CN Assignment-4

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1 Question 1

1.1 (a)

The maximum expected value (theoretical) of throughput is **7 Mbps**.

The throughput of a TCP flow is limited by the link with the smallest capacity (**bottleneck link**). In this case, the maximum throughput is limited by the bottleneck link **N1-N2**, as it has a lower bandwidth of **7 Mbps** compared to **10 Mbps** of the **N0-N1** link. Thus, the bottleneck link dictates the maximum achievable throughput.

1.2 (b)

Using the formula:

$$\text{BDP} = \text{Bottleneck Bandwidth} \times \text{RTT (Round-Trip Time)}$$

- **Bandwidth of the bottleneck link (N1-N2)**: $7\,\text{Mbps}$
- **RTT**:

$$\text{RTT} = 2 \times (\text{N0-N1 delay} + \text{N1-N2 delay})$$

  Substituting the values:

$$\text{RTT} = 2 \times (100\,\text{ms} + 10\,\text{ms}) = 220\,\text{ms}$$

Now, calculate BDP:

$$\text{BDP} = 7 \times 10^6\,\text{bits/sec} \times 220 \times 10^{-3}\,\text{sec}$$

$$\text{BDP} = 1.54 \times 10^6\,\text{bits} = 1.54\,\text{Mb}$$

Therefore, the BDP is **1.54 Mb**.

Next, calculate the **BDP in terms of packets**:

- **Packet size**: $1460\,\text{bytes} = 1460 \times 8 = 11,680\,\text{bits}$
- **Number of packets**:

$$\text{Number of packets} = \frac{\text{BDP (bits)}}{\text{Packet size (bits)}}$$

  Substituting the values:

$$\text{Number of packets} = \frac{1.54 \times 10^6}{11,680} \approx 131.84$$

Therefore, the number of packets is approximately **131 packets**.

1.3 (c)

To calculate the **average computed throughput**, I used Wireshark to analyze the `.pcap` files. Specifically, I analyzed the file `tcp-example-2-0.pcap`, as it captures packets received at the sink node (`10.1.2.2`), where the TCP transfer completes. This is because throughput is calculated based on the amount of data successfully received at the receiver.

Other `.pcap` files capture data at intermediate nodes or on the sending side, which do not accurately represent the actual throughput achieved at the receiver.

The image of the throughput statistics is shown below:

Statistics

Measurement	Captured	Displayed	Marked
Packets	9066	9066 (100.0%)	—
Time span, s	9.889	9.889	—
Average pps	916.7	916.7	—
Average packet size, B	395	395	—
Bytes	3578076	3578076 (100.0%)	0
Average bytes/s	361 k	361 k	—
Average bits/s	2894 k	2894 k	—

Figure 1: Average Throughput Statistics

The **average computed throughput** of the TCP transfer is **2.894 Mbps**.

1.4 d)

The **achieved throughput** (**2.894 Mbps**) is significantly lower than the **maximum expected value** (**7 Mbps**).

The lower throughput is due to TCP congestion control mechanisms, such as slow start and congestion avoidance, which limit the rate of data transfer to prevent congestion. Additionally, the queue size and link conditions (limited buffer sizes), including delay (such as queueing delay) and packet loss, further reduce the effective throughput.

1.5 (e)

The plot below shows the variation of the **Congestion Window (CWND)** over time:

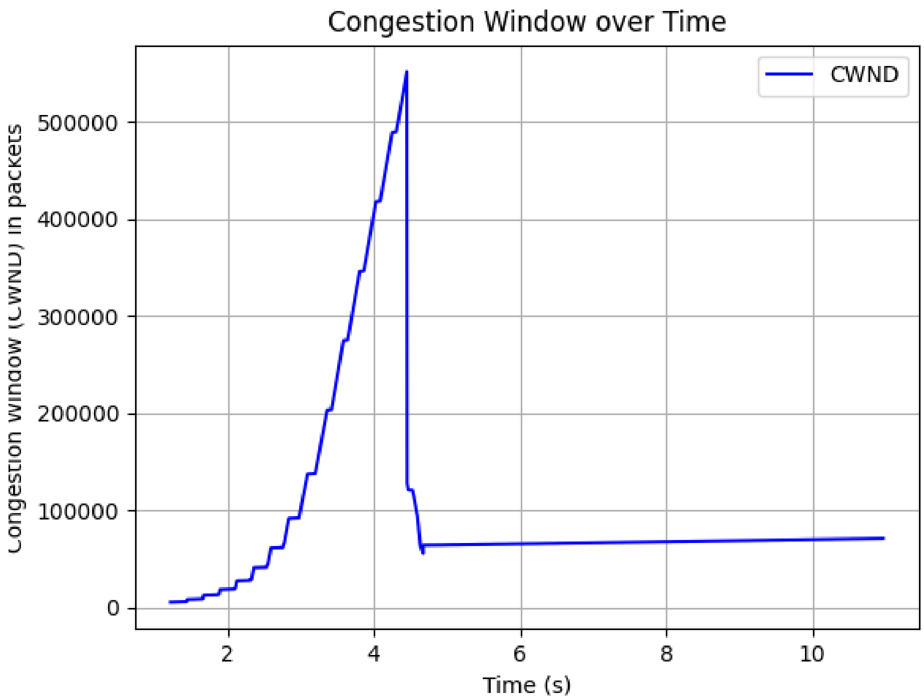

Figure 2: Variation of Congestion Window (CWND) Over Time

1.6 (f)

The plot below represents the **queueing delay** over time:

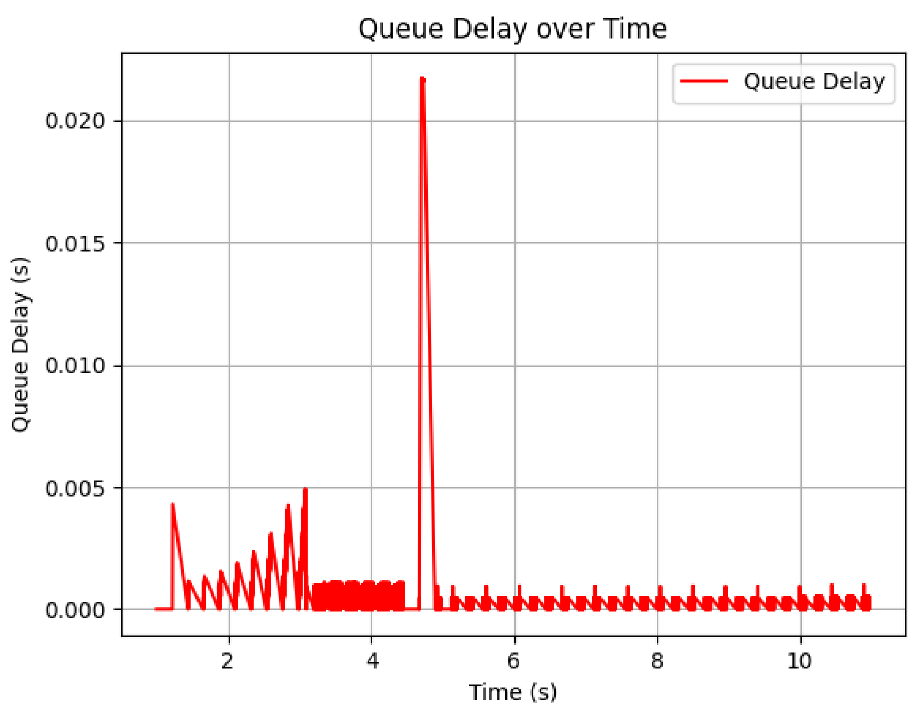

Figure 3: Queueing Delay Over Time

1.7 (g)

Yes, the plots in **1(e)** (Congestion Window vs. Time) and **1(f)** (Queueing Delay vs. Time) are closely related, as both are impacted by TCP congestion control mechanisms.

In the initial phase of the CWND plot, there is a steady increase during the **slow start phase**, which correlates with low queueing delay, indicating that the network is not congested. Around **4 seconds**, a sudden drop in the CWND represents a **congestion event**, likely due to buffer overflow or packet loss. This event is mirrored by a sharp spike in queueing delay. After this event, the CWND stabilizes at a lower value (around **100,000 packets**), and queueing delay also reduces, showing that TCP's **congestion avoidance mechanism** has effectively adjusted the sending rate to the available network capacity.

The two plots demonstrate how TCP reacts to congestion:

- As the CWND increases, more data is sent, causing the queues to fill, which increases queueing delay.
- Upon detecting congestion (via packet loss or high delay), TCP reduces the CWND to alleviate congestion, which in turn reduces the queueing delay.

2 Question 2

2.1 a)

The average computed throughput of the TCP transfer with the updated queue size (**1000 packets**) is **2.894 Mbps**, as measured using the Wireshark summary statistics. This throughput value is calculated based on the total bits transferred divided by the duration of the simulation.

The image of the throughput statistics is shown below:

Statistics

Measurement	Captured	Displayed	Marked
Packets	9066	9066 (100.0%)	—
Time span, s	9.889	9.889	—
Average pps	916.7	916.7	—
Average packet size, B	395	395	—
Bytes	3578076	3578076 (100.0%)	0
Average bytes/s	361 k	361 k	—
Average bits/s	2894 k	2894 k	—

Figure 4: Average Throughput Statistics for Queue Size = 1000

2.2 b)

The plot below shows the variation of the **Congestion Window (CWND)** over time for the updated queue size (**1000 packets**):

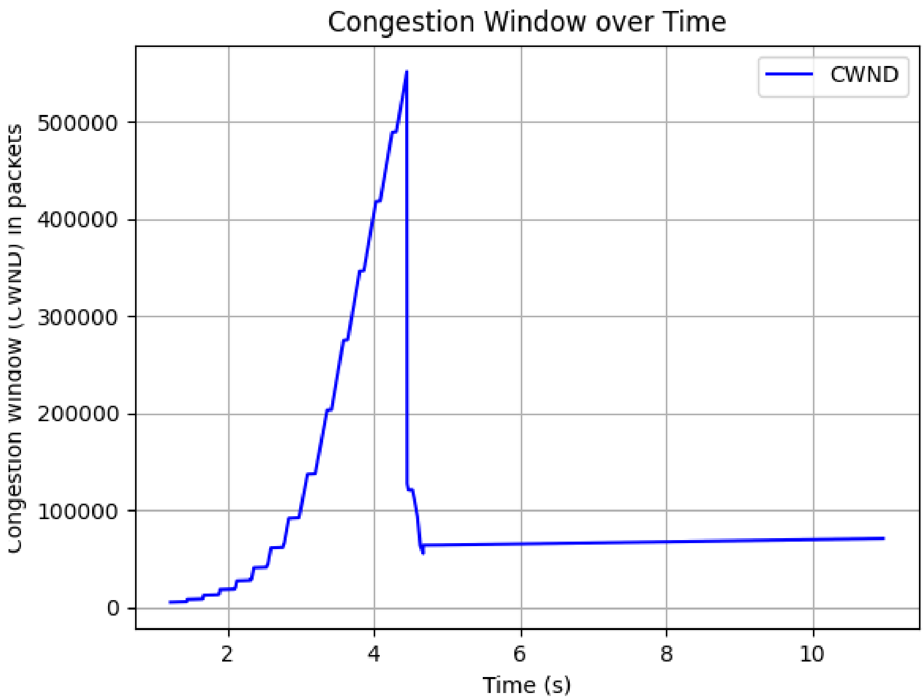

Figure 5: Variation of Congestion Window (CWND) Over Time for Queue Size = 1000

2.3 c)

The plot below represents the variation of the **Queueing Delay** over time for the updated queue size (**1000 packets**):

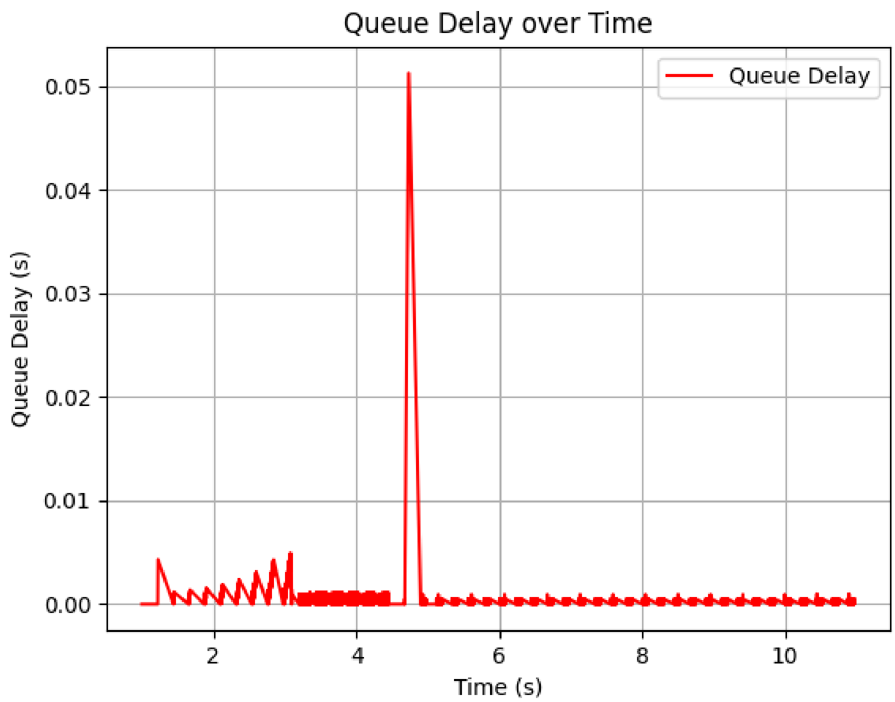

Figure 6: Queueing Delay Over Time for Queue Size = 1000

2.4 (d)

The CWND plots for both Q.1. and Q.2. are **identical**, indicating that the change in queue size did not impact the congestion window behavior. This suggests that **TCP's congestion control mechanisms**, which rely on factors like packet loss and round-trip time (RTT), responded similarly in both cases.

Despite the larger queue size in Q.2., which could potentially delay congestion and reduce packet loss, the congestion window **grew and dropped in the same manner** in both scenarios. This could be attributed to the **network conditions**, such as the bottleneck link's bandwidth and delay, remaining unchanged, meaning the queue size had little effect on the CWND behavior, with some other factor likely affecting congestion.

However, while the CWND remains unaffected, **throughput** and **queueing delay** might still vary with different queue sizes, as observed in the queueing delay plots.

3 Question 3

3.1 (a)

The average computed throughput of the TCP transfer, as shown in the Statistics section of the pcap file, is **1.708 Mbps**. This value represents the average rate at which data was transferred during the simulation. Below is the image of the statistics showing the average throughput:

Statistics

Measurement	Captured	Displayed	Marked
Packets	5446	5446 (100.0%)	—
Time span, s	9.779	9.779	—
Average pps	556.9	556.9	—
Average packet size, B	384	384	—
Bytes	2088692	2088692 (100.0%)	0
Average bytes/s	213 k	213 k	—
Average bits/s	1708 k	1708 k	—

Figure 7: Average Throughput Statistics for Updated Bandwidth and Delay

3.2 (b)

The plot below shows the variation of the **Congestion Window (CWND)** over time:

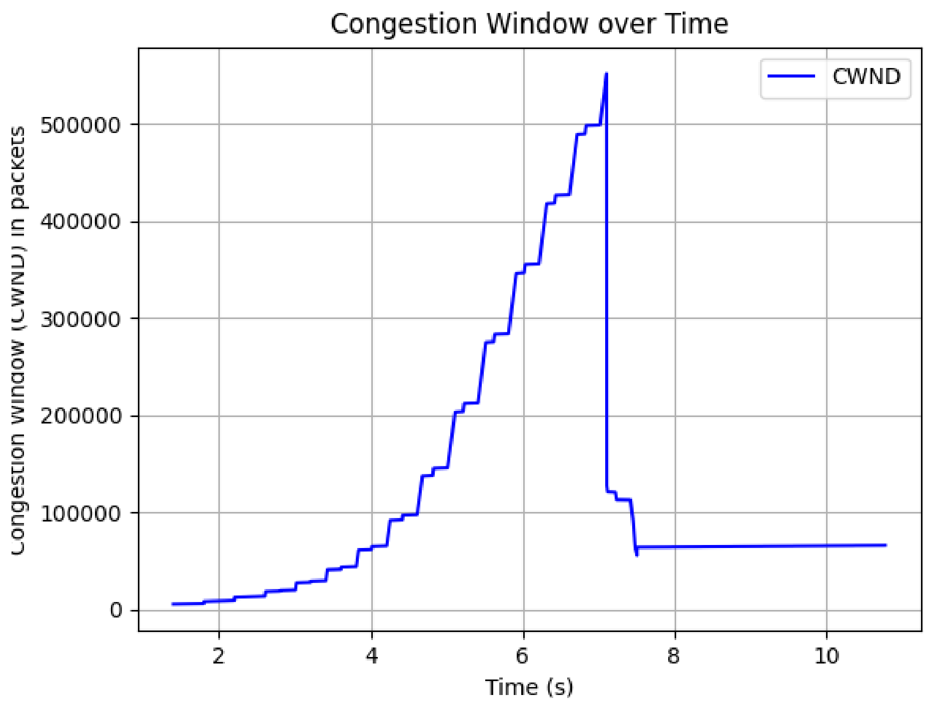

Figure 8: Variation of Congestion Window (CWND) Over Time for Updated Bandwidth and Delay

3.3 (c)

The plot below represents the variation of the **Queueing Delay** over time:

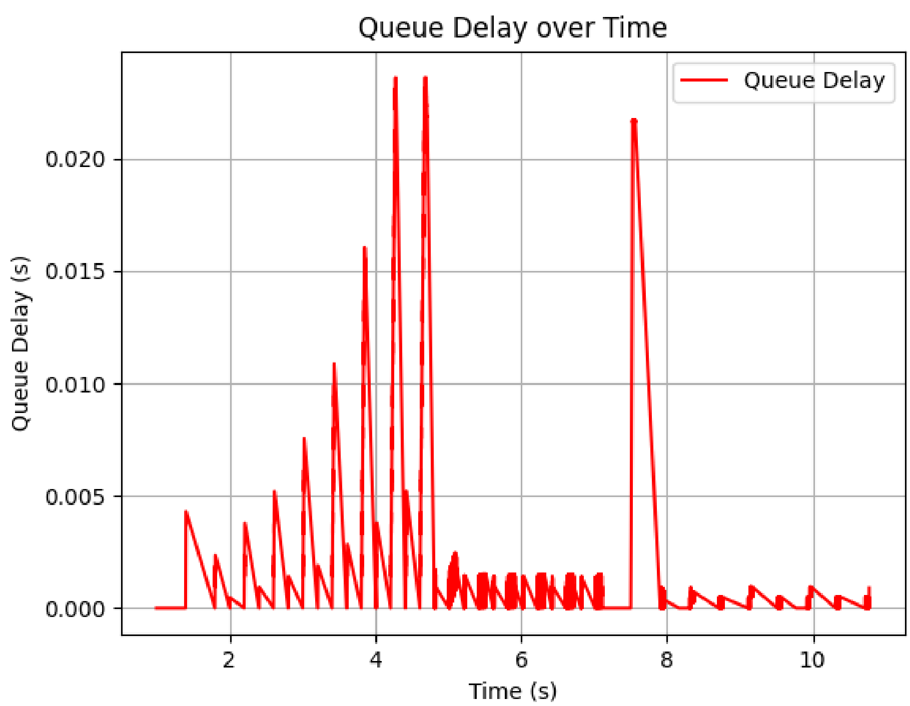

Figure 9: Queueing Delay Over Time for Updated Bandwidth and Delay

3.4 (d)

The queueing delay plots for Q.1. (default parameters) and Q.3. (with updated bandwidth and delay) show significant differences. In Q.3., delay spikes are more frequent, sharper, and persist longer, particularly until around 8 seconds. This is due to the increased delay on the N1-N2 link (100 ms), which raises the total RTT and delays TCP's reaction to congestion, causing queues to fill faster and remain saturated for longer. In contrast, Q.1. shows smaller, more transient delay spikes, indicating more stable queue utilization and quicker congestion resolution.

These differences highlight the critical role of RTT in TCP performance. Higher RTT in Q.3. reduces the efficiency of congestion control, making congestion events more frequent and severe, despite the removal of the bottleneck caused by mismatched link capacities in Q.1. The queueing delay plot emphasizes how balancing bandwidth and RTT is essential to minimizing latency and maintaining stable network performance.