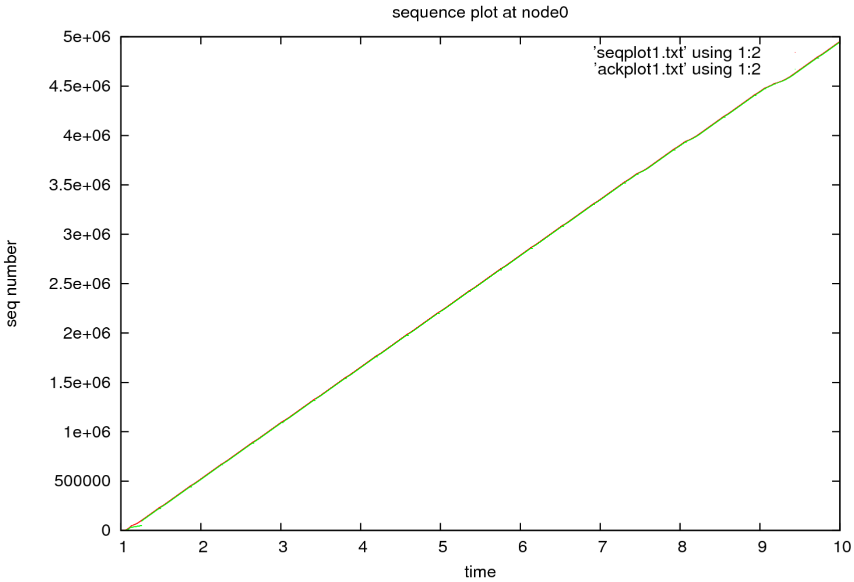
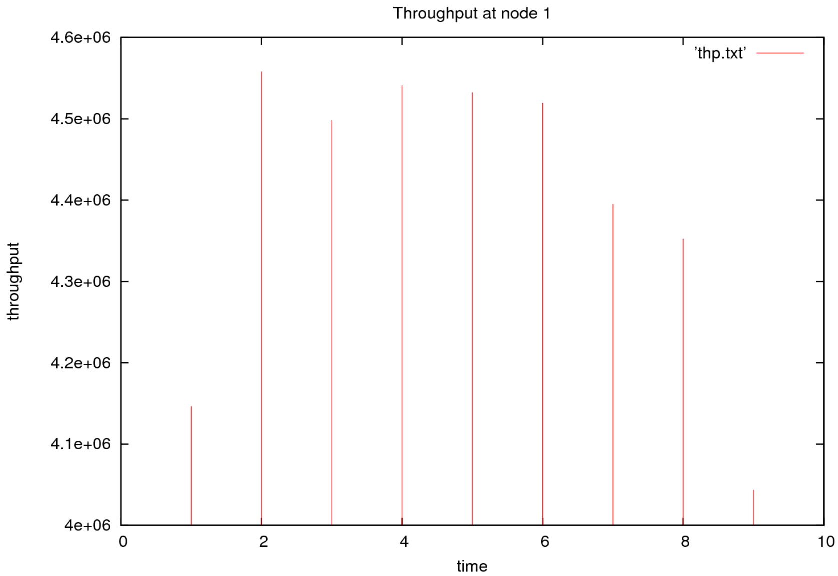
1.1

Plot1: sequence number graph



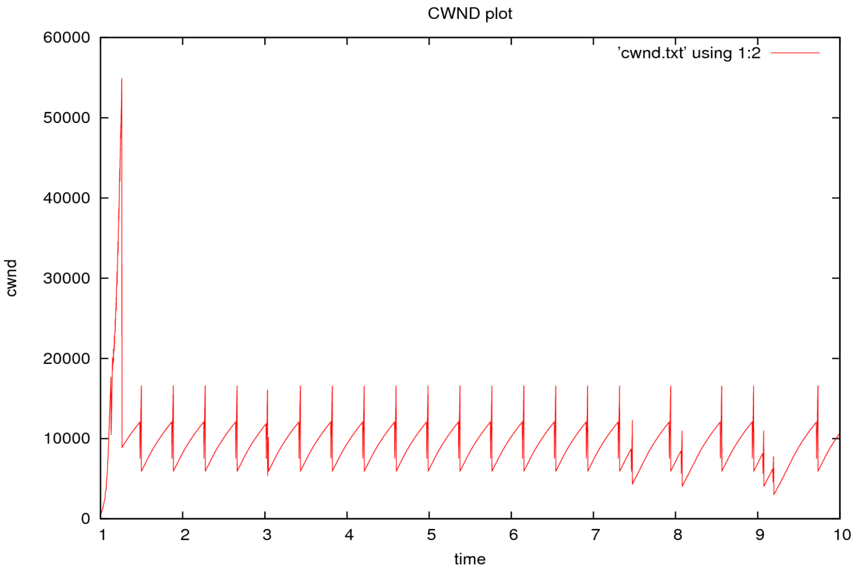
Plot2: Average throughput graph



The average throughtput in the default case is 4.39856Mbps. It is quite close to 5Mbps. But can be improved by increasing the buffr size to more than BDP. (or to BDP if delay needs to be considered)

BDP i.e. Bandwidth delay product = 5Mbps x 10ms / 8 = 6250 Bytes
Buffer size = 10 x 536 Bytes = 5360 Bytes
Buffer size is close to BDP but increasing it to more than BDP woud ensure full utilisation of link. Even after that throughput doesnt reach 5Mbps because TCP keeps increasing window size and falls to half after 3 dupacks are received. Thus oscillating between two values and would not utilize the link fully.

Plot 3: Window size variation along with time

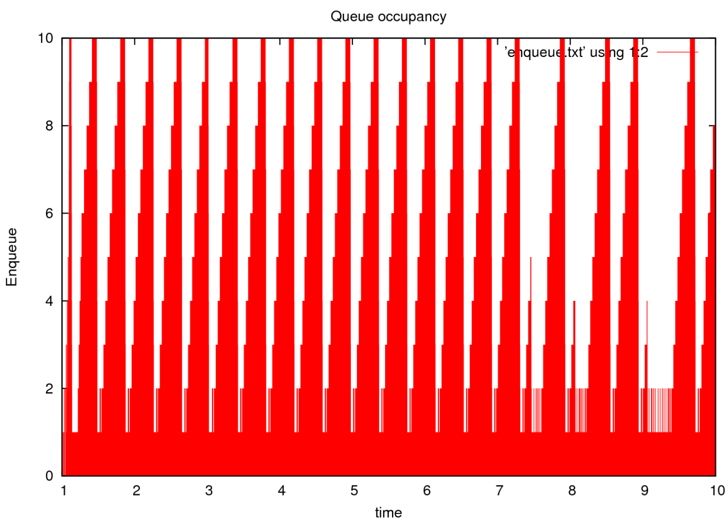


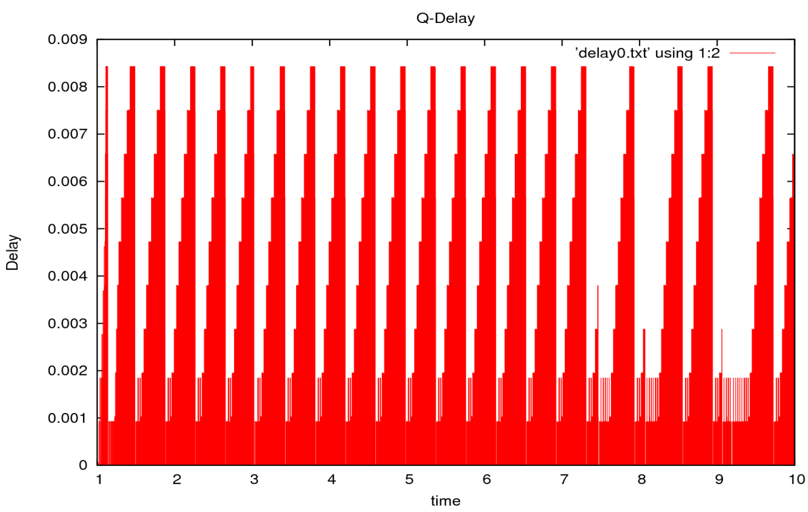
TCP reduced the window size as soon as packets are dropped which happens when window size is beyond BDP + buffer size. It happened every 0.39 seconds uniformly until last few seconds where there are more losses in the link and due to which window size would not grow so much and would fall before it reached the limit.

One important observation made is TCP decreases or keeps decreasing window size by small amounts every now and then which i presume to be due to delay in the Acks obtained.

At 8th, 9th seconds throughput falls due to loss in lot of packets. Its influence can also bee seen on window size at last 2 seconds.

Plot 4: Number of packets in queue vs time and Plot 5: queuing delay vs time

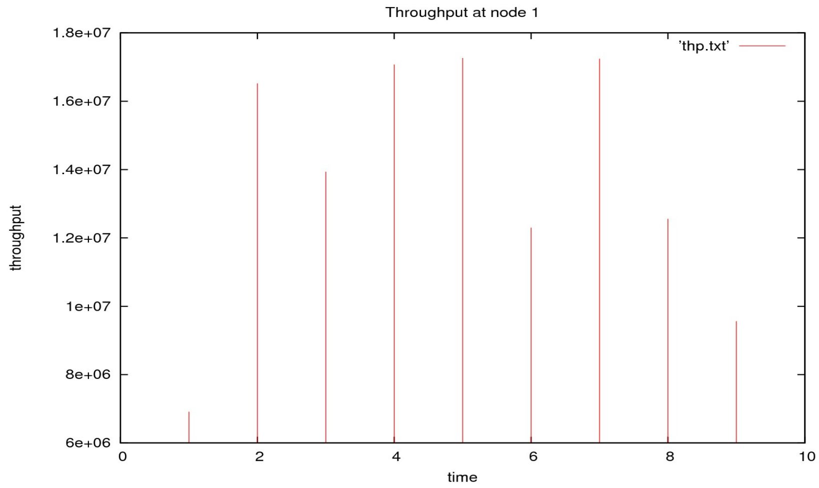




We see that Delay and number of packets in buffer vary along with window size. i.e. increase as window size increases and fall down when window size falls.

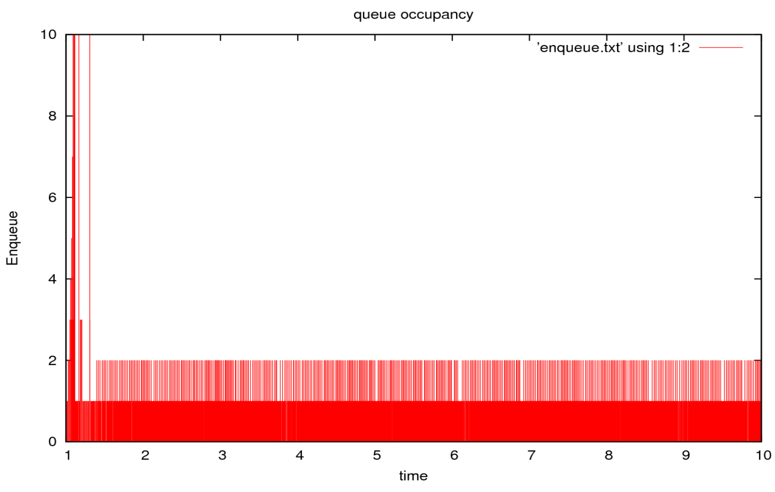
1.2 Bottleneck rate increased to 50Mbps..

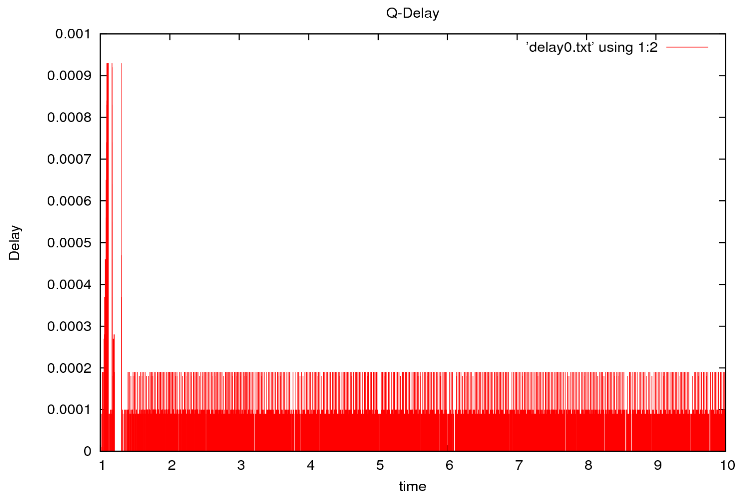
Plot: Throughput Plot



The average throughput is mere 13.5Mbps. Which is very less than actual bandwidth available. The reason for which can be given as these two parameters

1) The link loss rate of 10^-6. When we calculate the BDP + buffer size we get it as 68860 Bytes. So the window size could reach this point. But before it reached that value, It would see loss packets because of loss rate. I.e as window size grew to around 36000, more than a lakh packets are transmitted by now and so by defined loss rate atleast one of them would be lost. So transmitter node would get dupacks and thus halt growing window size, go to fast recovery and then go back to a size of half of 36000 Bytes i.e. 16000 Bytes. We see that except in the initial slow start phase the window size never grew byond limit of BDP + buffer size and so the buffer would never be full later on as shown in plots below



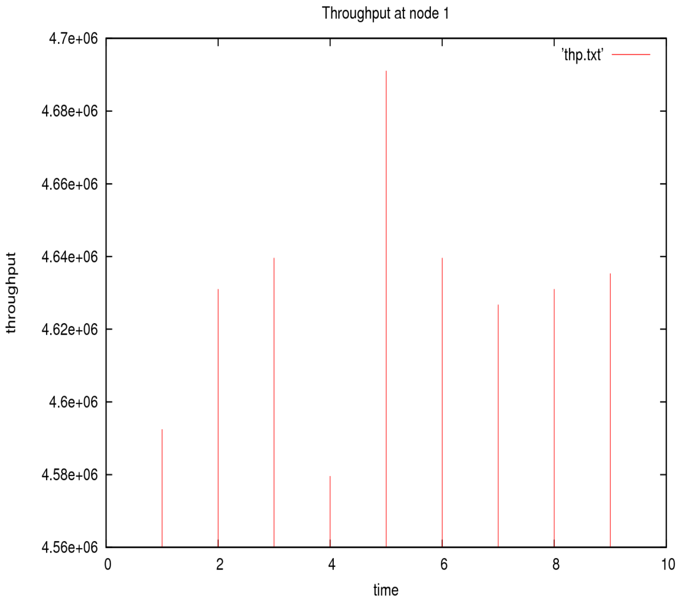


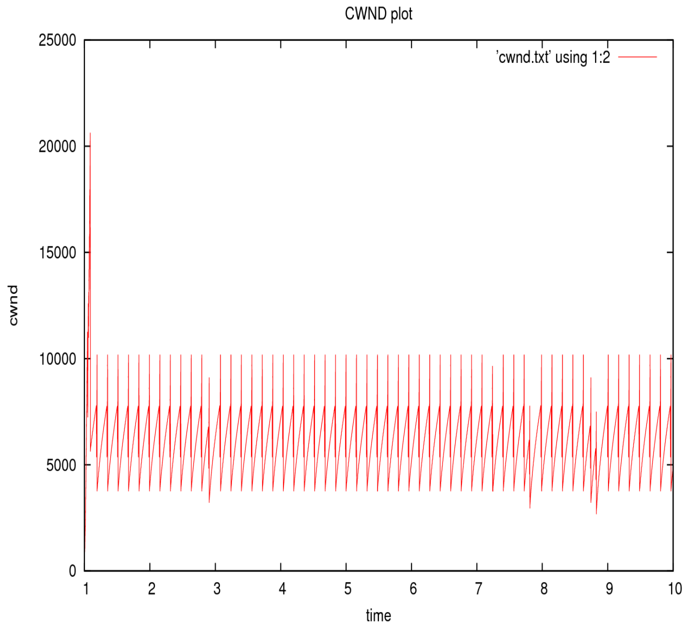
2) Even if the loss rate would be decreased to 10^-8, there is another parameter that would affect throughput. Buffer size. At default size of 5360 Bytes buffer size is no where near to the BDP and so the link would still be under utilised.

So the parameters to be varied to maximize throughput are loss rate make it lesser than 10^-8 or 10^09 and buffer size must be made more than or equal to BDP.

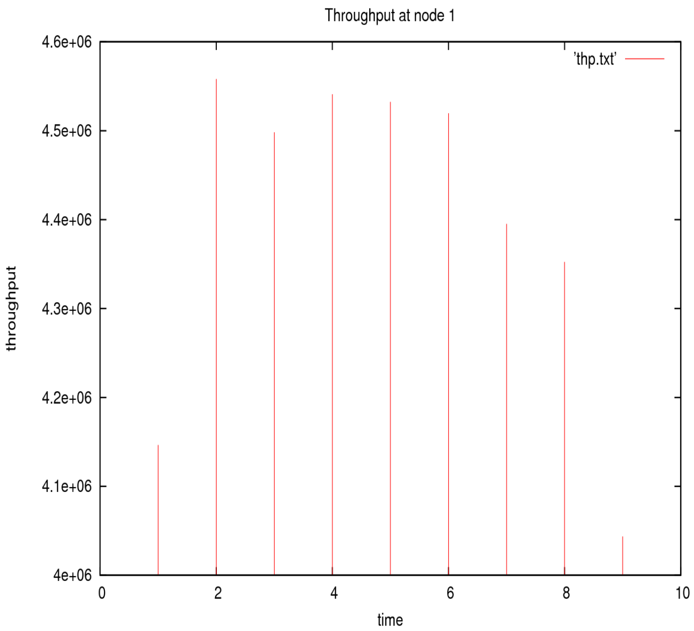
1.3
Throughput plots for various link delays

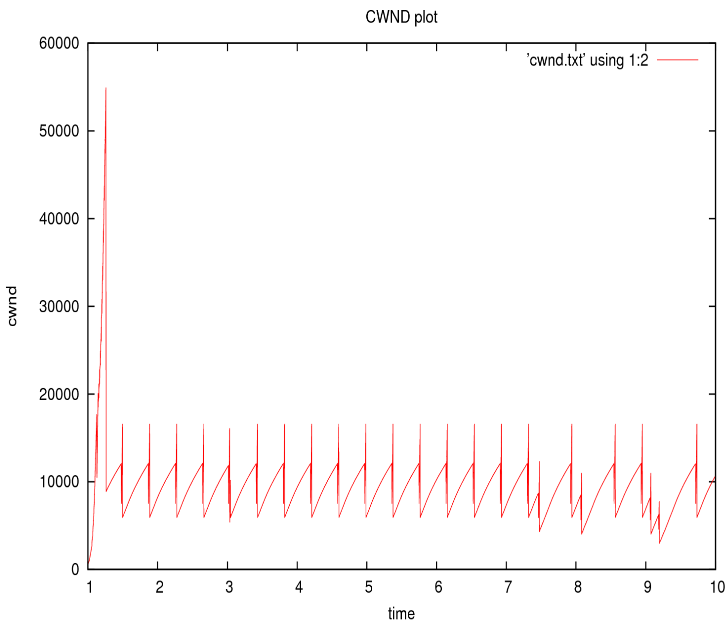
Link delay of 1ms



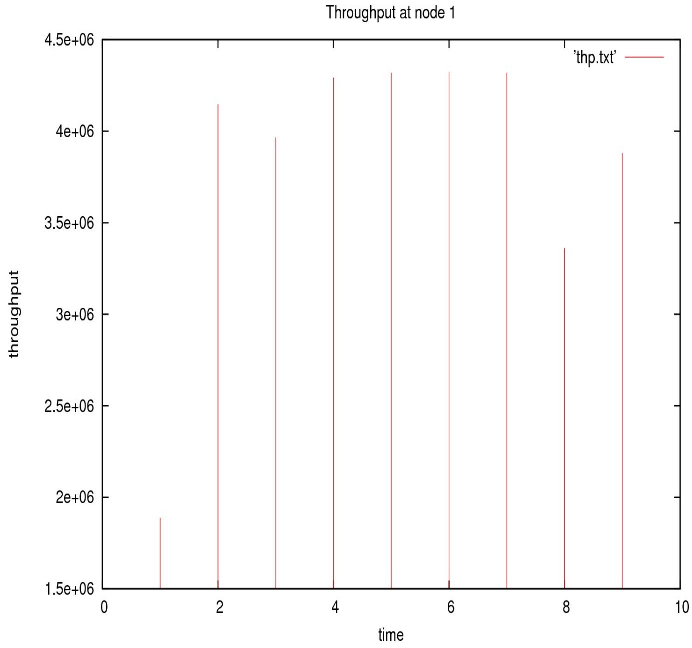


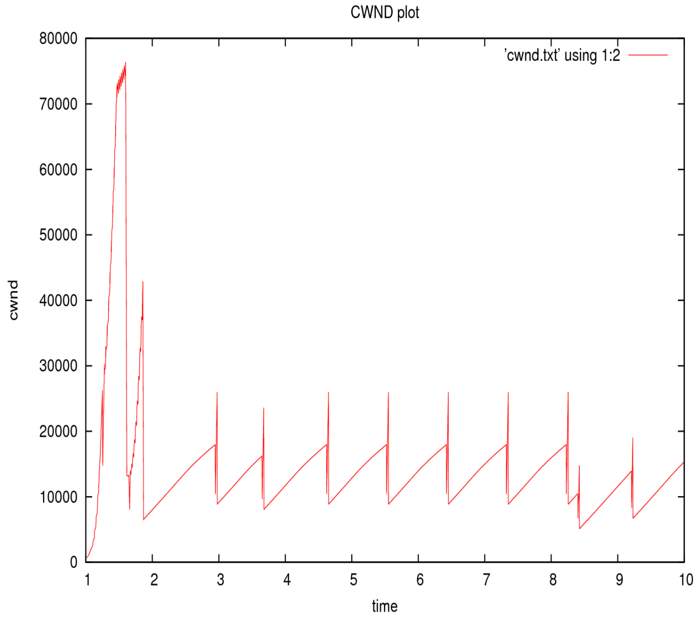
Link Delay of 5ms



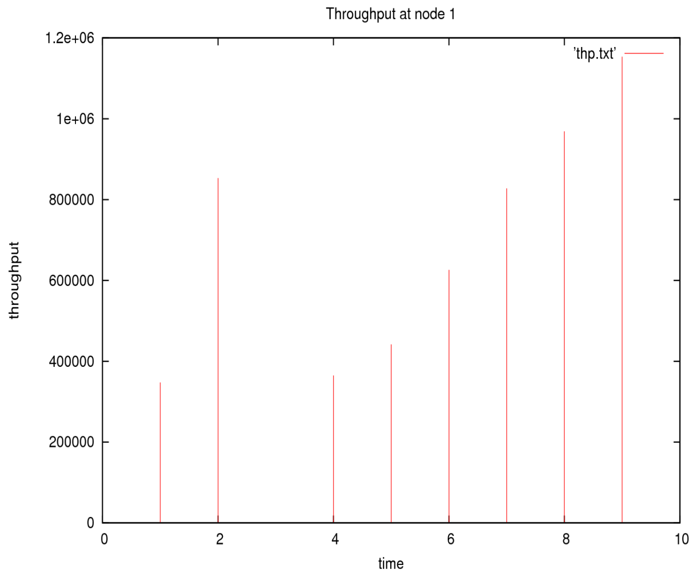


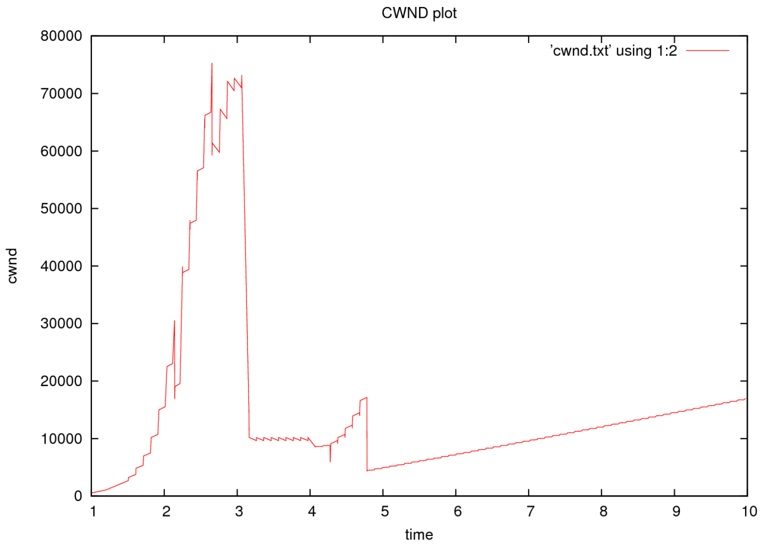
Link Delay of 10ms



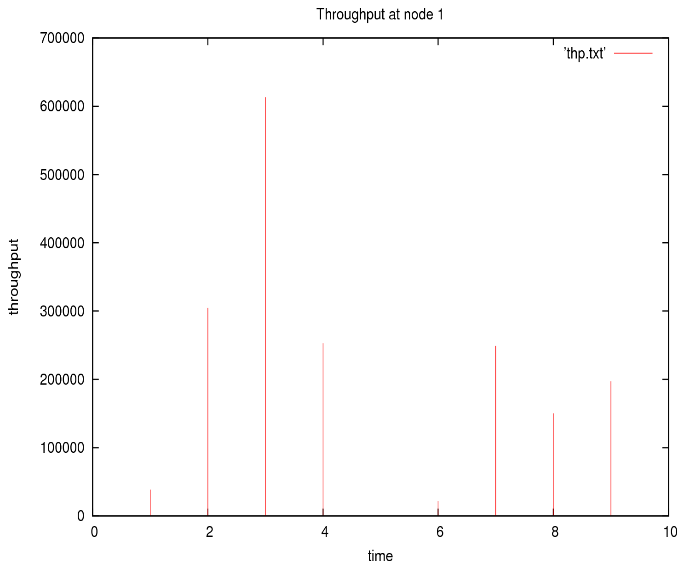


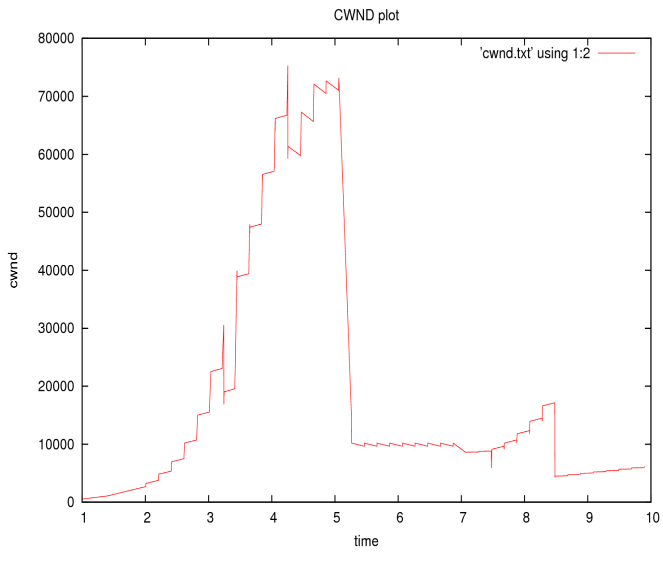
Link Delay of 50ms





Link Delay of 100ms

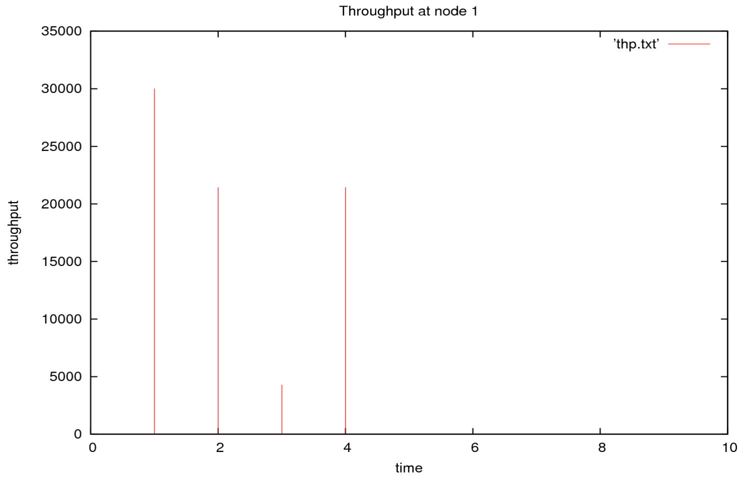


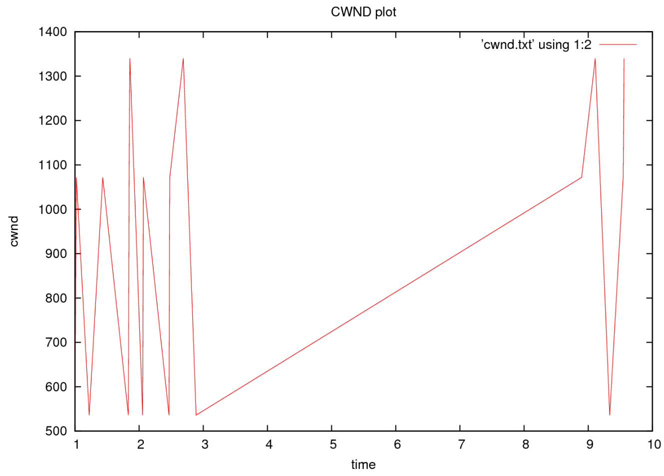


In all the 5 plots we see that as link delay increased throughput cam down. This is because of increase in link delay increases BDP which increases the window size limit (which would be reached during slow start) and so is the need for lesser loss rate and bigger buffer at receiver end. Due to loss rate and limited buffer size TCP would never be able to increase the window size to maximum and so would decrease the throughput.

1.4

Loss rate of 10^-3

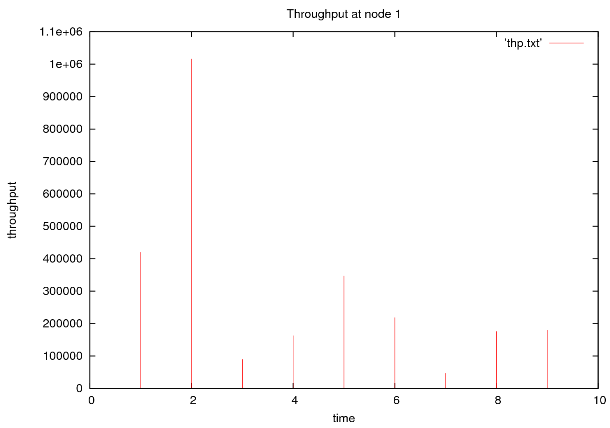


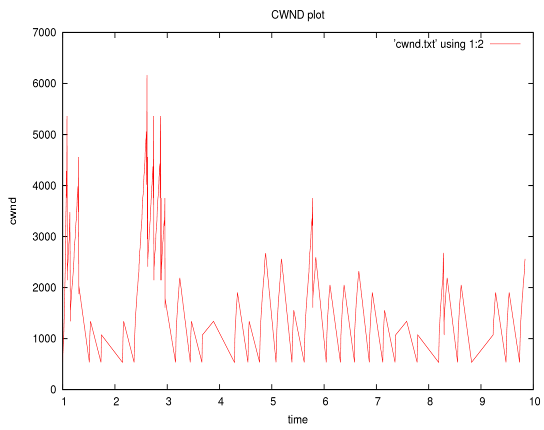


At a very high loss rate of 10^-3, we see that throughput is very very low. The window size never goes beyond 1000 to 1500 as there is a loss of 1 byte every 1000 bytes.
Thus underutilising the link and hence reducing the throughput.

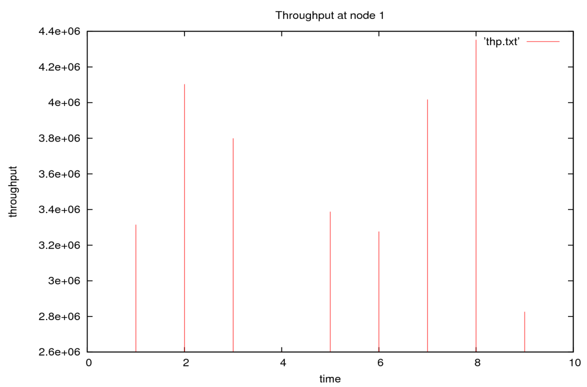
Same is the case with loss rate of 10^-4 and 10^-5.

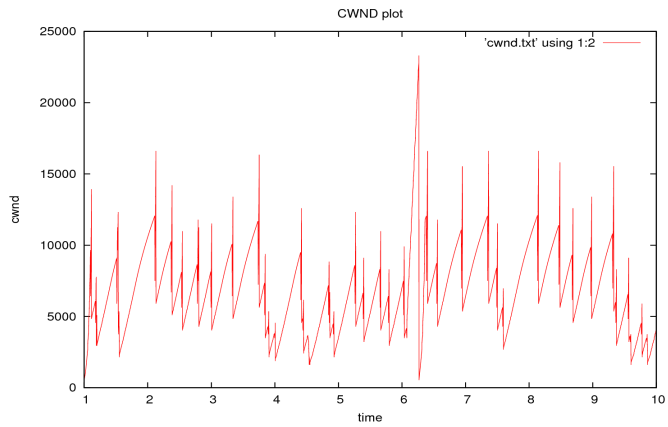
Link error rate of 10^-4





Link Rate of 10^-5





As the loss rate would be reached before TCP reached maximum window size limit. i.e. there would be atleast one loss by the time TCP grew to max limit at which buffer gets full.

This scenario with current BDP and buffersize is avoided only after loss rate becomes less than 10^-6 i.e. allowing TCP to reach max window limit defined by BDP + buffersize and so does utlise the link.

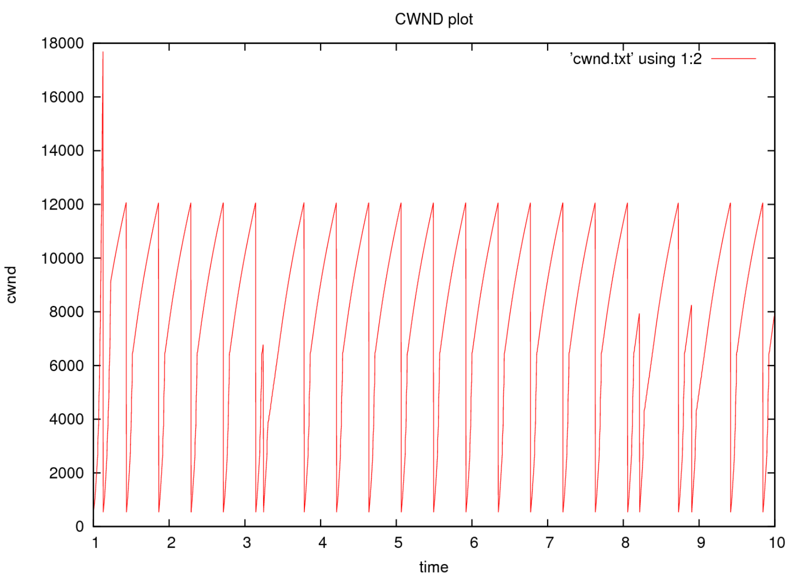
1.5

Table of comparisions

Buffer size	1	2	5	10	100	500	1000
Avg. Throughput (Mbps)	0.18	3.45	4.03	4.3	4.54	4.589	4.589
Avg. cwnd	1356.8	6141.7	7672.1	9884.8	29374.1	39339.9	39339.9
Avg. Queue Occupancy (packets)	0.5	0.7	1.768	4.54	38.8	58.5	58.5
Avg. Queue delay(secs)	0.00046	0.0007	0.00133	0.00386	0.03571	0.05319	0.05319

By observing the following metrics we see that as buffer size increases throughput increases, cwnd increases also delay increases. And beyond a certain point everything saturates.
We know that BDP = 5Mbps x 10ms = 6250 Bytes. Buffer size =12 would nearly be equal to BDP. Beyond which any size of buffer would allow full utilisation of bandwidth available but would add up to queue delay.

Based on the observation, queue value between 10 to 100 is a suitable value (also considerng delay into consideration). With only throughput into consideration buffer size of 500 is preferred.

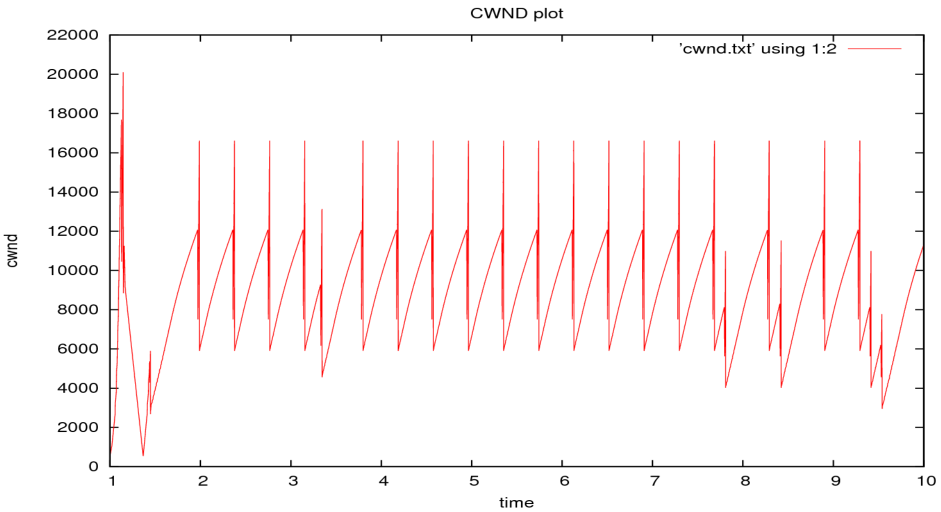


1.6
TCP Tahoe

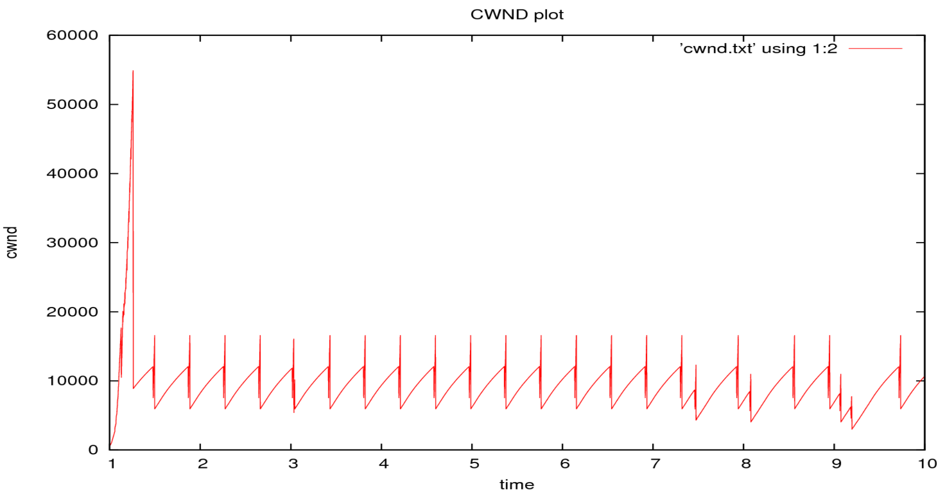
TCP Tahoe doesnt have fast recovery statee and goes back to slow start on 3 dupacks. On 3 dupacks, it sets sstresh as cwnd/2 and goes to slow start with new cwnd as 1packet. After reaching sstresh, It goes to congestion avoidance state and keeps increasing slowly till it reaches point where packets are lost/dropped. Throughput is less in TCP Tahoe compared to TCP Reno and newreno because evertime a loss occurs, window size goes to 1 packet and would take time to grow back to maximum limit again.

TCP Reno and NewReno

TCP Reno



TCP NewReno



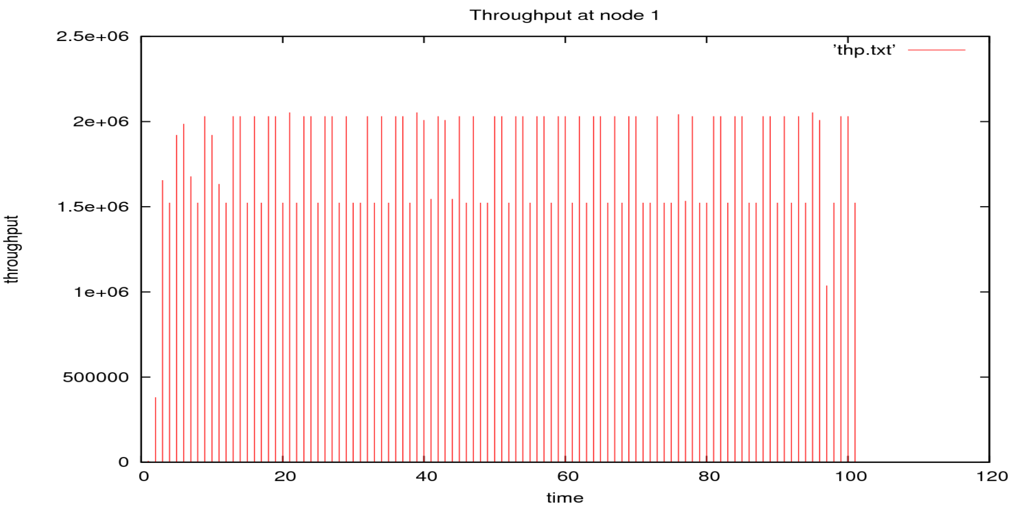
The major difference between TCP Reno and TCP NewReno is the ranges of temporary window size they reach in fast recovery. TCP remains in fast recovery until the ack is received for all the packets at point where dupacks were received and fast recovery mode was triggered. This is not the case in TCP Reno. It goes back to congestion avoidance state as soon as required number of acks are obtained (to limit window size to sstresh). This difference can be seen in initial increase in window size in both graphs. TCP NewReno grows beyond 50000 in this case remaining in fast recovery where as TCP Reno goes to congestion avoidance state soon.

Also as told before, both TCP Reno and TCP NewReno keep decreasing window size by a small amount before actually going to fast recovery during slow start and conestion avoidance (more prominent in slow start). I presume this is due to delay in acks received.

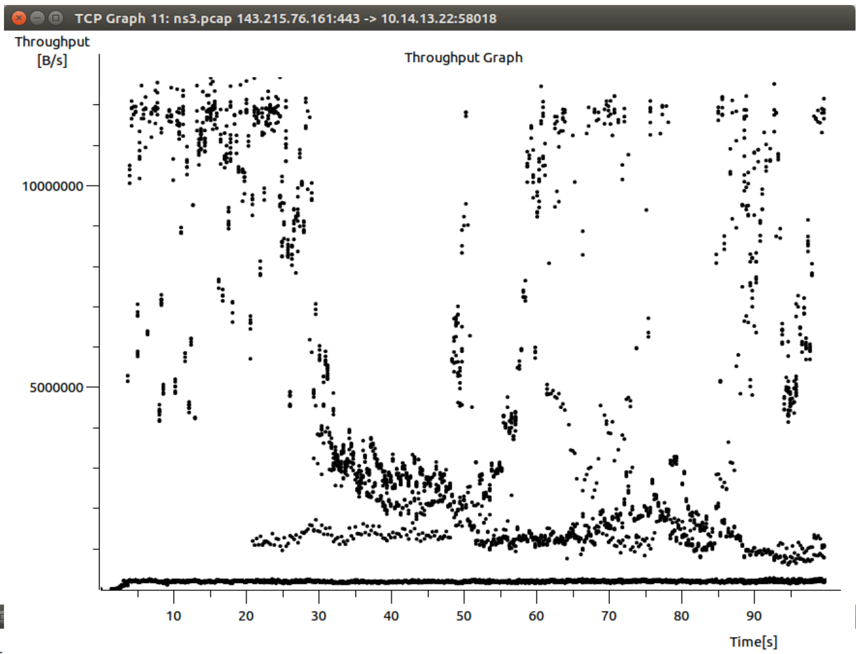
2.1

(i) Average throughput over entire transfer = 1.765 Mbps

Note: the entire transfer took place for 102 seconds for a 21.3 MB file (ns3 tarball)

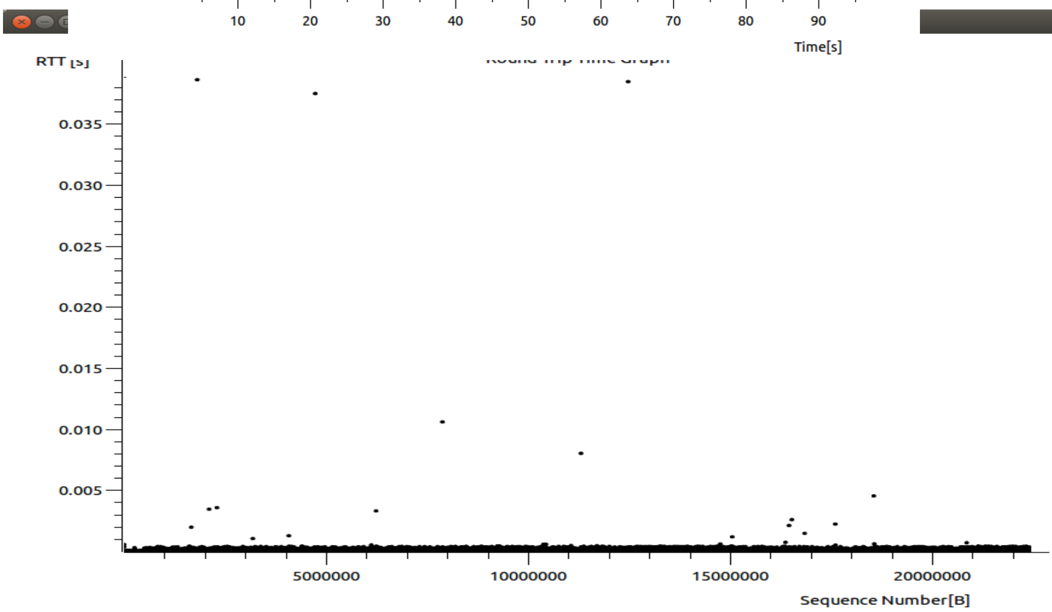


Also plotting throughput plot obtained from wireshark



(ii) No retransmissions were found even after many tries of downloading large files.

(iii) The RTT graph extracted from wireshark is show below.



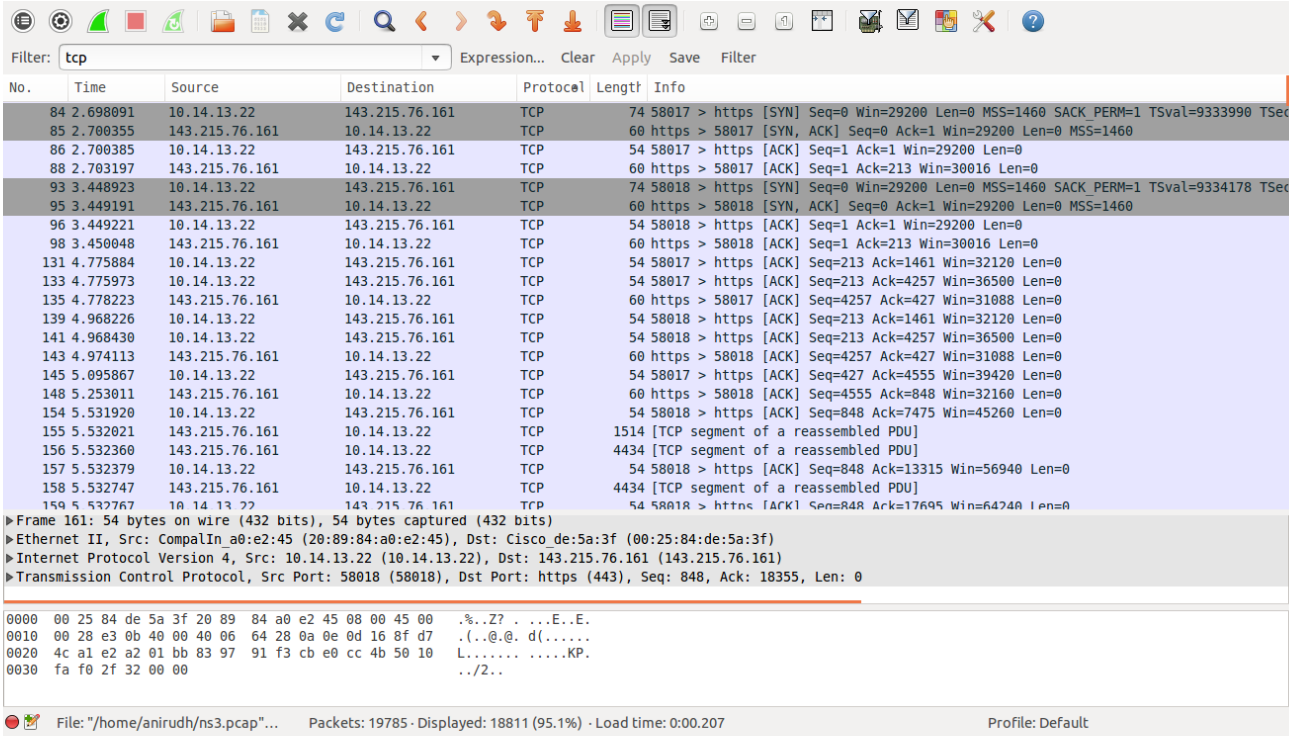
On close observation of this plot, it is seen that most of the packets have a RTT of around 300 to 400 micro seconds. The minimum RTT is around 300 micro seconds while the maximum RTT is 0.039 seconds.

2.2

As you see in the screen shot, two TCP connections are opened one one port 58017 and another on port 58018
Lets observe on port 58018..
As in screen shot, we can vaguely see the window size doubling at beginning and later increases by 1 MSS every RTT as shown in the two screen shots below
In 1st screen shot, the slow start phase is seen where the TCP window size increases as
1 to 1461 sequence number winsize of 1461
1461 to 4257 winsize of 2796
4257 to 7475 winsize of 3218
7475 to 13315 winsize of 5840 (4MSS Here MSS=1460)
13315 to 17695 winsize of 4380 (3MSS)

After this we see in the 2nd screen shot that the window size just increase by a MSS or 2MSS every RTT and continues to remain same way

screen shot 1



screen shot 2