Q1

a) Maximum expected throughput is 7Mbps because the bottleneck link between the N0 and N2 is the bandwidth of N1-N2 link is 7Mbps.

b) Bandwidth delay product = bottleneck bandwidth * RTT
One way delay = 100ms + 10ms = 110ms = 0.11s
RTT = 2*one way delay = 2*0.11 = 0.22s
BDP = 7Mbps*0.22 = 1540000 bits / 1460*8 bits = 131.84 packets

c) The average computed throughput of the TCP transfer is 3081 kbps = 3.08 Mbps

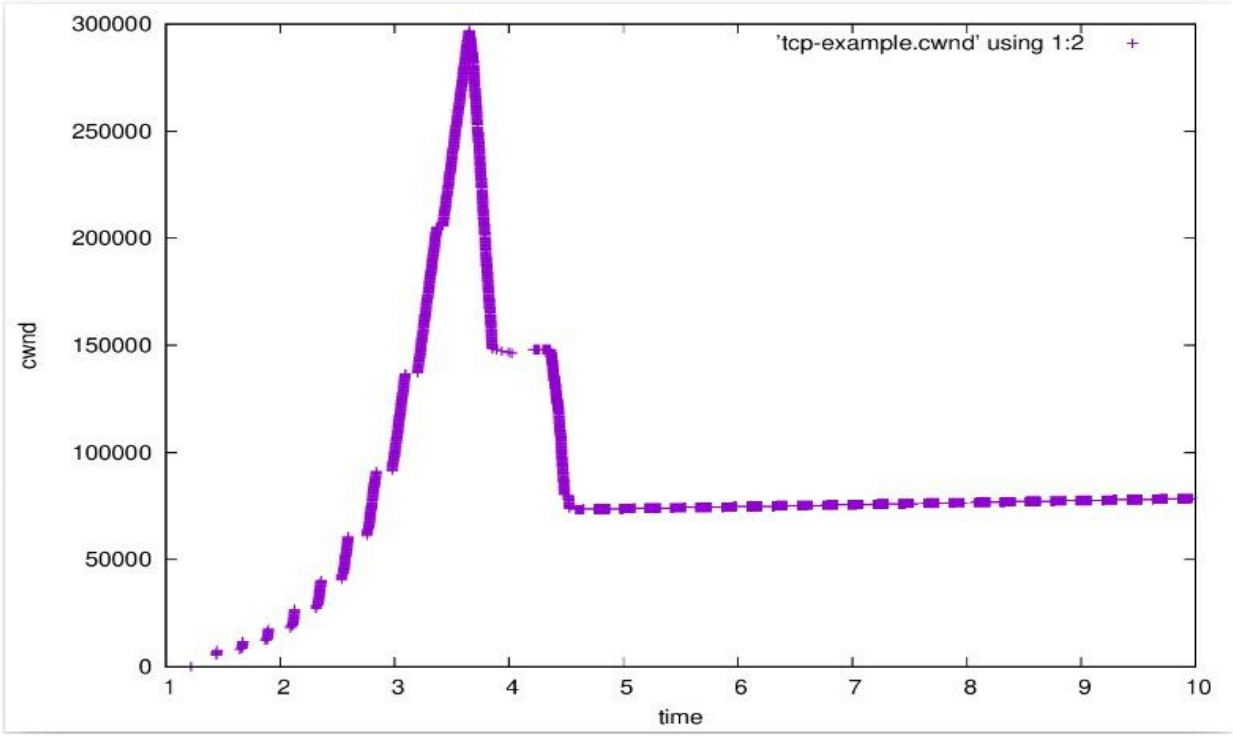
Wireshark · Conversations · tcp-example-2-0.pcap

Ethernet | IPv4 · 1 | IPv6 | TCP · 1 | UDP

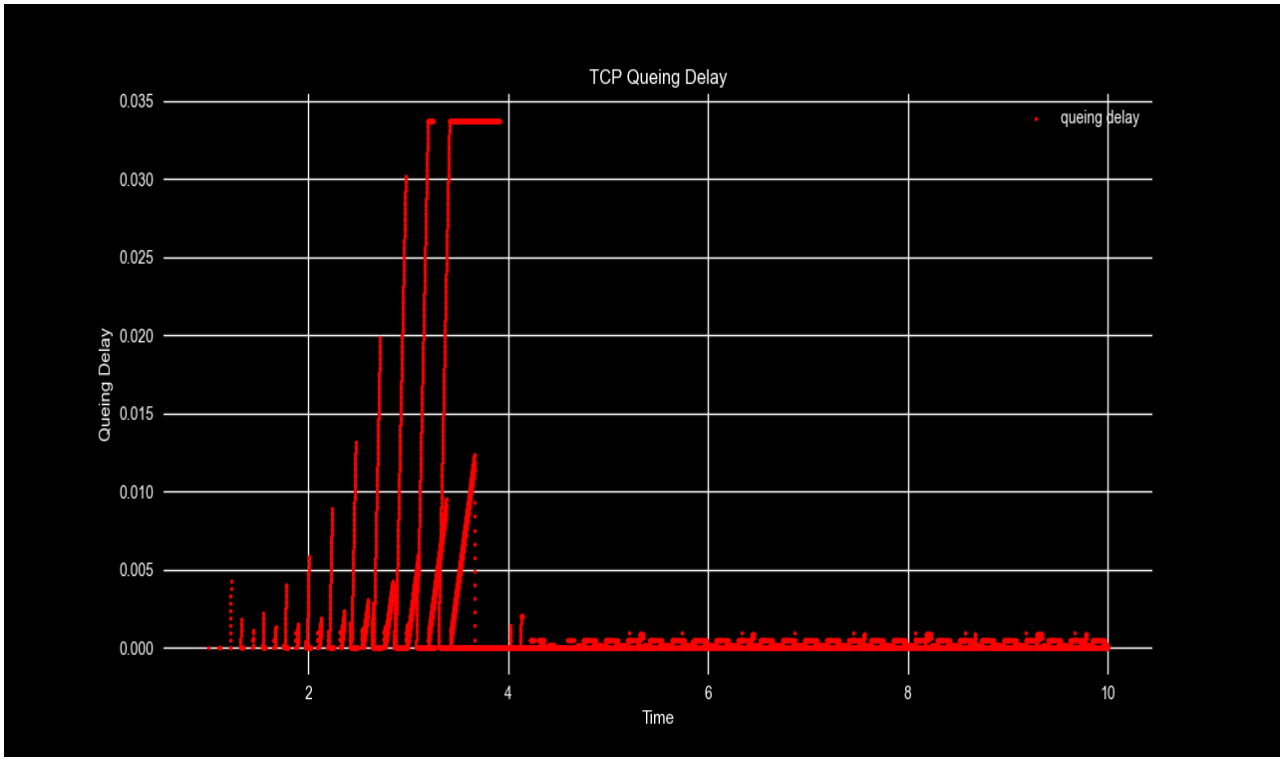
Address A	Port A	Address B	Port B	Packets	Bytes	Packets A → B	Bytes A → B	Packets B → A	Bytes B → A	Rel Start	Duration	Bits/s A → B	Bits/s B → A
10.1.1.1	49153	10.1.2.2	8080	9,239	3623 k	5,805	3423 k	3,434	200 k	0.000000	8.8895	3081 k	180 k

d) No, the achieved throughput is not the maximum expected value because of the packet losses and TCP congestion control. As a result, the network link cannot be fully utilised. Also, the large delay between the nodes also reduces the link utilisation.

e)



f)



g) Yes, they are related. Congestion window halves when the queueing delay increases or the queueing delay increases as the congestion window is increased and decreases when the congestion window decreases. As a result, the two graphs rise and fall at the same time.

Q2

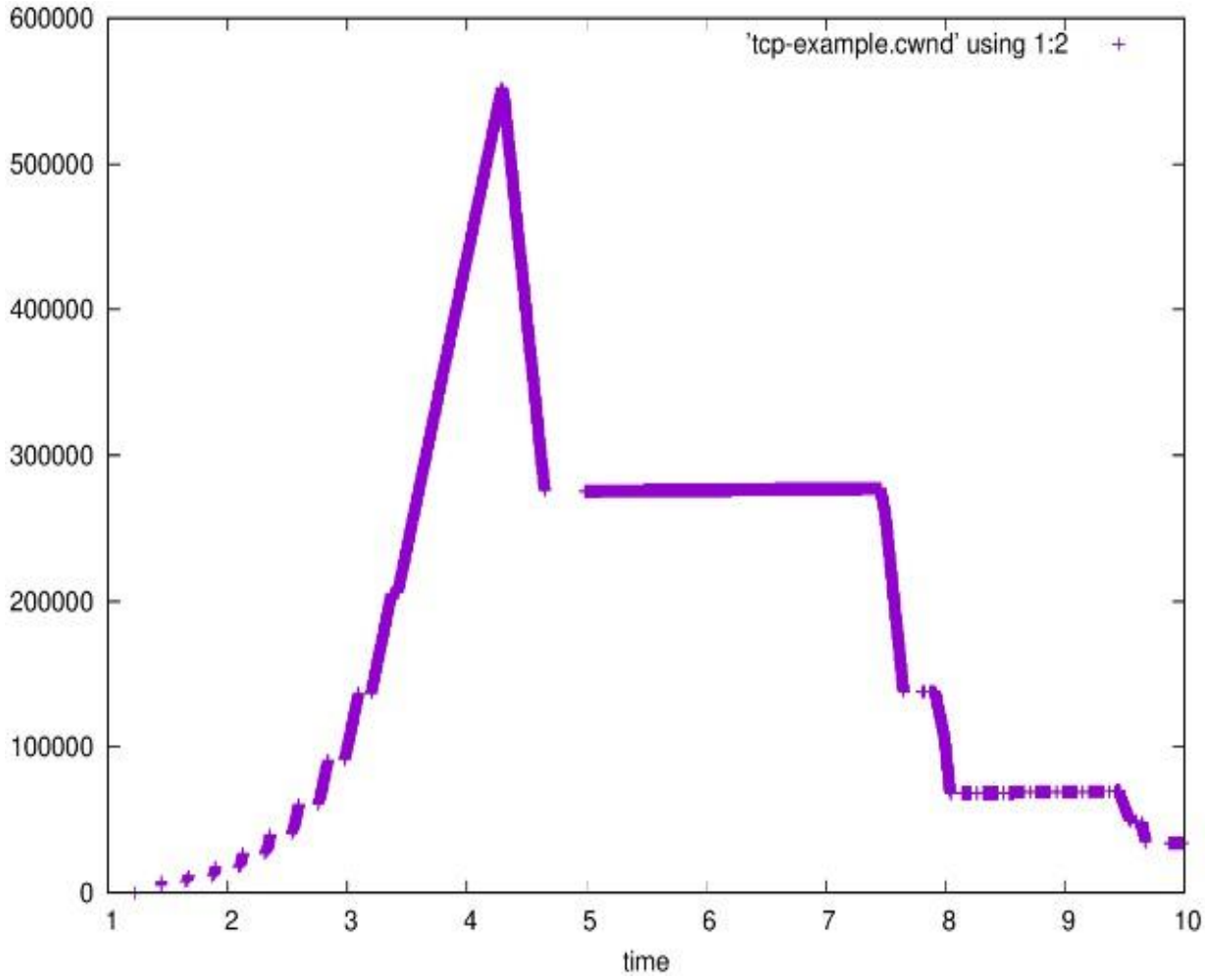
a) 4563 kbps or 4.56 Mbps

Wireshark · Conversations · tcp-example-2-0.pcap

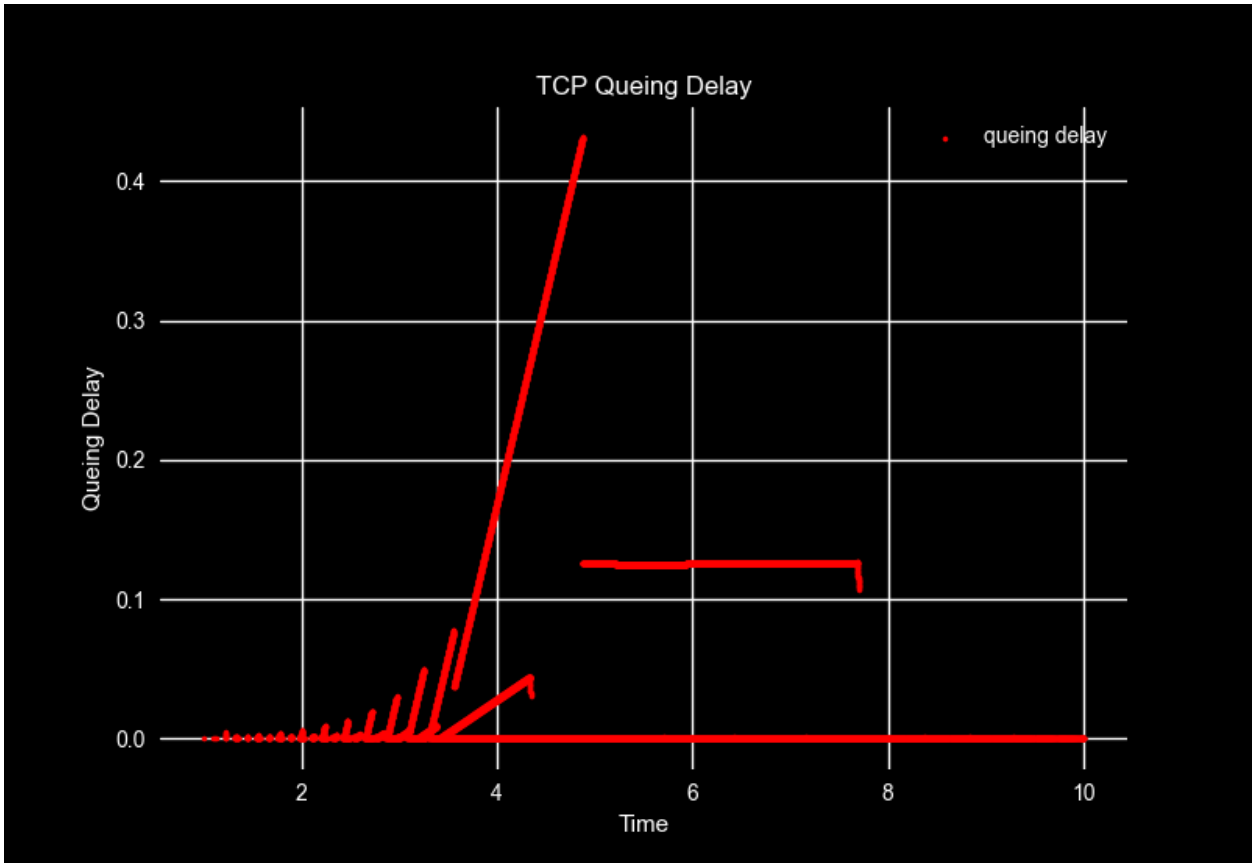
Ethernet | IPv4 · 1 | IPv6 | TCP · 1 | UDP

Address A	Port A	Address B	Port B	Packets	Bytes	Packets A → B	Bytes A → B	Packets B → A	Bytes B → A	Rel Start	Duration	Bits/s A → B	Bits/s B → A
10.1.1.1	49153	10.1.2.2	8080	13,885	5372 k	8,596	5070 k	5,289	301 k	0.000000	8.8886	4563 k	271 k

b)



c)



d) As the queue size increases, the congestion window size is higher in Q2 than in Q1. This means that the larger queue allows for more packets and hence the cwnd size increases. It thereby increases the network performance as throughput also increases. The delay increases because the packets have to wait longer in the queue because increased capacity of the queue.

Q3

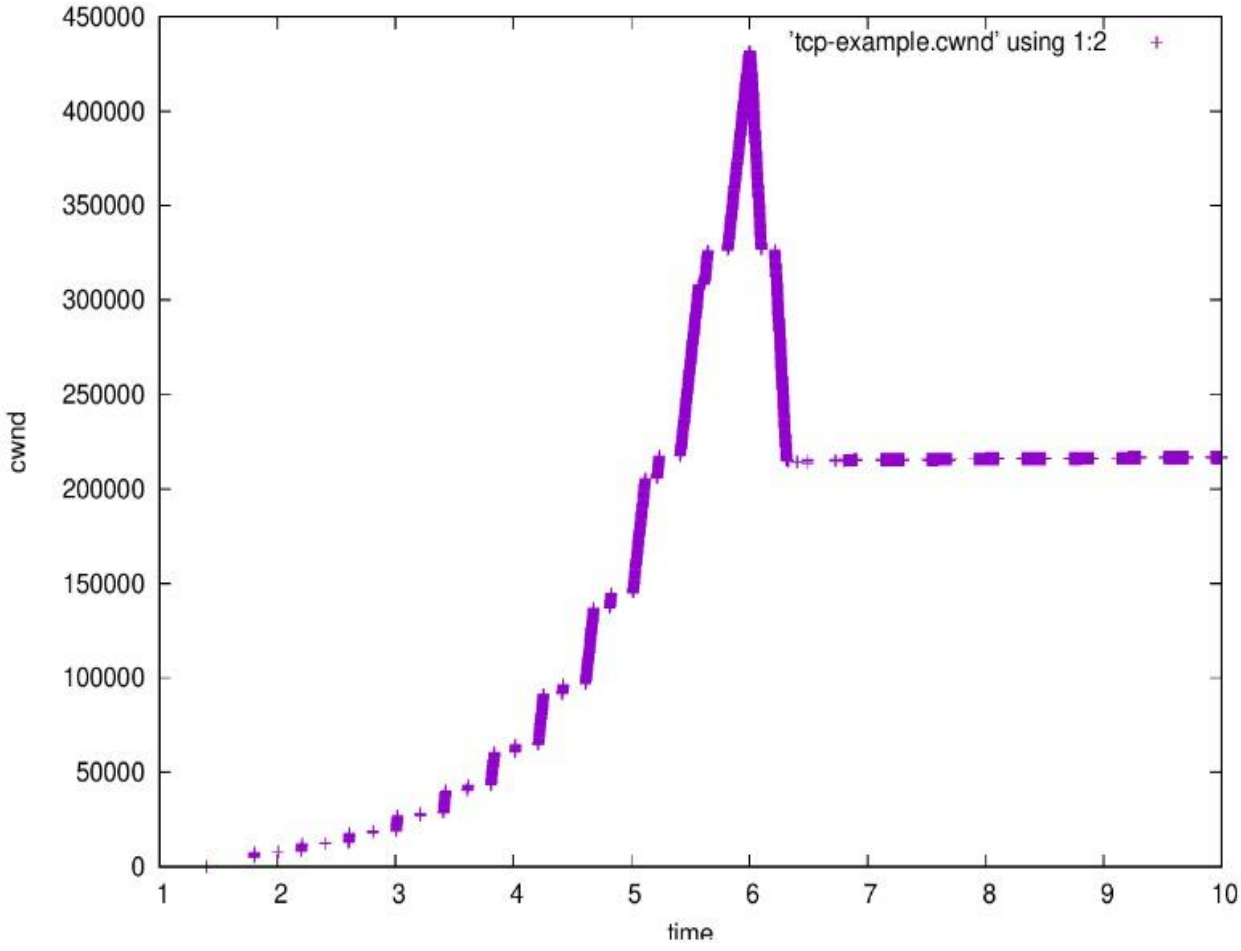
a) 3264 kbps or 3.26 Mbps

Wireshark · Conversations · tcp-example-2-0.pcap

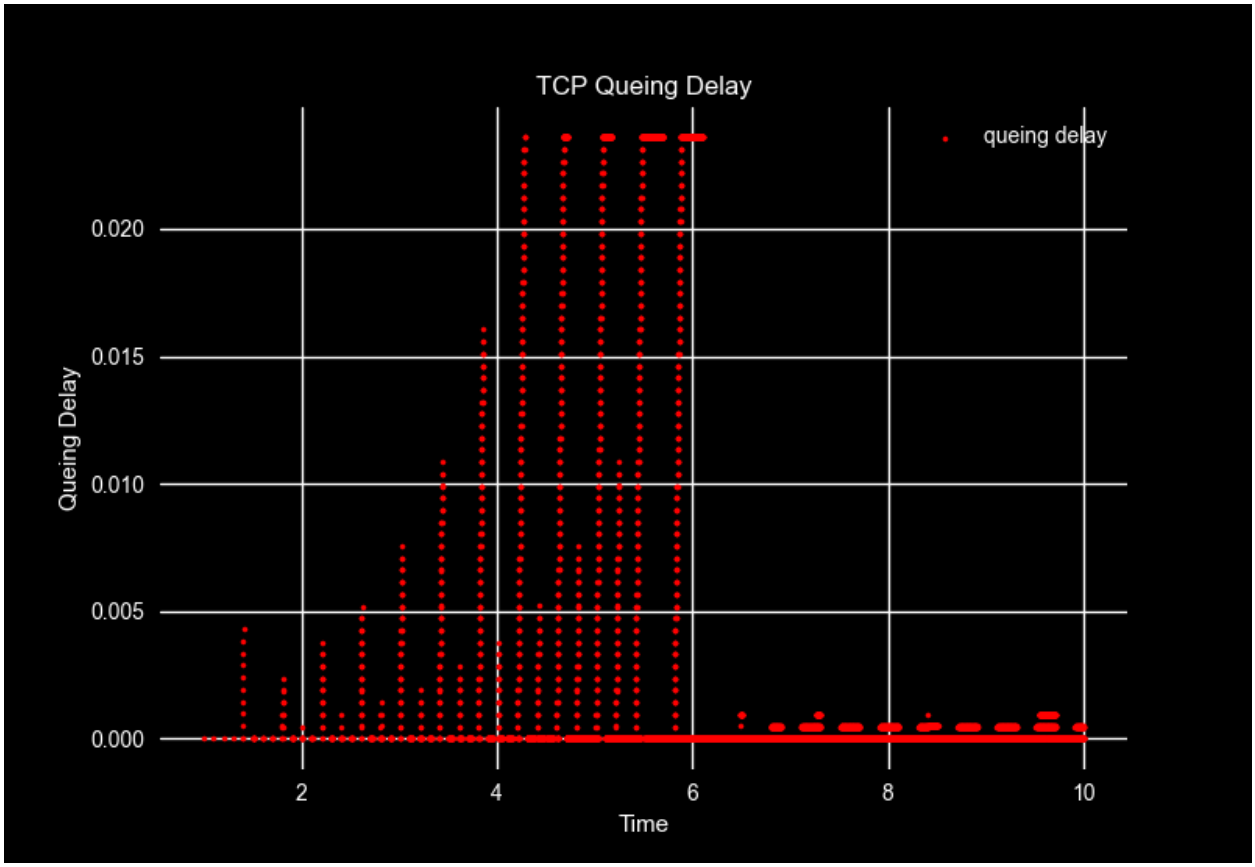
Ethernet | IPv4 · 1 | IPv6 | TCP · 1 | UDP

Address A	Port A	Address B	Port B	Packets	Bytes	Packets A → B	Bytes A → B	Packets B → A	Bytes B → A	Rel Start	Duration	Bits/s A → B	Bits/s B → A
10.1.1.1	49153	10.1.2.2	8080	9,549	3758 k	6,029	3556 k	3,520	202 k	0.000000	8.7144	3264 k	186 k

b)



c)



d) In Q1, the link between N1 and N2 was the bottleneck with lower bandwidth and higher delays. As a result, queueing time was significantly higher as observed in the queueing delay graph vs the queueing delay graph in Q3. The Q3 matches the bandwidth and delay between the two links and hence the queueing delay at N1 is almost neglegible close to 0. Also, the throughput observed in Q3 is higher and closer to maximum theoretical throughput 3265 vs 3081 kbps for Q1. So, lower queueing delay leads to better throughput.