

CS3543 : Computer Networks 2

Assignment 1



भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

Team Details :

Name	Roll No
Gantasala Naga Aneesh Ajaroy	CS19BTECH11010
Naga Hari Teja Peddi	CS19BTECH11021
Vemulapalli Aditya	CS19BTECH11025

Table Of Contents

Task 1 Report	2
Transmitting the 100MB file from the client to the server :	3
a) Under condition 1: without delay and packet loss	3
Time Taken and Throughput for 10 trials - Without Delay and Packet Loss	5
b) Under condition 2: with 50 ms delay and 5% packet loss	7
Time Taken and Throughput for 10 trials - With 50ms delay and 5% packet loss in both directions	8
Task 2 Report	10
Source Files	10
Application Header	11
Implementation of Sender	11
Implementation of Receiver	12
Features	12
Transmitting the 100MB file from the client to the server :	13
a) Under condition 1: without delay and packet loss	13
Time Taken and Throughput for 10 trials - Without Delay and Packet Loss	14
b) Under condition 2: with 50 ms delay and 5% packet loss	16
Time Taken and Throughput for 10 trials - With 50ms delay and 5% packet loss in both directions	17
Wireshark Results	19

Task 1 Report

Two ubuntu 20.04 servers are used.

Server 1: htserver1

Name: hari

IP Address: 192.168.122.189

Server 2: htserver2

Name: teja

IP Address: 192.168.122.156

- These 2 servers are connected using a local bridge bri0 which is set up in the terminal.
- To get the ip addresses of the 2 servers, `ip addr show` command is used.

```
hari@htserver1:~$ ip addr show
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN group default qlen 1000
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
        valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
        valid_lft forever preferred_lft forever
2: enp1s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group default qlen 1000
    link/ether 52:54:00:fa:11:50 brd ff:ff:ff:ff:ff:ff
    inet 192.168.122.189/24 brd 192.168.122.255 scope global dynamic enp1s0
        valid_lft 3431sec preferred_lft 3431sec
    inet6 fe80::5054:ff:fefa:1150/64 scope link
        valid_lft forever preferred_lft forever
hari@htserver1:~$ _
```

```
teja@htserver2:~$ ip addr show
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN group default qlen 1000
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
        valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
        valid_lft forever preferred_lft forever
2: enp1s0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group default qlen 1000
    link/ether 52:54:00:16:f6:c2 brd ff:ff:ff:ff:ff:ff
    inet 192.168.122.156/24 brd 192.168.122.255 scope global dynamic enp1s0
        valid_lft 3556sec preferred_lft 3556sec
    inet6 fe80::5054:ff:fe16:f6c2/64 scope link
        valid_lft forever preferred_lft forever
teja@htserver2:~$ _
```

- Ftp servers were installed in both of the servers.

- The command `sudo service vsftpd status` is used to find out about the status of ftp server in both the servers.

```
teja@htserver2:~$ sudo service vsftpd status
[sudo] password for teja:
• vsftpd.service - vsftpd FTP server
   Loaded: loaded (/lib/systemd/system/vsftpd.service; enabled; vendor preset: enabled)
   Active: active (running) since Fri 2022-02-18 15:19:06 UTC; 2min 52s ago
     Process: 661 ExecStartPre=/bin/mkdir -p /var/run/vsftpd/empty (code=exited, status=0/SUCCESS)
    Main PID: 667 (vsftpd)
      Tasks: 1 (limit: 1066)
     Memory: 812.0K
    CGroup: /system.slice/vsftpd.service
            └─667 /usr/sbin/vsftpd /etc/vsftpd.conf

Feb 18 15:19:06 htserver2 systemd[1]: Starting vsftpd FTP server...
Feb 18 15:19:06 htserver2 systemd[1]: Started vsftpd FTP server.
teja@htserver2:~$
```

Transmitting the 100MB file from the client to the server :

- We used server 1 as **client** and server 2 as **server** in our file transfer.

a) Under condition 1: without delay and packet loss

- In order to set up a link speed of 100Mbit between the two directly connected ubuntu servers, the command `sudo tc qdisc add dev enp1s0 root netem rate 100Mbit` is executed on both the servers.
- The link speed is verified using the command `tc qdisc show`

```
hari@htserver1:~$ sudo tc qdisc add dev enp1s0 root netem rate 100Mbit
hari@htserver1:~$ tc qdisc show
qdisc noqueue 0: dev lo root refcnt 2
qdisc netem 8001: dev enp1s0 root refcnt 2 limit 1000 rate 100Mbit
hari@htserver1:~$ _
```

```
teja@htserver2:~$ sudo tc qdisc add dev enp1s0 root netem rate 100Mbit
teja@htserver2:~$ tc qdisc show
qdisc noqueue 0: dev lo root refcnt 2
qdisc netem 8001: dev enp1s0 root refcnt 2 limit 1000 rate 100Mbit
teja@htserver2:~$ _
```

- Ftp server of ubuntu server 2 is opened in ubuntu server 1 using the command `ftp -p 192.168.122.156` for transfer of file. (Note that the IP address used is the address of server 2)
- Then to initiate the ftp we enter the server name and it's password.

```
hari@htserver1:~$ sudo tc qdisc add dev enp1s0 root netem rate 100Mbit
hari@htserver1:~$ tc qdisc show
qdisc noqueue 0: dev lo root refcnt 2
qdisc netem 8001: dev enp1s0 root refcnt 2 limit 1000 rate 100Mbit
hari@htserver1:~$ ftp -p 192.168.122.156
Connected to 192.168.122.156.
220 (vsFTPd 3.0.3)
Name (192.168.122.156:hari): hari_2
331 Please specify the password.
Password:
230 Login successful.
Remote system type is UNIX.
Using binary mode to transfer files.
ftp> _
```

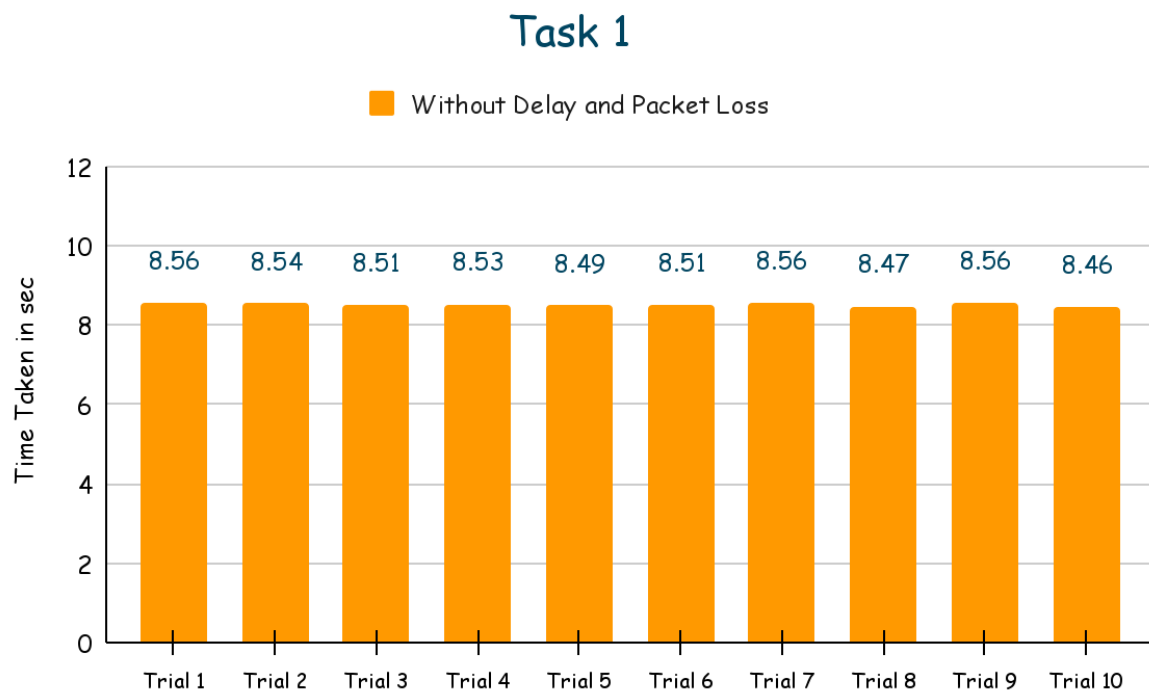
- Next 10 attempts of FTP were performed to transmit the file CS3453_100MB, by executing the command `put CS3543_100MB`

Some of the transfer results are shown below :

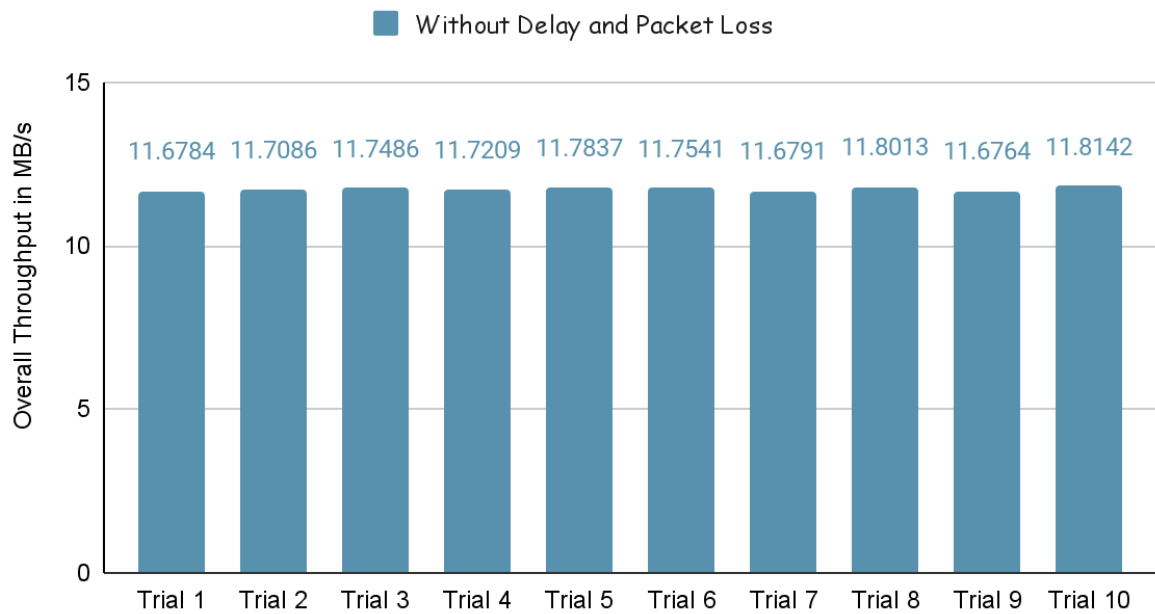
```
ftp> put CS3543_100MB
local: CS3543_100MB remote: CS3543_100MB
227 Entering Passive Mode (192,168,122,156,175,147).
150 Ok to send data.
226 Transfer complete.
104857600 bytes sent in 8.56 secs (11.6784 MB/s)
ftp>
```

```
ftp> put CS3543_100MB
local: CS3543_100MB remote: CS3543_100MB
227 Entering Passive Mode (192,168,122,156,166,192)
150 Ok to send data.
226 Transfer complete.
104857600 bytes sent in 8.54 secs (11.7086 MB/s)
```

Time Taken and Throughput for 10 trials - Without Delay and Packet Loss



Task 1



- The data plotted in above bar graphs can be observed in the below table.

Trial Number	Time Taken in seconds	Overall Throughput in MB/s
1	8.56	11.6784
2	8.54	11.7086
3	8.51	11.7486
4	8.53	11.7209
5	8.49	11.7837
6	8.51	11.7541
7	8.56	11.6791
8	8.47	11.8013
9	8.56	11.6764
10	8.46	11.8142

b) Under condition 2: with 50 ms delay and 5% packet loss

- In order to set up a delay of 50ms and loss percent of 5 between the two directly connected ubuntu servers, the command `sudo tc qdisc change dev enp1s0 root netem delay 50ms loss 5%` is executed on both server 1 and server 2.

```
hari@htserver1:~$ sudo tc qdisc add dev enp1s0 root netem rate 100Mbit
hari@htserver1:~$ sudo tc qdisc change dev enp1s0 root netem delay 50ms loss 5%
hari@htserver1:~$ tc qdisc show
qdisc noqueue 0: dev lo root refcnt 2
qdisc netem 8001: dev enp1s0 root refcnt 2 limit 1000 delay 50.0ms loss 5% rate 100Mbit
hari@htserver1:~$
```

- Ftp server of ubuntu server 2 is opened in ubuntu server 1 using the command `ftp -p 192.168.122.156` for transfer of file. (Note that the IP address used is the address of server 2)

```
hari@htserver1:~$ sudo tc qdisc add dev enp1s0 root netem rate 100Mbit
hari@htserver1:~$ sudo tc qdisc change dev enp1s0 root netem delay 50ms loss 5%
hari@htserver1:~$ tc qdisc show
qdisc noqueue 0: dev lo root refcnt 2
qdisc netem 8001: dev enp1s0 root refcnt 2 limit 1000 delay 50.0ms loss 5% rate 100Mbit
hari@htserver1:~$ ftp -p 192.168.122.156
Connected to 192.168.122.156.
220 (vsFTPd 3.0.3)
Name (192.168.122.156:hari): hari_2
331 Please specify the password.
Password:
230 Login successful.
Remote system type is UNIX.
Using binary mode to transfer files.
```

- Next 10 attempts of FTP were performed to transmit the file CS3453_100MB, by executing the command `put CS3543_100MB`

Some of the transfers are shown below:

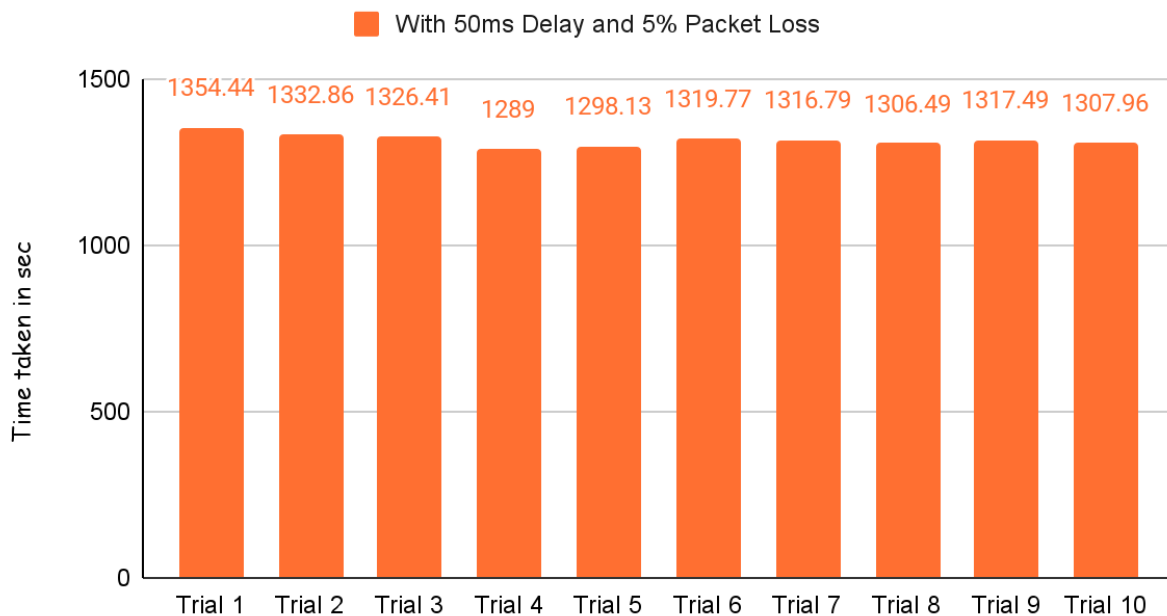
```
ftp> put CS3543_100MB
local: CS3543_100MB remote: CS3543_100MB
227 Entering Passive Mode (192,168,122,156,180,99)
150 Ok to send data.
226 Transfer complete.
104857600 bytes sent in 1354.44 secs (75.6032 kB/s)
ftp> _
```



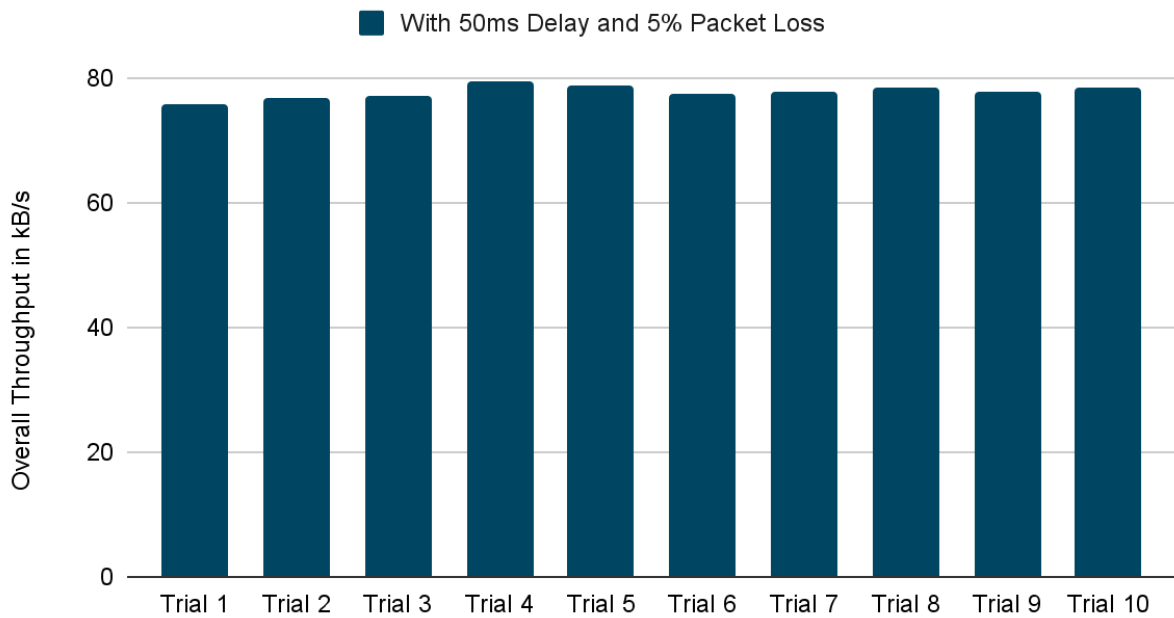
```
ftp> put CS3543_100MB
local: CS3543_100MB remote: CS3543_100MB
227 Entering Passive Mode (192,168,122,156,184,175)
150 Ok to send data.
226 Transfer complete.
104857600 bytes sent in 1332.86 secs (76.8270 kB/s)
ftp>
```

Time Taken and Throughput for 10 trials - With 50ms delay and 5% packet loss in both directions

Task 1



Task 1



- The data plotted in above bar graphs can be observed in the below table.

Trial Number	Time Taken in seconds	Overall Throughput in kB/s
1	1354.44	75.6032
2	1332.86	76.8270
3	1326.41	77.2008
4	1289	79.4413
5	1298.13	78.8830
6	1319.77	77.5891
7	1316.79	77.7649
8	1306.49	78.3779
9	1317.49	77.7234
10	1307.96	78.2898

Conclusion: It can be seen from the outputs that time taken under condition 2 is more than time taken under condition 1, throughput is more under condition 1 than throughput under condition 2.

Task 2 Report

Source Files

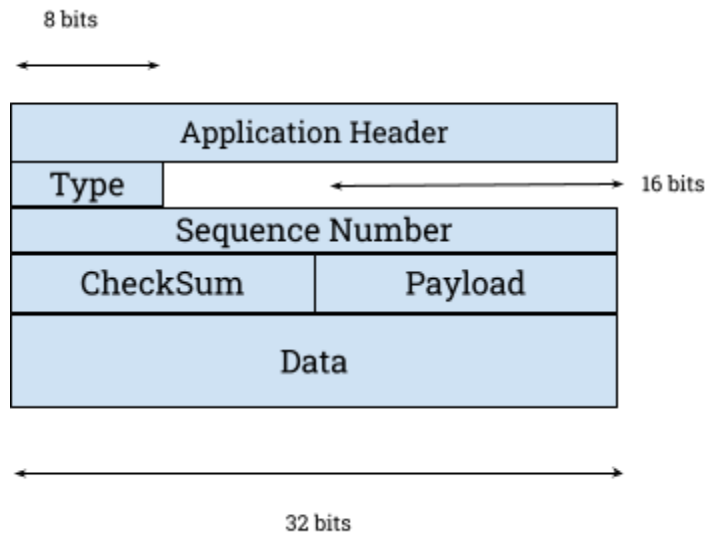
lib.py, sender.py, receiver.py

- Disable the firewall in the ubuntu servers before execution of these programs using [sudo ufw disable](#)
- Execute the programs with the following commands
[sudo python3 receiver.py \[receiver Port\] \[sender IP Addr\] \[sender Port\]](#)
[sudo python3 sender.py \[sender Port\] \[receiver IP Addr\] \[receiver Port\] \[filename\]](#)

```
teja@htserver2:~$ sudo tc qdisc add dev enp1s0 root netem rate 100Mbit
[sudo] password for teja:
teja@htserver2:~$ tc qdisc show
qdisc noqueue 0: dev lo root refcnt 2
qdisc netem 8001: dev enp1s0 root refcnt 2 limit 1000 rate 100Mbit
teja@htserver2:~$ sudo python3 receiver.py 2023 192.168.122.189 2022_
```

```
hari@htserver1:~$ sudo tc qdisc add dev enp1s0 root netem rate 100Mbit
[sudo] password for hari:
hari@htserver1:~$ tc qdisc show
qdisc noqueue 0: dev lo root refcnt 2
qdisc netem 8001: dev enp1s0 root refcnt 2 limit 1000 rate 100Mbit
hari@htserver1:~$ sudo python3 sender.py 2022 192.168.122.156 2023 CS3543_100MB_
```

Application Header



Implementation of Sender

Main Thread

- The program first sets port number for sender, IP Address for receiver, port number for receiver, file name from command line arguments.
- Opens the file, calculates the file size and how many packets are required to transmit the entire file data.
- Then it breaks down the file data into chunks, creates packets for transmission and stores them.
- It starts a thread for receiving ACKs from the receiver.
- It starts sending packets within the current window.
- It checks whether any new ACK has been received, updates the base pointer of the window accordingly and starts the timer accordingly.
- If timeout occurs then it retransmits the packets from the current window and the above process is repeated again.
- After transmission of all the packets, it sends a packet of type 3 to the receiver to indicate completion of file transfer and waits for the receive thread to join.
- After the receive thread stops, the program prints the time taken for file transfer in milliseconds.

Receive Thread

- It is started by the main thread before the start of transmission of packets.
- It waits for ACKs sent by the receiver.
- When it receives one, it performs checks such as whether the packet is of expected sequence number and whether the ACK is corrupted or not.
- If the checks are consistent, then it increments the cumulative ACK number otherwise just discards it.
- After it receives ACKs of all packets it waits for packet of type 3 from the sender which is indication for completion and when it receives one, the thread is stopped.

Implementation of Receiver

- The program first sets port number for receiver, IP Address for receiver, port number for sender from command line arguments.
- It gets the filename of the file which is being transferred from the sender.
- It starts receiving packets from the sender.
- Then it performs checks such as type of packet, whether the packet has expected sequence number, whether the packet is corrupted or not.
- If there is no problem, it sends ACK of the corresponding packet to the sender, otherwise sends the cumulative ACK to the sender.
- After sending all the packets it waits for a packet with type 3 for confirmation and stops when it receives it.

Features

Corrupted Packet Detection

- Checksum is used to help the receiver determine whether the data in the packets transmitted is corrupted or not. If the packet is corrupted then the receiver just discards the packet and sends the cumulative ACK to the sender.

Packet Loss Detection

- 32 bit sequence numbers are used in ordering of packets while sending them from sender to receiver. Packet loss is detected by the receiver when it encounters gaps in sequence numbers of received packets. The sender determines the lost packet or possibly corrupted when it does not receive ACK for that packet before it's timeout.

Acknowledgement

- The receiver uses acknowledgments to inform the sender that the packets have been received correctly without being corrupted. The acknowledgement implemented carries the cumulative sequence number of the packets received.

Packet Retransmission

- If a packet's ACK is not received by the sender before the timeout, the sender retransmits the packet until the packet's ACK is obtained.

Flow Control

- The sliding window protocol Go Back N is implemented to restrict flow control so that the sender doesn't overwhelm the receiver with packets.

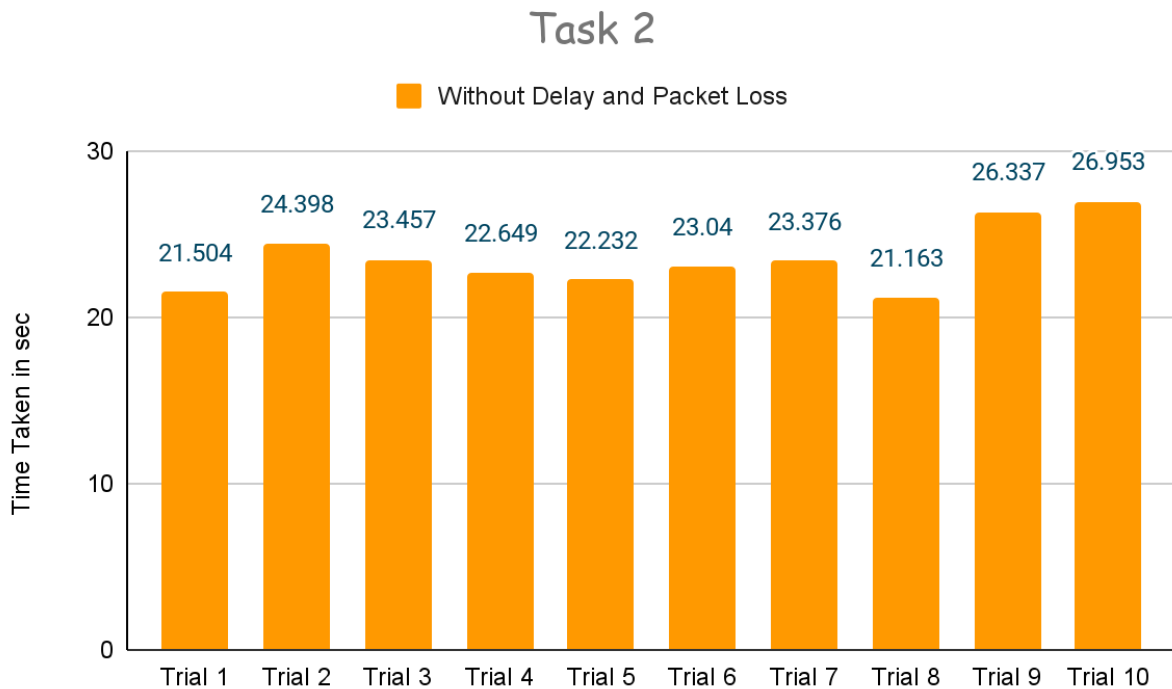
Transmitting the 100MB file from the client to the server :

a) Under condition 1: without delay and packet loss

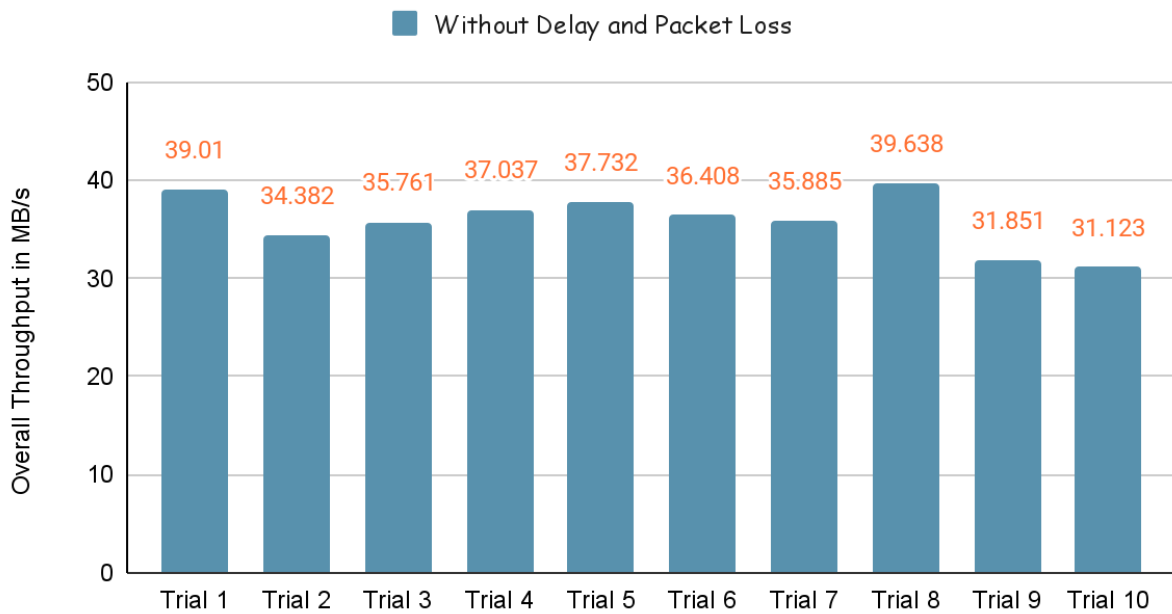
```
teja@htserver2:~$ sudo tc qdisc add dev enp1s0 root netem rate 100Mbit
[sudo] password for teja:
teja@htserver2:~$ tc qdisc show
qdisc noqueue 0: dev lo root refcnt 2
qdisc netem 8001: dev enp1s0 root refcnt 2 limit 1000 rate 100Mbit
teja@htserver2:~$ sudo python3 receiver.py 2023 192.168.122.189 2022
Waiting for Client...
Client Connected. File being transfered : CS3543_100MB
File Transfer Complete...
Received : 104857600 bytes
teja@htserver2:~$
```

```
hari@htserver1:~$ sudo tc qdisc add dev enp1s0 root netem rate 100Mbit
[sudo] password for hari:
hari@htserver1:~$ tc qdisc show
qdisc noqueue 0: dev lo root refcnt 2
qdisc netem 8001: dev enp1s0 root refcnt 2 limit 1000 rate 100Mbit
hari@htserver1:~$ sudo python3 sender.py 2022 192.168.122.156 2023 CS3543_100MB
File being transfered : CS3543_100MB
File Size : 104857600 bytes
Total Packets need to be transmitted : 25600
File Transfer Complete...
Time Taken For File Transfer : 21504 ms
```

Time Taken and Throughput for 10 trials - Without Delay and Packet Loss



Task 2



- The data plotted in the above bar plots can be observed in the below table.

Trial Number	Time Taken in seconds	Overall Throughput in MB/s
1	21.504	39.010
2	24.398	34.382
3	23.457	35.761
4	22.649	37.037
5	22.232	37.732
6	23.040	36.408
7	23.376	35.885
8	21.163	39.638
9	26.337	31.851
10	26.953	31.123

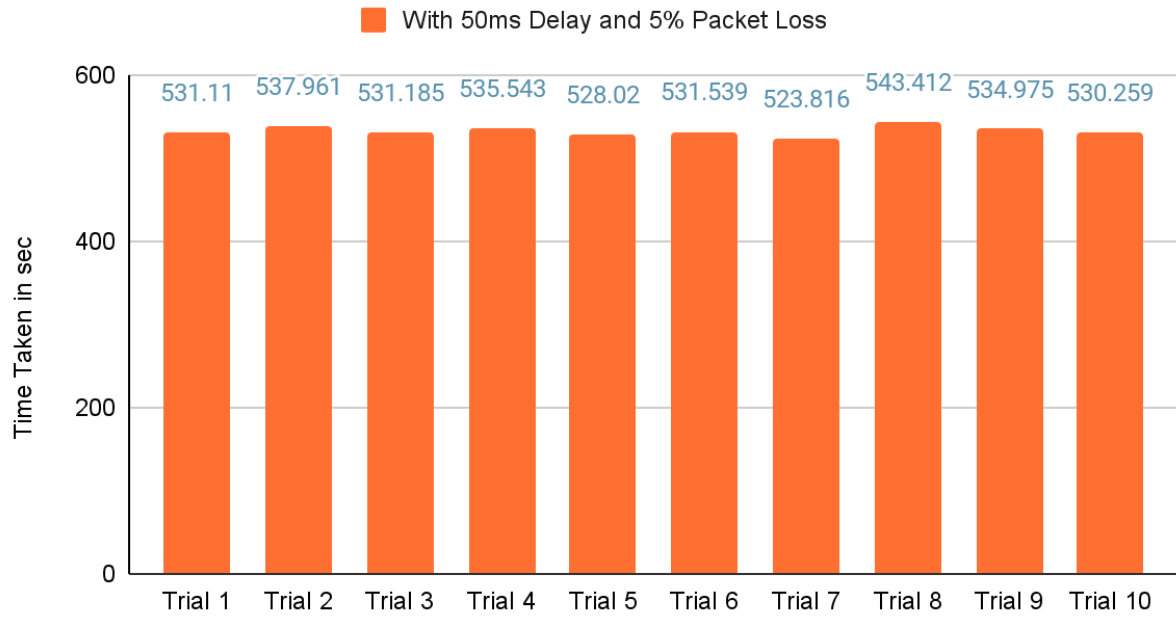
b) Under condition 2: with 50 ms delay and 5% packet loss

```
teja@htserver2:~$ sudo tc qdisc add dev enp1s0 root netem rate 100Mbit
[sudo] password for teja:
teja@htserver2:~$ sudo tc qdisc change dev enp1s0 root netem delay 50ms loss 5%
teja@htserver2:~$ tc qdisc show
qdisc noqueue 0: dev lo root refcnt 2
qdisc netem 8001: dev enp1s0 root refcnt 2 limit 1000 delay 50.0ms loss 5% rate 100Mbit
teja@htserver2:~$ sudo python3 receiver.py 2023 192.168.122.189 2022
Waiting for Client...
Client Connected. File being transfered : CS3543_100MB
File Transfer Complete...
Received : 104857600 bytes
teja@htserver2:~$
```

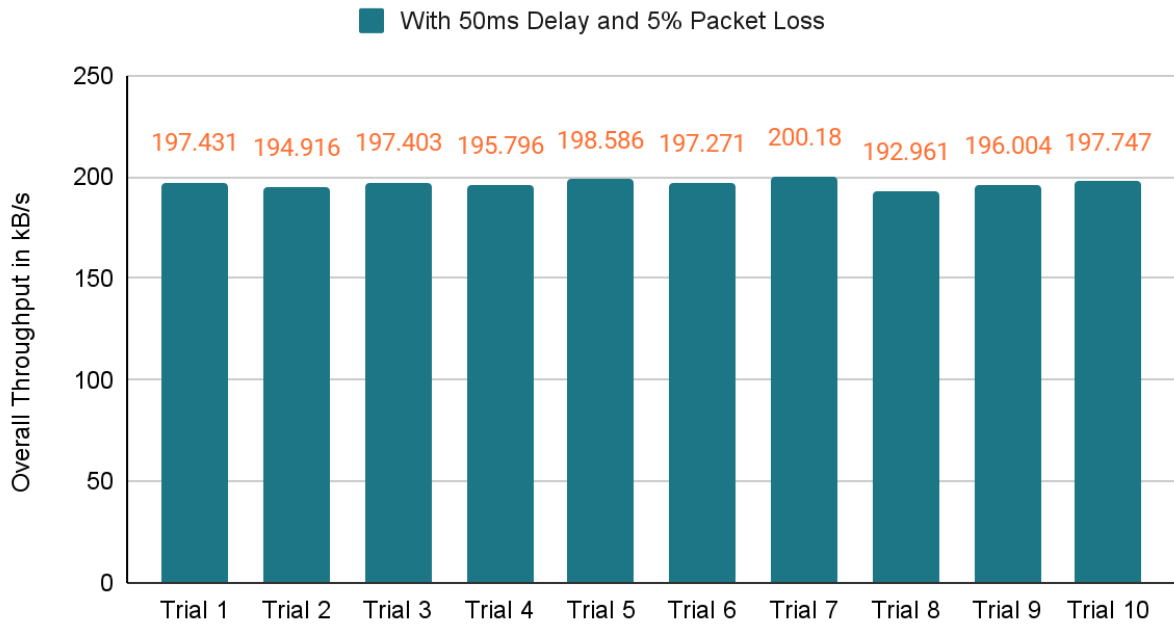
```
hari@htserver1:~$ sudo tc qdisc add dev enp1s0 root netem rate 100Mbit
[sudo] password for hari:
hari@htserver1:~$ sudo tc qdisc change dev enp1s0 root netem delay 50ms loss 5%
hari@htserver1:~$ tc qdisc show
qdisc noqueue 0: dev lo root refcnt 2
qdisc netem 8001: dev enp1s0 root refcnt 2 limit 1000 delay 50.0ms loss 5% rate 100Mbit
hari@htserver1:~$ sudo python3 sender.py 2022 192.168.122.156 2023 CS3543_100MB
File being transfered : CS3543_100MB
File Size : 104857600 bytes
Total Packets need to be transmitted : 25600
File Transfer Complete...
Time Taken For File Transfer : 531110 ms
```

Time Taken and Throughput for 10 trials - With 50ms delay and 5% packet loss in both directions

Task 2



Task 2



- The data plotted in the above bar plots can be observed in the below table.

Trial Number	Time Taken in seconds	Overall Throughput in kB/s
1	531.110	197.431
2	537.961	194.916
3	531.185	197.403
4	535.543	195.796
5	528.020	198.586
6	531.539	197.271
7	523.816	200.180
8	543.412	192.961
9	534.975	196.004
10	530.259	197.747

Wireshark Results

At the start of file transfer

No.	Time	Source	Destination	Protocol	Length	Info
5	6.983697153	RealtekU_16:f6:c2	RealtekU_fa:11:50	ARP	42	192.168.122.156 is at 52:54:00:16:f6:c2
6	22.010333210	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=0, ID=a410) [Reasse...
7	22.010446530	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=1480, ID=a410) [Rea...
8	22.010526262	192.168.122.189	192.168.122.156	UDP	1187	49953 → 2031 Len=4105
9	22.010656080	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=0, ID=a411) [Reasse...
10	22.010743697	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=1480, ID=a411) [Rea...
11	22.010877434	192.168.122.189	192.168.122.156	UDP	1187	49953 → 2031 Len=4105
12	22.010993764	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=0, ID=a412) [Reasse...
13	22.011081272	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=1480, ID=a412) [Rea...
14	22.011175642	192.168.122.189	192.168.122.156	UDP	1187	49953 → 2031 Len=4105
15	22.011296667	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=0, ID=a413) [Reasse...
16	22.011418513	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=1480, ID=a413) [Rea...
17	22.011513108	192.168.122.189	192.168.122.156	UDP	1187	49953 → 2031 Len=4105
18	22.011634085	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=0, ID=a414) [Reasse...
19	22.011732176	192.168.122.189	192.168.122.156	IPv4	1187	Fragmented IP protocol (proto=UDP 17, off=2960, ID=a414) [Rea...
20	22.011850017	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=0, ID=a415) [Reasse...
21	22.011971196	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=1480, ID=a415) [Rea...
22	22.012092295	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=0, ID=a416) [Reasse...
23	22.012213450	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=1480, ID=a416) [Rea...
24	22.012308317	192.168.122.189	192.168.122.156	UDP	1187	49953 → 2031 Len=4105
25	22.012429822	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=0, ID=a417) [Reasse...
26	22.012550855	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=1480, ID=a417) [Rea...
27	22.012671706	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=0, ID=a418) [Reasse...
28	22.012822167	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=1480, ID=a418) [Rea...
29	22.012888618	192.168.122.189	192.168.122.156	UDP	1187	49953 → 2031 Len=4105
30	22.013008927	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=0, ID=a419) [Reasse...
31	22.013164103	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=1480, ID=a419) [Rea...
32	22.013225488	192.168.122.189	192.168.122.156	UDP	1187	49953 → 2031 Len=4105
33	22.013380395	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=0, ID=a41a) [Reasse...

▶ Frame 8: 1187 bytes on wire (9496 bits), 1187 bytes captured (9496 bits) on interface bri0, id 0

▶ Ethernet II, Src: RealtekU_fa:11:50 (52:54:00:fa:11:50), Dst: RealtekU_16:f6:c2 (52:54:00:16:f6:c2)

▶ Internet Protocol Version 4, Src: 192.168.122.189, Dst: 192.168.122.156

▶ User Datagram Protocol, Src Port: 49953, Dst Port: 2031

Source Port: 49953

Destination Port: 2031

Length: 4113

Checksum: 0x9e00 [unverified]

[Checksum Status: Unverified]

[Stream index: 0]

▶ [Timestamps]

▶ Data (4105 bytes)

Data: 000000000b89e1000c9db00f95799cef588ddc80de77c2...

[Length: 4105]

End of File Transfer

```
teja@htserver2:~$ sudo tc qdisc add dev enp1s0 root netem rate 100Mbit
[sudo] password for teja:
teja@htserver2:~$ tc qdisc show
qdisc noqueue 0: dev lo root refcnt 2
qdisc netem 8001: dev enp1s0 root refcnt 2 limit 1000 rate 100Mbit
teja@htserver2:~$ sudo tc qdisc change dev enp1s0 root netem delay 50ms loss 5%
teja@htserver2:~$ sudo python3 receiver.py 2031 192.168.122.189 2030
Waiting for Client...
Client Connected. File being transfered : CS3543_100MB
File Transfer Complete...
Received : 104857600 bytes
```

```

hari@htserver1:~$ sudo tc qdisc add dev enp1s0 root netem rate 100Mbit
[sudo] password for hari:
Sorry, try again.
[sudo] password for hari:
hari@htserver1:~$ tc qdisc show
qdisc noqueue 0: dev lo root refcnt 2
qdisc netem 8001: dev enp1s0 root refcnt 2 limit 1000 rate 100Mbit
hari@htserver1:~$ sudo tc qdisc change dev enp1s0 root netem delay 50ms loss 5%
hari@htserver1:~$ sudo python3 sender.py 2030 192.168.122.156 2031 CS3543_100MB
File being transfered : CS3543_100MB
File Size : 104857600 bytes
Total Packets need to be transmitted : 25600
File Transfer Complete...
Time Taken For File Transfer : 509953 ms
hari@htserver1:~$

```

No.	Time	Source	Destination	Protocol	Length	Info
4922..	531.720392106	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.721265492	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.763171496	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.763374884	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.764279941	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.764548514	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.764820522	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.765192306	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.765491416	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.765934292	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.766232637	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.766503445	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.766867449	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.767254050	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.767518120	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.767918377	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.769101427	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.823782735	192.168.122.189	192.168.122.156	IPv4	1514	Fragmented IP protocol (proto=UDP 17, off=0, ID=b054) [Reasse..
4922..	531.823815670	192.168.122.189	192.168.122.156	UDP	1514	49953 → 2031 Len=4105
4922..	531.823936032	192.168.122.189	192.168.122.156	IPv4	1187	Fragmented IP protocol (proto=UDP 17, off=2960, ID=b054)
4922..	531.823951609	192.168.122.189	192.168.122.156	UDP	52	49953 → 2031 Len=10
4922..	531.874281864	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.874303166	192.168.122.156	192.168.122.189	UDP	52	2031 → 2030 Len=10
4922..	531.889584263	RealtekU_fa:11:50	Broadcast	ARP	42	Who has 192.168.122.1? Tell 192.168.122.189
4922..	532.027223912	RealtekU_16:f6:c2	Broadcast	ARP	42	Who has 192.168.122.1? Tell 192.168.122.156
4922..	532.915011132	RealtekU_fa:11:50	Broadcast	ARP	42	Who has 192.168.122.1? Tell 192.168.122.189
4922..	533.052208359	RealtekU_16:f6:c2	Broadcast	ARP	42	Who has 192.168.122.1? Tell 192.168.122.156
4922..	533.691400531	192.168.122.156	192.168.122.189	ICMP	590	Time-to-live exceeded (Fragment reassembly time exceeded)
4922..	533.691428059	192.168.122.156	192.168.122.189	ICMP	590	Time-to-live exceeded (Fragment reassembly time exceeded)
▶ Frame 492233: 52 bytes on wire (416 bits), 52 bytes captured (416 bits) on interface bri0, id 0 ▶ Ethernet II, Src: RealtekU_16:f6:c2 (52:54:00:16:f6:c2), Dst: RealtekU_fa:11:50 (52:54:00:fa:11:50) ▶ Internet Protocol Version 4, Src: 192.168.122.156, Dst: 192.168.122.189 ▶ User Datagram Protocol, Src Port: 2031, Dst Port: 2030 Source Port: 2031 Destination Port: 2030 Length: 18 Checksum: 0x76ce [unverified] [Checksum Status: Unverified] [Stream index: 1] [Timestamps] ▶ Data (10 bytes) Data: 03000000000000000000 [Length: 10]						

- The time taken for the transfer as captured by wireshark (end - start = 531.874 - 22.010 = 509.864 seconds) is consistent with the time shown in the sender program results.