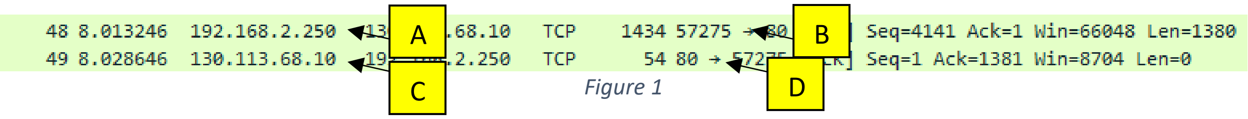
2. A first look at the captured trace

1. IP address: 192.168.2.250 (Figure 1, A)
   TCP port number: 57275 (Figure 1, B)
2. IP address: 130.113.68.10 (Figure 1, C)
   TCP port number: 80 (Figure 1, D)

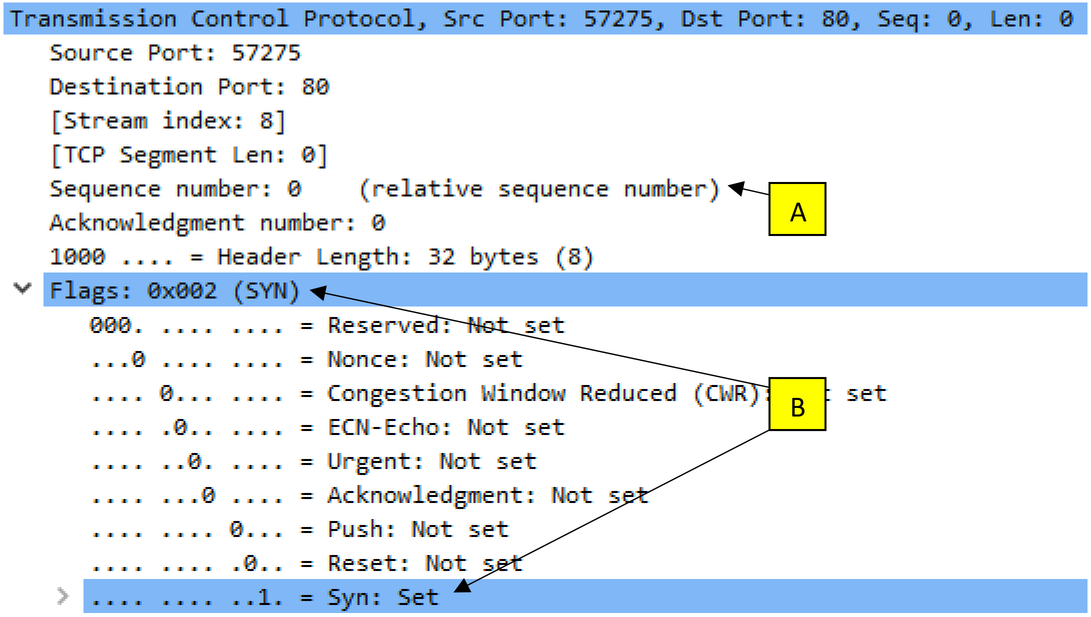


```
48 8.013246  192.168.2.250  13   .68.10   TCP    1434 57275 → 80   ] Seq=4141 Ack=1 Win=66048 Len=1380
49 8.028646  130.113.68.10  19   .2.250   TCP      54 80 → 5727   k] Seq=1 Ack=1381 Win=8704 Len=0
```

Figure 1

3. TCP Basics

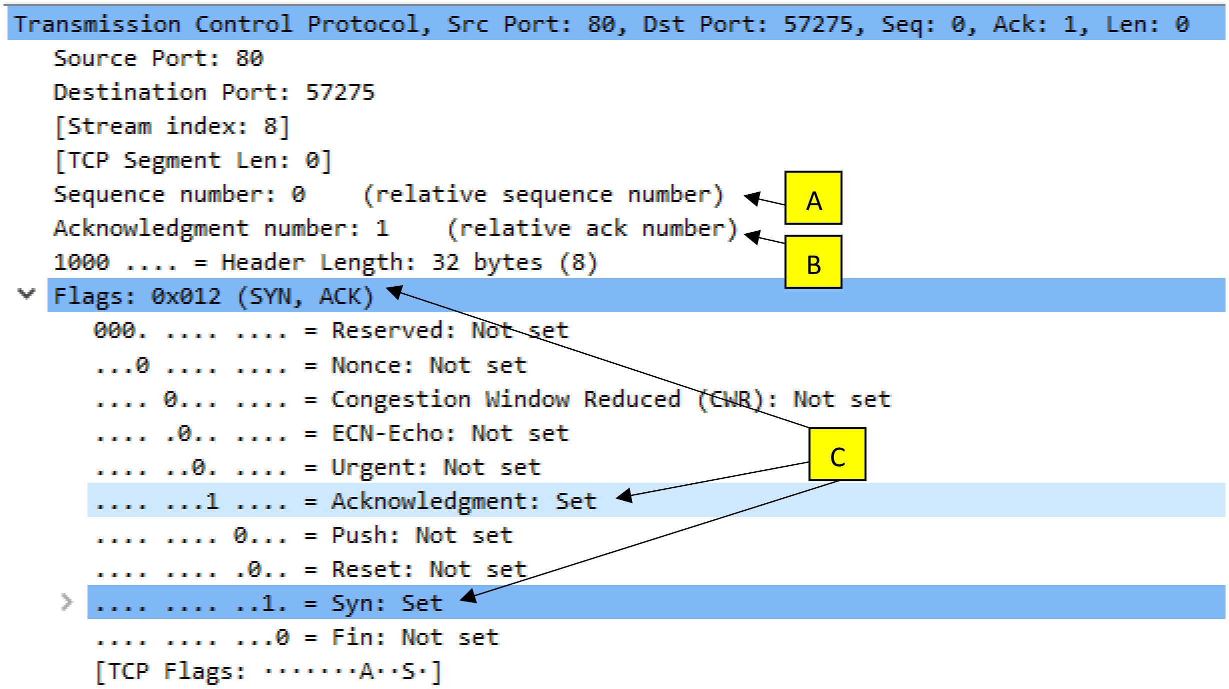
3. Sequence number: 0 (relative sequence number) (Figure 2, A)
   The 0x002 SYN flag identifies the segment by setting the Syn bit. (Figure 2, B)



```
Transmission Control Protocol, Src Port: 57275, Dst Port: 80, Seq: 0, Len: 0
   Source Port: 57275
   Destination Port: 80
   [Stream index: 8]
   [TCP Segment Len: 0]
   Sequence number: 0    (relative sequence number)
   Acknowledgment number: 0
   1000 .... = Header Length: 32 bytes (8)
 ⌄ Flags: 0x002 (SYN)
      000. .... .... = Reserved: Not set
      ...0 .... .... = Nonce: Not set
      .... 0... .... = Congestion Window Reduced (CWR)     set
      .... .0.. .... = ECN-Echo: Not set
      .... ..0. .... = Urgent: Not set
      .... ...0 .... = Acknowledgment: Not set
      .... .... 0... = Push: Not set
      .... .... .0.. = Reset: Not set
    > .... .... ..1. = Syn: Set
```

Figure 2

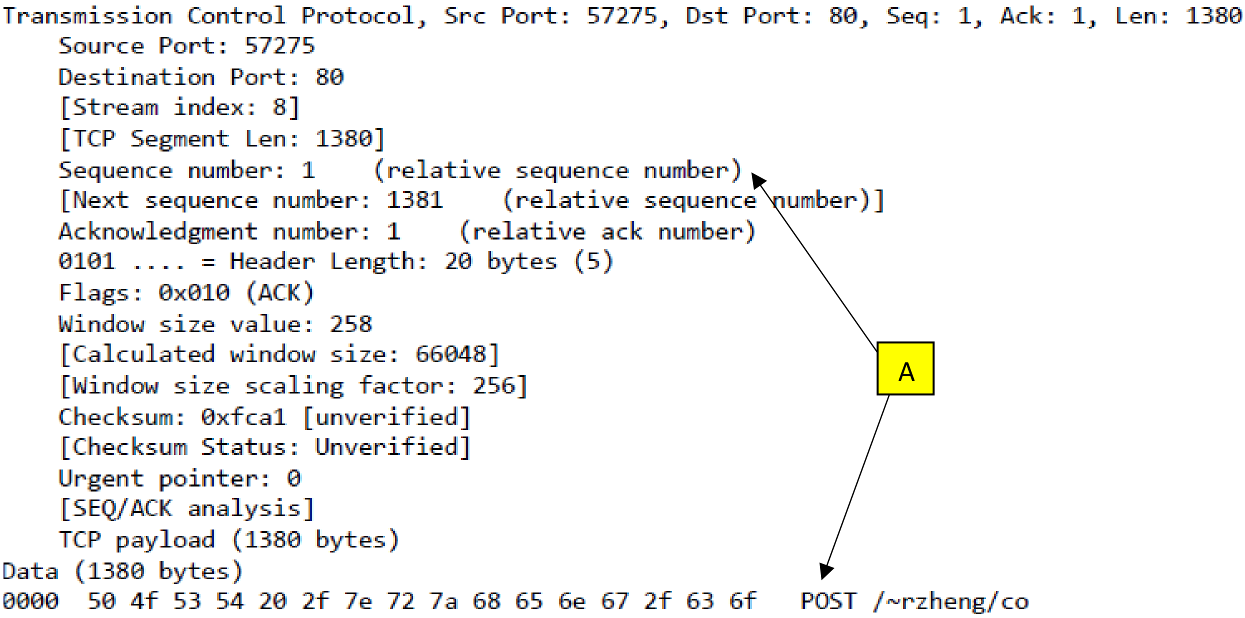
4. Sequence number: 0 (relative sequence number) (Figure 3, A)
   Acknowledge number: 1 (relative ack number) (Figure 3, B), determined by incrementing the SYN sequence number.
   The 0x012 SYN, ACK flag identifies the segment. (Figure 3, C)



```
Transmission Control Protocol, Src Port: 80, Dst Port: 57275, Seq: 0, Ack: 1, Len: 0
    Source Port: 80
    Destination Port: 57275
    [Stream index: 8]
    [TCP Segment Len: 0]
    Sequence number: 0    (relative sequence number)
    Acknowledgment number: 1    (relative ack number)
    1000 .... = Header Length: 32 bytes (8)
  Flags: 0x012 (SYN, ACK)
       000. .... .... = Reserved: Not set
       ...0 .... .... = Nonce: Not set
       .... 0... .... = Congestion Window Reduced (CWR): Not set
       .... .0.. .... = ECN-Echo: Not set
       .... ..0. .... = Urgent: Not set
       .... ...1 .... = Acknowledgment: Set
       .... .... 0... = Push: Not set
       .... .... .0.. = Reset: Not set
       .... .... ..1. = Syn: Set
       .... .... ...0 = Fin: Not set
       [TCP Flags: ·······A··S·]
```

Figure 3

5. Sequence number: 1 (relative sequence number) (Figure 4, A)



```
Transmission Control Protocol, Src Port: 57275, Dst Port: 80, Seq: 1, Ack: 1, Len: 1380
    Source Port: 57275
    Destination Port: 80
    [Stream index: 8]
    [TCP Segment Len: 1380]
    Sequence number: 1    (relative sequence number)
    [Next sequence number: 1381    (relative sequence number)]
    Acknowledgment number: 1    (relative ack number)
    0101 .... = Header Length: 20 bytes (5)
    Flags: 0x010 (ACK)
    Window size value: 258
    [Calculated window size: 66048]
    [Window size scaling factor: 256]
    Checksum: 0xfca1 [unverified]
    [Checksum Status: Unverified]
    Urgent pointer: 0
    [SEQ/ACK analysis]
    TCP payload (1380 bytes)
Data (1380 bytes)
0000  50 4f 53 54 20 2f 7e 72 7a 68 65 6e 67 2f 63 6f   POST /~rzheng/co
```

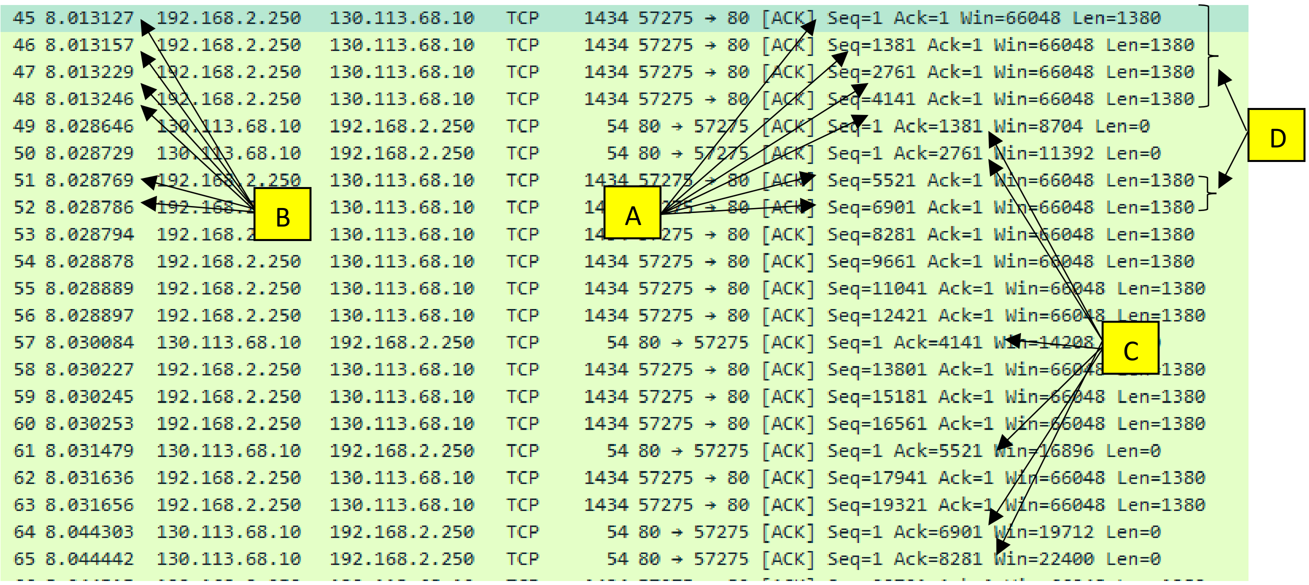
Figure 4

6.

Segment	Sequence Number	Time sent	ACK received	RTT	EstimatedRTT
1	1	8.013127	8.028646	0.015519	0.015519
2	1381	8.013157	8.028729	0.015572	0.015526
3	2761	8.013229	8.030084	0.016855	0.015692
4	4141	8.013246	8.031479	0.018233	0.01601
5	5521	8.028769	8.044303	0.015534	0.015951

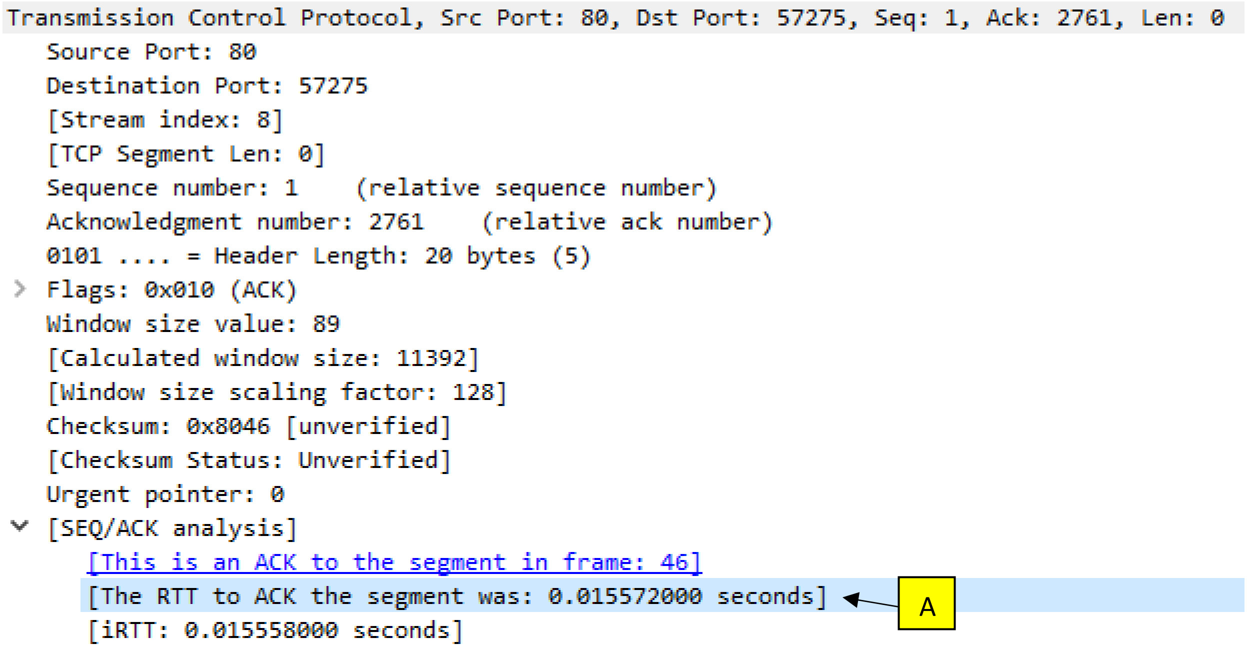
6	6901	8.028786	8.044442	0.015656	0.015914

Sequence Number (Figure 5, A)
Time sent (Figure 5, B)
ACK received (Figure 5, C)
RTT for packet with sequence number 1381 in frame number 46. (Figure 6, A)
Estimated RTT = (1-0.125) * EstimatedRTT + 0.125 * RTT



```
45 8.013127  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=1 Ack=1 Win=66048 Len=1380
46 8.013157  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=1381 Ack=1 Win=66048 Len=1380
47 8.013229  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=2761 Ack=1 Win=66048 Len=1380
48 8.013246  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=4141 Ack=1 Win=66048 Len=1380
49 8.028646  130.113.68.10  192.168.2.250  TCP     54 80 → 57275 [ACK] Seq=1 Ack=1381 Win=8704 Len=0
50 8.028729  130.113.68.10  192.168.2.250  TCP     54 80 → 57275 [ACK] Seq=1 Ack=2761 Win=11392 Len=0
51 8.028769  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=5521 Ack=1 Win=66048 Len=1380
52 8.028786  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=6901 Ack=1 Win=66048 Len=1380
53 8.028794  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=8281 Ack=1 Win=66048 Len=1380
54 8.028878  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=9661 Ack=1 Win=66048 Len=1380
55 8.028889  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=11041 Ack=1 Win=66048 Len=1380
56 8.028897  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=12421 Ack=1 Win=66048 Len=1380
57 8.030084  130.113.68.10  192.168.2.250  TCP     54 80 → 57275 [ACK] Seq=1 Ack=4141 Win=14208 Len=0
58 8.030227  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=13801 Ack=1 Win=66048 Len=1380
59 8.030245  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=15181 Ack=1 Win=66048 Len=1380
60 8.030253  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=16561 Ack=1 Win=66048 Len=1380
61 8.031479  130.113.68.10  192.168.2.250  TCP     54 80 → 57275 [ACK] Seq=1 Ack=5521 Win=16896 Len=0
62 8.031636  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=17941 Ack=1 Win=66048 Len=1380
63 8.031656  192.168.2.250  130.113.68.10  TCP   1434 57275 → 80 [ACK] Seq=19321 Ack=1 Win=66048 Len=1380
64 8.044303  130.113.68.10  192.168.2.250  TCP     54 80 → 57275 [ACK] Seq=1 Ack=6901 Win=19712 Len=0
65 8.044442  130.113.68.10  192.168.2.250  TCP     54 80 → 57275 [ACK] Seq=1 Ack=8281 Win=22400 Len=0
```

Figure 5

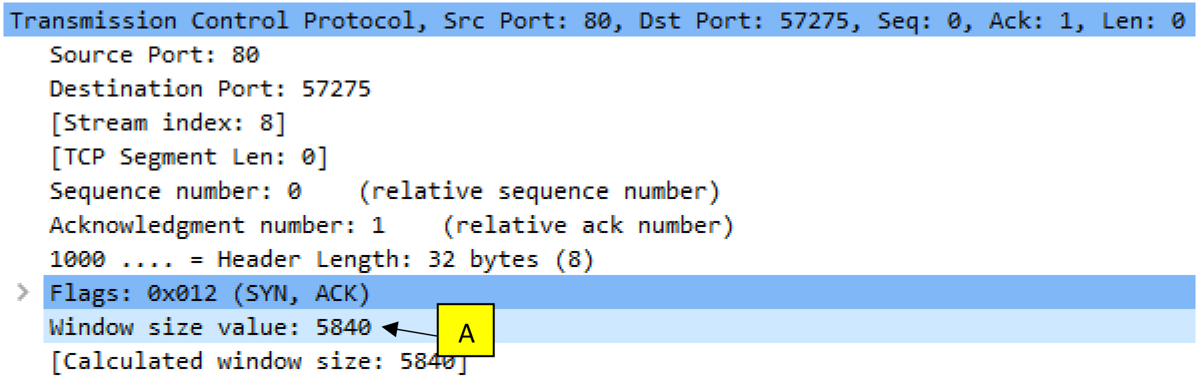


```
Transmission Control Protocol, Src Port: 80, Dst Port: 57275, Seq: 1, Ack: 2761, Len: 0
    Source Port: 80
    Destination Port: 57275
    [Stream index: 8]
    [TCP Segment Len: 0]
    Sequence number: 1    (relative sequence number)
    Acknowledgment number: 2761    (relative ack number)
    0101 .... = Header Length: 20 bytes (5)
  > Flags: 0x010 (ACK)
    Window size value: 89
    [Calculated window size: 11392]
    [Window size scaling factor: 128]
    Checksum: 0x8046 [unverified]
    [Checksum Status: Unverified]
    Urgent pointer: 0
  v [SEQ/ACK analysis]
        [This is an ACK to the segment in frame: 46]
        [The RTT to ACK the segment was: 0.015572000 seconds]
        [iRTT: 0.015558000 seconds]
```

Figure 6

7. 1380 bytes for all six packets (Figure 5, D)

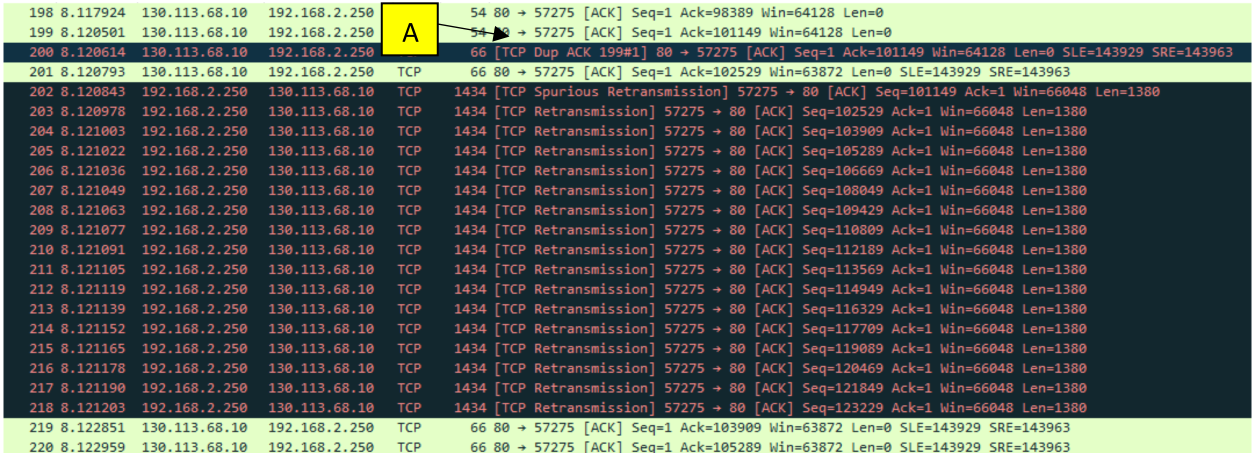
8. Minimum available buffer space (receiver window size value): 5840 (Figure 7, A) from the (SYN, ACK). The lack of receiver space does not throttle the sender due to lack of receiver buffer space.



```
Transmission Control Protocol, Src Port: 80, Dst Port: 57275, Seq: 0, Ack: 1, Len: 0
    Source Port: 80
    Destination Port: 57275
    [Stream index: 8]
    [TCP Segment Len: 0]
    Sequence number: 0    (relative sequence number)
    Acknowledgment number: 1    (relative ack number)
    1000 .... = Header Length: 32 bytes (8)
  > Flags: 0x012 (SYN, ACK)
    Window size value: 5840
    [Calculated window size: 5840]
```

Figure 7

9. Yes, there are retransmitted segments in the trace file. By checking for a TCP duplicate acknowledgement and [TCP Retransmission] packets in the trace. (Figure 8, A)

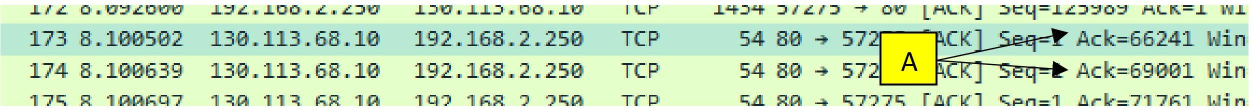


```
198 8.117924  130.113.68.10   192.168.2.250          54 80 → 57275 [ACK] Seq=1 Ack=98389 Win=64128 Len=0
199 8.120501  130.113.68.10   192.168.2.250          54 80 → 57275 [ACK] Seq=1 Ack=101149 Win=64128 Len=0
200 8.120614  130.113.68.10   192.168.2.250          66 [TCP Dup ACK 199#1] 80 → 57275 [ACK] Seq=1 Ack=101149 Win=64128 Len=0 SLE=143929 SRE=143963
201 8.120793  130.113.68.10   192.168.2.250   TCP    66 80 → 57275 [ACK] Seq=1 Ack=102529 Win=63872 Len=0 SLE=143929 SRE=143963
202 8.120843  192.168.2.250   130.113.68.10   TCP  1434 [TCP Spurious Retransmission] 57275 → 80 [ACK] Seq=101149 Ack=1 Win=66048 Len=1380
203 8.120978  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=102529 Ack=1 Win=66048 Len=1380
204 8.121003  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=103909 Ack=1 Win=66048 Len=1380
205 8.121022  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=105289 Ack=1 Win=66048 Len=1380
206 8.121036  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=106669 Ack=1 Win=66048 Len=1380
207 8.121049  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=108049 Ack=1 Win=66048 Len=1380
208 8.121063  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=109429 Ack=1 Win=66048 Len=1380
209 8.121077  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=110809 Ack=1 Win=66048 Len=1380
210 8.121091  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=112189 Ack=1 Win=66048 Len=1380
211 8.121105  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=113569 Ack=1 Win=66048 Len=1380
212 8.121119  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=114949 Ack=1 Win=66048 Len=1380
213 8.121139  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=116329 Ack=1 Win=66048 Len=1380
214 8.121152  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=117709 Ack=1 Win=66048 Len=1380
215 8.121165  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=119089 Ack=1 Win=66048 Len=1380
216 8.121178  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=120469 Ack=1 Win=66048 Len=1380
217 8.121190  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=121849 Ack=1 Win=66048 Len=1380
218 8.121203  192.168.2.250   130.113.68.10   TCP  1434 [TCP Retransmission] 57275 → 80 [ACK] Seq=123229 Ack=1 Win=66048 Len=1380
219 8.122851  130.113.68.10   192.168.2.250   TCP    66 80 → 57275 [ACK] Seq=1 Ack=103909 Win=63872 Len=0 SLE=143929 SRE=143963
220 8.122959  130.113.68.10   192.168.2.250   TCP    66 80 → 57275 [ACK] Seq=1 Ack=105289 Win=63872 Len=0 SLE=143929 SRE=143963
```

Figure 8

10. The difference between ACK sequence numbers of two consecutive ACKs is the amount of data acknowledged by the receiver. As seen below, the receiver typically acknowledges 1380 bytes, but I find some instances, such as acknowledgement sequence number 69001 where 2760 bytes of data was acknowledged. (Figure 9, A)

ACK Sequence Number	Data
1381	1380
2761	1380
4141	1380
5521	1380
6901	1380
8281	1380
9661	1380
…	
66241	…
69001	2760
…	



```
172 8.092600  192.168.2.250  130.113.68.10  TCP   1454 57275 → 80 [ACK] Seq=125989 Ack=1 Wi
173 8.100502  130.113.68.10  192.168.2.250  TCP     54 80 → 572   [ACK] Seq=1 Ack=66241 Win
174 8.100639  130.113.68.10  192.168.2.250  TCP     54 80 → 572   [ACK] Seq=1 Ack=69001 Win
175 8.100697  130.113.68.10  192.168.2.250  TCP     54 80 → 57275 [ACK] Seq=1 Ack=71761 Win
```

Figure 9

11. I calculate the throughput by averaging over the entire time duration during which the file was transferred.

$$\frac{143929 - 1}{8.104559 - 8.013127} = 1574153.47 \text{ bytes/seconds}$$

3. TCP congestion control in action

12. TCP slowstart phase begins at 0.015558 seconds and ends at 0.1056, after which congestion avoidance takes over. The ideal TCP sender behaviour follows the AIMD algorithm, sending plenty of data and then decreasing the window size upon detecting congestion. An application effects TCP behavior. For an application with several small objects where transmission time is less than the length of the slow start phase, transmission experiences long delays.

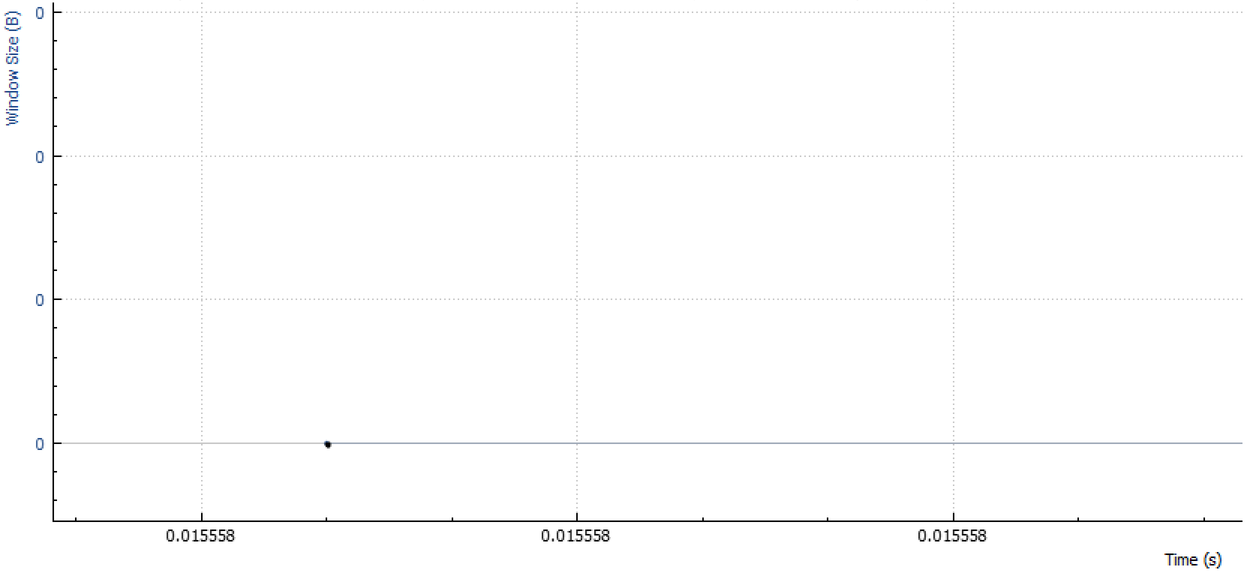
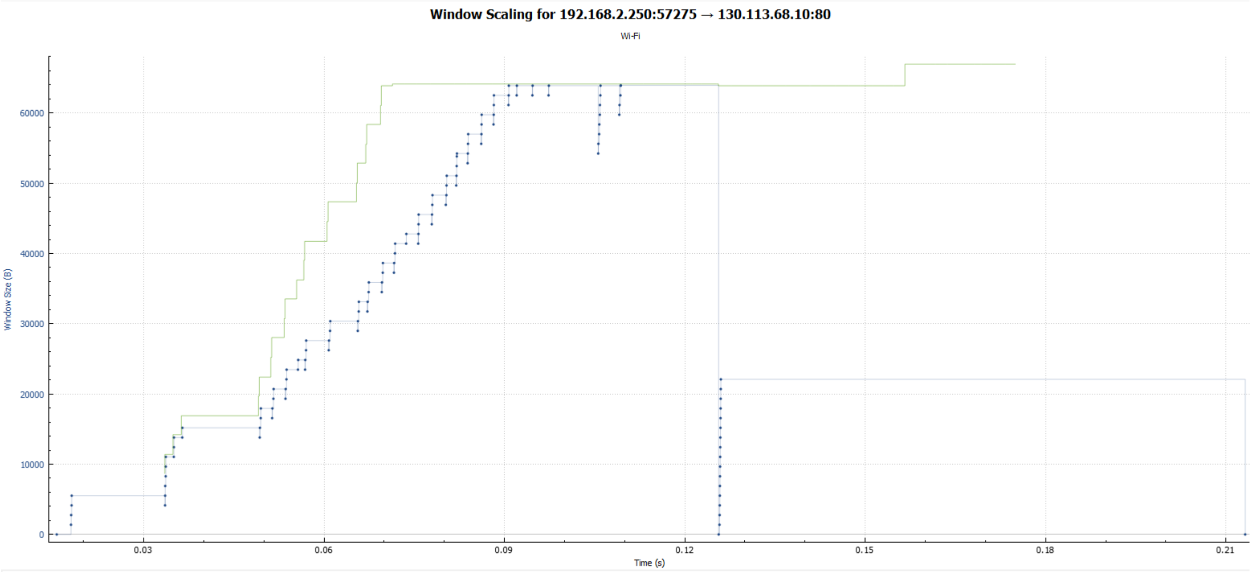


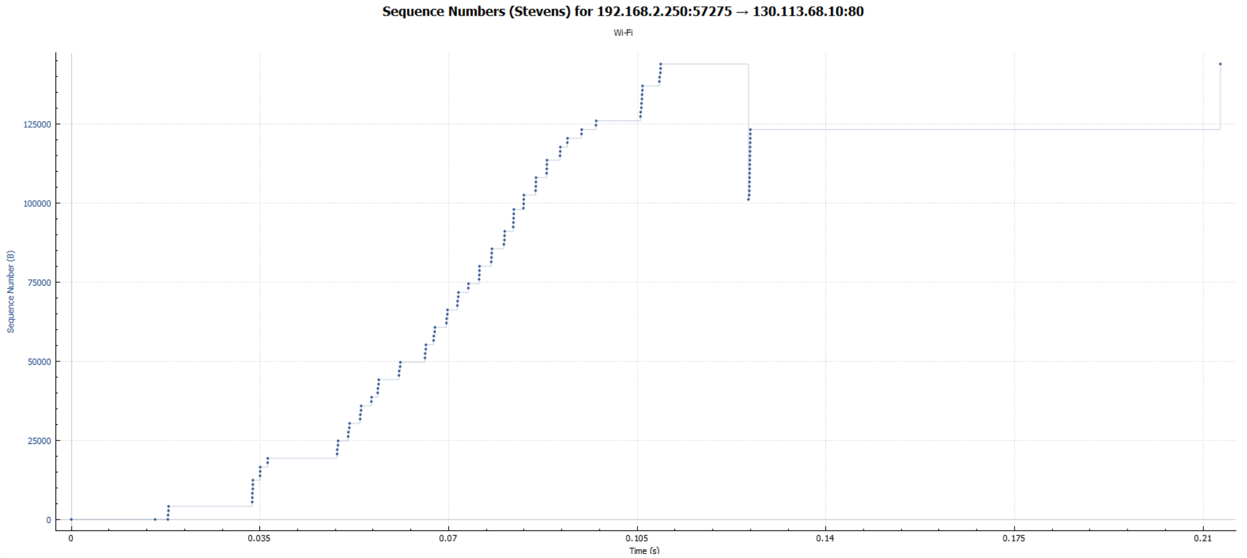
Figure 10

UMME SALMA GADRIWALA - 400021431

4C03 – ASSIGNMENT 2


Window Scaling for 192.168.2.250:57275 → 130.113.68.10:80

Wi-Fi


Sequence Numbers (Stevens) for 192.168.2.250:57275 → 130.113.68.10:80

Wi-Fi