



TAIBAH UNIVERSITY



College of Computer Science and Engineering

Computer Engineering Department

COE332
Computer Networks
Student's Lab Manual
V7

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LAB04

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Lab-4: TCP Protocol

In this lab, we'll investigate the behavior of the celebrated TCP protocol in detail. We'll do so by analyzing a trace of the TCP segments sent and received in transferring a 150KB file (containing the text of Lewis Carrol's *Alice's Adventures in Wonderland*) from your computer to a remote server. We'll study TCP's use of sequence and acknowledgement numbers for providing reliable data transfer; we'll see TCP's congestion control algorithm – slow start and congestion avoidance – in action; and we'll look at TCP's receiver-advertised flow control mechanism. We'll also briefly consider TCP connection setup and we'll investigate the performance (throughput and round-trip time) of the TCP connection between your computer and the server.

Before beginning this lab, you'll probably want to review sections 3.5 and 3.7 in the text⁶.

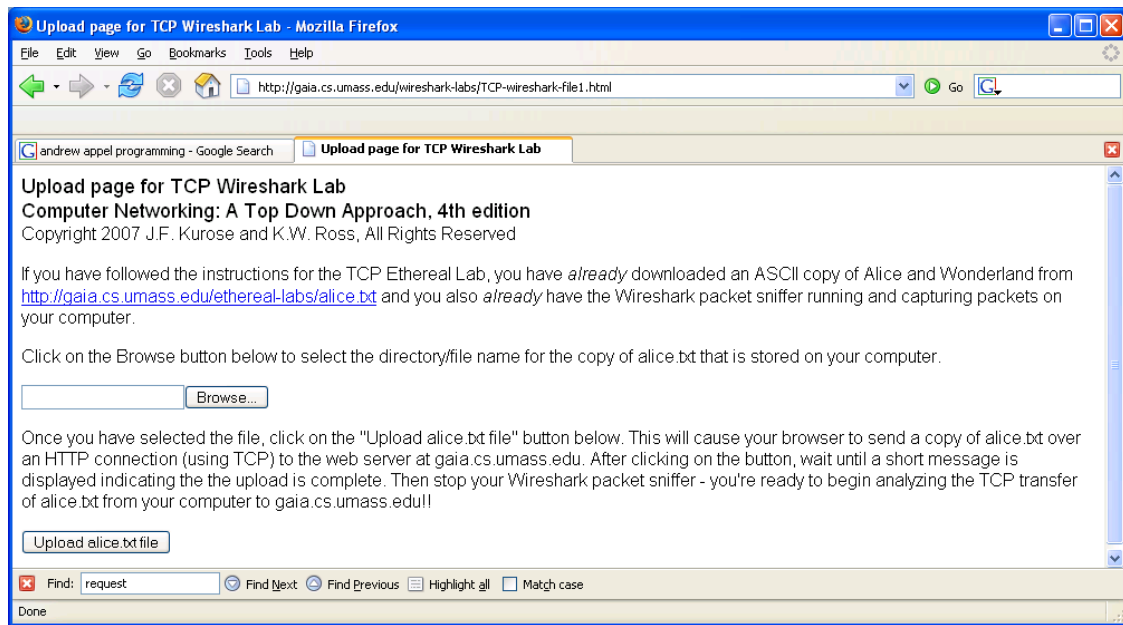
1. Capturing a bulk TCP transfer from your computer to a remote server

Before beginning our exploration of TCP, we'll need to use Wireshark to obtain a packet trace of the TCP transfer of a file from your computer to a remote server. You'll do so by accessing a Web page that will allow you to enter the name of a file stored on your computer (which contains the ASCII text of *Alice in Wonderland*), and then transfer the file to a Web server using the HTTP POST method (see section 2.2.3 in the text). We're using the POST method rather than the GET method as we'd like to transfer a large amount of data *from* your computer to another computer. Of course, we'll be running Wireshark during this time to obtain the trace of the TCP segments sent and received from your computer.

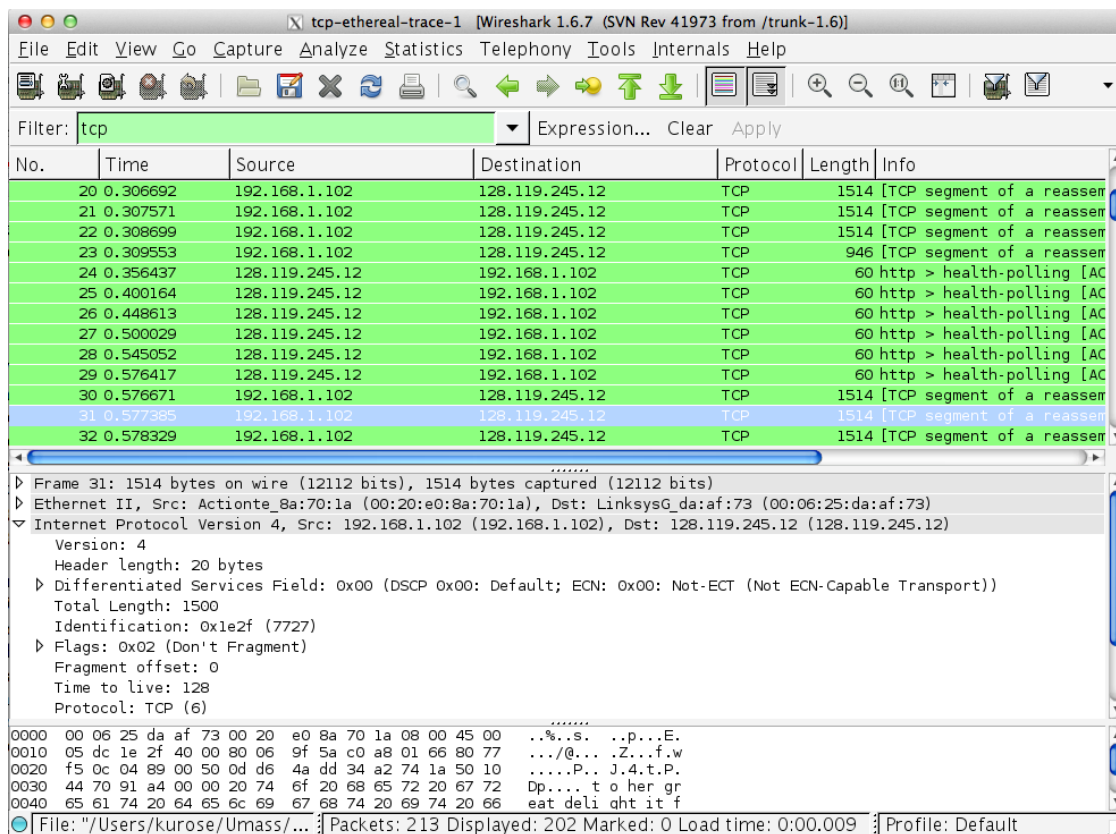
Do the following:

- Start up your web browser. Go the <http://gaia.cs.umass.edu/wireshark-labs/alice.txt> and retrieve an ASCII copy of *Alice in Wonderland*. Store this file somewhere on your computer.
- Next go to <http://gaia.cs.umass.edu/wireshark-labs/TCP-wireshark-file1.html>.
- You should see a screen that looks like:

⁶ References to figures and sections are for the 8th edition of our text, *Computer Networks, A Top-down Approach*, 8th ed., J.F. Kurose and K.W. Ross, Addison-Wesley/Pearson, 2020.



- Use the *Browse* button in this form to enter the name of the file (full path name) on your computer containing *Alice in Wonderland* (or do so manually). Don't yet press the *"Upload alice.txt file"* button.
- Now start up Wireshark and begin packet capture (*Capture->Start*) and then press *OK* on the Wireshark Packet Capture Options screen (we'll not need to select any options here).
- Returning to your browser, press the *"Upload alice.txt file"* button to upload the file to the gaia.cs.umass.edu server. Once the file has been uploaded, a short congratulations message will be displayed in your browser window.
- Stop Wireshark packet capture. Your Wireshark window should look similar to the window shown below.



If you are unable to run Wireshark on a live network connection, you can download a packet trace file that was captured while following the steps above on one of the author's computers⁷. You may well find it valuable to download this trace even if you've captured your own trace and use it, as well as your own trace, when you explore the questions below.

2. A first look at the captured trace

Before analyzing the behavior of the TCP connection in detail, let's take a high level view of the trace.

- First, filter the packets displayed in the Wireshark window by entering "tcp" (lowercase, no quotes, and don't forget to press return after entering!) into the display filter specification window towards the top of the Wireshark window.

What you should see is series of TCP and HTTP messages between your computer and gaia.cs.umass.edu. You should see the initial three-way handshake containing a SYN message. You should see an HTTP POST message. Depending on the version of Wireshark you are using, you might see a series of "HTTP Continuation" messages being sent from your computer to gaia.cs.umass.edu. Recall from our discussion in the earlier HTTP Wireshark lab, that is no such thing as an HTTP Continuation message – this is Wireshark's way of indicating that there are multiple TCP segments being used to carry a single HTTP message. In more recent versions of

⁷ Download the zip file <http://gaia.cs.umass.edu/wireshark-labs/wireshark-traces.zip> and extract the file tcp-ethereal-trace-1. The traces in this zip file were collected by Wireshark running on one of the author's computers, while performing the steps indicated in the Wireshark lab. Once you have downloaded the trace, you can load it into Wireshark and view the trace using the *File* pull down menu, choosing *Open*, and then selecting the tcp-ethereal-trace-1 trace file.

Wireshark, you'll see "[TCP segment of a reassembled PDU]" in the Info column of the Wireshark display to indicate that this TCP segment contained data that belonged to an upper layer protocol message (in our case here, HTTP). You should also see TCP ACK segments being returned from `gaia.cs.umass.edu` to your computer.

Answer the following questions, by opening the Wireshark captured packet file *tcp-ethereal-trace-1* in <http://gaia.cs.umass.edu/wireshark-labs/wireshark-traces.zip> (that is download the trace and open that trace in Wireshark; see footnote 2). Whenever possible, when answering a question you should hand in a printout of the packet(s) within the trace that you used to answer the question asked. Annotate the printout⁸ to explain your answer. To print a packet, use *File->Print*, choose *Selected packet only*, choose *Packet summary line*, and select the minimum amount of packet detail that you need to answer the question.

1. What is the IP address and TCP port number used by the client computer (source) that is transferring the file to `gaia.cs.umass.edu`? To answer this question, it's probably easiest to select an HTTP message and explore the details of the TCP packet used to carry this HTTP message, using the "details of the selected packet header window" (refer to Figure 2 in the "Getting Started with Wireshark" Lab if you're uncertain about the Wireshark windows).

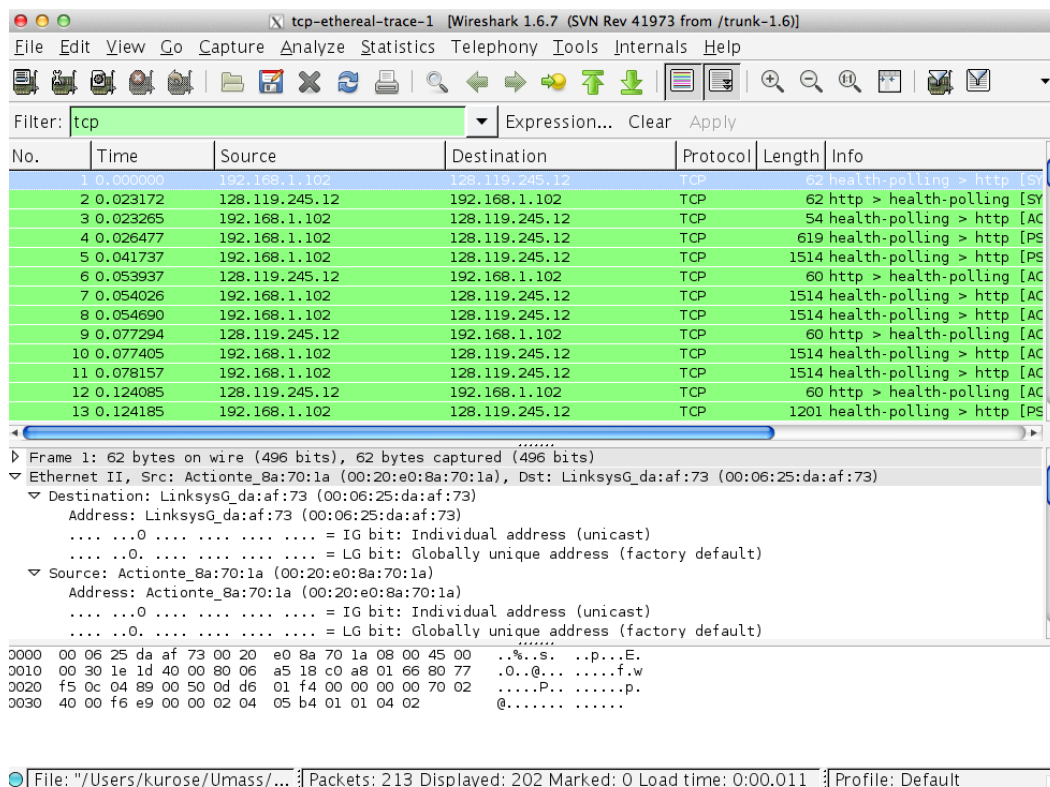
2. What is the IP address of `gaia.cs.umass.edu`? On what port number is it sending and receiving TCP segments for this connection?

If you have been able to create your own trace, answer the following question:

3. What is the IP address and TCP port number used by your client computer (source) to transfer the file to `gaia.cs.umass.edu`?

Since this lab is about TCP rather than HTTP, let's change Wireshark's "listing of captured packets" window so that it shows information about the TCP segments containing the HTTP messages, rather than about the HTTP messages. To have Wireshark do this, select *Analyze->Enabled Protocols*. Then uncheck the HTTP box and select *OK*. You should now see a Wireshark window that looks like:

⁸ What do we mean by "annotate"? If you hand in a paper copy, please highlight where in the printout you've found the answer and add some text (preferably with a colored pen) noting what you found in what you've highlight. If you hand in an electronic copy, it would be great if you could also highlight and annotate.



This is what we're looking for - a series of TCP segments sent between your computer and `gaia.cs.umass.edu`. We will use the packet trace that you have captured (and/or the packet trace *tcp-ethereal-trace-1* in <http://gaia.cs.umass.edu/wireshark-labs/wireshark-traces.zip>; see earlier footnote) to study TCP behavior in the rest of this lab.

3. TCP Basics

Answer the following questions for the TCP segments:

- What is the sequence number of the TCP SYN segment that is used to initiate the TCP connection between the client computer and `gaia.cs.umass.edu`? What is it in the segment that identifies the segment as a SYN segment?
- What is the sequence number of the SYNACK segment sent by `gaia.cs.umass.edu` to the client computer in reply to the SYN? What is the value of the Acknowledgement field in the SYNACK segment? How did `gaia.cs.umass.edu` determine that value? What is it in the segment that identifies the segment as a SYNACK segment?

6. What is the sequence number of the TCP segment containing the HTTP POST command? Note that in order to find the POST command, you'll need to dig into the packet content field at the bottom of the Wireshark window, looking for a segment with a "POST" within its DATA field.

7. Consider the TCP segment containing the HTTP POST as the first segment in the TCP connection. What are the sequence numbers of the first six segments in the TCP connection (including the segment containing the HTTP POST)? At what time was each segment sent? When was the ACK for each segment received? Given the difference between when each TCP segment was sent, and when its acknowledgement was received, what is the RTT value for each of the six segments? What is the `EstimatedRTT` value (see Section 3.5.3, page 242 in text) after the receipt of each ACK? Assume that the value of the `EstimatedRTT` is equal to the measured RTT for the first segment, and then is computed using the `EstimatedRTT` equation on page 242 for all subsequent segments.

Note: Wireshark has a nice feature that allows you to plot the RTT for each of the TCP segments sent. Select a TCP segment in the "listing of captured packets" window that is being sent from the client to the `gaia.cs.umass.edu` server. Then select: *Statistics->TCP Stream Graph->Round Trip Time Graph*.

8. What is the length of each of the first six TCP segments?⁹

9. What is the minimum amount of available buffer space advertised at the received for the entire trace? Does the lack of receiver buffer space ever throttle the sender?

⁹ The TCP segments in the `tcp-ethereal-trace-1` trace file are all less than 1460 bytes. This is because the computer on which the trace was gathered has an Ethernet card that limits the length of the maximum IP packet to 1500 bytes (40 bytes of TCP/IP header data and 1460 bytes of TCP payload). This 1500 byte value is the standard maximum length allowed by Ethernet. If your trace indicates a TCP length greater than 1500 bytes, and your computer is using an Ethernet connection, then Wireshark is reporting the wrong TCP segment length; it will likely also show only one large TCP segment rather than multiple smaller segments. Your computer is indeed probably sending multiple smaller segments, as indicated by the ACKs it receives. This inconsistency in reported segment lengths is due to the interaction between the Ethernet driver and the Wireshark software. We recommend that if you have this inconsistency, that you perform this lab using the provided trace file.

10. Are there any retransmitted segments in the trace file? What did you check for (in the trace) in order to answer this question?

11. How much data does the receiver typically acknowledge in an ACK? Can you identify cases where the receiver is ACKing every other received segment (see Table 3.2 on page 250 in the text).

1. What is the IP address and TCP port number used by the client computer (source) that is transferring the file to gaia.cs.umass.edu? **source IP address: 192.168.1.102 -- TCP port number: 1161**

198	5.297257	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=
+	199	5.297341	192.168.1.102	128.119.245.12	HTTP	104 POST /ethereal-labs/
200	5.389471	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=
201	5.447887	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=
202	5.455830	128.119.245.12	192.168.1.102	TCP	60	80 → 1161 [ACK] Seq=
-	203	5.461175	128.119.245.12	192.168.1.102	HTTP	784 HTTP/1.1 200 OK (te

```

> Frame 199: 104 bytes on wire (832 bits), 104 bytes captured (832 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: 164041, Ack: 1, Len: 50
  Source Port: 1161
  Destination Port: 80
  [Stream index: 0]
  [Conversation completeness: Incomplete, DATA (15)]
  [TCP Segment Len: 50]
  Sequence Number: 164041 (relative sequence number)
  Sequence Number (raw): 232293053
  [Next Sequence Number: 164091 (relative sequence number)]

```

2. What is the IP address of gaia.cs.umass.edu? On what port number is it sending and receiving TCP segments for this connection? **destination IP address: 128.119.245.12 -- TCP port number: 80**

+	204	10.220356	192.168.1.21	128.119.245.12	TCP	1466 62437 → 80 [ACK] Seq=149673 Ack=1 Win=512 Len=141
+	205	10.220356	192.168.1.21	128.119.245.12	TCP	1466 62437 → 80 [ACK] Seq=151085 Ack=1 Win=512 Len=141
+	206	10.220356	192.168.1.21	128.119.245.12	HTTP	599 POST /wireshark-labs/lab3-1-reply.htm HTTP/1.1 (-
207	10.230265	128.119.245.12	192.168.1.21	TCP	54	80 → 62437 [ACK] Seq=1 Ack=86133 Win=1403 Len=0
208	10.230265	128.119.245.12	192.168.1.21	TCP	54	80 → 62437 [ACK] Seq=1 Ack=93193 Win=1403 Len=0
209	10.230265	128.119.245.12	192.168.1.21	TCP	54	80 → 62437 [ACK] Seq=1 Ack=96017 Win=1388 Len=0
210	10.230265	128.119.245.12	192.168.1.21	TCP	54	80 → 62437 [ACK] Seq=1 Ack=98841 Win=1426 Len=0
211	10.380309	128.119.245.12	192.168.1.21	TCP	54	80 → 62437 [ACK] Seq=1 Ack=103077 Win=1419 Len=0
212	10.380309	128.119.245.12	192.168.1.21	TCP	54	80 → 62437 [ACK] Seq=1 Ack=110137 Win=1542 Len=0
-	213	10.390005	128.119.245.12	192.168.1.21	HTTP	831 HTTP/1.1 200 OK (text/html)

```

> Frame 206: 599 bytes on wire (4792 bits), 599 bytes captured (4792 bits) on interface \Device\NPF_{988EAC36-8A1D-440B-9902-CF19A
> Ethernet II, Src: IntelCor_78:63:29 (04:d3:b0:78:63:29), Dst: HuaweiTe_8c:26:c2 (2c:97:b1:8c:26:c2)
> Internet Protocol Version 4, Src: 192.168.1.21, Dst: 128.119.245.12
✓ Transmission Control Protocol, Src Port: 62437, Dst Port: 80, Seq: 152497, Ack: 1, Len: 545
  Source Port: 62437
  Destination Port: 80
  [Stream index: 10]
  [Conversation completeness: Incomplete (12)]
  [TCP Segment Len: 545]
  Sequence Number: 152497 (relative sequence number)
  Sequence Number (raw): 3161883761
  [Next Sequence Number: 153042 (relative sequence number)]
  Acknowledgment Number: 1 (relative ack number)
  Acknowledgment number (raw): 1553685161

```

3. What is the IP address and TCP port number used by your client computer (source) to transfer the file to gaia.cs.umass.edu? **source IP address: 192.168.1.21 -- source TCP port number: 62437**

4. What is the sequence number of the TCP SYN segment that is used to initiate the TCP connection between the client computer and gaia.cs.umass.edu? **sequence number of the TCP SYN is 0**

What is it in the segment that identifies the segment as a SYN segment? **The segment that identifies the segment as a SYN is Flags: (SYN)**

79	9.666078	192.168.1.21	128.119.245.12	TCP	54	62436 → 80 [RST, ACK] Seq=1 Ack=1 Win=0 L
80	9.666218	192.168.1.21	128.119.245.12	TCP	66	62441 → 80 [SYN] Seq=0 Win=64240 Len=0 MS
81	9.699833	192.168.1.21	128.119.245.12	TCP	1466	62437 → 80 [ACK] Seq=1 Ack=1 Win=512 Len=

```

> Frame 80: 66 bytes on wire (528 bits), 66 bytes captured (528 bits) on interface \Device\NPF_{988EAC36-8A1D-440B-9902
> Ethernet II, Src: IntelCor_78:63:29 (04:d3:b0:78:63:29), Dst: HuaweiTe_8c:26:c2 (2c:97:b1:8c:26:c2)
> Internet Protocol Version 4, Src: 192.168.1.21, Dst: 128.119.245.12
✓ Transmission Control Protocol, Src Port: 62441, Dst Port: 80, Seq: 0, Len: 0
  Source Port: 62441
  Destination Port: 80
  [Stream index: 15]
  [Conversation completeness: Incomplete, ESTABLISHED (7)]
  [TCP Segment Len: 0]
  Sequence Number: 0 (relative sequence number)
  Sequence Number (raw): 1003898325
  [Next Sequence Number: 1 (relative sequence number)]
  Acknowledgment Number: 0
  Acknowledgment number (raw): 0
  1000 .... = Header Length: 32 bytes (8)
> Flags: 0x002 (SYN)
  Window: 64240

```

5. What is the sequence number of the SYNACK segment sent by **gaia.cs.umass.edu** to the client computer in reply to the SYN? How did **gaia.cs.umass.edu** determine that value? **sequence number of the SYNACK is 0** What is the value of the Acknowledgement field in the SYNACK segment? **value of the Acknowledgement field in the SYNACK is 1** What is it in the segment that identifies the segment as a SYNACK segment? **The segment that identifies the segment as a SYN is Flags: (SYN, SCK)**

```

90 9.699833 192.168.1.21 128.119.245.12 TCP 1466 62437 → 80 [ACK] Seq=12709 Ack=1 Win=512 Len=1412
91 9.833299 128.119.245.12 192.168.1.21 TCP 66 80 → 62441 [SYN, ACK] Seq=0 Ack=1 Win=29200 Len=0
92 9.833645 192.168.1.21 128.119.245.12 TCP 54 62441 → 80 [ACK] Seq=1 Ack=1 Win=131072 Len=0
93 9.870935 128.119.245.12 192.168.1.21 TCP 54 80 → 62437 [ACK] Seq=1 Ack=1413 Win=251 Len=0
94 9.871117 192.168.1.21 128.119.245.12 TCP 1466 62437 → 80 [ACK] Seq=14121 Ack=1 Win=512 Len=1412

Frame 91: 66 bytes on wire (528 bits), 66 bytes captured (528 bits) on interface \Device\NPF_{988EAC36-8A1D-4408-9902-CF19ACF13}
Ethernet II, Src: HuaweiTe_8c:26:c2 (2c:97:b1:8c:26:c2), Dst: IntelCor_78:63:29 (04:d3:b0:78:63:29)
Internet Protocol Version 4, Src: 128.119.245.12, Dst: 192.168.1.21
Transmission Control Protocol, Src Port: 80, Dst Port: 62441, Seq: 0, Ack: 1, Len: 0
  Source Port: 80
  Destination Port: 62441
  [Stream index: 15]
  [Conversation completeness: Incomplete, ESTABLISHED (7)]
  [TCP Segment Len: 0]
  Sequence Number: 0 (relative sequence number)
  Sequence Number (raw): 3087180712
  [Next Sequence Number: 1 (relative sequence number)]
  Acknowledgment Number: 1 (relative ack number)
  Acknowledgment number (raw): 1003898326
  1000 .... = Header Length: 32 bytes (8)
  > Flags: 0x012 (SYN, ACK)
  Window: 29200
  [Calculated window size: 29200]
  Checksum: 0xf44d [unverified]

```

6. What is the sequence number of the TCP segment containing the HTTP POST command? **sequence number: 164041**

```

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

> Frame 199: 104 bytes on wire (832 bits), 104 bytes captured (832 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: 164041, Ack: 1, Len: 50
  Source Port: 1161
  Destination Port: 80
  [Stream index: 0]
  [Conversation completeness: Incomplete, DATA (15)]
  [TCP Segment Len: 50]
  Sequence Number: 164041 (relative sequence number)

```

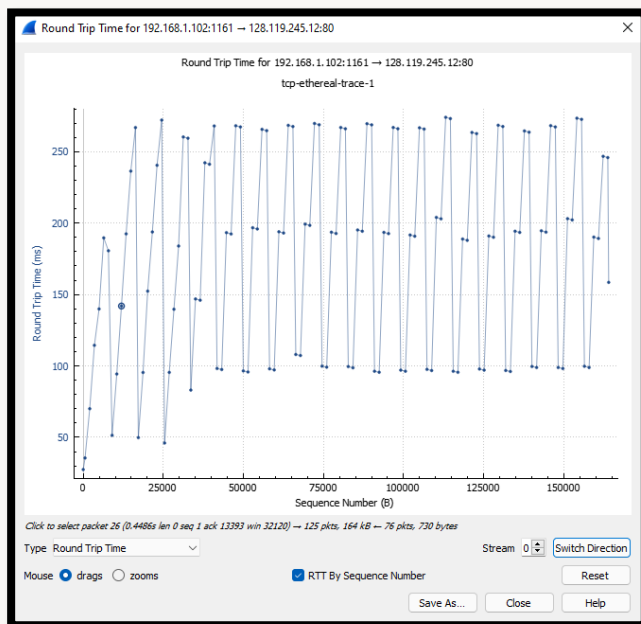
7. Consider the TCP segment containing the HTTP POST as the first segment in the TCP connection. What are the sequence numbers of the first six segments in the TCP connection (including the segment containing the HTTP POST)? At what time was each segment sent? When was the ACK for each segment received? Given the difference between when each TCP segment was sent, and when its acknowledgement was received, what is the RTT value for each of the six segments?

```

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 PDU]
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
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 segment of a reassembled PDU]
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

```

-----	Sent time	ACK received time	RTT
Segment1 (566)	0.041737	0.053937	0.0122
Segment2 (2026)	0.054026	0.077294	0.023268
Segment3 (3486)	0.054690	0.124085	0.069395
Segment4 (4946)	0.077405	0.169118	0.091713
Segment5 (6406)	0.078157	0.217299	0.139142
Segment6 (7866)	0.124185	0.267802	0.143617



8. What is the length of each of the first six TCP segments? **len=1460**

9. What is the minimum amount of available buffer space advertised at the receiver for the entire trace? Does the lack of receiver buffer space ever throttle the sender?

206	10.220356	192.168.1.21	128.119.245.12	HTTP	599
207	10.230265	128.119.245.12	192.168.1.21	TCP	54
208	10.230265	128.119.245.12	192.168.1.21	TCP	54
209	10.230265	128.119.245.12	192.168.1.21	TCP	54
210	10.230265	128.119.245.12	192.168.1.21	TCP	54
211	10.230265	128.119.245.12	192.168.1.21	TCP	54


```

.... ..0. = Syn: Not set
.... ..0. = Fin: Not set
[TCP Flags: .....A....]
Window: 1388
[Calculated window size: 1388]
[Window size scaling factor: -1 (unknown)]
Checksum: 0x6365 [unverified]

```

10. Are there any retransmitted segments in the trace file? What did you check for (in the trace) in order to answer this question? **There are no retransmitted segments in the trace file.** We can verify this by checking the sequence numbers of the TCP segments in the trace file. In the Time-Sequence-Graph (Stevens) of this trace, all sequence numbers from the source (192.168.1.102) to the destination (128.119.245.12) are increasing monotonically with respect to time. If there is a retransmitted segment, the sequence number of this retransmitted segment should be smaller than those of its neighbouring segments.

