Problem 1. (10 Points) Reading datasheets. Read the Cisco cloud service router (CSR 1000V)
datasheet.
https://www.cisco.com/c/en/us/products/collateral/routers/cloud-services-router-1000v-series/datasheet-c78-733443.html .

What is the CPU/Memory requirement for 500 Mbps, 1000 Mbps, and 5000 Mbps throughput for CSR routers.

Throughput	**Requirements as per features**			
	IP Base	**Security**	**AppX**	**AX**
500 Mbps	1 vCPU, 4 GB Memory	1 vCPU, 4 GB Memory	1 vCPU, 4 GB Memory	1 vCPU, 4 GB Memory
1000 Mbps	1 vCPU, 4 GB Memory	1 vCPU, 4 GB Memory	1 vCPU, 4 GB Memory	2 vCPU, 4 GB Memory
5000 Mbps	1 vCPU, 4 GB Memory	2 vCPU, 4 GB Memory	8 vCPU, 4 GB Memory	8 vCPU, 4 GB Memory

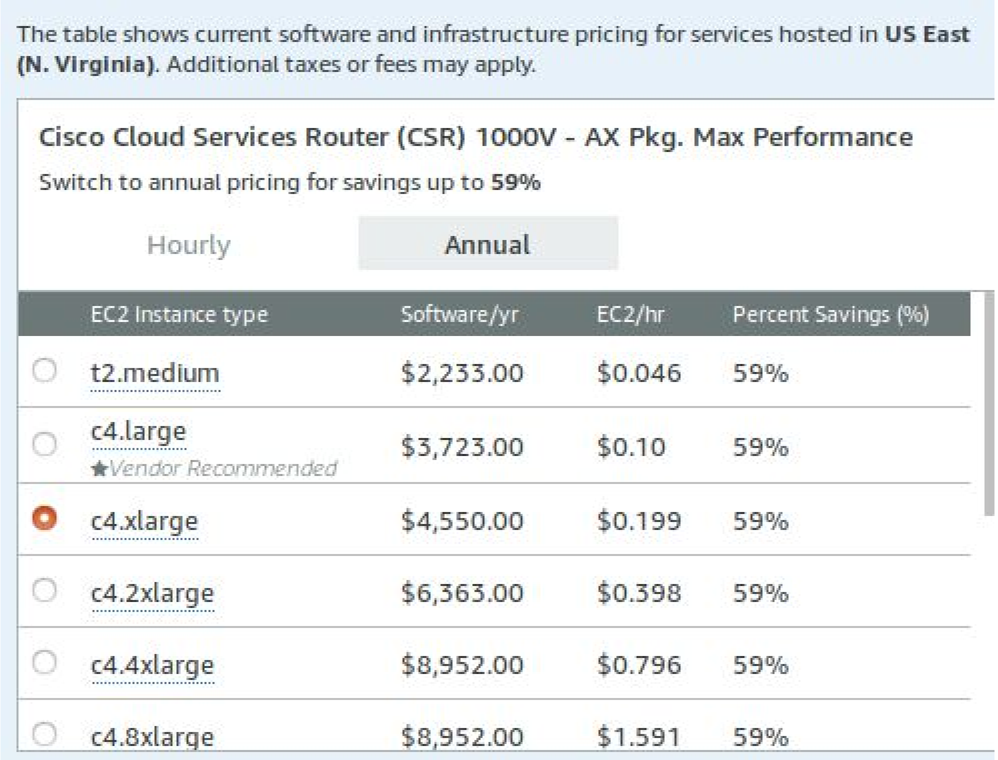
List three features of CSR for each of the following:
a) Networking
1) Routing: BGP, OSPF, EIGRP, Policy-Based Routing (PBR), IPv6, VRF-Lite, Multicast, LISP, GRE, and Connectionless Network Services (CLNS)
2) MPLS: MPLS VPN, VRF, and Bidirectional Forwarding Detection (BFD)
3) Addressing: DHCP, Domain Name System (DNS), NAT, 802.1Q VLAN, Ethernet Virtual Connection (EVC), and VXLAN

b) Security
1) VPN: IPsec VPN, DMVPN, Easy VPN, FlexVPN, and GetVPN
2) Firewall: ZBFW
3) Access control: ACL, AAA, RADIUS, and TACACS+

c) Management interface.
1) Virtual-machine creation and deployment: VMware vCenter and VMware vCloud Director
2) Provisioning and management: Cisco IOS XE CLI, Secure Shell (SSH) Protocol, Telnet, Cisco Prime Infrastructure, Cisco Prime
Network Services Controller, and OpenStack Configdrive
3) Monitoring and troubleshooting: Simple Network Management Protocol (SNMP), Syslog, NetFlow, IP SLA, and Embedded Event Manager (EEM)

What would be per year cost to use two 1000 Mbps CSR in Amazon cloud (Hint: Search CSR in AWS market place)?

For 1000 Mbps we would require c4.xlarge CSR instance type.
The cost for 1 c4.xlarge software = $4550.00/yr
The cost for ec2 infrastructure = 0.199$/hr = $1743.24/yr
Total cost for 1 1000 Mbps CSR = $4550.00 + $1743.24 = $6293.24/yr
Per year cost for 2, 1000 Mbps CSR in Amazon Cloud = $6293.24 * 2 = $12586.48

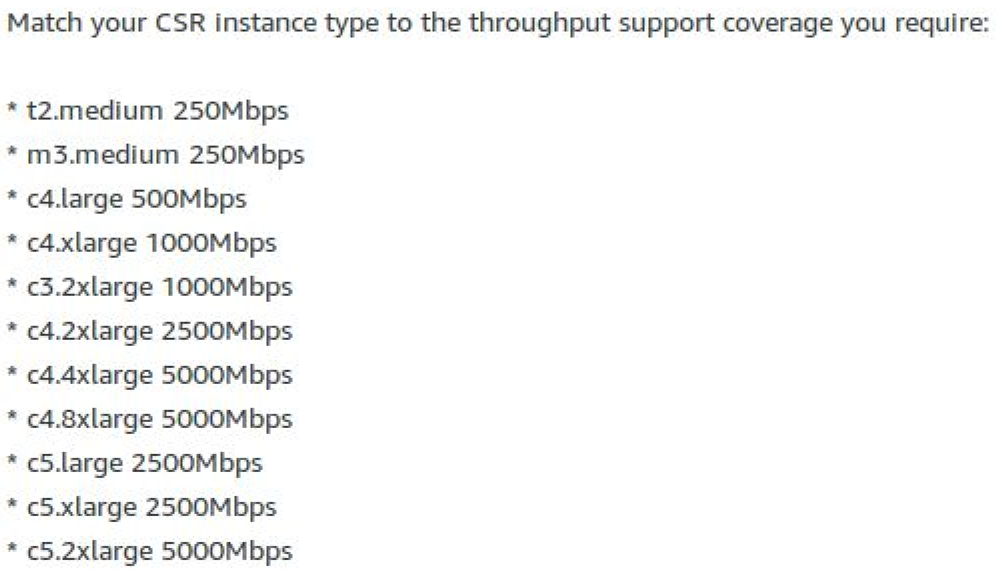


The table shows current software and infrastructure pricing for services hosted in **US East (N. Virginia)**. Additional taxes or fees may apply.

Cisco Cloud Services Router (CSR) 1000V - AX Pkg. Max Performance

Switch to annual pricing for savings up to **59%**

	EC2 Instance type	Software/yr	EC2/hr	Percent Savings (%)
○	t2.medium	$2,233.00	$0.046	59%
○	c4.large ★*Vendor Recommended*	$3,723.00	$0.10	59%
●	c4.xlarge	$4,550.00	$0.199	59%
○	c4.2xlarge	$6,363.00	$0.398	59%
○	c4.4xlarge	$8,952.00	$0.796	59%
○	c4.8xlarge	$8,952.00	$1.591	59%



Match your CSR instance type to the throughput support coverage you require:

* t2.medium 250Mbps
* m3.medium 250Mbps
* c4.large 500Mbps
* c4.xlarge 1000Mbps
* c3.2xlarge 1000Mbps
* c4.2xlarge 2500Mbps
* c4.4xlarge 5000Mbps
* c4.8xlarge 5000Mbps
* c5.large 2500Mbps
* c5.xlarge 2500Mbps
* c5.2xlarge 5000Mbps

Problem 2. (10 Points) Creating VMs. Create a VM (name the VM as < your − unity − id >VM1) and use apt get to install iperf Traffic generator and wireshark in newly created VM. We will use this VM frequently, in other problems in this homework. Answer the following questions related to the VM you just created.

VM commands:

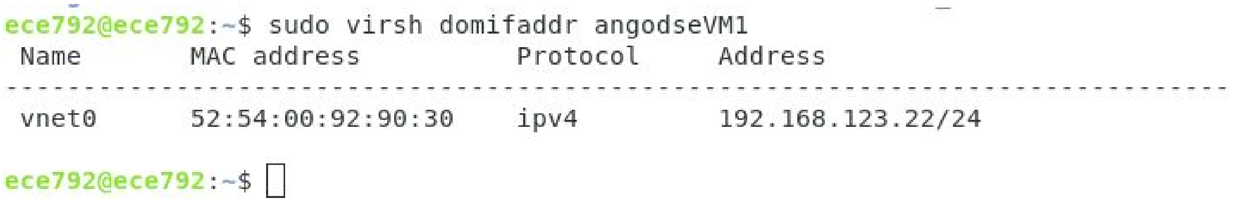
sudo virt-install -n angodseVM1 -r 2048 --vcpu=4 --cpu host --disk path=/var/lib/libvirt/images/angodseVM1.img,size=10 --network network=default -c CentOS-7-x86_64-Minimal-1708.iso -v --noautoconsole

1. What is the IP address and MAC address of the:

a) VM's NIC

IP addr: 192.168.123.22/24

MAC addr: 52:54:00:92:90:30

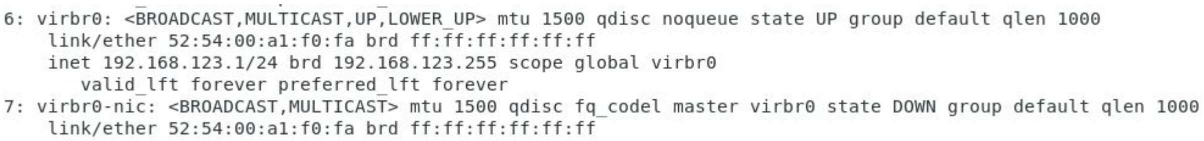


```
ece792@ece792:~$ sudo virsh domifaddr angodseVM1
 Name       MAC address          Protocol     Address
-------------------------------------------------------------------------------
 vnet0      52:54:00:92:90:30    ipv4         192.168.123.22/24

ece792@ece792:~$ 
```

b) Bridge l2 and SVI (switch virtual Interface)

IP addr: 192.168.123.1/24

MAC addr: 52:54:00:a1:f0:fa

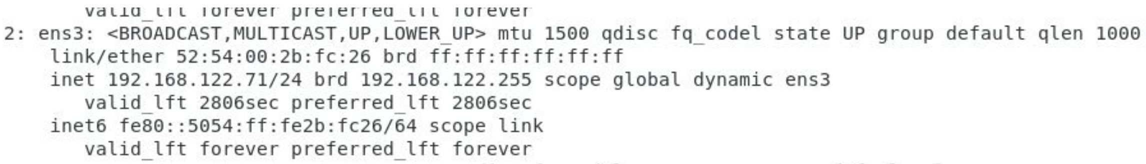


```
6: virbr0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP group default qlen 1000
    link/ether 52:54:00:a1:f0:fa brd ff:ff:ff:ff:ff:ff
    inet 192.168.123.1/24 brd 192.168.123.255 scope global virbr0
       valid_lft forever preferred_lft forever
7: virbr0-nic: <BROADCAST,MULTICAST> mtu 1500 qdisc fq_codel master virbr0 state DOWN group default qlen 1000
    link/ether 52:54:00:a1:f0:fa brd ff:ff:ff:ff:ff:ff
```

c) hypervisor NIC used to go to the Internet?

IP addr: 192.168.122.71/24

MAC addr: 52:54:00:2b:fc:26



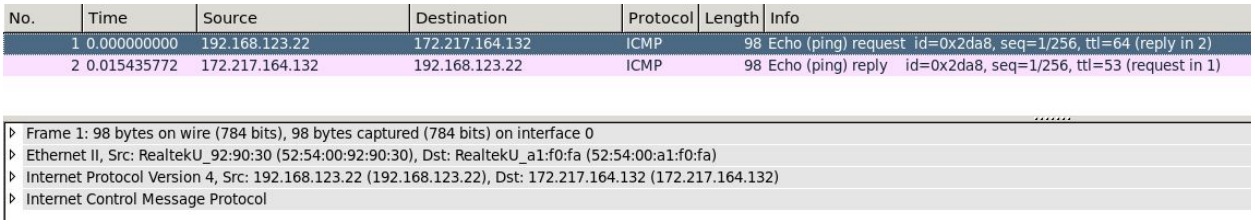
```
       valid_lft forever preferred_lft forever
2: ens3: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group default qlen 1000
    link/ether 52:54:00:2b:fc:26 brd ff:ff:ff:ff:ff:ff
    inet 192.168.122.71/24 brd 192.168.122.255 scope global dynamic ens3
       valid_lft 2806sec preferred_lft 2806sec
    inet6 fe80::5054:ff:fe2b:fc26/64 scope link
       valid_lft forever preferred_lft forever
```

2. Ping google.com from your VM. Use Wireshark to capture packets at a) the output interface of the VM, b) the output interface of the hypervisor. List 4 tuples (source IP, destination IP, source MAC, and destination MAC) of a packet going out of the VM and your hypervisor. Are these tuples the same or different? If different, explain why.

(source IP, destination IP, source MAC, destination MAC) for,

Packet going out of VM:

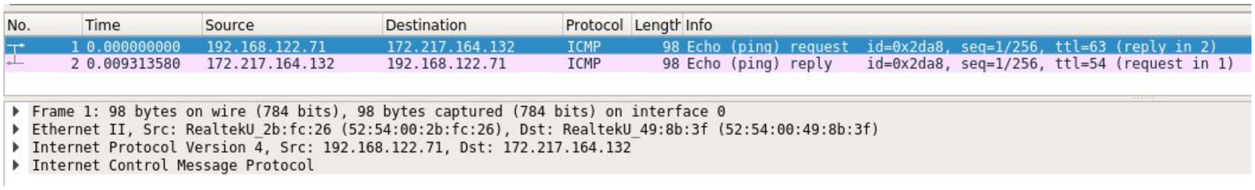
(192.168.123.22, 172.217.164.132, 52:54:00:92:90:30, 52:54:00:a1:f0:fa)



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	192.168.123.22	172.217.164.132	ICMP	98	Echo (ping) request id=0x2da8, seq=1/256, ttl=64 (reply in 2)
2	0.015435772	172.217.164.132	192.168.123.22	ICMP	98	Echo (ping) reply id=0x2da8, seq=1/256, ttl=53 (request in 1)

```
▷ Frame 1: 98 bytes on wire (784 bits), 98 bytes captured (784 bits) on interface 0
▷ Ethernet II, Src: RealtekU_92:90:30 (52:54:00:92:90:30), Dst: RealtekU_a1:f0:fa (52:54:00:a1:f0:fa)
▷ Internet Protocol Version 4, Src: 192.168.123.22 (192.168.123.22), Dst: 172.217.164.132 (172.217.164.132)
▷ Internet Control Message Protocol
```

Packet going out of hypervisor:
(192.168.122.71, 172.217.164.132, 52:54:00:2b:fc:26, 52:54:00:49:8b:3f)



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	192.168.122.71	172.217.164.132	ICMP	98	Echo (ping) request id=0x2da8, seq=1/256, ttl=63 (reply in 2)
2	0.009313580	172.217.164.132	192.168.122.71	ICMP	98	Echo (ping) reply id=0x2da8, seq=1/256, ttl=54 (request in 1)

```
▶ Frame 1: 98 bytes on wire (784 bits), 98 bytes captured (784 bits) on interface 0
▶ Ethernet II, Src: RealtekU_2b:fc:26 (52:54:00:2b:fc:26), Dst: RealtekU_49:8b:3f (52:54:00:49:8b:3f)
▶ Internet Protocol Version 4, Src: 192.168.122.71, Dst: 172.217.164.132
▶ Internet Control Message Protocol
```

These tuples are different.
Reason for difference in source IP address: It must be NAT enabled at hypervisor to get the reply back from google.com. Hence the hypervisor will replace the source IP with its own IP.

Destination IP address is the same.

Reason for difference in source MAC address:
Packet outgoing from VM will have MAC address of VM's NIC, whereas packet outgoing from hypervisor will have MAC address of hypervisor's NIC.

Reason reason for difference in destination MAC address:
Next layer2 hop for packet outgoing from VM will be the virtual bridge so the destination MAC address will be MAC address for the virtual bridge's interface.
Whereas, next layer2 hop for packet outgoing from hypervisor will be the default gateway, so the destination MAC address will be MAC address of default gateway.

Problem 3. (25 Points) virsh - managing VMs. In all tasks, provide the appropriate verification commands to verify that the task was successfully executed.
1. Use libvirt-CLI methods to add a network (name it as < your − unity − id >NETWORK2) in bridge mode.
Procedure:
1) cd /etc/libvirt/qemu/networks
2) sudo cp default.xml angodseNETWORK2.xml
2) edited file to:

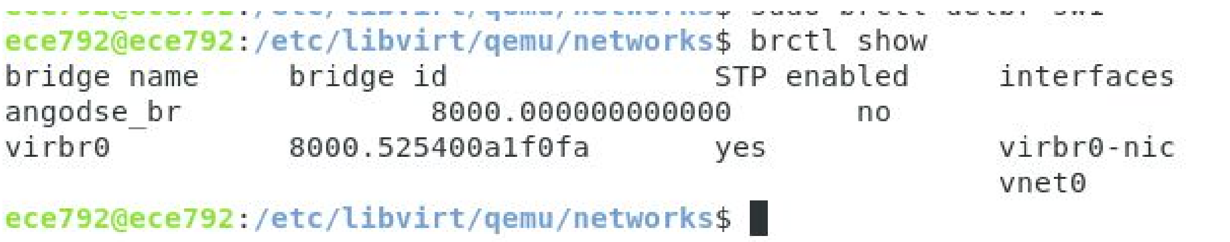
```
<network>
  <name>angodseNETWORK2</name>
  <forward mode='bridge'/>
  <bridge name='angodse_br'/>
```

</network>

4) sudo virsh net-define angodseNETWORK2.xml, to define new network from xml file

5) sudo virsh net-start angodseNETWORK2, to start created network

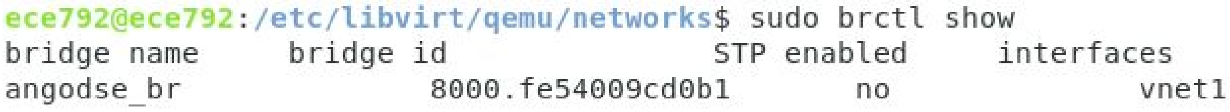
5) sudo brctl addbr angodse_br, to add the created bridge



```
ece792@ece792:/etc/libvirt/qemu/networks$ brctl show
bridge name     bridge id               STP enabled     interfaces
angodse_br              8000.000000000000       no
virbr0          8000.525400a1f0fa       yes             virbr0-nic
                                                        vnet0
ece792@ece792:/etc/libvirt/qemu/networks$ █
```

2. Use libvirt-CLI methods to add an interface to your VM to connect to < your−unity−id >NETWORK2.

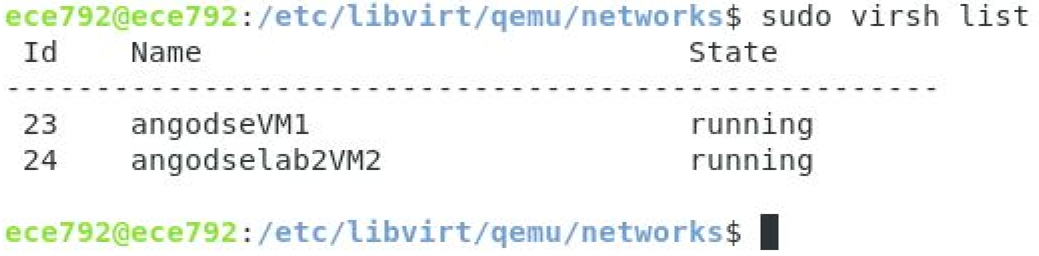
Command used:
sudo virsh attach-interface --domain angodseVM1 --type bridge --source angodse_br --model virtio --config --live



```
ece792@ece792:/etc/libvirt/qemu/networks$ sudo brctl show
bridge name     bridge id               STP enabled     interfaces
angodse_br              8000.fe54009cd0b1       no              vnet1
```

3. Use libvirt-CLI methods to clone your VM (name it as < your − unity − id >lab2VM2.

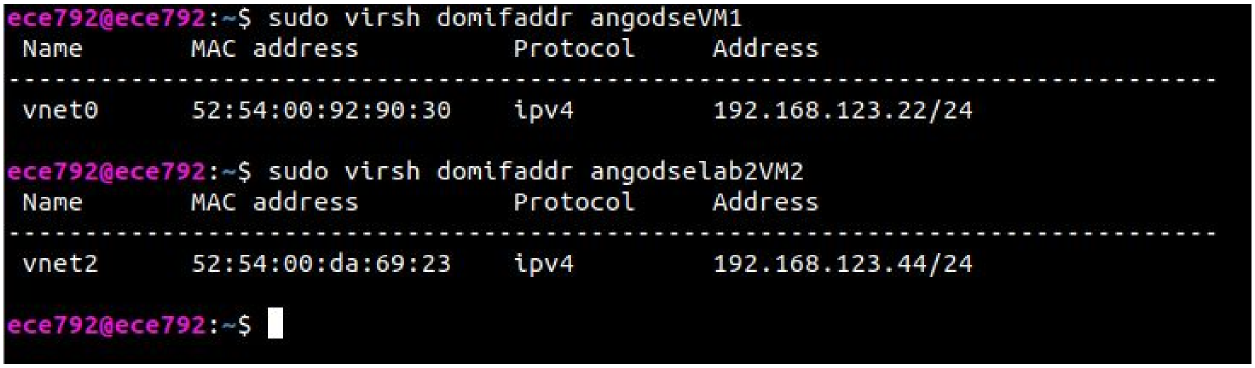
Command used:
sudo virt-clone --original angodseVM1 -n angodselab2VM2 --auto-clone



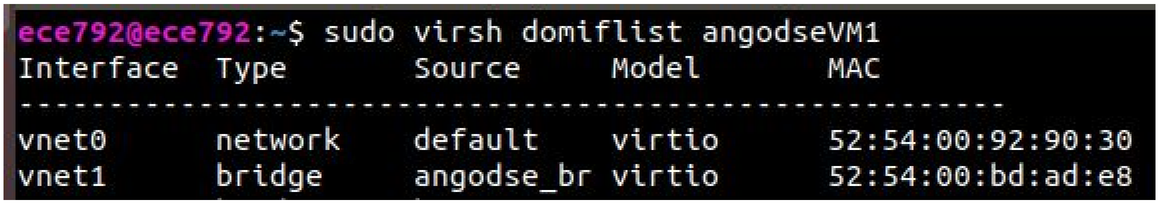
```
ece792@ece792:/etc/libvirt/qemu/networks$ sudo virsh list
 Id    Name                           State
----------------------------------------------------
 23    angodseVM1                     running
 24    angodselab2VM2                 running

ece792@ece792:/etc/libvirt/qemu/networks$ █
```

4. List MAC and IP addresses of all interfaces of each VM.

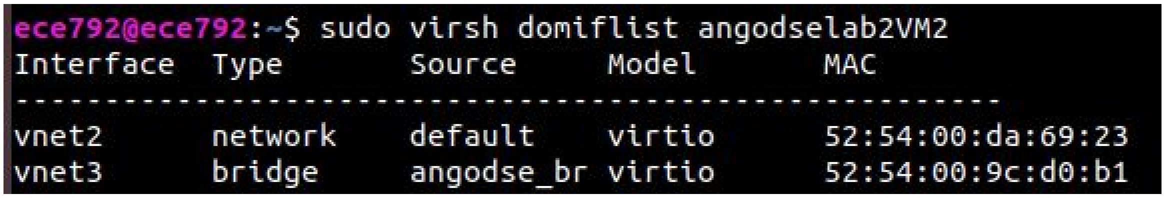
From Hypervisor:



```
ece792@ece792:~$ sudo virsh domifaddr angodseVM1
 Name       MAC address          Protocol     Address
-------------------------------------------------------------------------------
 vnet0      52:54:00:92:90:30    ipv4         192.168.123.22/24

ece792@ece792:~$ sudo virsh domifaddr angodselab2VM2
 Name       MAC address          Protocol     Address
-------------------------------------------------------------------------------
 vnet2      52:54:00:da:69:23    ipv4         192.168.123.44/24

ece792@ece792:~$ 
```



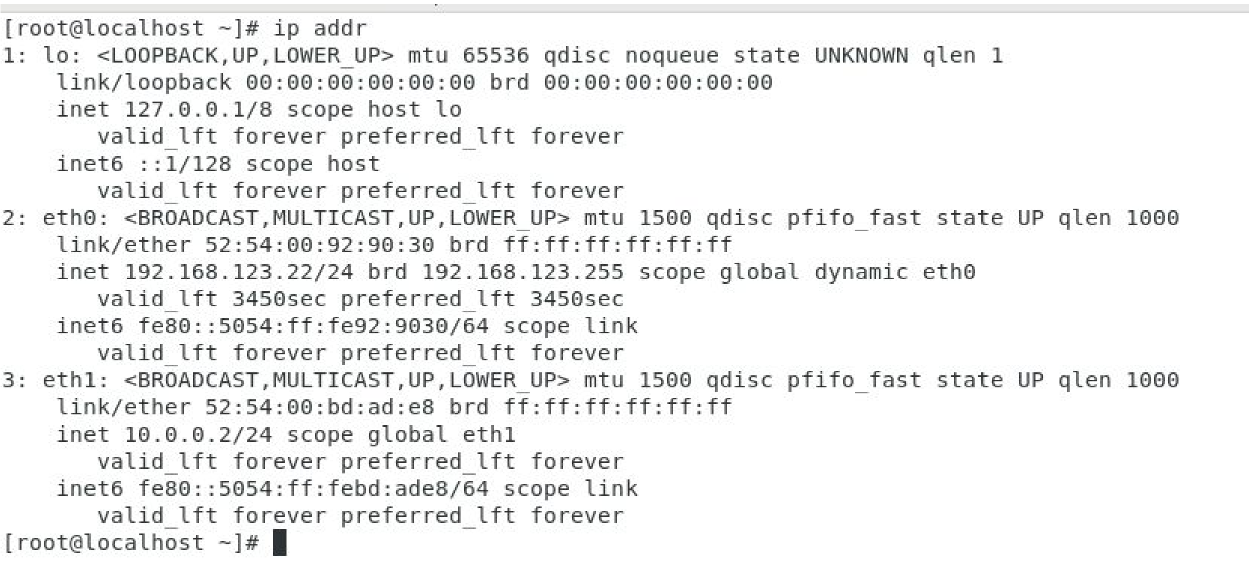
```
ece792@ece792:~$ sudo virsh domiflist angodseVM1
Interface  Type       Source     Model       MAC
-------------------------------------------------------
vnet0      network    default    virtio      52:54:00:92:90:30
vnet1      bridge     angodse_br virtio      52:54:00:bd:ad:e8
```



```
ece792@ece792:~$ sudo virsh domiflist angodselab2VM2
Interface  Type       Source     Model       MAC
-------------------------------------------------------
vnet2      network    default    virtio      52:54:00:da:69:23
vnet3      bridge     angodse_br virtio      52:54:00:9c:d0:b1
```

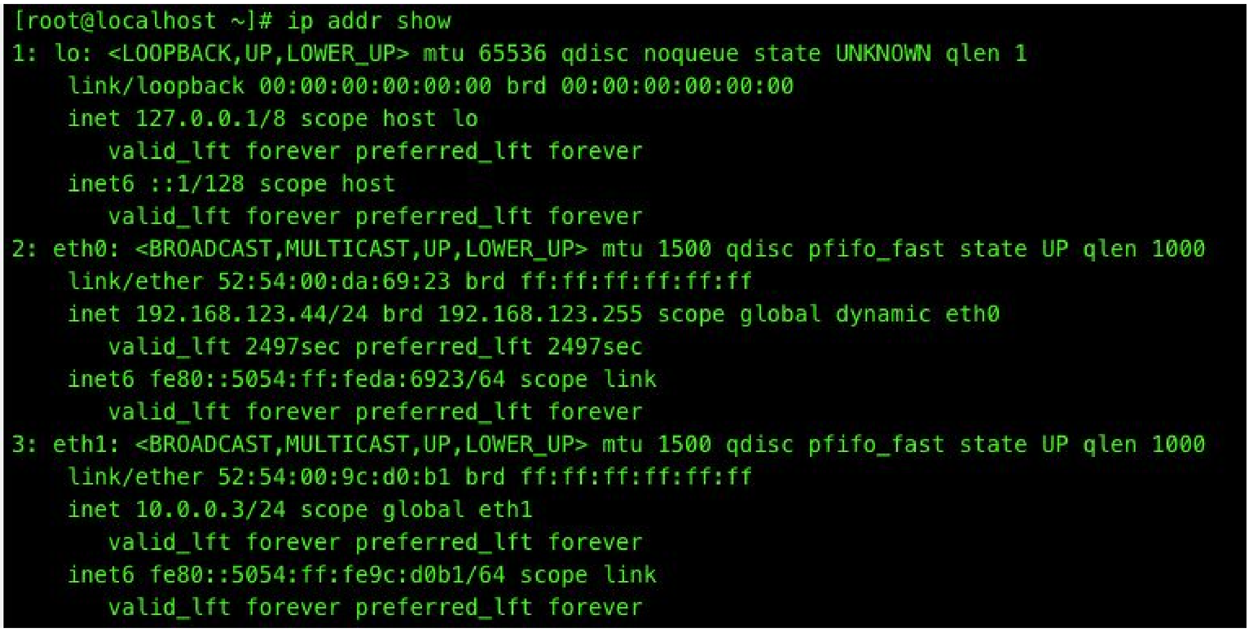
From VMs:

For angodseVM1:



```
[root@localhost ~]# ip addr
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN qlen 1
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:92:90:30 brd ff:ff:ff:ff:ff:ff
    inet 192.168.123.22/24 brd 192.168.123.255 scope global dynamic eth0
       valid_lft 3450sec preferred_lft 3450sec
    inet6 fe80::5054:ff:fe92:9030/64 scope link
       valid_lft forever preferred_lft forever
3: eth1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:bd:ad:e8 brd ff:ff:ff:ff:ff:ff
    inet 10.0.0.2/24 scope global eth1
       valid_lft forever preferred_lft forever
    inet6 fe80::5054:ff:febd:ade8/64 scope link
       valid_lft forever preferred_lft forever
[root@localhost ~]# 
```

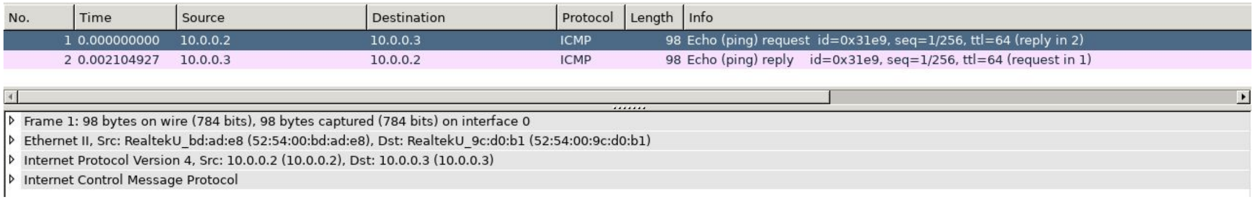
For angodselab2VM2



```
[root@localhost ~]# ip addr show
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN qlen 1
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:da:69:23 brd ff:ff:ff:ff:ff:ff
    inet 192.168.123.44/24 brd 192.168.123.255 scope global dynamic eth0
       valid_lft 2497sec preferred_lft 2497sec
    inet6 fe80::5054:ff:feda:6923/64 scope link
       valid_lft forever preferred_lft forever
3: eth1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:9c:d0:b1 brd ff:ff:ff:ff:ff:ff
    inet 10.0.0.3/24 scope global eth1
       valid_lft forever preferred_lft forever
    inet6 fe80::5054:ff:fe9c:d0b1/64 scope link
       valid_lft forever preferred_lft forever
```

5. Ping one VM from the other using IP from the < your − unity − id >NETWORK2 subnet. Use wireshark on the VMs and List down 4 tuples (srcIP, Dest IP, srcMAC and dest MAC) of packet going out at first VM and received at second VM. Are the tuple fields same or different for the packet? if different, explain why.

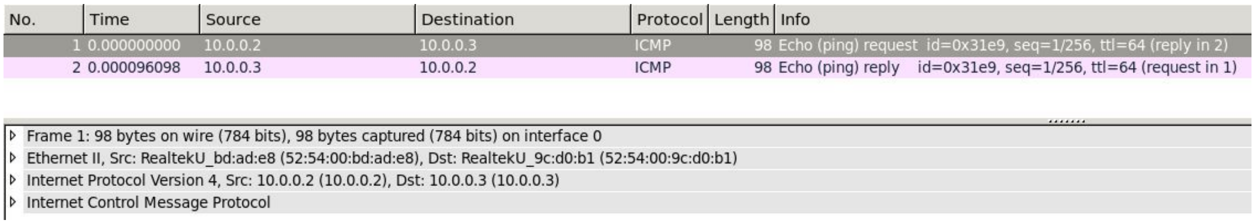
Ping request sent from angodseVM1: (10.0.0.2, 10.0.0.3, 52:54:00:bd:ad:e8, 52:54:00:9c:d0:b1)



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.0.0.2	10.0.0.3	ICMP	98	Echo (ping) request id=0x31e9, seq=1/256, ttl=64 (reply in 2)
2	0.002104927	10.0.0.3	10.0.0.2	ICMP	98	Echo (ping) reply id=0x31e9, seq=1/256, ttl=64 (request in 1)

Frame 1: 98 bytes on wire (784 bits), 98 bytes captured (784 bits) on interface 0
Ethernet II, Src: RealtekU_bd:ad:e8 (52:54:00:bd:ad:e8), Dst: RealtekU_9c:d0:b1 (52:54:00:9c:d0:b1)
Internet Protocol Version 4, Src: 10.0.0.2 (10.0.0.2), Dst: 10.0.0.3 (10.0.0.3)
Internet Control Message Protocol

Ping request received at angodselab2VM1: (10.0.0.2, 10.0.0.3, 52:54:00:bd:ad:e8, 52:54:00:9c:d0:b1)



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.0.0.2	10.0.0.3	ICMP	98	Echo (ping) request id=0x31e9, seq=1/256, ttl=64 (reply in 2)
2	0.000096098	10.0.0.3	10.0.0.2	ICMP	98	Echo (ping) reply id=0x31e9, seq=1/256, ttl=64 (request in 1)

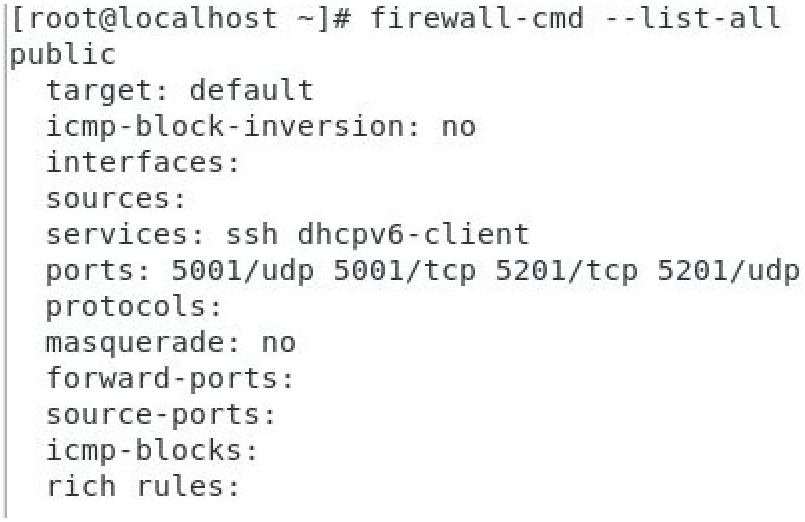
Frame 1: 98 bytes on wire (784 bits), 98 bytes captured (784 bits) on interface 0
Ethernet II, Src: RealtekU_bd:ad:e8 (52:54:00:bd:ad:e8), Dst: RealtekU_9c:d0:b1 (52:54:00:9c:d0:b1)
Internet Protocol Version 4, Src: 10.0.0.2 (10.0.0.2), Dst: 10.0.0.3 (10.0.0.3)
Internet Control Message Protocol

Tuples for packet sent and packet received are the same because 2 VMs are in the same network.

6. Set up a UDP traffic flow between the two VMs using iperf to answer the following question.

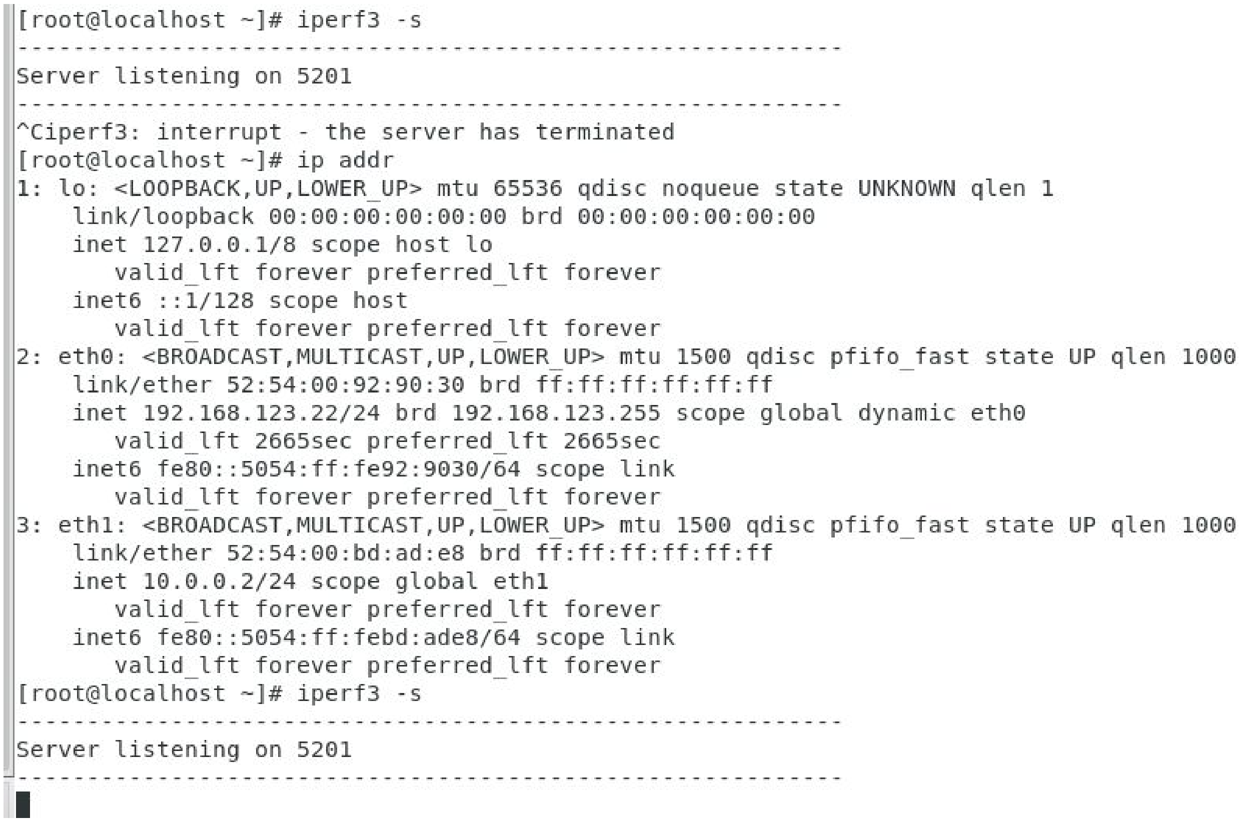
Pre-req:

Installed iperf3 and allowed TCP/UDP packets at server for iperf3 port 5201.



```
[root@localhost ~]# firewall-cmd --list-all
public
  target: default
  icmp-block-inversion: no
  interfaces:
  sources:
  services: ssh dhcpv6-client
  ports: 5001/udp 5001/tcp 5201/tcp 5201/udp
  protocols:
  masquerade: no
  forward-ports:
  source-ports:
  icmp-blocks:
  rich rules:
```

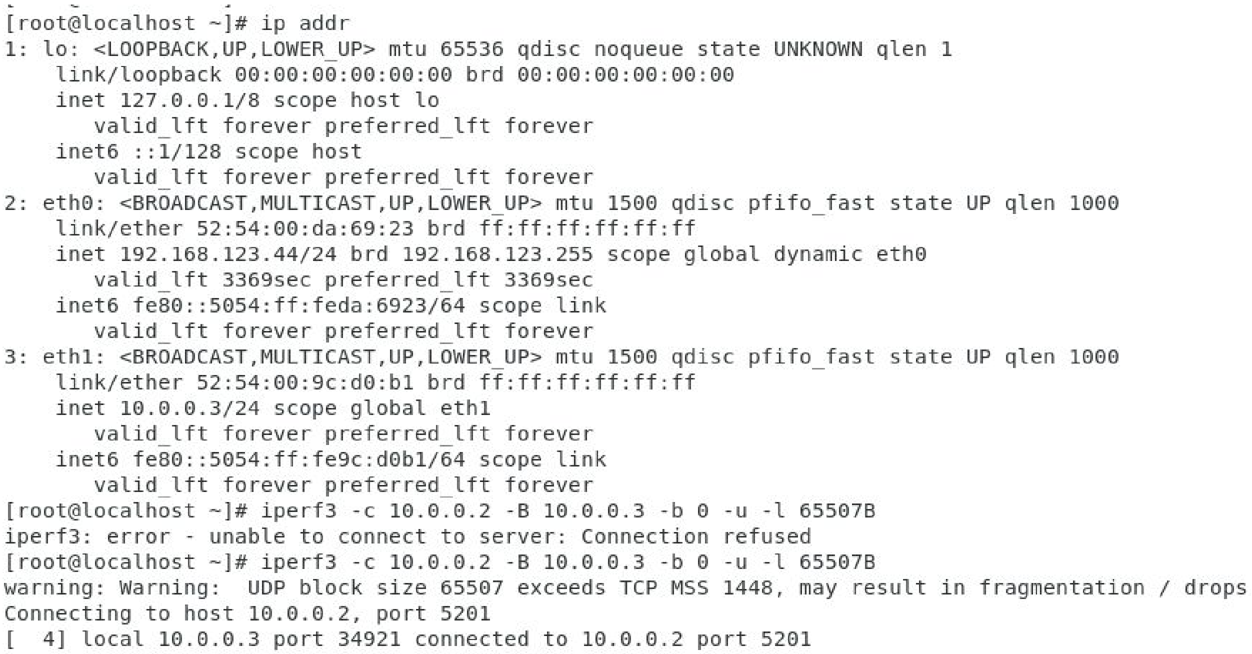
Starting server command: iperf3 -s



```
[root@localhost ~]# iperf3 -s
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
^Ciperf3: interrupt - the server has terminated
[root@localhost ~]# ip addr
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN qlen 1
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:92:90:30 brd ff:ff:ff:ff:ff:ff
    inet 192.168.123.22/24 brd 192.168.123.255 scope global dynamic eth0
       valid_lft 2665sec preferred_lft 2665sec
    inet6 fe80::5054:ff:fe92:9030/64 scope link
       valid_lft forever preferred_lft forever
3: eth1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:bd:ad:e8 brd ff:ff:ff:ff:ff:ff
    inet 10.0.0.2/24 scope global eth1
       valid_lft forever preferred_lft forever
    inet6 fe80::5054:ff:febd:ade8/64 scope link
       valid_lft forever preferred_lft forever
[root@localhost ~]# iperf3 -s
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
```

We are starting a server on eth1 of angodseVM1 i.e IP 10.0.0.2.

Starting client command: iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -l <packet_size> -u
For client we will use parameters:
As client is second VM i.e angodselab2VM2 we will bind it to its eth1 interface IP ie 10.0.0.2

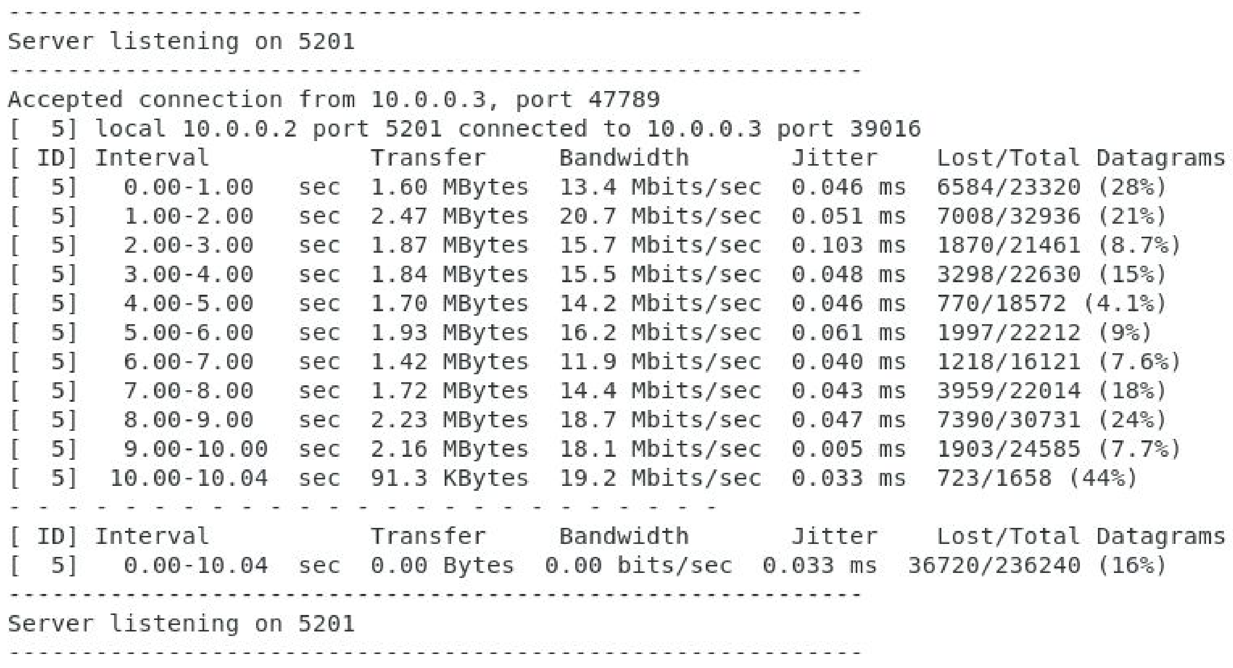


```
[root@localhost ~]# ip addr
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN qlen 1
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:da:69:23 brd ff:ff:ff:ff:ff:ff
    inet 192.168.123.44/24 brd 192.168.123.255 scope global dynamic eth0
       valid_lft 3369sec preferred_lft 3369sec
    inet6 fe80::5054:ff:feda:6923/64 scope link
       valid_lft forever preferred_lft forever
3: eth1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:9c:d0:b1 brd ff:ff:ff:ff:ff:ff
    inet 10.0.0.3/24 scope global eth1
       valid_lft forever preferred_lft forever
    inet6 fe80::5054:ff:fe9c:d0b1/64 scope link
       valid_lft forever preferred_lft forever
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 65507B
iperf3: error - unable to connect to server: Connection refused
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 65507B
warning: Warning:  UDP block size 65507 exceeds TCP MSS 1448, may result in fragmentation / drops
Connecting to host 10.0.0.2, port 5201
[  4] local 10.0.0.3 port 34921 connected to 10.0.0.2 port 5201
```

Further, -b 0 means allow unlimited bandwidth (its 1MBps by default)
-l <packet_size> we will try different packet sizes to achieve max throughput
-u for UDP traffic

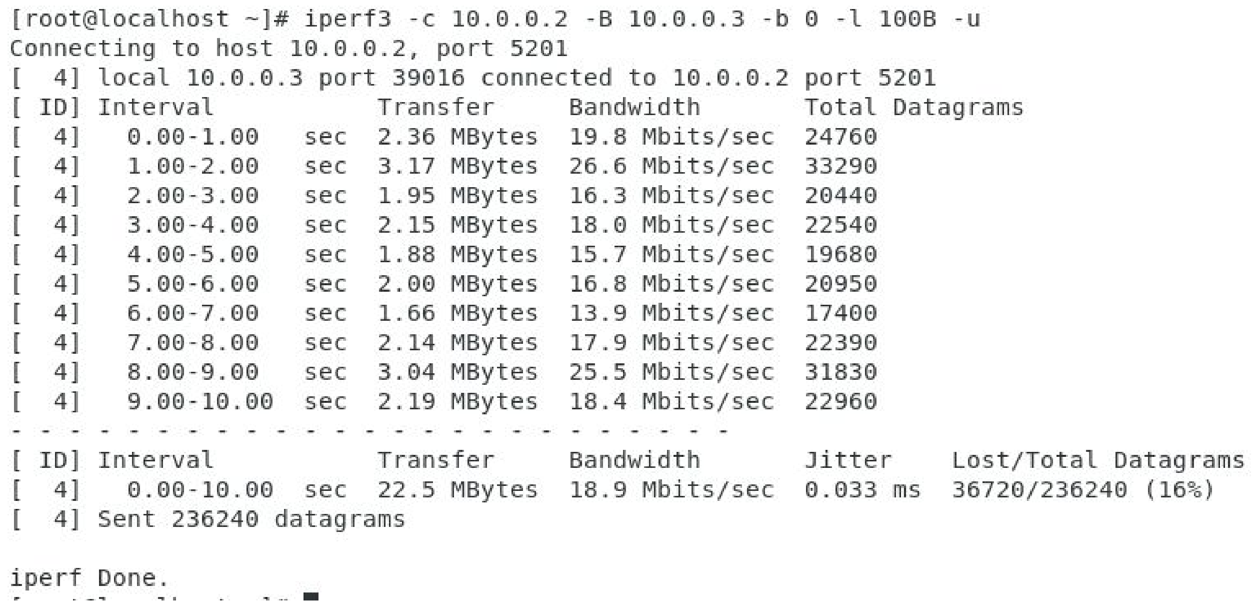
• What is the maximum UDP throughput achieved?
Let’s try with packet sizes from 100B and doubling them each time

Server Side:



```
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
Accepted connection from 10.0.0.3, port 47789
[  5] local 10.0.0.2 port 5201 connected to 10.0.0.3 port 39016
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-1.00   sec  1.60 MBytes  13.4 Mbits/sec  0.046 ms  6584/23320 (28%)
[  5]   1.00-2.00   sec  2.47 MBytes  20.7 Mbits/sec  0.051 ms  7008/32936 (21%)
[  5]   2.00-3.00   sec  1.87 MBytes  15.7 Mbits/sec  0.103 ms  1870/21461 (8.7%)
[  5]   3.00-4.00   sec  1.84 MBytes  15.5 Mbits/sec  0.048 ms  3298/22630 (15%)
[  5]   4.00-5.00   sec  1.70 MBytes  14.2 Mbits/sec  0.046 ms  770/18572 (4.1%)
[  5]   5.00-6.00   sec  1.93 MBytes  16.2 Mbits/sec  0.061 ms  1997/22212 (9%)
[  5]   6.00-7.00   sec  1.42 MBytes  11.9 Mbits/sec  0.040 ms  1218/16121 (7.6%)
[  5]   7.00-8.00   sec  1.72 MBytes  14.4 Mbits/sec  0.043 ms  3959/22014 (18%)
[  5]   8.00-9.00   sec  2.23 MBytes  18.7 Mbits/sec  0.047 ms  7390/30731 (24%)
[  5]   9.00-10.00  sec  2.16 MBytes  18.1 Mbits/sec  0.005 ms  1903/24585 (7.7%)
[  5]  10.00-10.04  sec  91.3 KBytes  19.2 Mbits/sec  0.033 ms  723/1658 (44%)
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-10.04  sec  0.00 Bytes  0.00 bits/sec  0.033 ms  36720/236240 (16%)
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
```

Client side: iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -l 100B -u



```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -l 100B -u
Connecting to host 10.0.0.2, port 5201
[  4] local 10.0.0.3 port 39016 connected to 10.0.0.2 port 5201
[ ID] Interval           Transfer     Bandwidth       Total Datagrams
[  4]   0.00-1.00   sec  2.36 MBytes  19.8 Mbits/sec  24760
[  4]   1.00-2.00   sec  3.17 MBytes  26.6 Mbits/sec  33290
[  4]   2.00-3.00   sec  1.95 MBytes  16.3 Mbits/sec  20440
[  4]   3.00-4.00   sec  2.15 MBytes  18.0 Mbits/sec  22540
[  4]   4.00-5.00   sec  1.88 MBytes  15.7 Mbits/sec  19680
[  4]   5.00-6.00   sec  2.00 MBytes  16.8 Mbits/sec  20950
[  4]   6.00-7.00   sec  1.66 MBytes  13.9 Mbits/sec  17400
[  4]   7.00-8.00   sec  2.14 MBytes  17.9 Mbits/sec  22390
[  4]   8.00-9.00   sec  3.04 MBytes  25.5 Mbits/sec  31830
[  4]   9.00-10.00  sec  2.19 MBytes  18.4 Mbits/sec  22960
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  4]   0.00-10.00  sec  22.5 MBytes  18.9 Mbits/sec  0.033 ms  36720/236240 (16%)
[  4] Sent 236240 datagrams

iperf Done.
```

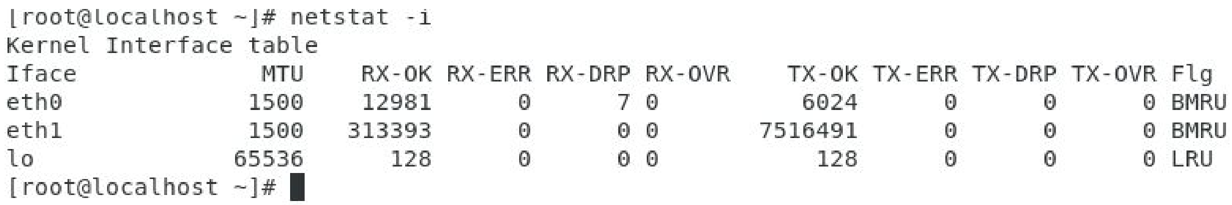
We can see that around 16% datagrams are lost.
Let’s investigate the reason for this loss.

Let’s check where exactly the packet loss is happening, To do this we will check where is packet loss happening in VM1-vnet1-vnet3-VM2 datapath.

We will check packet stats before and after at all above interfaces.

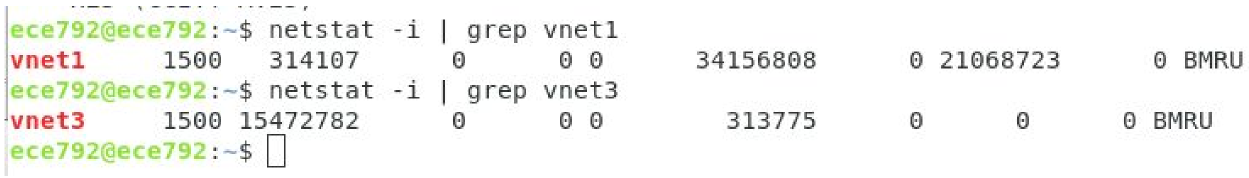
Before:

Client:



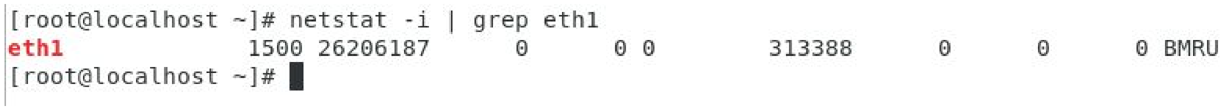
```
[root@localhost ~]# netstat -i
Kernel Interface table
Iface             MTU    RX-OK RX-ERR RX-DRP RX-OVR    TX-OK TX-ERR TX-DRP TX-OVR Flg
eth0             1500    12981      0      7 0          6024      0      0      0 BMRU
eth1             1500   313393      0      0 0       7516491      0      0      0 BMRU
lo              65536      128      0      0 0           128      0      0      0 LRU
[root@localhost ~]# 
```

vnet 1 and vnet 2:



```
ece792@ece792:~$ netstat -i | grep vnet1
vnet1      1500   314107      0      0 0      34156808      0 21068723      0 BMRU
ece792@ece792:~$ netstat -i | grep vnet3
vnet3      1500 15472782      0      0 0        313775      0      0      0 BMRU
ece792@ece792:~$ 
```

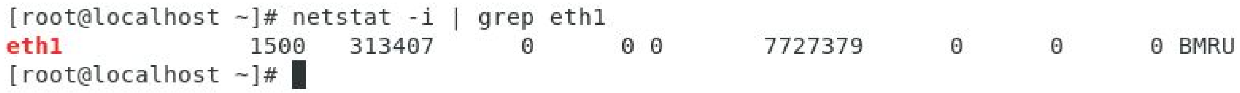
Server:



```
[root@localhost ~]# netstat -i | grep eth1
eth1             1500 26206187      0      0 0       313388      0      0      0 BMRU
[root@localhost ~]# 
```

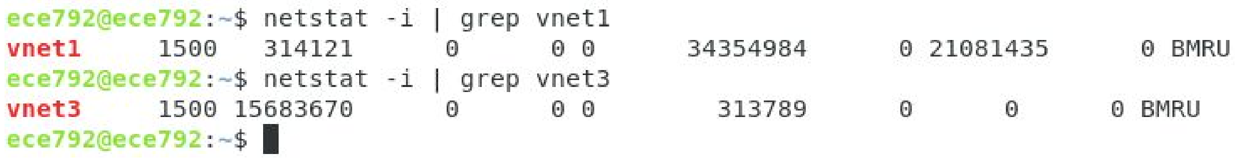
After:

Client:



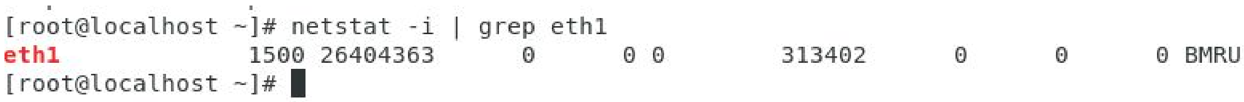
```
[root@localhost ~]# netstat -i | grep eth1
eth1             1500   313407      0      0 0      7727379      0      0      0 BMRU
[root@localhost ~]# 
```

vnet 1 and vnet 2:



```
ece792@ece792:~$ netstat -i | grep vnet1
vnet1      1500   314121      0      0 0      34354984      0 21081435      0 BMRU
ece792@ece792:~$ netstat -i | grep vnet3
vnet3      1500 15683670      0      0 0        313789      0      0      0 BMRU
ece792@ece792:~$ 
```

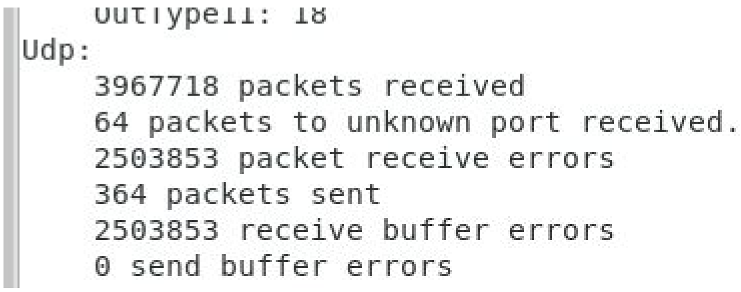
Server:



```
[root@localhost ~]# netstat -i | grep eth1
eth1             1500 26404363      0      0 0       313402      0      0      0 BMRU
[root@localhost ~]# 
```

We can clearly see that there are some packet drops at vnet1 interface of switch. But this loss is very less than actual observed.

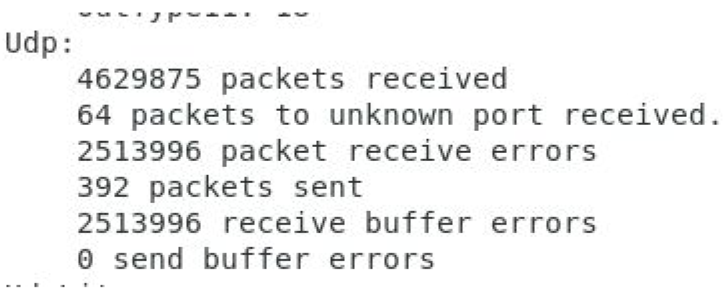
Checking UDP stats at server side:



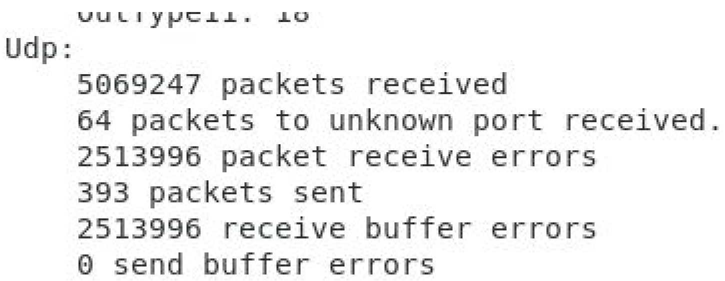
```
    OutType11: 18
Udp:
    3967718 packets received
    64 packets to unknown port received.
    2503853 packet receive errors
    364 packets sent
    2503853 receive buffer errors
    0 send buffer errors
```

It’s clear that the receiver i.e server has receiver buffer errors due to insufficient buffer size.
By default the UDP buffer size is 208K. Let’s try increasing this to 25MB.
This can be done using:
sudo sysctl -w net.core.rmem_max=26214400
sudo sysctl -w net.core.rmem_default=26214400

After increasing receive buffer size we can observe that receive buffer errors are same before and after UDP transfer as below:

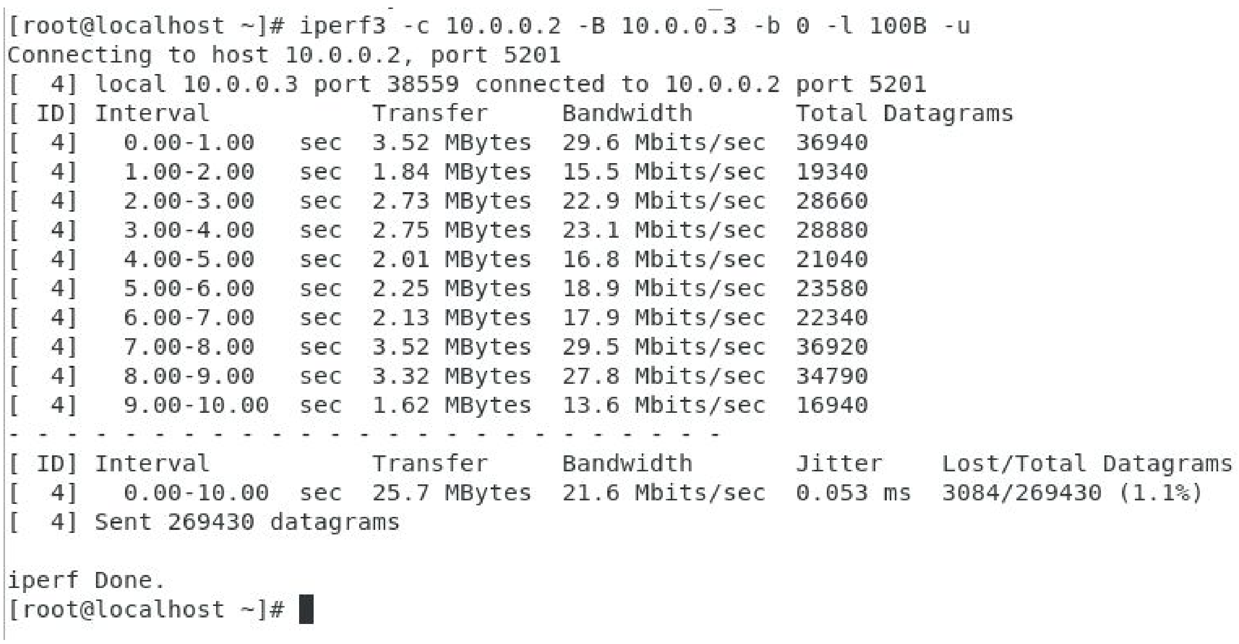


```
    OutType11: 18
Udp:
    4629875 packets received
    64 packets to unknown port received.
    2513996 packet receive errors
    392 packets sent
    2513996 receive buffer errors
    0 send buffer errors
```



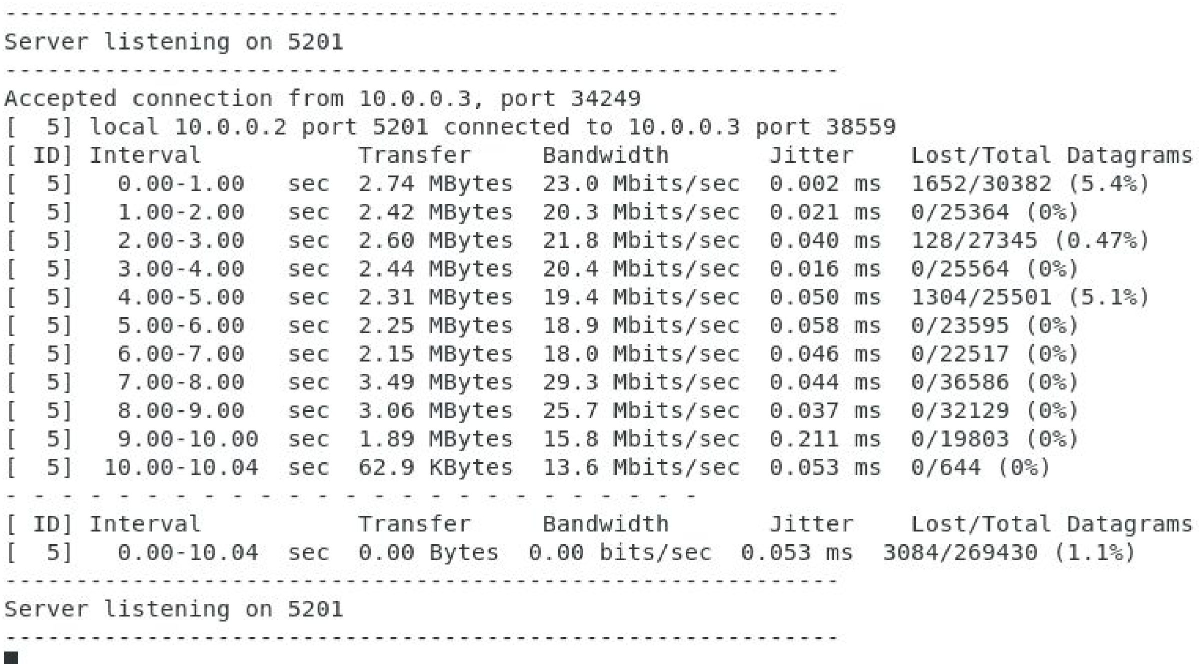
```
    OutType11: 18
Udp:
    5069247 packets received
    64 packets to unknown port received.
    2513996 packet receive errors
    393 packets sent
    2513996 receive buffer errors
    0 send buffer errors
```

Following is client server screen shots after increasing buffer size.
Client:



```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -l 100B -u
Connecting to host 10.0.0.2, port 5201
[  4] local 10.0.0.3 port 38559 connected to 10.0.0.2 port 5201
[ ID] Interval           Transfer     Bandwidth       Total Datagrams
[  4]   0.00-1.00   sec  3.52 MBytes  29.6 Mbits/sec  36940
[  4]   1.00-2.00   sec  1.84 MBytes  15.5 Mbits/sec  19340
[  4]   2.00-3.00   sec  2.73 MBytes  22.9 Mbits/sec  28660
[  4]   3.00-4.00   sec  2.75 MBytes  23.1 Mbits/sec  28880
[  4]   4.00-5.00   sec  2.01 MBytes  16.8 Mbits/sec  21040
[  4]   5.00-6.00   sec  2.25 MBytes  18.9 Mbits/sec  23580
[  4]   6.00-7.00   sec  2.13 MBytes  17.9 Mbits/sec  22340
[  4]   7.00-8.00   sec  3.52 MBytes  29.5 Mbits/sec  36920
[  4]   8.00-9.00   sec  3.32 MBytes  27.8 Mbits/sec  34790
[  4]   9.00-10.00  sec  1.62 MBytes  13.6 Mbits/sec  16940
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  4]   0.00-10.00  sec  25.7 MBytes  21.6 Mbits/sec  0.053 ms  3084/269430 (1.1%)
[  4] Sent 269430 datagrams

iperf Done.
[root@localhost ~]# 
```

Server:



```
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
Accepted connection from 10.0.0.3, port 34249
[  5] local 10.0.0.2 port 5201 connected to 10.0.0.3 port 38559
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-1.00   sec  2.74 MBytes  23.0 Mbits/sec  0.002 ms  1652/30382 (5.4%)
[  5]   1.00-2.00   sec  2.42 MBytes  20.3 Mbits/sec  0.021 ms  0/25364 (0%)
[  5]   2.00-3.00   sec  2.60 MBytes  21.8 Mbits/sec  0.040 ms  128/27345 (0.47%)
[  5]   3.00-4.00   sec  2.44 MBytes  20.4 Mbits/sec  0.016 ms  0/25564 (0%)
[  5]   4.00-5.00   sec  2.31 MBytes  19.4 Mbits/sec  0.050 ms  1304/25501 (5.1%)
[  5]   5.00-6.00   sec  2.25 MBytes  18.9 Mbits/sec  0.058 ms  0/23595 (0%)
[  5]   6.00-7.00   sec  2.15 MBytes  18.0 Mbits/sec  0.046 ms  0/22517 (0%)
[  5]   7.00-8.00   sec  3.49 MBytes  29.3 Mbits/sec  0.044 ms  0/36586 (0%)
[  5]   8.00-9.00   sec  3.06 MBytes  25.7 Mbits/sec  0.037 ms  0/32129 (0%)
[  5]   9.00-10.00  sec  1.89 MBytes  15.8 Mbits/sec  0.211 ms  0/19803 (0%)
[  5]  10.00-10.04  sec  62.9 KBytes  13.6 Mbits/sec  0.053 ms  0/644 (0%)
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-10.04  sec  0.00 Bytes  0.00 bits/sec  0.053 ms  3084/269430 (1.1%)
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
```

There is significant improvement in performance. 1.1 % loss as opposed to 16% before.

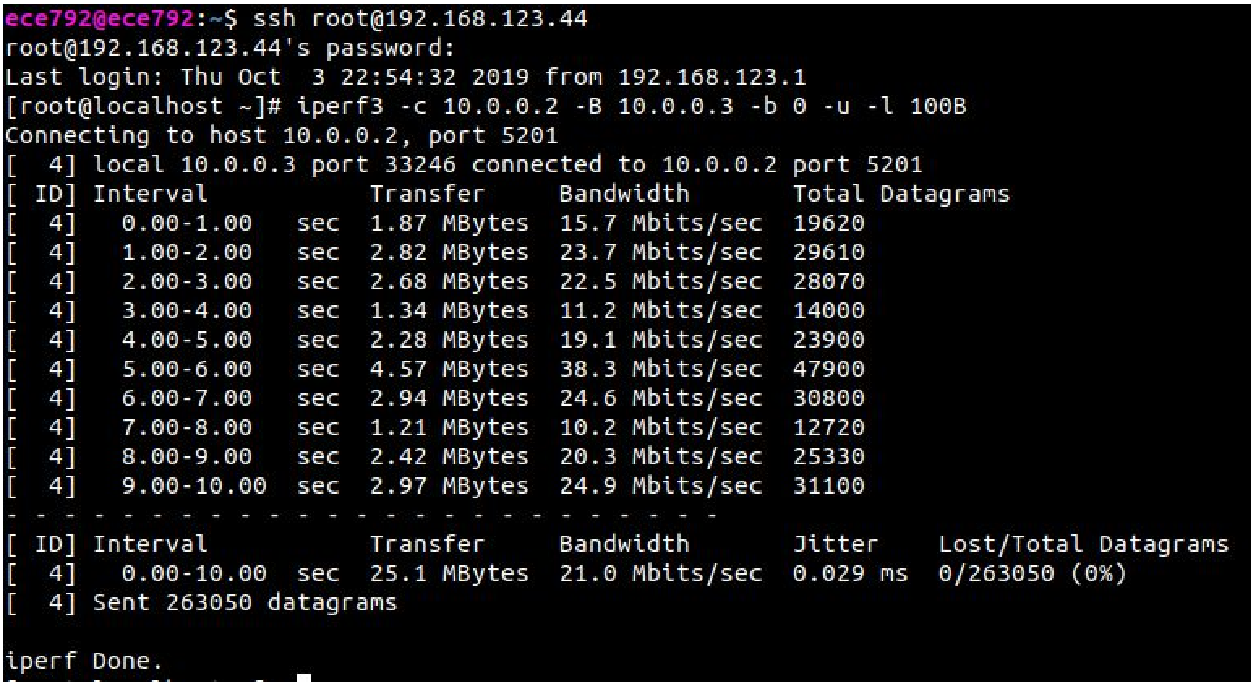
But still we have to solve packet loss issue at vnet1 interface of switch.

We can see that txqueuelen at vnet1 is 1000 by default

We set it max allowed size 524288

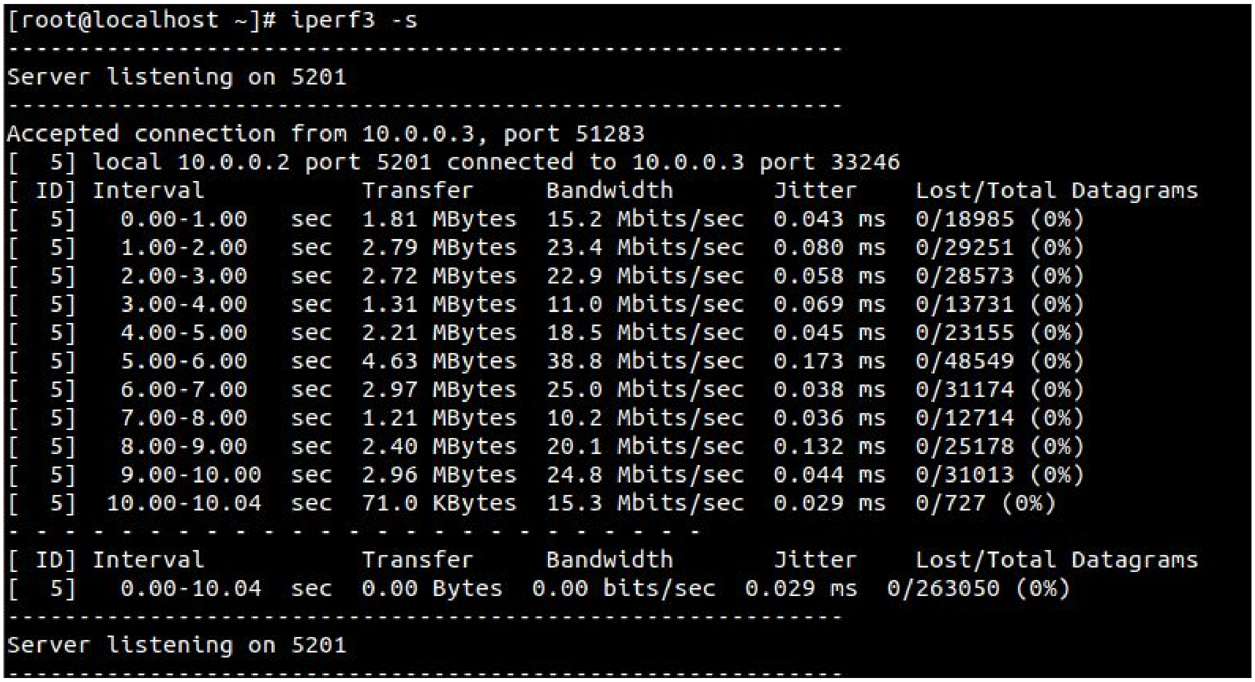
And again checking the throughput:

Client:



```
ece792@ece792:~$ ssh root@192.168.123.44
root@192.168.123.44's password:
Last login: Thu Oct  3 22:54:32 2019 from 192.168.123.1
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 100B
Connecting to host 10.0.0.2, port 5201
[  4] local 10.0.0.3 port 33246 connected to 10.0.0.2 port 5201
[ ID] Interval           Transfer     Bandwidth       Total Datagrams
[  4]   0.00-1.00   sec  1.87 MBytes  15.7 Mbits/sec  19620
[  4]   1.00-2.00   sec  2.82 MBytes  23.7 Mbits/sec  29610
[  4]   2.00-3.00   sec  2.68 MBytes  22.5 Mbits/sec  28070
[  4]   3.00-4.00   sec  1.34 MBytes  11.2 Mbits/sec  14000
[  4]   4.00-5.00   sec  2.28 MBytes  19.1 Mbits/sec  23900
[  4]   5.00-6.00   sec  4.57 MBytes  38.3 Mbits/sec  47900
[  4]   6.00-7.00   sec  2.94 MBytes  24.6 Mbits/sec  30800
[  4]   7.00-8.00   sec  1.21 MBytes  10.2 Mbits/sec  12720
[  4]   8.00-9.00   sec  2.42 MBytes  20.3 Mbits/sec  25330
[  4]   9.00-10.00  sec  2.97 MBytes  24.9 Mbits/sec  31100
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  4]   0.00-10.00  sec  25.1 MBytes  21.0 Mbits/sec  0.029 ms  0/263050 (0%)
[  4] Sent 263050 datagrams

iperf Done.
```

Server:

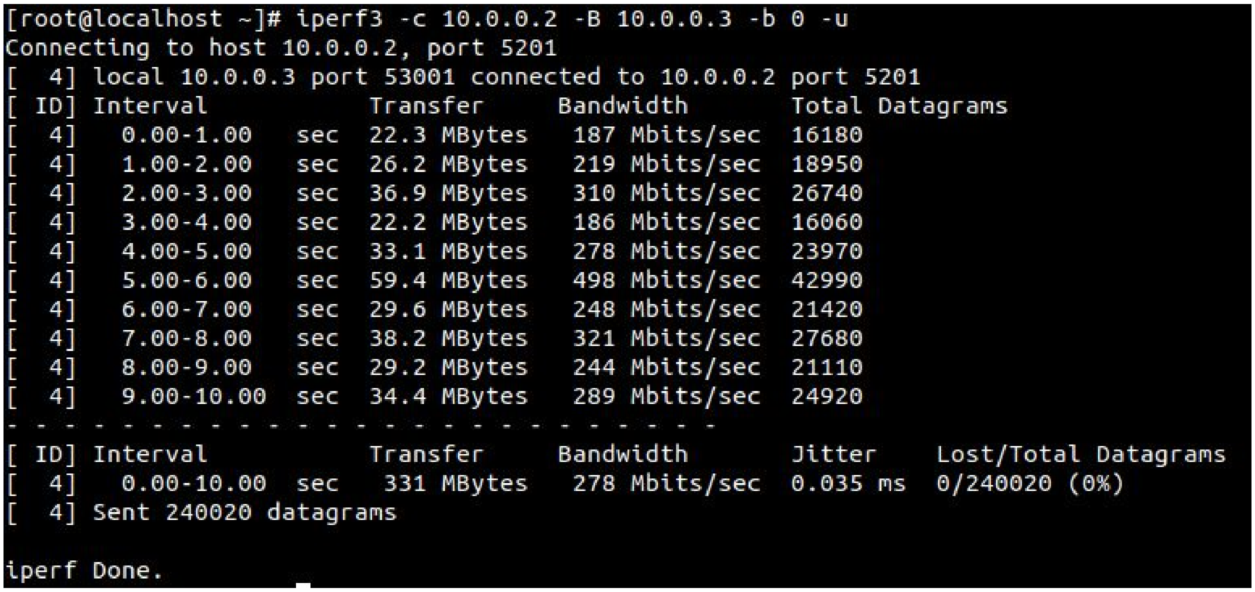


```
[root@localhost ~]# iperf3 -s
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
Accepted connection from 10.0.0.3, port 51283
[  5] local 10.0.0.2 port 5201 connected to 10.0.0.3 port 33246
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-1.00   sec  1.81 MBytes  15.2 Mbits/sec  0.043 ms  0/18985 (0%)
[  5]   1.00-2.00   sec  2.79 MBytes  23.4 Mbits/sec  0.080 ms  0/29251 (0%)
[  5]   2.00-3.00   sec  2.72 MBytes  22.9 Mbits/sec  0.058 ms  0/28573 (0%)
[  5]   3.00-4.00   sec  1.31 MBytes  11.0 Mbits/sec  0.069 ms  0/13731 (0%)
[  5]   4.00-5.00   sec  2.21 MBytes  18.5 Mbits/sec  0.045 ms  0/23155 (0%)
[  5]   5.00-6.00   sec  4.63 MBytes  38.8 Mbits/sec  0.173 ms  0/48549 (0%)
[  5]   6.00-7.00   sec  2.97 MBytes  25.0 Mbits/sec  0.038 ms  0/31174 (0%)
[  5]   7.00-8.00   sec  1.21 MBytes  10.2 Mbits/sec  0.036 ms  0/12714 (0%)
[  5]   8.00-9.00   sec  2.40 MBytes  20.1 Mbits/sec  0.132 ms  0/25178 (0%)
[  5]   9.00-10.00  sec  2.96 MBytes  24.8 Mbits/sec  0.044 ms  0/31013 (0%)
[  5]  10.00-10.04  sec  71.0 KBytes  15.3 Mbits/sec  0.029 ms  0/727 (0%)
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-10.04  sec  0.00 Bytes  0.00 bits/sec  0.029 ms  0/263050 (0%)
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
```

Now we can see we have 0% packet loss.

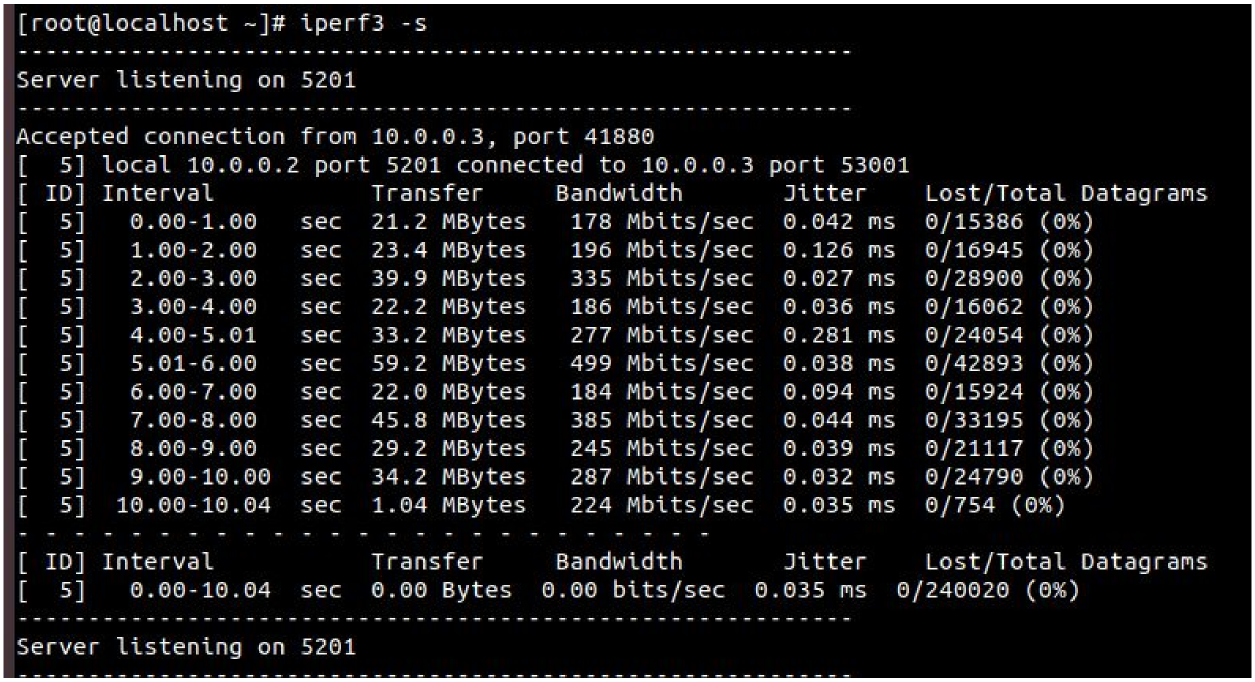
Let's try for default packet size:

Client:



```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u
Connecting to host 10.0.0.2, port 5201
[  4] local 10.0.0.3 port 53001 connected to 10.0.0.2 port 5201
[ ID] Interval           Transfer     Bandwidth       Total Datagrams
[  4]   0.00-1.00   sec  22.3 MBytes   187 Mbits/sec  16180
[  4]   1.00-2.00   sec  26.2 MBytes   219 Mbits/sec  18950
[  4]   2.00-3.00   sec  36.9 MBytes   310 Mbits/sec  26740
[  4]   3.00-4.00   sec  22.2 MBytes   186 Mbits/sec  16060
[  4]   4.00-5.00   sec  33.1 MBytes   278 Mbits/sec  23970
[  4]   5.00-6.00   sec  59.4 MBytes   498 Mbits/sec  42990
[  4]   6.00-7.00   sec  29.6 MBytes   248 Mbits/sec  21420
[  4]   7.00-8.00   sec  38.2 MBytes   321 Mbits/sec  27680
[  4]   8.00-9.00   sec  29.2 MBytes   244 Mbits/sec  21110
[  4]   9.00-10.00  sec  34.4 MBytes   289 Mbits/sec  24920
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  4]   0.00-10.00  sec   331 MBytes   278 Mbits/sec  0.035 ms  0/240020 (0%)
[  4] Sent 240020 datagrams

iperf Done.
```

Server:



```
[root@localhost ~]# iperf3 -s
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
Accepted connection from 10.0.0.3, port 41880
[  5] local 10.0.0.2 port 5201 connected to 10.0.0.3 port 53001
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-1.00   sec  21.2 MBytes   178 Mbits/sec  0.042 ms  0/15386 (0%)
[  5]   1.00-2.00   sec  23.4 MBytes   196 Mbits/sec  0.126 ms  0/16945 (0%)
[  5]   2.00-3.00   sec  39.9 MBytes   335 Mbits/sec  0.027 ms  0/28900 (0%)
[  5]   3.00-4.00   sec  22.2 MBytes   186 Mbits/sec  0.036 ms  0/16062 (0%)
[  5]   4.00-5.01   sec  33.2 MBytes   277 Mbits/sec  0.281 ms  0/24054 (0%)
[  5]   5.01-6.00   sec  59.2 MBytes   499 Mbits/sec  0.038 ms  0/42893 (0%)
[  5]   6.00-7.00   sec  22.0 MBytes   184 Mbits/sec  0.094 ms  0/15924 (0%)
[  5]   7.00-8.00   sec  45.8 MBytes   385 Mbits/sec  0.044 ms  0/33195 (0%)
[  5]   8.00-9.00   sec  29.2 MBytes   245 Mbits/sec  0.039 ms  0/21117 (0%)
[  5]   9.00-10.00  sec  34.2 MBytes   287 Mbits/sec  0.032 ms  0/24790 (0%)
[  5]  10.00-10.04  sec  1.04 MBytes   224 Mbits/sec  0.035 ms  0/754 (0%)
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-10.04  sec  0.00 Bytes  0.00 bits/sec  0.035 ms  0/240020 (0%)
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
```

• Does change in the packet size improves the throughput? Explain your answer and provide the maximum throughput achieved and corresponding packet size.

Throughput achieved for different packet sizes:

Client:

```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 100B
Connecting to host 10.0.0.2, port 5201 [ 4] local 10.0.0.3 port 57288 connected to 10.0.0.2 port
5201 [ ID] Interval Transfer Bandwidth Total Datagrams [ 4] 0.00-1.00 sec 2.74 MBytes 23.0
Mbits/sec 28780 [ 4] 1.00-2.00 sec 4.75 MBytes 39.9 Mbits/sec 49830 [ 4] 2.00-3.00 sec 3.62
MBytes 30.4 Mbits/sec 38000 [ 4] 3.00-4.00 sec 3.88 MBytes 32.6 Mbits/sec 40730 [ 4]
4.00-5.00 sec 3.99 MBytes 33.5 Mbits/sec 41870 [ 4] 5.00-6.00 sec 5.37 MBytes 45.1 Mbits/sec
56360 [ 4] 6.00-7.00 sec 1.64 MBytes 13.8 Mbits/sec 17200 [ 4] 7.00-8.00 sec 3.40 MBytes 28.6
Mbits/sec 35680 [ 4] 8.00-9.00 sec 3.31 MBytes 27.7 Mbits/sec 34670 [ 4] 9.00-10.01 sec 3.70
MBytes 30.8 Mbits/sec 38760 - - - - - - - - - - - - - - - - - - - - - - - - - [ ID] Interval Transfer
Bandwidth Jitter Lost/Total Datagrams [ 4] 0.00-10.01 sec 36.4 MBytes 30.5 Mbits/sec 0.333
ms 0/381880 (0%) [ 4] Sent 381880 datagrams iperf Done.
```

```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 200B
Connecting to host 10.0.0.2, port 5201 [ 4] local 10.0.0.3 port 36842 connected to 10.0.0.2 port
5201 [ ID] Interval Transfer Bandwidth Total Datagrams [ 4] 0.00-1.00 sec 4.35 MBytes 36.5
Mbits/sec 22790 [ 4] 1.00-2.00 sec 8.38 MBytes 70.3 Mbits/sec 43960 [ 4] 2.00-3.00 sec 9.18
MBytes 77.1 Mbits/sec 48150 [ 4] 3.00-4.00 sec 5.43 MBytes 45.6 Mbits/sec 28470 [ 4]
4.00-5.00 sec 4.16 MBytes 34.9 Mbits/sec 21830 [ 4] 5.00-6.00 sec 4.54 MBytes 38.1 Mbits/sec
23820 [ 4] 6.00-7.00 sec 8.98 MBytes 75.3 Mbits/sec 47070 [ 4] 7.00-8.00 sec 18.2 MBytes 152
Mbits/sec 95190 [ 4] 8.00-9.00 sec 15.0 MBytes 126 Mbits/sec 78750 [ 4] 9.00-10.00 sec 17.6
MBytes 147 Mbits/sec 92100 - - - - - - - - - - - - - - - - - - - - - - - - - [ ID] Interval Transfer
Bandwidth Jitter Lost/Total Datagrams [ 4] 0.00-10.00 sec 95.8 MBytes 80.3 Mbits/sec 0.054
ms 0/500632 (0%) [ 4] Sent 500632 datagrams iperf Done.
```

```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 400B
Connecting to host 10.0.0.2, port 5201 [ 4] local 10.0.0.3 port 43775 connected to 10.0.0.2 port
5201 [ ID] Interval Transfer Bandwidth Total Datagrams [ 4] 0.00-1.00 sec 24.4 MBytes 205
Mbits/sec 63990 [ 4] 1.00-2.00 sec 16.5 MBytes 138 Mbits/sec 43180 [ 4] 2.00-3.00 sec 18.5
MBytes 155 Mbits/sec 48530 [ 4] 3.00-4.00 sec 11.1 MBytes 93.2 Mbits/sec 29140 [ 4]
4.00-5.00 sec 6.79 MBytes 57.0 Mbits/sec 17810 [ 4] 5.00-6.00 sec 7.47 MBytes 62.6 Mbits/sec
19570 [ 4] 6.00-7.00 sec 11.9 MBytes 100 Mbits/sec 31270 [ 4] 7.00-8.00 sec 8.71 MBytes 73.1
Mbits/sec 22820 [ 4] 8.00-9.00 sec 19.7 MBytes 165 Mbits/sec 51600 [ 4] 9.00-10.00 sec 14.7
MBytes 123 Mbits/sec 38450 - - - - - - - - - - - - - - - - - - - - - - - - - [ ID] Interval Transfer
Bandwidth Jitter Lost/Total Datagrams [ 4] 0.00-10.00 sec 140 MBytes 117 Mbits/sec 0.057 ms
0/366359 (0%) [ 4] Sent 366359 datagrams iperf Done.
```

```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 800B
Connecting to host 10.0.0.2, port 5201 [ 4] local 10.0.0.3 port 55646 connected to 10.0.0.2 port
5201 [ ID] Interval Transfer Bandwidth Total Datagrams [ 4] 0.00-1.00 sec 58.9 MBytes 494
Mbits/sec 77200 [ 4] 1.00-2.00 sec 26.8 MBytes 225 Mbits/sec 35160 [ 4] 2.00-3.00 sec 39.6
MBytes 332 Mbits/sec 51880 [ 4] 3.00-4.00 sec 32.3 MBytes 271 Mbits/sec 42350 [ 4] 4.00-5.00
sec 37.4 MBytes 314 Mbits/sec 49020 [ 4] 5.00-6.00 sec 39.0 MBytes 327 Mbits/sec 51060 [ 4]
6.00-7.00 sec 12.6 MBytes 105 Mbits/sec 16470 [ 4] 7.00-8.00 sec 10.5 MBytes 88.3 Mbits/sec
13800 [ 4] 8.00-9.00 sec 22.2 MBytes 186 Mbits/sec 29120 [ 4] 9.00-10.00 sec 39.4 MBytes 331
Mbits/sec 51670 - - - - - - - - - - - - - - - - - - - - - - - - - [ ID] Interval Transfer Bandwidth Jitter
Lost/Total Datagrams [ 4] 0.00-10.00 sec 319 MBytes 267 Mbits/sec 0.064 ms 0/417730 (0%) [
4] Sent 417730 datagrams iperf Done.
```

```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 1600B
warning: Warning: UDP block size 1600 exceeds TCP MSS 1448, may result in fragmentation /
drops Connecting to host 10.0.0.2, port 5201 [ 4] local 10.0.0.3 port 47587 connected to
10.0.0.2 port 5201 [ ID] Interval Transfer Bandwidth Total Datagrams [ 4] 0.00-1.00 sec 160
MBytes 1.34 Gbits/sec 104990 [ 4] 1.00-2.00 sec 141 MBytes 1.18 Gbits/sec 92420 [ 4]
2.00-3.00 sec 114 MBytes 959 Mbits/sec 74900 [ 4] 3.00-4.00 sec 29.6 MBytes 248 Mbits/sec
19400 [ 4] 4.00-5.00 sec 86.9 MBytes 729 Mbits/sec 56920 [ 4] 5.00-6.00 sec 61.7 MBytes 517
Mbits/sec 40430 [ 4] 6.00-7.00 sec 95.9 MBytes 805 Mbits/sec 62870 [ 4] 7.00-8.00 sec 112
MBytes 939 Mbits/sec 73390 [ 4] 8.00-9.00 sec 73.4 MBytes 616 Mbits/sec 48100 [ 4]
9.00-10.00 sec 49.7 MBytes 417 Mbits/sec 32550 - - - - - - - - - - - - - - - - - - - - - - - - - [ ID]
Interval Transfer Bandwidth Jitter Lost/Total Datagrams [ 4] 0.00-10.00 sec 925 MBytes 776
Mbits/sec 0.048 ms 0/605970 (0%) [ 4] Sent 605970 datagrams iperf Done.
```

```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 3200B
warning: Warning: UDP block size 3200 exceeds TCP MSS 1448, may result in fragmentation /
drops Connecting to host 10.0.0.2, port 5201 [ 4] local 10.0.0.3 port 43934 connected to
10.0.0.2 port 5201 [ ID] Interval Transfer Bandwidth Total Datagrams [ 4] 0.00-1.00 sec 146
MBytes 1.22 Gbits/sec 47740 [ 4] 1.00-2.00 sec 177 MBytes 1.49 Gbits/sec 58010 [ 4] 2.00-3.00
sec 189 MBytes 1.58 Gbits/sec 61800 [ 4] 3.00-4.00 sec 133 MBytes 1.12 Gbits/sec 43600 [ 4]
4.00-5.00 sec 223 MBytes 1.87 Gbits/sec 72970 [ 4] 5.00-6.00 sec 188 MBytes 1.58 Gbits/sec
61570 [ 4] 6.00-7.00 sec 135 MBytes 1.13 Gbits/sec 44320 [ 4] 7.00-8.00 sec 250 MBytes 2.10
Gbits/sec 81910 [ 4] 8.00-9.00 sec 193 MBytes 1.62 Gbits/sec 63380 [ 4] 9.00-10.00 sec 214
MBytes 1.79 Gbits/sec 70040 - - - - - - - - - - - - - - - - - - - - - - - - - [ ID] Interval Transfer
Bandwidth Jitter Lost/Total Datagrams [ 4] 0.00-10.00 sec 1.80 GBytes 1.55 Gbits/sec 0.003
ms 0/605218 (0%) [ 4] Sent 605218 datagrams iperf Done.
```

```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 6400B
warning: Warning: UDP block size 6400 exceeds TCP MSS 1448, may result in fragmentation /
drops Connecting to host 10.0.0.2, port 5201 [ 4] local 10.0.0.3 port 37797 connected to
10.0.0.2 port 5201 [ ID] Interval Transfer Bandwidth Total Datagrams [ 4] 0.00-1.00 sec 450
MBytes 3.77 Gbits/sec 73740 [ 4] 1.00-2.00 sec 386 MBytes 3.24 Gbits/sec 63190 [ 4] 2.00-3.00
```

sec 387 MBytes 3.24 Gbits/sec 63410 [4] 3.00-4.00 sec 459 MBytes 3.85 Gbits/sec 75210 [4] 4.00-5.00 sec 446 MBytes 3.74 Gbits/sec 73140 [4] 5.00-6.00 sec 292 MBytes 2.44 Gbits/sec 47810 [4] 6.00-7.00 sec 359 MBytes 3.02 Gbits/sec 58850 [4] 7.00-8.00 sec 360 MBytes 3.02 Gbits/sec 58980 [4] 8.00-9.00 sec 299 MBytes 2.51 Gbits/sec 49030 [4] 9.00-10.00 sec 529 MBytes 4.43 Gbits/sec 86670 - [ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams [4] 0.00-10.00 sec 3.87 GBytes **3.33 Gbits/sec** 0.002 ms 13595/649646 (2.1%) [4] Sent 649646 datagrams iperf Done.

[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 12800B
warning: Warning: UDP block size 12800 exceeds TCP MSS 1448, may result in fragmentation / drops Connecting to host 10.0.0.2, port 5201 [4] local 10.0.0.3 port 50837 connected to 10.0.0.2 port 5201 [ID] Interval Transfer Bandwidth Total Datagrams [4] 0.00-1.00 sec 517 MBytes 4.34 Gbits/sec 42350 [4] 1.00-2.00 sec 733 MBytes 6.13 Gbits/sec 60060 [4] 2.00-3.00 sec 655 MBytes 5.49 Gbits/sec 53670 [4] 3.00-4.00 sec 665 MBytes 5.60 Gbits/sec 54480 [4] 4.00-5.03 sec 712 MBytes 5.81 Gbits/sec 58300 [4] 5.03-6.00 sec 594 MBytes 5.12 Gbits/sec 48630 [4] 6.00-7.00 sec 671 MBytes 5.63 Gbits/sec 54960 [4] 7.00-8.00 sec 941 MBytes 7.88 Gbits/sec 77060 [4] 8.00-9.00 sec 420 MBytes 3.53 Gbits/sec 34430 [4] 9.00-10.00 sec 739 MBytes 6.20 Gbits/sec 60550 - [ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams [4] 0.00-10.00 sec 6.49 GBytes **5.58 Gbits/sec** 0.007 ms 85221/543858 (16%) [4] Sent 543858 datagrams iperf Done.

[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 25600B warning: Warning: UDP block size 25600 exceeds TCP MSS 1448, may result in fragmentation / drops Connecting to host 10.0.0.2, port 5201 [4] local 10.0.0.3 port 57075 connected to 10.0.0.2 port 5201 [ID] Interval Transfer Bandwidth Total Datagrams [4] 0.00-1.00 sec 967 MBytes 8.11 Gbits/sec 39590 [4] 1.00-2.00 sec 1007 MBytes 8.45 Gbits/sec 41240 [4] 2.00-3.00 sec 1.30 GBytes 11.2 Gbits/sec 54710 [4] 3.00-4.00 sec 1.23 GBytes 10.6 Gbits/sec 51550 [4] 4.00-5.00 sec 1.42 GBytes 12.2 Gbits/sec 59610 [4] 5.00-6.00 sec 1.33 GBytes 11.4 Gbits/sec 55820 [4] 6.00-7.00 sec 1.25 GBytes 10.8 Gbits/sec 52570 [4] 7.00-8.00 sec 1.02 GBytes 8.78 Gbits/sec 42860 [4] 8.00-9.01 sec 898 MBytes 7.43 Gbits/sec 36780 [4] 9.01-10.00 sec 964 MBytes 8.21 Gbits/sec 39500 - [ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams [4] 0.00-10.00 sec 11.3 GBytes **9.71 Gbits/sec** 0.110 ms 241768/473010 (51%) [4] Sent 473010 datagrams iperf Done.

[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 51200B
warning: Warning: UDP block size 51200 exceeds TCP MSS 1448, may result in fragmentation / drops Connecting to host 10.0.0.2, port 5201 [4] local 10.0.0.3 port 44391 connected to 10.0.0.2 port 5201 [ID] Interval Transfer Bandwidth Total Datagrams [4] 0.00-1.00 sec 1.18 GBytes 10.2 Gbits/sec 24820 [4] 1.00-2.00 sec 1.07 GBytes 9.20 Gbits/sec 22430 [4] 2.00-3.00 sec 1.40 GBytes 12.0 Gbits/sec 29360 [4] 3.00-4.00 sec 1.58 GBytes 13.6 Gbits/sec 33170 [4] 4.00-5.00 sec 1.35 GBytes 11.6 Gbits/sec 28340 [4] 5.00-6.00 sec 1.71 GBytes 14.7 Gbits/sec 35820 [4] 6.00-7.00 sec 1.45 GBytes 12.4 Gbits/sec 30360 [4] 7.00-8.01 sec 972 MBytes 8.14 Gbits/sec 19900 [4] 8.01-9.00 sec 1.32 GBytes 11.4 Gbits/sec 27700 [4]

```
9.00-10.00 sec 1.23 GBytes 10.6 Gbits/sec 25800 - - - - - - - - - - - - - - - - - - - - - - - - - [ ID]
Interval Transfer Bandwidth Jitter Lost/Total Datagrams [ 4] 0.00-10.00 sec 13.2 GBytes 11.4
Gbits/sec 0.179 ms 172521/276923 (62%) [ 4] Sent 276923 datagrams iperf Done.
```

```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -u -l 65507B warning: Warning: UDP
block size 65507 exceeds TCP MSS 1448, may result in fragmentation / drops Connecting to
host 10.0.0.2, port 5201 [ 4] local 10.0.0.3 port 37123 connected to 10.0.0.2 port 5201 [ ID]
Interval Transfer Bandwidth Total Datagrams [ 4] 0.00-1.01 sec 1.23 GBytes 10.5 Gbits/sec
20220 [ 4] 1.01-2.00 sec 1.09 GBytes 9.41 Gbits/sec 17850 [ 4] 2.00-3.00 sec 1.58 GBytes 13.6
Gbits/sec 25980 [ 4] 3.00-4.01 sec 1.32 GBytes 11.3 Gbits/sec 21640 [ 4] 4.01-5.00 sec 1.53
GBytes 13.3 Gbits/sec 25120 [ 4] 5.00-6.00 sec 1.65 GBytes 14.2 Gbits/sec 27020 [ 4]
6.00-7.00 sec 1.65 GBytes 14.2 Gbits/sec 27080 [ 4] 7.00-8.01 sec 1.57 GBytes 13.4 Gbits/sec
25670 [ 4] 8.01-9.00 sec 1.68 GBytes 14.5 Gbits/sec 27520 [ 4] 9.00-10.00 sec 1.29 GBytes
11.1 Gbits/sec 21130 - - - - - - - - - - - - - - - - - - - - - - - - - [ ID] Interval Transfer Bandwidth Jitter
Lost/Total Datagrams [ 4] 0.00-10.00 sec 14.6 GBytes 12.5 Gbits/sec 0.137 ms 155914/238981
(65%) [ 4] Sent 238981 datagrams iperf Done. [root@localhost ~]#
```

Server:

```
[root@localhost ~]# iperf3 -s ----------------------------------------------------------- Server listening on
5201 ----------------------------------------------------------- Accepted connection from 10.0.0.3, port
46598 [ 5] local 10.0.0.2 port 5201 connected to 10.0.0.3 port 57288 [ ID] Interval Transfer
Bandwidth Jitter Lost/Total Datagrams [ 5] 0.00-1.00 sec 2.47 MBytes 20.7 Mbits/sec 0.043 ms
0/25862 (0%) [ 5] 1.00-2.00 sec 4.97 MBytes 41.7 Mbits/sec 0.042 ms 0/52075 (0%) [ 5]
2.00-3.00 sec 3.58 MBytes 30.0 Mbits/sec 0.036 ms 0/37555 (0%) [ 5] 3.00-4.00 sec 3.93
MBytes 32.9 Mbits/sec 0.054 ms 0/41172 (0%) [ 5] 4.00-5.00 sec 3.90 MBytes 32.8 Mbits/sec
0.092 ms 0/40943 (0%) [ 5] 5.00-6.00 sec 5.46 MBytes 45.8 Mbits/sec 0.544 ms 0/57251 (0%) [
5] 6.00-7.00 sec 1.66 MBytes 13.9 Mbits/sec 0.072 ms 0/17362 (0%) [ 5] 7.00-8.00 sec 3.24
MBytes 27.2 Mbits/sec 0.041 ms 0/33991 (0%) [ 5] 8.00-9.00 sec 3.34 MBytes 28.0 Mbits/sec
0.049 ms 0/35003 (0%) [ 5] 9.00-10.00 sec 3.51 MBytes 29.4 Mbits/sec 0.002 ms 0/36806 (0%)
[ 5] 10.00-10.05 sec 377 KBytes 66.7 Mbits/sec 0.333 ms 0/3860 (0%) - - - - - - - - - - - - - - - - - -
- - - - - - - [ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams [ 5] 0.00-10.05 sec 0.00
Bytes 0.00 bits/sec 0.333 ms 0/381880 (0%)
```

```
 ----------------------------------------------------------- Server listening on 5201
----------------------------------------------------------- Accepted connection from 10.0.0.3, port 34690 [ 5]
local 10.0.0.2 port 5201 connected to 10.0.0.3 port 36842 [ ID] Interval Transfer Bandwidth Jitter
Lost/Total Datagrams [ 5] 0.00-1.00 sec 4.09 MBytes 34.3 Mbits/sec 0.048 ms 0/21469 (0%) [ 5]
1.00-2.00 sec 7.51 MBytes 63.0 Mbits/sec 0.034 ms 0/39378 (0%) [ 5] 2.00-3.00 sec 9.14
MBytes 76.7 Mbits/sec 0.042 ms 0/47923 (0%) [ 5] 3.00-4.00 sec 6.48 MBytes 54.3 Mbits/sec
0.021 ms 0/33951 (0%) [ 5] 4.00-5.00 sec 3.94 MBytes 33.0 Mbits/sec 0.040 ms 0/20649 (0%) [
5] 5.00-6.00 sec 4.15 MBytes 34.8 Mbits/sec 0.015 ms 0/21760 (0%) [ 5] 6.00-7.00 sec 9.00
MBytes 75.5 Mbits/sec 0.004 ms 0/47186 (0%) [ 5] 7.00-8.00 sec 17.7 MBytes 149 Mbits/sec
0.003 ms 0/92822 (0%) [ 5] 8.00-9.00 sec 15.3 MBytes 128 Mbits/sec 0.027 ms 0/80210 (0%) [
5] 9.00-10.00 sec 17.5 MBytes 147 Mbits/sec 0.043 ms 0/91813 (0%) [ 5] 10.00-10.04 sec 678
KBytes 140 Mbits/sec 0.054 ms 0/3471 (0%) - - - - - - - - - - - - - - - - - - - - - - - - - [ ID] Interval
Transfer Bandwidth Jitter Lost/Total Datagrams [ 5] 0.00-10.04 sec 0.00 Bytes 0.00 bits/sec
0.054 ms 0/500632 (0%)

--------------------------------------------------------- Server listening on 5201
--------------------------------------------------------- Accepted connection from 10.0.0.3, port 49177 [ 5]
local 10.0.0.2 port 5201 connected to 10.0.0.3 port 43775 [ ID] Interval Transfer Bandwidth Jitter
Lost/Total Datagrams [ 5] 0.00-1.00 sec 23.2 MBytes 195 Mbits/sec 0.003 ms 0/60930 (0%) [ 5]
1.00-2.00 sec 17.4 MBytes 146 Mbits/sec 0.037 ms 0/45703 (0%) [ 5] 2.00-3.00 sec 15.3
MBytes 128 Mbits/sec 0.045 ms 0/40075 (0%) [ 5] 3.00-4.00 sec 14.2 MBytes 119 Mbits/sec
0.045 ms 0/37326 (0%) [ 5] 4.00-5.00 sec 6.88 MBytes 57.7 Mbits/sec 0.031 ms 0/18036 (0%) [
5] 5.00-6.00 sec 7.44 MBytes 62.4 Mbits/sec 0.034 ms 0/19494 (0%) [ 5] 6.00-7.00 sec 11.9
MBytes 100 Mbits/sec 0.041 ms 0/31258 (0%) [ 5] 7.00-8.00 sec 8.77 MBytes 73.6 Mbits/sec
0.064 ms 0/22995 (0%) [ 5] 8.00-9.00 sec 14.1 MBytes 118 Mbits/sec 0.002 ms 0/36837 (0%) [
5] 9.00-10.00 sec 20.3 MBytes 170 Mbits/sec 0.057 ms 0/53113 (0%) [ 5] 10.00-10.04 sec 231
KBytes 47.8 Mbits/sec 0.057 ms 0/592 (0%) - - - - - - - - - - - - - - - - - - - - - - - - - [ ID] Interval
Transfer Bandwidth Jitter Lost/Total Datagrams [ 5] 0.00-10.04 sec 0.00 Bytes 0.00 bits/sec
0.057 ms 0/366359 (0%)

 --------------------------------------------------------- Server listening on 5201
--------------------------------------------------------- Accepted connection from 10.0.0.3, port 54750 [ 5]
local 10.0.0.2 port 5201 connected to 10.0.0.3 port 55646 [ ID] Interval Transfer Bandwidth Jitter
Lost/Total Datagrams [ 5] 0.00-1.00 sec 56.8 MBytes 476 Mbits/sec 0.084 ms 0/74438 (0%) [ 5]
1.00-2.00 sec 28.5 MBytes 239 Mbits/sec 0.032 ms 0/37305 (0%) [ 5] 2.00-3.00 sec 39.2
MBytes 329 Mbits/sec 0.040 ms 0/51333 (0%) [ 5] 3.00-4.00 sec 32.7 MBytes 274 Mbits/sec
0.038 ms 0/42832 (0%) [ 5] 4.00-5.00 sec 34.9 MBytes 293 Mbits/sec 0.064 ms 0/45779 (0%) [
5] 5.00-6.00 sec 41.3 MBytes 347 Mbits/sec 0.043 ms 0/54194 (0%) [ 5] 6.00-7.00 sec 12.8
MBytes 107 Mbits/sec 0.034 ms 0/16748 (0%) [ 5] 7.00-8.00 sec 10.5 MBytes 88.4 Mbits/sec
0.056 ms 0/13811 (0%) [ 5] 8.00-9.00 sec 14.4 MBytes 121 Mbits/sec 0.044 ms 0/18829 (0%) [
5] 9.00-10.00 sec 46.1 MBytes 387 Mbits/sec 0.038 ms 0/60417 (0%) [ 5] 10.00-10.04 sec 1.56
MBytes 332 Mbits/sec 0.064 ms 0/2044 (0%) - - - - - - - - - - - - - - - - - - - - - - - - - [ ID] Interval
Transfer Bandwidth Jitter Lost/Total Datagrams [ 5] 0.00-10.04 sec 0.00 Bytes 0.00 bits/sec
0.064 ms 0/417730 (0%)

 --------------------------------------------------------- Server listening on 5201
--------------------------------------------------------- Accepted connection from 10.0.0.3, port 57197 [ 5]
local 10.0.0.2 port 5201 connected to 10.0.0.3 port 47587 [ ID] Interval Transfer Bandwidth Jitter
Lost/Total Datagrams [ 5] 0.00-1.00 sec 110 MBytes 926 Mbits/sec 0.001 ms 0/72356 (0%) [ 5]
1.00-2.00 sec 174 MBytes 1.46 Gbits/sec 0.038 ms 0/114240 (0%) [ 5] 2.00-3.00 sec 129
MBytes 1.08 Gbits/sec 0.168 ms 0/84452 (0%) [ 5] 3.00-4.00 sec 30.4 MBytes 255 Mbits/sec
0.049 ms 0/19897 (0%) [ 5] 4.00-5.00 sec 87.2 MBytes 732 Mbits/sec 0.062 ms 0/57174 (0%) [
5] 5.00-6.00 sec 61.7 MBytes 518 Mbits/sec 0.043 ms 0/40443 (0%) [ 5] 6.00-7.00 sec 95.9
```

```
MBytes 804 Mbits/sec 0.053 ms 0/62821 (0%) [ 5] 7.00-8.00 sec 112 MBytes 940 Mbits/sec
0.045 ms 0/73446 (0%) [ 5] 8.00-9.00 sec 73.2 MBytes 614 Mbits/sec 0.057 ms 0/47940 (0%) [
5] 9.00-10.00 sec 49.3 MBytes 413 Mbits/sec 0.051 ms 0/32302 (0%) [ 5] 10.00-10.04 sec 1.37
MBytes 298 Mbits/sec 0.048 ms 0/899 (0%) - - - - - - - - - - - - - - - - - - - - - - - - - [ ID] Interval
Transfer Bandwidth Jitter Lost/Total Datagrams [ 5] 0.00-10.04 sec 0.00 Bytes 0.00 bits/sec
0.048 ms 0/605970 (0%)
```

```
----------------------------------------------------------- Server listening on 5201
----------------------------------------------------------- Accepted connection from 10.0.0.3, port 55305 [ 5]
local 10.0.0.2 port 5201 connected to 10.0.0.3 port 43934 [ ID] Interval Transfer Bandwidth Jitter
Lost/Total Datagrams [ 5] 0.00-1.00 sec 144 MBytes 1.21 Gbits/sec 0.058 ms 0/47254 (0%) [ 5]
1.00-2.00 sec 177 MBytes 1.48 Gbits/sec 0.049 ms 0/57997 (0%) [ 5] 2.00-3.00 sec 186 MBytes
1.56 Gbits/sec 0.138 ms 0/61054 (0%) [ 5] 3.00-4.00 sec 104 MBytes 868 Mbits/sec 0.500 ms
0/33982 (0%) [ 5] 4.00-5.00 sec 252 MBytes 2.12 Gbits/sec 0.056 ms 0/82587 (0%) [ 5]
5.00-6.00 sec 190 MBytes 1.60 Gbits/sec 0.050 ms 0/62328 (0%) [ 5] 6.00-7.00 sec 135 MBytes
1.13 Gbits/sec 0.058 ms 0/44238 (0%) [ 5] 7.00-8.00 sec 203 MBytes 1.70 Gbits/sec 0.140 ms
0/66633 (0%) [ 5] 8.00-9.00 sec 219 MBytes 1.84 Gbits/sec 0.364 ms 0/71762 (0%) [ 5]
9.00-10.00 sec 227 MBytes 1.91 Gbits/sec 0.129 ms 0/74504 (0%) [ 5] 10.00-10.06 sec 8.79
MBytes 1.30 Gbits/sec 0.003 ms 0/2879 (0%) - - - - - - - - - - - - - - - - - - - - - - - - - [ ID] Interval
Transfer Bandwidth Jitter Lost/Total Datagrams [ 5] 0.00-10.06 sec 0.00 Bytes 0.00 bits/sec
0.003 ms 0/605218 (0%)
```

```
----------------------------------------------------------- Server listening on 5201
----------------------------------------------------------- Accepted connection from 10.0.0.3, port 33098 [ 5]
local 10.0.0.2 port 5201 connected to 10.0.0.3 port 37797 [ ID] Interval Transfer Bandwidth Jitter
Lost/Total Datagrams [ 5] 0.00-1.00 sec 320 MBytes 2.68 Gbits/sec 0.104 ms 1124/53521
(2.1%) [ 5] 1.00-2.00 sec 458 MBytes 3.85 Gbits/sec 0.074 ms 0/75064 (0%) [ 5] 2.00-3.00 sec
329 MBytes 2.76 Gbits/sec 0.085 ms 1170/55130 (2.1%) [ 5] 3.00-4.00 sec 415 MBytes 3.48
Gbits/sec 0.154 ms 1898/69892 (2.7%) [ 5] 4.00-5.00 sec 454 MBytes 3.81 Gbits/sec 0.005 ms
2881/77308 (3.7%) [ 5] 5.00-6.00 sec 375 MBytes 3.14 Gbits/sec 0.133 ms 0/61363 (0%) [ 5]
6.00-7.00 sec 267 MBytes 2.24 Gbits/sec 0.038 ms 2467/46265 (5.3%) [ 5] 7.00-8.00 sec 444
MBytes 3.72 Gbits/sec 0.003 ms 0/72739 (0%) [ 5] 8.00-9.00 sec 291 MBytes 2.44 Gbits/sec
0.027 ms 1732/49470 (3.5%) [ 5] 9.00-10.01 sec 391 MBytes 3.25 Gbits/sec 0.665 ms
2323/66335 (3.5%) [ 5] 10.01-10.25 sec 138 MBytes 4.77 Gbits/sec 0.002 ms 0/22559 (0%) - - -
- - - - - - - - - - - - - - - - - - - - - - [ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams [ 5]
0.00-10.25 sec 0.00 Bytes 0.00 bits/sec 0.002 ms 13595/649646 (2.1%)
```

```
----------------------------------------------------------- Server listening on 5201
----------------------------------------------------------- Accepted connection from 10.0.0.3, port 33796 [ 5]
local 10.0.0.2 port 5201 connected to 10.0.0.3 port 50837 [ ID] Interval Transfer Bandwidth Jitter
Lost/Total Datagrams [ 5] 0.00-1.00 sec 369 MBytes 3.10 Gbits/sec 0.002 ms 0/30266 (0%) [ 5]
1.00-2.00 sec 591 MBytes 4.96 Gbits/sec 0.030 ms 185/48607 (0.38%) [ 5] 2.00-3.00 sec 544
MBytes 4.57 Gbits/sec 0.002 ms 969/45571 (2.1%) [ 5] 3.00-4.00 sec 464 MBytes 3.89
```

```
Gbits/sec 0.709 ms 7127/45118 (16%) [ 5] 4.00-5.00 sec 539 MBytes 4.53 Gbits/sec 0.396 ms
1010/45192 (2.2%) [ 5] 5.00-6.00 sec 570 MBytes 4.78 Gbits/sec 0.031 ms 8880/55583 (16%) [
5] 6.00-7.00 sec 454 MBytes 3.81 Gbits/sec 0.006 ms 6784/44010 (15%) [ 5] 7.00-8.00 sec 628
MBytes 5.26 Gbits/sec 0.078 ms 2113/53528 (3.9%) [ 5] 8.00-9.00 sec 518 MBytes 4.34
Gbits/sec 0.072 ms 33752/76157 (44%) [ 5] 9.00-10.00 sec 535 MBytes 4.48 Gbits/sec 0.044
ms 5538/49329 (11%) [ 5] 10.00-10.93 sec 386 MBytes 3.49 Gbits/sec 0.007 ms 18863/50497
(37%) - - - - - - - - - - - - - - - - - - - - - - - - - [ ID] Interval Transfer Bandwidth Jitter Lost/Total
Datagrams [ 5] 0.00-10.93 sec 0.00 Bytes 0.00 bits/sec 0.007 ms 85221/543858 (16%)
```

```
----------------------------------------------------------- Server listening on 5201
----------------------------------------------------------- Accepted connection from 10.0.0.3, port 57952 [ 5]
local 10.0.0.2 port 5201 connected to 10.0.0.3 port 57075 [ ID] Interval Transfer Bandwidth Jitter
Lost/Total Datagrams [ 5] 0.00-1.00 sec 558 MBytes 4.68 Gbits/sec 0.014 ms 2602/25477
(10%) [ 5] 1.00-2.00 sec 615 MBytes 5.16 Gbits/sec 0.090 ms 1914/27124 (7.1%) [ 5] 2.00-3.00
sec 515 MBytes 4.32 Gbits/sec 0.018 ms 3419/24510 (14%) [ 5] 3.00-4.00 sec 495 MBytes 4.15
Gbits/sec 0.020 ms 25565/45839 (56%) [ 5] 4.00-5.00 sec 469 MBytes 3.93 Gbits/sec 0.417 ms
21869/41093 (53%) [ 5] 5.00-6.00 sec 415 MBytes 3.48 Gbits/sec 0.087 ms 38711/55689 (70%)
[ 5] 6.00-7.02 sec 502 MBytes 4.15 Gbits/sec 1.031 ms 49418/69999 (71%) [ 5] 7.02-8.00 sec
414 MBytes 3.53 Gbits/sec 0.109 ms 36620/53582 (68%) [ 5] 8.00-9.00 sec 632 MBytes 5.30
Gbits/sec 0.089 ms 23895/49787 (48%) [ 5] 9.00-10.00 sec 467 MBytes 3.92 Gbits/sec 0.302
ms 5338/24471 (22%) [ 5] 10.00-11.00 sec 551 MBytes 4.63 Gbits/sec 0.074 ms 32417/54992
(59%) [ 5] 11.00-11.03 sec 10.9 MBytes 3.36 Gbits/sec 0.110 ms 0/447 (0%) - - - - - - - - - - - - - -
- - - - - - - - - - - [ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams [ 5] 0.00-11.03 sec
0.00 Bytes 0.00 bits/sec 0.110 ms 241768/473010 (51%)
```

```
----------------------------------------------------------- Server listening on 5201
----------------------------------------------------------- Accepted connection from 10.0.0.3, port 43568 [ 5]
local 10.0.0.2 port 5201 connected to 10.0.0.3 port 44391 [ ID] Interval Transfer Bandwidth Jitter
Lost/Total Datagrams [ 5] 0.00-1.00 sec 492 MBytes 4.13 Gbits/sec 0.098 ms 2651/12723
(21%) [ 5] 1.00-2.00 sec 809 MBytes 6.79 Gbits/sec 0.021 ms 920/17488 (5.3%) [ 5] 2.00-3.00
sec 600 MBytes 5.03 Gbits/sec 0.798 ms 1682/13978 (12%) [ 5] 3.00-4.00 sec 441 MBytes 3.70
Gbits/sec 0.591 ms 18077/27110 (67%) [ 5] 4.00-5.00 sec 305 MBytes 2.56 Gbits/sec 0.304 ms
21268/27516 (77%) [ 5] 5.00-6.00 sec 322 MBytes 2.70 Gbits/sec 0.186 ms 25015/31601 (79%)
[ 5] 6.00-7.00 sec 327 MBytes 2.74 Gbits/sec 0.157 ms 25108/31802 (79%) [ 5] 7.00-8.00 sec
534 MBytes 4.48 Gbits/sec 0.059 ms 32566/43508 (75%) [ 5] 8.00-9.00 sec 467 MBytes 3.92
Gbits/sec 0.106 ms 8469/18040 (47%) [ 5] 9.00-10.00 sec 399 MBytes 3.35 Gbits/sec 0.791 ms
19119/27296 (70%) [ 5] 10.00-11.00 sec 327 MBytes 2.74 Gbits/sec 0.097 ms 13341/20032
(67%) [ 5] 11.00-11.11 sec 74.4 MBytes 5.87 Gbits/sec 0.179 ms 4305/5829 (74%) - - - - - - - - -
- - - - - - - - - - - - - - - - [ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams [ 5]
0.00-11.11 sec 0.00 Bytes 0.00 bits/sec 0.179 ms 172521/276923 (62%)
```

```
----------------------------------------------------------- Server listening on 5201
----------------------------------------------------------- Accepted connection from 10.0.0.3, port 52168 [ 5]
```

```
local 10.0.0.2 port 5201 connected to 10.0.0.3 port 37123 [ ID] Interval Transfer Bandwidth Jitter
Lost/Total Datagrams [ 5] 0.00-1.00 sec 471 MBytes 3.95 Gbits/sec 0.044 ms 529/8072 (6.6%) [
5] 1.00-2.00 sec 666 MBytes 5.58 Gbits/sec 0.253 ms 3174/13834 (23%) [ 5] 2.00-3.00 sec 626
MBytes 5.26 Gbits/sec 0.211 ms 2009/12036 (17%) [ 5] 3.00-4.00 sec 445 MBytes 3.72
Gbits/sec 0.395 ms 20159/27286 (74%) [ 5] 4.00-5.00 sec 427 MBytes 3.60 Gbits/sec 0.187 ms
13191/20033 (66%) [ 5] 5.00-6.00 sec 356 MBytes 2.99 Gbits/sec 0.176 ms 12560/18263 (69%)
[ 5] 6.00-7.00 sec 390 MBytes 3.27 Gbits/sec 0.071 ms 25102/31337 (80%) [ 5] 7.00-8.00 sec
376 MBytes 3.15 Gbits/sec 0.347 ms 21282/27304 (78%) [ 5] 8.00-9.00 sec 458 MBytes 3.84
Gbits/sec 0.145 ms 20442/27766 (74%) [ 5] 9.00-10.00 sec 424 MBytes 3.56 Gbits/sec 0.353
ms 24479/31269 (78%) [ 5] 10.00-10.98 sec 549 MBytes 4.72 Gbits/sec 0.137 ms 12987/21781
(60%) - - - - - - - - - - - - - - - - - - - - - - - - - [ ID] Interval Transfer Bandwidth Jitter Lost/Total
Datagrams [ 5] 0.00-10.98 sec 0.00 Bytes 0.00 bits/sec 0.137 ms 155914/238981 (65%)
----------------------------------------------------------- Server listening on 5201
----------------------------------------------------------- ^Ciperf3: interrupt - the server has terminated
[root@localhost ~]#
```

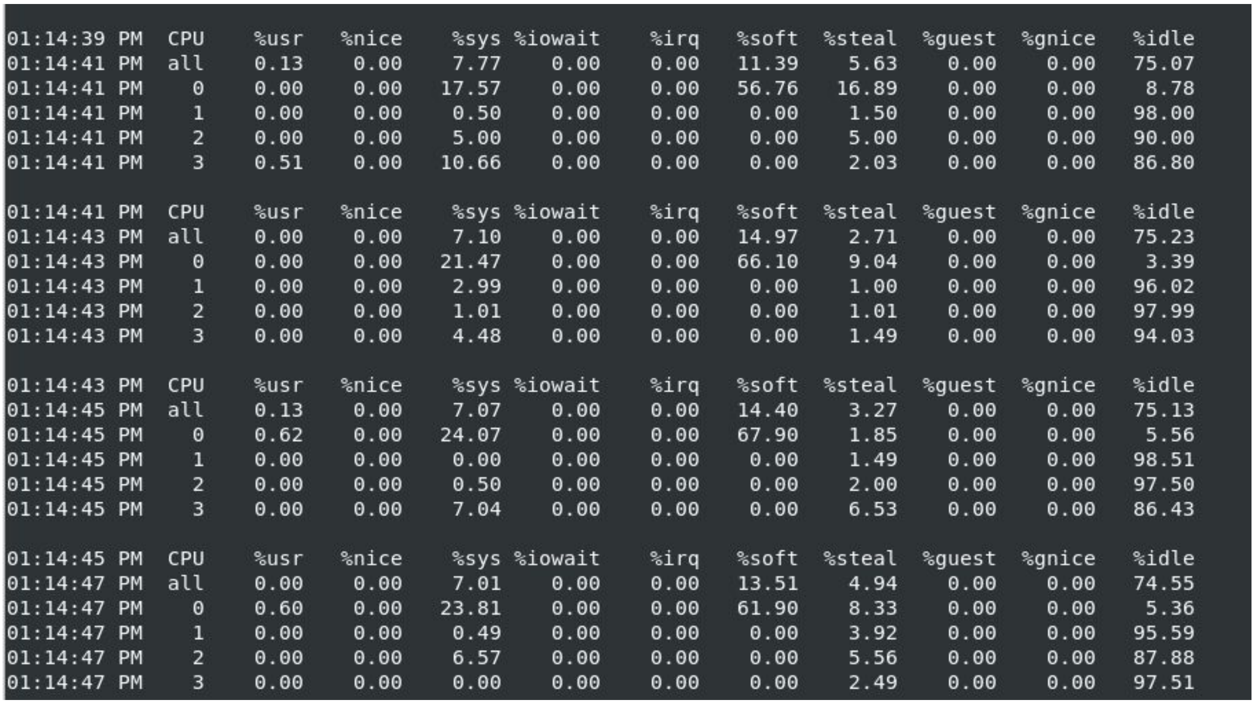
We could achieve max throughput of 12.5Gbps as highlighted above for UDP packet size of 65507Bytes.

• Which is the bottleneck resource, CPU, memory, or I/O? Why? Provide logs of system commands to support your answer.

When above experiment was conducted we monitored memory, cpu and io usage using following commands on server:

```
vmstat 2 1000
mpstat -p ALL 2 1000
iostat 2 1000
```

We observed that memory and I/O was not bottleneck but could see very high CPU usage on CPU1. This might be because of a very large number of packets.



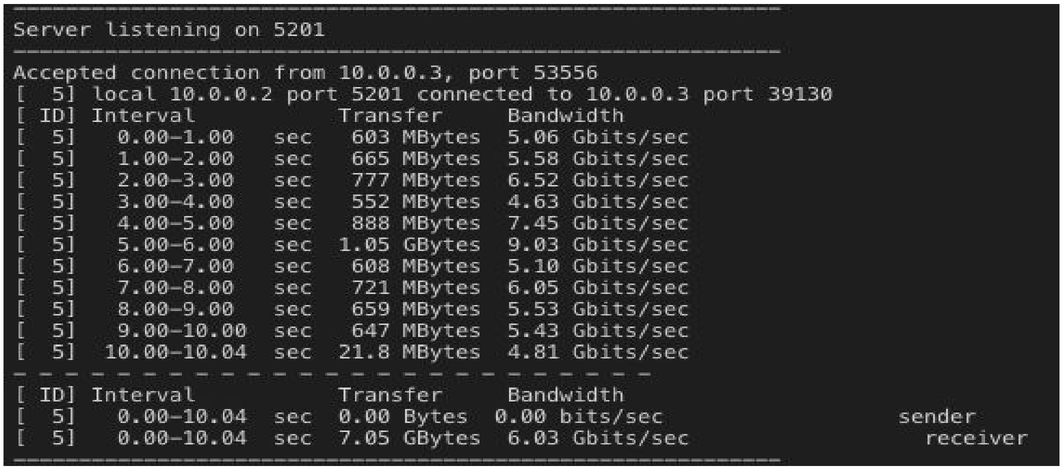
```
01:14:39 PM  CPU    %usr   %nice    %sys %iowait    %irq   %soft  %steal  %guest  %gnice   %idle
01:14:41 PM  all    0.13    0.00    7.77    0.00    0.00   11.39    5.63    0.00    0.00   75.07
01:14:41 PM    0    0.00    0.00   17.57    0.00    0.00   56.76   16.89    0.00    0.00    8.78
01:14:41 PM    1    0.00    0.00    0.50    0.00    0.00    0.00    1.50    0.00    0.00   98.00
01:14:41 PM    2    0.00    0.00    5.00    0.00    0.00    0.00    5.00    0.00    0.00   90.00
01:14:41 PM    3    0.51    0.00   10.66    0.00    0.00    0.00    2.03    0.00    0.00   86.80

01:14:41 PM  CPU    %usr   %nice    %sys %iowait    %irq   %soft  %steal  %guest  %gnice   %idle
01:14:43 PM  all    0.00    0.00    7.10    0.00    0.00   14.97    2.71    0.00    0.00   75.23
01:14:43 PM    0    0.00    0.00   21.47    0.00    0.00   66.10    9.04    0.00    0.00    3.39
01:14:43 PM    1    0.00    0.00    2.99    0.00    0.00    0.00    1.00    0.00    0.00   96.02
01:14:43 PM    2    0.00    0.00    1.01    0.00    0.00    0.00    1.01    0.00    0.00   97.99
01:14:43 PM    3    0.00    0.00    4.48    0.00    0.00    0.00    1.49    0.00    0.00   94.03

01:14:43 PM  CPU    %usr   %nice    %sys %iowait    %irq   %soft  %steal  %guest  %gnice   %idle
01:14:45 PM  all    0.13    0.00    7.07    0.00    0.00   14.40    3.27    0.00    0.00   75.13
01:14:45 PM    0    0.62    0.00   24.07    0.00    0.00   67.90    1.85    0.00    0.00    5.56
01:14:45 PM    1    0.00    0.00    0.00    0.00    0.00    0.00    1.49    0.00    0.00   98.51
01:14:45 PM    2    0.00    0.00    0.50    0.00    0.00    0.00    2.00    0.00    0.00   97.50
01:14:45 PM    3    0.00    0.00    7.04    0.00    0.00    0.00    6.53    0.00    0.00   86.43

01:14:45 PM  CPU    %usr   %nice    %sys %iowait    %irq   %soft  %steal  %guest  %gnice   %idle
01:14:47 PM  all    0.00    0.00    7.01    0.00    0.00   13.51    4.94    0.00    0.00   74.55
01:14:47 PM    0    0.60    0.00   23.81    0.00    0.00   61.90    8.33    0.00    0.00    5.36
01:14:47 PM    1    0.00    0.00    0.49    0.00    0.00    0.00    3.92    0.00    0.00   95.59
01:14:47 PM    2    0.00    0.00    6.57    0.00    0.00    0.00    5.56    0.00    0.00   87.88
01:14:47 PM    3    0.00    0.00    0.00    0.00    0.00    0.00    2.49    0.00    0.00   97.51
```

7. Set up a TCP traffic flow between the two VMs with default packet sizes. What is the maximum TCP throughput achieved?
Explain any difference in throughput as compared to UDP traffic flow.

Tune any TCP
parameter to increase the throughput. Explain your TCP tuning experiment with supporting logs.

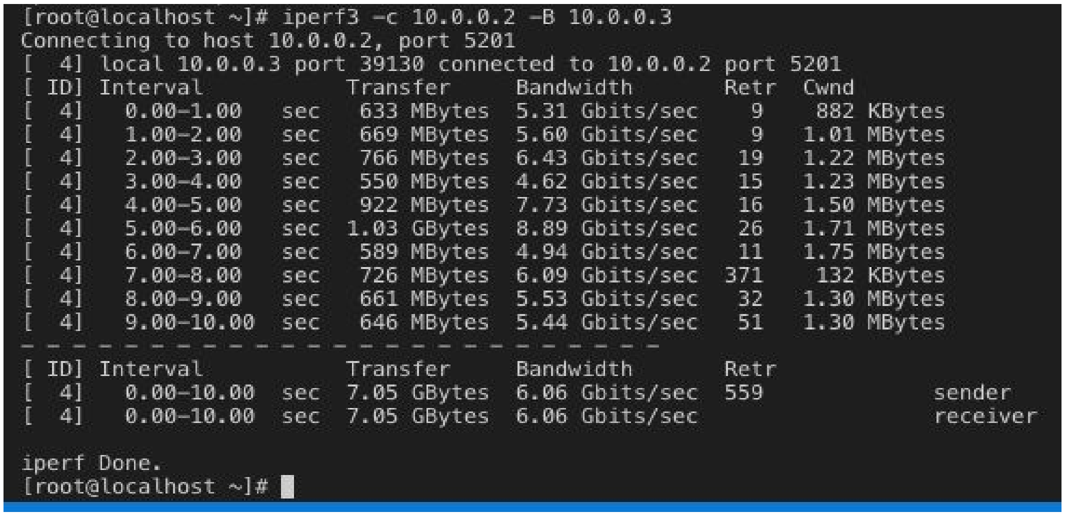
<u>Answer:</u>
Commands:
Server: iperf3 -s
Client: iperf 3 -c 10.0.0.3 -B 10.0.0.2 -b 0 -l 100B

MAX throughput without tuning: 9.03 Gbits/sec
Server:



```
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
Accepted connection from 10.0.0.3, port 53556
[  5] local 10.0.0.2 port 5201 connected to 10.0.0.3 port 39130
[ ID] Interval           Transfer     Bandwidth
[  5]   0.00-1.00   sec   603 MBytes  5.06 Gbits/sec
[  5]   1.00-2.00   sec   665 MBytes  5.58 Gbits/sec
[  5]   2.00-3.00   sec   777 MBytes  6.52 Gbits/sec
[  5]   3.00-4.00   sec   552 MBytes  4.63 Gbits/sec
[  5]   4.00-5.00   sec   888 MBytes  7.45 Gbits/sec
[  5]   5.00-6.00   sec  1.05 GBytes  9.03 Gbits/sec
[  5]   6.00-7.00   sec   608 MBytes  5.10 Gbits/sec
[  5]   7.00-8.00   sec   721 MBytes  6.05 Gbits/sec
[  5]   8.00-9.00   sec   659 MBytes  5.53 Gbits/sec
[  5]   9.00-10.00  sec   647 MBytes  5.43 Gbits/sec
[  5]  10.00-10.04  sec  21.8 MBytes  4.81 Gbits/sec
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth
[  5]   0.00-10.04  sec  0.00 Bytes  0.00 bits/sec                  sender
[  5]   0.00-10.04  sec  7.05 GBytes  6.03 Gbits/sec                  receiver
-----------------------------------------------------------
```

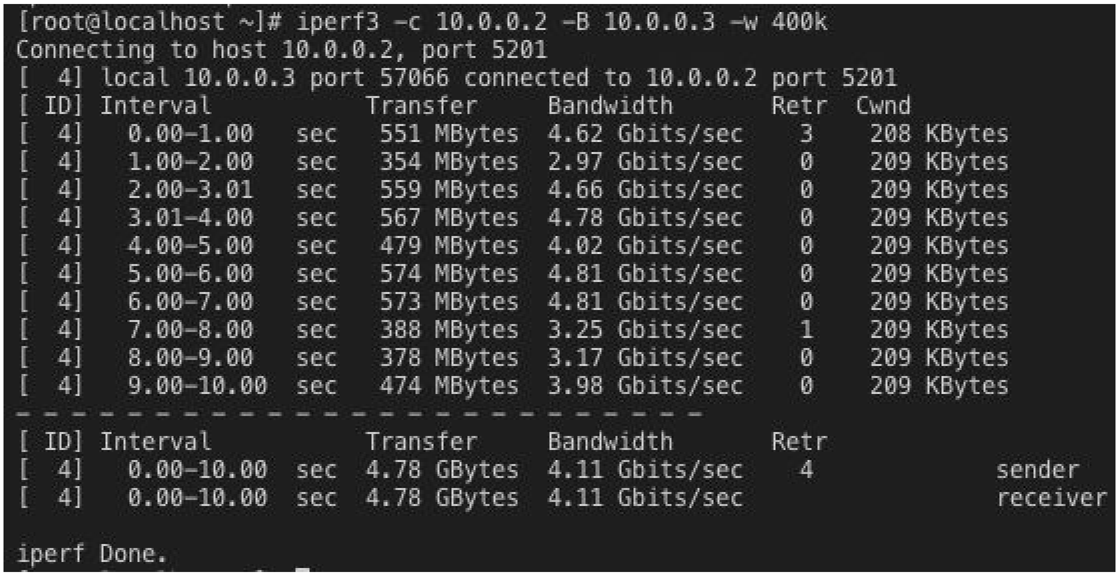
Client:



```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3
Connecting to host 10.0.0.2, port 5201
[  4] local 10.0.0.3 port 39130 connected to 10.0.0.2 port 5201
[ ID] Interval           Transfer     Bandwidth       Retr  Cwnd
[  4]   0.00-1.00   sec   633 MBytes  5.31 Gbits/sec    9    882 KBytes
[  4]   1.00-2.00   sec   669 MBytes  5.60 Gbits/sec    9   1.01 MBytes
[  4]   2.00-3.00   sec   766 MBytes  6.43 Gbits/sec   19   1.22 MBytes
[  4]   3.00-4.00   sec   550 MBytes  4.62 Gbits/sec   15   1.23 MBytes
[  4]   4.00-5.00   sec   922 MBytes  7.73 Gbits/sec   16   1.50 MBytes
[  4]   5.00-6.00   sec  1.03 GBytes  8.89 Gbits/sec   26   1.71 MBytes
[  4]   6.00-7.00   sec   589 MBytes  4.94 Gbits/sec   11   1.75 MBytes
[  4]   7.00-8.00   sec   726 MBytes  6.09 Gbits/sec  371    132 KBytes
[  4]   8.00-9.00   sec   661 MBytes  5.53 Gbits/sec   32   1.30 MBytes
[  4]   9.00-10.00  sec   646 MBytes  5.44 Gbits/sec   51   1.30 MBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Retr
[  4]   0.00-10.00  sec  7.05 GBytes  6.06 Gbits/sec  559             sender
[  4]   0.00-10.00  sec  7.05 GBytes  6.06 Gbits/sec                  receiver

iperf Done.
[root@localhost ~]# █
```

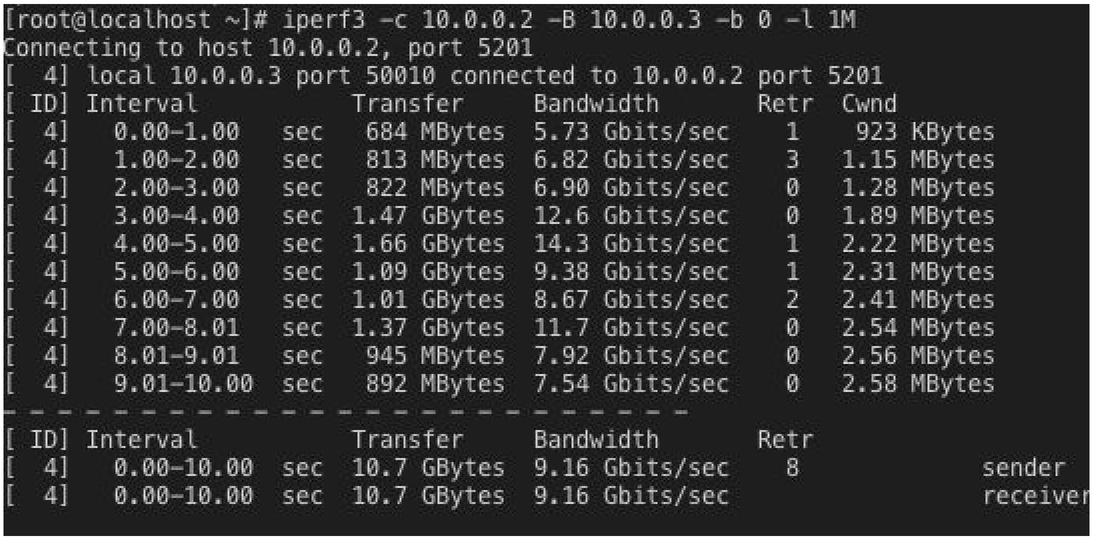
Compared to UDP, TCP(default config) has a slight reduction in the bandwidth i.e. ~9Gbps whereas UDP throughput maxed at 12.5 Gbps. This could be due to the extra overhead of maintaining the state by the TCP protocol and handling lost packets.

Tuning:
Setting window size:
This experiment led to a decrease in the throughput achieved, max being 4.78 Gbps



```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -w 400k
Connecting to host 10.0.0.2, port 5201
[  4] local 10.0.0.3 port 57066 connected to 10.0.0.2 port 5201
[ ID] Interval           Transfer     Bandwidth       Retr  Cwnd
[  4]   0.00-1.00   sec   551 MBytes  4.62 Gbits/sec    3    208 KBytes
[  4]   1.00-2.00   sec   354 MBytes  2.97 Gbits/sec    0    209 KBytes
[  4]   2.00-3.01   sec   559 MBytes  4.66 Gbits/sec    0    209 KBytes
[  4]   3.01-4.00   sec   567 MBytes  4.78 Gbits/sec    0    209 KBytes
[  4]   4.00-5.00   sec   479 MBytes  4.02 Gbits/sec    0    209 KBytes
[  4]   5.00-6.00   sec   574 MBytes  4.81 Gbits/sec    0    209 KBytes
[  4]   6.00-7.00   sec   573 MBytes  4.81 Gbits/sec    0    209 KBytes
[  4]   7.00-8.00   sec   388 MBytes  3.25 Gbits/sec    1    209 KBytes
[  4]   8.00-9.00   sec   378 MBytes  3.17 Gbits/sec    0    209 KBytes
[  4]   9.00-10.00  sec   474 MBytes  3.98 Gbits/sec    0    209 KBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Retr
[  4]   0.00-10.00  sec  4.78 GBytes  4.11 Gbits/sec    4             sender
[  4]   0.00-10.00  sec  4.78 GBytes  4.11 Gbits/sec                  receiver

iperf Done.
```

Increasing Buffer size:
Increasing the buffer size led to a max throughput of 14.3 Gbps, as below.



```
[root@localhost ~]# iperf3 -c 10.0.0.2 -B 10.0.0.3 -b 0 -l 1M
Connecting to host 10.0.0.2, port 5201
[  4] local 10.0.0.3 port 50010 connected to 10.0.0.2 port 5201
[ ID] Interval           Transfer     Bandwidth       Retr  Cwnd
[  4]   0.00-1.00   sec   684 MBytes  5.73 Gbits/sec    1    923 KBytes
[  4]   1.00-2.00   sec   813 MBytes  6.82 Gbits/sec    3   1.15 MBytes
[  4]   2.00-3.00   sec   822 MBytes  6.90 Gbits/sec    0   1.28 MBytes
[  4]   3.00-4.00   sec  1.47 GBytes  12.6 Gbits/sec    0   1.89 MBytes
[  4]   4.00-5.00   sec  1.66 GBytes  14.3 Gbits/sec    1   2.22 MBytes
[  4]   5.00-6.00   sec  1.09 GBytes  9.38 Gbits/sec    1   2.31 MBytes
[  4]   6.00-7.00   sec  1.01 GBytes  8.67 Gbits/sec    2   2.41 MBytes
[  4]   7.00-8.01   sec  1.37 GBytes  11.7 Gbits/sec    0   2.54 MBytes
[  4]   8.01-9.01   sec   945 MBytes  7.92 Gbits/sec    0   2.56 MBytes
[  4]   9.01-10.00  sec   892 MBytes  7.54 Gbits/sec    0   2.58 MBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Retr
[  4]   0.00-10.00  sec  10.7 GBytes  9.16 Gbits/sec    8             sender
[  4]   0.00-10.00  sec  10.7 GBytes  9.16 Gbits/sec                  receiver
```

Question 4) Ansible

Install Ansible on Ubuntu hybervisor

```
$ sudo apt update
$ sudo apt install software-properties-common
$ sudo apt-add-repository --yes --update ppa:ansible/ansible
$ sudo apt install ansible
```

Run playbook:

```
sudo ansible-playbook create-vm-playbook.yml -i inventory/hosts.yml
sudo ansible-playbook load-avg-playbook.yml -i inventory/hosts.yml  --extra-vars "TP=600"
```

Question 5) Python lib-virt

1) Host Information:

Command: `python3 p5_python_libvirt_1.py`

2) Guest Information:

Command: `python3 p5_python_libvirt_2.py <VM_NAME>`

e.g. python3 p5_python_libvirt_2.py yjkamdarVM1

3) Performance monitoring:

Command: `python3 p5_python_libvirt_3.py <USAGE_TYPE>`

Usage types: CPU, MEM

e.g. python3 p5_python_libvirt_3.py CPU

Problem 6. (15 Points)

What if : Set up a lab emxperiment to support your explanation to answer the following questions. What breaks if:

1. Two VMs connected to same bridge (bridge mode) have:

(a) same mac addresses,

Changed mac address of VM1 interface eth1 to mac address of VM2 interface eth1's mac address

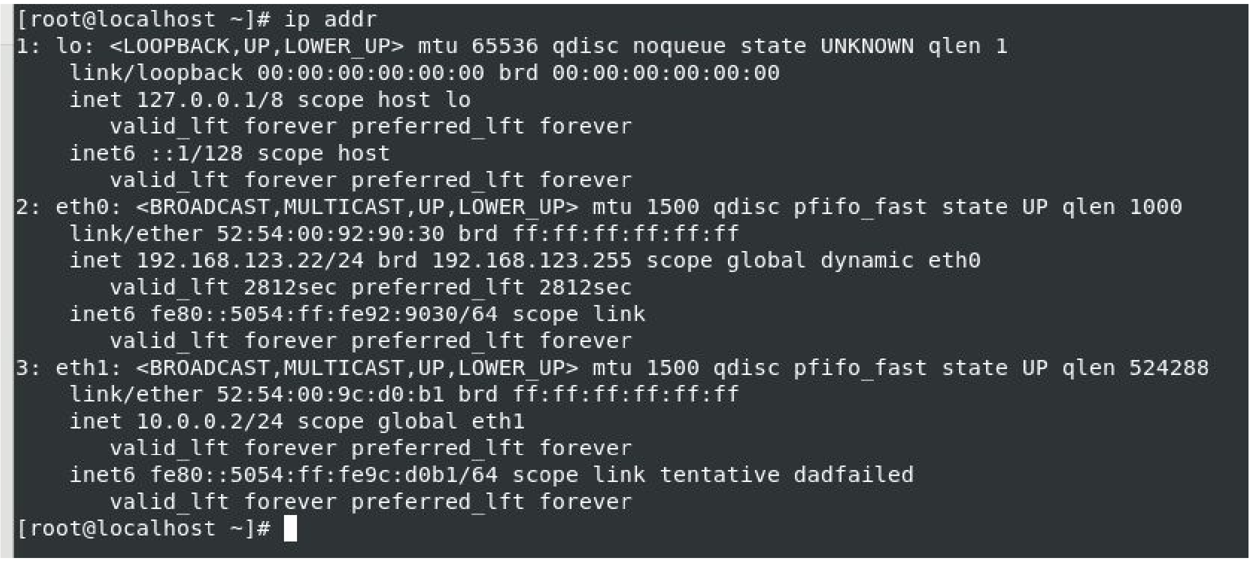
Command used:

1) ip link set eth1 down
2) ip link set eth1 address 52:54:00:9c:d0:b1
3) ip link set eth1 up

Here, 52:54:00:9c:d0:b1 is mac address of eth1 interface of VM2

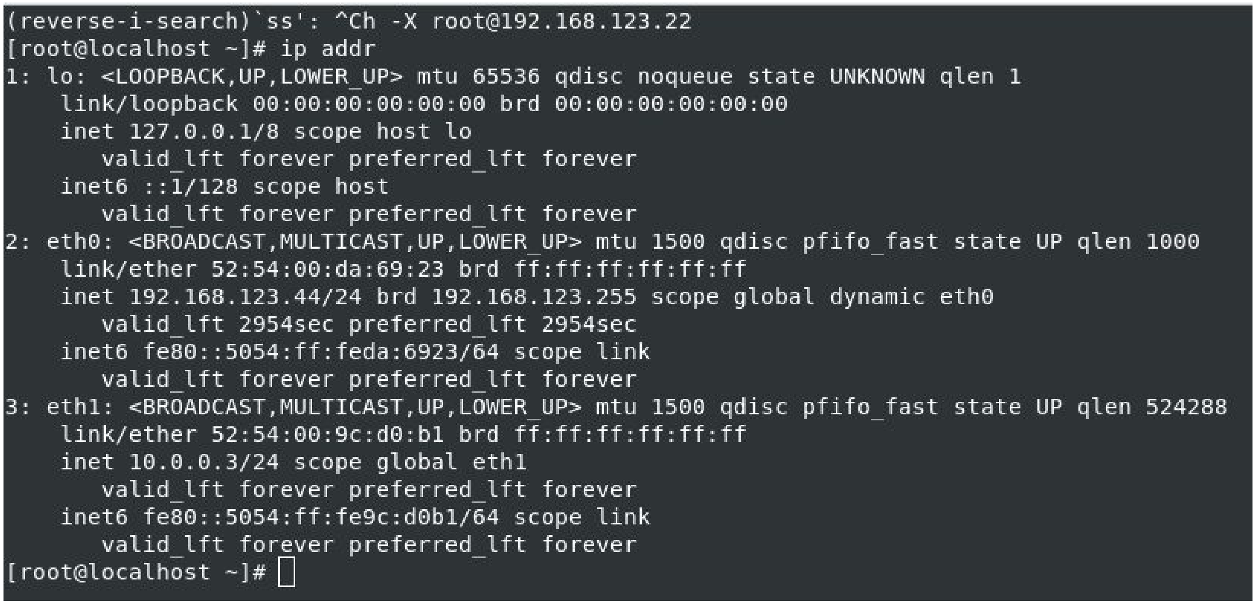
After changing MAC address,

VM1



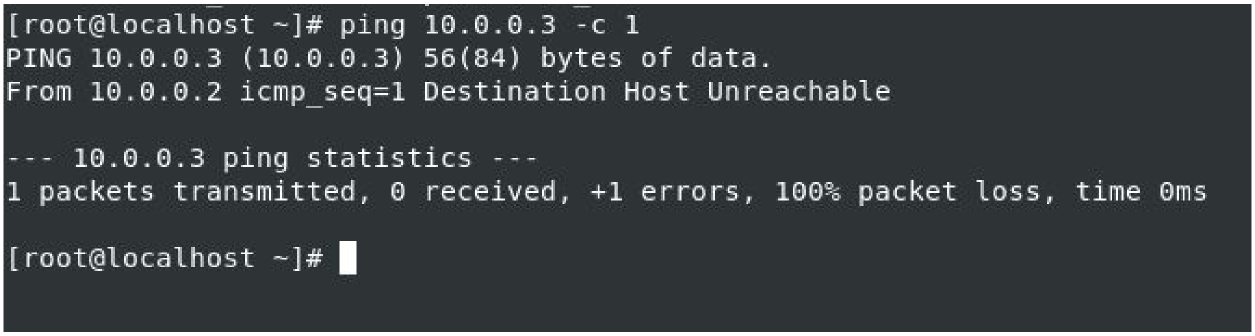
```
[root@localhost ~]# ip addr
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN qlen 1
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:92:90:30 brd ff:ff:ff:ff:ff:ff
    inet 192.168.123.22/24 brd 192.168.123.255 scope global dynamic eth0
       valid_lft 2812sec preferred_lft 2812sec
    inet6 fe80::5054:ff:fe92:9030/64 scope link
       valid_lft forever preferred_lft forever
3: eth1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 524288
    link/ether 52:54:00:9c:d0:b1 brd ff:ff:ff:ff:ff:ff
    inet 10.0.0.2/24 scope global eth1
       valid_lft forever preferred_lft forever
    inet6 fe80::5054:ff:fe9c:d0b1/64 scope link tentative dadfailed
       valid_lft forever preferred_lft forever
[root@localhost ~]# 
```

VM2:



```
(reverse-i-search)`ss': ^Ch -X root@192.168.123.22
[root@localhost ~]# ip addr
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN qlen 1
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:da:69:23 brd ff:ff:ff:ff:ff:ff
    inet 192.168.123.44/24 brd 192.168.123.255 scope global dynamic eth0
       valid_lft 2954sec preferred_lft 2954sec
    inet6 fe80::5054:ff:feda:6923/64 scope link
       valid_lft forever preferred_lft forever
3: eth1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 524288
    link/ether 52:54:00:9c:d0:b1 brd ff:ff:ff:ff:ff:ff
    inet 10.0.0.3/24 scope global eth1
       valid_lft forever preferred_lft forever
    inet6 fe80::5054:ff:fe9c:d0b1/64 scope link
       valid_lft forever preferred_lft forever
[root@localhost ~]# 
```

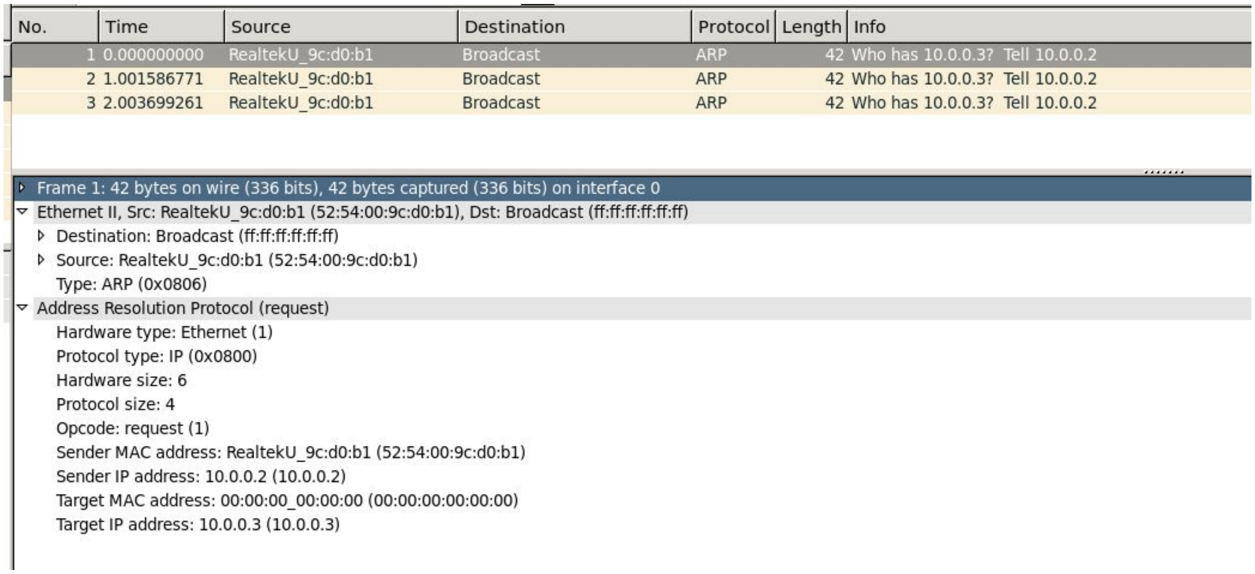
We will try ping from VM1 to VM2:



```
[root@localhost ~]# ping 10.0.0.3 -c 1
PING 10.0.0.3 (10.0.0.3) 56(84) bytes of data.
From 10.0.0.2 icmp_seq=1 Destination Host Unreachable

--- 10.0.0.3 ping statistics ---
1 packets transmitted, 0 received, +1 errors, 100% packet loss, time 0ms

[root@localhost ~]# 
```

And, capture eth1 packets for both VM1 and VM2 with wireshark

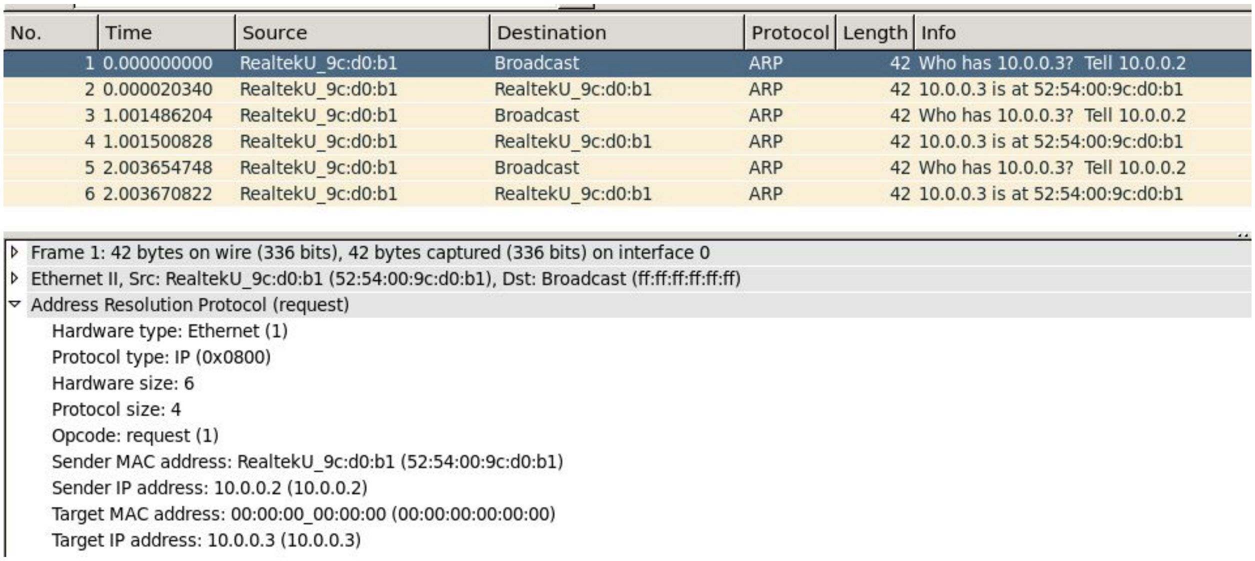
Wireshark capture at VM1:



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	RealtekU_9c:d0:b1	Broadcast	ARP	42	Who has 10.0.0.3? Tell 10.0.0.2
2	1.001586771	RealtekU_9c:d0:b1	Broadcast	ARP	42	Who has 10.0.0.3? Tell 10.0.0.2
3	2.003699261	RealtekU_9c:d0:b1	Broadcast	ARP	42	Who has 10.0.0.3? Tell 10.0.0.2

```
▷ Frame 1: 42 bytes on wire (336 bits), 42 bytes captured (336 bits) on interface 0
▽ Ethernet II, Src: RealtekU_9c:d0:b1 (52:54:00:9c:d0:b1), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
  ▷ Destination: Broadcast (ff:ff:ff:ff:ff:ff)
  ▷ Source: RealtekU_9c:d0:b1 (52:54:00:9c:d0:b1)
    Type: ARP (0x0806)
▽ Address Resolution Protocol (request)
    Hardware type: Ethernet (1)
    Protocol type: IP (0x0800)
    Hardware size: 6
    Protocol size: 4
    Opcode: request (1)
    Sender MAC address: RealtekU_9c:d0:b1 (52:54:00:9c:d0:b1)
    Sender IP address: 10.0.0.2 (10.0.0.2)
    Target MAC address: 00:00:00_00:00:00 (00:00:00:00:00:00)
    Target IP address: 10.0.0.3 (10.0.0.3)
```

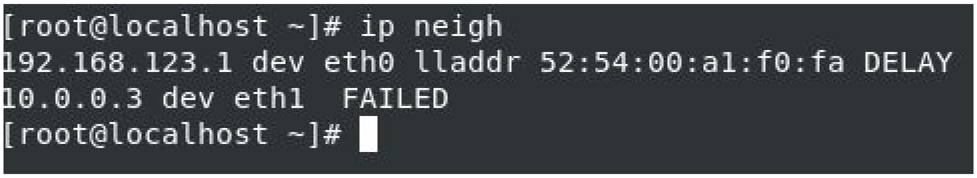
Wireshark capture at VM2:



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	RealtekU_9c:d0:b1	Broadcast	ARP	42	Who has 10.0.0.3? Tell 10.0.0.2
2	0.000020340	RealtekU_9c:d0:b1	RealtekU_9c:d0:b1	ARP	42	10.0.0.3 is at 52:54:00:9c:d0:b1
3	1.001486204	RealtekU_9c:d0:b1	Broadcast	ARP	42	Who has 10.0.0.3? Tell 10.0.0.2
4	1.001500828	RealtekU_9c:d0:b1	RealtekU_9c:d0:b1	ARP	42	10.0.0.3 is at 52:54:00:9c:d0:b1
5	2.003654748	RealtekU_9c:d0:b1	Broadcast	ARP	42	Who has 10.0.0.3? Tell 10.0.0.2
6	2.003670822	RealtekU_9c:d0:b1	RealtekU_9c:d0:b1	ARP	42	10.0.0.3 is at 52:54:00:9c:d0:b1

```
▷ Frame 1: 42 bytes on wire (336 bits), 42 bytes captured (336 bits) on interface 0
▷ Ethernet II, Src: RealtekU_9c:d0:b1 (52:54:00:9c:d0:b1), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
▽ Address Resolution Protocol (request)
    Hardware type: Ethernet (1)
    Protocol type: IP (0x0800)
    Hardware size: 6
    Protocol size: 4
    Opcode: request (1)
    Sender MAC address: RealtekU_9c:d0:b1 (52:54:00:9c:d0:b1)
    Sender IP address: 10.0.0.2 (10.0.0.2)
    Target MAC address: 00:00:00_00:00:00 (00:00:00:00:00:00)
    Target IP address: 10.0.0.3 (10.0.0.3)
```

ARP table at VM1:



```
[root@localhost ~]# ip neigh
192.168.123.1 dev eth0 lladdr 52:54:00:a1:f0:fa DELAY
10.0.0.3 dev eth1  FAILED
[root@localhost ~]#
```

As we can see that ARP resolution for destination ip 10.0.0.3 fails and hence ping is failing

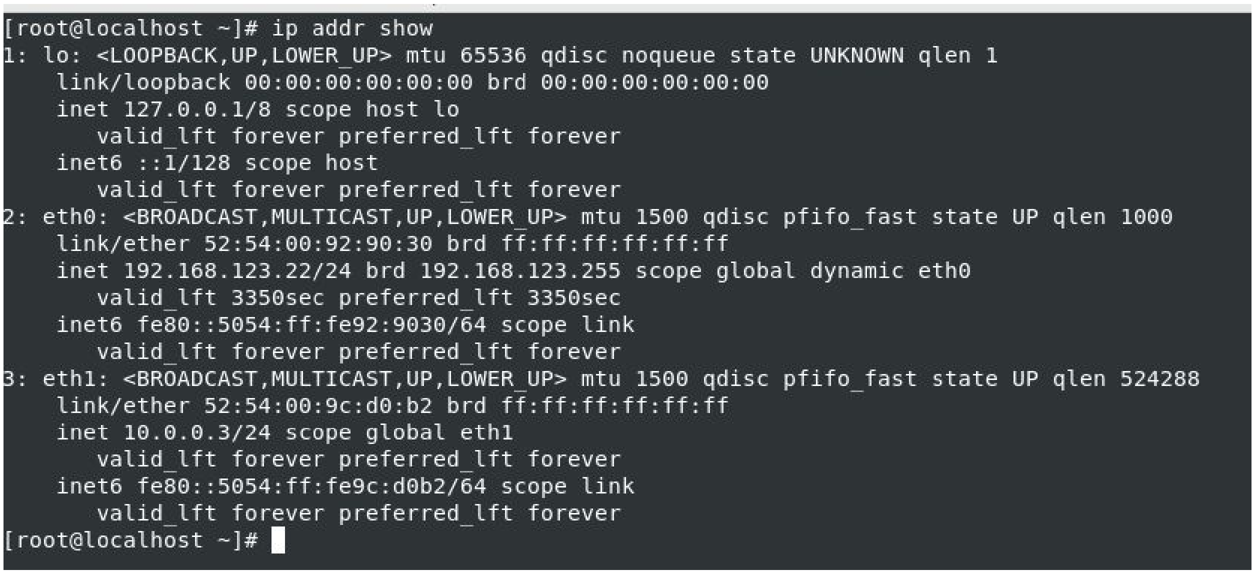
Explanation:
1) VM1 makes ping request to VM2 (10.0.0.3)
2) VM1 will generate ARP request for 10.0.0.3 to know its mac address and will broadcast this request
3) bridge will receive the ARP packet at vnet1 (VM1 connected interface) and map MAC of incoming packet src (52:54:00:9c:d0:b1) to vnet1 and will broadcast this packet.
4) VM2 will receive this ARP request and will respond to it having destination IP as 10.0.0.2 and destination MAC as (52:54:00:9c:d0:b1) and src MAC as 52:54:00:9c:d0:b1
5) bridge will receive the response and now update it’s mapping which previously was 52:54:00:9c:d0:b1::vnet1 and will now update to 52:54:00:9c:d0:b1::vnet3.
6) Now the incoming packet has src mac as 52:54:00:9c:d0:b1 which maps to vnet3 but bridge will drop this packet as it won’t send it back to same interface it received from
7) Hence the ARP request fails, hence PING fails

Hence we can conclude that L2 forwarding at bridge fails if two interfaces connected to same bridge have same MAC addresses.

(b) same IP addresses.

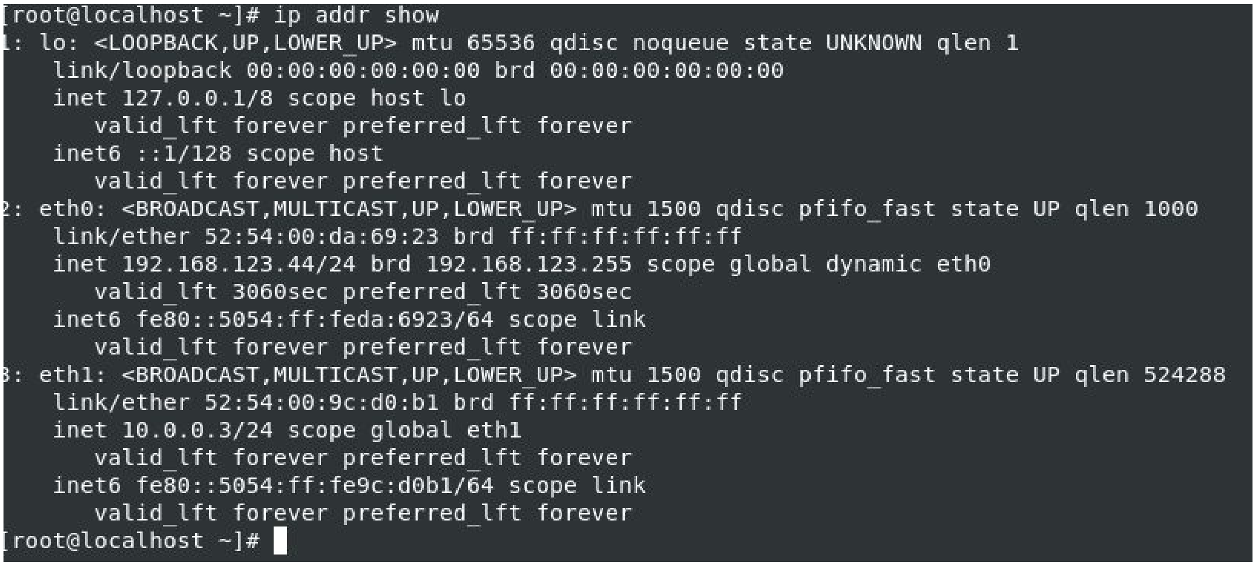
Command used: On VM1
1) ip link set eth1 down
2) ip link addr add 10.0.0.3/24 dev eth1
3) ip link set eth1 up

Configuration: VM1 eth1 IP 10.0.0.3/24, VM2 eth1 IP 10.0.0.3/24
VM1



```
[root@localhost ~]# ip addr show
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN qlen 1
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:92:90:30 brd ff:ff:ff:ff:ff:ff
    inet 192.168.123.22/24 brd 192.168.123.255 scope global dynamic eth0
       valid_lft 3350sec preferred_lft 3350sec
    inet6 fe80::5054:ff:fe92:9030/64 scope link
       valid_lft forever preferred_lft forever
3: eth1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 524288
    link/ether 52:54:00:9c:d0:b2 brd ff:ff:ff:ff:ff:ff
    inet 10.0.0.3/24 scope global eth1
       valid_lft forever preferred_lft forever
    inet6 fe80::5054:ff:fe9c:d0b2/64 scope link
       valid_lft forever preferred_lft forever
[root@localhost ~]# 
```

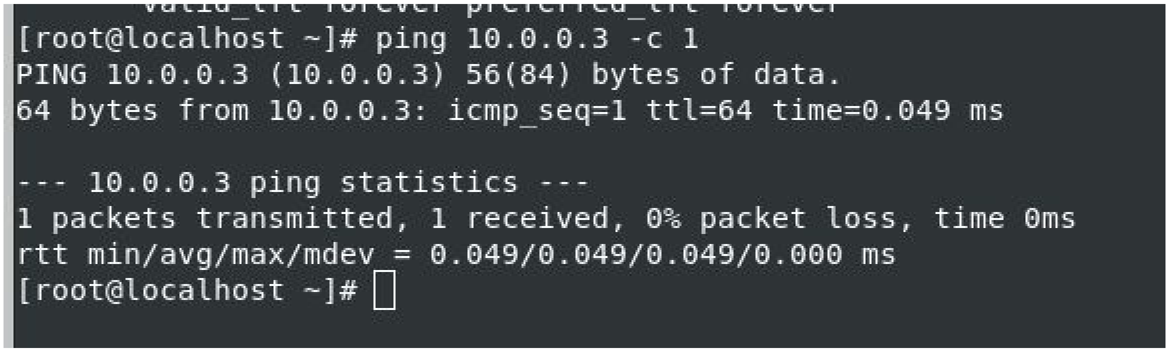
VM2



```
[root@localhost ~]# ip addr show
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN qlen 1
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:da:69:23 brd ff:ff:ff:ff:ff:ff
    inet 192.168.123.44/24 brd 192.168.123.255 scope global dynamic eth0
       valid_lft 3060sec preferred_lft 3060sec
    inet6 fe80::5054:ff:feda:6923/64 scope link
       valid_lft forever preferred_lft forever
3: eth1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 524288
    link/ether 52:54:00:9c:d0:b1 brd ff:ff:ff:ff:ff:ff
    inet 10.0.0.3/24 scope global eth1
       valid_lft forever preferred_lft forever
    inet6 fe80::5054:ff:fe9c:d0b1/64 scope link
       valid_lft forever preferred_lft forever
[root@localhost ~]# 
```

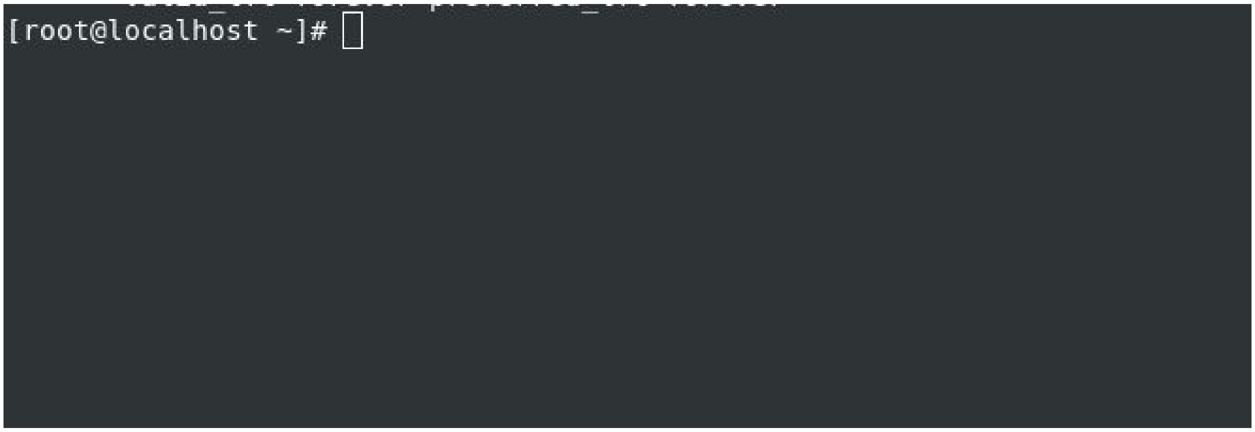
Ping VM2 from VM1:

VM1:



```
       valid_lft forever preferred_lft forever
[root@localhost ~]# ping 10.0.0.3 -c 1
PING 10.0.0.3 (10.0.0.3) 56(84) bytes of data.
64 bytes from 10.0.0.3: icmp_seq=1 ttl=64 time=0.049 ms

--- 10.0.0.3 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.049/0.049/0.049/0.000 ms
[root@localhost ~]# 
```

VM2:



```
       valid_lft forever preferred_lft forever
[root@localhost ~]# 
```

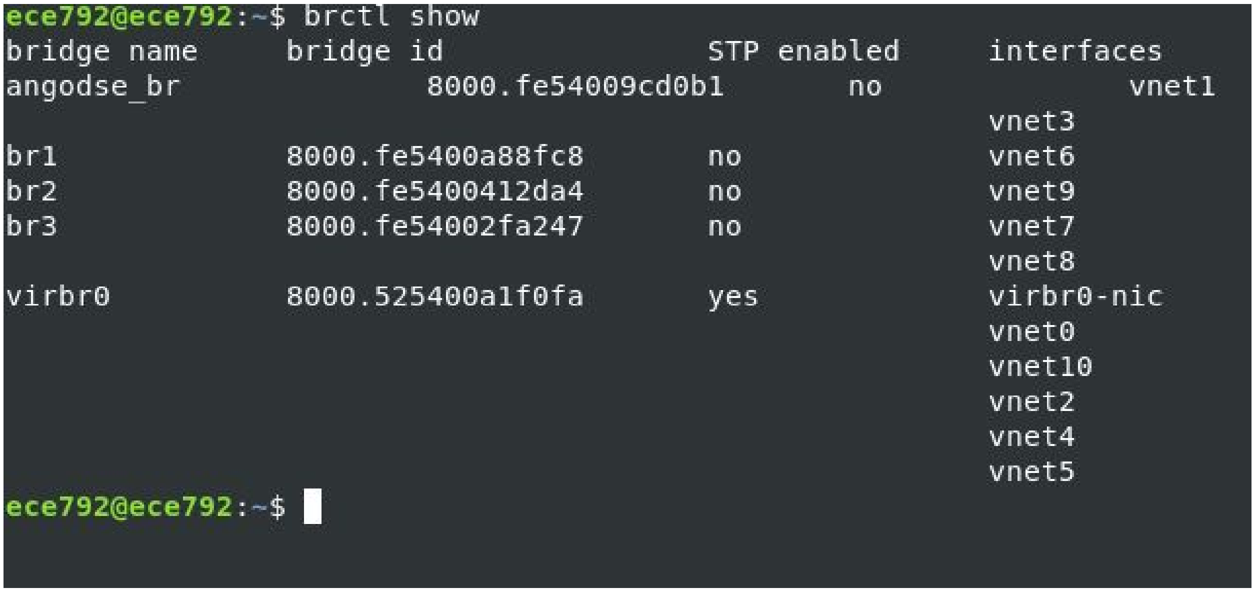
Moreover nothing is observed at eth1 interfaces at both VMs in wireshark.

Conclusion:
Nothing breaks. But the intended receiver VM2 never received ping.

Explanation:
1) Ping from VM1 to VM2 (10.0.0.3)
2) Packet arrives at L3 of VM1 but as the destination address is same as its own interface the packet will never go out of VM1 and loopback to itself

2. Two VM connected to different bridge (both bridges in ’bridge’ mode) have:

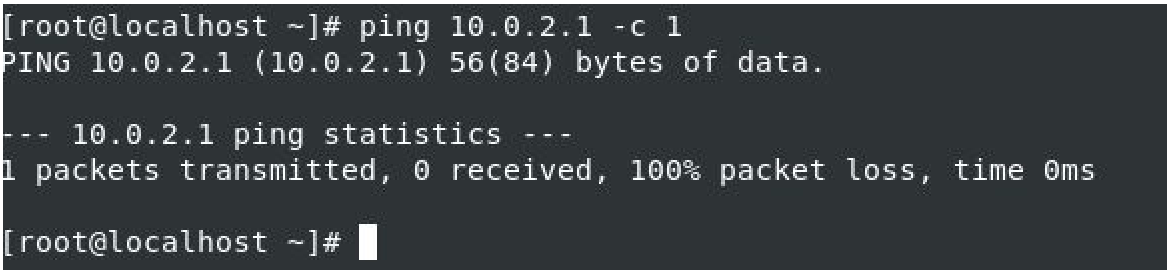
(a) same mac addresses,
Assuming both bridges are not connected.
Created br1 and br2



```
ece792@ece792:~$ brctl show
bridge name     bridge id               STP enabled     interfaces
angodse_br              8000.fe54009cd0b1       no              vnet1
                                                        vnet3
br1             8000.fe5400a88fc8       no              vnet6
br2             8000.fe5400412da4       no              vnet9
br3             8000.fe54002fa247       no              vnet7
                                                        vnet8
virbr0          8000.525400a1f0fa       yes             virbr0-nic
                                                        vnet0
                                                        vnet10
                                                        vnet2
                                                        vnet4
                                                        vnet5
ece792@ece792:~$ 
```

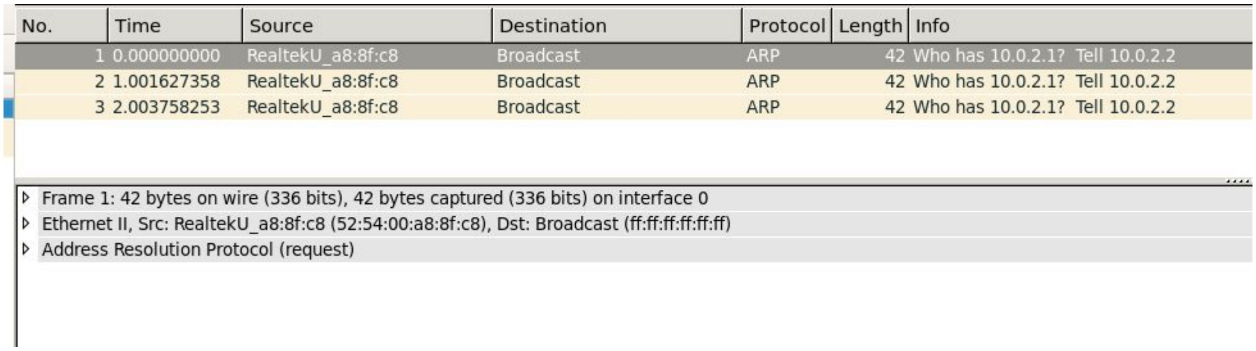
Attached interface eth2 of VM1 to br1 and interface eth3 of VM2 to br2
IP address given to eth2 interface of VM1: 10.0.2.2/24
IP address given to eth3 interface of VM3: 10.0.2.2/24

Ping VM2 (10.0.2.2) from VM1



```
[root@localhost ~]# ping 10.0.2.1 -c 1
PING 10.0.2.1 (10.0.2.1) 56(84) bytes of data.

--- 10.0.2.1 ping statistics ---
1 packets transmitted, 0 received, 100% packet loss, time 0ms

[root@localhost ~]# 
```

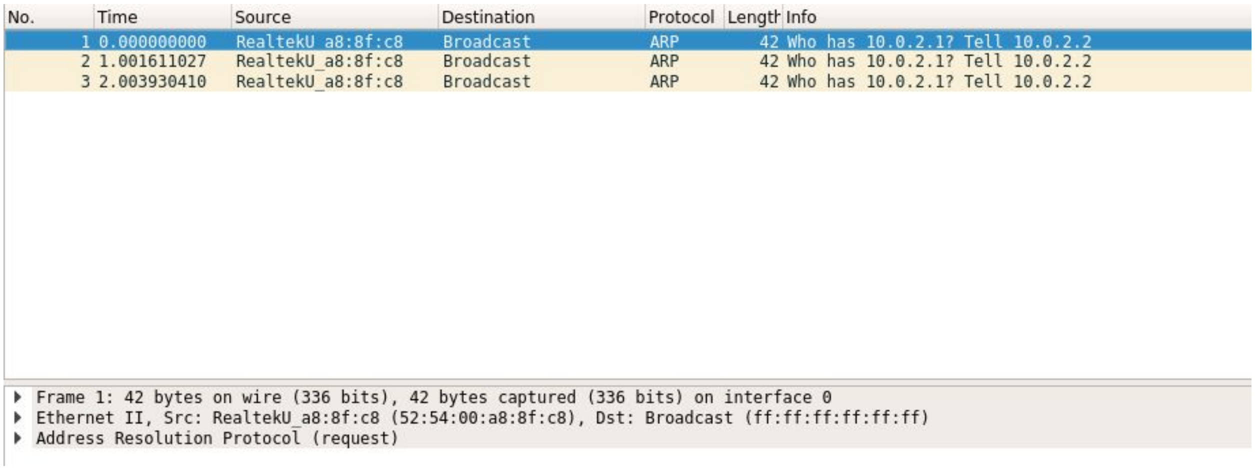
Packets from eth2 of VM1:



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	RealtekU_a8:8f:c8	Broadcast	ARP	42	Who has 10.0.2.1? Tell 10.0.2.2
2	1.001627358	RealtekU_a8:8f:c8	Broadcast	ARP	42	Who has 10.0.2.1? Tell 10.0.2.2
3	2.003758253	RealtekU_a8:8f:c8	Broadcast	ARP	42	Who has 10.0.2.1? Tell 10.0.2.2

```
▷ Frame 1: 42 bytes on wire (336 bits), 42 bytes captured (336 bits) on interface 0
▷ Ethernet II, Src: RealtekU_a8:8f:c8 (52:54:00:a8:8f:c8), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
▷ Address Resolution Protocol (request)
```

Packets at vnet6



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	RealtekU_a8:8f:c8	Broadcast	ARP	42	Who has 10.0.2.1? Tell 10.0.2.2
2	1.001611027	RealtekU_a8:8f:c8	Broadcast	ARP	42	Who has 10.0.2.1? Tell 10.0.2.2
3	2.003930410	RealtekU_a8:8f:c8	Broadcast	ARP	42	Who has 10.0.2.1? Tell 10.0.2.2

```
▸ Frame 1: 42 bytes on wire (336 bits), 42 bytes captured (336 bits) on interface 0
▸ Ethernet II, Src: RealtekU_a8:8f:c8 (52:54:00:a8:8f:c8), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
▸ Address Resolution Protocol (request)
```

Ping is unsuccessful

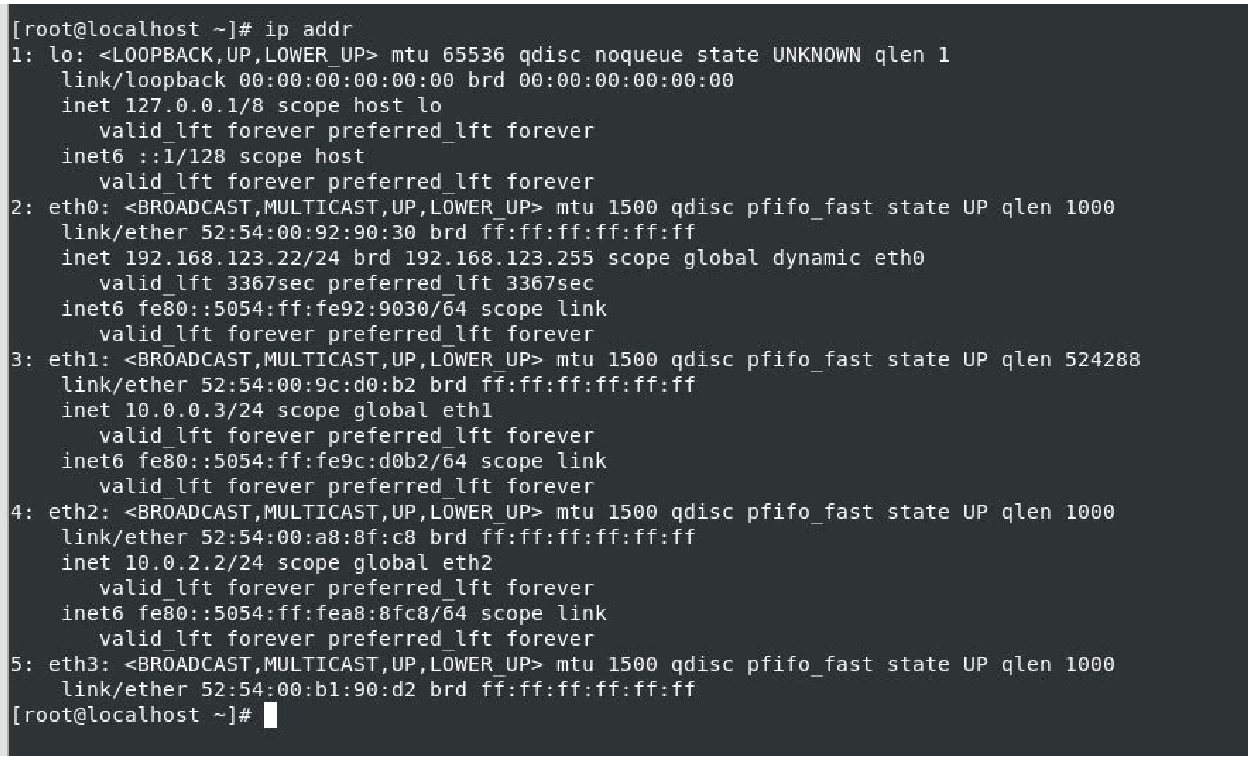
Explanation:

1) ARP request for 10.0.2.2 will arrive at br1 but as no other interfaces are connected the ARP request will fail

(b) same IP addresses.

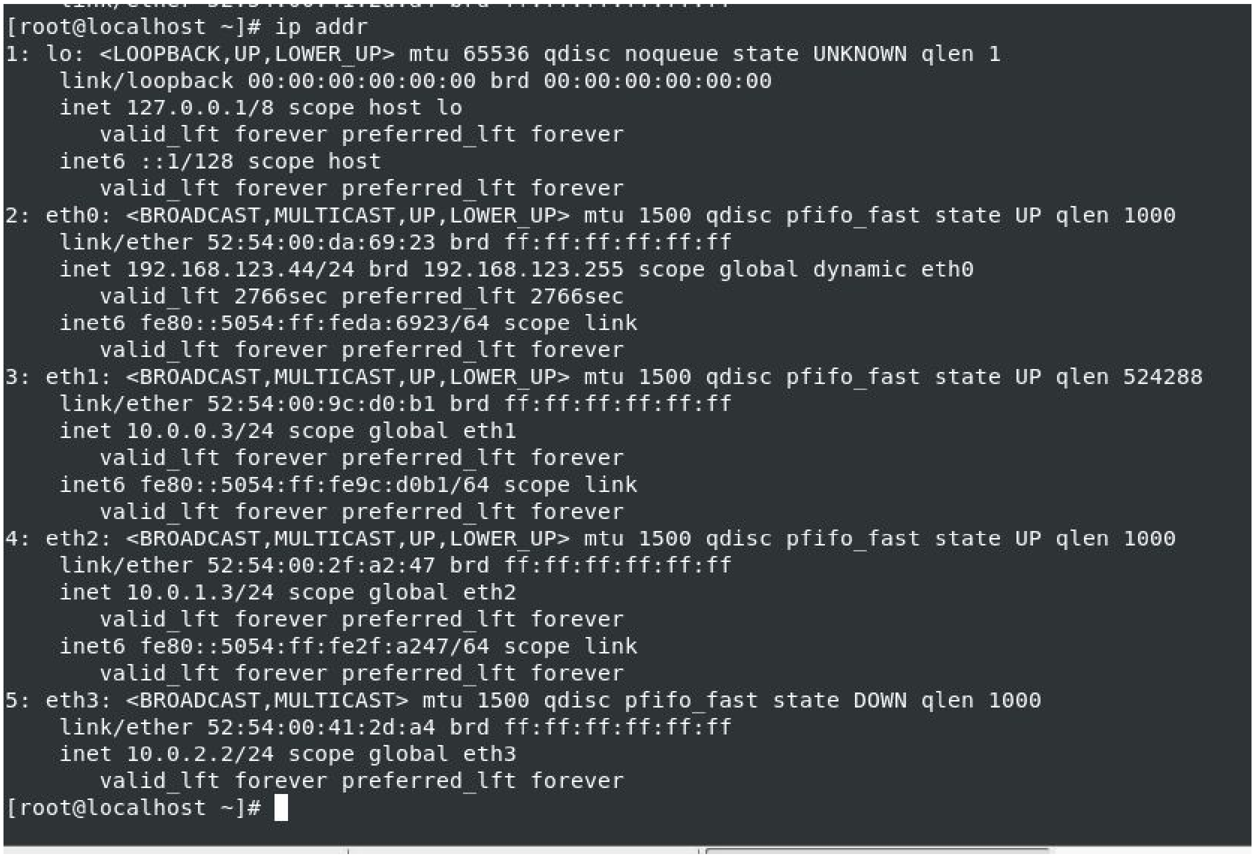
Set ip of eth3 of VM2 same as eth2 of VM1 i.e 10.0.2.2

VM1:



```
[root@localhost ~]# ip addr
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN qlen 1
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:92:90:30 brd ff:ff:ff:ff:ff:ff
    inet 192.168.123.22/24 brd 192.168.123.255 scope global dynamic eth0
       valid_lft 3367sec preferred_lft 3367sec
    inet6 fe80::5054:ff:fe92:9030/64 scope link
       valid_lft forever preferred_lft forever
3: eth1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 524288
    link/ether 52:54:00:9c:d0:b2 brd ff:ff:ff:ff:ff:ff
    inet 10.0.0.3/24 scope global eth1
       valid_lft forever preferred_lft forever
    inet6 fe80::5054:ff:fe9c:d0b2/64 scope link
       valid_lft forever preferred_lft forever
4: eth2: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:a8:8f:c8 brd ff:ff:ff:ff:ff:ff
    inet 10.0.2.2/24 scope global eth2
       valid_lft forever preferred_lft forever
    inet6 fe80::5054:ff:fea8:8fc8/64 scope link
       valid_lft forever preferred_lft forever
5: eth3: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:b1:90:d2 brd ff:ff:ff:ff:ff:ff
[root@localhost ~]#
```

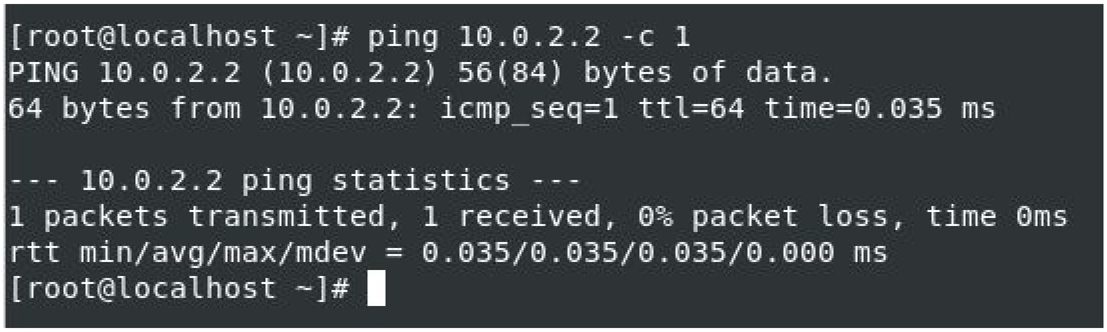
VM2:



```
[root@localhost ~]# ip addr
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN qlen 1
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:da:69:23 brd ff:ff:ff:ff:ff:ff
    inet 192.168.123.44/24 brd 192.168.123.255 scope global dynamic eth0
       valid_lft 2766sec preferred_lft 2766sec
    inet6 fe80::5054:ff:feda:6923/64 scope link
       valid_lft forever preferred_lft forever
3: eth1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 524288
    link/ether 52:54:00:9c:d0:b1 brd ff:ff:ff:ff:ff:ff
    inet 10.0.0.3/24 scope global eth1
       valid_lft forever preferred_lft forever
    inet6 fe80::5054:ff:fe9c:d0b1/64 scope link
       valid_lft forever preferred_lft forever
4: eth2: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:2f:a2:47 brd ff:ff:ff:ff:ff:ff
    inet 10.0.1.3/24 scope global eth2
       valid_lft forever preferred_lft forever
    inet6 fe80::5054:ff:fe2f:a247/64 scope link
       valid_lft forever preferred_lft forever
5: eth3: <BROADCAST,MULTICAST> mtu 1500 qdisc pfifo_fast state DOWN qlen 1000
    link/ether 52:54:00:41:2d:a4 brd ff:ff:ff:ff:ff:ff
    inet 10.0.2.2/24 scope global eth3
       valid_lft forever preferred_lft forever
[root@localhost ~]#
```

Ping:

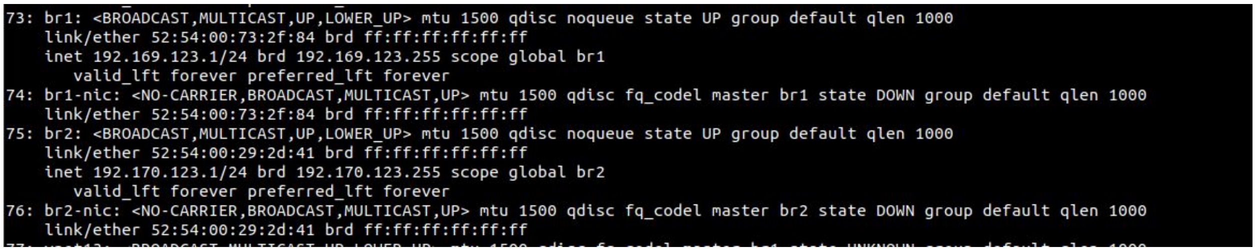
Same as 1b) as ping will be loopback ping



```
[root@localhost ~]# ping 10.0.2.2 -c 1
PING 10.0.2.2 (10.0.2.2) 56(84) bytes of data.
64 bytes from 10.0.2.2: icmp_seq=1 ttl=64 time=0.035 ms

--- 10.0.2.2 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.035/0.035/0.035/0.000 ms
[root@localhost ~]#
```

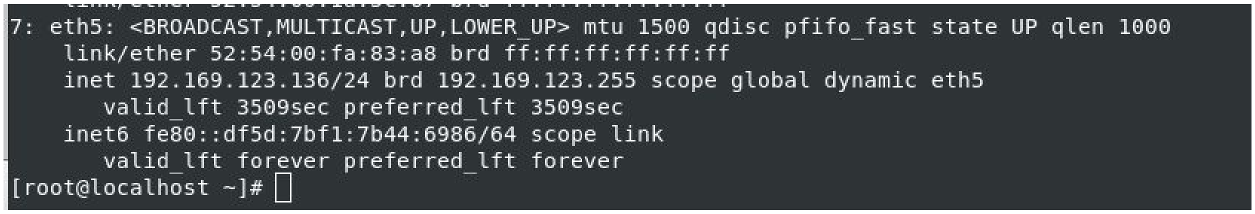
3. Two VMs connected to different bridge (both Bridges in routed mode) have:

br1 br2 created in routed mode



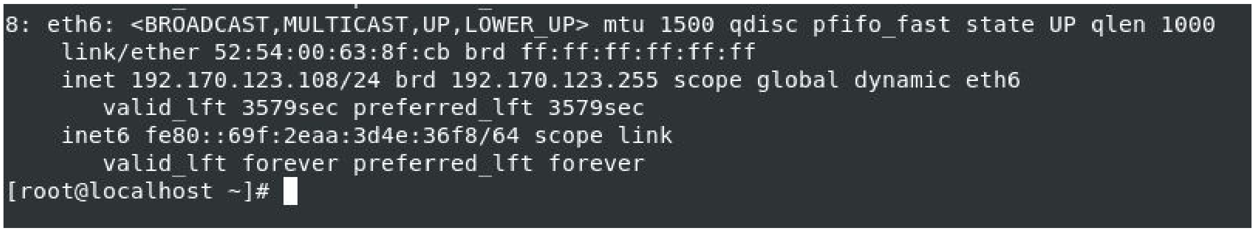
```
73: br1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP group default qlen 1000
    link/ether 52:54:00:73:2f:84 brd ff:ff:ff:ff:ff:ff
    inet 192.169.123.1/24 brd 192.169.123.255 scope global br1
       valid_lft forever preferred_lft forever
74: br1-nic: <NO-CARRIER,BROADCAST,MULTICAST,UP> mtu 1500 qdisc fq_codel master br1 state DOWN group default qlen 1000
    link/ether 52:54:00:73:2f:84 brd ff:ff:ff:ff:ff:ff
75: br2: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP group default qlen 1000
    link/ether 52:54:00:29:2d:41 brd ff:ff:ff:ff:ff:ff
    inet 192.170.123.1/24 brd 192.170.123.255 scope global br2
       valid_lft forever preferred_lft forever
76: br2-nic: <NO-CARRIER,BROADCAST,MULTICAST,UP> mtu 1500 qdisc fq_codel master br2 state DOWN group default qlen 1000
    link/ether 52:54:00:29:2d:41 brd ff:ff:ff:ff:ff:ff
```

Address assigned to eth5 of VM1 is 192.169.123.136/24



```
7: eth5: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:fa:83:a8 brd ff:ff:ff:ff:ff:ff
    inet 192.169.123.136/24 brd 192.169.123.255 scope global dynamic eth5
       valid_lft 3509sec preferred_lft 3509sec
    inet6 fe80::df5d:7bf1:7b44:6986/64 scope link
       valid_lft forever preferred_lft forever
[root@localhost ~]#
```

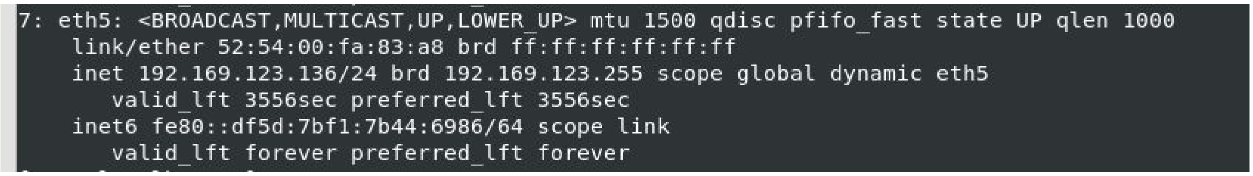
Address assigned to eth6 of VM2 is 192.170.123.108/24



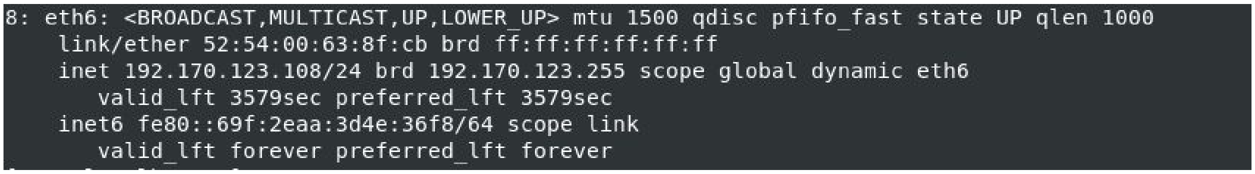
```
8: eth6: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:63:8f:cb brd ff:ff:ff:ff:ff:ff
    inet 192.170.123.108/24 brd 192.170.123.255 scope global dynamic eth6
       valid_lft 3579sec preferred_lft 3579sec
    inet6 fe80::69f:2eaa:3d4e:36f8/64 scope link
       valid_lft forever preferred_lft forever
[root@localhost ~]#
```

(a) same mac addresses,

Both eth5 of VM1 and eth6 of VM2's mac address was made same



```
7: eth5: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:fa:83:a8 brd ff:ff:ff:ff:ff:ff
    inet 192.169.123.136/24 brd 192.169.123.255 scope global dynamic eth5
       valid_lft 3556sec preferred_lft 3556sec
    inet6 fe80::df5d:7bf1:7b44:6986/64 scope link
       valid_lft forever preferred_lft forever
```

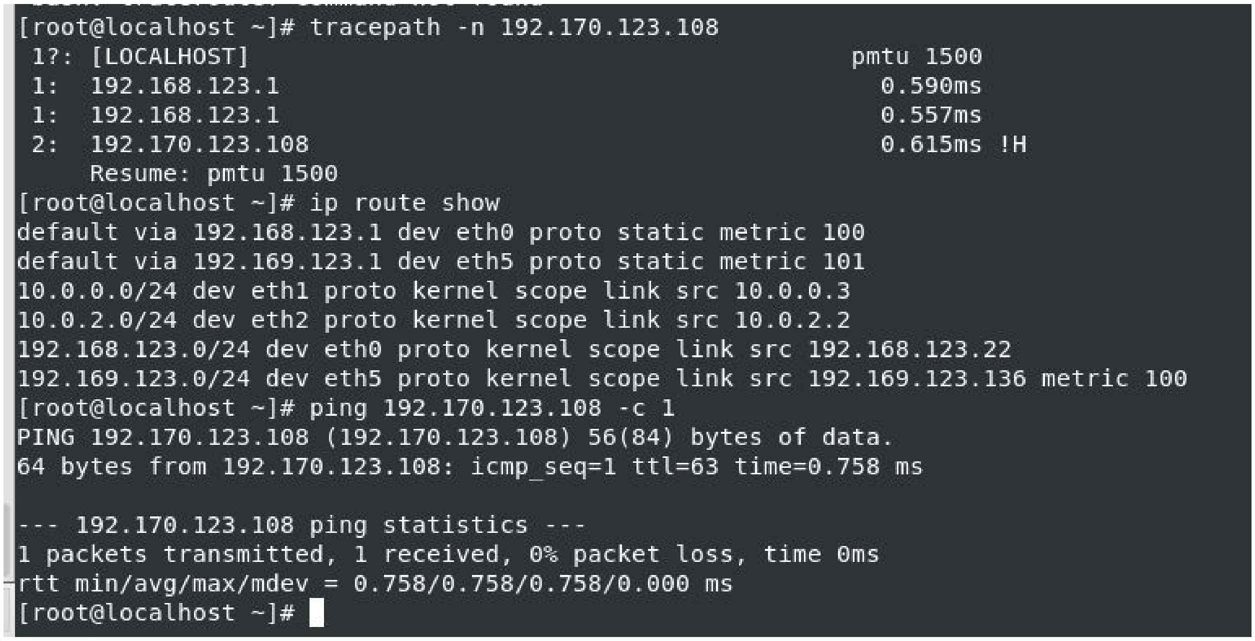


```
8: eth6: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP qlen 1000
    link/ether 52:54:00:63:8f:cb brd ff:ff:ff:ff:ff:ff
    inet 192.170.123.108/24 brd 192.170.123.255 scope global dynamic eth6
       valid_lft 3579sec preferred_lft 3579sec
    inet6 fe80::69f:2eaa:3d4e:36f8/64 scope link
       valid_lft forever preferred_lft forever
```

Ping is successful.

Tracepath shows that this packet goes via eth0 i.e via host to another VM.

Same MAC address doesn't cause any issue here as both VMs are in seperate networks



```
[root@localhost ~]# tracepath -n 192.170.123.108
 1?: [LOCALHOST]                                         pmtu 1500
 1:  192.168.123.1                                         0.590ms
 1:  192.168.123.1                                         0.557ms
 2:  192.170.123.108                                       0.615ms !H
     Resume: pmtu 1500
[root@localhost ~]# ip route show
default via 192.168.123.1 dev eth0 proto static metric 100
default via 192.169.123.1 dev eth5 proto static metric 101
10.0.0.0/24 dev eth1 proto kernel scope link src 10.0.0.3
10.0.2.0/24 dev eth2 proto kernel scope link src 10.0.2.2
192.168.123.0/24 dev eth0 proto kernel scope link src 192.168.123.22
192.169.123.0/24 dev eth5 proto kernel scope link src 192.169.123.136 metric 100
[root@localhost ~]# ping 192.170.123.108 -c 1
PING 192.170.123.108 (192.170.123.108) 56(84) bytes of data.
64 bytes from 192.170.123.108: icmp_seq=1 ttl=63 time=0.758 ms

--- 192.170.123.108 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.758/0.758/0.758/0.000 ms
[root@localhost ~]# 
```

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(b) same IP addresses.
As dhcp pools for both networks are different, both won’t get the same IP address.
If we forced them to have the same IP address then the ping will loop back to the same host.