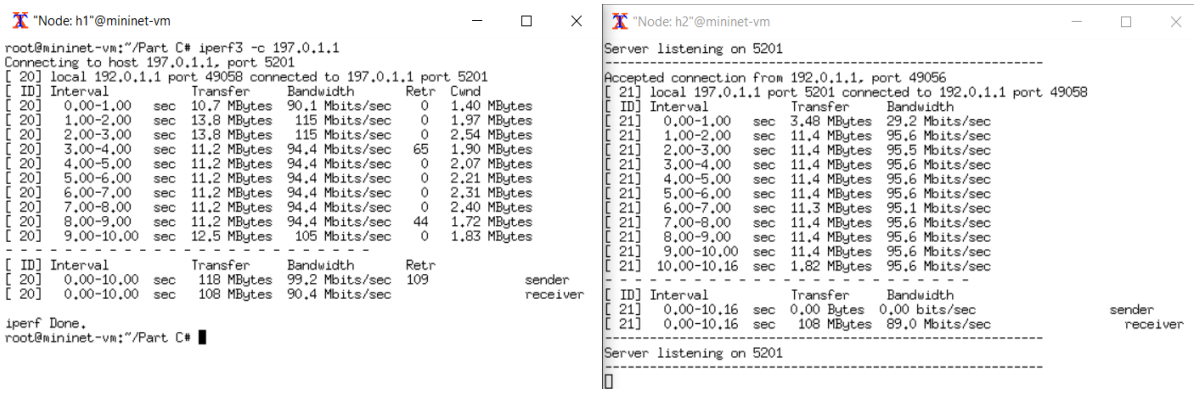
PART C

(a) MyIperf.py has been submitted along with the folder (inside Part C folder).

(b) Screenshots of 3 scenarios:

Case 1 (buffer size: 10K, Bandwidth: 100 Mb, Delay: 30ms):



"Node: h1"@mininet-vm

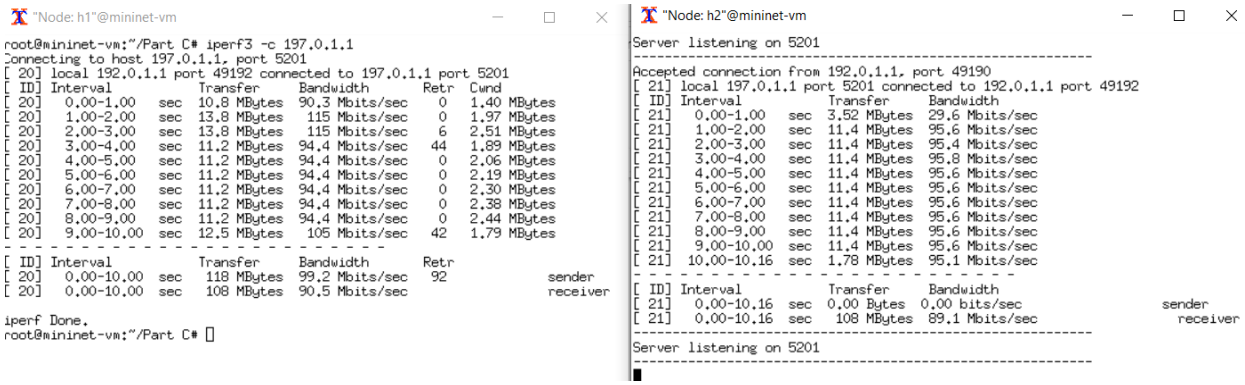
```
root@mininet-vm:~/Part C# iperf3 -c 197.0.1.1
Connecting to host 197.0.1.1, port 5201
[ 20] local 192.0.1.1 port 49058 connected to 197.0.1.1 port 5201
[ ID] Interval           Transfer     Bandwidth       Retr  Cwnd
[ 20]   0.00-1.00   sec  10.7 MBytes  90.1 Mbits/sec    0   1.40 MBytes
[ 20]   1.00-2.00   sec  13.8 MBytes   115 Mbits/sec    0   1.97 MBytes
[ 20]   2.00-3.00   sec  13.8 MBytes   115 Mbits/sec    0   2.54 MBytes
[ 20]   3.00-4.00   sec  11.2 MBytes  94.4 Mbits/sec   65   1.90 MBytes
[ 20]   4.00-5.00   sec  11.2 MBytes  94.4 Mbits/sec    0   2.07 MBytes
[ 20]   5.00-6.00   sec  11.2 MBytes  94.4 Mbits/sec    0   2.21 MBytes
[ 20]   6.00-7.00   sec  11.2 MBytes  94.4 Mbits/sec    0   2.31 MBytes
[ 20]   7.00-8.00   sec  11.2 MBytes  94.4 Mbits/sec    0   2.40 MBytes
[ 20]   8.00-9.00   sec  11.2 MBytes  94.4 Mbits/sec   44   1.72 MBytes
[ 20]   9.00-10.00  sec  12.5 MBytes   105 Mbits/sec    0   1.83 MBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Retr
[ 20]   0.00-10.00  sec   118 MBytes  99.2 Mbits/sec  109             sender
[ 20]   0.00-10.00  sec   108 MBytes  90.4 Mbits/sec                  receiver

iperf Done.
root@mininet-vm:~/Part C#
```

"Node: h2"@mininet-vm

```
Server listening on 5201
-----------------------------------------------------------
Accepted connection from 192.0.1.1, port 49056
[ 21] local 197.0.1.1 port 5201 connected to 192.0.1.1 port 49058
[ ID] Interval           Transfer     Bandwidth
[ 21]   0.00-1.00   sec  3.48 MBytes  29.2 Mbits/sec
[ 21]   1.00-2.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   2.00-3.00   sec  11.4 MBytes  95.5 Mbits/sec
[ 21]   3.00-4.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   4.00-5.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   5.00-6.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   6.00-7.00   sec  11.3 MBytes  95.1 Mbits/sec
[ 21]   7.00-8.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   8.00-9.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   9.00-10.00  sec  11.4 MBytes  95.6 Mbits/sec
[ 21]  10.00-10.16  sec  1.82 MBytes  95.6 Mbits/sec
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth
[ 21]   0.00-10.16  sec  0.00 Bytes  0.00 bits/sec                  sender
[ 21]   0.00-10.16  sec   108 MBytes  89.0 Mbits/sec                receiver
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
```

Case 2 (buffer size: 5Mb, Bandwidth: 100 Mb, Delay: 30ms):



"Node: h1"@mininet-vm

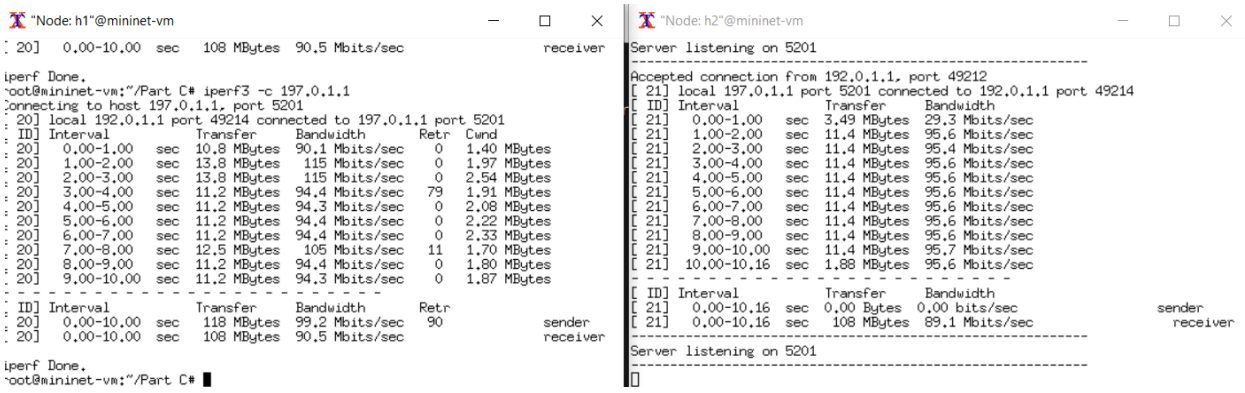
```
root@mininet-vm:~/Part C# iperf3 -c 197.0.1.1
Connecting to host 197.0.1.1, port 5201
[ 20] local 192.0.1.1 port 49192 connected to 197.0.1.1 port 5201
[ ID] Interval           Transfer     Bandwidth       Retr  Cwnd
[ 20]   0.00-1.00   sec  10.8 MBytes  90.3 Mbits/sec    0   1.40 MBytes
[ 20]   1.00-2.00   sec  13.8 MBytes   115 Mbits/sec    0   1.97 MBytes
[ 20]   2.00-3.00   sec  13.8 MBytes   115 Mbits/sec    6   2.51 MBytes
[ 20]   3.00-4.00   sec  11.2 MBytes  94.4 Mbits/sec   44   1.89 MBytes
[ 20]   4.00-5.00   sec  11.2 MBytes  94.4 Mbits/sec    0   2.06 MBytes
[ 20]   5.00-6.00   sec  11.2 MBytes  94.4 Mbits/sec    0   2.19 MBytes
[ 20]   6.00-7.00   sec  11.2 MBytes  94.4 Mbits/sec    0   2.30 MBytes
[ 20]   7.00-8.00   sec  11.2 MBytes  94.4 Mbits/sec    0   2.38 MBytes
[ 20]   8.00-9.00   sec  11.2 MBytes  94.4 Mbits/sec    0   2.44 MBytes
[ 20]   9.00-10.00  sec  12.5 MBytes   105 Mbits/sec   42   1.79 MBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Retr
[ 20]   0.00-10.00  sec   118 MBytes  99.2 Mbits/sec   92             sender
[ 20]   0.00-10.00  sec   108 MBytes  90.5 Mbits/sec                  receiver

iperf Done.
root@mininet-vm:~/Part C#
```

"Node: h2"@mininet-vm

```
Server listening on 5201
-----------------------------------------------------------
Accepted connection from 192.0.1.1, port 49190
[ 21] local 197.0.1.1 port 5201 connected to 192.0.1.1 port 49192
[ ID] Interval           Transfer     Bandwidth
[ 21]   0.00-1.00   sec  3.52 MBytes  29.6 Mbits/sec
[ 21]   1.00-2.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   2.00-3.00   sec  11.4 MBytes  95.4 Mbits/sec
[ 21]   3.00-4.00   sec  11.4 MBytes  95.8 Mbits/sec
[ 21]   4.00-5.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   5.00-6.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   6.00-7.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   7.00-8.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   8.00-9.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   9.00-10.00  sec  11.4 MBytes  95.6 Mbits/sec
[ 21]  10.00-10.16  sec  1.78 MBytes  95.1 Mbits/sec
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth
[ 21]   0.00-10.16  sec  0.00 Bytes  0.00 bits/sec                  sender
[ 21]   0.00-10.16  sec   108 MBytes  89.1 Mbits/sec                receiver
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
```

Case 3 (buffer size: 25Mb, Bandwidth: 100 Mb, Delay: 30ms):



"Node: h1"@mininet-vm

```
[ 20]   0.00-10.00  sec   108 MBytes  90.5 Mbits/sec                  receiver

iperf Done.
root@mininet-vm:~/Part C# iperf3 -c 197.0.1.1
Connecting to host 197.0.1.1, port 5201
[ 20] local 192.0.1.1 port 49214 connected to 197.0.1.1 port 5201
[ ID] Interval           Transfer     Bandwidth       Retr  Cwnd
[ 20]   0.00-1.00   sec  10.8 MBytes  90.1 Mbits/sec    0   1.40 MBytes
[ 20]   1.00-2.00   sec  13.8 MBytes   115 Mbits/sec    0   1.97 MBytes
[ 20]   2.00-3.00   sec  13.8 MBytes   115 Mbits/sec    0   2.54 MBytes
[ 20]   3.00-4.00   sec  11.2 MBytes  94.4 Mbits/sec   79   1.91 MBytes
[ 20]   4.00-5.00   sec  11.2 MBytes  94.3 Mbits/sec    0   2.08 MBytes
[ 20]   5.00-6.00   sec  11.2 MBytes  94.4 Mbits/sec    0   2.22 MBytes
[ 20]   6.00-7.00   sec  11.2 MBytes  94.4 Mbits/sec    0   2.33 MBytes
[ 20]   7.00-8.00   sec  12.5 MBytes   105 Mbits/sec   11   1.70 MBytes
[ 20]   8.00-9.00   sec  11.2 MBytes  94.4 Mbits/sec    0   1.80 MBytes
[ 20]   9.00-10.00  sec  11.2 MBytes  94.3 Mbits/sec    0   1.87 MBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Retr
[ 20]   0.00-10.00  sec   118 MBytes  99.2 Mbits/sec   90             sender
[ 20]   0.00-10.00  sec   108 MBytes  90.5 Mbits/sec                  receiver

iperf Done.
root@mininet-vm:~/Part C#
```

"Node: h2"@mininet-vm

```
Server listening on 5201
-----------------------------------------------------------
Accepted connection from 192.0.1.1, port 49212
[ 21] local 197.0.1.1 port 5201 connected to 192.0.1.1 port 49214
[ ID] Interval           Transfer     Bandwidth
[ 21]   0.00-1.00   sec  3.49 MBytes  29.3 Mbits/sec
[ 21]   1.00-2.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   2.00-3.00   sec  11.4 MBytes  95.4 Mbits/sec
[ 21]   3.00-4.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   4.00-5.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   5.00-6.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   6.00-7.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   7.00-8.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   8.00-9.00   sec  11.4 MBytes  95.6 Mbits/sec
[ 21]   9.00-10.00  sec  11.4 MBytes  95.7 Mbits/sec
[ 21]  10.00-10.16  sec  1.88 MBytes  95.6 Mbits/sec
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth
[ 21]   0.00-10.16  sec  0.00 Bytes  0.00 bits/sec                  sender
[ 21]   0.00-10.16  sec   108 MBytes  89.1 Mbits/sec                receiver
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
```

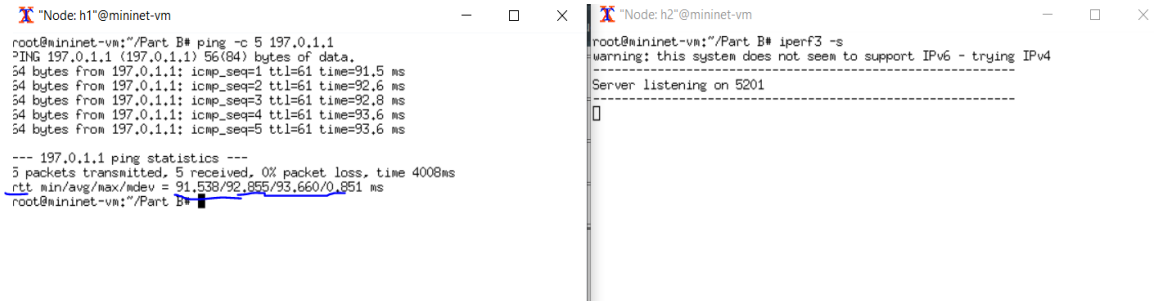
(c) BDP stands for bandwidth delay product and is calculated by using below formula:

BDP = Bandwidth * RTT

Here, bandwidth is given as 100 Mbps and RTT is the delay i.e. 30 ms

Therefore, BDP = 100 Mbps * 30 ms = **384 KB * 8 = 3072 Kb (kilobits)**

In the below screenshot, we can see that the average RTT is around 90 ms which is understandable because h1 has to travel through 3 routers to reach h2 and each of them contributes 30 ms each.



Case 1 (buffer size: 10Kb, Bandwidth: 100 Mb, Delay: 30ms):

- Here, the buffer size is 10Kb which is the value of 'limit' parameter in tc command. Also, I have taken the burst size as a constant value of 100kbit.
- From the perspective of TCP flow control, if the receiver buffer size is greater than or equal to the BDP, then it will achieve the optimal throughput. If the buffer is smaller than the BDP, then the throughput will be lower than optimal.
- In our scenario, as the buffer size was less than the BDP value, the throughput was the lowest and retransmitted packets were the highest in number (Please refer to Screenshot 1 above)

Case 2 (buffer size: 5Mb, Bandwidth: 100 Mb, Delay: 30ms):

- Here, the buffer size is 5000Kbit which is the value of 'limit' parameter in tc command. Also, I have taken the burst size as a constant value of 100kbit.
- In this scenario, as the buffer size was greater than the BDP value, the throughput was optimal and retransmitted packets were also lower than Case 1. (Please refer to Screenshot 2 above).

Case 3 (buffer size: 25Mb, Bandwidth: 100 Mb, Delay: 30ms):

- Here, the buffer size is 25000Kbit which is the value of 'limit' parameter in tc command. Also, I have taken the burst size as a constant value of 100kbit.
- In this scenario, as the buffer size was greater than the BDP value, the throughput was optimal and retransmitted packets were also lower than Case 1. (Please refer to Screenshot 3 above).

Notes:

1. In this experiment, we can notice that the last 2 cases performed in a similar manner as the buffer size was greater than the BDP in both the cases.
2. Also, I tried to change the burst parameter in the tc command which is used to process packets in an instant. I observed that on increasing the burst value, the throughput (iperf calls it as bandwidth) also increased.
3. Another thing I noticed is the window size.This value in the TCP header indicates how much free buffer space is available in the TCP buffer. By default the window size can be found via command: sysctl net.ipv4.tcp_rmem (for receiver window)
   Default window size values:
   Minimum: 4,096 • Default: 65,536 • Maximum: 33,554,432
4. If we increase the window size, then we can achieve the optimal maximum throughput as well.