

1. Number of Tcp Connections = 3

Calculated the number of tcp connections by counting the number of (syn, ack) packets, every (syn, ack) denotes a successful handshake. So, number of handshaking packets denotes number of TCP flows.

2. For each TCP flow

**a. For the first 2 transactions after the TCP connection is set up (from sender to receiver), get the values of the Sequence number, Ack number, and Receive Window size. Use the raw values for the sequence number and ack number. Explain these values.**

----- Connection 1 -----

For the first 2 transactions after the TCP connection is set up

seq# (raw) = 705669103 | ack# (raw) = 1921750144 | receive window size = 3

seq# (raw) = 705669127 | ack# (raw) = 1921750144 | receive window size = 3

----- Connection 2 -----

For the first 2 transactions after the TCP connection is set up

seq# (raw) = 3636173852 | ack# (raw) = 2335809728 | receive window size = 3

seq# (raw) = 3636173876 | ack# (raw) = 2335809728 | receive window size = 3

----- Connection 3 -----

For the first 2 transactions after the TCP connection is set up

seq# (raw) = 2558634630 | ack# (raw) = 3429921723 | receive window size = 3

seq# (raw) = 2558634654 | ack# (raw) = 3429921723 | receive window size = 3

For each of these, the sequence number represents the byte that we start off at, the ack number represents the next byte that we expect to receive, and the window size represents that we can receive the number given times 16384 bytes of data.

For example, in the first transaction of connection 1, we say that we start off at the 705669103rd byte, and we expect the next byte to be at the 1921750144th byte. The window size would be  $3 \times 16384$  which is equal to 49152 bytes. For all transactions within this example, the window size is equal to 49152 bytes.

**b. Compute the throughput at the receiver. You can make assumptions on what you want to include as part of the throughput estimation.**

To calculate throughput, packet size is used to calculate the total packet size at destination. Timestamp field is used over the first and last packet, to find the total time taken for receiving all packets at destination. Throughput = (total packet size) / total time taken.

Theoretical throughput is calculated from formula

$$\text{Throughput} = \frac{\sqrt{\frac{3}{2}} * MSS}{\sqrt{p} * RTT}$$

where p = loss rate,

RTT = Avg Round trip time

MSS = 1460 (calculated in code)

Connection 1

Estimated Throughput = 42.01083 *Mbs*

$$\text{Theoretical throughput} = \frac{\sqrt{\frac{3}{2}} * MSS}{\sqrt{p} * RTT} = 8.18543 \text{ } Mbs$$

Connection 2

Estimated Throughput = 10.28329 *Mbs*

$$\text{Theoretical throughput} = \frac{\sqrt{\frac{3}{2}} * MSS}{\sqrt{p} * RTT} = 1.69728 \text{ } Mbs$$

Connection 3

Throughput = 11.85125 *Mbs*

$$\text{Estimated throughput} = \frac{\sqrt{\frac{3}{2}} * MSS}{\sqrt{p} * RTT} = 5.25824 \text{ } Mbs$$

**c. Compute the loss rate for each flow. Loss rate is the number of packets not received divided by the number of packets sent. Loss rate is an application layer metric. So, think about what makes sense when defining loss rate.**

Loss is calculated by counting the retransmissions of a packet with the same sequence number. If a sequence number appears multiple times, then packet is lost, and sender must resend it.

Total loss = (Total number of packets which are retransmitted).

Loss rate = total loss/ total number of packets.

Connection 1

Loss Rate = 0.00057

Connection 2

Loss Rate = 0.01344

Connection 3

Loss Rate = 0.00137

**d. Estimate the average RTT. Now compare your empirical throughput from (b) and then theoretical throughput (estimated using the formula derived in class). Explain your comparison.**

For calculating RTT, Time stamps of all the packets sent are stored from both sender to receiver and from receiver to sender in a dictionary where key = sequence number of the packet. For every packet sent, sequence number from sender to receiver = acknowledgment number from receiver to sender's packet. Difference in time between a packet sent with sequence number x and the corresponding packet's acknowledgment number from receiver to sender is calculated.

Average RTT = (total time taken / total no. of transactions)

Connection 1

Average RTT = 73.00401 ms

Connection 2

Average RTT = 72.70503 ms

Connection 3

Average RTT = 73.50779 ms

Compare

Theoretical throughput < Empirical throughput

To achieve the calculated throughput of 42 Mbs, we need the loss rate to be .000024 seconds that is one loss for 50000 segments. However, we have around 11000 segments. In this scenario, using this formula, empirical throughput would always be greater than theoretical.