

# EE450

## TCP Lab Report

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# Abstract

This report investigates the behavior of the celebrated TCP protocol in detail. We analyze a trace of the TCP segments sent and received in transferring a 150KB file from client computer to `gaia.cs.umass.edu`. Through the first 12 questions, the sequence and acknowledgement numbers for providing reliable data transfer in TCP protocol is discussed. TCP connection setup and the performance (throughput and round-trip time) of the TCP connection between client computer and the remote server are also investigated. The last two question discuss the congestion control algorithm – slow start and congestion avoidance, and TCP’s receiver-advertised flow control mechanism.

1.

Source:

IP address: 192.168.1.102

TCP Port number: 1161

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	192.168.1.102	128.119.245.12	TCP	62	1161 → 80 [SYN] Seq=0 Win=16384 Len=0 MSS=1460 SACK_PERM=1
2	0.023172	128.119.245.12	192.168.1.102	TCP	62	80 → 1161 [SYN, ACK] Seq=0 Ack=1 Win=5840 Len=0 MSS=1460 SACK_PERM=1
3	0.023265	192.168.1.102	128.119.245.12	TCP	54	1161 → 80 [ACK] Seq=1 Ack=1 Win=17520 Len=0
4	0.026477	192.168.1.102	128.119.245.12	TCP	619	1161 → 80 [PSH, ACK] Seq=1 Ack=1 Win=17520 Len=565 TCP segment of a reassembled PDU
5	0.041737	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [PSH, ACK] Seq=566 Ack=1 Win=17520 Len=1460 [TCP segment of a reassembled ...
6	0.053937	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=566 Win=6780 Len=0
7	0.054026	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=2026 Ack=1 Win=17520 Len=1460 [TCP segment of a reassembled PDU]
8	0.054690	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=3486 Ack=1 Win=17520 Len=1460 [TCP segment of a reassembled PDU]
9	0.077294	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=2026 Win=8760 Len=0
10	0.077405	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=4946 Ack=1 Win=17520 Len=1460 [TCP segment of a reassembled PDU]
11	0.078157	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=6406 Ack=1 Win=17520 Len=1460 [TCP segment of a reassembled PDU]
12	0.124085	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=3486 Win=11680 Len=0

> Frame 4: 619 bytes on wire (4952 bits), 619 bytes captured (4952 bits)

> Ethernet II, Src: Actionte\_8a:70:1a (00:20:e0:8a:70:1a), Dst: LinksysG\_da:af:73 (00:06:25:da:af:73)

> Internet Protocol Version 4, Src: 192.168.1.102, Dst: 128.119.245.12

> Transmission Control Protocol, Src Port: 1161, Dst Port: 80, Seq: 1, Ack: 1, Len: 565

2.

According to the above figure,

Destination: gaia.cs.umass.edu

IP address: 128.119.245.12

TCP Port number: 80

3.

Source:

IP address: 100.65.1.103

TCP Port number: 53848

No.	Time	Source	Destination	Protocol	Length	Info
5231	17.354302	52.11.218.199	100.65.1.103	TLSv1...	99	Application Data
5236	17.369042	100.65.1.103	52.11.218.199	TCP	66	56812 → 443 [ACK] Seq=2103 Ack=136 Win=2047 Len=0 TSval=7213230
5478	18.102154	100.65.1.103	173.234.158.67	TCP	54	53846 → 443 [RST, ACK] Seq=1579 Ack=750 Win=131008 Len=0
5489	18.150067	100.65.1.103	128.119.245.12	TCP	684	53848 → 80 [PSH, ACK] Seq=1 Ack=1 Win=131712 Len=618 TSval=1374
5496	18.163171	100.65.1.103	128.119.245.12	TCP	1514	53848 → 80 [ACK] Seq=619 Ack=1 Win=131712 Len=1448 TSval=137405
5497	18.163172	100.65.1.103	128.119.245.12	TCP	1514	53848 → 80 [ACK] Seq=2067 Ack=1 Win=131712 Len=1448 TSval=13740
5498	18.163173	100.65.1.103	128.119.245.12	TCP	1514	53848 → 80 [ACK] Seq=3515 Ack=1 Win=131712 Len=1448 TSval=13740
5499	18.163173	100.65.1.103	128.119.245.12	TCP	1514	53848 → 80 [ACK] Seq=4963 Ack=1 Win=131712 Len=1448 TSval=13740
5500	18.163174	100.65.1.103	128.119.245.12	TCP	1514	53848 → 80 [ACK] Seq=6411 Ack=1 Win=131712 Len=1448 TSval=13740
5501	18.163174	100.65.1.103	128.119.245.12	TCP	1514	53848 → 80 [ACK] Seq=7859 Ack=1 Win=131712 Len=1448 TSval=13740

> Frame 5489: 684 bytes on wire (5472 bits), 684 bytes captured (5472 bits) on interface en0, id 0

> Ethernet II, Src: Apple\_cd:74:12 (08:6d:41:cd:74:12), Dst: IETF-VRRP-VRID\_01 (00:00:5e:00:01:01)

> Internet Protocol Version 4, Src: 100.65.1.103, Dst: 128.119.245.12

> Transmission Control Protocol, Src Port: 53848, Dst Port: 80, Seq: 1, Ack: 1, Len: 618

4.

According to the figure below,

TCP SYN segment uses sequence number 0 to initiate the TCP connection.

The SYN flag is set to 1 to indicate it's a SYN segment.

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	192.168.1.102	128.119.245.12	TCP	62	1161 → 80 [SYN] Seq=0 Win=16384 Len=0 MSS=1460 SACK_PERM=1
2	0.023172	128.119.245.12	192.168.1.102	TCP	62	80 → 1161 [SYN, ACK] Seq=0 Ack=1 Win=5840 Len=0 MSS=1460 SACK_P

Ethernet II, Src: Actionte_8a:70:1a (00:20:e0:8a:70:1a), Dst: LinksysG_da:af:73 (00:06:25:da:af:73)						
Internet Protocol Version 4, Src: 192.168.1.102, Dst: 128.119.245.12						
Transmission Control Protocol, Src Port: 1161, Dst Port: 80, Seq: 0, Len: 0						
Source Port: 1161 Destination Port: 80 [Stream index: 0] [Conversation completeness: Incomplete, DATA (15)] [TCP Segment Len: 0]						
Sequence Number: 0 (relative sequence number)						
Sequence Number (raw): 232129012 [Next Sequence Number: 1 (relative sequence number)] Acknowledgment Number: 0 Acknowledgment number (raw): 0 0111 .... = Header Length: 28 bytes (7)						
Flags: 0x002 (SYN)						
000. .... = Reserved: Not set ...0 .... = Nonce: Not set .... 0... = Congestion Window Reduced (CWR): Not 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 .... .... ...0 = Fin: Not set [TCP Flags: .....S.]						

- The sequence number of SYNACK segment is 0.

The value of Acknowledgement field is 1.

The value is determined by adding 1 to the sequence number 0 in the initial SYN segment.

The Syn flag and Acknowledgement flag is set to 1 to indicate it's a SYNACK segment.

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	192.168.1.102	128.119.245.12	TCP	62	1161 → 80 [SYN] Seq=0 Win=16384 Len=0 MSS=1460 SACK_PERM=1
2	0.023172	128.119.245.12	192.168.1.102	TCP	62	80 → 1161 [SYN, ACK] Seq=0 Ack=1 Win=5840 Len=0 MSS=1460 SACK_P

Ethernet II, Src: LinksysG_da:af:73 (00:06:25:da:af:73), Dst: Actionte_8a:70:1a (00:20:e0:8a:70:1a)						
Internet Protocol Version 4, Src: 128.119.245.12, Dst: 192.168.1.102						
Transmission Control Protocol, Src Port: 80, Dst Port: 1161, Seq: 0, Ack: 1, Len: 0						
Source Port: 80 Destination Port: 1161 [Stream index: 0] [Conversation completeness: Incomplete, DATA (15)] [TCP Segment Len: 0]						
Sequence Number: 0 (relative sequence number)						
Sequence Number (raw): 883061785 [Next Sequence Number: 1 (relative sequence number)]						
Acknowledgment Number: 1 (relative ack number)						
Acknowledgment number (raw): 232129013 0111 .... = Header Length: 28 bytes (7)						
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.]						

- According to the figure below,

The TCP segment with sequence number 1 containing the HTTP POST command.

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> Frame 4: 619 bytes on wire (4952 bits), 619 bytes captured (4952 bits)
> Ethernet II, Src: Actionte_8a:70:1a (00:20:e0:8a:70:1a), Dst: LinksysG_da:af:73 (00:06:25:da:af:73)
> Internet Protocol Version 4, Src: 192.168.1.102, Dst: 128.119.245.12
> Transmission Control Protocol, Src Port: 1161, Dst Port: 80, Seq: 1, Ack: 1, Len: 565
  Source Port: 1161
  Destination Port: 80
  [Stream index: 0]
  [Conversation completeness: Incomplete, DATA (15)]
  [TCP Segment Len: 565]
  Sequence Number: 1 (relative sequence number)
  Sequence Number (raw): 232129013
  [Next Sequence Number: 566 (relative sequence number)]
  Acknowledgment Number: 1 (relative ack number)
  Acknowledgment number (raw): 883061786
  0101 .... = Header Length: 20 bytes (5)
  > Flags: 0x018 (PSH, ACK)

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0020 f5 0c 04 89 00 50 0d d6 01 f5 34 a2 74 1a 50 18 ... P...4-t-P.
0030 44 70 1f bd 00 00 50 4f 53 54 20 2f 65 74 68 65 Dp...PO ST /ethe
0040 72 65 61 6c 2d 6c 61 62 73 2f 6c 61 62 33 2d 31 real-lab s/lab3-1
0050 2d 72 65 70 6c 79 2e 68 74 6d 20 48 54 54 50 2f -reply.htm HTTP/
0060 31 2e 31 0d 0a 48 6f 73 74 3a 20 67 61 69 61 2e 1.1..Host: gaia.
0070 63 73 2e 75 6d 61 73 73 2e 65 64 75 0d 0a 55 73 cs.umass .edu..Us
0080 65 72 2d 41 67 65 6e 74 3a 20 4d 6f 7a 69 6c 6c er-Agent : Mozill
0090 61 2f 35 2e 30 20 28 57 69 6e 64 6f 77 73 3b 20 a/5.0 (Windows;
00a0 55 3b 20 57 69 6e 64 6f 77 73 20 4e 54 20 35 2e U; Windo ws NT 5.
00b0 31 3b 20 65 6e 2d 55 53 3b 20 72 76 3a 31 2e 30 1; en-US ; rv:1.0

```

7.

The sequence numbers of the first six segments in the TCP connection are 1, 566, 2026, 3486, 4946, 6406.

Each segment was sent at 0.026477, 0.041737, 0.054026, 0.054690, 0.077405 and 0.078157 respectively.

Each ACK was received at 0.053937, 0.077294, 0.124085, 0.169118, 0.217299 and 0.267802 respectively.

Thus, the RTT value of each segment is 0.027460, 0.035557, 0.070059, 0.114430, 0.139890 and 0.189640 respectively.

Based on the equation,

$$\text{EstimatedRTT} = 0.875 \text{ EstimatedRTT} + 0.125 \text{ SampleRTT}$$

we can get the EstimatedRTT for each segment is 0.02746, 0.0285, 0.0337, 0.0438, 0.0558 and 0.0725 respectively.

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	192.168.1.102	128.119.245.12	TCP	62	1161 → 80 [SYN] Seq=0 Win=16384 Len=0 MSS=1460 SACK_PERM=1
2	0.023172	128.119.245.12	192.168.1.102	TCP	62	80 → 1161 [SYN, ACK] Seq=0 Ack=1 Win=5840 Len=0 MSS=1460 SACK_P
3	0.023265	192.168.1.102	128.119.245.12	TCP	54	1161 → 80 [ACK] Seq=1 Ack=1 Win=17520 Len=0
4	0.026477	192.168.1.102	128.119.245.12	TCP	619	1161 → 80 [PSH, ACK] Seq=1 Ack=1 Win=17520 Len=565 [TCP segment
5	0.041737	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [PSH, ACK] Seq=566 Ack=1 Win=17520 Len=1460 [TCP segm
6	0.053937	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=566 Win=6780 Len=0
7	0.054026	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=2026 Ack=1 Win=17520 Len=1460 [TCP segment
8	0.054690	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=3486 Ack=1 Win=17520 Len=1460 [TCP segment
9	0.077294	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=2026 Win=8760 Len=0
10	0.077405	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=4946 Ack=1 Win=17520 Len=1460 [TCP segment
11	0.078157	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=6406 Ack=1 Win=17520 Len=1460 [TCP segment
12	0.124085	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=3486 Win=11680 Len=0
13	0.124185	192.168.1.102	128.119.245.12	TCP	1201	1161 → 80 [PSH, ACK] Seq=7866 Ack=1 Win=17520 Len=1147 [TCP seg
14	0.169118	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=4946 Win=14600 Len=0
15	0.217299	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=6406 Win=17520 Len=0
16	0.267802	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=7866 Win=20440 Len=0
17	0.304807	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=9013 Win=23360 Len=0
18	0.305040	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=9013 Ack=1 Win=17520 Len=1460 [TCP segment

8.

According to the figure below,

the lengths of the first six TCP segments are 565 B, 1460 B, 1460 B, 1460 B, 1460 B and 1460 B respectively.

3	0.023265	192.168.1.102	128.119.245.12	TCP	54	1161 → 80	[ACK] Seq=1 Ack=1 Win=17520 Len=0
4	0.026477	192.168.1.102	128.119.245.12	TCP	619	1161 → 80	[PSH, ACK] Seq=1 Ack=1 Win=17520 Len=565 [TCP segment
5	0.041737	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80	[PSH, ACK] Seq=566 Ack=1 Win=17520 Len=1460 [TCP segm
6	0.053937	128.119.245.12	192.168.1.102	TCP	60	80 → 1161	[ACK] Seq=1 Ack=566 Win=6780 Len=0
7	0.054026	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80	[ACK] Seq=2026 Ack=1 Win=17520 Len=1460 [TCP segment
8	0.054690	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80	[ACK] Seq=3486 Ack=1 Win=17520 Len=1460 [TCP segment
9	0.077294	128.119.245.12	192.168.1.102	TCP	60	80 → 1161	[ACK] Seq=1 Ack=2026 Win=8760 Len=0
10	0.077405	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80	[ACK] Seq=4946 Ack=1 Win=17520 Len=1460 [TCP segment
11	0.078157	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80	[ACK] Seq=6406 Ack=1 Win=17520 Len=1460 [TCP segment
12	0.124885	128.119.245.12	192.168.1.102	TCP	60	80 → 1161	[ACK] Seq=1 Ack=3486 Win=11680 Len=0
13	0.124185	192.168.1.102	128.119.245.12	TCP	1201	1161 → 80	[PSH, ACK] Seq=7866 Ack=1 Win=17520 Len=1147 [TCP seg
14	0.169118	128.119.245.12	192.168.1.102	TCP	60	80 → 1161	[ACK] Seq=1 Ack=4946 Win=14600 Len=0
15	0.217299	128.119.245.12	192.168.1.102	TCP	60	80 → 1161	[ACK] Seq=1 Ack=6406 Win=17520 Len=0
16	0.267802	128.119.245.12	192.168.1.102	TCP	60	80 → 1161	[ACK] Seq=1 Ack=7866 Win=20440 Len=0
17	0.304807	128.119.245.12	192.168.1.102	TCP	60	80 → 1161	[ACK] Seq=1 Ack=9013 Win=23360 Len=0

9.

The minimum amount of buffer space is 5840 B. The sender is never throttled because the buffer space grows gradually and reaches 62780 B.

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	192.168.1.102	128.119.245.12	TCP	62	1161 → 80 [SYN] Seq=0 Win=16384 Len=0 MSS=1460 SACK_PERM=1
2	0.023172	128.119.245.12	192.168.1.102	TCP	62	80 → 1161 [SYN, ACK] Seq=0 Ack=1 Win=5840 Len=0 MSS=1460 SACK_P
3	0.023265	192.168.1.102	128.119.245.12	TCP	54	1161 → 80 [ACK] Seq=1 Ack=1 Win=17520 Len=0
4	0.026477	192.168.1.102	128.119.245.12	TCP	619	1161 → 80 [PSH, ACK] Seq=1 Ack=1 Win=17520 Len=565 [TCP segment
5	0.041737	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [PSH, ACK] Seq=566 Ack=1 Win=17520 Len=1460 [TCP segm
6	0.053937	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=566 Win=6780 Len=0
7	0.054026	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=2026 Ack=1 Win=17520 Len=1460 [TCP segment
8	0.054690	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=3486 Ack=1 Win=17520 Len=1460 [TCP segment
9	0.077294	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=2026 Win=8760 Len=0

```

[Stream index: 0]
[Conversation completeness: Incomplete, DATA (15)]
[TCP Segment Len: 0]
Sequence Number: 0 (relative sequence number)
Sequence Number (raw): 883061785
[Next Sequence Number: 1 (relative sequence number)]
Acknowledgment Number: 1 (relative ack number)
Acknowledgment number (raw): 232129013
0111 .... = Header Length: 28 bytes (7)
> Flags: 0x012 (SYN, ACK)
Window: 5840
[Calculated window size: 5840]
Checksum: 0x774d [unverified]
[Checksum Status: Unverified]
Urgent Pointer: 0
> Options: (8 bytes), Maximum segment size, No-Operation (NOP), No-Operation (NOP), SACK permitted
> [Timestamps]
> [SEQ/ACK analysis]

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No.	Time	Source	Destination	Protocol	Length	Info
197	5.202024	192.168.1.102	128.119.245.12	TCP	326	1161 → 80 [PSH, ACK] Seq=163769 Ack=1 Win=17520 Len=272 [TCP se
198	5.297257	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=159389 Win=62780 Len=0
199	5.297341	192.168.1.102	128.119.245.12	HTTP	104	POST /etherreal-labs/lab3-1-reply.htm HTTP/1.1 (text/plain)
200	5.389471	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=162309 Win=62780 Len=0
201	5.447887	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=164041 Win=62780 Len=0
202	5.455830	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=164091 Win=62780 Len=0
203	5.461175	128.119.245.12	192.168.1.102	HTTP	784	HTTP/1.1 200 OK (text/html)
206	5.651141	192.168.1.102	128.119.245.12	TCP	54	1161 → 80 [ACK] Seq=164091 Ack=731 Win=16790 Len=0
213	7.595557	192.168.1.102	199.2.53.206	TCP	62	1162 → 631 [SYN] Seq=0 Win=16384 Len=0 MSS=1460 SACK_PERM=1

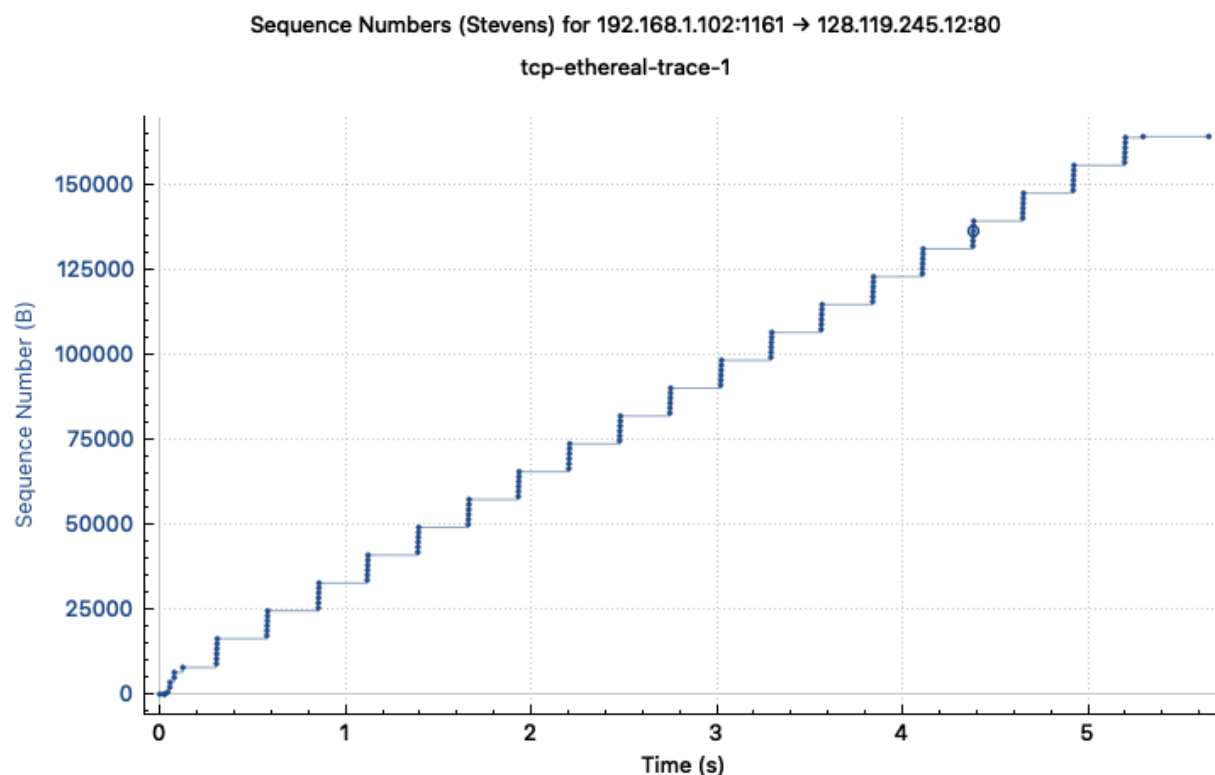
```

Destination Port: 1161
[Stream index: 0]
[Conversation completeness: Incomplete, DATA (15)]
[TCP Segment Len: 0]
Sequence Number: 1 (relative sequence number)
Sequence Number (raw): 883061786
[Next Sequence Number: 1 (relative sequence number)]
Acknowledgment Number: 164091 (relative ack number)
Acknowledgment number (raw): 232293103
0101 .... = Header Length: 20 bytes (5)
> Flags: 0x010 (ACK)
Window: 62780
[Calculated window size: 62780]
[Window size scaling factor: -2 (no window scaling used)]
Checksum: 0x44a8 [unverified]
[Checksum Status: Unverified]
Urgent Pointer: 0
> [Timestamps]

```

10.

According to the Time-Sequence-Graph, we can find that the sequence number sent from source to destination increases monotonically. Thus, there is no retransmitted segments in this trace.



11.

The receiver typically acknowledges 1460 B data in one ACK, which is exactly one TCP segment. There are cases where the receiver is ACKing other received segments. For example, No. 78, 79, 80 frame acknowledges 2 segments, which is 2920 B.

No.	Time	Source	Destination	Protocol	Length	Info
69	1.488313	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=44701 Win=62780 Len=0
70	1.584980	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=47621 Win=62780 Len=0
71	1.661513	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=49973 Win=62780 Len=0
72	1.661734	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=49973 Ack=1 Win=17520 Len=1460 [TCP segment]
73	1.662474	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=51433 Ack=1 Win=17520 Len=1460 [TCP segment]
74	1.663315	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=52893 Ack=1 Win=17520 Len=1460 [TCP segment]
75	1.664198	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=54353 Ack=1 Win=17520 Len=1460 [TCP segment]
76	1.665254	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=55813 Ack=1 Win=17520 Len=1460 [TCP segment]
77	1.666151	192.168.1.102	128.119.245.12	TCP	946	1161 → 80 [PSH, ACK] Seq=57273 Ack=1 Win=17520 Len=892 [TCP seg]
78	1.758227	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=52893 Win=62780 Len=0
79	1.860063	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=55813 Win=62780 Len=0
80	1.930880	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=58165 Win=62780 Len=0
81	1.931099	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=58165 Ack=1 Win=17520 Len=1460 [TCP segment]
82	1.931879	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=59625 Ack=1 Win=17520 Len=1460 [TCP segment]

12.

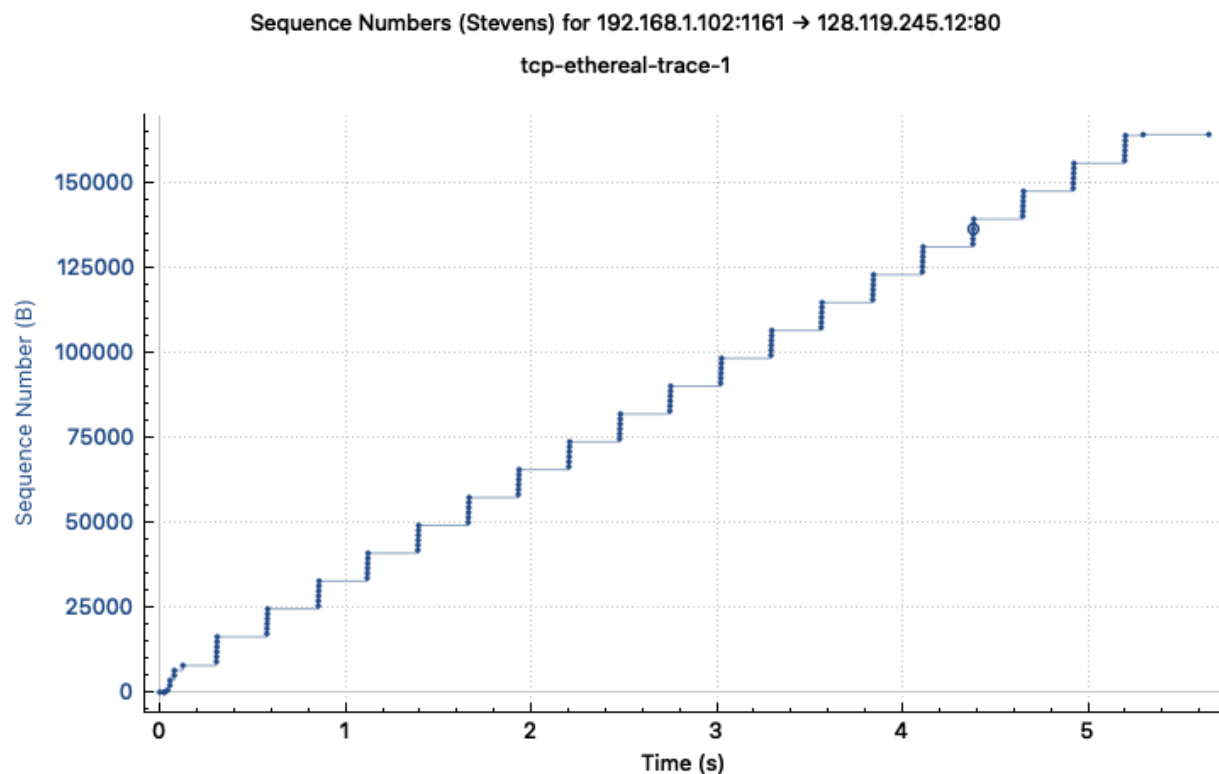
We can compute the throughput by dividing the total data transferred by the total time of the TCP connection. Notice that the ACK number is equal to the number of bytes reliably transferred plus one. Thus, we can get the total data transferred via the last ACK segment, which is  $164091 - 1 = 164090$  B. The total time can also be derived, which is the last ACK time minus the time when the

first segment starts transmitting. That is  $5.455830 - 0.026477 = 5.429353$ . Hence, the throughput is  $164090 / 5.429353 = 30222.8$  B/s.

No.	Time	Source	Destination	Protocol	Length	Info
192	5.197308	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=156469 Ack=1 Win=17520 Len=1460 [TCP segment of data length 1460 bytes]
193	5.198388	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=157929 Ack=1 Win=17520 Len=1460 [TCP segment of data length 1460 bytes]
194	5.199275	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=159389 Ack=1 Win=17520 Len=1460 [TCP segment of data length 1460 bytes]
195	5.200252	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=160849 Ack=1 Win=17520 Len=1460 [TCP segment of data length 1460 bytes]
196	5.201150	192.168.1.102	128.119.245.12	TCP	1514	1161 → 80 [ACK] Seq=162309 Ack=1 Win=17520 Len=1460 [TCP segment of data length 1460 bytes]
197	5.202024	192.168.1.102	128.119.245.12	TCP	326	1161 → 80 [PSH, ACK] Seq=163769 Ack=1 Win=17520 Len=272 [TCP segment of data length 272 bytes]
198	5.297257	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=159389 Win=62780 Len=0
199	5.297341	192.168.1.102	128.119.245.12	HTTP	104	POST /ethereal-labs/lab3-1-reply.htm HTTP/1.1 (text/plain)
200	5.389471	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=162309 Win=62780 Len=0
201	5.447887	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=164041 Win=62780 Len=0
202	5.455830	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=1 Ack=164091 Win=62780 Len=0
203	5.461175	128.119.245.12	192.168.1.102	HTTP	784	HTTP/1.1 200 OK (text/html)
206	5.651141	192.168.1.102	128.119.245.12	TCP	54	1161 → 80 [ACK] Seq=164091 Ack=731 Win=16790 Len=0
213	7.595557	192.168.1.102	199.2.53.206	TCP	62	1162 → 631 [SYN] Seq=0 Win=16384 Len=0 MSS=1460 SACK_PERM=1

13.

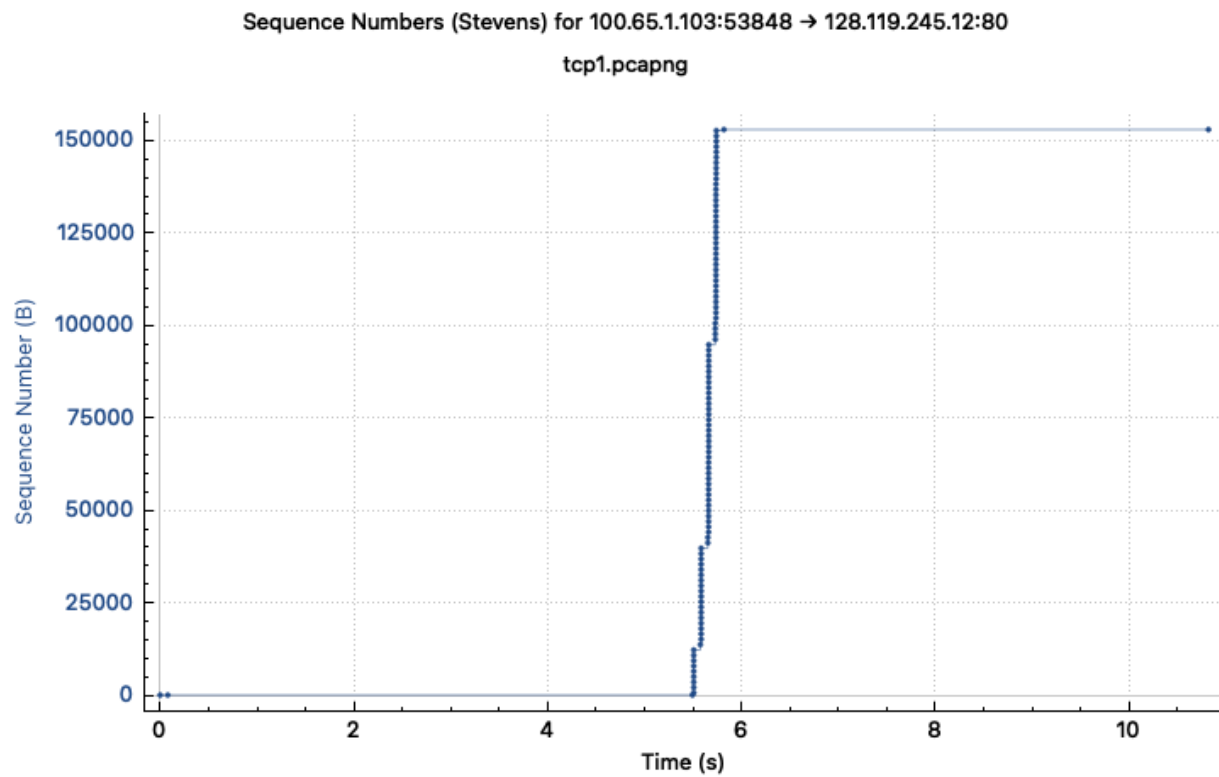
The TCP's slowstart begins at about 0 and ends at about 0.2s. After that, the congestion avoidance takes over. Observe that the sender always transmits the frames in a batch of 6. However, the receiver's advertised window size grows during connection and bigger than 6 frames, which means the limitation is not caused by flow control. It may be caused by some rate limit enforced by the HTTP server. Thus, compared to idealized TCP, the slowstart phase ends very quickly and the window size doesn't grow linearly during the congestion avoidance phase.





14.

The TCP's slowstart time begins at about 5.5s and before the end of slowstart phase, the transmission is over. Compared to idealized TCP, in this case, the slowstart phase follow the idealized behavior, during which the window size grows exponentially. However, the TCP behavior also depends on the application. When the web object is of very small size, the transmission will terminate very quickly even before the end of slowstart phase.



# Conclusion

This report investigates the behavior of the celebrated TCP protocol in detail. A trace of the TCP segments sent and received in transferring a 150KB file from client computer to `gaia.cs.umass.edu` is analyzed. The first 12 questions explore TCP connection setup (SYN and SYNACK), the sequence numbers and ACK numbers for providing reliable data transfer and the performance (averaging throughput and EstimatedRTT) of the TCP connection between client computer and the remote server. The congestion control algorithm – slow start and congestion avoidance, and TCP's receiver-advertised flow control mechanism are investigated in the last two questions. The behavior of TCP protocol is well discussed in this report.