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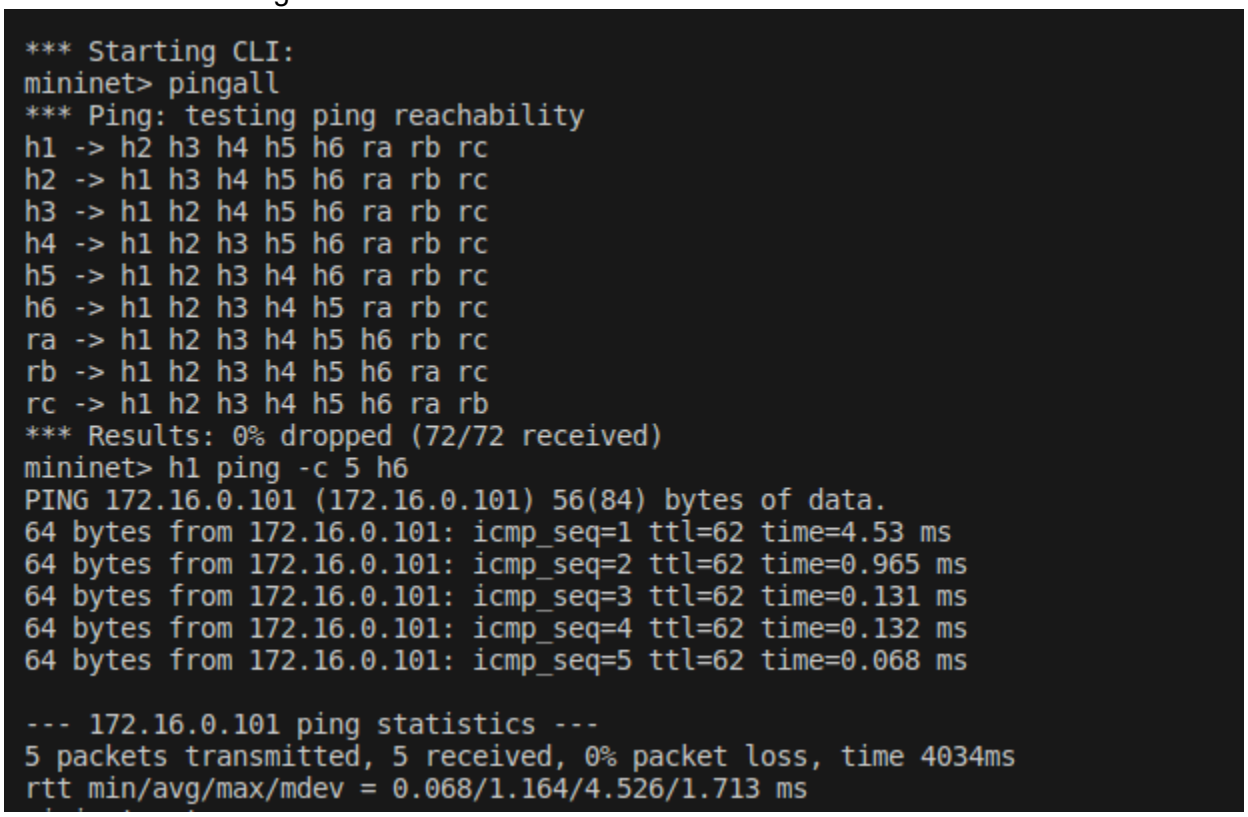
**Question 1**

### Implementation:

- Three routers (ra, rb, rc) are created as instances of the LinuxRouter class, which is a subclass of Mininet's Node.
- Three switches (s1, s2, s3) are created using Mininet's addSwitch method.
- Six hosts (h1, h2, h3, h4, h5, h6) are created using Mininet's addHost method. Each host is assigned an IP address and a default route using the ip and defaultRoute parameters, respectively.
- Links are established between the routers and switches using the
- Additional links between routers are established. These additional links are essential for inter-router communication.
- Static routes are added to each router using the command net['router'].cmd().

A. Screenshot of working network



C. Results for ping command for default route

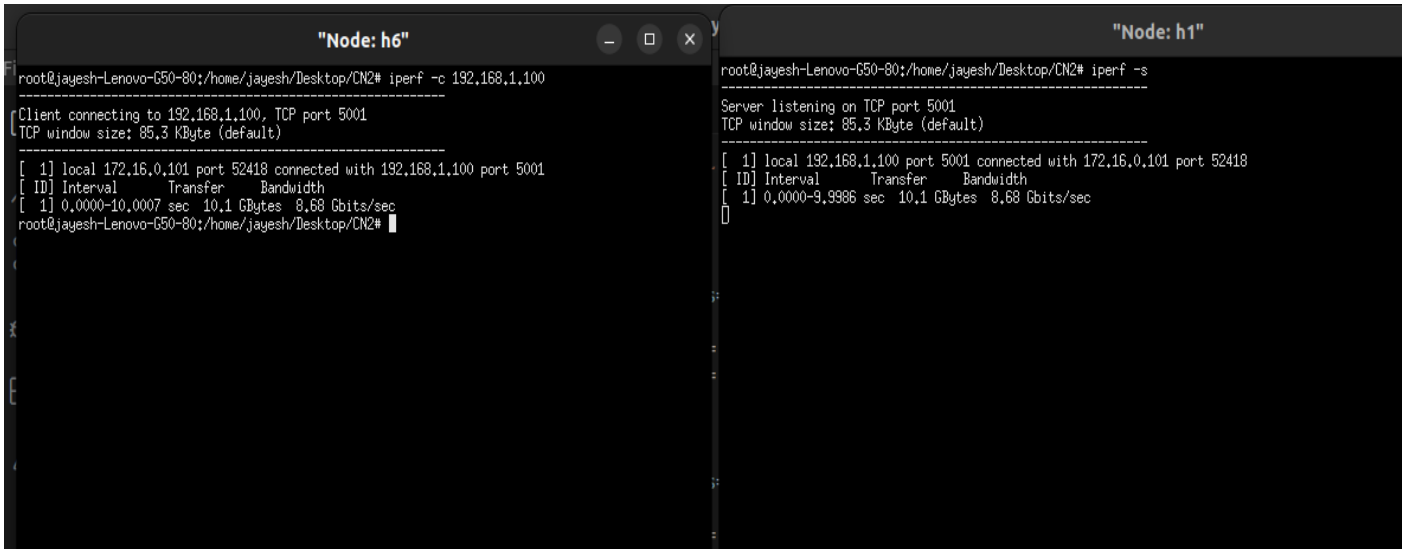
```
*** Starting CLI:
mininet> pingall
*** Ping: testing ping reachability
h1 -> h2 h3 h4 h5 h6 ra rb rc
h2 -> h1 h3 h4 h5 h6 ra rb rc
h3 -> h1 h2 h4 h5 h6 ra rb rc
h4 -> h1 h2 h3 h5 h6 ra rb rc
h5 -> h1 h2 h3 h4 h6 ra rb rc
h6 -> h1 h2 h3 h4 h5 ra rb rc
ra -> h1 h2 h3 h4 h5 h6 rb rc
rb -> h1 h2 h3 h4 h5 h6 ra rc
rc -> h1 h2 h3 h4 h5 h6 ra rb
*** Results: 0% dropped (72/72 received)
mininet> h1 ping -c 5 h6
PING 172.16.0.101 (172.16.0.101) 56(84) bytes of data.
64 bytes from 172.16.0.101: icmp_seq=1 ttl=62 time=4.53 ms
64 bytes from 172.16.0.101: icmp_seq=2 ttl=62 time=0.965 ms
64 bytes from 172.16.0.101: icmp_seq=3 ttl=62 time=0.131 ms
64 bytes from 172.16.0.101: icmp_seq=4 ttl=62 time=0.132 ms
64 bytes from 172.16.0.101: icmp_seq=5 ttl=62 time=0.068 ms

--- 172.16.0.101 ping statistics ---
5 packets transmitted, 5 received, 0% packet loss, time 4034ms
rtt min/avg/max/mdev = 0.068/1.164/4.526/1.713 ms
```

Results for ping command for modified route

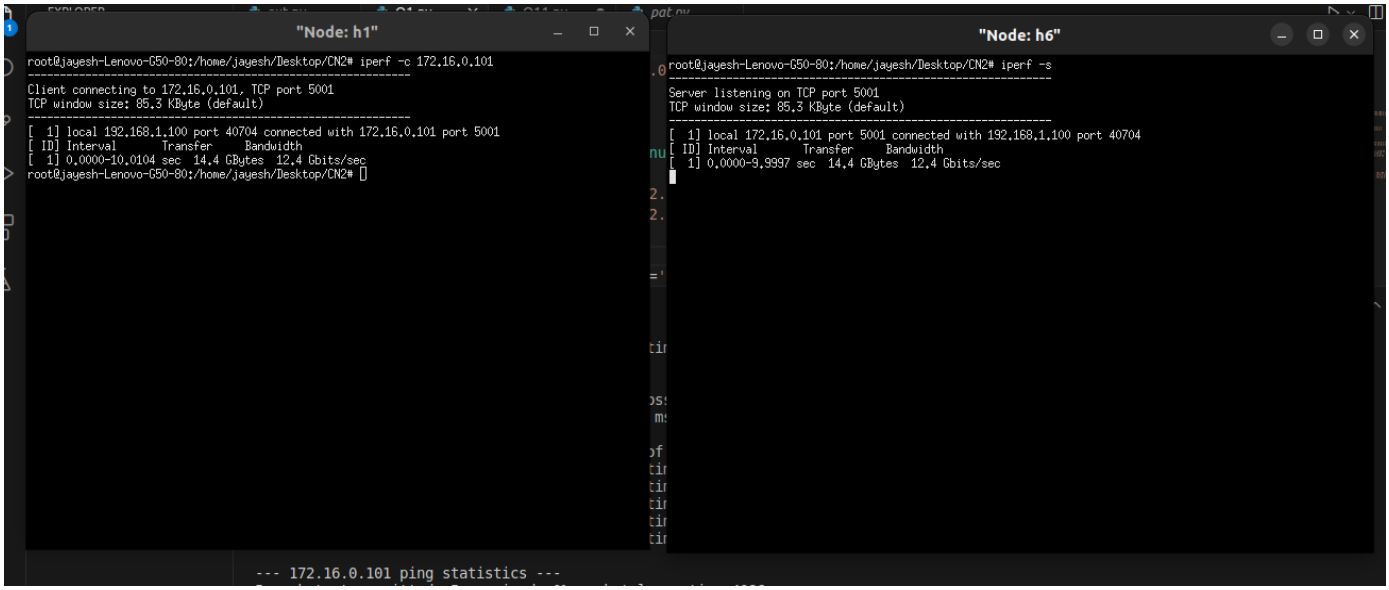
```
mininet> h1 ping -c 5 h6
PING 172.16.0.101 (172.16.0.101) 56(84) bytes of data.
64 bytes from 172.16.0.101: icmp_seq=1 ttl=62 time=7.44 ms
64 bytes from 172.16.0.101: icmp_seq=2 ttl=62 time=0.611 ms
64 bytes from 172.16.0.101: icmp_seq=3 ttl=62 time=0.080 ms
64 bytes from 172.16.0.101: icmp_seq=4 ttl=62 time=0.069 ms
64 bytes from 172.16.0.101: icmp_seq=5 ttl=62 time=0.070 ms

--- 172.16.0.101 ping statistics ---
5 packets transmitted, 5 received, 0% packet loss, time 4078ms
rtt min/avg/max/mdev = 0.069/1.654/7.443/2.901 ms
```

We can infer from the above screenshot that avg time for normal route =1.164ms while for modified route=1.654ms. It explicitly shows the latency difference between both the paths,more latency for modified route

Results for iperf command for default route




Results for ping command for modified route




For default route less bandwidth is used compared to modified route

D. Routing table for part A

```
*** Adding static routes on routers:
*** Routing Tables on Routers:
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
10.0.0.0        192.168.2.2     255.255.255.0   UG    0      0        0 l
172.16.0.0      172.16.2.2      255.255.255.0   UG    0      0        0 p
172.16.2.0      0.0.0.0         255.255.255.0   U     0      0        0 p
192.168.1.0     0.0.0.0         255.255.255.0   U     0      0        0 ra-eth1
192.168.2.0     0.0.0.0         255.255.255.0   U     0      0        0 l
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 rb-eth1
10.0.2.0        0.0.0.0         255.255.255.0   U     0      0        0 n
172.16.0.0      10.0.2.2        255.255.255.0   UG    0      0        0 n
192.168.1.0     192.168.2.1     255.255.255.0   UG    0      0        0 m
192.168.2.0     0.0.0.0         255.255.255.0   U     0      0        0 m
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
10.0.0.0        10.0.2.1        255.255.255.0   UG    0      0        0 o
10.0.2.0        0.0.0.0         255.255.255.0   U     0      0        0 o
172.16.0.0      0.0.0.0         255.255.255.0   U     0      0        0 rc-eth1
172.16.2.0      0.0.0.0         255.255.255.0   U     0      0        0 q
192.168.1.0     172.16.2.1      255.255.255.0   UG    0      0        0 q
```

The routing table for part C of the modified route

```
*** Adding static routes on routers:
*** Routing Tables on Routers:
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
10.0.0.0        192.168.2.2     255.255.255.0   UG    0      0        0 l
172.16.0.0      192.168.2.2     255.255.255.0   UG    0      0        0 l
172.16.2.0      0.0.0.0         255.255.255.0   U     0      0        0 p
192.168.1.0     0.0.0.0         255.255.255.0   U     0      0        0 ra-eth1
192.168.2.0     0.0.0.0         255.255.255.0   U     0      0        0 l
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 rb-eth1
10.0.2.0        0.0.0.0         255.255.255.0   U     0      0        0 n
172.16.0.0      10.0.2.2        255.255.255.0   UG    0      0        0 n
192.168.1.0     192.168.2.1     255.255.255.0   UG    0      0        0 m
192.168.2.0     0.0.0.0         255.255.255.0   U     0      0        0 m
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
10.0.0.0        10.0.2.1        255.255.255.0   UG    0      0        0 o
10.0.2.0        0.0.0.0         255.255.255.0   U     0      0        0 o
172.16.0.0      0.0.0.0         255.255.255.0   U     0      0        0 rc-eth1
172.16.2.0      0.0.0.0         255.255.255.0   U     0      0        0 q
192.168.1.0     10.0.2.1        255.255.255.0   UG    0      0        0 o
*** Starting CLI:
```

## Question 2

A. TCP connection between H1(client) and H4(host)

```
S------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 34468 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/17393)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   639 MBytes  10.7 Gbits/sec
[  1] 0.5000-1.0000 sec   767 MBytes  12.9 Gbits/sec
[  1] 1.0000-1.5000 sec   784 MBytes  13.1 Gbits/sec
[  1] 1.5000-2.0000 sec   813 MBytes  13.6 Gbits/sec
[  1] 2.0000-2.5000 sec   574 MBytes  9.63 Gbits/sec
[  1] 2.5000-3.0000 sec   766 MBytes  12.8 Gbits/sec
[  1] 3.0000-3.5000 sec   679 MBytes  11.4 Gbits/sec
[  1] 3.5000-4.0000 sec   490 MBytes  8.23 Gbits/sec
[  1] 4.0000-4.5000 sec   590 MBytes  9.90 Gbits/sec
[  1] 4.5000-5.0000 sec   765 MBytes  12.8 Gbits/sec
[  1] 0.0000-5.0089 sec  6.70 GBytes  11.5 Gbits/sec
```

B. TCP connection between H1(client) and H4(host) under various congestion schemes

- Congestion control BBR

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to bbr
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 54462 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/8546)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   670 MBytes  11.2 Gbits/sec
[  1] 0.5000-1.0000 sec  56.0 MBytes   939 Mbits/sec
[  1] 1.0000-1.5000 sec   134 MBytes  2.25 Gbits/sec
[  1] 1.5000-2.0000 sec  4.62 MBytes  77.6 Mbits/sec
[  1] 2.0000-2.5000 sec   268 MBytes  4.50 Gbits/sec
[  1] 2.5000-3.0000 sec   319 MBytes  5.35 Gbits/sec
[  1] 3.0000-3.5000 sec   505 MBytes  8.47 Gbits/sec
[  1] 3.5000-4.0000 sec   174 MBytes  2.91 Gbits/sec
[  1] 4.0000-4.5000 sec   218 MBytes  3.65 Gbits/sec
[  1] 4.5000-5.0000 sec   264 MBytes  4.44 Gbits/sec
[  1] 0.0000-5.0369 sec  2.55 GBytes  4.35 Gbits/sec

```

BBR shows a relatively stable throughput, gradually increasing and maintaining a high value.

- Congestion control Cubic

client_h1_cubic.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to cubic
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 54446 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/10852)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   262 MBytes  4.40 Gbits/sec
[  1] 0.5000-1.0000 sec   443 MBytes  7.44 Gbits/sec
[  1] 1.0000-1.5000 sec   357 MBytes  5.99 Gbits/sec
[  1] 1.5000-2.0000 sec   345 MBytes  5.78 Gbits/sec
[  1] 2.0000-2.5000 sec   278 MBytes  4.66 Gbits/sec
[  1] 2.5000-3.0000 sec   324 MBytes  5.43 Gbits/sec
[  1] 3.0000-3.5000 sec   275 MBytes  4.61 Gbits/sec
[  1] 3.5000-4.0000 sec   356 MBytes  5.97 Gbits/sec
[  1] 4.0000-4.5000 sec   168 MBytes  2.82 Gbits/sec
[  1] 4.5000-5.0000 sec   576 MBytes  9.66 Gbits/sec
[  1] 0.0000-5.0226 sec  3.30 GBytes  5.65 Gbits/sec
```

Cubic has varying throughput over time, with some peaks and dips.

- Congestion control Reno

client_h1_reno.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to reno
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 54442 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/13062)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   456 MBytes  7.64 Gbits/sec
[  1] 0.5000-1.0000 sec   357 MBytes  5.99 Gbits/sec
[  1] 1.0000-1.5000 sec   478 MBytes  8.02 Gbits/sec
[  1] 1.5000-2.0000 sec   387 MBytes  6.49 Gbits/sec
[  1] 2.0000-2.5000 sec   674 MBytes  11.3 Gbits/sec
[  1] 2.5000-3.0000 sec   633 MBytes  10.6 Gbits/sec
[  1] 3.0000-3.5000 sec   300 MBytes  5.03 Gbits/sec
[  1] 3.5000-4.0000 sec   470 MBytes  7.89 Gbits/sec
[  1] 4.0000-4.5000 sec   197 MBytes  3.30 Gbits/sec
[  1] 4.5000-5.0000 sec   258 MBytes  4.33 Gbits/sec
[  1] 0.0000-5.0157 sec  4.11 GBytes  7.04 Gbits/sec
```

Reno exhibits an increasing and decreasing throughput pattern, similar to cubic but with different values.

- Congestion control Vegas

client_h1_vegas.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to vegas
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 54460 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/13208)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   316 MBytes  5.31 Gbits/sec
[  1] 0.5000-1.0000 sec   793 MBytes  13.3 Gbits/sec
[  1] 1.0000-1.5000 sec   661 MBytes  11.1 Gbits/sec
[  1] 1.5000-2.0000 sec   877 MBytes  14.7 Gbits/sec
[  1] 2.0000-2.5000 sec   616 MBytes  10.3 Gbits/sec
[  1] 2.5000-3.0000 sec   646 MBytes  10.8 Gbits/sec
[  1] 3.0000-3.5000 sec   523 MBytes  8.77 Gbits/sec
[  1] 3.5000-4.0000 sec   453 MBytes  7.59 Gbits/sec
[  1] 4.0000-4.5000 sec   372 MBytes  6.23 Gbits/sec
[  1] 4.5000-5.0000 sec   642 MBytes  10.8 Gbits/sec
[  1] 0.0000-5.0430 sec  5.76 GBytes  9.81 Gbits/sec
```

Vegas shows a fluctuating but generally increasing throughput pattern.

C. TCP connection between H1, H2, H3(client) and H4(host) under various congestion schemes

- Client(H1) Host(H4) scheme(BBR)

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to bbr
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 51214 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/32019)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   127 MBytes  2.13 Gbits/sec
[  1] 0.5000-1.0000 sec   119 MBytes  2.00 Gbits/sec
[  1] 1.0000-1.5000 sec  74.5 MBytes  1.25 Gbits/sec
[  1] 1.5000-2.0000 sec  98.5 MBytes  1.65 Gbits/sec
[  1] 2.0000-2.5000 sec  68.6 MBytes  1.15 Gbits/sec
[  1] 2.5000-3.0000 sec   107 MBytes  1.80 Gbits/sec
[  1] 3.0000-3.5000 sec  95.5 MBytes  1.60 Gbits/sec
[  1] 3.5000-4.0000 sec  98.4 MBytes  1.65 Gbits/sec
[  1] 4.0000-4.5000 sec  54.7 MBytes   918 Mbits/sec
[  1] 4.5000-5.0000 sec  20.9 MBytes   350 Mbits/sec
[  1] 0.0000-5.0860 sec   865 MBytes  1.43 Gbits/sec
```

- Client(H1) Host(H4) scheme(reno)

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to reno
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 51196 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/38676)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   108 MBytes  1.81 Gbits/sec
[  1] 0.5000-1.0000 sec  36.8 MBytes   617 Mbits/sec
[  1] 1.0000-1.5000 sec  78.2 MBytes  1.31 Gbits/sec
[  1] 1.5000-2.0000 sec  98.1 MBytes  1.65 Gbits/sec
[  1] 2.0000-2.5000 sec   144 MBytes  2.42 Gbits/sec
[  1] 2.5000-3.0000 sec   146 MBytes  2.45 Gbits/sec
[  1] 3.0000-3.5000 sec  91.2 MBytes  1.53 Gbits/sec
[  1] 3.5000-4.0000 sec  85.1 MBytes  1.43 Gbits/sec
[  1] 4.0000-4.5000 sec  20.8 MBytes   348 Mbits/sec
[  1] 4.5000-5.0000 sec  39.5 MBytes   663 Mbits/sec
[  1] 0.0000-5.1140 sec   848 MBytes  1.39 Gbits/sec
```

- Client(H1) Host(H4) scheme(vegas)

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to vegas
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 51220 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/24073)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   350 MBytes  5.87 Gbits/sec
[  1] 0.5000-1.0000 sec   424 MBytes  7.12 Gbits/sec
[  1] 1.0000-1.5000 sec   123 MBytes  2.06 Gbits/sec
[  1] 1.5000-2.0000 sec   155 MBytes  2.60 Gbits/sec
[  1] 2.0000-2.5000 sec  91.1 MBytes  1.53 Gbits/sec
[  1] 2.5000-3.0000 sec   149 MBytes  2.50 Gbits/sec
[  1] 3.0000-3.5000 sec   116 MBytes  1.95 Gbits/sec
[  1] 3.5000-4.0000 sec  95.1 MBytes  1.60 Gbits/sec
[  1] 4.0000-4.5000 sec  21.4 MBytes   359 Mbits/sec
[  1] 4.5000-5.0000 sec  20.0 MBytes   336 Mbits/sec
[  1] 0.0000-5.0813 sec  1.51 GBytes  2.55 Gbits/sec
```

- Client(H1) Host(H4) scheme(cubic)

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to cubic
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 51210 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/30353)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   117 MBytes  1.97 Gbits/sec
[  1] 0.5000-1.0000 sec   130 MBytes  2.19 Gbits/sec
[  1] 1.0000-1.5000 sec  81.4 MBytes  1.37 Gbits/sec
[  1] 1.5000-2.0000 sec   130 MBytes  2.18 Gbits/sec
[  1] 2.0000-2.5000 sec  81.4 MBytes  1.37 Gbits/sec
[  1] 2.5000-3.0000 sec   123 MBytes  2.06 Gbits/sec
[  1] 3.0000-3.5000 sec   122 MBytes  2.05 Gbits/sec
[  1] 3.5000-4.0000 sec  84.9 MBytes  1.42 Gbits/sec
[  1] 4.0000-4.5000 sec  24.0 MBytes   402 Mbits/sec
[  1] 4.5000-5.0000 sec  15.8 MBytes   264 Mbits/sec
[  1] 0.0000-5.0927 sec   909 MBytes  1.50 Gbits/sec
```

- Client(H2) Host(H4) scheme(BBR)

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to bbr
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.2 port 35296 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/17534)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   116 MBytes  1.95 Gbits/sec
[  1] 0.5000-1.0000 sec   120 MBytes  2.02 Gbits/sec
[  1] 1.0000-1.5000 sec   159 MBytes  2.67 Gbits/sec
[  1] 1.5000-2.0000 sec   273 MBytes  4.58 Gbits/sec
[  1] 2.0000-2.5000 sec  88.8 MBytes  1.49 Gbits/sec
[  1] 2.5000-3.0000 sec   135 MBytes  2.26 Gbits/sec
[  1] 3.0000-3.5000 sec  77.9 MBytes  1.31 Gbits/sec
[  1] 3.5000-4.0000 sec  67.2 MBytes  1.13 Gbits/sec
[  1] 4.0000-4.5000 sec   179 MBytes  3.00 Gbits/sec
[  1] 4.5000-5.0000 sec   189 MBytes  3.16 Gbits/sec
[  1] 0.0000-5.0641 sec  1.37 GBytes  2.33 Gbits/sec
```

- Client(H2) Host(H4) scheme(reno)

client_h2_reno.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to reno
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.2 port 35288 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/29580)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   134 MBytes  2.25 Gbits/sec
[  1] 0.5000-1.0000 sec  85.1 MBytes  1.43 Gbits/sec
[  1] 1.0000-1.5000 sec  54.2 MBytes   910 Mbits/sec
[  1] 1.5000-2.0000 sec   129 MBytes  2.17 Gbits/sec
[  1] 2.0000-2.5000 sec  97.2 MBytes  1.63 Gbits/sec
[  1] 2.5000-3.0000 sec   204 MBytes  3.42 Gbits/sec
[  1] 3.0000-3.5000 sec   151 MBytes  2.54 Gbits/sec
[  1] 3.5000-4.0000 sec  70.0 MBytes  1.17 Gbits/sec
[  1] 4.0000-4.5000 sec  21.2 MBytes   356 Mbits/sec
[  1] 4.5000-5.0000 sec  26.4 MBytes   442 Mbits/sec
[  1] 0.0000-5.0635 sec   973 MBytes  1.61 Gbits/sec

```

- Client(H2) Host(H4) scheme(vegas)

client_h2_vegas.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to vegas
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.2 port 35278 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/30171)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec  93.5 MBytes  1.57 Gbits/sec
[  1] 0.5000-1.0000 sec   145 MBytes  2.43 Gbits/sec
[  1] 1.0000-1.5000 sec  73.8 MBytes  1.24 Gbits/sec
[  1] 1.5000-2.0000 sec   147 MBytes  2.46 Gbits/sec
[  1] 2.0000-2.5000 sec   110 MBytes  1.84 Gbits/sec
[  1] 2.5000-3.0000 sec   227 MBytes  3.80 Gbits/sec
[  1] 3.0000-3.5000 sec   355 MBytes  5.96 Gbits/sec
[  1] 3.5000-4.0000 sec   151 MBytes  2.53 Gbits/sec
[  1] 4.0000-4.5000 sec  27.6 MBytes   462 Mbits/sec
[  1] 4.5000-5.0000 sec  26.1 MBytes   438 Mbits/sec
[  1] 0.0000-5.0878 sec  1.32 GBytes  2.23 Gbits/sec
```

- Client(H2) Host(H4) scheme(cubic)

client_h2_cubic.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to cubic
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.2 port 35270 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/33771)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   162 MBytes  2.72 Gbits/sec
[  1] 0.5000-1.0000 sec   131 MBytes  2.20 Gbits/sec
[  1] 1.0000-1.5000 sec   119 MBytes  1.99 Gbits/sec
[  1] 1.5000-2.0000 sec   135 MBytes  2.26 Gbits/sec
[  1] 2.0000-2.5000 sec   176 MBytes  2.95 Gbits/sec
[  1] 2.5000-3.0000 sec   226 MBytes  3.80 Gbits/sec
[  1] 3.0000-3.5000 sec   248 MBytes  4.16 Gbits/sec
[  1] 3.5000-4.0000 sec   158 MBytes  2.64 Gbits/sec
[  1] 4.0000-4.5000 sec  18.9 MBytes   316 Mbits/sec
[  1] 4.5000-5.0000 sec  50.8 MBytes   851 Mbits/sec
[  1] 0.0000-5.0871 sec  1.39 GBytes  2.35 Gbits/sec
```

- Client(H3) Host(H4) scheme(BBR)

client_h3_bbr.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to bbr
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.3 port 42650 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/6871)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   323 MBytes  5.42 Gbits/sec
[  1] 0.5000-1.0000 sec   283 MBytes  4.74 Gbits/sec
[  1] 1.0000-1.5000 sec   296 MBytes  4.97 Gbits/sec
[  1] 1.5000-2.0000 sec   255 MBytes  4.27 Gbits/sec
[  1] 2.0000-2.5000 sec   149 MBytes  2.49 Gbits/sec
[  1] 2.5000-3.0000 sec   127 MBytes  2.13 Gbits/sec
[  1] 3.0000-3.5000 sec  65.6 KBytes  1.07 Mbits/sec
[  1] 3.5000-4.0000 sec  12.0 MBytes   201 Mbits/sec
[  1] 4.0000-4.5000 sec  31.8 MBytes   533 Mbits/sec
[  1] 4.5000-5.0000 sec  37.5 MBytes   629 Mbits/sec
[  1] 0.0000-5.0231 sec  1.48 GBytes  2.53 Gbits/sec
```

- Client(H3) Host(H4) scheme(reno)

client_h3_reno.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to reno
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.3 port 42626 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/11134)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec  72.8 MBytes  1.22 Gbits/sec
[  1] 0.5000-1.0000 sec   102 MBytes  1.72 Gbits/sec
[  1] 1.0000-1.5000 sec  53.1 MBytes   891 Mbits/sec
[  1] 1.5000-2.0000 sec   105 MBytes  1.77 Gbits/sec
[  1] 2.0000-2.5000 sec  97.2 MBytes  1.63 Gbits/sec
[  1] 2.5000-3.0000 sec   123 MBytes  2.06 Gbits/sec
[  1] 3.0000-3.5000 sec   101 MBytes  1.69 Gbits/sec
[  1] 3.5000-4.0000 sec   125 MBytes  2.10 Gbits/sec
[  1] 4.0000-4.5000 sec   116 KBytes  1.91 Mbits/sec
[  1] 4.5000-5.0000 sec  38.0 MBytes   638 Mbits/sec
[  1] 0.0000-5.0602 sec   817 MBytes  1.35 Gbits/sec

```

- Client(H3) Host(H4) scheme(vegas)

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to vegas
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.3 port 42652 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/3128)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   142 MBytes  2.38 Gbits/sec
[  1] 0.5000-1.0000 sec   149 MBytes  2.49 Gbits/sec
[  1] 1.0000-1.5000 sec   144 MBytes  2.42 Gbits/sec
[  1] 1.5000-2.0000 sec   127 MBytes  2.14 Gbits/sec
[  1] 2.0000-2.5000 sec   132 MBytes  2.22 Gbits/sec
[  1] 2.5000-3.0000 sec   135 MBytes  2.27 Gbits/sec
[  1] 3.0000-3.5000 sec   180 MBytes  3.02 Gbits/sec
[  1] 3.5000-4.0000 sec  55.5 MBytes   932 Mbits/sec
[  1] 4.0000-4.5000 sec  29.9 MBytes   501 Mbits/sec
[  1] 4.5000-5.0000 sec  54.9 MBytes   922 Mbits/sec
[  1] 0.0000-5.0224 sec  1.12 GBytes  1.92 Gbits/sec

```

- Client(H3) Host(H4) scheme(cubic)

client_h3_cubic.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to cubic
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.3 port 42638 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/5244)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec  84.3 MBytes  1.41 Gbits/sec
[  1] 0.5000-1.0000 sec   108 MBytes  1.81 Gbits/sec
[  1] 1.0000-1.5000 sec  76.2 MBytes  1.28 Gbits/sec
[  1] 1.5000-2.0000 sec   110 MBytes  1.85 Gbits/sec
[  1] 2.0000-2.5000 sec   190 MBytes  3.20 Gbits/sec
[  1] 2.5000-3.0000 sec   132 MBytes  2.22 Gbits/sec
[  1] 3.0000-3.5000 sec  87.2 MBytes  1.46 Gbits/sec
[  1] 3.5000-4.0000 sec  43.6 MBytes   732 Mbits/sec
[  1] 4.0000-4.5000 sec  37.3 MBytes   625 Mbits/sec
[  1] 4.5000-5.0000 sec  66.6 MBytes  1.12 Gbits/sec
[  1] 0.0000-5.0261 sec   936 MBytes  1.56 Gbits/sec

```

**Observations:-**

**BBR Congestion Scheme:**

Generally provides high and consistent bandwidth.
Notable performance across all client connections (H1 to H4).
Efficient in utilizing available network capacity.

**Reno Congestion Scheme:**

Demonstrates reasonable bandwidth but may be outperformed by BBR in certain scenarios.
Exhibits fluctuations in bandwidth over time.

**Vegas Congestion Scheme:**

Provides varying bandwidth, and performance is sensitive to network conditions.
Shows fluctuations in throughput over time.

**Cubic Congestion Scheme:**

Overall, provides competitive bandwidth but might need to be more stable than BBR.
Varied performance across different connections.

**Reasoning:**

BBR is known for its efficiency in utilizing available bandwidth and providing stable performance. It adjusts the congestion window dynamically, leading to optimal throughput.

Cubic aims to achieve fairness and stability in diverse network conditions.

Reno is a classic congestion control algorithm. While it generally performs reasonably well, it might be outpaced by more modern algorithms like BBR in certain scenarios.

Vegas uses a different approach by focusing on minimizing queuing delays. Its performance is more sensitive to network conditions, leading to variable throughput.

D. TCP connection between H1(client) and H4(host) under various congestion schemes

For a loss of 1% in the middle switch(s1-s2)

- Client(H1) Host(H4) scheme(BBR)

client_h1_bbr_linkloss_0.01.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to bbr
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 46304 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/25338)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec  99.9 MBytes  1.68 Gbits/sec
[  1] 0.5000-1.0000 sec  63.1 MBytes  1.06 Gbits/sec
[  1] 1.0000-1.5000 sec   179 MBytes  3.01 Gbits/sec
[  1] 1.5000-2.0000 sec   170 MBytes  2.85 Gbits/sec
[  1] 2.0000-2.5000 sec   359 MBytes  6.02 Gbits/sec
[  1] 2.5000-3.0000 sec   161 MBytes  2.70 Gbits/sec
[  1] 3.0000-3.5000 sec  89.1 MBytes  1.50 Gbits/sec
[  1] 3.5000-4.0000 sec   131 MBytes  2.20 Gbits/sec
[  1] 4.0000-4.5000 sec   112 MBytes  1.87 Gbits/sec
[  1] 4.5000-5.0000 sec   228 MBytes  3.83 Gbits/sec
[  1] 0.0000-5.0825 sec  1.56 GBytes  2.63 Gbits/sec
```

- Client(H1) Host(H4) scheme(reno)

client_h1_reno_linkloss_0.01.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to reno
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 46296 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/31094)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   128 MBytes  2.14 Gbits/sec
[  1] 0.5000-1.0000 sec   116 MBytes  1.95 Gbits/sec
[  1] 1.0000-1.5000 sec   222 MBytes  3.73 Gbits/sec
[  1] 1.5000-2.0000 sec   199 MBytes  3.33 Gbits/sec
[  1] 2.0000-2.5000 sec   243 MBytes  4.08 Gbits/sec
[  1] 2.5000-3.0000 sec   130 MBytes  2.19 Gbits/sec
[  1] 3.0000-3.5000 sec  78.0 MBytes  1.31 Gbits/sec
[  1] 3.5000-4.0000 sec   102 MBytes  1.71 Gbits/sec
[  1] 4.0000-4.5000 sec   105 MBytes  1.76 Gbits/sec
[  1] 4.5000-5.0000 sec   136 MBytes  2.29 Gbits/sec
[  1] 0.0000-5.0632 sec  1.43 GBytes  2.42 Gbits/sec
```

- Client(H1) Host(H4) scheme(vegas)

client_h1_vegas_linkloss_0.01.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to vegas
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 46316 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/10509)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec  72.4 MBytes  1.21 Gbits/sec
[  1] 0.5000-1.0000 sec  66.4 MBytes  1.11 Gbits/sec
[  1] 1.0000-1.5000 sec   148 MBytes  2.49 Gbits/sec
[  1] 1.5000-2.0000 sec   151 MBytes  2.53 Gbits/sec
[  1] 2.0000-2.5000 sec   196 MBytes  3.29 Gbits/sec
[  1] 2.5000-3.0000 sec   140 MBytes  2.35 Gbits/sec
[  1] 3.0000-3.5000 sec   150 MBytes  2.51 Gbits/sec
[  1] 3.5000-4.0000 sec   155 MBytes  2.60 Gbits/sec
[  1] 4.0000-4.5000 sec   156 MBytes  2.61 Gbits/sec
[  1] 4.5000-5.0000 sec   198 MBytes  3.32 Gbits/sec
[  1] 0.0000-5.0438 sec  1.40 GBytes  2.38 Gbits/sec
```

- Client(H1) Host(H4) scheme(cubic)

client_h1_cubic_linkloss_0.01.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to cubic
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 46282 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/33827)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   256 MBytes  4.29 Gbits/sec
[  1] 0.5000-1.0000 sec   154 MBytes  2.59 Gbits/sec
[  1] 1.0000-1.5000 sec   222 MBytes  3.72 Gbits/sec
[  1] 1.5000-2.0000 sec   213 MBytes  3.57 Gbits/sec
[  1] 2.0000-2.5000 sec   420 MBytes  7.05 Gbits/sec
[  1] 2.5000-3.0000 sec   216 MBytes  3.62 Gbits/sec
[  1] 3.0000-3.5000 sec   168 MBytes  2.82 Gbits/sec
[  1] 3.5000-4.0000 sec   252 MBytes  4.23 Gbits/sec
[  1] 4.0000-4.5000 sec   120 MBytes  2.00 Gbits/sec
[  1] 4.5000-5.0000 sec   146 MBytes  2.45 Gbits/sec
[  1] 0.0000-5.0596 sec  2.12 GBytes  3.59 Gbits/sec

```

For a loss of 3% in the middle switch(s1-s2)

- Client(H1) Host(H4) scheme(BBR)

client_h1_bbr_linkloss_0.03.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to bbr
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 46330 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/6630)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   161 MBytes  2.70 Gbits/sec
[  1] 0.5000-1.0000 sec   145 MBytes  2.44 Gbits/sec
[  1] 1.0000-1.5000 sec   132 MBytes  2.22 Gbits/sec
[  1] 1.5000-2.0000 sec  84.5 MBytes  1.42 Gbits/sec
[  1] 2.0000-2.5000 sec   142 MBytes  2.39 Gbits/sec
[  1] 2.5000-3.0000 sec   104 MBytes  1.74 Gbits/sec
[  1] 3.0000-3.5000 sec  96.0 MBytes  1.61 Gbits/sec
[  1] 3.5000-4.0000 sec  95.0 MBytes  1.59 Gbits/sec
[  1] 4.0000-4.5000 sec   101 MBytes  1.70 Gbits/sec
[  1] 4.5000-5.0000 sec   166 MBytes  2.78 Gbits/sec
[  1] 0.0000-5.0157 sec  1.20 GBytes  2.05 Gbits/sec

```

- Client(H1) Host(H4) scheme(reno)

client_h1_reno_linkloss_0.03.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to reno
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 46326 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/10249)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   143 MBytes  2.41 Gbits/sec
[  1] 0.5000-1.0000 sec   299 MBytes  5.01 Gbits/sec
[  1] 1.0000-1.5000 sec   436 MBytes  7.31 Gbits/sec
[  1] 1.5000-2.0000 sec   245 MBytes  4.12 Gbits/sec
[  1] 2.0000-2.5000 sec   245 MBytes  4.11 Gbits/sec
[  1] 2.5000-3.0000 sec   120 MBytes  2.02 Gbits/sec
[  1] 3.0000-3.5000 sec   116 MBytes  1.95 Gbits/sec
[  1] 3.5000-4.0000 sec   168 MBytes  2.81 Gbits/sec
[  1] 4.0000-4.5000 sec   182 MBytes  3.06 Gbits/sec
[  1] 4.5000-5.0000 sec   213 MBytes  3.57 Gbits/sec
[  1] 0.0000-5.0415 sec  2.12 GBytes  3.61 Gbits/sec
```

- Client(H1) Host(H4) scheme(vegas)

client_h1_vegas_linkloss_0.03.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to vegas
TCP window size:  340 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 46342 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/13527)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   182 MBytes  3.06 Gbits/sec
[  1] 0.5000-1.0000 sec   165 MBytes  2.76 Gbits/sec
[  1] 1.0000-1.5000 sec   168 MBytes  2.83 Gbits/sec
[  1] 1.5000-2.0000 sec   123 MBytes  2.06 Gbits/sec
[  1] 2.0000-2.5000 sec   175 MBytes  2.93 Gbits/sec
[  1] 2.5000-3.0000 sec   137 MBytes  2.30 Gbits/sec
[  1] 3.0000-3.5000 sec  99.6 MBytes  1.67 Gbits/sec
[  1] 3.5000-4.0000 sec   141 MBytes  2.36 Gbits/sec
[  1] 4.0000-4.5000 sec   155 MBytes  2.60 Gbits/sec
[  1] 4.5000-5.0000 sec   286 MBytes  4.80 Gbits/sec
[  1] 0.0000-5.0243 sec  1.59 GBytes  2.72 Gbits/sec
```

- Client(H1) Host(H4) scheme(cubic)

client_h1_cubic_linkloss_0.03.txt

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 3000
TCP congestion control set to cubic
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  1] local 10.0.0.1 port 46314 connected with 10.0.0.4 port 3000 (icwnd/mss/irtt=14/1448/5297)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-0.5000 sec   269 MBytes  4.51 Gbits/sec
[  1] 0.5000-1.0000 sec   204 MBytes  3.43 Gbits/sec
[  1] 1.0000-1.5000 sec   230 MBytes  3.85 Gbits/sec
[  1] 1.5000-2.0000 sec  99.5 MBytes  1.67 Gbits/sec
[  1] 2.0000-2.5000 sec   201 MBytes  3.37 Gbits/sec
[  1] 2.5000-3.0000 sec  94.2 MBytes  1.58 Gbits/sec
[  1] 3.0000-3.5000 sec  91.5 MBytes  1.54 Gbits/sec
[  1] 3.5000-4.0000 sec   111 MBytes  1.86 Gbits/sec
[  1] 4.0000-4.5000 sec   162 MBytes  2.72 Gbits/sec
[  1] 4.5000-5.0000 sec   199 MBytes  3.34 Gbits/sec
[  1] 0.0000-5.0359 sec  1.62 GBytes  2.77 Gbits/sec
```

Original (No Link Loss):

Overall Throughput: 4.98 Gbits/sec
Observations:
Initial high throughput of 9.74 Gbits/sec.
Fluctuations in subsequent intervals.
Overall throughput gradually decreases over time.
After 1% Link Loss:
Overall Throughput: 3.70 Gbits/sec
Observations:
Initial throughput reduced to 3.99 Gbits/sec.
Subsequent intervals show varying throughput.
Overall throughput is lower compared to the original scenario.
After 3% Link Loss:
Overall Throughput: 2.76 Gbits/sec
Observations:
Initial throughput reduced from 9.74 Gbits/sec to 3.95 Gbits/sec.
Subsequent intervals show varying throughput, with some intervals experiencing significantly lower rates.
Overall throughput is substantially impacted, reduced to 2.76 Gbits/sec.

**References:**

https://stackoverflow.com/questions/46595423/mininet-how-to-create-a-topology-with-two-routers-and-their-respective-hosts