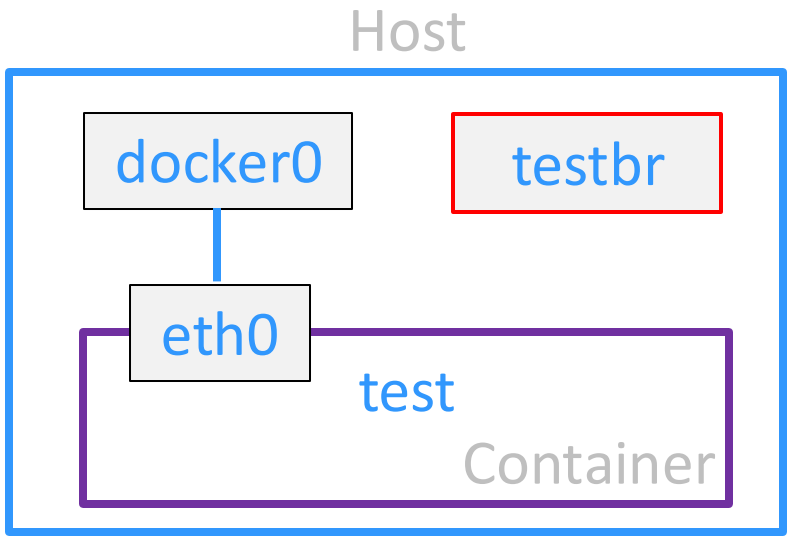
- E.g., Create a network bridge “testbr”

```
$ docker network create testbr
```

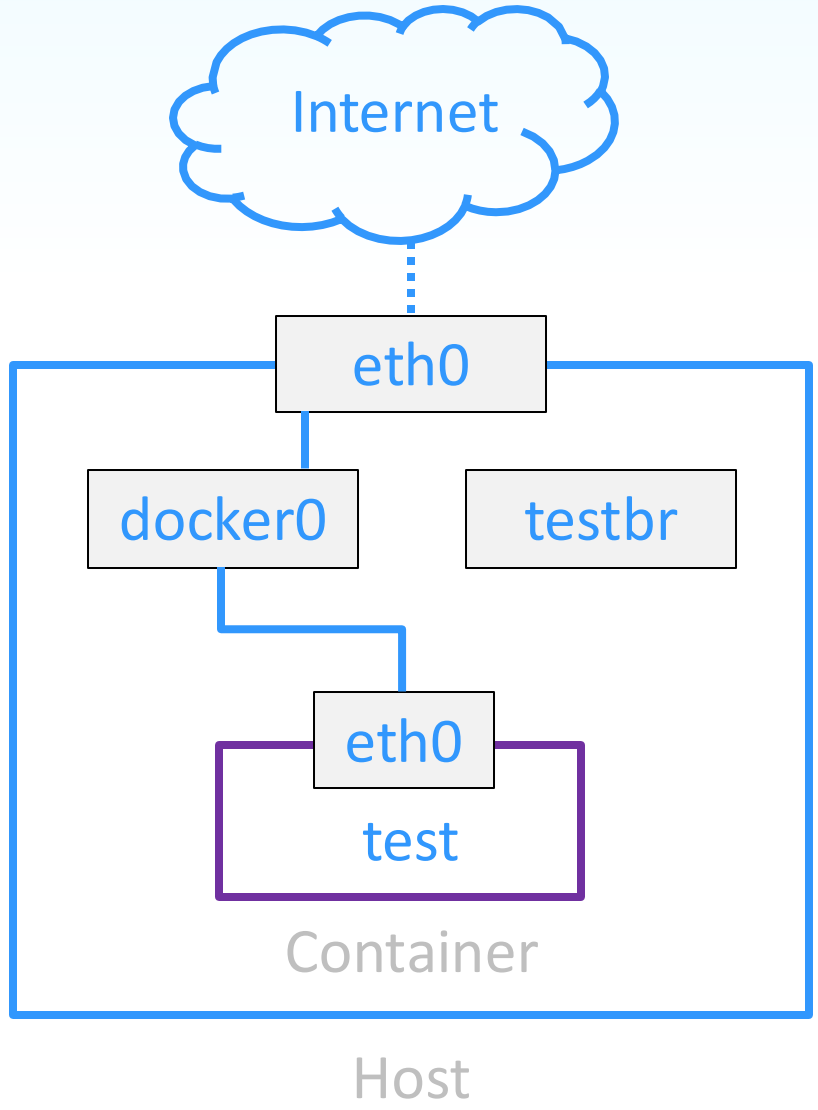
- List networks

```
$ docker network ls
```

```
cu@SDN-NFV:~$ docker network ls
NETWORK ID     NAME      DRIVER    SCOPE
35c1f8ddd132   bridge    bridge    local
b9d64cd68f56   host      host      local
5e0125ebf294   none      null      local
376b09c5a977   testbr    bridge    local
```



Network Environment after testbr Creation



Docker network - Connect

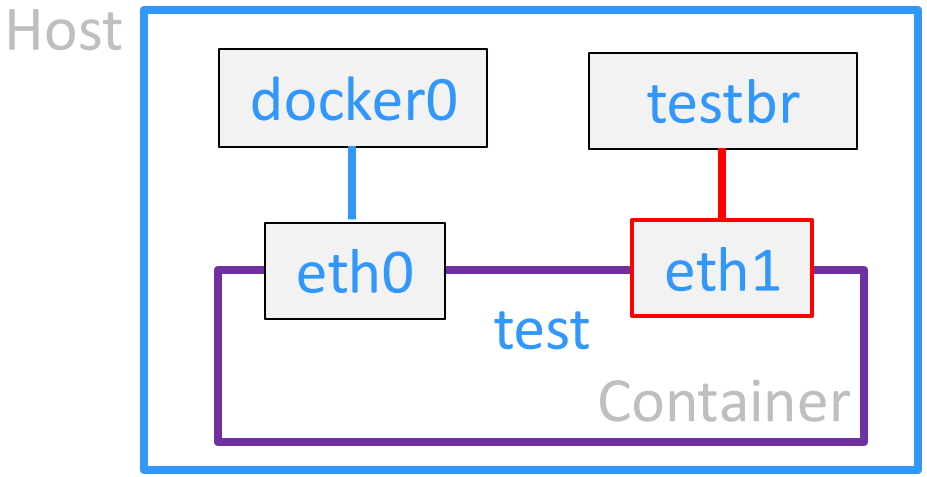
- Connect to a bridge network
- Usage

```
$ docker network connect <network> <container>
```

- E.g., Connect container “test” to bridge “testbr”

```
$ docker network connect testbr test
```

  - Docker will add an interface on the container and assign an IP



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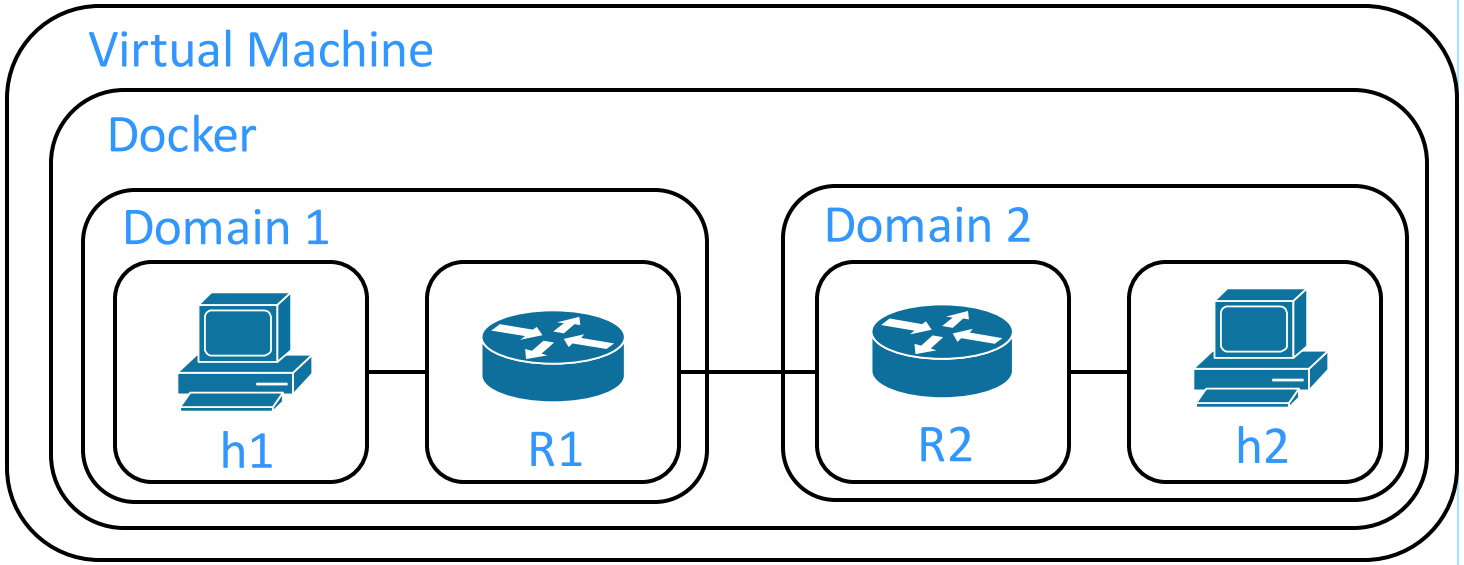
Steps to Setup Example Scenario

1. Prepare Docker images
2. Create containers
3. Setup container networks
   - Setup network for domains
   - Connect domains
4. Configure host gateways
   - Gateway of h1 = R1
   - Gateway of h2 = R2
5. Setup routers
6. Check routes



Step 1 – Prepare Docker images (1/3)

- Prepare docker image “host”
- Write Dockerfile
  - Create configuration file **host.Dockerfile**

```
$ vi host.Dockerfile
```

```
FROM ubuntu:22.04

RUN apt-get update -y \
&& apt-get install -y traceroute \
&& apt-get install -y net-tools \
&& apt-get install -y iproute2 \
&& apt-get install -y iputils-ping

CMD ["sleep","infinity"]
```

Step 1 – Prepare Docker images (2/3)

- Build docker image with Dockerfile

```
$ docker build -t host -f host.Dockerfile .
```

  - -t: Name and optionally a tag in the “name:tag” format
  - -f: Name of the Dockerfile (Default is 'PATH/Dockerfile')

- List image

```
$ docker images
```

REPOSITORY	TAG	IMAGE ID	CREATED	SIZE
host	latest	97085d108578	About an hour ago	129MB
ubuntu	22.04	e4c58958181a	2 weeks ago	77.8MB

Step 1 – Prepare Docker images (3/3)

- Prepare Docker image frrouting
- Pull image frrouting/frr-debian from docker hub

```
$ docker pull frrouting/frr-debian
```

- List image

```
$ docker images
```

REPOSITORY	TAG	IMAGE ID	CREATED	SIZE
frr-debian	latest	649949e63ade	2 days ago	372MB
frr	alpine-c60f439098	aa15955dc3db	5 days ago	165MB
frr-fpm	latest	aa15955dc3db	5 days ago	165MB
<none>	<none>	6df23db9d8f2	5 days ago	164MB
host	latest	07970c916d32	5 days ago	139MB
quay.io/frrouting/frr	10.1.0	044587961d97	5 weeks ago	165MB
onosproject/onos	latest	2a4338117eab	4 months ago	876MB
frrouting/frr	latest	d19bacb84eae	22 months ago	151MB
frrouting/frr-debian	latest	c22c56056653	3 years ago	348MB
onosproject/onos	2.2-latest	b517cd3fdb88	3 years ago	854MB

Note: Do not use frrouting/frr image as it doesn't have the necessary component built for this lab.

Step 2 – Create Containers (1/2)

- Create a container with prepared image

```
$ docker run --privileged --cap-add NET_ADMIN \
  --cap-add NET_BROADCAST -d -it \
  --name <container name> <image>
```

- --privileged: Give extended privileges to this container
- --cap-add: Add Linux capabilities
  - NET_ADMIN: Enable network administration operations
  - NET_BROADCAST: Make socket able to broadcasts, and listen to multicasts

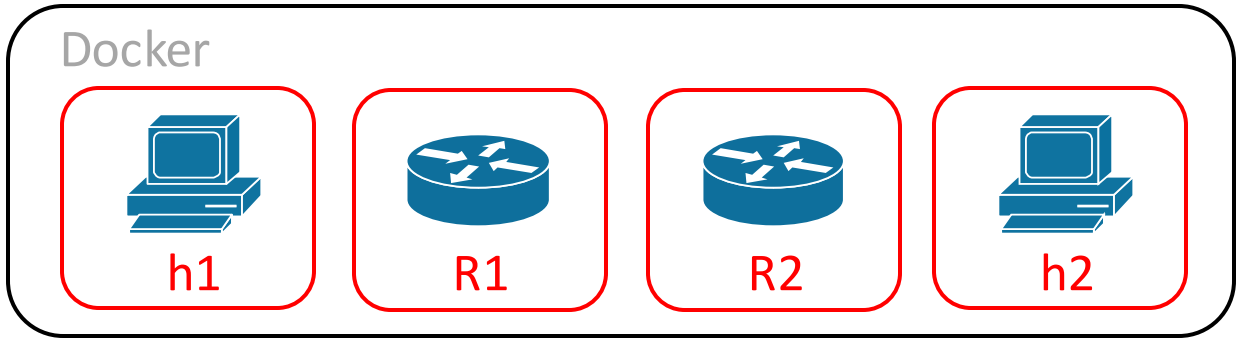
Step 2 – Create Containers (2/2)

- Create container for a host h1 (h2)

```
$ docker run --privileged --cap-add NET_ADMIN \
  --cap-add NET_BROADCAST -d -it \
  --name h1 host
```

- Create container for a virtual router R1 (R2)

```
$ docker run --privileged --cap-add NET_ADMIN \
  --cap-add NET_BROADCAST -d -it \
  --name R1 frrouting/frr-debian
```



Step 3 – Setup Container Networks (1/3)

- Setup network for domains
- Create a bridge network R1h1br

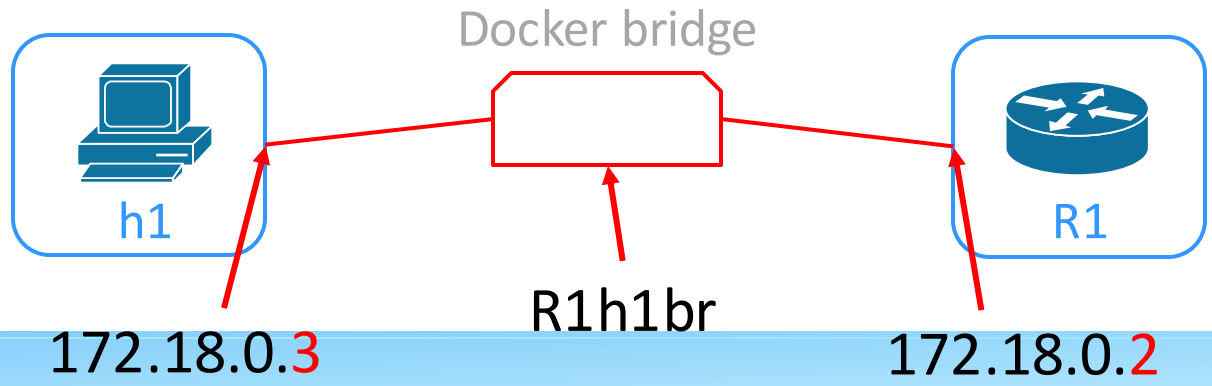
```
$ docker network create R1h1br
```

  - R1h1br: Bridge name

- Connect containers h1 and R1 to bridge R1h1br

```
$ docker network connect R1h1br R1
$ docker network connect R1h1br h1
```

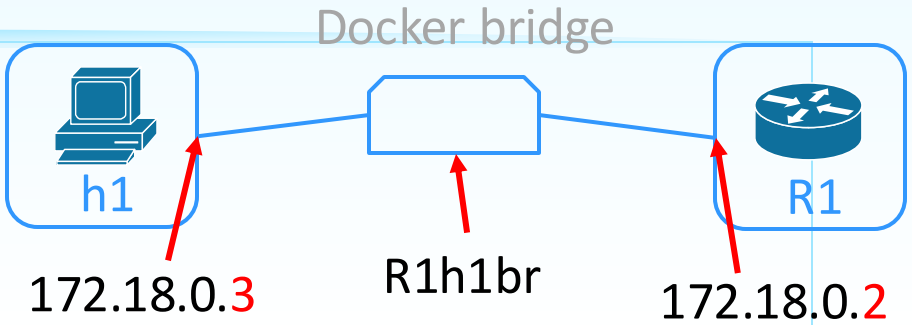
  - Docker will assign IP to interfaces automatically



Step 3 – Setup Container Networks (2/3)

- Check the IP addresses of network interfaces

```
$ docker inspect h1 (R1)
```



- Inspected result for h1

```
"Networks": {
    "R1h1br": {
        "IPAMConfig": {},
        "Links": null,
        "Aliases": [
            "6e5f213a2112"
        ],
        "NetworkID": "39e76624b298ff26
        "EndpointID": "1f02cbd6d908505
        "Gateway": "172.18.0.1",
        "IPAddress": "172.18.0.3",
```

- Inspected result for R1

```
"Networks": {
    "R1h1br": {
        "IPAMConfig": {},
        "Links": null,
        "Aliases": [
            "6e3cc0bcd4dc"
        ],
        "NetworkID": "39e76624b298ff2
        "EndpointID": "580ccc41869ffc
        "Gateway": "172.18.0.1",
        "IPAddress": "172.18.0.2",
```

- Repeat network setup procedure for another domain
  - Create bridge network R2h2br
  - Connect containers R2 and h2

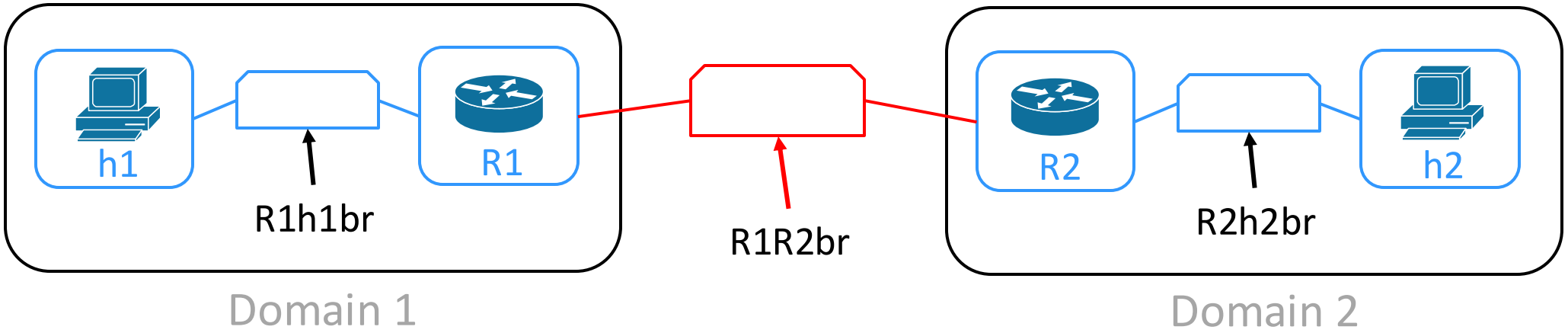
Step 3 – Setup Container Networks (3/3)

- Connect two domains
- Create inter domain bridge

```
$ docker network create R1R2br
```

- Connect containers R1 and R2 to bridge R1R2br

```
$ docker network connect R1R2br R1
$ docker network connect R1R2br R2
```



Step 4 – Configure Host Gateways (1/1)

- Run bash on h1 (h2)

```
$ docker exec -it h1 bash
```

- Set R1 (R2) as default gateway of h1 (h2)

```
h1/# ip route del default
h1/# ip route add default via 172.18.0.2
```

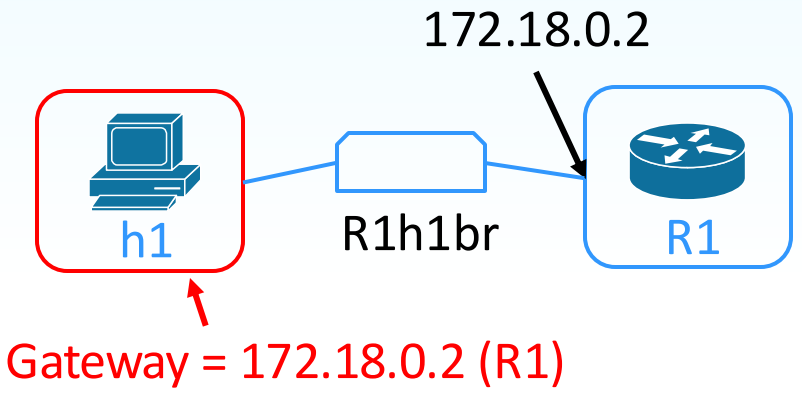
- Check route on h1 (h2)

```
h1/# route
```

h1's bash prompt

```
root@6e5f213a2112:/# route
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
default         R1.R1h1br       0.0.0.0         UG    0      0        0 eth1
172.17.0.0      *               255.255.0.0     U     0      0        0 eth0
172.18.0.0      *               255.255.0.0     U     0      0        0 eth1
```

- Exit h1 bash via CTRL+D



Step 5 – Setup Routers (1/4)

- Run bash on R1 (R2)

```
$ docker exec -it R1 bash
```

- Enable IP forwarding on R1 (R2)

```
R1/# vi /etc/sysctl.conf
```

  - Uncomment "net.ipv4.ip_forward=1"

```
# Note: This may impact IPv6 TCP sessions too
#net.ipv4.tcp_syncookies=1

# Uncomment the next line to enable packet forwarding for IPv4
#net.ipv4.ip_forward=1

# Uncomment the next line to enable packet forwarding for IPv6
```

- Run sysctl to load configuration

```
R1/# sysctl -p
```

```
# Note: This may impact IPv6 TCP sessions too
#net.ipv4.tcp_syncookies=1

# Uncomment the next line to enable packet forwarding for IPv4
net.ipv4.ip_forward=1
```

Step 5 – Setup Routers (2/4)

- FRR daemons config file R1(R2)
  - Edit FRR daemon configuration file on R1 (R2)

```
R1/# vi /etc/frr/daemons
```

  - Edit **bgpd=yes** to turn on bgp routing daemon

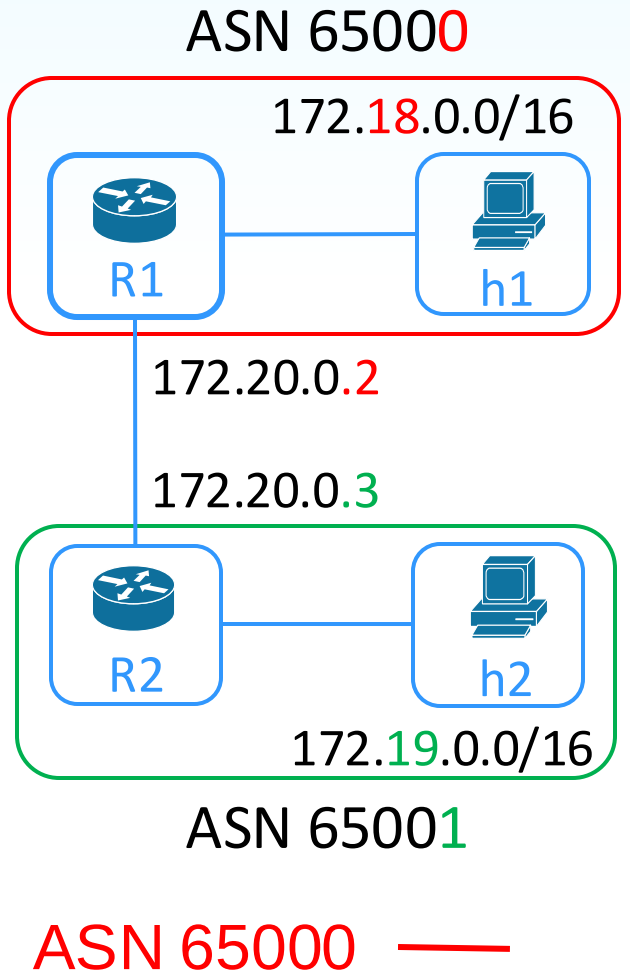
```
15  # The watchfrr, zebra and staticd daemons are always started.
16  #
17  bgpd=yes
18  ospfd=no
19  ospf6d=no
20  ripd=no
21  ripngd=no
22  isisd=no
```

Step 5 – Setup Routers (3/4)

- Set BGP configuration for routers
  - Edit configuration file **frr.conf** on R1

```
R1/# vi /etc/frr/frr.conf
```

```
! FRR configuration for R1
!
frr defaults datacenter
!
router bgp 65000
   bgp router-id 172.20.0.2
   timers bgp 3 9
   neighbor 172.20.0.3 remote-as 65001
   neighbor 172.20.0.3 ebgp-multihop
   neighbor 172.20.0.3 timers connect 5
   neighbor 172.20.0.3 advertisement-interval 5
   network 172.18.0.0/16
!
log stdout
line vty
```

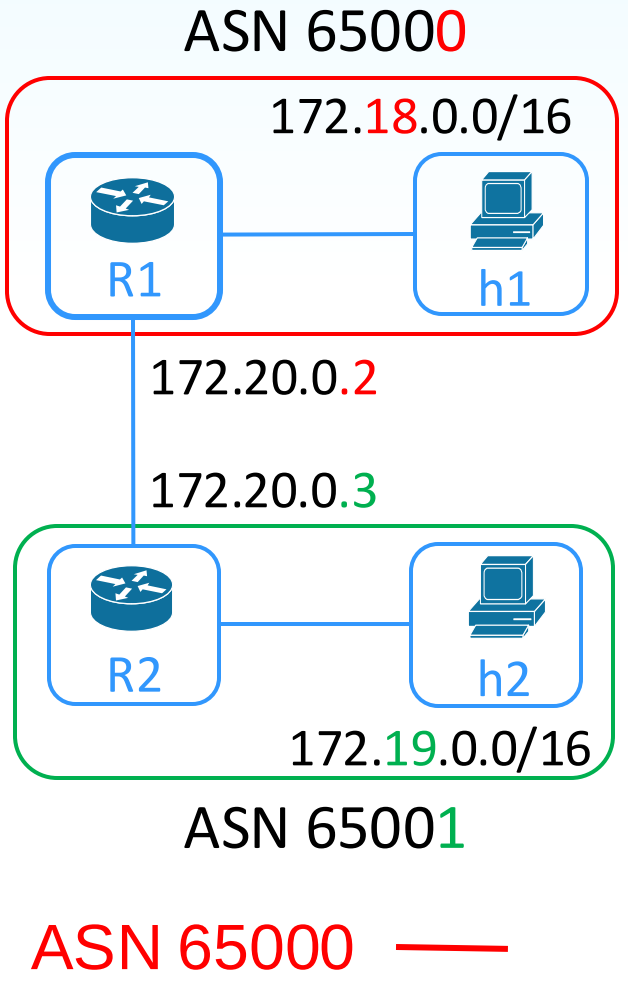


Step 5 – Setup Routers (4/4)

- Set BGP configuration for routers
  - Edit configuration file **frr.conf** on R2

```
R2/# vi /etc/frr/frr.conf
```

```
! FRR configuration for R2
!
frr defaults datacenter
!
router bgp 65001
   bgp router-id 172.20.0.3
   timers bgp 3 9
   neighbor 172.20.0.2 remote-as 65000
   neighbor 172.20.0.2 ebgp-multihop
   neighbor 172.20.0.2 timers connect 5
   neighbor 172.20.0.2 advertisement-interval 5
   network 172.19.0.0/16
!
log stdout
line vty
```



Step 6 – Check Routes (1/2)

- Restart R1 (R2)

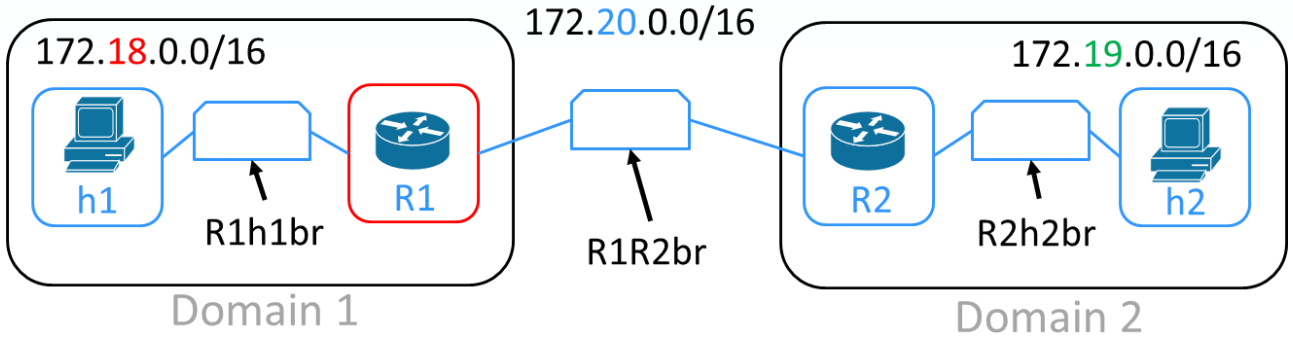
```
$ docker restart R1
```

- Interact with FRR daemons

```
R1/#  vtysh
```

- Show routes on R1 (R2)

```
R1FRR>  show ip route
```




```
Hello, this is FRRouting (version 8.0).
Copyright 1996-2005 Kunihiro Ishiguro, et al.

R1# show ip route
Codes: K - kernel route, C - connected, S - static, R - RIP,
       O - OSPF, I - IS-IS, B - BGP, E - EIGRP, N - NHRP,
       T - Table, v - VNC, V - VNC-Direct, A - Babel, F - PBR,
       f - OpenFabric,
       > - selected route, * - FIB route, q - queued, r - rejected, b - backup
       t - trapped, o - offload failure

K>* 0.0.0.0/0 [0/0] via 172.20.0.1, eth0, 00:01:45
C>* 172.18.0.0/16 is directly connected, eth1, 00:01:45
B>* 172.19.0.0/16 [20/0] via 172.20.0.3, eth0, weight 1, 00:01:43
C>* 172.20.0.0/16 is directly connected, eth0, 00:01:45
```

Step 6 – Check Routes (2/2)

- Show bgp route in R1 FRR (in vtysh)

R1FRR> show ip route bgp

```
R1# show ip route bgp
Codes: K - kernel route, C - connected, S - static, R - RIP,
       O - OSPF, I - IS-IS, B - BGP, E - EIGRP, N - NHRP,
       T - Table, v - VNC, V - VNC-Direct, A - Babel, F - PBR,
       f - OpenFabric,
       > - selected route, * - FIB route, q - queued, r - rejected, b - backup
       t - trapped, o - offload failure

B>* 172.19.0.0/16 [20/0] via 172.20.0.3, eth0, weight 1, 00:05:52
```

- Show bgp summary in R1 FRR (in vtysh)

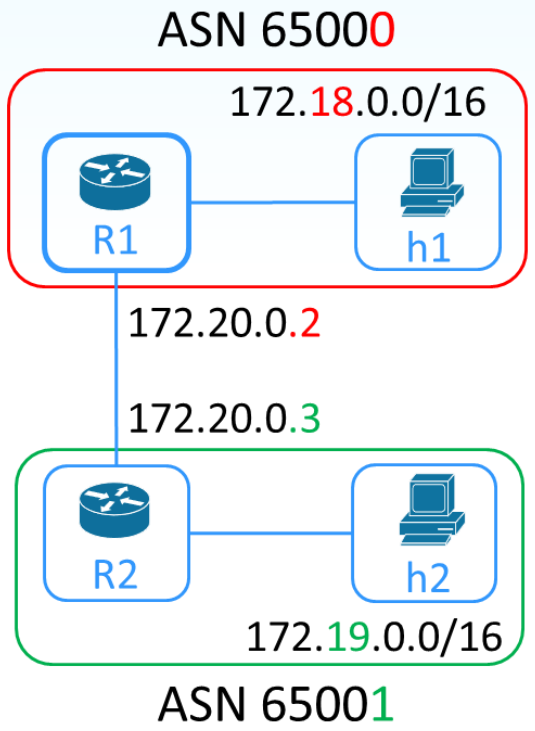
R1FRR> show ip bgp summary

```
R1# show ip bgp summary

IPv4 Unicast Summary:
BGP router identifier 172.20.0.2, local AS number 65000 vrf-id 0
BGP table version 2
RIB entries 3, using 552 bytes of memory
Peers 1, using 727 KiB of memory

Neighbor        V         AS   MsgRcvd   MsgSent   TblVer  InQ OutQ  Up/Down State/PfxRcd   PfxSnt Desc
R2(172.20.0.3)  4      65001       153       153        0    0    0 00:07:25            1        2 N/A

Total number of neighbors 1
```



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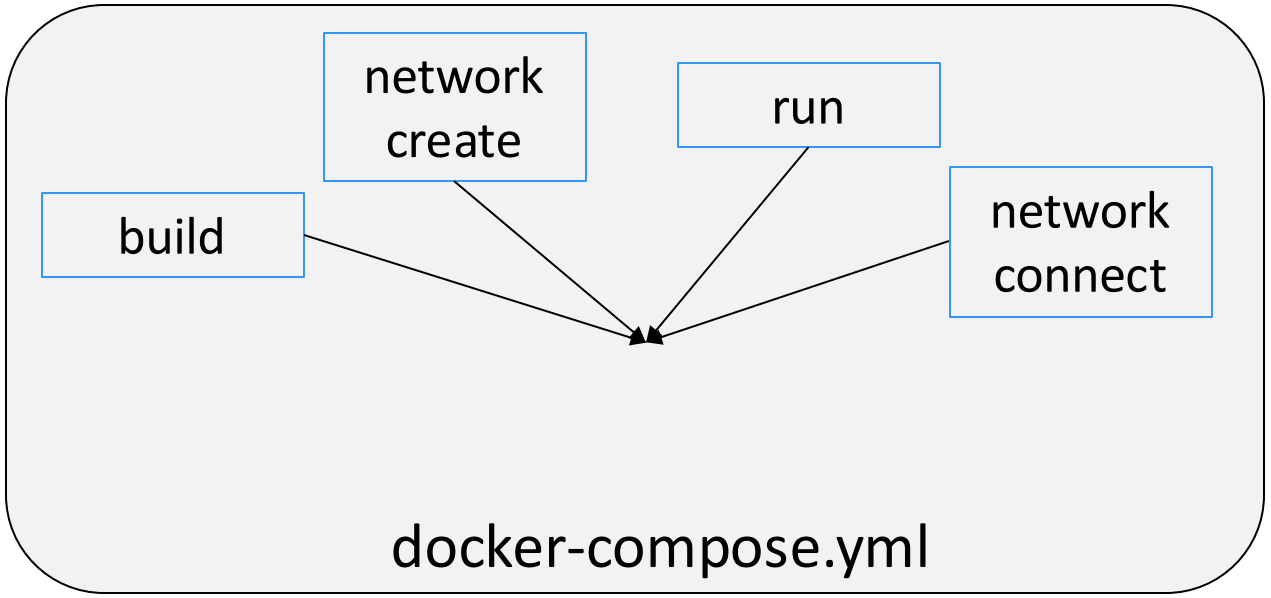
Introduction to Docker Compose

- A tool for **defining** and **running multi-container** Docker applications
- Use a **YAML file** to configure your application services
- Start all the services from your configuration with a **single command**
- The default name for Compose file is **docker-compose.yml**



- Yaml template for example docker application

```
• services
  – h1
      …
  – R1
      …
• networks
  – R1h1br
      …
```

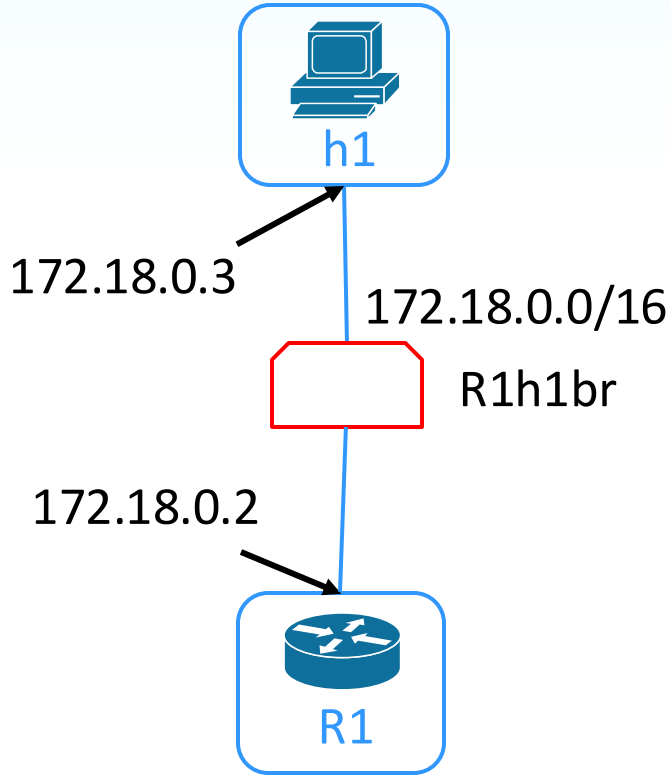
docker-compose.yml

Docker Compose Example (1/4)

- Create bridge R1h1br

network create

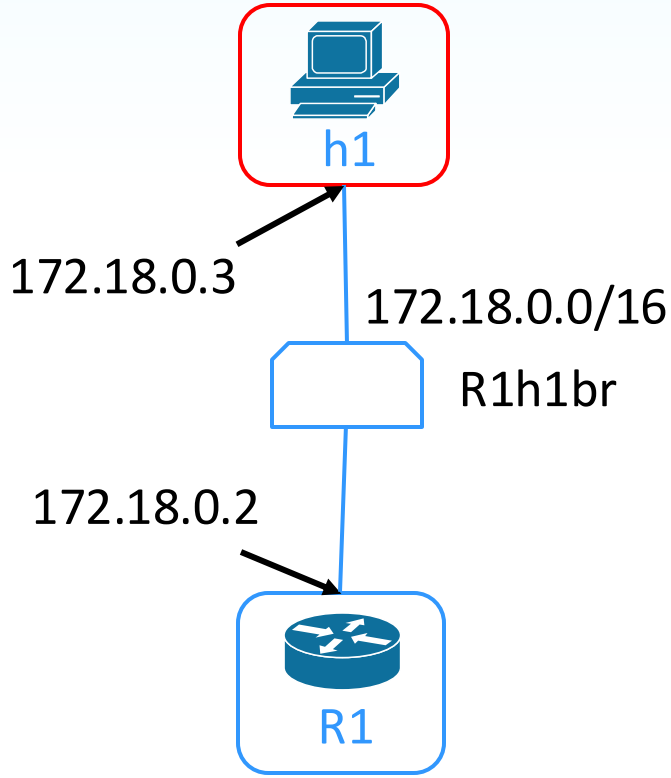
```
networks:
  R1h1br:
    driver: bridge
    ipam:
      config:
        - subnet: 172.18.0.0/16
```



Docker Compose Example (2/4)

- Create container h1 build, run, network connect

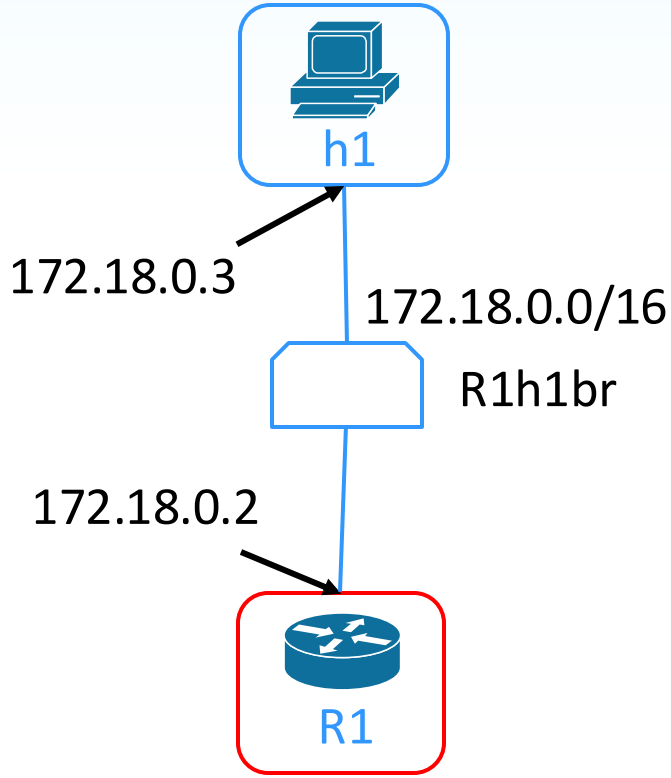
```
services:
  h1:
    image: host
    container_name: h1
    privileged: true
    build:
      context: .
      dockerfile: host.Dockerfile
    cap_add:
      - NET_ADMIN
      - NET_BROADCAST
    networks:
      R1h1br:
        ipv4_address: 172.18.0.3
    entrypoint: ["/bin/sh","-c"]
    command:
    - |
      ip route del default
      ip route add default via 172.18.0.2
      sleep infinity
```



Docker Compose Example (3/4)

- Create container R1 build, run, network connect

```
services:
  R1:
    image: frrouting/frr-debian
    container_name: R1
    privileged: true
    sysctls:
      - net.ipv4.ip_forward=1
    cap_add:
      - NET_ADMIN
      - NET_BROADCAST
    networks:
      R1h1br:
        ipv4_address: 172.18.0.2
    volumes:
      - ./config/daemons:/etc/frr/daemons
      - ./config/R1/frr.conf:/etc/frr/frr.conf
```



Docker Compose Example (4/4)

- At the root of the app project, write file docker-compose.yml
- Start the Docker application

```
$ docker compose up -d
```

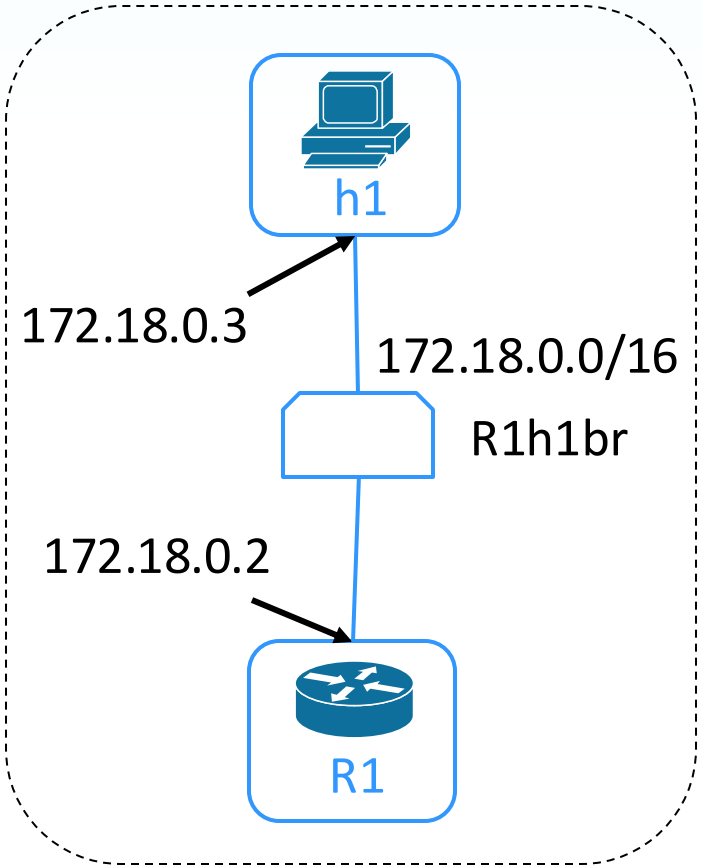
- List the running containers

```
$ docker ps
```

```
CONTAINER ID   IMAGE                    NAMES
6b539d9c0387   frrouting/frr-debian     R1
6eee0a771914   host                     h1
```

- Stop and remove the Docker application

```
$ docker compose down
```



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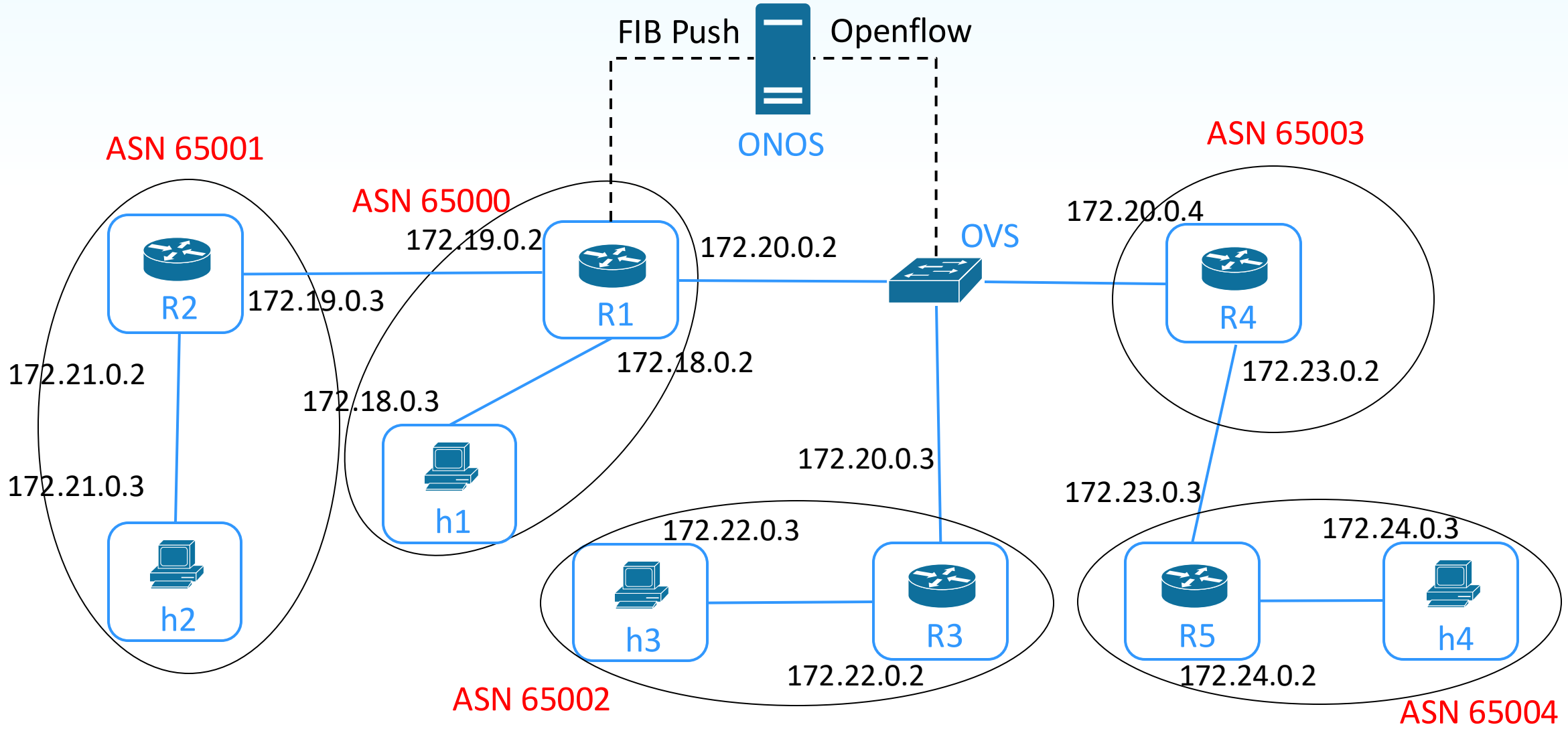
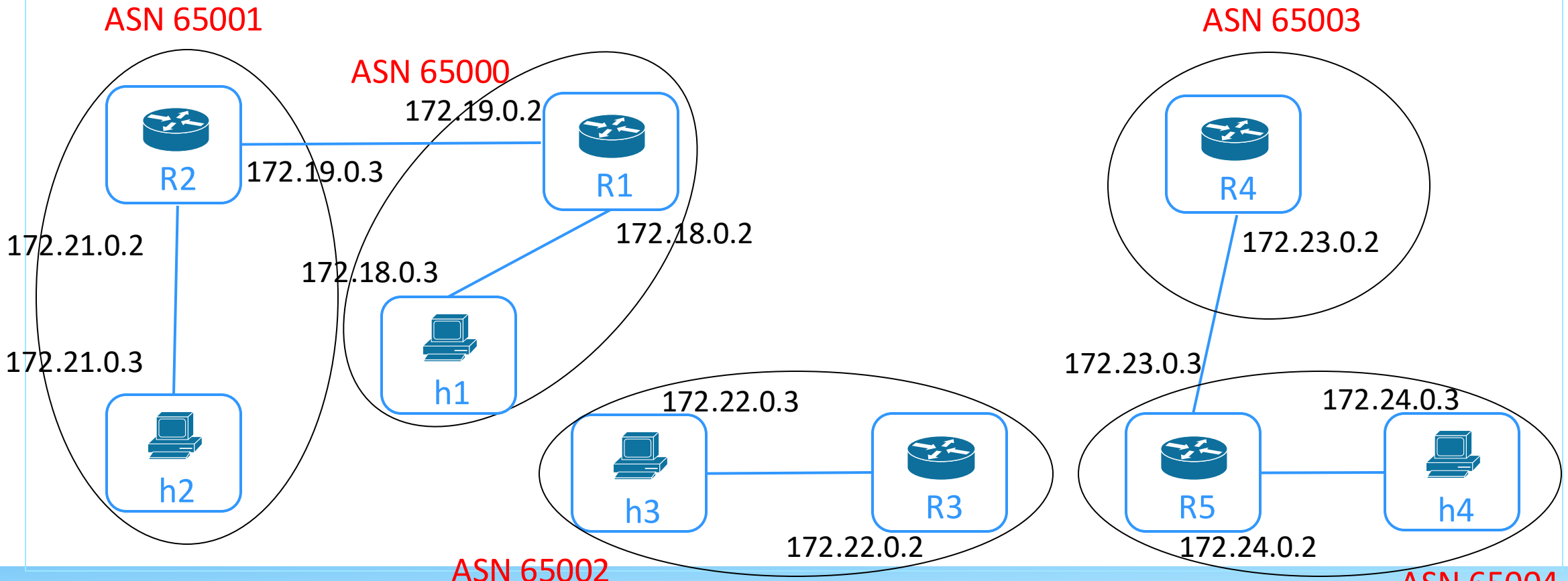
Topology of Lab 5



Step 1 – Create Containers

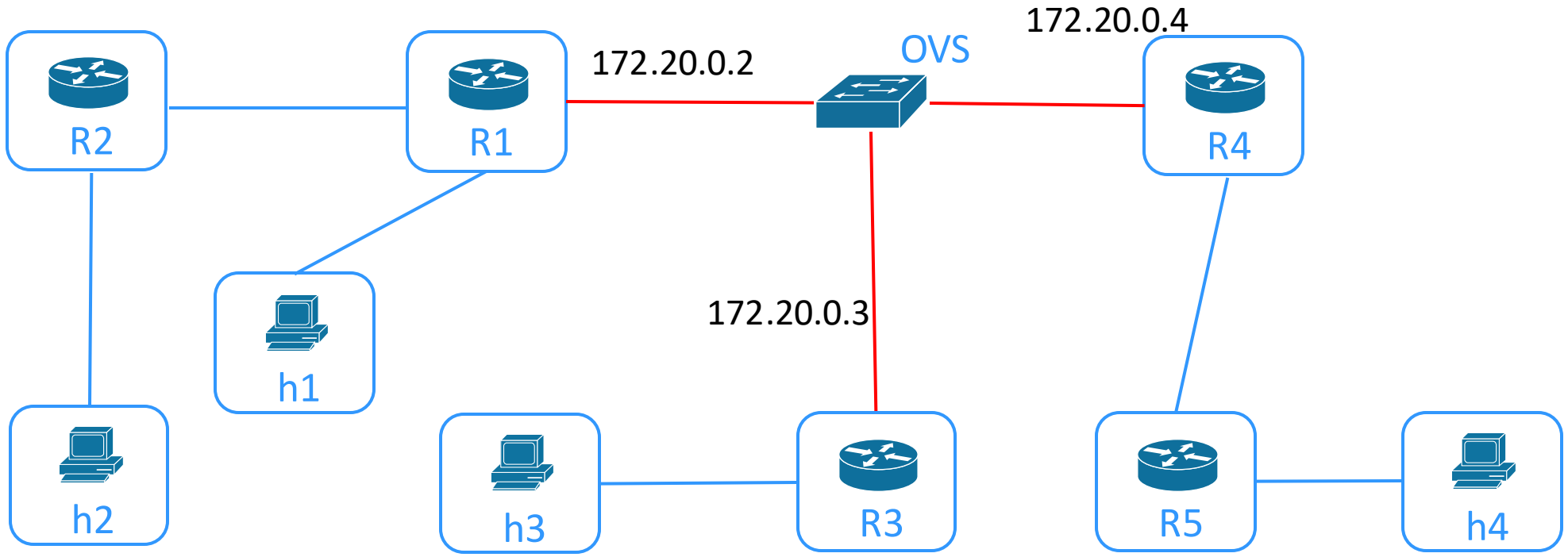
- Prepare docker-compose.yml for following network segments
- Create containers and networks with your docker-compose.yml

```
$ docker compose up -d
```



Step 2 – Create OVS Bridge

- Create an OVS bridge to connect to network segments
  - Use ovs-vsctl to create OVS bridge
  - Use ip or ovs-docker to set a connection between bridge and container

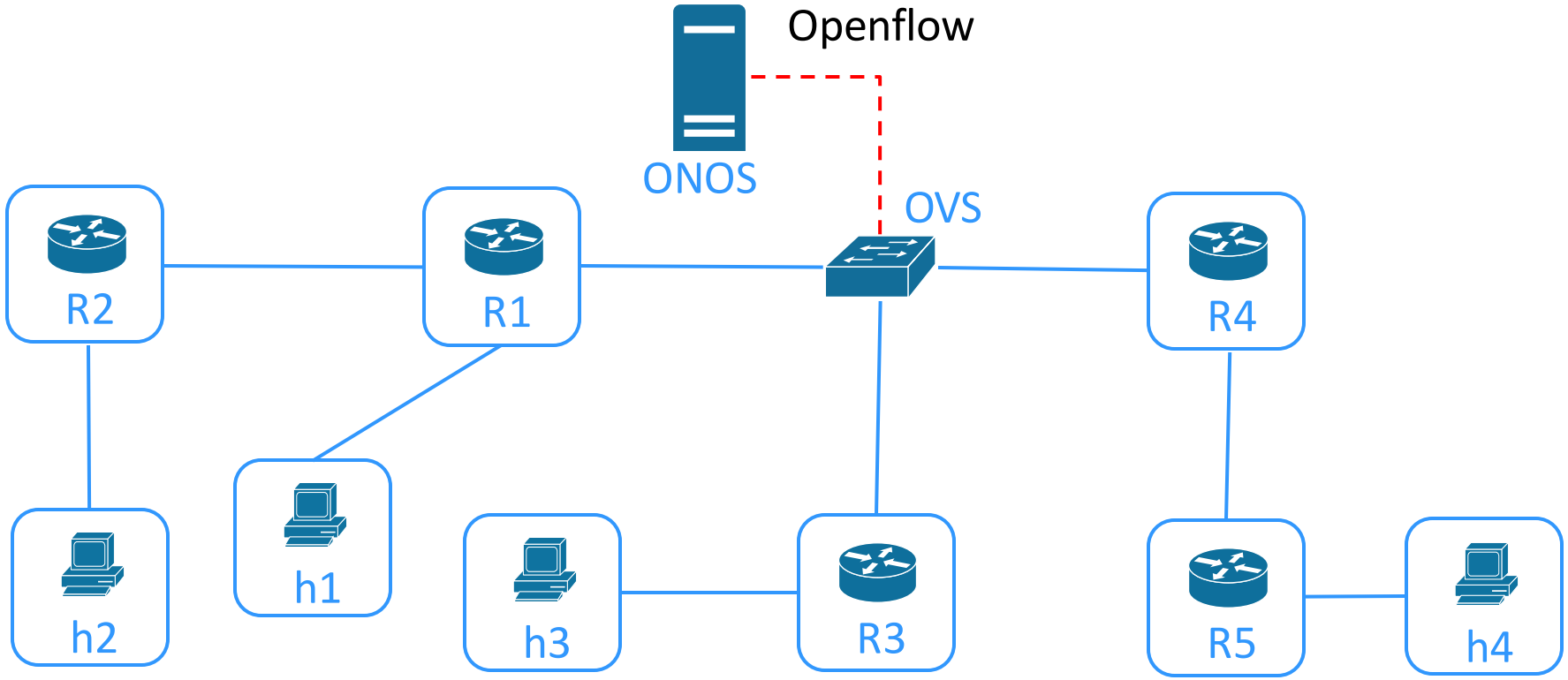


Step 3 – Enable ONOS fwd Application

- Enable ONOS reactive forwarding

```
onos@root > app activate fwd
```

Hint: Set OVS bridge controller to ONOS and set protocol to Openflow 1.4

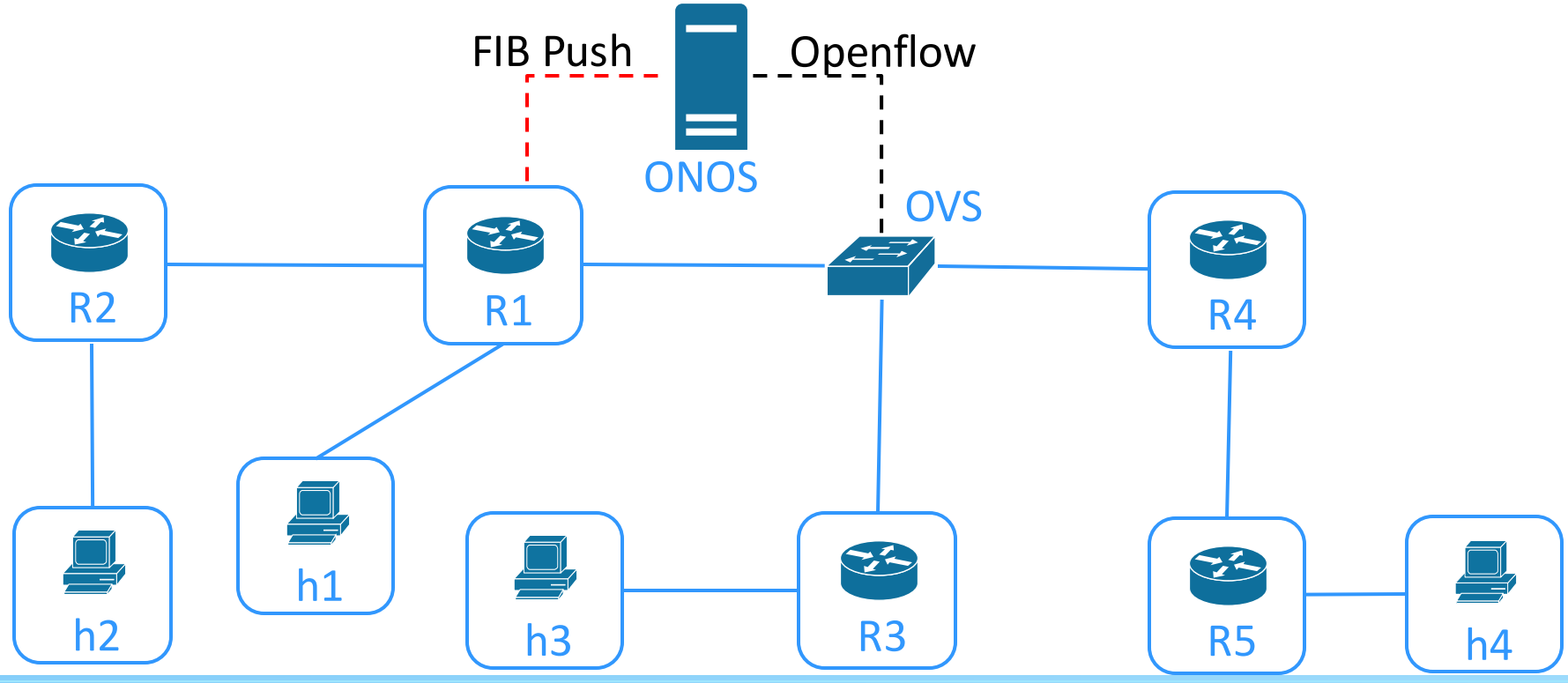


Step 4 – Enable FPI and FPM

- Set FIB Push configuration on R1 FRR Zebra
- Enable ONOS FPM manager

```
onos@root > app activate fpm
```

  - Then, ONOS can receive FIB information from R1



Step 5 - Create Makefile

- Write a **Makefile** for your application which contains:
  - ONOS service creation and setup
  - Container creation
  - OVS bridge creation
  - Link setup
- Create the application with a single command

```
$ make
```

- Stop the application with a single command

```
$ make clean
```

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How to Test Your App (1/3)

- Check IP configuration

```
$ docker exec h1 ifconfig
```

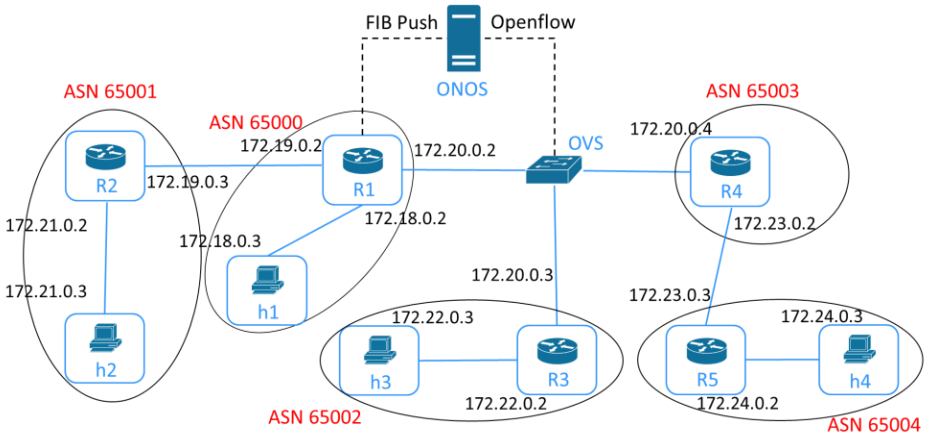
```
eth0      Link encap:Ethernet  HWaddr 02:42:ac:12:00:03
          inet addr:172.18.0.3  Bcast:172.18.255.255  Mask:255.255.0.0
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:95 errors:0 dropped:0 overruns:0 frame:0
          TX packets:9 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:10725 (10.7 KB)  TX bytes:714 (714.0 B)
```

- Activate ONOS fwd application

```
onos@root > app activate fwd
```

- Check host communication (h1 -> h3)

```
$ docker exec -it h1 ping 172.22.0.3 -c 3
```



How to Test Your App (2/3)

- Run bash on R1

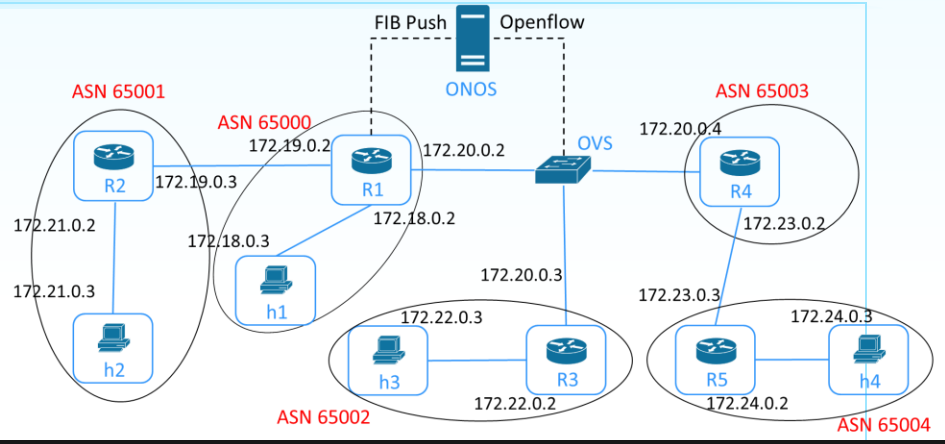
```
$ docker exec -it R1 bash
```

- Interact with FRR daemons

```
R1/#  vtysh
```

- Show R1 bgp

```
R1FRR> show ip bgp
```




```
R1# show ip bgp
BGP table version is 4, local router ID is 172.20.0.2, vrf id 0
Default local pref 100, local AS 65000
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
RPKI validation codes: V valid, I invalid, N Not found

   Network          Next Hop            Metric LocPrf Weight Path
*> 172.18.0.0/16    0.0.0.0(R1)              0         32768 i
*> 172.21.0.0/16    172.19.0.3(R2)           0             0 65001 i
*  172.22.0.0/16    172.20.0.3(R4)                         0 65003 65002 i
*>                   172.20.0.3(R3)           0             0 65002 i
*  172.24.0.0/16    172.20.0.4(R3)                         0 65002 65003 65004 i
*>                   172.20.0.4(R4)                         0 65003 65004 i

Displayed  4 routes and 6 total paths
```

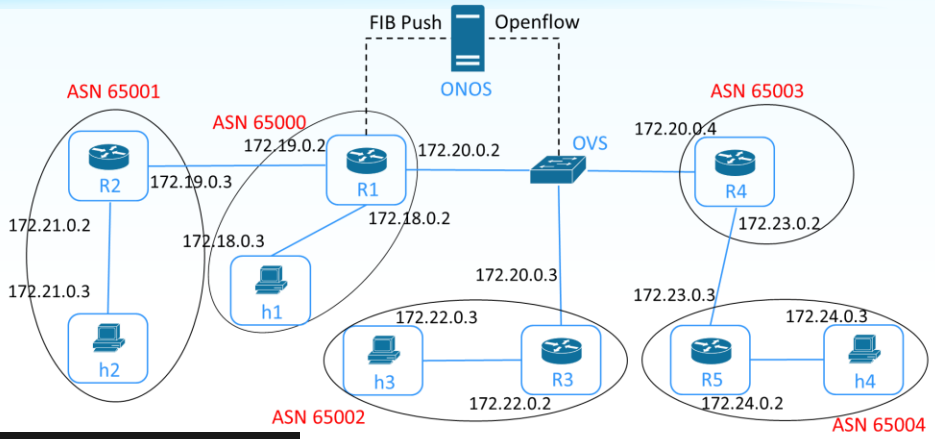
How to Test Your App (3/3)

- Activate ONOS FIB Push Manager (FPM)

```
onos@root > app activate fpm
```

- Show routing message from ONOS

```
onos@root > routes
```




```
onos@root > routes
B: Best route, R: Resolved route

Table: ipv4
B R  Network             Next Hop         Source (Node)
     172.21.0.0/16       172.19.0.3       FPM (172.10.0.2)
     172.22.0.0/16       172.20.0.3       FPM (172.10.0.2)
     172.24.0.0/16       172.20.0.4       FPM (172.10.0.2)
   Total: 3

Table: ipv6
B R  Network             Next Hop         Source (Node)
   Total: 0
```

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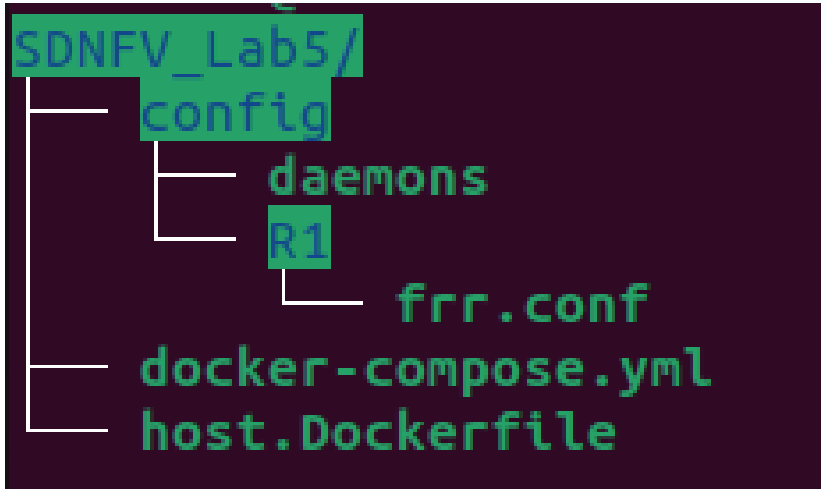
Supplements (1/2)

- TA will provide the following



  - The files contain the basic configs for h1 and R1 that you can start the containers using Docker Compose.

Supplements (2/3)

- The docker compose file also defined a ONOS service for you to use
- Configure your app to connect to this ONOS instead of your local ONOS environment.
- ONOS service ports are exposed to host
- Connect to ONOS CLI

```
$ ssh -o "StrictHostKeyChecking=no"
      -o GlobalKnownHostsFile=/dev/null
      -o UserKnownHostsFile=/dev/null
      onos@localhost -p 8101
```

```yaml
onos:
  image: onosproject/onos:latest
  container_name: onos
  hostname: onos
  privileged: true
  networks:
    - default
  environment:
    - ONOS_APPS=fpm,fwd
  ports:
    - "2620:2620"
    - "6653:6653"
    - "8101:8101"
    - "8181:8181"
  tty: true
  stdin_open: true
```

Supplements (3/3)

- R1 is configured to connect to the host's localhost.
- You can connect to ONOS services via 172.17.0.1 or the docker0 interface ip address in your container

```
R1:
  image: frrouting/frr-debian
  container_name: R1
  hostname: R1
  privileged: true
  sysctls:
    - net.ipv4.ip_forward=1
  cap_add:
    - NET_ADMIN
    - NET_BROADCAST
  networks:
    R1h1br:
      ipv4_address: 172.18.0.2
  extra_hosts:
    - "host.docker.internal:host-gateway"
  volumes:
    - ./config/daemons:/etc/frr/daemons
    - ./config/R1/frr.conf:/etc/frr/frr.conf
```

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Scoring Criteria (1/3)

- Create Makefile
  - You must provide Makefile, which creates the application with a make command
  - Makefile should be placed at the root of the project directory
  - TA will use your Makefile to build your application
  - You will not earn any credit if Makefile is not provided
- **(18%)** Create containers
  - Use Docker to create four host and five router containers
  - You lose two credits for each container that is not created
- **(10%)** Create an OVS bridge
  - You must use the ovs-vsctl command
    - You will not earn any credit if you do not conform to the above regulation

Scoring Criteria (2/3)

- **(18%)** Setup links
  - Set the connections and IPs based on the topology
  - Use the Docker network to set a connection between each pair of container
  - Use ip or ovs-docker to set a connection between a bridge and a container
  - Each link with a wrong setting will result in two points deduction
- **(20%)** Setup BGP configurations
  - Set the AS number based on the topology
  - TA will check your settings in frr.conf for each router
  - Each router with a wrong setting will result in four points deduction
- **(20%)** Ping test
  - Every host in the topology should be able to ping each other
  - Each host failing to reach some hosts will result in five points deduction

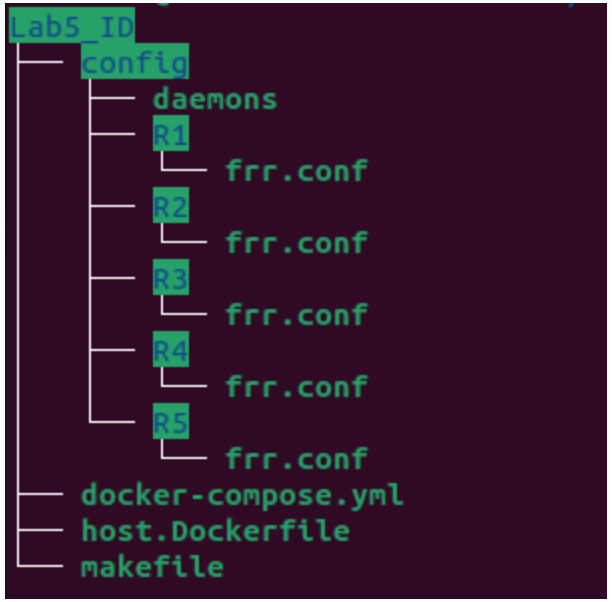
Scoring Criteria (3/3)

- **(14%)** Setup FIB Pushing
  - ONOS can receive FIB information from R1
- Reminders
  - Use the docker ONOS environment and activate the needed apps.
  - You should not use ONOS environment other than the docker one.

```
cu@root > apps -a -s
*   3 org.onosproject.route-service          2.7.0    Route Service Server
*  11 org.onosproject.drivers                2.7.0    Default Drivers
*  15 org.onosproject.fwd                    2.7.0    Reactive Forwarding
*  21 org.onosproject.optical-model          2.7.0    Optical Network Model
*  23 org.onosproject.gui2                   2.7.0    ONOS GUI2
*  35 org.onosproject.fpm                    2.7.0    FIB Push Manager (FPM) Route Receiver
*  44 org.onosproject.openflow-base          2.7.0    OpenFlow Base Provider
*  45 org.onosproject.lldpprovider           2.7.0    LLDP Link Provider
*  46 org.onosproject.hostprovider           2.7.0    Host Location Provider
*  72 org.onosproject.openflow               2.7.0    OpenFlow Provider Suite
```

Submission Naming Convention

- Rename your directory as **lab5_<student ID>**
- Compress the directory into a **zip** file named **lab5_<student ID>.zip**
- Upload your zip file to E3
- Wrong file name or format will result in 10 points deduction
- 20% deduction for late submission in one week
  - Won't accept submissions over one week



Demo

- TA will open a demo time-reserved table a week before the demo
- The dates will be chosen after the deadline
- Demo questions will appear at the start of the demo
- The score of the demo is **40%** total score of this lab
  - For example:
    - You earn 100% of the credits for submission
    - You earn 80% of the credits for the demo
    - then your total score for this lab will be:
      - **100 x 60% + 80 x 40% = 92.**

About help!

- For any lab problem, ask at the e3 forum
  - Ask at the e3 forum
  - TAs will help to clarify lab contents instead of giving answers!
  - Please describe your questions with sufficient context,
    - E.g., Environment setup, Input/Output, Screenshots, ...
- For personal problems, mail to **sdnta@win.cs.nycu.edu.tw**
  - You have particular problems so that you can't meet the deadline
  - You got a weird score with the lab
- No Fixed TA hour

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References

- Docker overview
- Docker commandline reference
- Docker compose reference
- FRRouting User Guide v8.0