Lab 2

EE 542

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1 Member Information

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2 Lab Question

Q: As you can observe in Case 2 and Case 3, throughputs of iperf UDP are similar, but TCP differ by up to 20x. Think about your configuration and describe in the report exactly what might be happening for Case 2 and Case 3 in terms of network buffering, packet loss, latencies, and window sizes.

UDP is an unreliable protocol, and does not have built in congestion control and retransmission. Therefore, UDP simply sends packets at the rate specified, which in case 2 is 100Mbps. Since roughly 20% of packets are lost, the effective throughput is around 80Mbps. Similarly in case 3, UDP sends packets at 100Mbps. However, since the router bandwidth is only 80Mbps, the router buffer overflows and drops some packets. Therefore the effective throughput is around 80Mbps.

However, TCP is a reliable protocol and has built in congestion control and retransmission. In case 2, the network buffer is large enough to hold all packets sent by the sender, so no packets are dropped due to buffer overflow. However, since 20% of packets are lost due to the network conditions, TCP thinks that the network is congested and reduces its window size exponentially. This means that it is never able to send packets close to the 100Mbps rate, which reduces the throughput. Moreover, TCP also waits for acknowledgements for each packet sent, and if a packet is not acknowledged, it retransmits the packet. This means some packets are sent multiple times, which further reduces the effective throughput. In case 3, the router buffer is not large enough to hold all packets sent by the sender, so some packets are dropped due to buffer overflow. This means that TCP thinks that the network is congested and reduces its window size exponentially. This means that it is never able to send packets close to the 80Mbps rate, which reduces the throughput.

3 Custom Fast and Reliable Protocol Design

In order to reliably transfer a file from a sender to a receiver given the three test cases for the lab, we decided to take a simple approach in the interest of time, and use a NACK based approach.

The entire file transfer is performed over UDP to make sure that we use the entire available bandwidth. TCP would provide reliable transfer, but would not be able to use the entire available bandwidth as it would severly limit its own window size in case of a lossy network.

To ensure reliability, we developed a simple retransmission mechanism. The pseudocode of the file transfer algorithm for the sender and receiver is described in the next section.

3.1 Transfer Algorithm

We used a multithreaded sender and receiver where each thread performed a distinct function. The sender and receiver algorithms are detailed below.

Sender algorithm

```
First, transmit the entire file in order.
Listen for NACKs from the receiver, and add NACK'd chunks to a retransmit queue.
While the retransmit queue is not empty and we have not received a FIN signal:
    Retransmit chunks in retransmit queue
```

First, the sender sends the entire file without listening for NACKs. Then, it switches to retransmission mode. It listens for NACKs from the receiver and continuously keeps retransmitting NACK'd packets.

The sender has two threads. The main thread is responsible for sending packets in the retransmit queue, and the nack listener thread is responsible for listening for NACKs from the receiver and queueing missing packets for retransmission.

This way, we make sure that the entire bandwidth is utilized and we are not limited by a sender window. As long as NACK packets keep coming back, we keep transmitting. Once a NACK is received, the corresponding chunks of the file are queued for retransmission and it is assumed that the packets will be delivered. If they are not, the receiver will send a NACK for the same packets once more, and they will be retransmitted again. This means that all chunks of the file will be delivered correctly as long as the receiver keeps sending NACKs for missing chunks continuously.

Receiver algorithm

```
For each incoming packet, decode it and extract its sequence number.
Maintain a list of received sequence numbers and the maximum sequence number received so
    far.
If there exists a gap between received sequence numbers, periodically send a NACK for
    each gap in received sequence numbers.
```

The receiver has two threads. One thread is responsible for receiving and ordering packets according to their sequence number, and the other thread is responsible for periodically sending batched NACKs. As the data packets keep coming in, the first thread keeps ordering them and storing the payload in memory. Every few milliseconds, the nack thread runs, scans through the list of received packets and calculates which sequence numbers are missing. Then it sends out NACK packets for the ranges of sequence numbers that are missing.

We tried various intervals for sending batched NACKs, and we observed the best performance for an interval of 5ms. Every 5ms, the nack thread scans for missing sequence numbers, and sends NACK packets to the sender.

The flow chart for file transfer is shown in Figure 1.

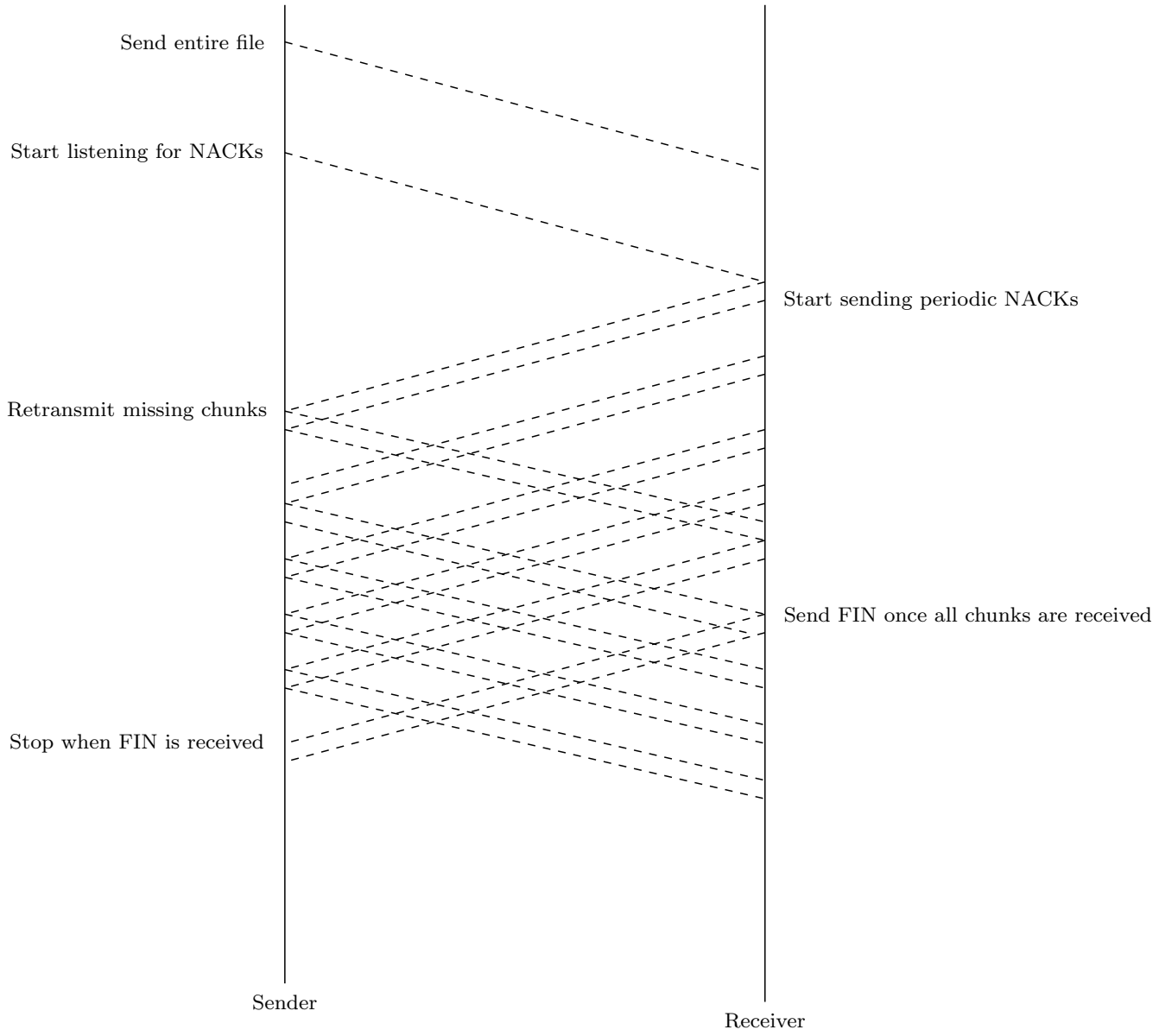

Figure 1: File Transfer Flow Chart

3.2 Results

We first tested the program for all three cases with an MTU of 1500 (the default for ethernet).

Case 1: RTT of 10ms, Packet loss of 1% (MTU 1500)

First we set up the network with the given constraints using the commands given in the lab. For the simple case of 10ms RTT and 1% loss, we observed a throughput of 80.64Mbps.

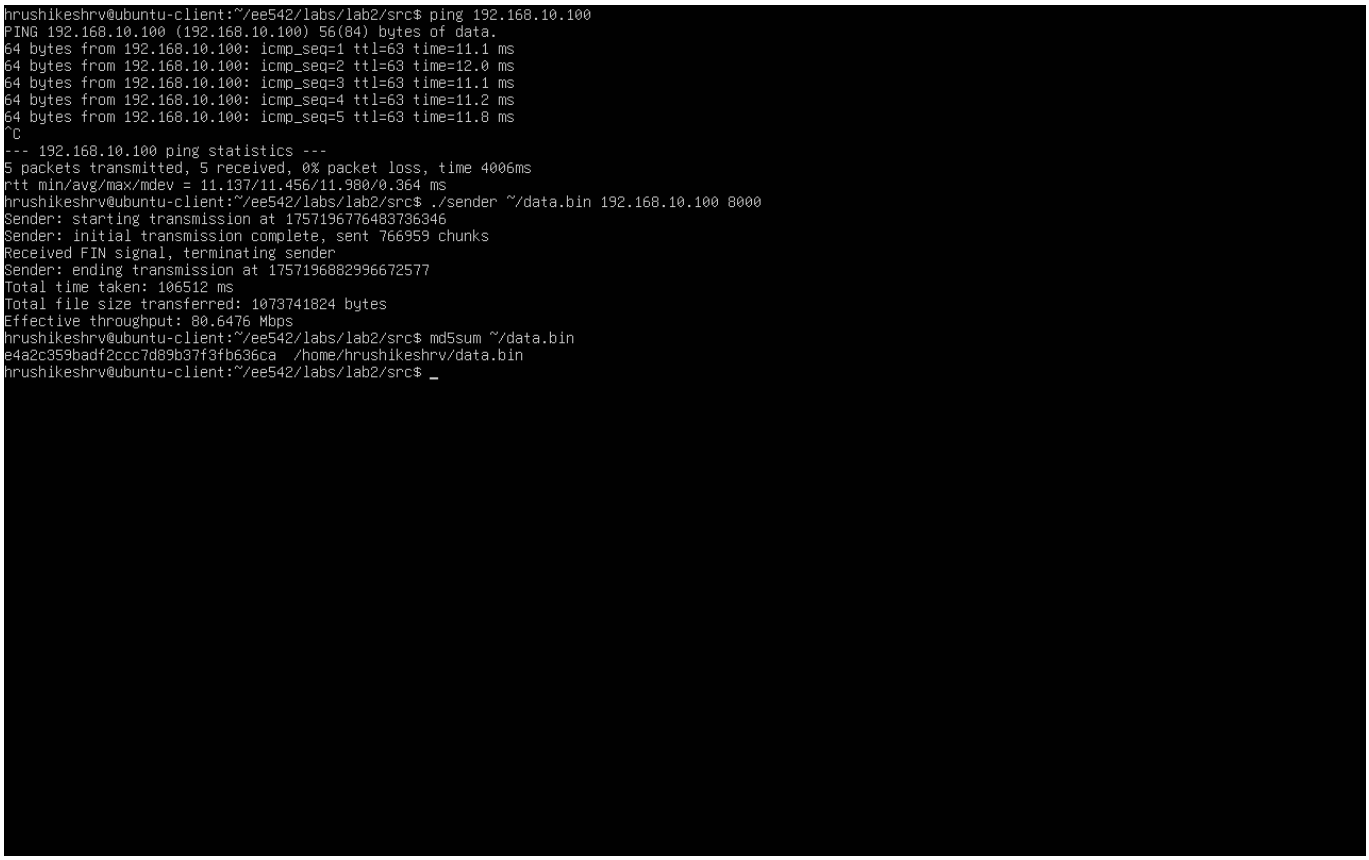

Figure 2: Client side throughtput and MD5 sum

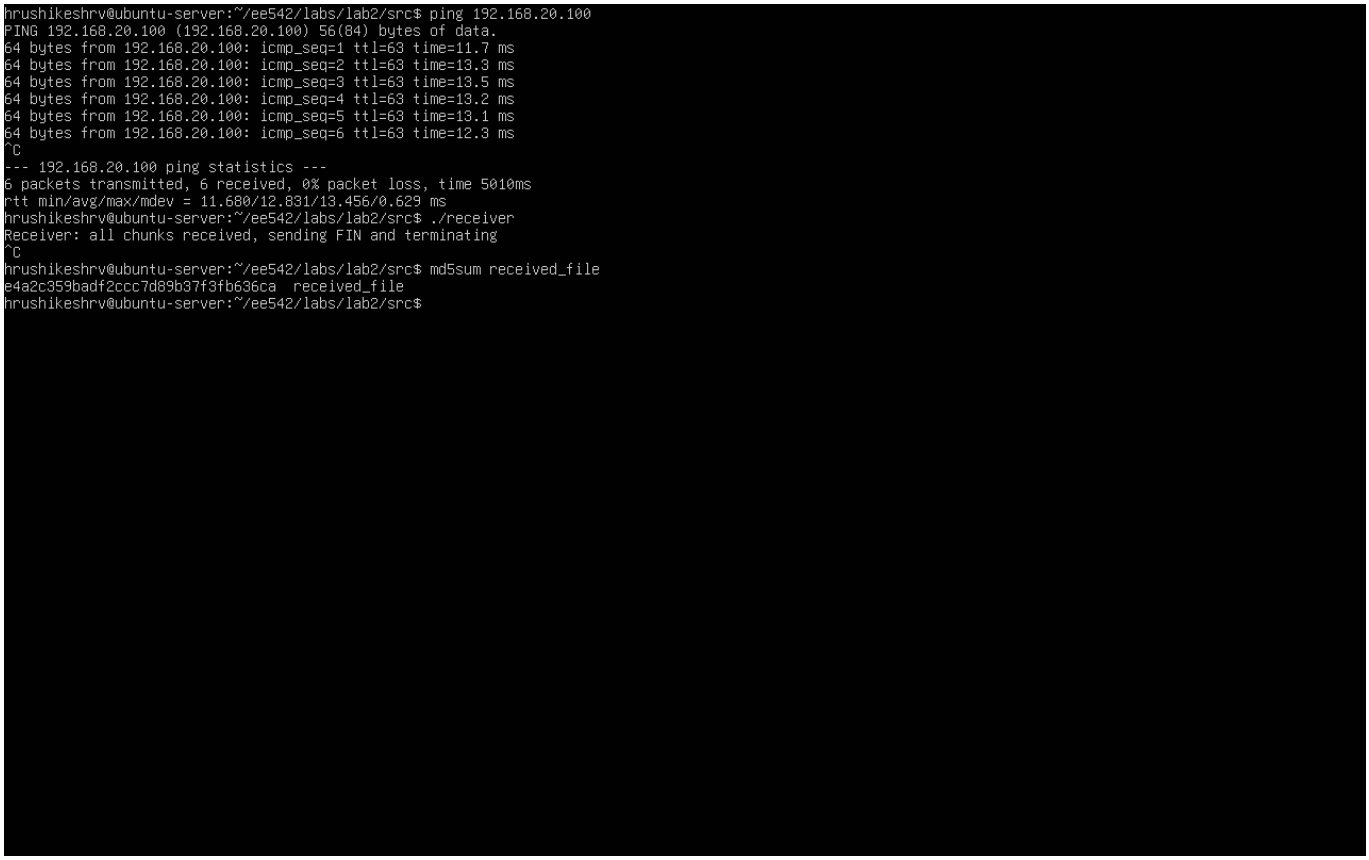

Figure 3: Server side MD5 sum

Case 2: RTT of 200ms, Packet loss of 20% (MTU 1500)

First we set up the network with the given constrains and verified them using the commands given in the lab. For the high loss case of 20%, we observed a throughput of 32.33Mbps.

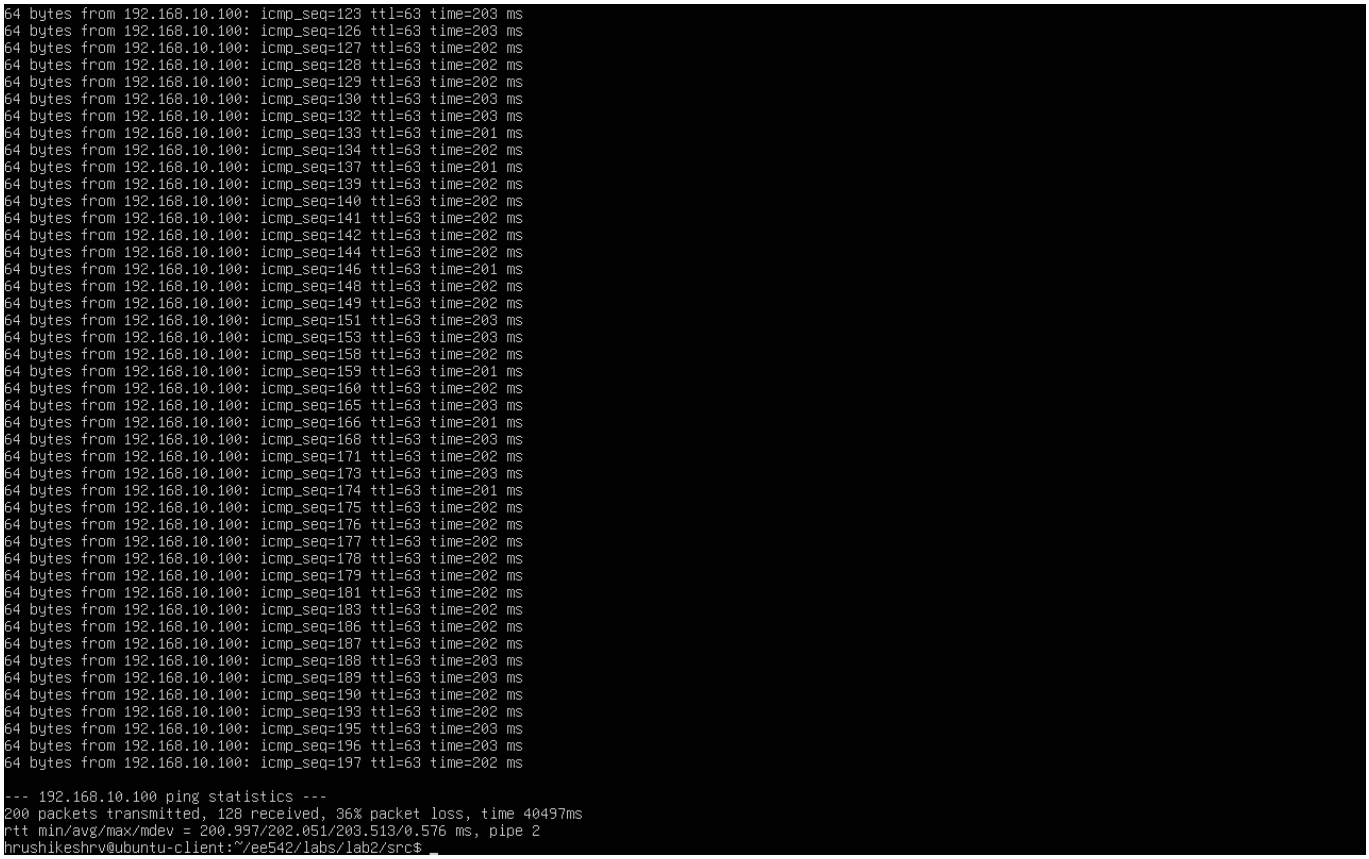

Figure 4: Case 2 setup - client side

```
64 bytes from 192.168.20.100: icmp_seq=137 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=138 ttl=63 time=204 ms
64 bytes from 192.168.20.100: icmp_seq=140 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=141 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=142 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=144 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=145 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=147 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=148 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=149 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=151 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=152 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=153 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=154 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=156 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=157 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=158 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=159 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=161 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=163 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=165 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=167 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=169 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=171 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=172 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=173 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=174 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=175 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=176 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=177 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=181 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=182 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=183 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=184 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=185 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=186 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=187 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=189 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=190 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=192 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=193 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=195 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=196 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=197 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=200 ttl=63 time=201 ms

--- 192.168.20.100 ping statistics ---
200 packets transmitted, 141 received, 29.5% packet loss, time 40344ms
rtt min/avg/max/mdev = 201.099/201.985/204.176/0.555 ms, pipe 2
hrushikeshrv@ubuntu-server:~/ee542/labs/lab2/src$ _
```

Figure 5: Case 2 setup - server side

```
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ iperf -u -c 192.168.10.100 -b 100mbit
------------------------------------------------------------
Client connecting to 192.168.10.100, UDP port 5001
Sending 1470 byte datagrams, IPG target: 117.60 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  1] local 192.168.20.100 port 36350 connected with 192.168.10.100 port 5001
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-10.0000 sec   119 MBytes   100 Mbits/sec
[  1] Sent 85037 datagrams
[  1] Server Report:
[ ID] Interval       Transfer     Bandwidth        Jitter   Lost/Total Datagrams
[  1] 0.0000-10.0223 sec  92.5 MBytes  77.4 Mbits/sec   0.191 ms 19033/85037 (22%)
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ iperf -c 192.168.10.100 -b 100mbit
------------------------------------------------------------
Client connecting to 192.168.10.100, TCP port 5001
TCP window size: 16.0 KByte (default)
------------------------------------------------------------
[  1] local 192.168.20.100 port 59182 connected with 192.168.10.100 port 5001 (icwnd/mss/irtt=14/1448/1248000)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-25.2574 sec   281 KBytes  91.3 Kbits/sec
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ iperf -c 192.168.10.100 -b 100mbit
------------------------------------------------------------
Client connecting to 192.168.10.100, TCP port 5001
TCP window size: 16.0 KByte (default)
------------------------------------------------------------
[  1] local 192.168.20.100 port 56628 connected with 192.168.10.100 port 5001 (icwnd/mss/irtt=14/1448/201779)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-23.0758 sec  1.21 MBytes   439 Kbits/sec
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$
```

Figure 6: Case 2 iperf results

```
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ iperf -u -c 192.168.10.100 -b 100mbit
------------------------------------------------------------
Client connecting to 192.168.10.100, UDP port 5001
Sending 1470 byte datagrams, IPG target: 117.60 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  1] local 192.168.20.100 port 36350 connected with 192.168.10.100 port 5001
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-10.0000 sec   119 MBytes   100 Mbits/sec
[  1] Sent 85037 datagrams
[  1] Server Report:
[ ID] Interval       Transfer     Bandwidth        Jitter   Lost/Total Datagrams
[  1] 0.0000-10.0223 sec  92.5 MBytes  77.4 Mbits/sec   0.191 ms 19033/85037 (22%)
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ iperf -c 192.168.10.100 -b 100mbit
------------------------------------------------------------
Client connecting to 192.168.10.100, TCP port 5001
TCP window size: 16.0 KByte (default)
------------------------------------------------------------
[  1] local 192.168.20.100 port 59182 connected with 192.168.10.100 port 5001 (icwnd/mss/irtt=14/1448/1248000)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-25.2574 sec   281 KBytes  91.3 Kbits/sec
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ iperf -c 192.168.10.100 -b 100mbit
------------------------------------------------------------
Client connecting to 192.168.10.100, TCP port 5001
TCP window size: 16.0 KByte (default)
------------------------------------------------------------
[  1] local 192.168.20.100 port 56628 connected with 192.168.10.100 port 5001 (icwnd/mss/irtt=14/1448/201779)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-23.0758 sec  1.21 MBytes   439 Kbits/sec
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ ./sender ~/data.bin 192.168.10.100 8000
Sender: starting transmission at 1757197965440548252
Sender: initial transmission complete, sent 766959 chunks
^C
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ ./sender ~/data.bin 192.168.10.100 8000
Sender: starting transmission at 1757198714161037212
Sender: initial transmission complete, sent 766959 chunks
Received FIN signal, terminating sender
Sender: ending transmission at 1757198979791684163
Total time taken: 265630 ms
Total file size transferred: 1073741824 bytes
Effective throughput: 32.338 Mbps
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ md5sum ~/data.bin
e4a2c359badf2ccc7d89b37f3fb636ca  /home/hrushikeshrv/data.bin
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ _
```

Figure 7: Client side throughput and MD5 sum

```
Received 764586 chunks. Missing 2373 chunks. Max received chunk is 766958
Received 764629 chunks. Missing 2330 chunks. Max received chunk is 766958
Received 764762 chunks. Missing 2197 chunks. Max received chunk is 766958
Received 764816 chunks. Missing 2143 chunks. Max received chunk is 766958
Received 764880 chunks. Missing 2079 chunks. Max received chunk is 766958
Received 764961 chunks. Missing 1998 chunks. Max received chunk is 766958
Received 765032 chunks. Missing 1927 chunks. Max received chunk is 766958
Received 765098 chunks. Missing 1861 chunks. Max received chunk is 766958
Received 765163 chunks. Missing 1796 chunks. Max received chunk is 766958
Received 765331 chunks. Missing 1628 chunks. Max received chunk is 766958
Received 765445 chunks. Missing 1514 chunks. Max received chunk is 766958
Received 765556 chunks. Missing 1403 chunks. Max received chunk is 766958
Received 765638 chunks. Missing 1321 chunks. Max received chunk is 766958
Received 765691 chunks. Missing 1268 chunks. Max received chunk is 766958
Received 765760 chunks. Missing 1199 chunks. Max received chunk is 766958
Received 765850 chunks. Missing 1109 chunks. Max received chunk is 766958
Received 765928 chunks. Missing 1031 chunks. Max received chunk is 766958
Received 766001 chunks. Missing 958 chunks. Max received chunk is 766958
Received 766076 chunks. Missing 883 chunks. Max received chunk is 766958
Received 766179 chunks. Missing 780 chunks. Max received chunk is 766958
Received 766245 chunks. Missing 714 chunks. Max received chunk is 766958
Received 766336 chunks. Missing 623 chunks. Max received chunk is 766958
Received 766397 chunks. Missing 562 chunks. Max received chunk is 766958
Received 766437 chunks. Missing 522 chunks. Max received chunk is 766958
Received 766466 chunks. Missing 493 chunks. Max received chunk is 766958
Received 766504 chunks. Missing 455 chunks. Max received chunk is 766958
Received 766537 chunks. Missing 422 chunks. Max received chunk is 766958
Received 766569 chunks. Missing 390 chunks. Max received chunk is 766958
Received 766586 chunks. Missing 373 chunks. Max received chunk is 766958
Received 766621 chunks. Missing 338 chunks. Max received chunk is 766958
Received 766667 chunks. Missing 292 chunks. Max received chunk is 766958
Received 766703 chunks. Missing 256 chunks. Max received chunk is 766958
Received 766722 chunks. Missing 237 chunks. Max received chunk is 766958
Received 766740 chunks. Missing 219 chunks. Max received chunk is 766958
Received 766758 chunks. Missing 201 chunks. Max received chunk is 766958
Received 766799 chunks. Missing 160 chunks. Max received chunk is 766958
Received 766818 chunks. Missing 141 chunks. Max received chunk is 766958
Received 766846 chunks. Missing 113 chunks. Max received chunk is 766958
Received 766873 chunks. Missing 86 chunks. Max received chunk is 766958
Received 766888 chunks. Missing 71 chunks. Max received chunk is 766958
Received 766904 chunks. Missing 55 chunks. Max received chunk is 766958
Received 766919 chunks. Missing 40 chunks. Max received chunk is 766958
Received 766932 chunks. Missing 27 chunks. Max received chunk is 766958
Received 766945 chunks. Missing 14 chunks. Max received chunk is 766958
Received 766959 chunks. Missing 0 chunks. Max received chunk is 766958
Receiver: all chunks received, sending FIN and terminating
^C
hrushikeshrv@ubuntu-server:~/ee542/labs/lab2/src$ md5sum received_file
e4a2c359badf2ccc7d89b37f3fb636ca  received_file
hrushikeshrv@ubuntu-server:~/ee542/labs/lab2/src$ _
```

Figure 8: Server side MD5 sum

Case 3: RTT of 200ms, Packet loss of 0%, router bandwith of 80Mbps (MTU 1500)

First we set up the network with the given constraints and verified them using the commands given in the lab. For the router bottleneck case, we observed a throughput of 32.23Mbps.

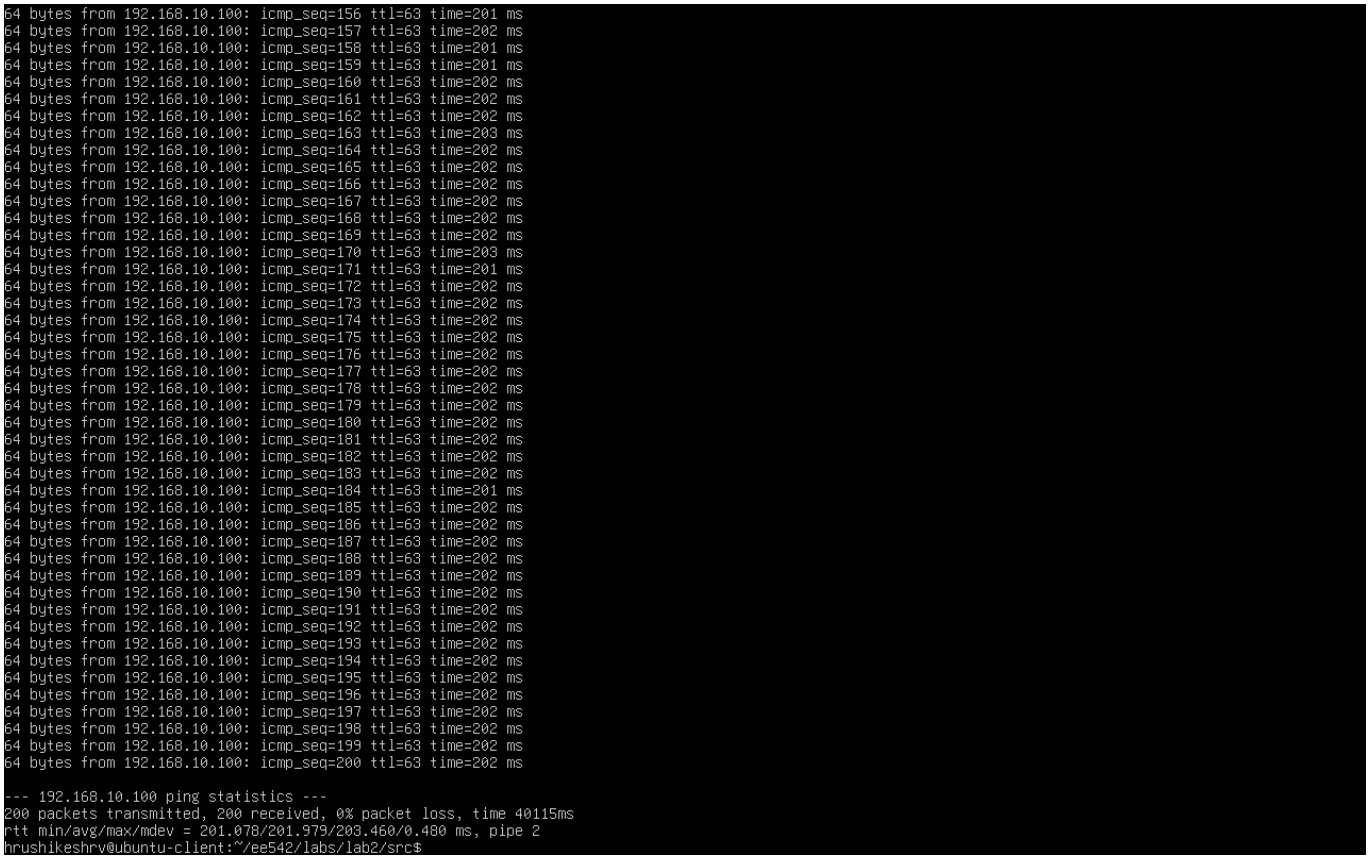

Figure 9: Case 3 setup - client side

```
64 bytes from 192.168.20.100: icmp_seq=156 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=157 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=158 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=159 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=160 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=161 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=162 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=163 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=164 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=165 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=166 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=167 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=168 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=169 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=170 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=171 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=172 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=173 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=174 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=175 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=176 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=177 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=178 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=179 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=180 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=181 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=182 ttl=63 time=204 ms
64 bytes from 192.168.20.100: icmp_seq=183 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=184 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=185 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=186 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=187 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=188 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=189 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=190 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=191 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=192 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=193 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=194 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=195 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=196 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=197 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=198 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=199 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=200 ttl=63 time=202 ms

--- 192.168.20.100 ping statistics ---
200 packets transmitted, 200 received, 0% packet loss, time 40139ms
rtt min/avg/max/mdev = 201.037/202.069/204.404/0.633 ms, pipe 2
hrushikeshrv@ubuntu-server:~/ee542/labs/lab2/src$
```

Figure 10: Case 3 setup - server side

```
[  1] 0.0000-23.0758 sec  1.21 MBytes   439 Kbits/sec
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ ./sender ~/data.bin 192.168.10.100 8000
Sender: starting transmission at 1757197965440548252
Sender: initial transmission complete, sent 766959 chunks
^C
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ ./sender ~/data.bin 192.168.10.100 8000
Sender: starting transmission at 1757198714161037212
Sender: initial transmission complete, sent 766959 chunks
Received FIN signal, terminating sender
Sender: ending transmission at 1757198979791684163
Total time taken: 265630 ms
Total file size transferred: 1073741824 bytes
Effective throughput: 32.338 Mbps
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ md5sum ~/data.bin
e4a2c359badf2ccc7d89b37f3fb636ca  /home/hrushikeshrv/data.bin
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ iperf -c 192.168.10.100 -u -b 100mbit
------------------------------------------------------------
Client connecting to 192.168.10.100, UDP port 5001
Sending 1470 byte datagrams, IPG target: 117.60 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  1] local 192.168.20.100 port 43729 connected with 192.168.10.100 port 5001
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-10.0001 sec   119 MBytes   100 Mbits/sec
[  1] Sent 85038 datagrams
[  1] Server Report:
[ ID] Interval       Transfer     Bandwidth        Jitter   Lost/Total Datagrams
[  1] 0.0000-10.0021 sec   116 MBytes  97.2 Mbits/sec   0.119 ms 2360/85037 (2.8%)
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ iperf -c 192.168.10.100 -u -b 100mbit
------------------------------------------------------------
Client connecting to 192.168.10.100, UDP port 5001
Sending 1470 byte datagrams, IPG target: 117.60 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  1] local 192.168.20.100 port 45879 connected with 192.168.10.100 port 5001
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-10.0003 sec   119 MBytes   100 Mbits/sec
[  1] Sent 85039 datagrams
[  1] Server Report:
[ ID] Interval       Transfer     Bandwidth        Jitter   Lost/Total Datagrams
[  1] 0.0000-10.0519 sec  93.2 MBytes  77.8 Mbits/sec   0.157 ms 18554/85039 (22%)
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ iperf -c 192.168.10.100 -b 100mbit
------------------------------------------------------------
Client connecting to 192.168.10.100, TCP port 5001
TCP window size: 16.0 KByte (default)
------------------------------------------------------------
[  1] local 192.168.20.100 port 32994 connected with 192.168.10.100 port 5001 (icwnd/mss/irtt=14/1448/201625)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-11.0854 sec  20.7 MBytes  15.7 Mbits/sec
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ _
```

Figure 11: Case 3 iperf results

```
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ ./sender ~/data.bin 192.168.10.100 8000
Sender: starting transmission at 1757199845049530046
Sender: initial transmission complete, sent 766959 chunks
^C
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ ./sender ~/data.bin 192.168.10.100 8000
Sender: starting transmission at 1757200071662571472
Sender: initial transmission complete, sent 766959 chunks
Received FIN signal, terminating sender
Sender: ending transmission at 1757200338187684538
Total time taken: 266525 ms
Total file size transferred: 1073741824 bytes
Effective throughput: 32.2294 Mbps
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ md5sum ~/data.bin
e4a2c359badf2ccc7d89b37f3fb636ca  /home/hrushikeshrv/data.bin
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$
```

Figure 12: Client side throughput and MD5 sum

```
Received 764136 chunks. Missing 2823 chunks. Max received chunk is 766958
Received 764174 chunks. Missing 2785 chunks. Max received chunk is 766958
Received 764311 chunks. Missing 2648 chunks. Max received chunk is 766958
Received 764478 chunks. Missing 2481 chunks. Max received chunk is 766958
Received 764657 chunks. Missing 2302 chunks. Max received chunk is 766958
Received 764813 chunks. Missing 2146 chunks. Max received chunk is 766958
Received 764932 chunks. Missing 2027 chunks. Max received chunk is 766958
Received 765068 chunks. Missing 1891 chunks. Max received chunk is 766958
Received 765153 chunks. Missing 1806 chunks. Max received chunk is 766958
Received 765251 chunks. Missing 1708 chunks. Max received chunk is 766958
Received 765390 chunks. Missing 1569 chunks. Max received chunk is 766958
Received 765491 chunks. Missing 1468 chunks. Max received chunk is 766958
Received 765523 chunks. Missing 1436 chunks. Max received chunk is 766958
Received 765583 chunks. Missing 1376 chunks. Max received chunk is 766958
Received 765624 chunks. Missing 1335 chunks. Max received chunk is 766958
Received 765728 chunks. Missing 1231 chunks. Max received chunk is 766958
Received 765784 chunks. Missing 1175 chunks. Max received chunk is 766958
Received 765844 chunks. Missing 1115 chunks. Max received chunk is 766958
Received 765895 chunks. Missing 1064 chunks. Max received chunk is 766958
Received 765976 chunks. Missing 983 chunks. Max received chunk is 766958
Received 766025 chunks. Missing 934 chunks. Max received chunk is 766958
Received 766099 chunks. Missing 860 chunks. Max received chunk is 766958
Received 766153 chunks. Missing 806 chunks. Max received chunk is 766958
Received 766252 chunks. Missing 707 chunks. Max received chunk is 766958
Received 766329 chunks. Missing 630 chunks. Max received chunk is 766958
Received 766385 chunks. Missing 574 chunks. Max received chunk is 766958
Received 766431 chunks. Missing 528 chunks. Max received chunk is 766958
Received 766481 chunks. Missing 478 chunks. Max received chunk is 766958
Received 766516 chunks. Missing 443 chunks. Max received chunk is 766958
Received 766534 chunks. Missing 425 chunks. Max received chunk is 766958
Received 766592 chunks. Missing 367 chunks. Max received chunk is 766958
Received 766636 chunks. Missing 323 chunks. Max received chunk is 766958
Received 766661 chunks. Missing 298 chunks. Max received chunk is 766958
Received 766686 chunks. Missing 273 chunks. Max received chunk is 766958
Received 766715 chunks. Missing 244 chunks. Max received chunk is 766958
Received 766743 chunks. Missing 216 chunks. Max received chunk is 766958
Received 766780 chunks. Missing 179 chunks. Max received chunk is 766958
Received 766803 chunks. Missing 156 chunks. Max received chunk is 766958
Received 766829 chunks. Missing 130 chunks. Max received chunk is 766958
Received 766862 chunks. Missing 97 chunks. Max received chunk is 766958
Received 766901 chunks. Missing 58 chunks. Max received chunk is 766958
Received 766925 chunks. Missing 34 chunks. Max received chunk is 766958
Received 766941 chunks. Missing 18 chunks. Max received chunk is 766958
Received 766957 chunks. Missing 2 chunks. Max received chunk is 766958
Received 766959 chunks. Missing 0 chunks. Max received chunk is 766958
Receiver: all chunks received, sending FIN and terminating
^C
hrushikeshrv@ubuntu-server:~/ee542/labs/lab2/src$ md5sum received_file
e4a2c359badf2ccc7d89b37f3fb636ca  received_file
hrushikeshrv@ubuntu-server:~/ee542/labs/lab2/src$
```

Figure 13: Server side MD5 sum

We then changed the MTU of all the network interfaces on the network to 9000, and tried all three cases again.

3.3 Case 1: RTT of 10ms, Packet loss of 1% (MTU 9000)

First we set up the network with the given constraints using the commands given in the lab. For the simple case of 10ms RTT and 1% loss, we observed a throughput of 83.59Mbps.

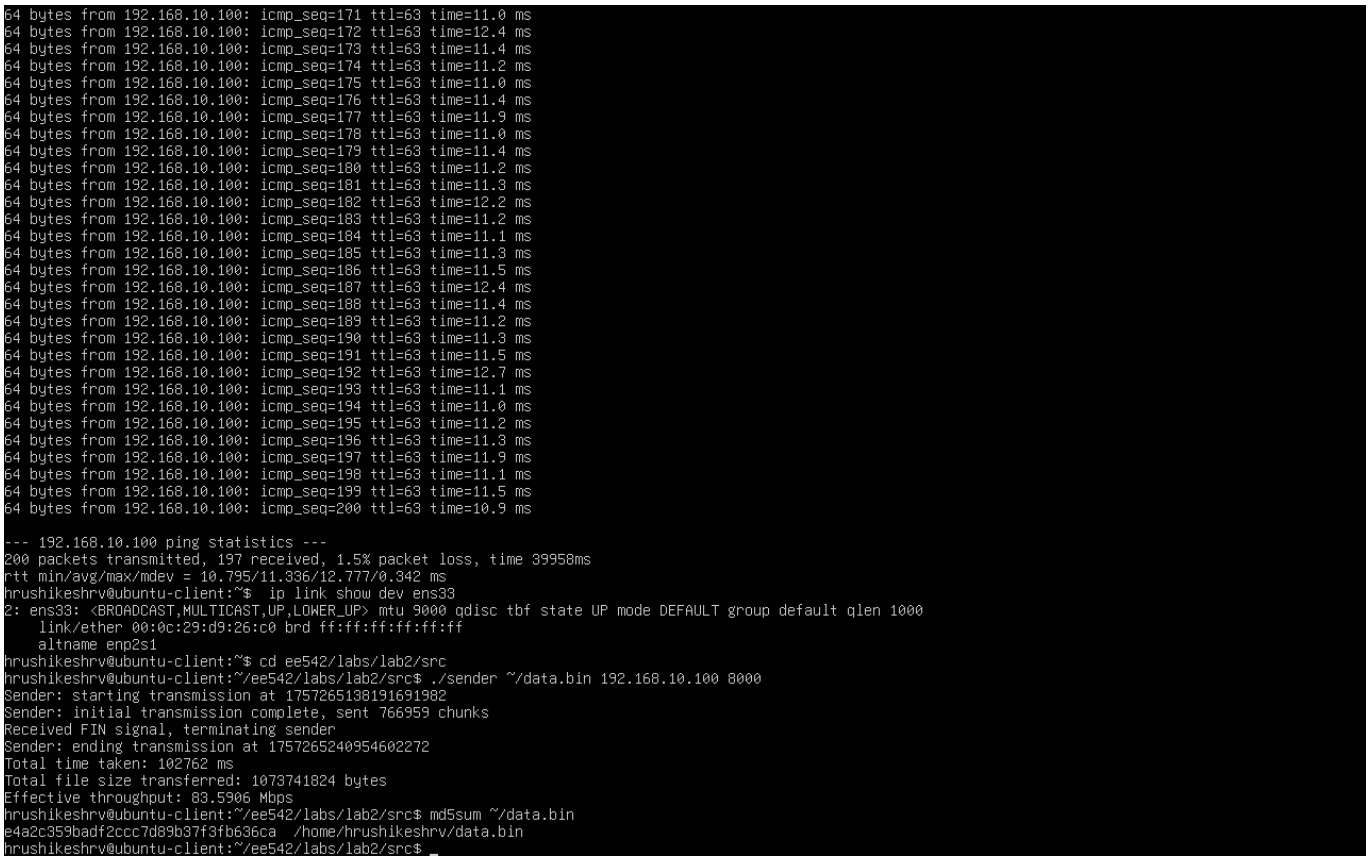

Figure 14: Client side throughtput and MD5 sum

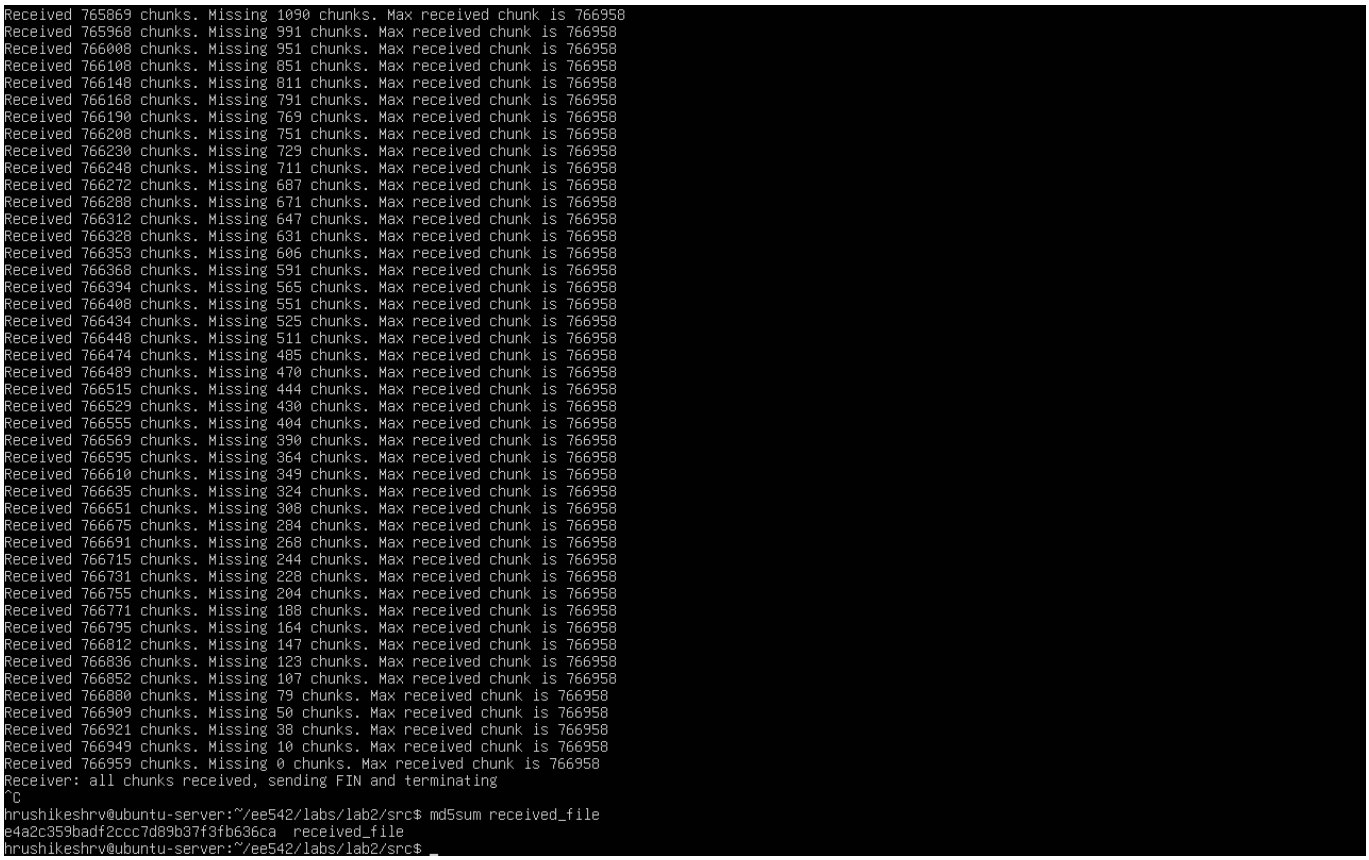

Figure 15: Server side MD5 sum

Case 2: RTT of 200ms, Packet loss of 20% (MTU 9000)

First we set up the network with the given constrains and verified them using the commands given in the lab. For the high loss case of 20%, we observed a throughput of 56.10Mbps.

```
64 bytes from 192.168.10.100: icmp_seq=135 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=137 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=139 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=140 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=141 ttl=63 time=203 ms
64 bytes from 192.168.10.100: icmp_seq=143 ttl=63 time=203 ms
64 bytes from 192.168.10.100: icmp_seq=144 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=146 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=148 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=149 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=151 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=153 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=154 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=155 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=156 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=157 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=158 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=159 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=160 ttl=63 time=204 ms
64 bytes from 192.168.10.100: icmp_seq=162 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=163 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=164 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=165 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=166 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=167 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=168 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=169 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=170 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=171 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=173 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=176 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=178 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=180 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=182 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=184 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=185 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=187 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=190 ttl=63 time=203 ms
64 bytes from 192.168.10.100: icmp_seq=191 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=193 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=196 ttl=63 time=203 ms
64 bytes from 192.168.10.100: icmp_seq=197 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=198 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=199 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=200 ttl=63 time=201 ms

--- 192.168.10.100 ping statistics ---
200 packets transmitted, 124 received, 38% packet loss, time 40475ms
rtt min/avg/max/mdev = 201.022/201.778/204.412/0.512 ms, pipe 2
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ _
```

Figure 16: Case 2 setup - client side

```
64 bytes from 192.168.20.100: icmp_seq=142 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=143 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=144 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=146 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=147 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=148 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=149 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=151 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=152 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=153 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=154 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=155 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=157 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=158 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=159 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=160 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=162 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=163 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=165 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=168 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=169 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=170 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=171 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=174 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=176 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=177 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=178 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=179 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=180 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=181 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=182 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=183 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=184 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=185 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=186 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=187 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=188 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=189 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=191 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=192 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=194 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=195 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=196 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=197 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=199 ttl=63 time=201 ms

--- 192.168.20.100 ping statistics ---
200 packets transmitted, 134 received, 33% packet loss, time 40425ms
rtt min/avg/max/mdev = 200.951/201.965/203.255/0.529 ms, pipe 2
hrushikeshrv@ubuntu-server:~/ee542/labs/lab2/src$ _
```

Figure 17: Case 2 setup - server side

```
64 bytes from 192.168.10.100: icmp_seq=155 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=156 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=157 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=158 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=159 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=160 ttl=63 time=204 ms
64 bytes from 192.168.10.100: icmp_seq=162 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=163 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=164 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=165 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=166 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=167 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=168 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=169 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=170 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=171 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=173 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=176 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=178 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=180 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=182 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=184 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=185 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=187 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=190 ttl=63 time=203 ms
64 bytes from 192.168.10.100: icmp_seq=191 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=193 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=196 ttl=63 time=203 ms
64 bytes from 192.168.10.100: icmp_seq=197 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=198 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=199 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=200 ttl=63 time=201 ms

--- 192.168.10.100 ping statistics ---
200 packets transmitted, 124 received, 38% packet loss, time 40475ms
rtt min/avg/max/mdev = 201.022/201.778/204.412/0.512 ms, pipe 2
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ iperf -c 192.168.10.100 -u -b 100mbit
------------------------------------------------------------
Client connecting to 192.168.10.100, UDP port 5001
Sending 1470 byte datagrams, IPG target: 117.60 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  1] local 192.168.20.100 port 48017 connected with 192.168.10.100 port 5001
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-10.0003 sec   119 MBytes   100 Mbits/sec
[  1] Sent 85039 datagrams
[  1] Server Report:
[ ID] Interval       Transfer     Bandwidth        Jitter   Lost/Total Datagrams
[  1] 0.0000-10.0108 sec  92.8 MBytes  77.8 Mbits/sec   0.196 ms 18814/85038 (22%)
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ _
```

Figure 18: Case 2 iperf results

```
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ ./sender ~/data.bin 192.168.10.100 8000
Sender: starting transmission at 1757265917368398352
Sender: initial transmission complete, sent 766959 chunks
Received FIN signal, terminating sender
Sender: ending transmission at 1757266070482029415
Total time taken: 153113 ms
Total file size transferred: 1073741824 bytes
Effective throughput: 56.1019 Mbps
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ md5sum ~/data.bin
e4a2c359badf2ccc7d89b37f3fb636ca  /home/hrushikeshrv/data.bin
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ _
```

Figure 19: Client side throughput and MD5 sum

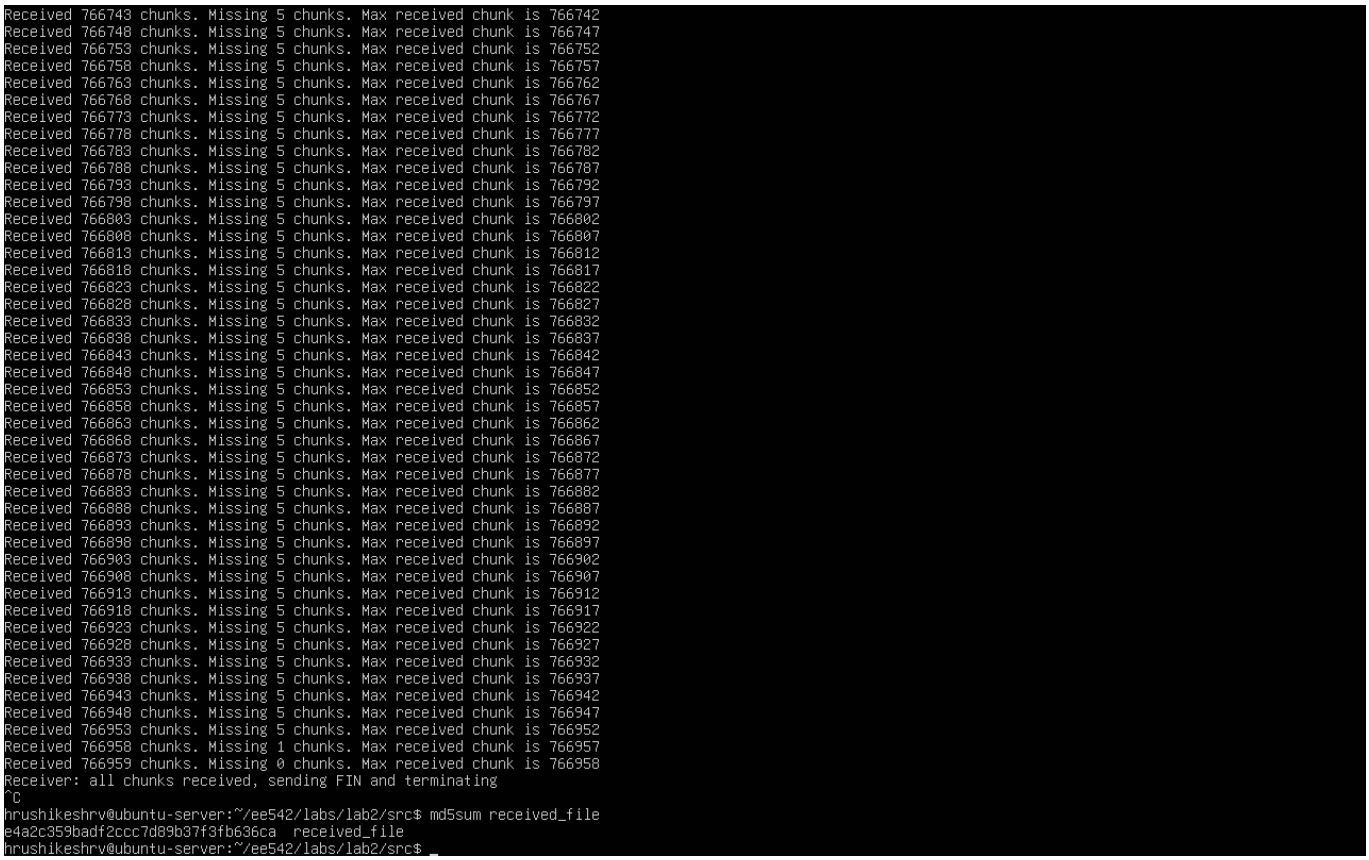

Figure 20: Server side MD5 sum

Case 3: RTT of 200ms, Packet loss of 0%, router bandwith of 80Mbps (MTU 9000)

First we set up the network with the given constraints and verified them using the commands given in the lab. For the router bottleneck case, we observed a throughput of 65.55Mbps.

```
64 bytes from 192.168.10.100: icmp_seq=156 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=157 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=158 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=159 ttl=63 time=203 ms
64 bytes from 192.168.10.100: icmp_seq=160 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=161 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=162 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=163 ttl=63 time=203 ms
64 bytes from 192.168.10.100: icmp_seq=164 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=165 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=166 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=167 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=168 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=169 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=170 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=171 ttl=63 time=204 ms
64 bytes from 192.168.10.100: icmp_seq=172 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=173 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=174 ttl=63 time=203 ms
64 bytes from 192.168.10.100: icmp_seq=175 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=176 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=177 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=178 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=179 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=180 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=181 ttl=63 time=203 ms
64 bytes from 192.168.10.100: icmp_seq=182 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=183 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=184 ttl=63 time=203 ms
64 bytes from 192.168.10.100: icmp_seq=185 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=186 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=187 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=188 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=189 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=190 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=191 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=192 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=193 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=194 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=195 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=196 ttl=63 time=201 ms
64 bytes from 192.168.10.100: icmp_seq=197 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=198 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=199 ttl=63 time=202 ms
64 bytes from 192.168.10.100: icmp_seq=200 ttl=63 time=202 ms

--- 192.168.10.100 ping statistics ---
200 packets transmitted, 200 received, 0% packet loss, time 40128ms
rtt min/avg/max/mdev = 200.916/201.857/204.197/0.550 ms, pipe 2
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$
```

Figure 21: Case 3 setup - client side

```
64 bytes from 192.168.20.100: icmp_seq=156 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=157 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=158 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=159 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=160 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=161 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=162 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=163 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=164 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=165 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=166 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=167 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=168 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=169 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=170 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=171 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=172 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=173 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=174 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=175 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=176 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=177 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=178 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=179 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=180 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=181 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=182 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=183 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=184 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=185 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=186 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=187 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=188 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=189 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=190 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=191 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=192 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=193 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=194 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=195 ttl=63 time=201 ms
64 bytes from 192.168.20.100: icmp_seq=196 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=197 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=198 ttl=63 time=203 ms
64 bytes from 192.168.20.100: icmp_seq=199 ttl=63 time=202 ms
64 bytes from 192.168.20.100: icmp_seq=200 ttl=63 time=202 ms

--- 192.168.20.100 ping statistics ---
200 packets transmitted, 200 received, 0% packet loss, time 40130ms
rtt min/avg/max/mdev = 201.135/202.058/204.687/0.597 ms, pipe 2
hrushikeshrv@ubuntu-server:~/ee542/labs/lab2/src$
```

Figure 22: Case 3 setup - server side

```
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ iperf -c 192.168.10.100 -u -b 100mbit
------------------------------------------------------------
Client connecting to 192.168.10.100, UDP port 5001
Sending 1470 byte datagrams, IPG target: 117.60 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  1] local 192.168.20.100 port 37026 connected with 192.168.10.100 port 5001
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-10.0002 sec   119 MBytes   100 Mbits/sec
[  1] Sent 85039 datagrams
[  1] Server Report:
[ ID] Interval       Transfer     Bandwidth        Jitter   Lost/Total Datagrams
[  1] 0.0000-10.0587 sec  93.3 MBytes  77.8 Mbits/sec   0.153 ms 18455/85038 (22%)
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ iperf -c 192.168.10.100
------------------------------------------------------------
Client connecting to 192.168.10.100, TCP port 5001
TCP window size: 16.0 KByte (default)
------------------------------------------------------------
[  1] local 192.168.20.100 port 47370 connected with 192.168.10.100 port 5001 (icwnd/mss/irtt=87/8948/201680)
[ ID] Interval       Transfer     Bandwidth
[  1] 0.0000-10.4172 sec  87.0 MBytes  70.1 Mbits/sec
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ _
```

Figure 23: Case 3 iperf results

```
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ ./sender ~/data.bin 192.168.10.100 8000
Sender: starting transmission at 1757267357782945099
Sender: initial transmission complete, sent 766959 chunks
Received FIN signal, terminating sender
Sender: ending transmission at 1757267488829253551
Total time taken: 131046 ms
Total file size transferred: 1073741824 bytes
Effective throughput: 65.549 Mbps
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ md5sum ~/data.bin
e4a2c359badf2ccc7d89b37f3fb636ca  /home/hrushikeshrv/data.bin
hrushikeshrv@ubuntu-client:~/ee542/labs/lab2/src$ _
```

Figure 24: Client side throughput and MD5 sum

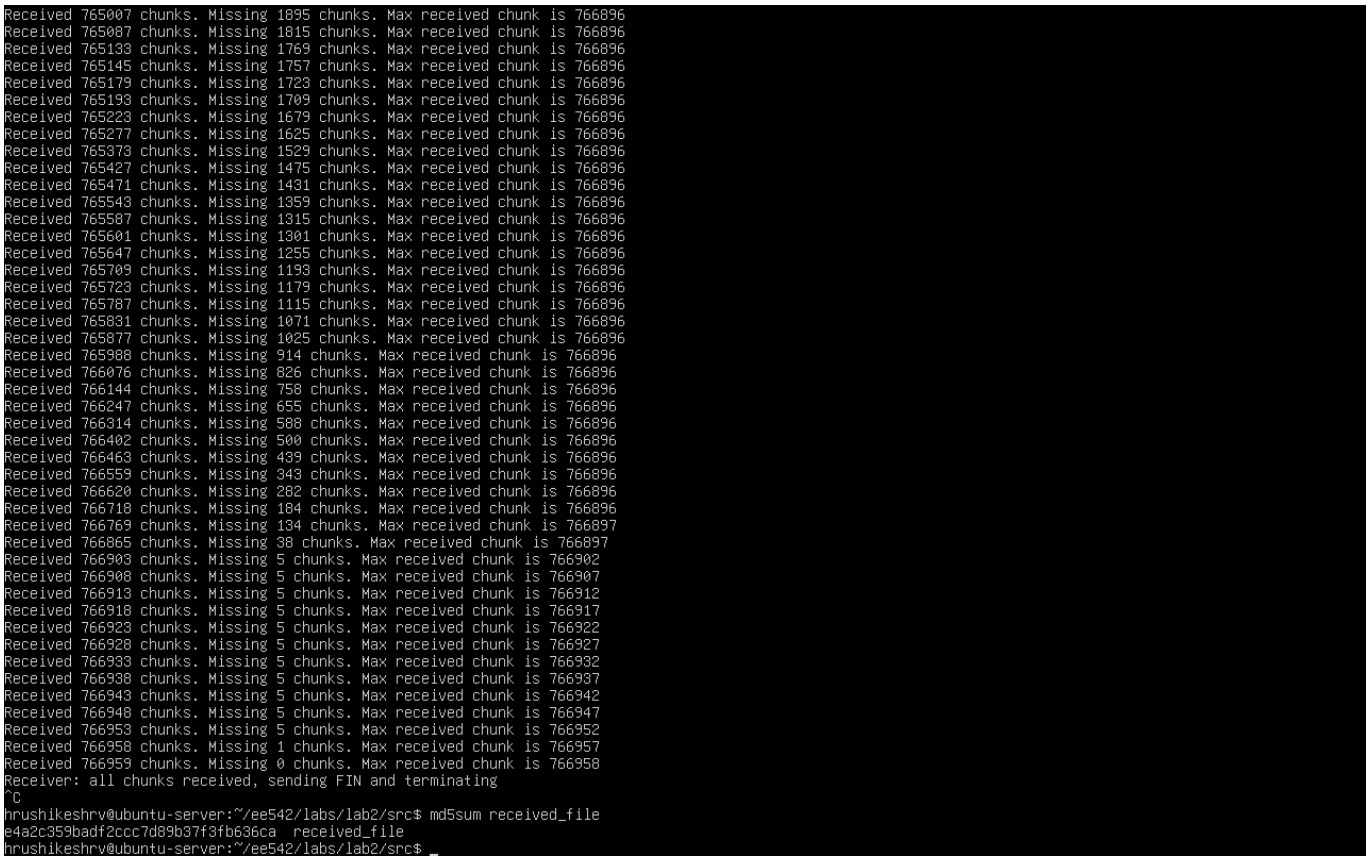

Figure 25: Server side MD5 sum

3.4 Results Table

Case	MTU	Throughput
1	1500	80.64Mbps
2	1500	32.33Mbps
3	1500	32.23Mbps
1	9000	83.59Mbps
2	9000	56.10Mbps
3	9000	65.55Mbps