#### 2. A first look at the captured trace

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

TCP port number: 80 (Figure 1, D)

Figure 1

#### 3. TCP Basics

3. Sequence number: 0 (relative sequence number) (Figure 2, A)

The  $0 \times 002$  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]
                         (relative sequence number)
  Sequence number: 0
  Acknowledgment number: 0
  1000 .... = Header Length: 32 bytes (8)
Y 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  $0 \times 0.12$  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
       .... = 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]
                                                                Α
    [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	

8.044442

8.028786

0.015656

0.015914

6

6901

	<b>/</b>					
Sequence Number	r (Figure 5, A)					
Time sent (Figure 5, B)						
. •						
	ACK received (Figure 5, C)					
RTT for packet wit	h sequence numbe	r 1381 in frame number 46. (Figure 6, A)				
Estimated RTT = (1	L-0.125) * Estimate	HRTT + 0 125 * RTT				
Estimated IVI - (1	LO.123/ Estimate	3KTT - 0.123 KTT				
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	- N				
47 8.013229 192.168.2.250	130.113.68.10 TCP					
48 8.013246 192.168.2.250						
49 8.028646 130 13.68.10	192.168.2.250 TCP	54 80 ± 57275 ACV Sex-1 Ack-1381 Win-8704 Len-0				
50 8.028729 130 13.68.10	192.168.2.250 TCP					
51 8.028769 <b>√</b> 192.18 <b>1</b> 2.250						
52 8.028786 <del>192.168.</del> □	130.113.68.10 TCP					
53 8.028794 192.168.2 B	130.113.68.10 TCP	\				
54 8.028878 192.168.2.250						
55 8.028889 192.168.2.250						
56 8.028897 192.168.2.250						
57 8.030084 130.113.68.10						
58 8.030227 192.168.2.250						
59 8.030245 192.168.2.250	130.113.68.10 TCP					
60 8.030253 192.168.2.250	130.113.68.10 TCP	1434 57275 → 80 [ACK] Seq=16561 Ack=1 Win=#6048 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 W17=66048 Len=1380				
63 8.031656 192.168.2.250	130.113.68.10 TCP					
64 8.044303 130.113.68.10	192.168.2.250 TCP					
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				
		<b>3</b>				
Transmission Control P	rotocol, Src Por	t: 80, Dst Port: 57275, Seq: 1, Ack: 2761, Len: 0				
Source Port: 80		,,,,,,				
	7075					
Destination Port: 5	7275					
[Stream index: 8]						
[TCP Segment Len: 0	1					
Sequence number: 1	-	uence number)				
Acknowledgment numb	•	· ·				
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: U	nverified]					
Urgent pointer: 0	•					
✓ [SEQ/ACK analysis]						
[This is an ACK to the segment in frame: 46]						
[The RTT to ACK	[The RTT to ACK the segment was: 0.015572000 seconds]  ▲ A					
[iRTT: 0.0155580	00 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 

A

[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)

acknowledgement and	וטון	rei netransmission packets in the trace. (rigare o, 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	A	54-10 → 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] Seg=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] Seg=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] Seg=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

1/2 0.092000	192.100.2.200	120.112.00.10	TCP	T+>+ >\(\(\alpha\)\) > OA [WCK] >Ed=T<>AOA WCK=T MT
173 8.100502	130.113.68.10	192.168.2.250	TCP	
174 8.100639	130.113.68.10	192.168.2.250	TCP	54 80 → 572 A ACK] Seq=▶ Ack=69001 Win
175 8 100697	130 113 68 10	192 168 2 250	TCP	54 80 → 57275 [ACK] Sen=1 Ack=71761 Win
		Fi	gure 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 0.05 seconds, 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.

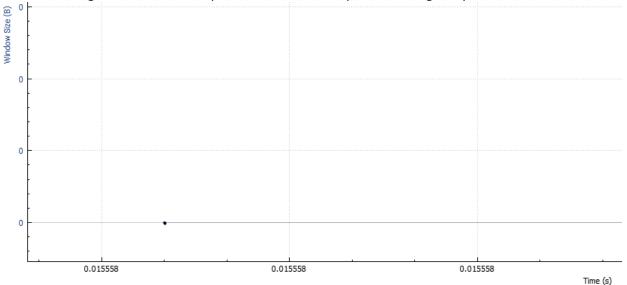


Figure 10

