CSE232 Monsoon 2024: PA04
Network simulation and TCP congestion control analysis using ns3

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Question-1

Default Parameter Values:
Link bandwidth between the two nodes: N0-N1 = 10Mbps, N1-N2 = 7Mbps
One way delay of the link: N0-N1 = 100ms, N1-N2 = 10ms
Loss rate of packets on the link: 0.000001
Queue size of the buffer at node 1: 50 packets
TCP variant used: TcpNewReno
Simulation time: 10 seconds
Application payload size: 1460 bytes

(a)

The **maximum theoretical throughput** is the bottleneck link in the network because it limits the rate at which data can be transferred.

From the above configuration,

- [ ] **Link N0-N1** bandwidth is 10 Mbps and delay = 100 ms
- [ ] **Link N1-N2** bandwidth is 7 Mbps and delay is 10 ms.

Even if the N0-N1 link can support up to 10 Mbps, the data leaving N1 for N2 is restricted to 7 Mbps due to the lower capacity of the N1-N2 link. Any excess data at N1 will queue up or be dropped if buffers are full. Therefore the bottleneck is the **N1-N2 link** with a bandwidth of **7 Mbps**. **Hence, the maximum expected value of throughput is 7 Mbps.**

(b)

The **Bandwidth-Delay Product (BDP)** is defined as the amount of data (in bits) that can fit in the network, given the bandwidth and round-trip delay so that the bandwidth can be utilized to its full capacity.

BDP Formula:

1. BDP (in terms of bits) = BW * delay

BW = bottleneck bandwidth = 7 Mbps
Delay = RTT = 2 * (N0-N1 + N1-N2) = 2*(100+10) = 220 ms = 0.22 sec
So, **BDP (in terms of bits) = 7 * 10^6 * 0.22 = 1540000 bits = 1.54 Mb**

2. BDP (in terms of packets) = BDP (in bits) / packet size (in bits)
   Packet size = 1460 bytes = 1460*8 = 11680 bits
   So, **BDP (in terms of packets) = 1540000 / 11680 = 132 pkts**

(c)

Using the command we can get the total bytes transferred along with the time duration:
“tshark -r tcp-example-2-0.pcap -q -z conv,tcp”

```
subham-maurya@subham-maurya-VirtualBox:~/ns-allinone-3.42/ns-3.42$ tshark -r tcp-example-2-0.pcap -q -z conv,tcp
================================================================================
TCP Conversations
Filter:<No Filter>
                                                 |       <-      | |       ->      | |     Total     |    Relative    |   Duration   |
                                                 | Frames  Bytes | | Frames  Bytes | | Frames  Bytes |      Start     |              |
10.1.1.1:49153             <-> 10.1.2.2:8080       2879 157 kB     5389 3,092 kB     8268 3,249 kB     0.000000000         8.8599
================================================================================
```

From the above observation:
Total bytes transferred = 3249 kB
Total time duration = 8.599

Average throughput = Total data transferred (in bits) / time duration (in seconds)
= 3249*1024*8 / 8.599
= 3.0952 Mbps
~ 3.1 Mbps

The **average throughput** of the TCP transfer is approximately **3.1 Mbps**.

(d)

In part-(a), the maximum expected throughput is **7 Mbps**, determined by the bottleneck link (N1-N2 with a bandwidth of 7 Mbps) while in part- (b), the achieved throughput is approximately **3.1 Mbps**, which is significantly lower than the theoretical maximum.

Reason for the difference in maximum and average expected Throughput:

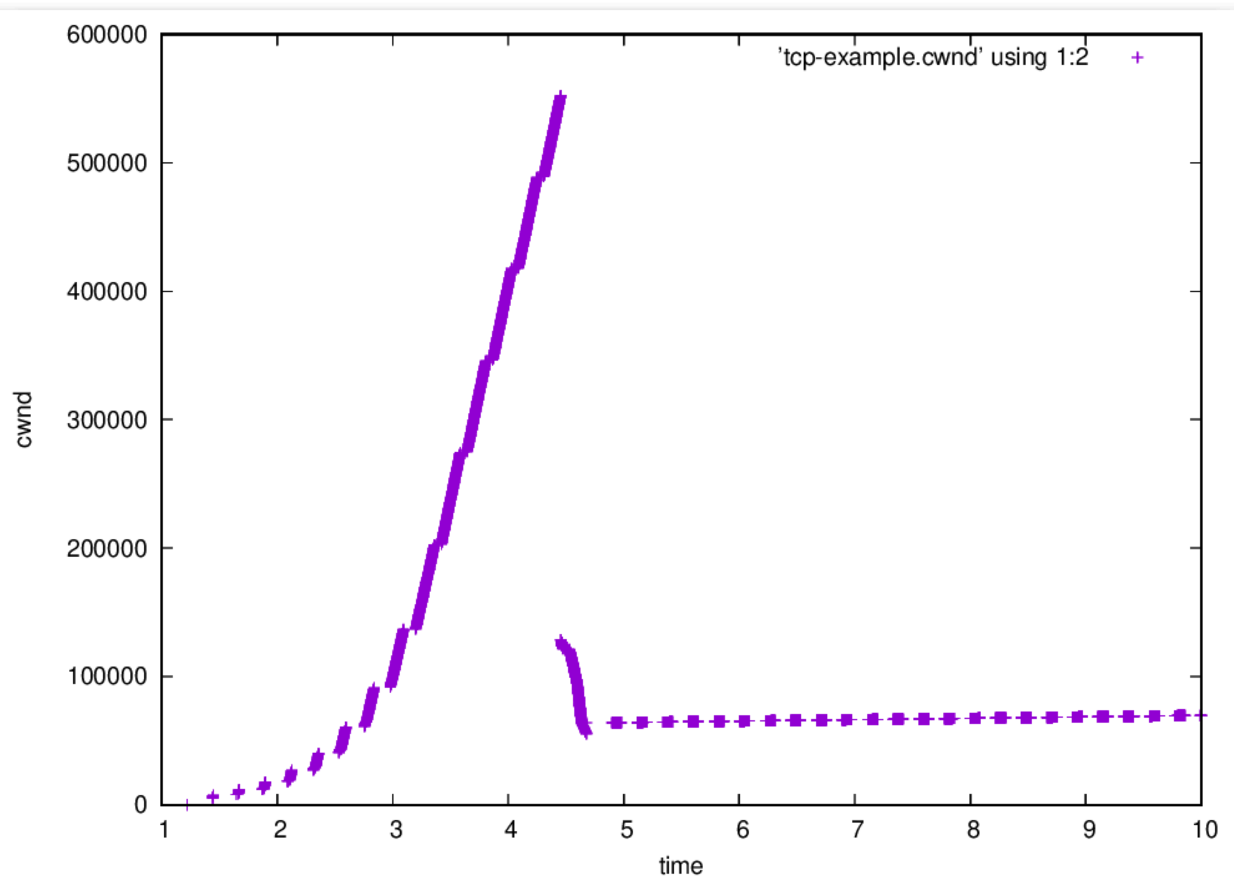
1. **Bandwidth Utilization:** TCP might not fully utilize the bottleneck link due to its congestion control mechanisms (e.g., slow start, congestion avoidance). Therefore, If any packet losses occur or RTT increases, then TCP reduces its sending rate.
2. **Buffering Delays:** Buffering delays or insufficient queue sizes at N1 can also restrict throughput.

3. **Packet Loss:** Even with a small packet loss rate, TCP may experience retransmissions, reducing effective throughput. Losses due to buffer overflow at N1 further exacerbate this.
4. **Congestion Window (cwnd) Dynamics:** If the TCP sender's congestion window grows slowly or fluctuates due to losses, the sender cannot sustain high transmission rates.

(e)

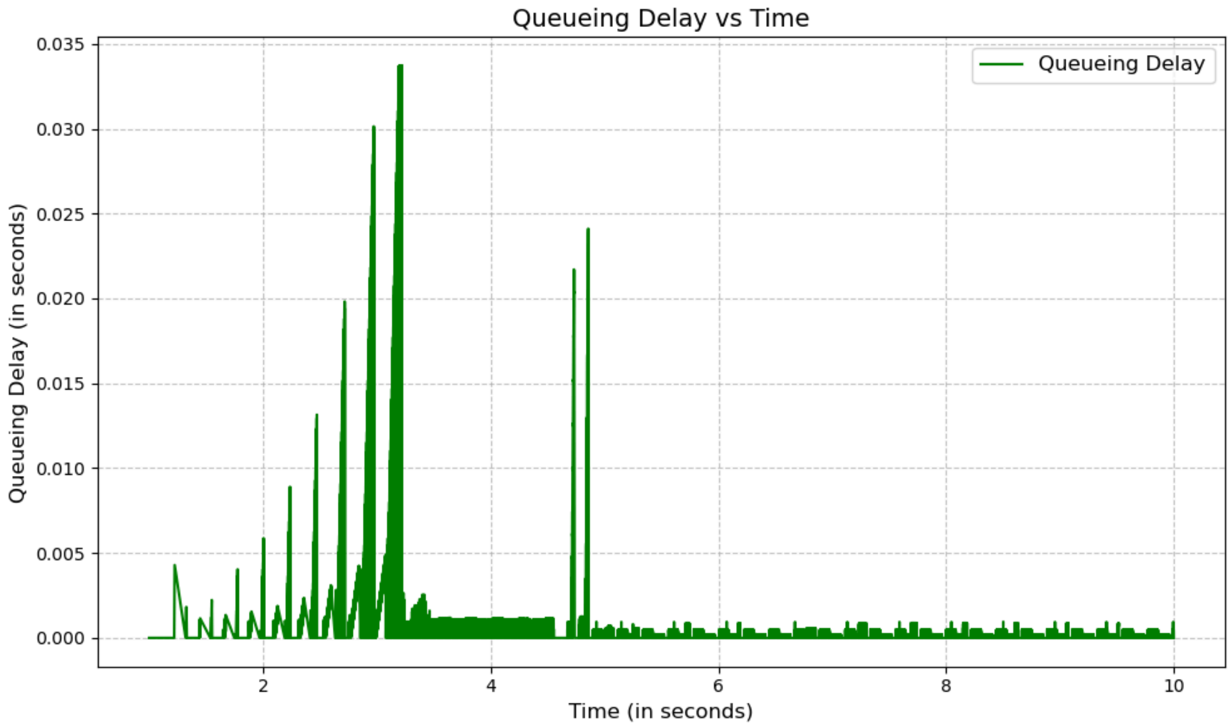
After running the command **"gnuplot example.gp",** we get the following graph

```
set term postscript eps color
set output 'cwnd.eps'
set ylabel 'cwnd'
set xlabel 'time'
plot 'tcp-example.cwnd' using 1:2
```



(f)

For plotting this graph we have used the **tcp-example.tr** to get the enqueue and dequeue time of the packets in the buffer which is further used to calculate the queueing delay via **dequeue time - enqueue time.**



(g)

Yes, the plots in 1(e) and 1(f) are related.

Reason:

- [ ] When the CWND increases, you can see an increase in the queueing delay in the corresponding timeframe on the queueing delay plot.
- [ ] When the CWND decreases such as due to congestion events like packet loss, you can see that the queueing delay reduces as the queue drains.

Question-2

(a)

Using the command we can get the total bytes transferred along with the time duration:
“tshark -r tcp-example-2-0.pcap -q -z conv,tcp”

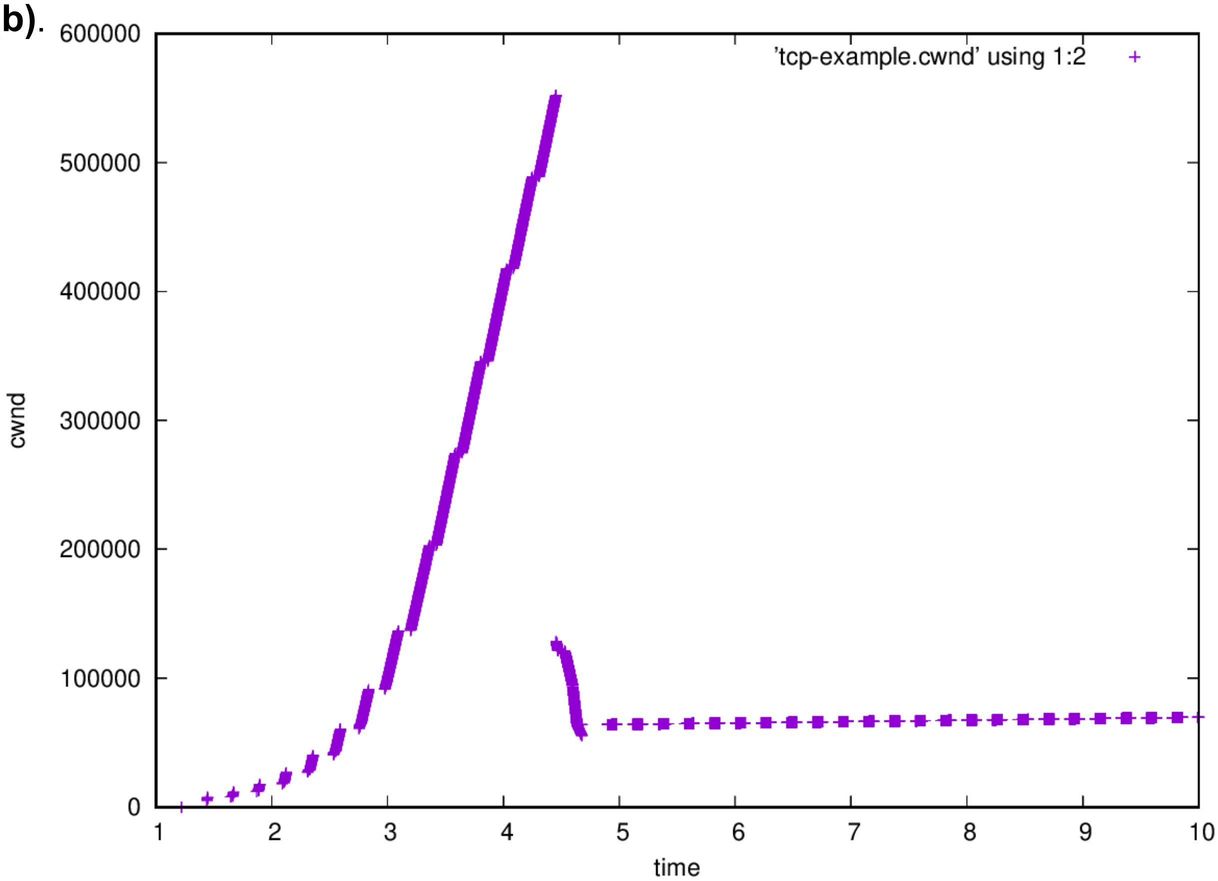
```
subham-maurya@subham-maurya-VirtualBox:~/ns-allinone-3.42/ns-3.42$ tshark -r tcp-example-2-0.pcap -q -z conv,tcp
================================================================================
TCP Conversations
Filter:<No Filter>
                                                  |       <-      | |       ->      | |     Total     |    Relative    |   Duration   |
                                                  | Frames  Bytes | | Frames  Bytes | | Frames  Bytes |      Start     |              |
10.1.1.1:49153             <-> 10.1.2.2:8080        2879 157 kB      5389 3,092 kB      8268 3,249 kB     0.000000000         8.8599
================================================================================
```

From the above observation:
Total bytes transferred = 3249 kB
Total time duration = 8.599

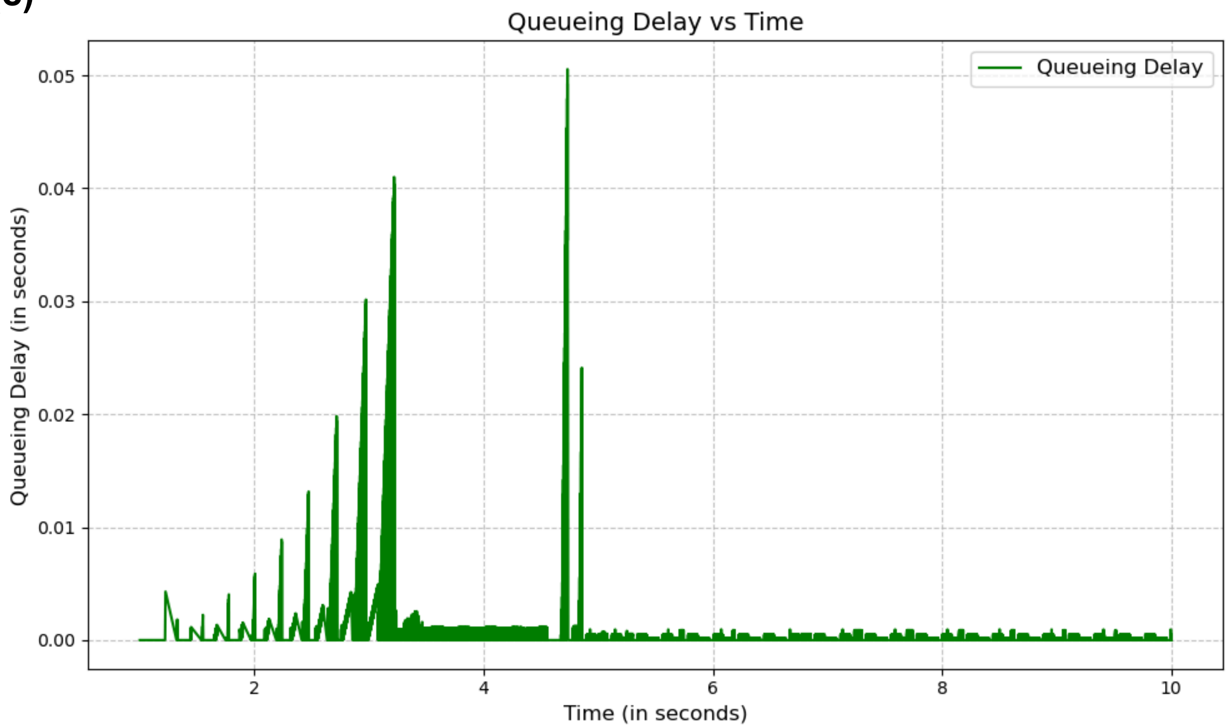
Average throughput = Total data transferred (in bits) / time duration (in seconds)
= 3249*1024*8 / 8.599
= 3.0952 Mbps
~ 3.1 Mbps

The **average throughput** of the TCP transfer is approximately **3.1 Mbps** which is same as Q1.

(b).



(c)



(d)

On comparing CWND plots of Q1 and Q2 we can say that both graph are exactly same along with same average throughput.
This shows below potential insights:

1. Increasing the queue size from 50 to 1000 has no impact on CWND, it suggests that the queue was rarely or never full even with the smaller size (50 packets) which can also be seen from queueing delay.
2. The CWND growth is governed by **congestion control algorithms** like **TcpNewReno**. If CWND remains unaffected, it indicates that TCP is not experiencing significant packet loss or congestion-related events caused by the queue.
3. If CWND shows no significant drops or fluctuations, TCP is not detecting losses. This suggests:
    - No buffer overflows occurred even with a 50-packet queue.
    - Losses, if present, are due to other factors (e.g., link errors or limited receiver window).

Question-3

Assuming that the changes are directly applied to default parameters only.

(a)

Using the command we can get the total bytes transferred along with the time duration:
“tshark -r tcp-example-2-0.pcap -q -z conv,tcp”

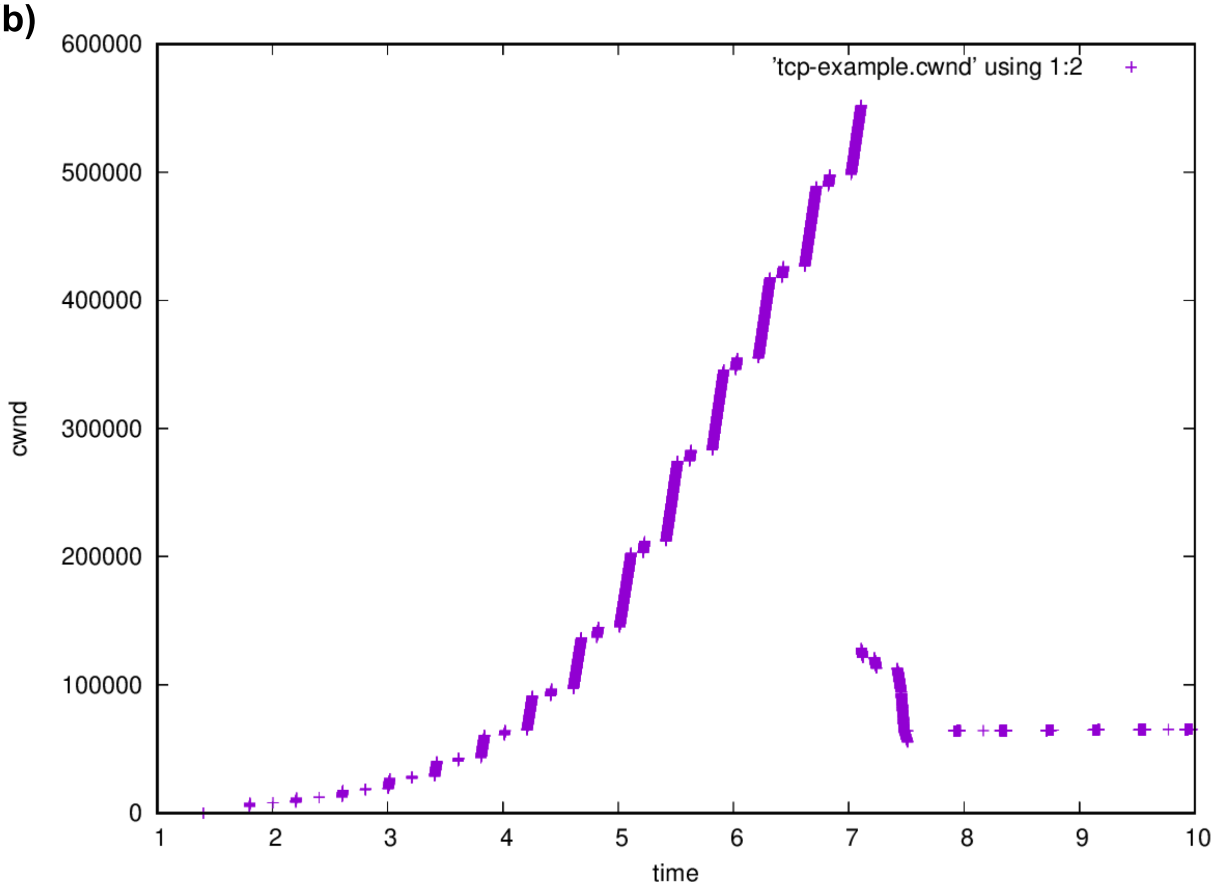
```
subham-maurya@subham-maurya-VirtualBox:~/ns-allinone-3.42/ns-3.42$ tshark -r tcp-example-2-0.pcap -q -z conv,tcp
================================================================================
TCP Conversations
Filter:<No Filter>
                                                       |       <-      | |       ->      | |     Total     |    Relative    |   Duration   |
                                                       | Frames  Bytes | | Frames  Bytes | | Frames  Bytes |      Start     |              |
10.1.1.1:49153             <-> 10.1.2.2:8080             1756 96 kB      3141 1,765 kB     4897 1,862 kB     0.000000000         8.7733
================================================================================
```

From the above observation:
Total bytes transferred = 1862 kB
Total time duration = 8.7733

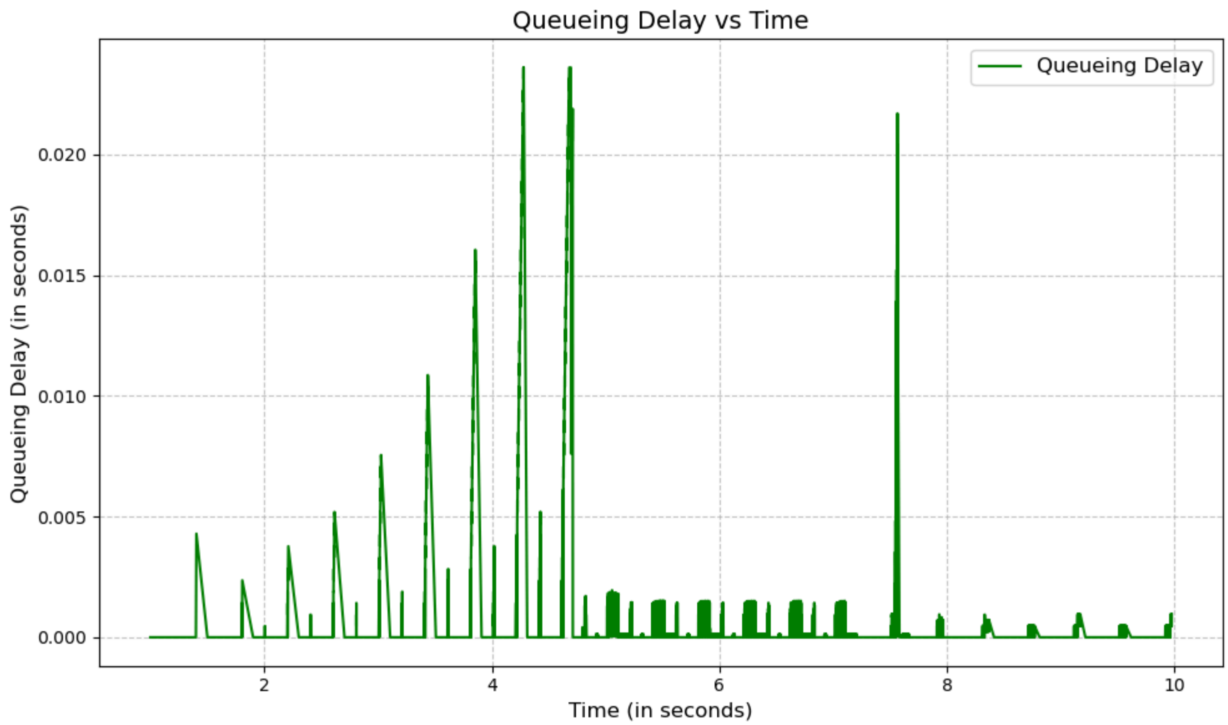
Average throughput = Total data transferred (in bits) / time duration (in seconds)
= 1862*1024*8 / 8.7733
= 1.7386 Mbps
~ 1.74 Mbps

The **average throughput** of the TCP transfer is approximately **1.74 Mbps**.

(b)



(c)



(d)

On comparing Queueing delay plots of Q1 and Q3 we can say that:

1. Q1 the queueing delays appears to be more concentrated with sharp increases and decreases while the queueing delay in Q3 is smoother and more spread over time because the higher N1-N2 delay time in Q3 causes the packet to take longer to traverse the network which eventually decreases the congestion but increase queue persistence.
2. Q1 exhibits higher queueing delay peaks (~0.05) while Q3 shows smaller (max ~0.025) but persistence queueing delay peaks because higher bandwidth in Q3 allows more packets to arrive in shorter interval.