1.a

Maximum expected value of throughput would be Min(10Mbps, 7Mbps) = **7Mbps**

Because for N0-N1 bandwidth is 7 Mbps and for N1-N2 is 10 Mbps, So the maximum traffic would have bandwidth of the smaller pipe that is 7 Mbps.

1.b

For N0 - N1 link

Bandwidth-Delay-Product = Bandwidth * RTT

Bandwidth = 10Mbps = $10 * 10^6$

RTT = (100)*2 = 200ms = $200 * 10^{-3}$ s

BDP = $200 * 10^{-3} * 10 * 10^6$

= 2000000 bits = 2,50,000 bytes

1 packet contains 1460 bytes

BDP = 171.23 packets = approx 171 packets

For N1 - N2 link

Bandwidth-Delay-Product = Bandwidth * RTT

Bandwidth = 7Mbps = $7 * 10^6$

RTT = (10)*2 = 20ms = $20 * 10^{-3}$ s

BDP = $20 * 10^{-3} * 7 * 10^6$

= 1,40,000 bits = 17,500bytes

1 packet contains 1460 bytes

BDP = 11.9packets = approx 11 packets

For N0-N2 link

Bandwidth-Delay-Product = Bandwidth * RTT

Bandwidth = 7Mbps = $7 * 10^6$

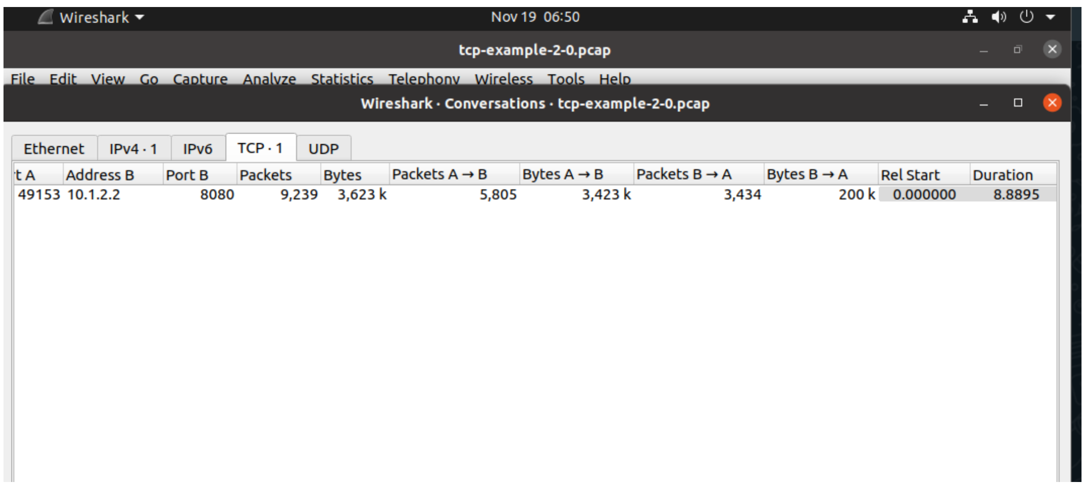
RTT = (100+10)*2 = 220ms = 220 * 10^{-3}

BDP = 220 * 10^{-3} * 7 * 10^{6}
= 1540 * 10^{3} bits = 192500 bytes

1 packet contains 1460 bytes

BDP = 19250 / 1460 = 131.84 = approx **131 packets**

1.c



average computed throughput of the TCP transfer N0- N2 receiver side=

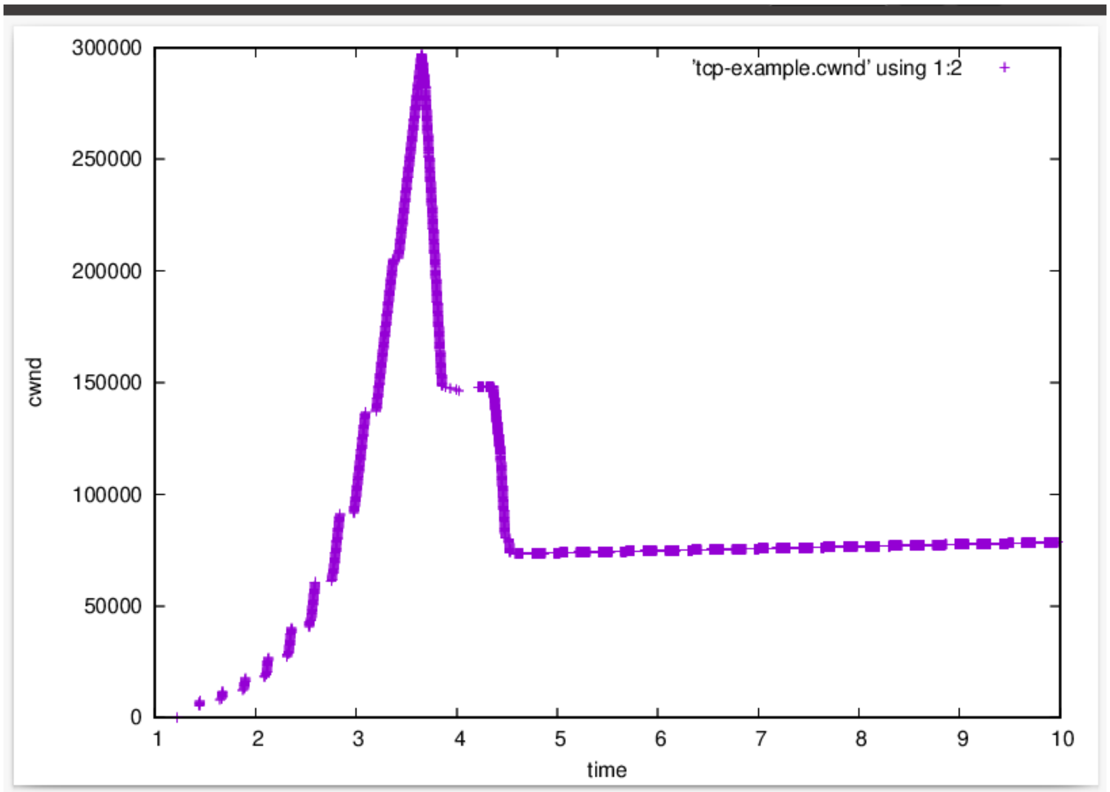
= Bits Transfered / Time taken
= 3623*8k / 8.8895 = 3260 Kbps = **3.26 Mbps**

1.d

No the achieved throughput is less than the theoretical throughput calculated in 1.a. This is because of other delays like processing, transmitting, propagation and queuing that adds on affecting the throughput. Data packets may be dropped due to low queue size or traffic which means that some packets have to retransmitted again from N0 and N1 which never earlier reached N2. This causes an increase in time taken for the TCP transfer

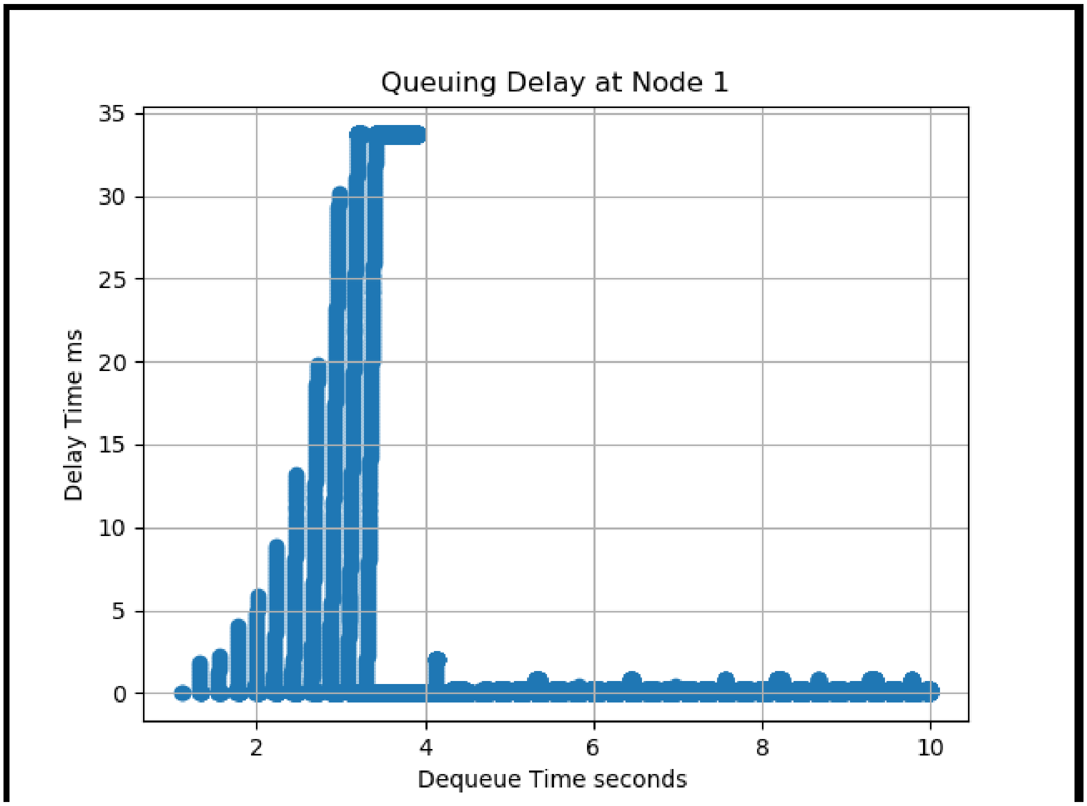
1.e

1.e



'tcp-example.cwnd' using 1:2
cwnd
time
300000
250000
200000
150000
100000
50000
0
1
2
3
4
5
6
7
8
9
10

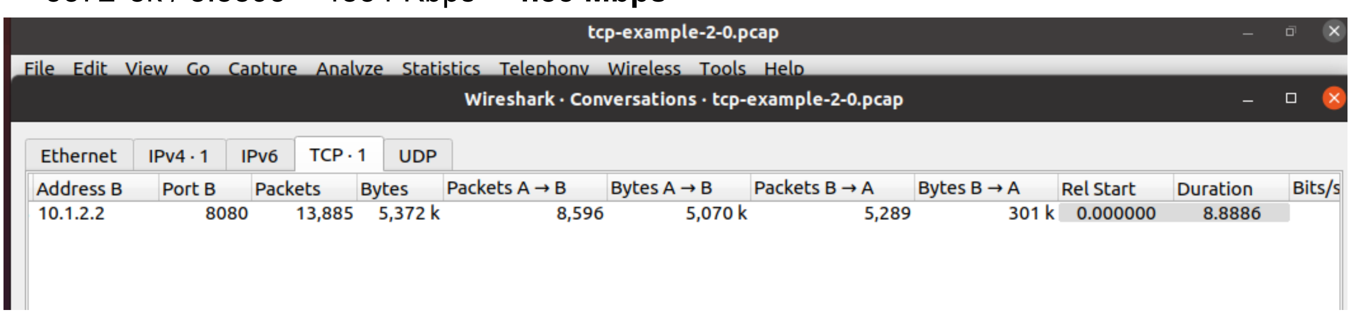
1.f



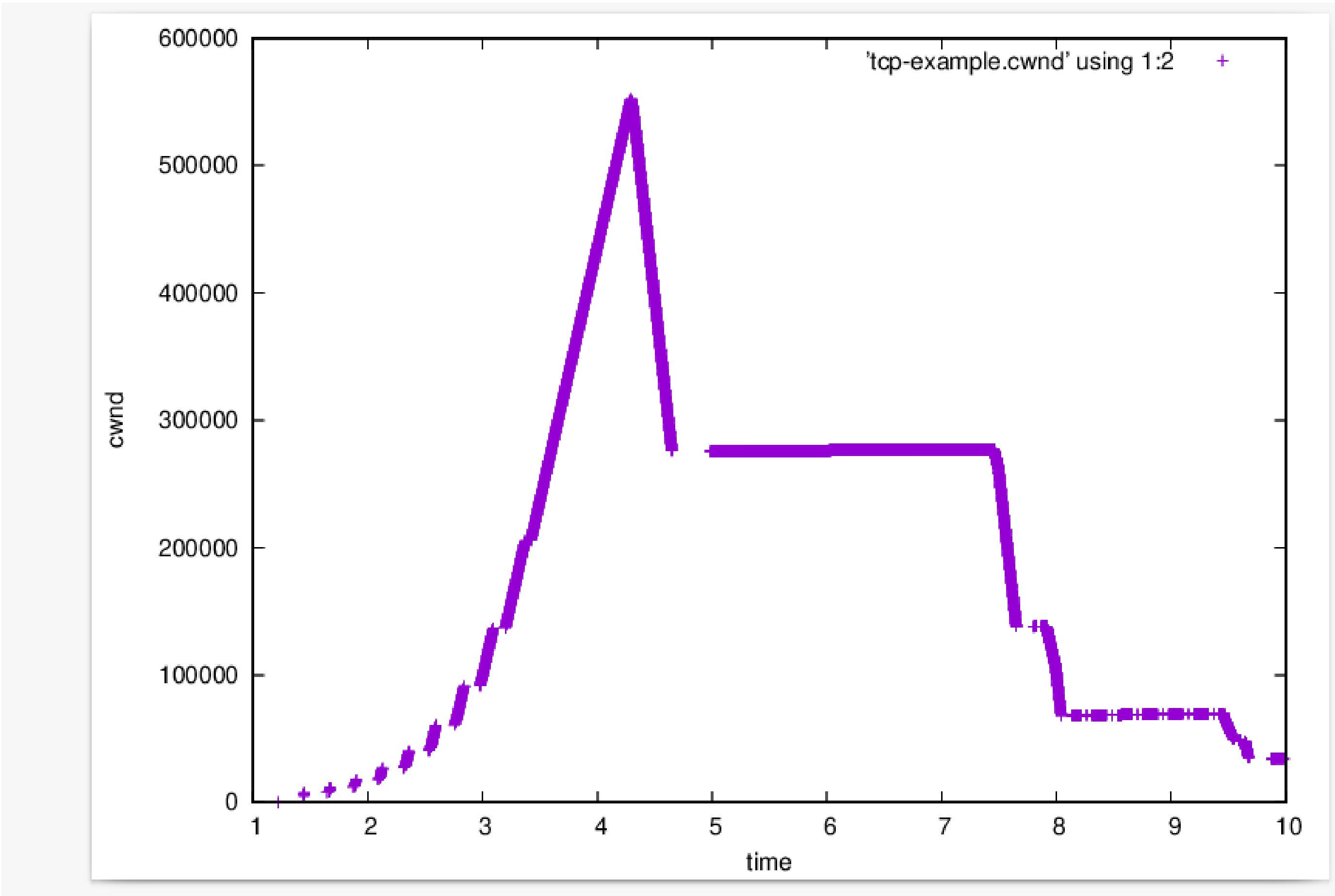
1.g

Plots in 1(e) Cwnd vs time and 1(f)- queuing delay vs time are related. As value of Cwnd increases more number of packets reach the node hence queuing delay also increases.

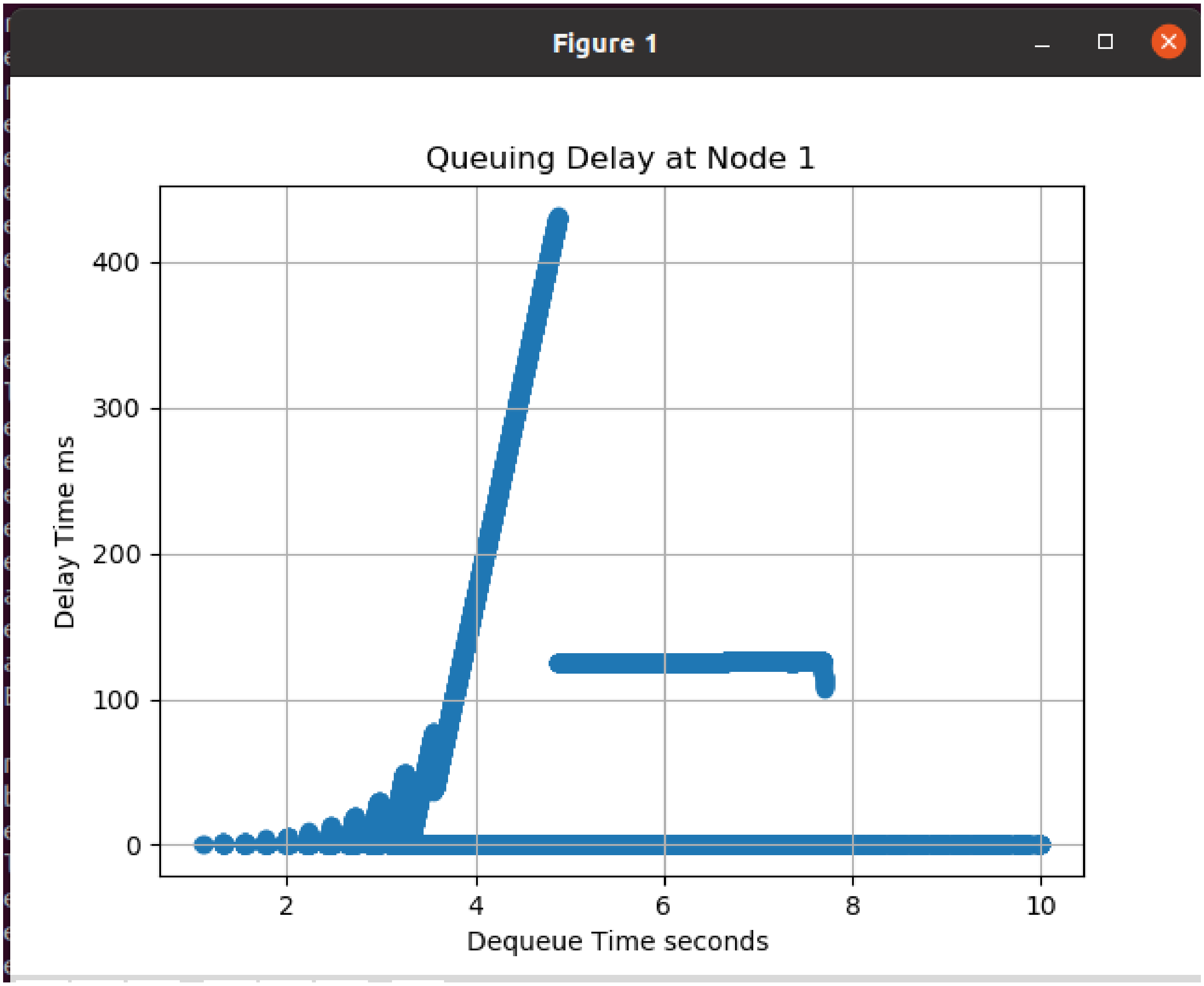
2.a
average computed throughput of the TCP transfer =
= Bits Transferred / Time taken
= 5372*8k / 8.8895 = 4834 Kbps = **4.83 Mbps**



2.b
Plot CWND with time



2.c Plot queueing delay with time



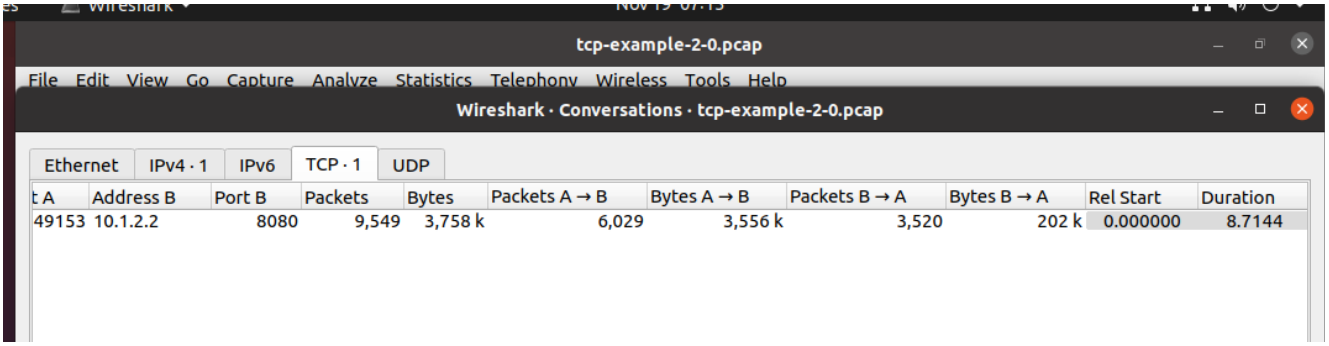
2.d Compare CWND plots of Q.1. and Q.2., what insights did you gain?

In Q1 CWND maximum value is 3,00,000 in Q2 maximum value is around 5.00,000. Thus a little more time is also taken in Q2 to reach the peak. In both graphs general trend is the same. First CWND keeps on increasing till peak then a stable value is reached.
The stable value is also different in both parts, Inj first it is around 70,000 while in second it is 300000 which was the max peak value in Q1.

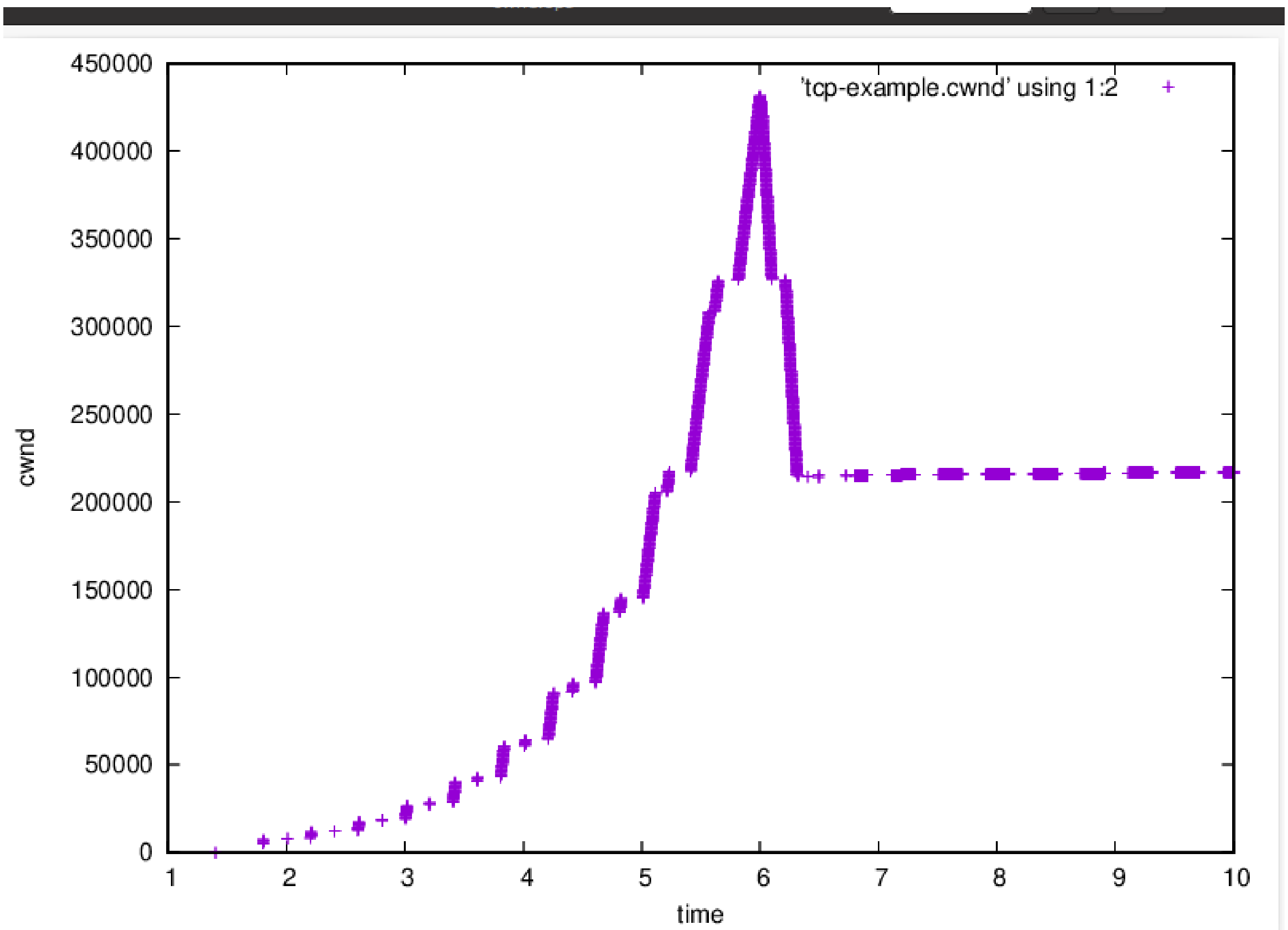
Q.3. Change N1-N2 bandwidth to 10 Mbps and N1-N2 delay as 100ms (rest of the parameter values are same as default values)

3.a

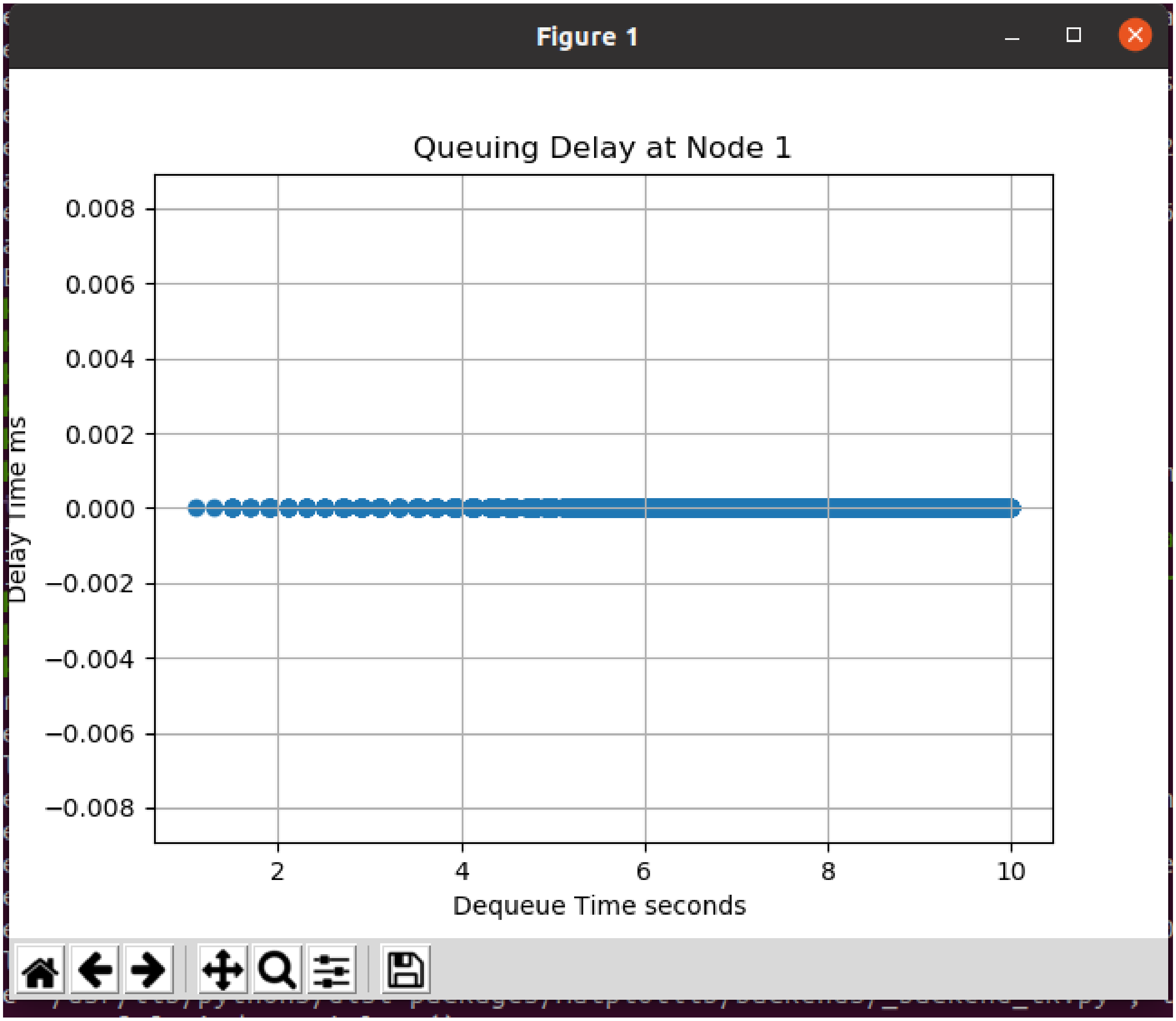
average computed throughput of the TCP transfer =
= Bits Transferred / Time taken
= 3758*8k / 8.7144 =3450 Kbps = **3.45 Mbps**



3.b



3.c



3.d

Compare queuing delay plots of Q.1. and Q.3., what insights did you gain?

We can see different values of queuing delay in Q1 as the CWND changes value and adjusts. In Q3 there is very less queuing delay.
In Q3 the bandwidths for both links is same i.e 10 Mbps, Thus, the rate at which the packets en-queued at N0 is same as rate at which they are de-queued at N1. Thus we get very less queuing delay :)
In Q1 Bandwidth at link N0-N1 is more than that at link N1-N2 , Thus the rate at which packets are en-queued is more than the rate at which they are de-queued at N1. Thus they suffer more queuing delay.