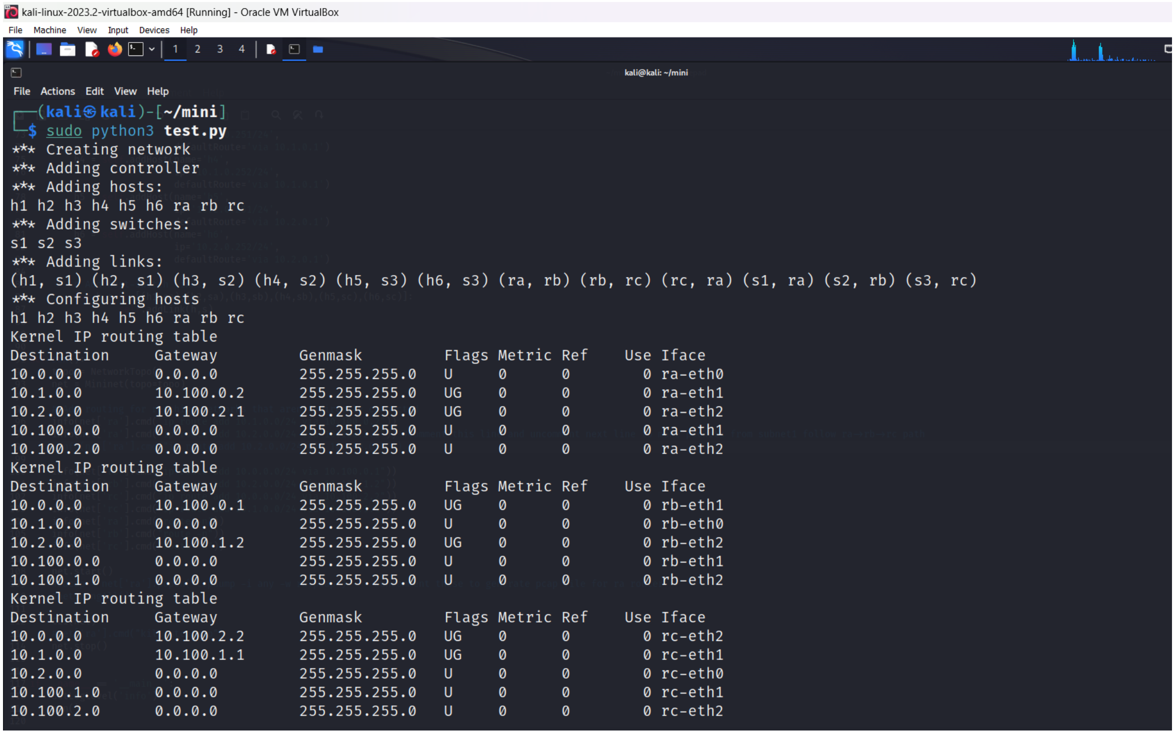
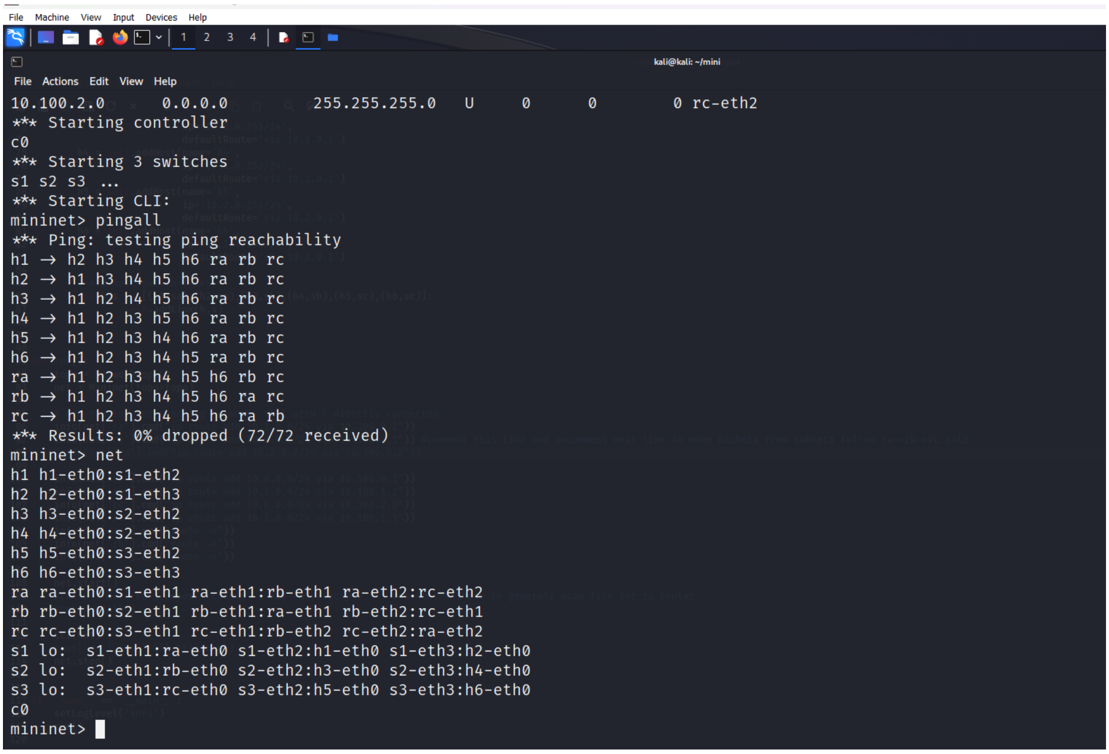
Q1. **Part(a)**: The

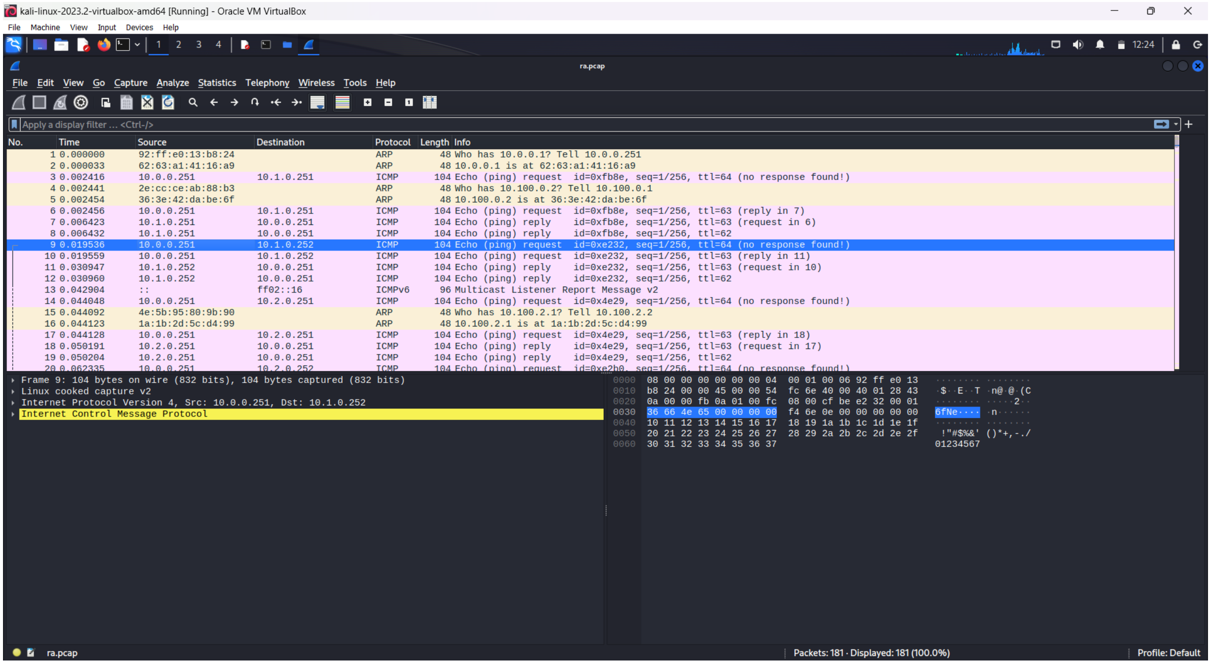

kali-linux-2023.2-virtualbox-amd64 [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
1 2 3 4
kali@kali: ~/mini
File Actions Edit View Help

```
┌──(kali㉿kali)-[~/mini]
└─$ sudo python3 test.py
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2 h3 h4 h5 h6 ra rb rc
*** Adding switches:
s1 s2 s3
*** Adding links:
(h1, s1) (h2, s1) (h3, s2) (h4, s2) (h5, s3) (h6, s3) (ra, rb) (rb, rc) (rc, ra) (s1, ra) (s2, rb) (s3, rc)
*** Configuring hosts
h1 h2 h3 h4 h5 h6 ra rb rc
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
10.0.0.0        0.0.0.0         255.255.255.0   U     0      0        0 ra-eth0
10.1.0.0        10.100.0.2      255.255.255.0   UG    0      0        0 ra-eth1
10.2.0.0        10.100.2.1      255.255.255.0   UG    0      0        0 ra-eth2
10.100.0.0      0.0.0.0         255.255.255.0   U     0      0        0 ra-eth1
10.100.2.0      0.0.0.0         255.255.255.0   U     0      0        0 ra-eth2
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
10.0.0.0        10.100.0.1      255.255.255.0   UG    0      0        0 rb-eth1
10.1.0.0        0.0.0.0         255.255.255.0   U     0      0        0 rb-eth0
10.2.0.0        10.100.1.2      255.255.255.0   UG    0      0        0 rb-eth2
10.100.0.0      0.0.0.0         255.255.255.0   U     0      0        0 rb-eth1
10.100.1.0      0.0.0.0         255.255.255.0   U     0      0        0 rb-eth2
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
10.0.0.0        10.100.2.2      255.255.255.0   UG    0      0        0 rc-eth2
10.1.0.0        10.100.1.1      255.255.255.0   UG    0      0        0 rc-eth1
10.2.0.0        0.0.0.0         255.255.255.0   U     0      0        0 rc-eth0
10.100.1.0      0.0.0.0         255.255.255.0   U     0      0        0 rc-eth1
10.100.2.0      0.0.0.0         255.255.255.0   U     0      0        0 rc-eth2
```


File Machine View Input Devices Help
1 2 3 4
kali@kali: ~/mini
File Actions Edit View Help

```
10.100.2.0      0.0.0.0         255.255.255.0   U     0      0        0 rc-eth2
*** Starting controller
c0
*** Starting 3 switches
s1 s2 s3 ...
*** Starting CLI:
mininet> pingall
*** Ping: testing ping reachability
h1 → h2 h3 h4 h5 h6 ra rb rc
h2 → h1 h3 h4 h5 h6 ra rb rc
h3 → h1 h2 h4 h5 h6 ra rb rc
h4 → h1 h2 h3 h5 h6 ra rb rc
h5 → h1 h2 h3 h4 h6 ra rb rc
h6 → h1 h2 h3 h4 h5 ra rb rc
ra → h1 h2 h3 h4 h5 h6 rb rc
rb → h1 h2 h3 h4 h5 h6 ra rc
rc → h1 h2 h3 h4 h5 h6 ra rb
*** Results: 0% dropped (72/72 received)
mininet> net
h1 h1-eth0:s1-eth2
h2 h2-eth0:s1-eth3
h3 h3-eth0:s2-eth2
h4 h4-eth0:s2-eth3
h5 h5-eth0:s3-eth2
h6 h6-eth0:s3-eth3
ra ra-eth0:s1-eth1 ra-eth1:rb-eth1 ra-eth2:rc-eth2
rb rb-eth0:s2-eth1 rb-eth1:ra-eth1 rb-eth2:rc-eth1
rc rc-eth0:s3-eth1 rc-eth1:rb-eth2 rc-eth2:ra-eth2
s1 lo:  s1-eth1:ra-eth0 s1-eth2:h1-eth0 s1-eth3:h2-eth0
s2 lo:  s2-eth1:rb-eth0 s2-eth2:h3-eth0 s2-eth3:h4-eth0
s3 lo:  s3-eth1:rc-eth0 s3-eth2:h5-eth0 s3-eth3:h6-eth0
c0
mininet> 
```

Part(b): Wireshark output collected from router **ra**. Pcap file for this can be generated again by uncommenting line 109,110 and 113 from submitted Q1 code


kali-linux-2023.2-virtualbox-amd64 [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
ra.pcap
File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Apply a display filter … <Ctrl-/>
12:24

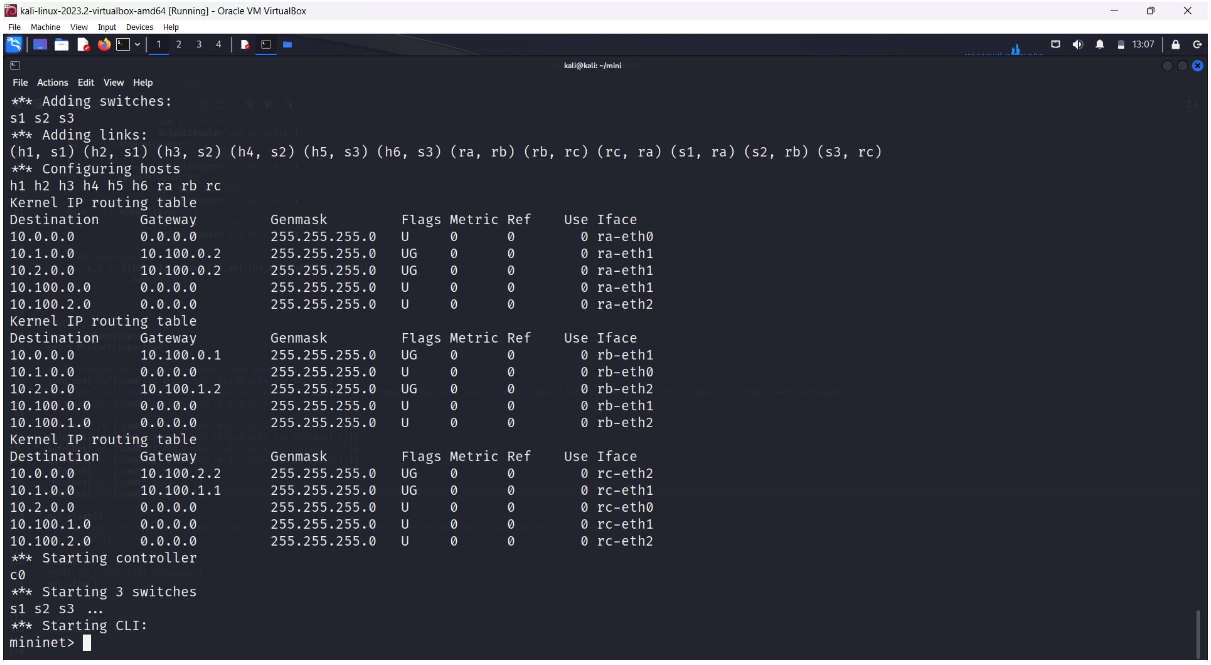
```
No.   Time       Source              Destination   Protocol Length Info
    1 0.000000   92:ff:e0:13:b8:24                 ARP       48 Who has 10.0.0.1? Tell 10.0.0.251
    2 0.000033   62:63:a1:41:16:a9                 ARP       48 10.0.0.1 is at 62:63:a1:41:16:a9
    3 0.002416   10.0.0.251          10.1.0.251    ICMP     104 Echo (ping) request  id=0xfb8e, seq=1/256, ttl=64 (no response found!)
    4 0.002441   2e:cc:ce:ab:88:b3                 ARP       48 Who has 10.100.0.2? Tell 10.100.0.1
    5 0.002454   36:3e:42:da:be:6f                 ARP       48 10.100.0.2 is at 36:3e:42:da:be:6f
    6 0.002456   10.0.0.251          10.1.0.251    ICMP     104 Echo (ping) request  id=0xfb8e, seq=1/256, ttl=63 (reply in 7)
    7 0.006423   10.1.0.251          10.0.0.251    ICMP     104 Echo (ping) reply    id=0xfb8e, seq=1/256, ttl=63 (request in 6)
    8 0.006432   10.1.0.251          10.0.0.251    ICMP     104 Echo (ping) reply    id=0xfb8e, seq=1/256, ttl=62
    9 0.019536   10.0.0.251          10.1.0.252    ICMP     104 Echo (ping) request  id=0xe232, seq=1/256, ttl=64 (no response found!)
   10 0.019559   10.0.0.251          10.1.0.252    ICMP     104 Echo (ping) request  id=0xe232, seq=1/256, ttl=63 (reply in 11)
   11 0.030947   10.1.0.252          10.0.0.251    ICMP     104 Echo (ping) reply    id=0xe232, seq=1/256, ttl=63 (request in 10)
   12 0.030960   10.1.0.252          10.0.0.251    ICMP     104 Echo (ping) reply    id=0xe232, seq=1/256, ttl=62
   13 0.042904   ::                  ff02::16      ICMPv6    96 Multicast Listener Report Message v2
   14 0.044048   10.0.0.251          10.2.0.251    ICMP     104 Echo (ping) request  id=0x4e29, seq=1/256, ttl=64 (no response found!)
   15 0.044092   4e:5b:95:80:9b:90                 ARP       48 Who has 10.100.2.1? Tell 10.100.2.2
   16 0.044123   1a:1b:2d:5c:d4:99                 ARP       48 10.100.2.1 is at 1a:1b:2d:5c:d4:99
   17 0.044128   10.0.0.251          10.2.0.251    ICMP     104 Echo (ping) request  id=0x4e29, seq=1/256, ttl=63 (reply in 18)
   18 0.050191   10.2.0.251          10.0.0.251    ICMP     104 Echo (ping) reply    id=0x4e29, seq=1/256, ttl=63 (request in 17)
   19 0.050204   10.2.0.251          10.0.0.251    ICMP     104 Echo (ping) reply    id=0x4e29, seq=1/256, ttl=62
   20 0.062335   10.0.0.251          10.2.0.252    ICMP     104 Echo (ping) request  id=0xe2b0, seq=1/256, ttl=64 (no response found!)

› Frame 9: 104 bytes on wire (832 bits), 104 bytes captured (832 bits)
› Linux cooked capture v2
› Internet Protocol Version 4, Src: 10.0.0.251, Dst: 10.1.0.252
› Internet Control Message Protocol

0000  08 00 00 00 00 00 00 04  00 01 00 06 92 ff e0 13   ········ ········
0010  b8 24 00 00 45 00 00 54  fc 6e 40 00 40 01 28 43   ·$··E··T ·n@·@·(C
0020  0a 00 00 fb 0a 01 00 fc  08 00 cf be e2 32 00 01   ········ ·····2··
0030  36 66 4e 65 00 00 00 00  f4 6e 0e 00 00 00 00 00   6fNe···· ·n······
0040  10 11 12 13 14 15 16 17  18 19 1a 1b 1c 1d 1e 1f   ········ ········
0050  20 21 22 23 24 25 26 27  28 29 2a 2b 2c 2d 2e 2f    !"#$%&' ()*+,-./
0060  30 31 32 33 34 35 36 37                            01234567

ra.pcap    Packets: 181 · Displayed: 181 (100.0%)    Profile: Default
```

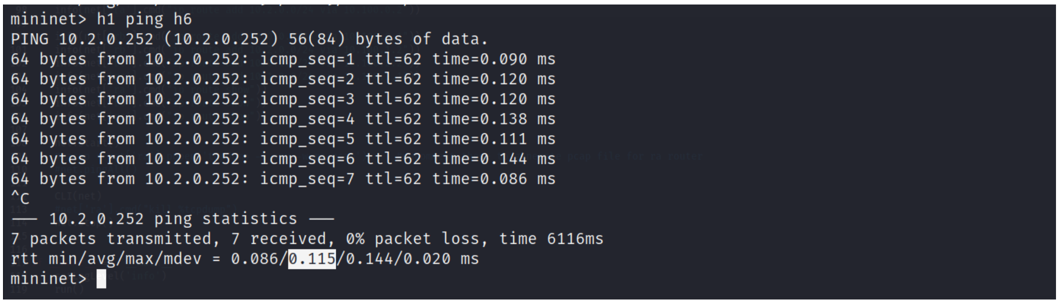
Part(c): below are the route tables for changed route. To change the route you can comment line 97 and uncomment 98.


kali-linux-2023.2-virtualbox-amd64 [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
kali@kali: ~/mini
File Actions Edit View Help
13:07

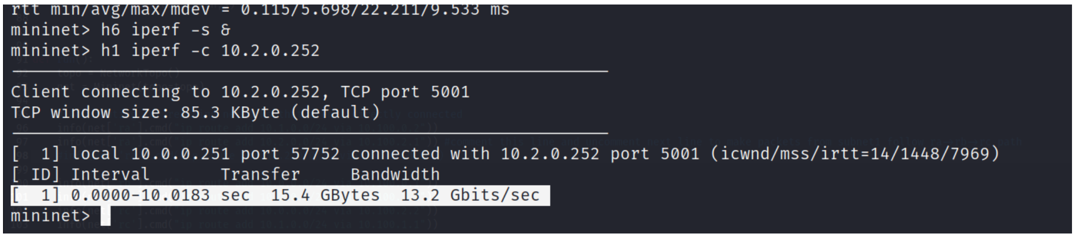
```
*** Adding switches:
s1 s2 s3
*** Adding links:
(h1, s1) (h2, s1) (h3, s2) (h4, s2) (h5, s3) (h6, s3) (ra, rb) (rb, rc) (rc, ra) (s1, ra) (s2, rb) (s3, rc)
*** Configuring hosts
h1 h2 h3 h4 h5 h6 ra rb rc
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
10.0.0.0        0.0.0.0         255.255.255.0   U     0      0        0 ra-eth0
10.1.0.0        10.100.0.2      255.255.255.0   UG    0      0        0 ra-eth1
10.2.0.0        10.100.0.2      255.255.255.0   UG    0      0        0 ra-eth1
10.100.0.0      0.0.0.0         255.255.255.0   U     0      0        0 ra-eth1
10.100.2.0      0.0.0.0         255.255.255.0   U     0      0        0 ra-eth2
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
10.0.0.0        10.100.0.1      255.255.255.0   UG    0      0        0 rb-eth1
10.1.0.0        0.0.0.0         255.255.255.0   U     0      0        0 rb-eth0
10.2.0.0        10.100.1.2      255.255.255.0   UG    0      0        0 rb-eth2
10.100.0.0      0.0.0.0         255.255.255.0   U     0      0        0 rb-eth1
10.100.1.0      0.0.0.0         255.255.255.0   U     0      0        0 rb-eth2
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
10.0.0.0        10.100.2.2      255.255.255.0   UG    0      0        0 rc-eth2
10.1.0.0        10.100.1.1      255.255.255.0   UG    0      0        0 rc-eth1
10.2.0.0        0.0.0.0         255.255.255.0   U     0      0        0 rc-eth0
10.100.1.0      0.0.0.0         255.255.255.0   U     0      0        0 rc-eth1
10.100.2.0      0.0.0.0         255.255.255.0   U     0      0        0 rc-eth2
*** Starting controller
c0
*** Starting 3 switches
s1 s2 s3 ...
*** Starting CLI:
mininet> 
```

Here in route table of ra for destination rc the gateway taken is same as the one for taken rb destination. This shows that the path for from ra to rc now goes through rb.

Below are ping and iperf results for h1 to h6 transmissions when ra and rc go normal path. Key results highlighted

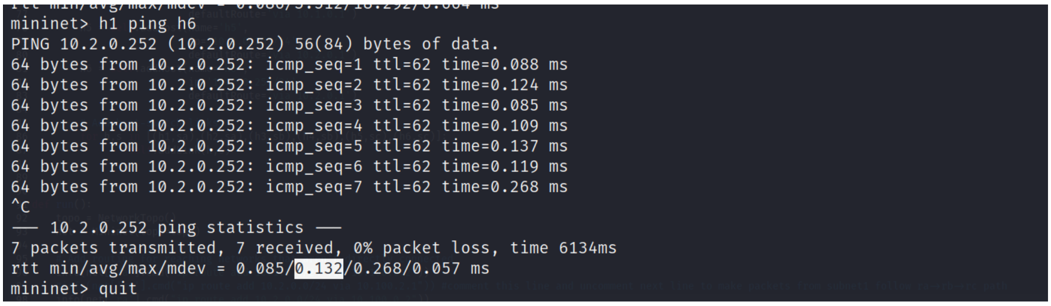


```
mininet> h1 ping h6
PING 10.2.0.252 (10.2.0.252) 56(84) bytes of data.
64 bytes from 10.2.0.252: icmp_seq=1 ttl=62 time=0.090 ms
64 bytes from 10.2.0.252: icmp_seq=2 ttl=62 time=0.120 ms
64 bytes from 10.2.0.252: icmp_seq=3 ttl=62 time=0.120 ms
64 bytes from 10.2.0.252: icmp_seq=4 ttl=62 time=0.138 ms
64 bytes from 10.2.0.252: icmp_seq=5 ttl=62 time=0.111 ms
64 bytes from 10.2.0.252: icmp_seq=6 ttl=62 time=0.144 ms
64 bytes from 10.2.0.252: icmp_seq=7 ttl=62 time=0.086 ms
^C
—— 10.2.0.252 ping statistics ——
7 packets transmitted, 7 received, 0% packet loss, time 6116ms
rtt min/avg/max/mdev = 0.086/0.115/0.144/0.020 ms
mininet> 
```

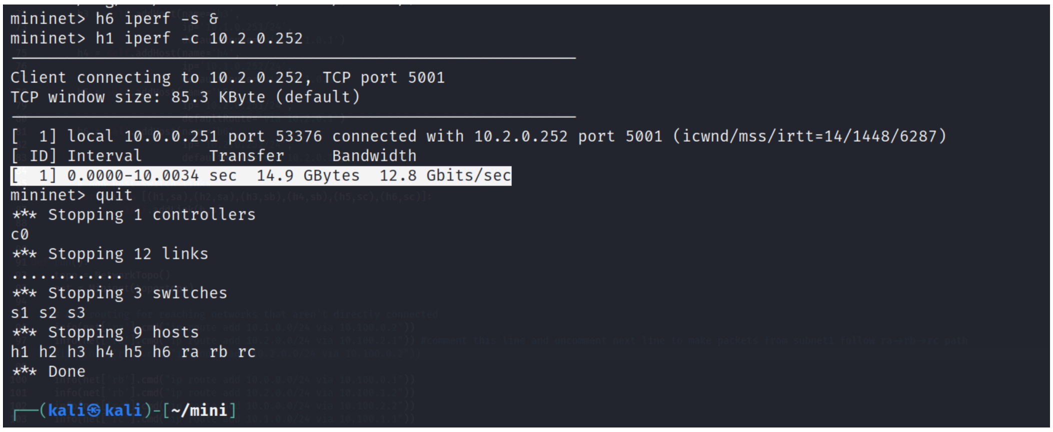


```
rtt min/avg/max/mdev = 0.115/5.698/22.211/9.533 ms
mininet> h6 iperf -s &
mininet> h1 iperf -c 10.2.0.252
————————————————————————————————————————————————————————————
Client connecting to 10.2.0.252, TCP port 5001
TCP window size: 85.3 KByte (default)
————————————————————————————————————————————————————————————
[  1] local 10.0.0.251 port 57752 connected with 10.2.0.252 port 5001 (icwnd/mss/irtt=14/1448/7969)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-10.0183 sec  15.4 GBytes  13.2 Gbits/sec
mininet> 
```

Now below are results when ra to rc path is indirect.



```
mininet> h1 ping h6
PING 10.2.0.252 (10.2.0.252) 56(84) bytes of data.
64 bytes from 10.2.0.252: icmp_seq=1 ttl=62 time=0.088 ms
64 bytes from 10.2.0.252: icmp_seq=2 ttl=62 time=0.124 ms
64 bytes from 10.2.0.252: icmp_seq=3 ttl=62 time=0.085 ms
64 bytes from 10.2.0.252: icmp_seq=4 ttl=62 time=0.109 ms
64 bytes from 10.2.0.252: icmp_seq=5 ttl=62 time=0.137 ms
64 bytes from 10.2.0.252: icmp_seq=6 ttl=62 time=0.119 ms
64 bytes from 10.2.0.252: icmp_seq=7 ttl=62 time=0.268 ms
^C
—— 10.2.0.252 ping statistics ——
7 packets transmitted, 7 received, 0% packet loss, time 6134ms
rtt min/avg/max/mdev = 0.085/0.132/0.268/0.057 ms
mininet> quit
```



```
mininet> h6 iperf -s &
mininet> h1 iperf -c 10.2.0.252
————————————————————————————————————————————————————————————
Client connecting to 10.2.0.252, TCP port 5001
TCP window size: 85.3 KByte (default)
————————————————————————————————————————————————————————————
[  1] local 10.0.0.251 port 53376 connected with 10.2.0.252 port 5001 (icwnd/mss/irtt=14/1448/6287)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-10.0034 sec  14.9 GBytes  12.8 Gbits/sec
mininet> quit
*** Stopping 1 controllers
c0
*** Stopping 12 links
............
*** Stopping 3 switches
s1 s2 s3
*** Stopping 9 hosts
h1 h2 h3 h4 h5 h6 ra rb rc
*** Done

┌──(kali㉿kali)-[~/mini]
```

As expected, performance dipped a little when the path from ra to rc was made indirect.

Part(d): route tables already in the screenshots above, as well as will be printed when the code runs.