Lab3

Dynamic Routing

and

Network Address Translation

Deadline: 2022/03/28 (Mon) 23:59

Outline

- Objective
- Quagga
- Docker
- Dynamic Routing
- iptables overview
- NAT scenarios
- Lab requirement
- Appendix

Objective

- How Linux kernel handle incoming packet
- Observe packet before/after NAT
- Configure NAT rules on routers with iptables
  - Source NAT
  - Destination NAT (Port forwarding)
- Docker setup
- Dynamic routing configuration

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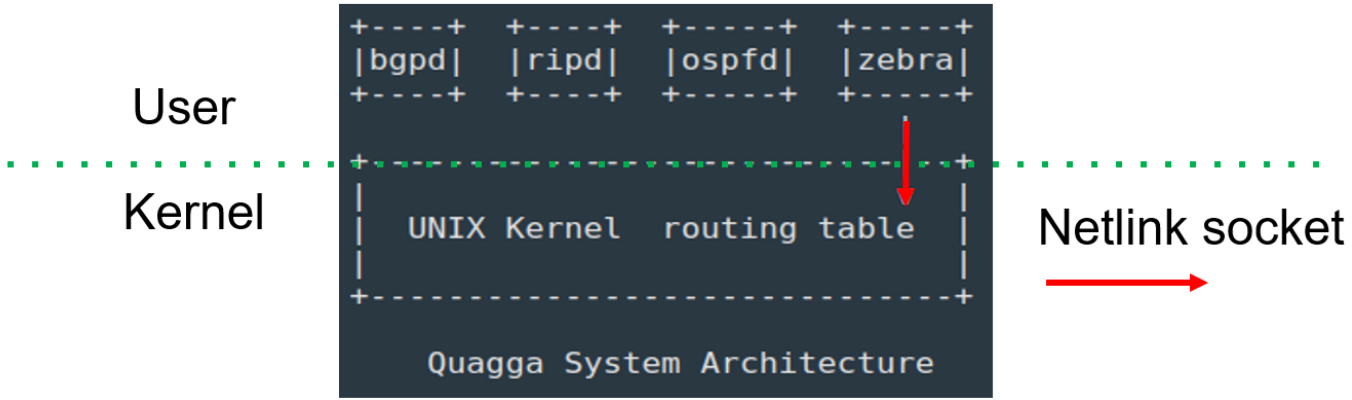
Quagga

- Quagga is an open source software that provides routing services
  - Consists of a **core daemon Zebra** and separate **routing protocol** daemons
  - Supports common routing protocols: BGP, OSPF, RIP, and IS-IS
- Routing Protocols (daemons) communicate their best routes to Zebra
- Zebra computes best routes and modifies **kernel routing table** through netlink



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  - Docker Object and Docker Registry
  - Docker Installation
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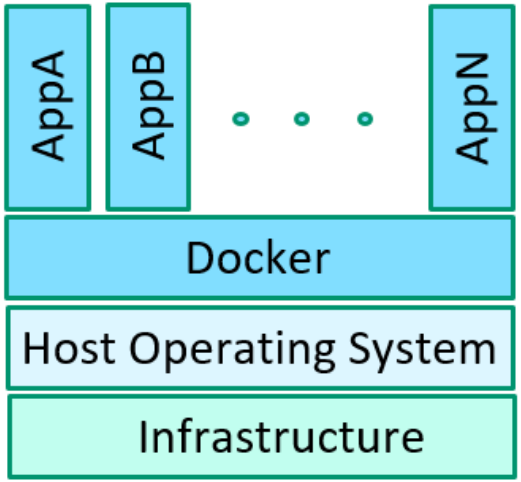
Docker Objects

- Docker images
  - An image is a read-only template with instructions for creating a Docker container
  - An image could be based on another image, with some additional customization
- Docker containers
  - A runnable instance of an image



Docker Registry

- A database of images where users can pull or push images
  - Public (Docker Hub)
    - https://hub.docker.com/
  - Private (e.g. your computer)
    - Default path: /var/docker/lib

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Docker Installation

- Update apt

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

- Install curl for data transfer

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

- Retrieve Docker installation script and install Docker

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

Docker Permission Setup

- By default, Docker daemon runs as the root user
  - Need root permission (sudo) to run Docker commands
- To run docker commands without root permission
  1. Create a Unix group called docker
  2. Add users to docker group

```
bash$ sudo groupadd docker  # add a docker group
bash$ sudo usermod -aG docker $USER # add $USER into docker group
```

     - -a: append the user to the supplemental Groups
     - -G: new list of supplemental Groups
  3. Log out and log back / Reboot your computer

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    - Docker network

Pull Images from Docker Hub Registry

- Usage

```
bash$ sudo docker pull [NAME]:[TAG]
```

- Example

```
bash$ sudo  docker pull ubuntu:18.04
```

- List images

```
bash$ sudo docker images
```

```
jin@ubuntu:~$ sudo docker images
REPOSITORY          TAG                 IMAGE ID            CREATED
SIZE
ubuntu              18.04               c090eaba6b94        2 weeks ago
63.3MB
```

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Create Dockerfile

- Create a file named Dockerfile
- Dockerfile: a text file contains all the commands for Ducker to build a container mage automatically
  - Including
    - A base image command
    - Other custom commands

Base image

Custom commands for building custom image

- Example Dockerfile

```
1  FROM ubuntu:18.04
2
3  MAINTAINER jin
4
5  RUN apt-get update
6
7  RUN apt-get install iptables -y
8  RUN apt-get install iputils-ping -y
9  RUN apt-get install net-tools -y
10 RUN apt-get install iproute2 -y
11 RUN apt-get install tcpdump -y
12 RUN apt-get install vim -y
13 RUN apt-get install sudo -y
14 RUN apt-get install git -y
15 RUN apt-get install isc-dhcp-server -y
16 RUN apt-get install isc-dhcp-client -y
17 RUN apt-get install mininet -y
```

Build Docker Image

- Build image

```
bash$ docker build -t [image_name] [path of dockerfile]
```

  - Execution steps
    1. Load Dockerfile
    2. Pull and load base image
    3. Run custom commands
    4. Save the image to local docker registry

Example: Build Docker Image

- Build a custom image named test

```
jin@ubuntu:~/Desktop$ docker build -t test .
```

  - Default filename: Dockerfile

- Show docker images

```
jin@ubuntu:~/Desktop$ sudo docker images
REPOSITORY          TAG                 IMAGE ID            CREATED
SIZE
test                latest              94fa41d40498        11 minutes ago
268MB
ubuntu              18.04               c090eaba6b94        2 weeks ago
63.3MB
```

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Docker run

- Run a command in a new container
- Usage

```
bash$ sudo docker run [OPTIONS] [IMAGE:TAG] [COMMAND] [ARG]
```

Create and Run a new container

A Command runs in the new container (Optional)

- **Create** and **Start** a container “sample”

```
bash$ sudo docker run -d -it --name sample Ubuntu:18.04
```

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

List Docker Containers

- Command to list Docker containers

```
bash$ sudo docker ps –a
```

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

```
jin@ubuntu:~/Desktop$ sudo docker run -d -it --name sample ubuntu:18.04
[sudo] password for jin:
be95d7141f15663ff624d226f08c95a99f7946467ac36b24329cfe7cdf1bf517
jin@ubuntu:~/Desktop$ sudo docker ps -a
CONTAINER ID        IMAGE               COMMAND             CREATED
 STATUS              PORTS               NAMES
be95d7141f15        ubuntu:18.04        "/bin/bash"         16 seconds ago
 Up 13 seconds                           sample
```

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Docker exec

- Execute a command in a **running** container
- Usage

```
bash$ sudo docker exec [OPTIONS] [CONTAINER] [COMMAND]
```

- E.g., Execute *bash* command in a **running** container “sample”

```
jin@ubuntu:~/Desktop$ sudo docker exec -it sample bash
root@be95d7141f15:/#
```

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Docker network – Create

- Usage

```
bash$ sudo docker network create [OPTIONS] [Network name]
```

[OPTIONS]: Choose the network mode, default mode is *bridge*

- E.g. create a network named **testbr**

```
bash$ sudo docker network create testbr
```

- List existing docker networks

```
bash$ sudo docker network ls
```

```
jin@ubuntu:~/Desktop$ sudo docker network ls
NETWORK ID          NAME                DRIVER              SCOPE
d8d101d5687d        bridge              bridge              local
1529c9f8db21        host                host                local
d99e273e7e4c        none                null                local
b85856850a7e        testbr              bridge              local
```

Docker network – Connect

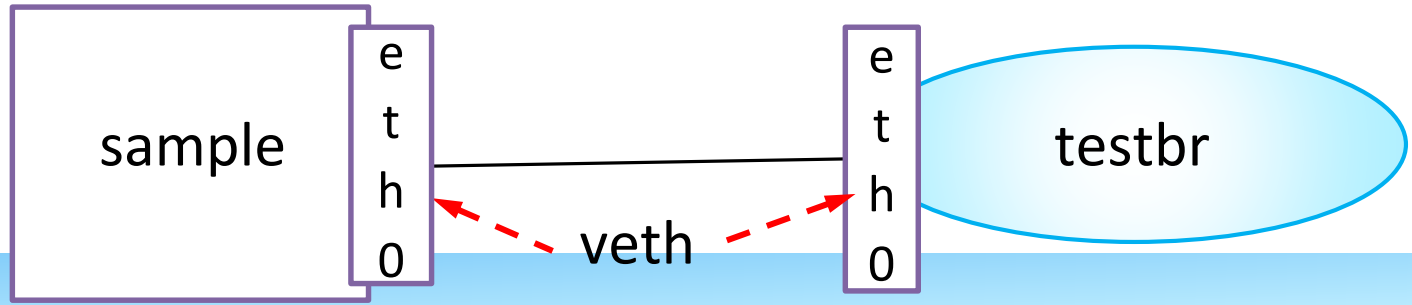
- Connect a container to a network
- Usage

```
bash$ sudo docker network connect [NETWORK] [CONTAINER]
```

- E.g. connect **sample** to **testbr**

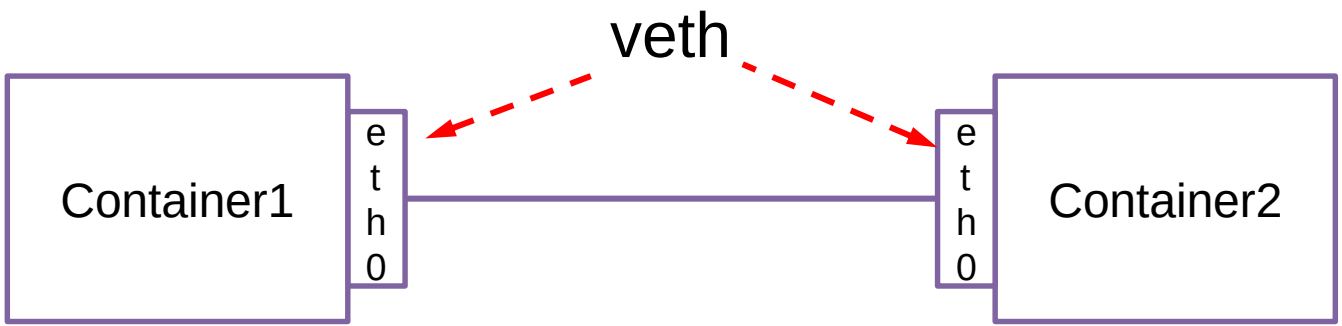
```
bash$ sudo docker network connect testbr sample
```

- Docker will create a pair of virtual interfaces (next slide)
  - One for the **testbr** and the other for the **sample** container
  - Assigns an IP address to the interface of



Virtual Ethernet Device

- veth: Virtual Ethernet device
  - A local Ethernet tunnel
  - Normally, created in pairs
- Containers could be created without network then manually set veth pairs to connect containers



Create veth Pair without Docker Network

- Create two contains without network

```
bash$ docker run -it  --cap-add=NET_ADMIN --name left --net=none --privileged test
bash$ docker run -it  --cap-add=NET_ADMIN --name right --net=none --privileged test
```

  - --cap-add=NET_ADIM: Add Linux capabilities to modify network interfaces
  - --privileged: Give extended privilege to this container
  - **test**: custom image

- Create veth pair

```
bash$ sudo ip link add leftVeth type veth peer name rightVeth
```

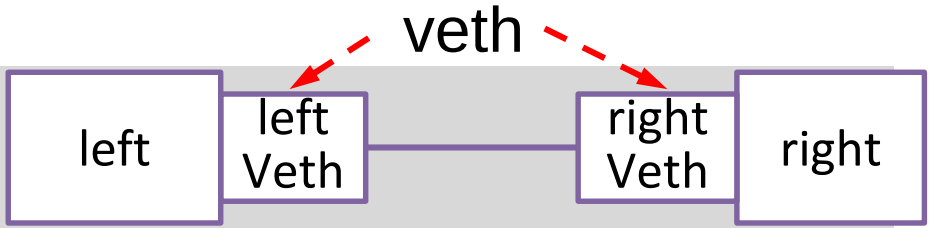
veth Pair connect to Container

- Set veth pairs into containers **left** and **right**

```
bash$ sudo ip link set leftVeth netns $(sudo docker inspect -f '{{.State.Pid}}' left)
bash$ sudo ip link set rightVeth netns $(sudo docker inspect -f '{{.State.Pid}}' right)
```

- Set veth pair up

```
bash$ ip link set leftVeth up #left
bash$ ip link set rightVeth up #right
bash$ ifconfig #left
```




```
root@1c27c6b58ca7:/# ip link set leftVeth up
root@1c27c6b58ca7:/# ifconfig
leftVeth: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500
        ether 96:43:84:b0:5a:e7  txqueuelen 1000  (Ethernet)
        RX packets 0  bytes 0 (0.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 0  bytes 0 (0.0 B)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
```

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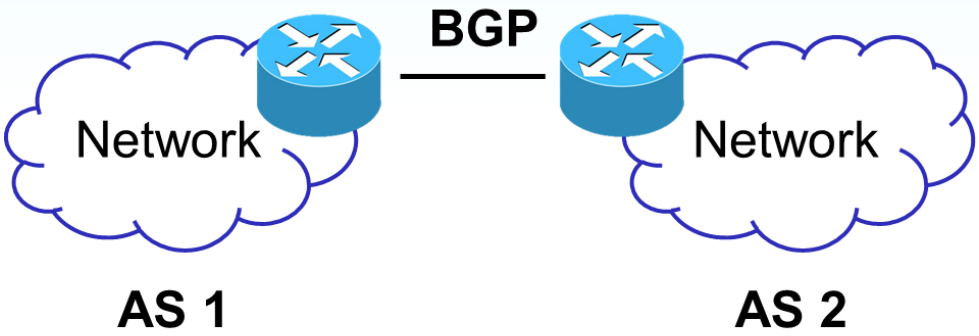
Example Scenario

- Interconnection of two networks



- BGP: Border Gateway Protocol
  - AS: Autonomous System

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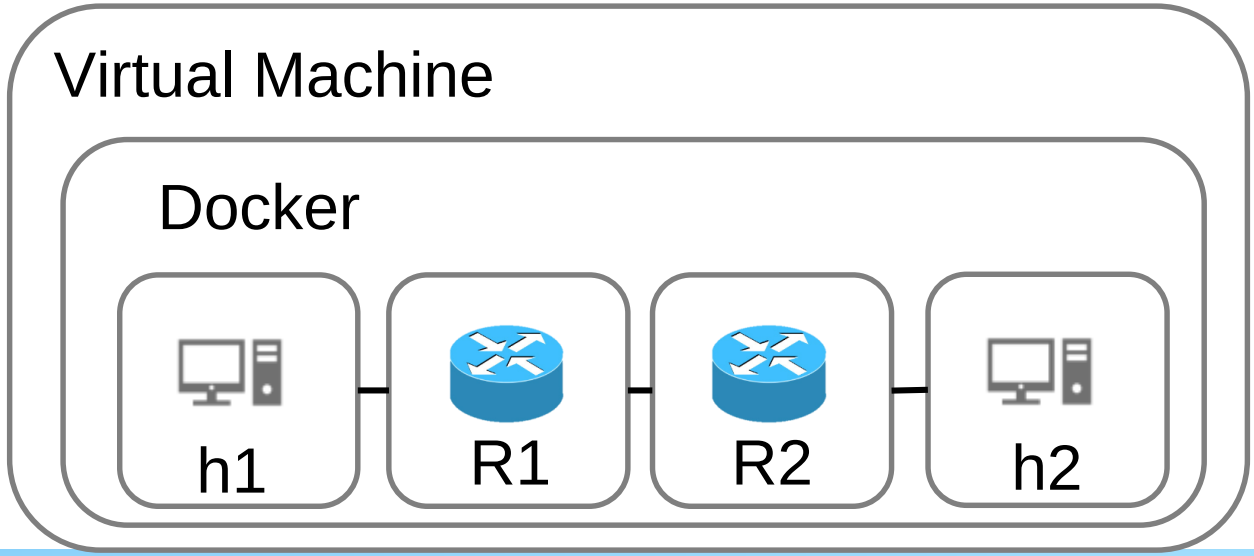
Steps to Setup Example Scenario

1. Create Containers
2. Set up Container Networks
3. Configure Host Gateways
4. Setup Routers



Step 1 – Create Containers (1/2)

- We use Ubuntu 16.04 for all hosts and routers
- Create a Container with Ubuntu as OS

```
bash$ sudo docker run --privileged --cap-add NET_ADMIN \
      --cap-add NET_BROADCAST -d –it \
      --name <ContainerName> ubuntu:16.04
```

  - NET_BROADCAST: Make socket broadcast, and listen to multicasts.

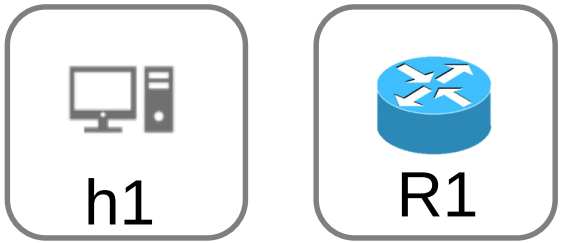
Step 1. Create Containers – example

- Create container for a host h1 (h2)

```
bash$ sudo docker run --privileged --cap-add NET_ADMIN \
      --cap-add NET_BROADCAST -d -it \
      --name h1 ubuntu:16.04
```

- Create container for a virtual router R1 (R2)

```
bash$ sudo docker run --privileged --cap-add NET_ADMIN \
      --cap-add NET_BROADCAST -d -it \
      --name R1 ubuntu:16.04
```



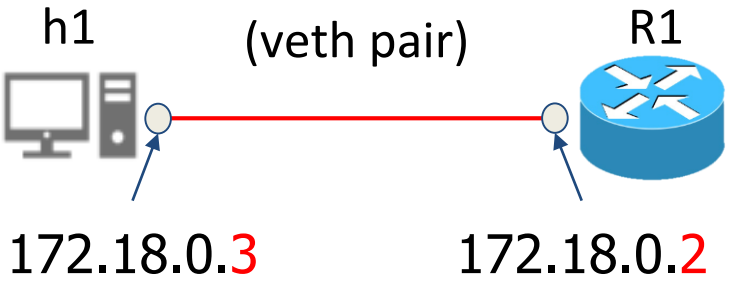
Step 2 – Setup Container Networks (1/3)

- Create a veth pair

```
bash$ sudo ip link add h1R1veth type peer name R1h1veth
```

- Connect containers h1 and R1 with veth pair

```
bash$ sudo ip link set R1h1veth netns $(docker inspect -f {{.State.Pid}} R1)
bash$ sudo ip link set h1R1veth netns $(docker inspect -f {{.State.Pid}} h1)
```



Step 2 – Setup Container Networks (2/3)

- Set IP addresses of network interfaces

```
bash$ docker exec h1 ip addr add 172.18.0.3 dev h1R1veth
bash$ docker exec R1 ip addr add 172.18.0.2 dev R1h1veth
bash$ docker exec h1 ip link set h1R1veth up
bash$ docker exec R1 ip link set R1h1veth up
```

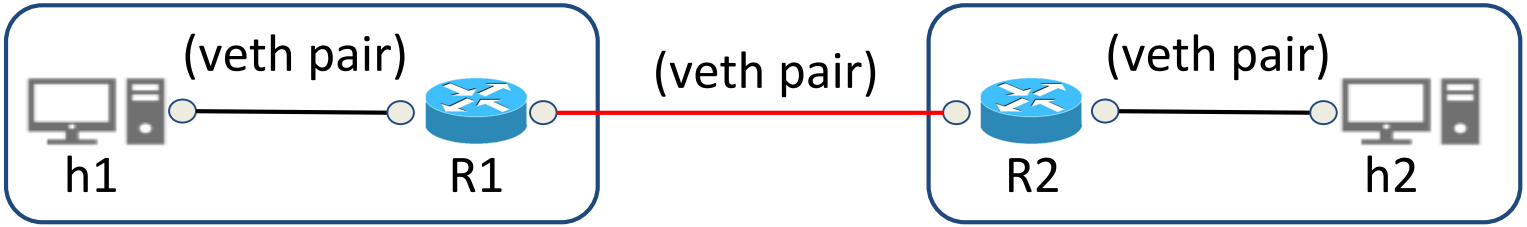
Step 2 – Setup Container Networks (3/3)

- Connect two domains
  - Create inter domain link

```
bash$ sudo ip link add R1R2veth type peer name R2R1veth
```

  - Connect containers R1 and R2 to veth pair

```
bash$ sudo ip link set R1R2veth netns $(docker inspect -f {{.State.Pid}} R1)
bash$ sudo ip link set R2R1veth netns $(docker inspect -f {{.State.Pid}} R2)
```



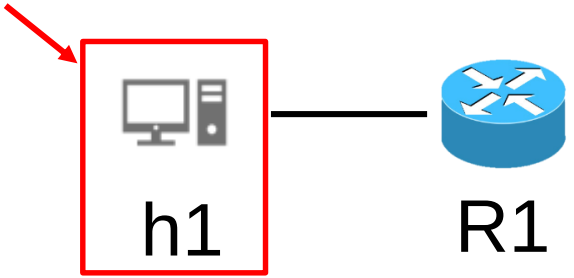
Step3 – Configure Host Gateways (1/2)

- Run bash on h1 (h2)

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

- Install net-tools and iproute2 on h1 (h2)

```
/# apt-get update
/# apt-get install -y net-tools
/# apt-get install -y iproute2
```



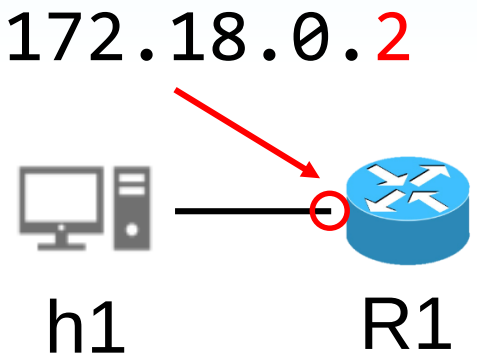
Step3 – Configure Host Gateways (2/2)

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

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

- Check route in h1 (h2)

```
/# ip route show
```




```
root@f4ac43b5f92a:/# ip r
default via 172.18.0.2 dev h1R1veth
172.17.0.0/16 dev eth0  proto kernel  scope link  src 172.17.0.2
172.18.0.0/16 dev h1R1veth  proto kernel  scope link  src 172.18.0.1
```

Step 4 – Setup Routers (1/6)

4.1 Install vim and quagga on R1 (R2)

- Run bash on R1 (R2)

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

```
/# apt-get update
/# apt-get install -y vim
/# apt-get install -y quagga
```

Step 4 – Setup Routers (2/6)

4.2 Enable IP forwarding of R1 (R2)

- Edit system control configuration file

```
/# vim /etc/sysctl.conf
```

- Uncomment “net.ipv4.ip_forward=1” in sysctl.conf
  - 1: enable
  - 0: disable
- Run sysctl to load the configuration

```
/# sysctl -p
```

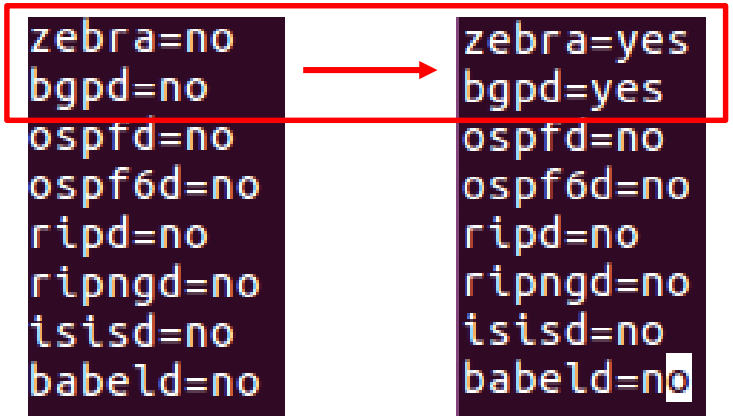
Step 4 – Setup Routers (3/6)

4.3 Enable routing function of Quagga

- Edit Quagga daemons on R1 (R2)

```
/# vim /etc/quagga/daemons
```

- Enable zebra and bgpd deamons
  - Change zebra and bgpd to yes



Step 4 – Setup Routers (4/6)

4.4 Set Hostname and Password of Zebra on R1 (R2)

- Edit configuration file zebra.conf of Quagga on R1 (R2)

```
/# vim /etc/quagga/zebra.conf
```

- Add router name and password in zebra configuration file

```
hostname R1zebra (R2zebra)
password vRouter
log stdout
```

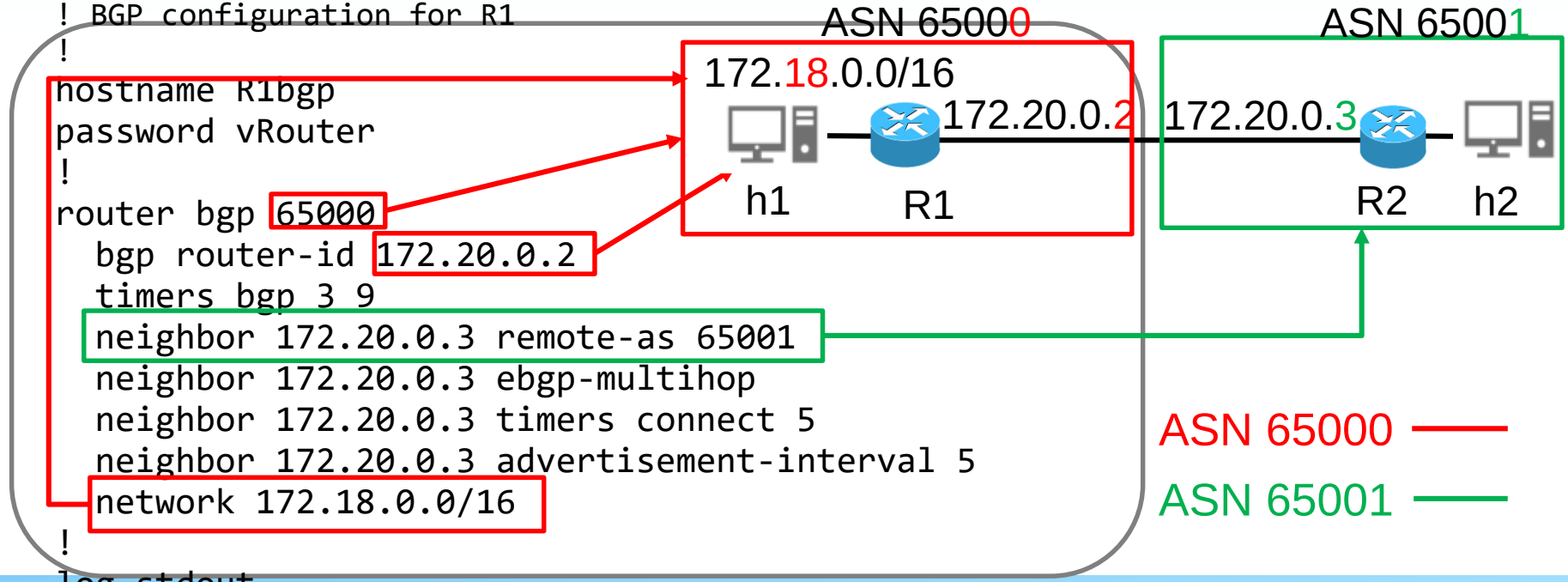
- Hostname for identifying zebra on R1 or R2 (for shell prompt)
- Password for user access verification

Step 4 – Setup Routers (5/6)

4.5 Set BGP configuration of routers

```
/# vim /etc/quagga/bgpd.conf
```

```
! BGP configuration for R1
!
hostname R1bgp
password vRouter
!
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
```

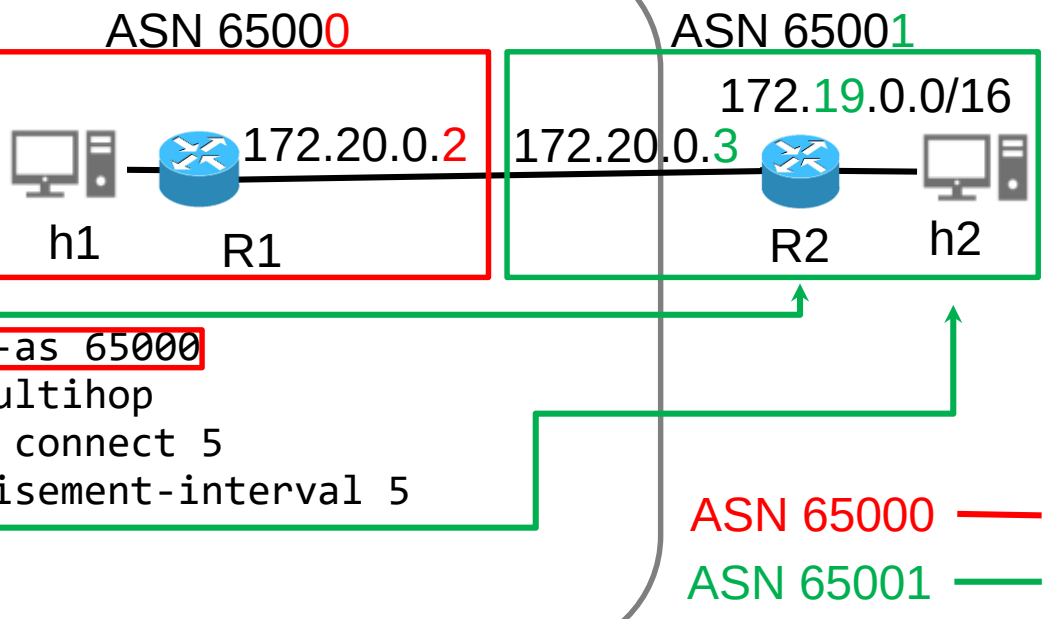


Step 4 – Setup Routers (6/6)

- Edit configuration file bgpd.conf of Quagga on R2

```
/# vim /etc/quagga/bgpd.conf
```

```
! BGP configuration for R2
!
hostname R2bgp
password vRouter
!
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
```



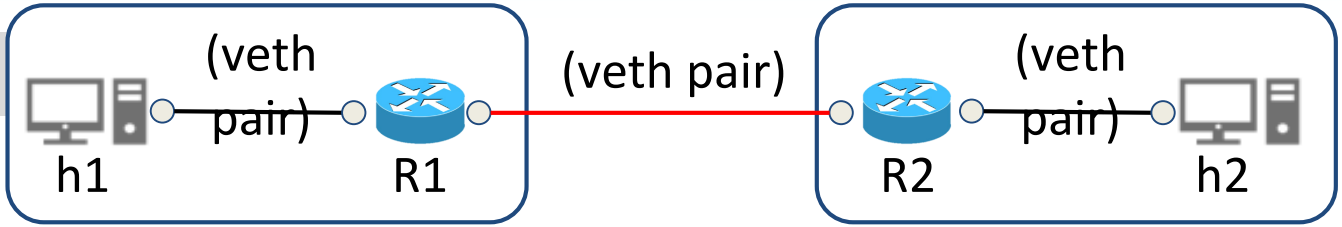
Check Route (1/3)

- Restart Quagga on R1 and R2

```
/# /etc/init.d/quagga restart
```

- Check Route

```
/# ip r
```




```
root@13d4701fa1a8:/# ip route
default via 172.17.0.1 dev eth0
172.17.0.0/16 dev eth0  proto kernel  scope link  src 172.17.0.4
172.18.0.0/16 dev R1h1veth  proto kernel  scope link  src 172.18.0.2
172.19.0.0/16 via 172.20.0.3 dev R1R2veth  proto zebra
172.20.0.0/16 dev R1R2veth  proto kernel  scope link  src 172.20.0.2
```

Check Route (2/3)

- Telnet R1 zebra daemons (on port 2601)

```
/# apt-get install -y telnet
/# telnet localhost 2601
```

```
User Access Verification

Password:
R1zebra>
```

- Show bgp route in R1zebra

```
R1zebra> show ip route bgp
```

```
R1zebra> show ip route bgp
Codes: K - kernel route, C - connected, S - static, R - RIP,
       O - OSPF, I - IS-IS, B - BGP, P - PIM, A - Babel,
       > - selected route, * - FIB route

B>* 172.19.0.0/16 [20/0] via 172.20.0.3, R1R2veth, 00:05:55
```

Check Route (3/3)

- Telnet R1 bgpd daemons (on port 2605)

```
/# telnet localhost 2605
```

```
User Access Verification

Password:
R1bgp>
```

- Show R1 bgp summary

```
R1bgp> show ip bgp summary
```

```
R1bgp> show ip bgp summary
BGP router identifier 172.20.0.2, local AS number 65000
RIB entries 3, using 336 bytes of memory
Peers 1, using 4568 bytes of memory

Neighbor        V         AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
172.20.0.3      4 65001     150     153        0    0    0 00:07:22        1

Total number of neighbors 1
```

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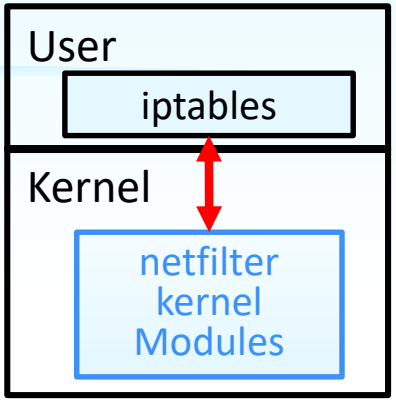
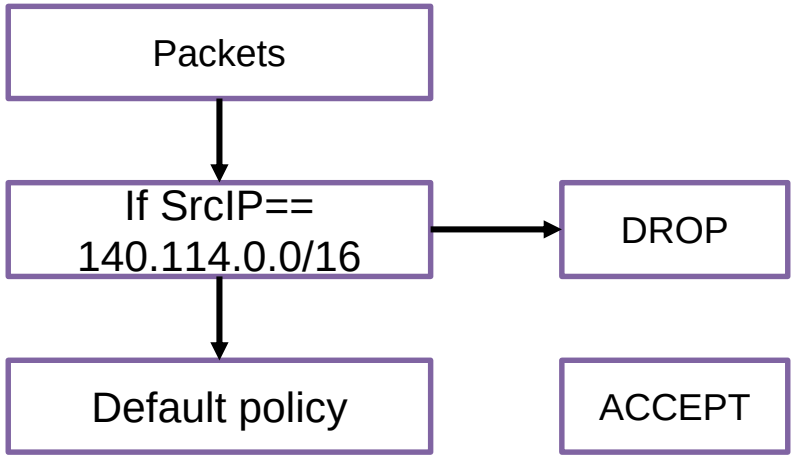
iptables overview



- **iptables**:
  A user-space utility program that allows a system administrator to configure **Linux kernel firewall**
- **Linux kernel firewall** implemented as different **Netfilter modules**
- Netfilter:
  A framework provided by Linux kernel to implemented various networking operations with some match-action rules
  - Network address translation
  - Packet filtering
    - e.g., Filtering packet from NTHU



Tables and Chains in iptables

- iptables contains several tables to implement networking operations
- Linux has at least three basic tables
  - Filter: Packet filtering
  - NAT: Network Address translation
  - Mangle: Special tags on packets
- Each table contains several chains
  - Each chain contains match-actions rules to perform networking operation
  - Different chains will be applied in a order in Linux kernel

Ref: https://zh.wikipedia.org/wiki/Iptables#/media/File:Netfilter-packet-flow.svg

Table and chain in iptables

- Linux basic tables and their default chains

iptables

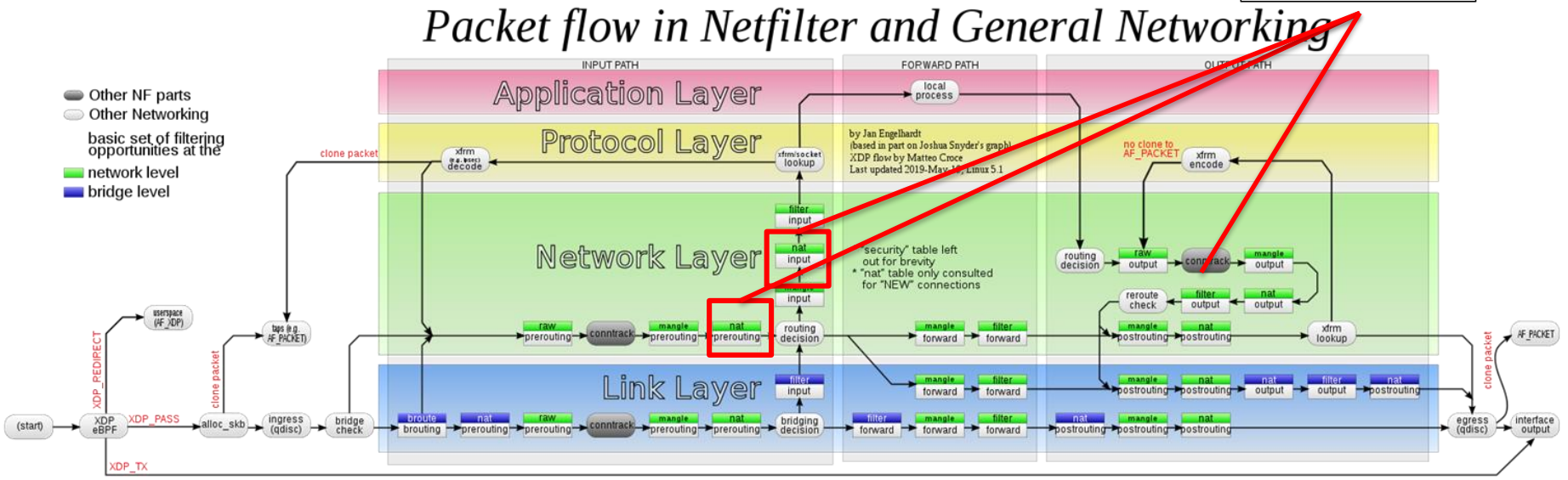
Filter	NAT	Mangle
Chain: INPUT Rule 1 … Chain: OUTPUT Rule 1 … Chain: FORWARD Rule1 …	Chain: PREROUTING Rule 1 … Chain: OUTPUT Rule 1 … Chain: POSTROUTING Rule1 …	Chain: PREROUTING Rule 1 … Chain: OUTPUT Rule 1 …

Custom tables (option)
Chain: custom chain Rule 1

Packet flow in Netfilter

- Applied order example:
  - Chains of NAT table

NAT
Chain: PREROUTING Rule 1 … Chain: OUTPUT Rule 1 … Chain: POSTROUTING Rule1 …



Outline

- Objective
- Quagga
- Docker
- Dynamic Routing
- Iptables
  - Overview
  - Basic usage
- NAT scenarios
- Lab requirement
- Appendix

iptables basic usage – add rule

- Append rules to a chain of a table

```
bash$ sudo iptables -t [table] -A [chain] [match field] -j [Actions]
```

- Example:
  - `sudo iptables -t nat -A POSTROUTING -s 172.20.0.0/16 -d 172.87.0.0/16 -o eth2 -j SNAT --to-source 172.20.0.1`
  - Append a SNAT rules to change source address in chain POSTROUTING of NAT table if packet matched following fields
    - source addresses: 172.20.0.0/16
    - destination addresses: 172.87.0.0/16
    - output interface: eth2
    - action: SNAT

iptables basic usage – list rule

- Show all chains and rules in a table

```
bash$ sudo iptables -nvL -t [table name]
```

Default Chains

```
root@a232042897b2:/# sudo iptables -t nat -nvL
Chain PREROUTING (policy ACCEPT 4 packets, 323 bytes)
 pkts bytes target     prot opt in     out     source               destination

Chain INPUT (policy ACCEPT 1 packets, 71 bytes)
 pkts bytes target     prot opt in     out     source               destination

Chain OUTPUT (policy ACCEPT 0 packets, 0 bytes)
 pkts bytes target     prot opt in     out     source               destination

Chain POSTROUTING (policy ACCEPT 3 packets, 252 bytes)
 pkts bytes target     prot opt in     out     source               destination
    0     0 SNAT       all  --  *      h1R1veth  172.20.0.0/16        172.87.0.0/16
```

Outline

- Objective
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  - Destination NAT
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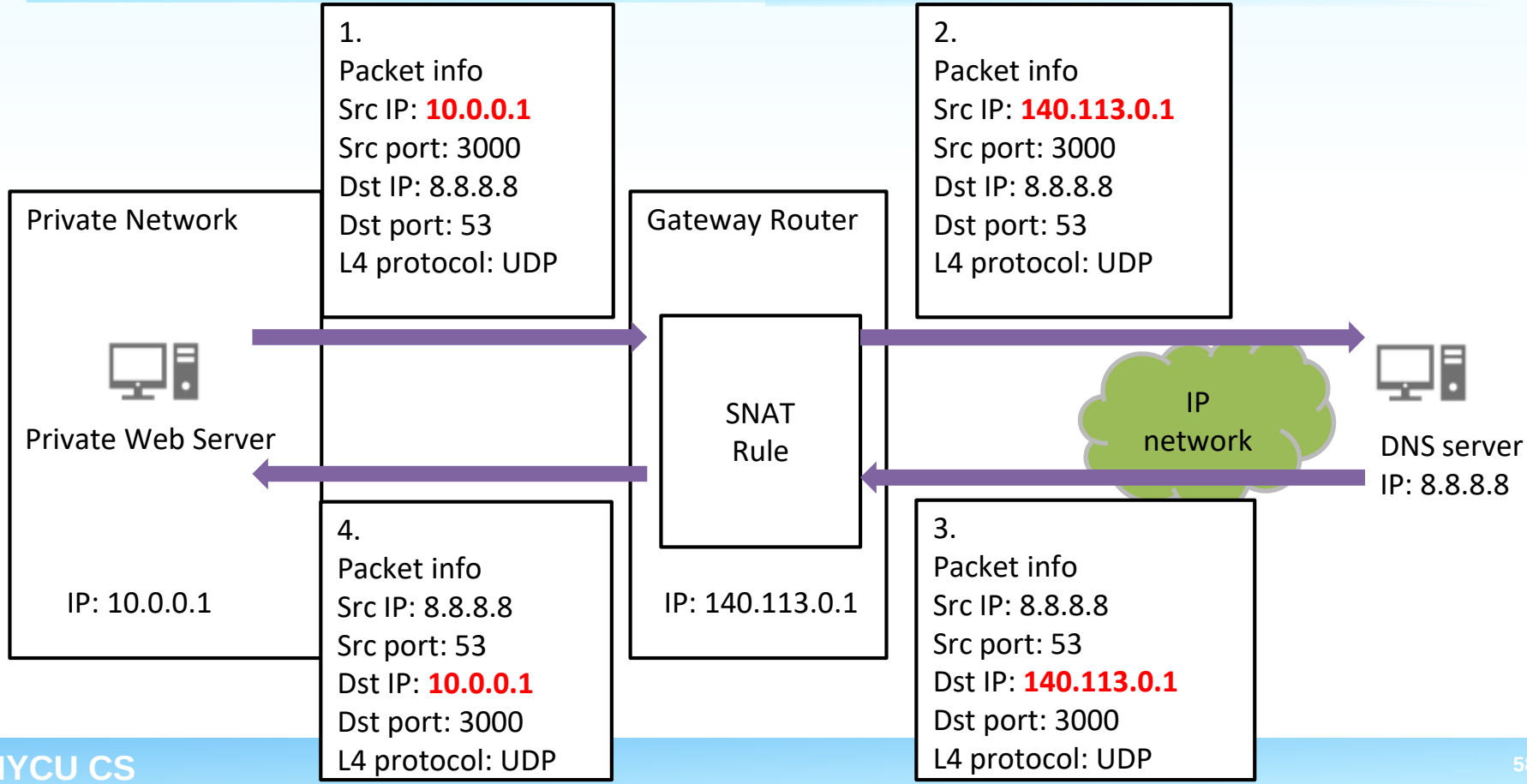
Source NAT


1.
Packet info
Src IP: 10.0.0.1
Src port: 3000
Dst IP: 8.8.8.8
Dst port: 53
L4 protocol: UDP
2.
Packet info
Src IP: 140.113.0.1
Src port: 3000
Dst IP: 8.8.8.8
Dst port: 53
L4 protocol: UDP
Private Network
Gateway Router
Private Web Server
SNAT
Rule
IP
network
DNS server
IP: 8.8.8.8
IP: 10.0.0.1
IP: 140.113.0.1
4.
Packet info
Src IP: 8.8.8.8
Src port: 53
Dst IP: 10.0.0.1
Dst port: 3000
L4 protocol: UDP
3.
Packet info
Src IP: 8.8.8.8
Src port: 53
Dst IP: 140.113.0.1
Dst port: 3000
L4 protocol: UDP

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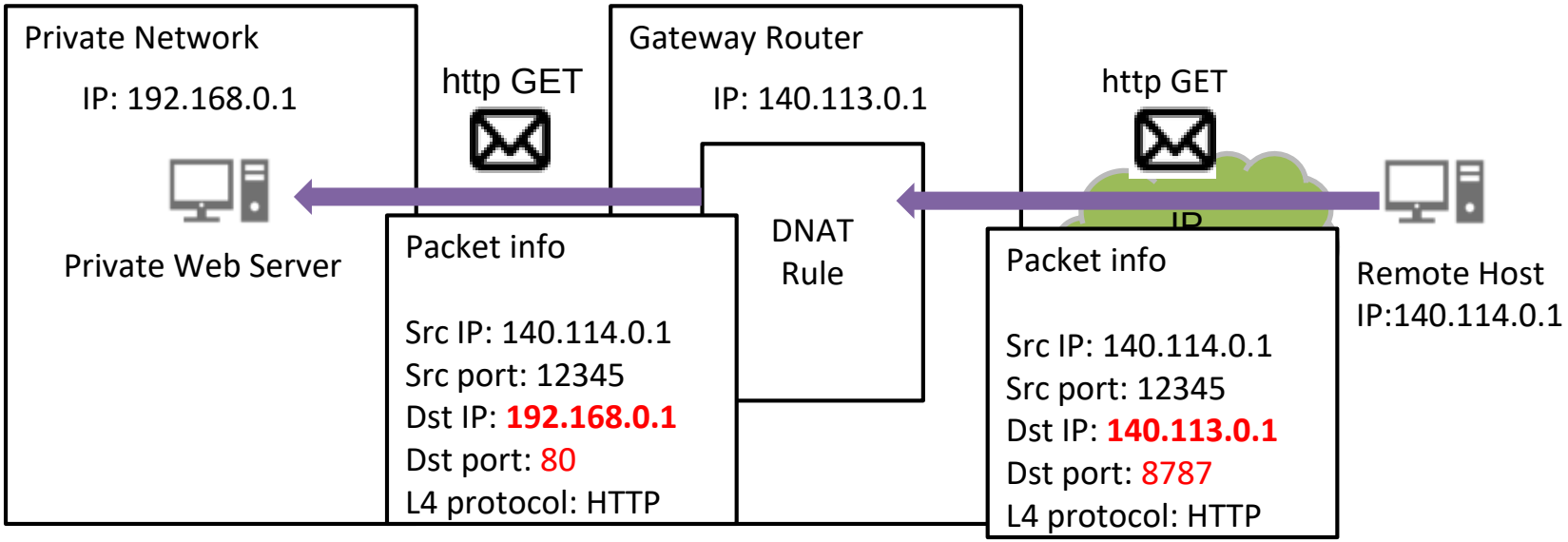
Destination NAT

- System administrator should add some rules in DNAT Rule Table
  - Provide a specific port for remote host to request
  - Every packet send to this port will forward to a specific port of host in private network



Outline

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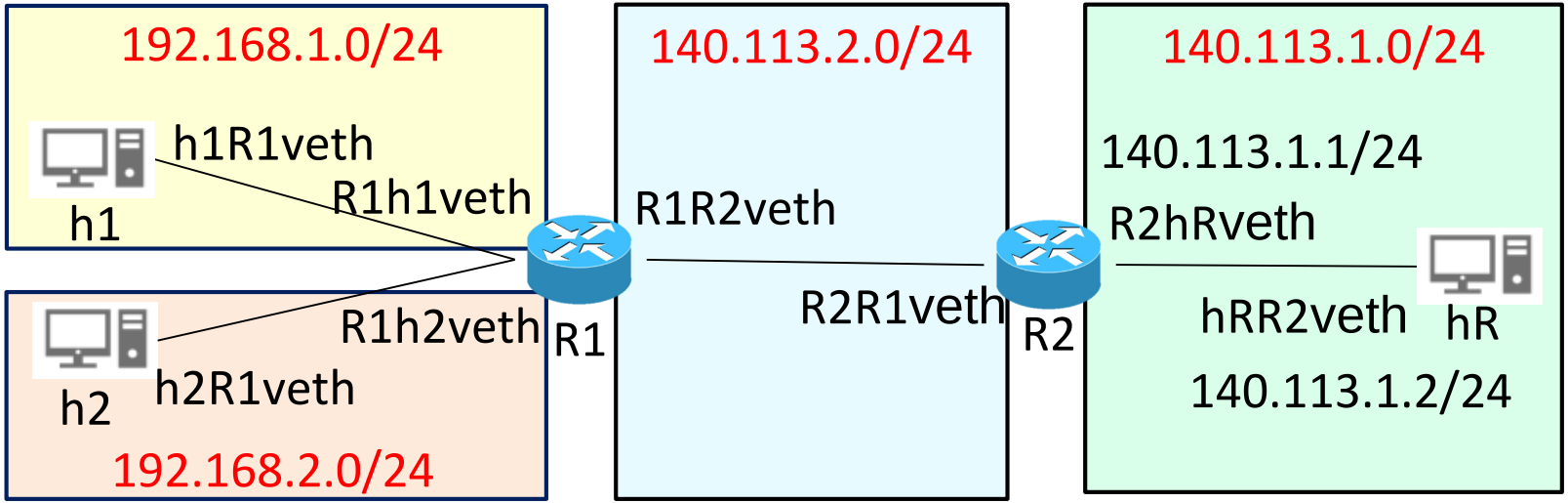
  - Lab topology
  - About submission

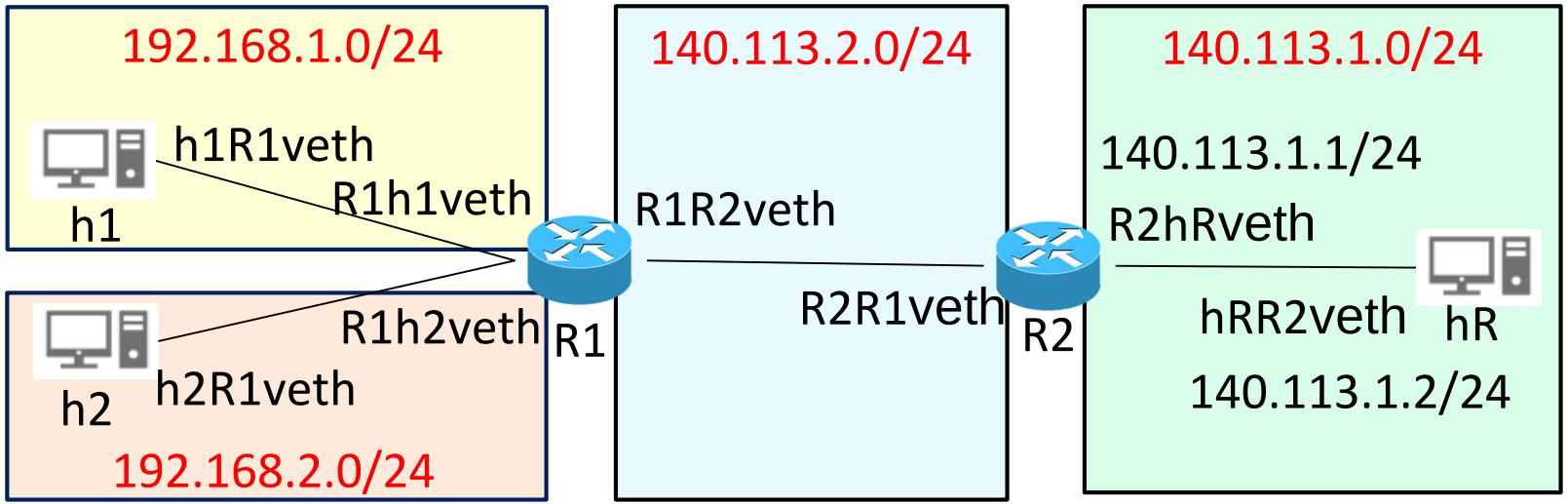
Lab Topology

- Build this topology with containers
  - Two private network behind R1, each with one host (h1 and h2)
  - A remote Host hR
  - R1 and R2 use BGP to exchange routing information



Part2: Source NAT

- Let node R1 perform Source NAT with corresponding iptables NAT table rules
  - Modify 192.168.1.0/24 to 140.113.2.30
  - Modify 192.168.2.0/24 to 140.113.2.40



Part1: Setup Environment

- Part1 Requirement: (Use Screenshot to justify your answers)
  - Topology setup (20%)
    - List all containers interfaces
    - Each container is 5 points
  - Quagga info (20%)
    - Show R1 and R2 bgp summary (5% + 5%)
    - R1 and R2 bgpd.conf (5% + 5%)

Part2: Source NAT

- Part2 Requirement:
  - Reachability: (10%)
    - h1 and h2 can ping hR or not
    - Take screenshot and explain your answers
  - Source NAT rules (20%)
    - Invoke 2 terminals of R1
    - tcpdump on R1R2veth and R1h1veth with commands
      - tcpdump -i R1h1veth –eXX
      - tcpdump -i R1R2veth –eXX
      - Take screen shot to show packet bytes before/after NAT rules

Part3: Destination NAT (1/2)

- Run http servers on h1 and h2 respectively
  - h1> python -m SimpleHTTPServer 8080
  - h2> python -m SimpleHTTPServer 9090
- Set DNAT rules on node R1
- Send http requests from host hR
  - hR> curl 140.113.2.1:[port A]
  - hR> curl 140.113.2.1:[port B]
  - DNAT rules should forward requests to h1_IP:8080 and h2_IP:9090, respectively

Part3: Destination NAT (2/2)

- Part 3 requirement:
  - Take screen shots to show the results of hR curl h1 and h2, respectively (10%)
  - Destination NAT rules (20%)
    - Invoke 2 terminals of R1
    - tcpdump on R1R2veth and R1h1veth with commands
      - tcpdump -i R1R2veth
      - tcpdump -i R1h1veth
    - Take screen shots to show packet bytes before and after DNAT

About Submission

- Files
  - A report: lab3_<studentID>.pdf
    - bgp_R1.conf
    - bgp_R2.conf
    - Part1, Part 2 and Part3 Question Answers
- Submission
  - Zip the report, bgp_R1.conf and bgp_R2.con into a zip file
    - Zip fule Name: lab3_<studentID>.zip
  - Wrong file name or format subjects to 10 points deduction

Appendix

- iptables man page
  - https://linux.die.net/man/8/iptables

Q&A