CPSC 644 - Computer Networks

Assignment 1

Submitted by

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Exercise 1

Consider a packet of length L that begins at end system A and travels over three links to the destination end system. These three links are connected by *two* packets switches. Let d_i, s_i, and R_i denote the length, propagation speed, and the transmission rate of link $i \in \{1, 2, 3\}$. The packet switches delay each packet by d_{proc}.

Hint: the processing delay is the same for each switch and there are no queuing delays.

a)

Question: What is the total end-to-end delay in terms of d_i, s_i, R_i and d_{proc}?

The network considered in this exercise is drawn in Figure 1.

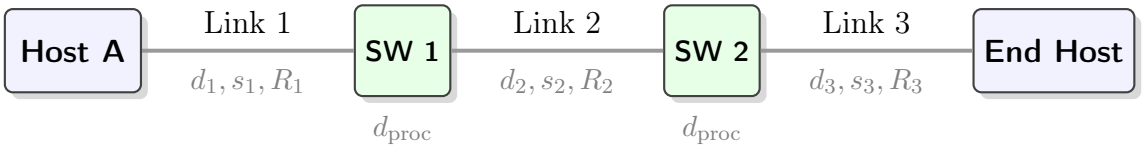


Figure 1: Drawing of Network Topology

To calculate the end-to-end delay, we need to calculate the delay for each single hop on the way from Host A to the End Host. This nodal delay can be expressed by the formula:

$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

where:

- d_{proc}: nodal processing delay (e.g. check for bit errors, check headers)
- d_{queue}: queueing delay (waiting at output link for transmission)
- d_{trans}: transmission delay (time to transmit packet onto link)
- d_{prop}: propagation delay (time for packet to completely propagate from one hop to next)

Furthermore, transmission and propagation delay can be calculated using the above given link lengths d_i, propagation speeds s_i, and transmission rates R_i for all links $i \in \{1, 2, 3\}$ and the packet lenght L.

$$d_{\text{trans}}^{(i)} = \frac{L}{R_i} \qquad d_{\text{prop}}^{(i)} = \frac{d_i}{s_i}$$

As processing delay d_{proc} is the same for each packet switch and there are no queueing delays, the formula to calculate the end-to-end delay in this scenario is given by:

$$\begin{aligned} d_{\text{end-to-end}} &= 2 \cdot d_{\text{proc}} + \sum_{i=1}^{3} \frac{L}{R_i} + \sum_{i=1}^{3} \frac{d_i}{s_i} \\ d_{\text{end-to-end}} &= 2 \cdot d_{\text{proc}} + \sum_{i=1}^{3} d_{\text{trans}}^{(i)} + \sum_{i=1}^{3} d_{\text{prop}}^{(i)} \end{aligned} \tag{1}$$

The transmission delay needs to be included for each link, as the links do not directly push incoming bits through. Instead, the routers work in a store-and-forward way, meaning the entire packet needs to arrive at router before it can be transmitted on the next link.

b)

Question: For the given values, what is the end-to-end delay?

$$L = 1,500 \text{ bytes } = 12,000 \text{ bits}$$
$$\forall i \in \{1,2,3\} : s_i = 2.5 \cdot 10^8 \text{ m/s} = 2.5 \cdot 10^5 \text{ km/s}$$
$$\forall i \in \{1,2,3\} : R_i = 2.5 \text{ Mbps} = 2,500,000 \text{ bps}$$
$$d_{\text{proc}} = 3 \text{ ms} = 0.003 \text{ s}$$
$$d_1 = 5,000 \text{ km} \quad d_2 = 4,000 \text{ km} \quad d_3 = 1,000 \text{ km}$$

To calculate the end-to-end delay we use Equation 1 from the previous exercise:

$$d_{\text{end-to-end}} = 2 \cdot 0.003 \text{ s} + 3 \cdot \frac{12,000 \text{ bits}}{2,500,000 \text{ bits/s}} + \frac{5,000 \text{ km} + 4,000 \text{ km} + 1,000 \text{ km}}{2.5 \cdot 10^5 \text{ km/s}}$$

$$= 0.006 \text{ s} + 0.0144 \text{ s} + 0.04 \text{ s} = \mathbf{0.0604} \text{ s}$$

The end-to-end delay in this scenario is 0.0604 seconds.

c)

Question: What is the end-to-end delay formula, when there is no processing delay, the transmission rate is the same for all hops (R), and the packet switch doesn't store-and-forward?

As a receiver of data can immediately start transmitting the bits it received again onto the next link, there is only the transmission delay from the Host A to push all the bits of the packet onto the first link. Therefore, the other transmission delays are not existent in this scenario.

Furthermore, as there is no processing delay, i.e. $d_{\text{proc}} = 0$, the final formula changes to:

$$d_{\text{end-to-end}} = 2 \cdot d_{\text{proc}} + \frac{L}{R} + \sum_{i=1}^{3} \frac{d_i}{s_i}$$
$$d_{\text{end-to-end}} = \frac{L}{R} + \sum_{i=1}^{3} \frac{d_i}{s_i} \tag{2}$$

Exercise 2

In modern packet-switched networks, including the Internet, the source host segments long, application-layer messages (for example, an image or a music file) into smaller packets and sends the packets into the network. The receiver then reassembles the packets back into the original message. We refer to this process as message segmentation.

Figure 2 shows the end-to-end transport with and without message segmentation. In this example, the message L sent from source to destination is 10^6 bits long and each link has 5 Mbps. Propagation, queueing, and processing delay are ignored.

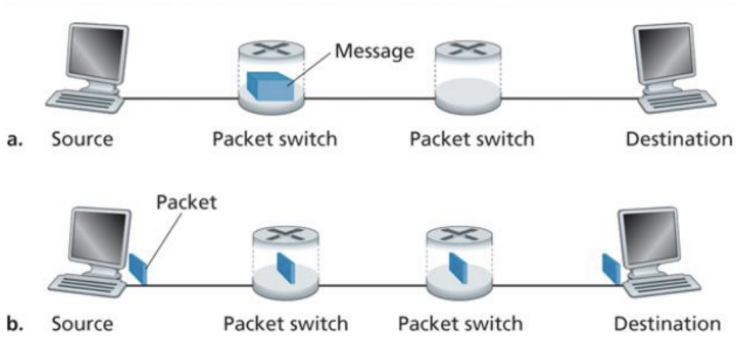


Figure 2: End-to-end message transport. a) without message segmentation and b) with message segmentation.

a)

1. Question: How long does it take to move the message from the source host to the first packet switch without message segmentation?

Information that we have:

- Transmission happens at $R = 5$ Mbps $= 5,000,000$ bits/s.
- Store-and-forward is used, i.e. entire packet must arrive at switch before forwarding
- Formula for calculating transmission delay $\frac{L}{R}$
- $L = 10^6$ bits $= 1,000,000$ bits

Therefore, moving from source to the first packet switch takes:

$$d_{\text{1-hop}} = \frac{L}{R} = \frac{1,000,000 \text{ bits}}{5,000,000 \text{ bits/s}} = \mathbf{0.2} \text{ s}$$

2. Question: What is the total time to move the message from source host to destination host?

As we have have 3 links, the whole packet needs to be transmitted 3 times. Therefore the total is given by:

$$d_{\text{total}} = 3 \cdot \frac{L}{R} = 3 \cdot \frac{1,000,000 \text{ bits}}{5,000,000 \text{ bits/s}} = \mathbf{0.6} \text{ s}$$

b)

Setup: Message segmented in 100 packets, each size 10,000 bits.

1. Question: How long does it take to move the first packet from source host to the first switch?

As the transmission rate remains equal and the number of bits reduced to 10,000, the result is:

$$d_{\text{first-packet-at-1-hop}} = \frac{L}{R} = \frac{10,000 \text{ bits}}{5,000,000 \text{ bits/s}} = \mathbf{0.002} \text{ s}$$

2. Question: At what time will the second packet be fully received at the first switch?

As the transmission of the second packet begins, when the first packet is fully transmitted (after 0.002 seconds), we just need to add the transmission time for the second packet (also 10,000 bits large) onto that:

$$d_{\text{second-packet-at-1-hop}} = 0.002 + \frac{L}{R} = 0.002 + \frac{10,000 \text{ bits}}{5,000,000 \text{ bits/s}} = \mathbf{0.004} \text{ s}$$

c)

Question: How long does it take to move the file from source host to the destination host when message segmentation is used?

To answer this, we need to determine, when the last packet gets transmitted by the source host and sum it up with the time, it takes for the last packet to go through all 3 links to the destination host:

$$d_{\text{last-packet-at-destination}} = \underbrace{99 \cdot \frac{10,000 \text{ bits}}{5,000,000 \text{ bits/s}}}_{\substack{\text{Point of time, when} \\ \text{transmission of last packet starts}}} + \underbrace{3 \cdot \frac{10,000 \text{ bits}}{5,000,000 \text{ bits/s}}}_{\substack{\text{3 transmission delays until} \\ \text{last packet arrives at destination}}}$$

$$= 102 \cdot 0.002 \text{ s} = \mathbf{0.204} \text{ s}$$

Comparison: of this result with the result from section a).

With message segmentation we are able to reduce the time it takes to transmit the whole data to the destiantion from 0.6 seconds to 0.204 seconds. This equals to a reduction of end-to-end delay by almost 66%.

In general, increasing the number of hops also increases the benefits of message segmentation. Without message segmentation, each hops adds another $\frac{L}{R}$ seconds to the total end-to-end delay. With message segmentation, each hops adds only $\frac{l}{R}$ seconds where l is only the size of one single packet. Conversely, decreasing the number of hops, reduces this advantage of message segmentation. With only a single link, sending a message with and without segmentation takes equally long.

d)

Advantages of Message Segmentation

- **Error Recovery:** when the buffer of a packet switch is full or when there is a bit error in an incoming packet, this packet gets dropped. This can especially happen if large packets arrive at the switch. Dropped packets will then need to be retransmitted. With message segmentation, the system only needs to worry about the specific packet that got dropped, not about the entire message.
- **Sharing Switches:** A single large message blocks the link for a long time. During this time the traffic from other hosts cannot be served. With message segmentation, packets from different sources can be interleaved more easily, so that more people can fairly share the resources of the switch.

e)

Disadvantages of Message Segmentation

- **Encapsulation:** Each packet must have its own header attached to it when it goes down the protocol stack. Sending all these headers increases the total amount of data to be sent, bandwidth is therefore wasted on administrative data rather than on actual payload data.
- **Message Reassembly:** Not all packets of a segmented message take the same path throughout the network. Therefore, the destination host must use compute power and memory to hold this data in a buffer and to later reassemble it correctly before an application can use them.

Exercise 3

Perform a traceroute between source and destination on the same continent at three different hours of the day.

5 PM

```
~ ❯ traceroute -I harvard.edu                                                    base 05:34:01 PM
traceroute to harvard.edu (192.0.66.20), 64 hops max, 48 byte packets
 1  142.207.103.1 (142.207.103.1)  88.418 ms  22.958 ms  25.163 ms
 2  10.101.1.49 (10.101.1.49)  12.388 ms  5.708 ms  14.614 ms
 3  10.101.2.41 (10.101.2.41)  3.689 ms  3.924 ms  3.166 ms
 4  * 204.239.83.195 (204.239.83.195)  3.794 ms  3.176 ms
 5  775-tx-unbc.pgrg1.bc.net (207.23.242.21)  3.387 ms  3.442 ms  3.663 ms
 6  * * *
 7  rd1ht-be31-100.ok.shawcable.net (66.163.72.189)  13.492 ms  11.647 ms  11.776 ms
 8  rd1cs-be5.ok.shawcable.net (66.163.72.253)  14.143 ms  13.643 ms  13.547 ms
 9  * * rc2st-be1.vc.shawcable.net (66.163.72.233)  186.513 ms
10  rc2wt-be50-1.wa.shawcable.net (66.163.70.106)  23.494 ms  23.059 ms  23.380 ms
11  rc1wt-be18-1.wa.shawcable.net (66.163.64.81)  24.106 ms  23.563 ms  65.697 ms
12  six.automattic.net (206.81.81.70)  23.679 ms  23.432 ms  121.339 ms
13  192.0.66.20 (192.0.66.20)  23.190 ms  39.053 ms  23.580 ms
~ ❯                                                                  31s base 05:34:34 PM
```

11 PM

```
~ ❯ traceroute -I harvard.edu                                                    base 11:38:12 PM
traceroute to harvard.edu (192.0.66.20), 64 hops max, 48 byte packets
 1  142.207.57.65 (142.207.57.65)  19.392 ms  21.167 ms  21.691 ms
 2  10.101.1.97 (10.101.1.97)  4.575 ms  8.696 ms  8.306 ms
 3  10.101.2.41 (10.101.2.41)  3.418 ms  3.011 ms  2.879 ms
 4  204.239.83.195 (204.239.83.195)  3.559 ms  3.480 ms  6.046 ms
 5  775-tx-unbc.pgrg1.bc.net (207.23.242.21)  3.912 ms  3.532 ms  3.471 ms
 6  * * *
 7  rd1ht-be31-100.ok.shawcable.net (66.163.72.189)  13.724 ms  13.051 ms  12.165 ms
 8  rd1cs-be5.ok.shawcable.net (66.163.72.253)  13.871 ms  13.799 ms  13.897 ms
 9  rc2st-be1.vc.shawcable.net (66.163.72.233)  20.723 ms  18.281 ms  22.901 ms
10  rc2wt-be50-1.wa.shawcable.net (66.163.70.106)  23.669 ms  23.426 ms  25.343 ms
11  rc1wt-be18-1.wa.shawcable.net (66.163.64.81)  24.025 ms  23.553 ms  26.353 ms
12  six.automattic.net (206.81.81.70)  23.576 ms  23.330 ms  23.807 ms
13  192.0.66.20 (192.0.66.20)  23.680 ms  23.265 ms  23.120 ms
~ ❯                                                                  16s base 11:38:30 PM
```

12 PM

```
~ ❯ traceroute -I harvard.edu                                                    base 12:23:37 PM
traceroute to harvard.edu (192.0.66.20), 64 hops max, 48 byte packets
 1  142.207.103.1 (142.207.103.1)  29.284 ms  22.160 ms  24.984 ms
 2  10.101.1.49 (10.101.1.49)  9.180 ms  10.122 ms  15.344 ms
 3  10.101.2.41 (10.101.2.41)  6.524 ms  5.941 ms  3.440 ms
 4  * * *
 5  * 775-tx-unbc.pgrg1.bc.net (207.23.242.21)  188.097 ms  1109.013 ms
 6  * * *
 7  rd1ht-be31-100.ok.shawcable.net (66.163.72.189)  625.637 ms  218.311 ms  312.799 ms
 8  rd1cs-be5.ok.shawcable.net (66.163.72.253)  278.658 ms  147.234 ms  51.146 ms
 9  rc2st-be1.vc.shawcable.net (66.163.72.233)  33.600 ms  24.685 ms *
10  rc2wt-be50-1.wa.shawcable.net (66.163.70.106)  567.120 ms  807.423 ms  45.791 ms
11  * rc1wt-be18-1.wa.shawcable.net (66.163.64.81)  188.922 ms  28.773 ms
12  six.automattic.net (206.81.81.70)  102.356 ms  23.546 ms  128.743 ms
13  192.0.66.20 (192.0.66.20)  41.508 ms  38.641 ms  26.387 ms
~ ❯                                                                  51s base 12:24:34 PM
```

Figure 3: Traceroute of harvard.edu for three different hours of the day.

a)

The sample average and standard deviation are given by:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{3} x_i \qquad\qquad s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{3}(x_i - \bar{x})^2}$$

With this, we can calculate the following:

$$\bar{x}_{\text{5-PM}} = \frac{23.190 + 39.053 + 23.580}{3} = \mathbf{28.608}$$

$$s_{\text{5-PM}} = \sqrt{\frac{(23.190 - 28.608)^2 + (39.053 - 28.608)^2 + (23.580 - 28.608)^2}{2}} = \mathbf{9.048}$$

$$\bar{x}_{\text{11-PM}} = \frac{23.680 + 23.265 + 23.120}{3} = \mathbf{23.355}$$

$$s_{\text{11-PM}} = \sqrt{\frac{(23.680 - 23.355)^2 + (23.265 - 23.355)^2 + (23.120 - 23.355)^2}{2}} = \mathbf{0.291}$$

$$\bar{x}_{\text{12-PM}} = \frac{41.508 + 38.641 + 26.387}{3} = \mathbf{35.512}$$

$$s_{\text{12-PM}} = \sqrt{\frac{(41.508 - 35.512)^2 + (38.641 - 35.512)^2 + (26.387 - 35.512)^2}{2}} = \mathbf{8.031}$$

b)

Number of routers in the path for each of the three hours:

- **5 PM**: 13 routers
- **11 PM**: 13 routers
- **12 PM**: 13 routers

For each of the three hours, the traceroute command passes through 13 routers until it reaches its destination.

c)

Number of ISPs

As the routing for the three different hours is always quite similar, we can assume the **4** different ISPs:

- **Hop 1-4**: Local institutional network of UNBC
- **Hop 5**: BCNET (network for higher education and research in BC)
- **Hop 6**: *** * *** the router did not respond to traceroute (often due to security reasons)(no ISP)
- **Hop 7-11**: Shawcable commercial ISP operator
- **Hop 12-13**: Automattic network of destination

Largest Delay

The largest increases in delay actually seems to appear when going from the BCNET ISP to the Shawcable ISP. Within the Shawcable ISP there are only small increases in the delay, that can be explained through the large distance between British Columbia and Harvard University. Furthermore, the delays in the 12 PM screenshot vary a lot, e.g. one delay at the BCNET ISP takes around 1100 ms, where as the final delay at the destination is still between 26 and 42 ms.

d)

Perform a traceroute between source and destination on a different continent at three different hourse of the day.

5 PM

```
~ ❯ traceroute -I uni-bonn.de                                                                                    base 05:35:21 PM
traceroute to uni-bonn.de (131.220.250.29), 64 hops max, 48 byte packets
 1  142.207.103.1 (142.207.103.1)  21.909 ms  23.143 ms  8.657 ms
 2  10.101.1.49 (10.101.1.49)  8.393 ms  7.032 ms  6.747 ms
 3  10.101.2.41 (10.101.2.41)  3.458 ms  3.202 ms  3.251 ms
 4  204.239.83.195 (204.239.83.195)  3.543 ms  5.522 ms  3.140 ms
 5  781-oran-unbc.pgrg1.bc.net (207.23.242.37)  5.048 ms  3.465 ms  3.314 ms
 6  205.189.32.45 (205.189.32.45)  9.992 ms  11.295 ms  11.778 ms
 7  toro1rtr1.network.canarie.ca (205.189.32.44)  16.809 ms  15.800 ms  119.823 ms
 8  rgna1rtr3.network.canarie.ca (205.189.32.234)  25.008 ms  24.356 ms  24.319 ms
 9  wnpg2rtr3.network.canarie.ca (205.189.32.239)  31.010 ms  30.862 ms  32.940 ms
10  toro3rtr3.network.canarie.ca (205.189.32.210)  53.184 ms  52.469 ms  52.459 ms
11  toro1rtr3.network.canarie.ca (205.189.32.119)  53.263 ms  52.987 ms  133.331 ms
12  nycn1rtr3.network.canarie.ca (208.75.75.75)  63.647 ms  63.109 ms  63.372 ms
13  canarie.rt0.par.fr.geant.net (62.40.124.221)  130.702 ms  190.059 ms  130.990 ms
14  * * *
15  * * *
16  dfn-gw.rt1.fra.de.geant.net (62.40.124.218)  330.522 ms  146.117 ms  145.608 ms
17  kr-bon168-0.x-win.dfn.de (188.1.236.42)  148.966 ms  148.321 ms  148.438 ms
18  * * *
19  * * *
20  * * *
21  * * *
22  * * *
23  * * *
24  * * *
25  * * *
26  * * *
27  * * *
28  * * *
29  * * *
30  * * *
31  * * *
32  * * *
33  *^C
~ ❯                                                                                  ✘ INT 4m 26s  base 05:39:50 PM
```

11 PM

```
~ ❯ traceroute -I uni-bonn.de                                                                                    base 11:49:48 PM
traceroute to uni-bonn.de (131.220.250.29), 64 hops max, 48 byte packets
 1  142.207.57.65 (142.207.57.65)  56.590 ms  19.441 ms  21.274 ms
 2  10.101.1.97 (10.101.1.97)  4.520 ms  5.706 ms  8.654 ms
 3  10.101.2.41 (10.101.2.41)  12.281 ms  3.096 ms  3.004 ms
 4  204.239.83.195 (204.239.83.195)  3.634 ms  3.262 ms  3.363 ms
 5  781-oran-unbc.pgrg1.bc.net (207.23.242.37)  3.706 ms  3.331 ms  3.533 ms
 6  205.189.32.45 (205.189.32.45)  9.572 ms  9.415 ms  9.280 ms
 7  toro1rtr1.network.canarie.ca (205.189.32.44)  16.476 ms  16.167 ms  15.982 ms
 8  rgna1rtr3.network.canarie.ca (205.189.32.234)  24.708 ms  24.522 ms  24.498 ms
 9  wnpg2rtr3.network.canarie.ca (205.189.32.239)  30.831 ms  30.452 ms  30.436 ms
10  toro3rtr3.network.canarie.ca (205.189.32.210)  52.945 ms  100.866 ms  53.565 ms
11  toro1rtr3.network.canarie.ca (205.189.32.119)  53.690 ms  53.210 ms  52.990 ms
12  nycn1rtr3.network.canarie.ca (208.75.75.75)  63.654 ms  63.087 ms  63.013 ms
13  canarie.rt0.par.fr.geant.net (62.40.124.221)  130.101 ms  129.735 ms  129.416 ms
14  * * *
15  * * *
16  cr-fra1.x-win.dfn.de (62.40.124.218)  150.791 ms  149.370 ms  149.254 ms
17  kr-bon168-0.x-win.dfn.de (188.1.236.42)  183.623 ms  154.111 ms  151.920 ms
18  * * *
19  *^C
~ ❯                                                                                  ✘ INT 53s  base 11:50:44 PM
```

1 PM

```
~ ❯ traceroute -I uni-bonn.de                                                                                ✘ INT  base 01:02:18 PM
traceroute to uni-bonn.de (131.220.250.29), 64 hops max, 48 byte packets
 1  142.207.124.1 (142.207.124.1)  99.550 ms  20.000 ms  37.823 ms
 2  10.101.1.81 (10.101.1.81)  5.646 ms  6.607 ms  8.284 ms
 3  10.101.2.41 (10.101.2.41)  3.348 ms  2.917 ms  3.526 ms
 4  204.239.83.195 (204.239.83.195)  3.745 ms  3.400 ms  3.121 ms
 5  781-oran-unbc.pgrg1.bc.net (207.23.242.37)  3.766 ms  3.429 ms  3.269 ms
 6  205.189.32.45 (205.189.32.45)  11.526 ms  9.452 ms  9.817 ms
 7  toro1rtr1.network.canarie.ca (205.189.32.44)  16.588 ms  16.564 ms  16.135 ms
 8  rgna1rtr3.network.canarie.ca (205.189.32.234)  25.292 ms  25.388 ms  99.994 ms
 9  wnpg2rtr3.network.canarie.ca (205.189.32.239)  31.764 ms  31.046 ms  30.514 ms
10  toro3rtr3.network.canarie.ca (205.189.32.210)  53.183 ms  52.814 ms  52.440 ms
11  toro1rtr3.network.canarie.ca (205.189.32.119)  53.762 ms  53.545 ms  89.768 ms
12  nycn1rtr3.network.canarie.ca (208.75.75.75)  63.515 ms  64.437 ms  63.034 ms
13  canarie.rt0.par.fr.geant.net (62.40.124.221)  130.268 ms  130.044 ms  129.447 ms
14  * * *
15  * * *
16  dfn-gw.rt1.fra.de.geant.net (62.40.124.218)  150.958 ms  149.227 ms  175.581 ms
17  kr-bon168-0.x-win.dfn.de (188.1.236.42)  149.186 ms  148.691 ms  148.644 ms
18  * * *
19  * * *
20  * * *
21  * * *
22  * * *
^C
~ ❯                                                                                  ✘ INT 1m 54s  base 01:04:15 PM
```

Figure 4: Traceroute of uni-bonn.de for three different hours of the day.

Averages and standard deviations

$$\bar{x}_{\text{5-PM}} = \frac{148.966 + 148.321 + 148.438}{3} = \mathbf{148.575}$$

$$s_{5\text{-PM}} = \sqrt{\frac{(148.966 - 148.575)^2 + (148.321 - 148.575)^2 + (148.438 - 148.575)^2}{2}} = \mathbf{0.344}$$

$$\bar{x}_{11\text{-PM}} = \frac{183.623 + 154.111 + 151.92}{3} = \mathbf{163.218}$$

$$s_{11\text{-PM}} = \sqrt{\frac{(183.623 - 163.218)^2 + (154.111 - 163.218)^2 + (151.92 - 163.218)^2}{2}} = \mathbf{17.705}$$

$$\bar{x}_{1\text{-PM}} = \frac{149.186 + 148.691 + 148.644}{3} = \mathbf{148.8403}$$

$$s_{1\text{-PM}} = \sqrt{\frac{(149.186 - 148.8403)^2 + (148.691 - 148.8403)^2 + (148.644 - 148.8403)^2}{2}} = \mathbf{0.300}$$

Number of routers

- **5 PM**: terminated after 33 routers but only until the 17th there were useful responses (further packets probably lost in firewall)
- **11 PM**: terminated after 19 routers but last useful response at 17th router
- **1 PM**: terminated after 22 routers but last useful at 17th router

For each of the three hours, we seemed to have reached our destination (dfn.de) after 17 routers. After that we are just stuck in a firewall and the traceroute packets are not returning to us anymore.

Number of ISPs

As the routing for the three different hours is quite similar, we can assume the **5** different ISPs:

- **Hop 1-4**: Local institutional network of UNBC
- **Hop 5**: BCNET
- **Hop 6-12**: Canarie ISP (formerly Canadian Network for the Advancement of Research, Industry and Education)
- **Hop 13-15/16**: GEANT ISP (European Academic Network)
- **Hop 16/17-end**: DFN (German Research Network)

Largest Delay

The largest increase in delay is observed when going from the Canarie ISP in New York City to the GEANT ISP, by almost doubling the delay due to the trans-oceanic link between North America and Europe which causes a ”long” propagation time. The delays within Europe don’t increase too much.

Exercise 4

Use the HTTP/1.1 specification in RFC 2616 [1] to answer the following questions.

a)

Mechanism between Client and Server to close a persistent connection

- "If either the client or the server sends the close token in the connection header, that request becomes the last one for that connection" found on page 44 [1]
- Once the closing header is sent, both parties understand that the TCP connection should be closed after the current message got fully transmitted

Who can choose to close the connection?

- Both parties can always sent this header to signal the termination of the connection from their side, it is not restricted to only the server or only the client
- Client might terminate the connection when it has finished all planed requests for this particular server
- Server might terminate the connection when the connection has been idle for too long, so that it just takes up valuable resources to keep it open the whole time or same way if the server is approaching its maximum number of open connections

b)

What encryption services are provided by HTTP?

- HTTP does not provide any encryption, it was designed as a plain text protocol where information is broken into packets of data that can easily be sniffed using free software
- All communications in HTTP occur in plain text, including passwords, making them highly accessible and vulnerable for man-in-the-middle attacks
- Every ISP on the way from the destination server to the source host can sniff and read the traffic, it can even inject content into the webpages without approval of the website owner (commonly in the form of advertising) [2]
- HTTPS adds encryption so that the ISP can no longer sniff into the packet and maybe insert ads into it

c)

Can a client open three or more simultaneous connections with a given server according to the RFC standard?

- No, according to this RFC, in HTTP/1.1 a Client should limit its number of simultaneous connections to 2 to a given server
- "Clients that use persistent connections SHOULD limit the number of simultaneous connections that they maintain to a given server. A single-user client SHOULD NOT maintain more than 2 connections with any server or proxy" found on page 46 [1]

d)

Is it possible that one side starts closing a connection while the other side is transmitting data via this connection?

- Yes, it is possible that one side decides to close the connection while at the same time the other side tries to do a request, this occurrence is called ”asynchronous close event”
- Both Clients and Servers should always watch whether the other side tries to end the connection at some point
- No matter if client, server or proxy, everyone should be able to recover from such an asynchronous close event
  - Client software should just try to automatically reopen the connection and send the sequence of aborted requests again, if this sequence is idempotent, meaning that the side effects of performing $N > 0$ requests are the same as for performing only a single request, the methods GET, HEAD, PUT, and DELETE fulfill this property.
  - Non-idempotent methods must not automatically do this, but can ask the human operator whether he wants to submit the request again
- Because of the propagation delay between Client and Server, this event can happen, where both parties at the same time decide to make a move
- ”A client, server, or proxy MAY close the transport connection at any time. For example, a client might have started to send a new request at the same time that the server has decided to close the "idle" connection. From the server’s point of view, the connection is being closed while it was idle, but from the client’s point of view, a request is in progress.” found on page 46 [1]

Exercise 5

In this problem, we use the useful dig tool to explore the hierarchy of DNS servers. A DNS server in the DNS hierarchy delegates a DNS query to a DNS server lower in the hierarchy, by sending back to the DNS client the name of that lower-level DNS server.

a)

Initiate a sequence of queries, starting from one of the root servers ([a-m].root-servers.net, for the IP address of your UNBC’s webserver (`www.unbc.ca`).

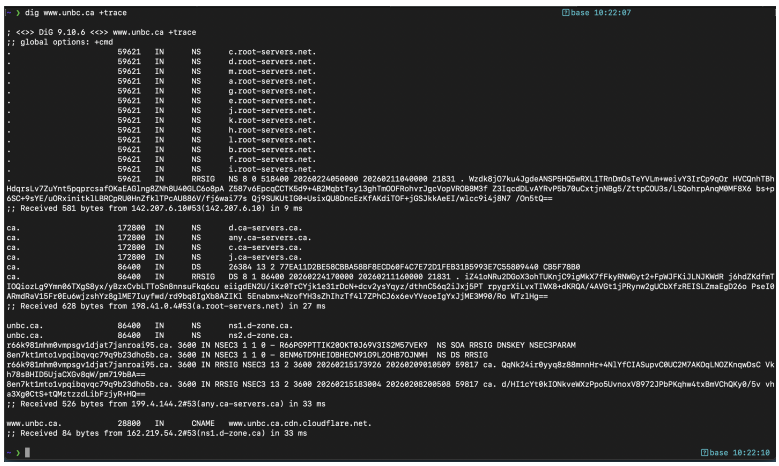


Figure 5: Dig trace for UNBC webserver

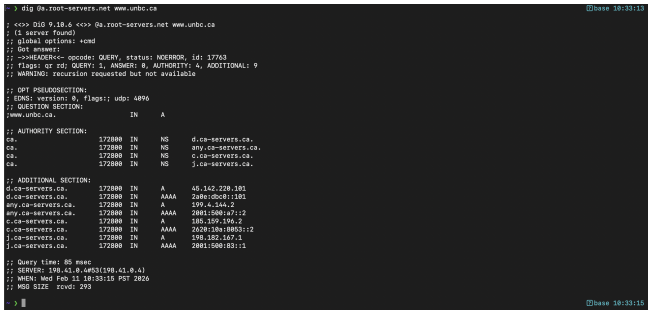
Figure 5 shows the delegation chain:

- **Root DNS Server**: `a.root-servers.net` with IP address 198.41.0.4
- **TLD DNS Server**: `any.ca-servers.ca` with IP address 199.4.144.2
- **Authoritative DNS Server**: `ns1.d-zone.ca` with IP address 162.219.54.2

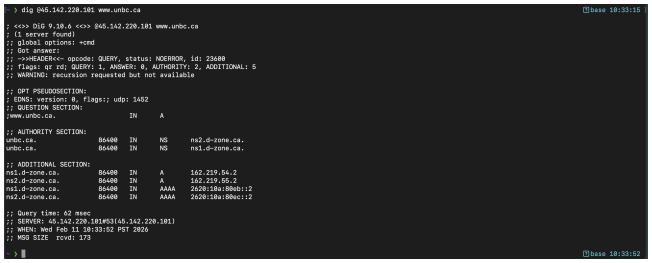
Alternative Approach

Iteratively, query each server manually (use `@server` option of dig to include either the hostname or IP address), by the IP address provided from the query to the server higher in the hierarchy. Start with a query to the root server.

Root DNS Server



TLD DNS Server



Authoritative DNS Server

Figure 6: Manual iterative DNS query from root server to authoritative name server.

b)

Repeat part a) for the webserver of University of Bonn, i.e. `www.uni-bonn.de`.

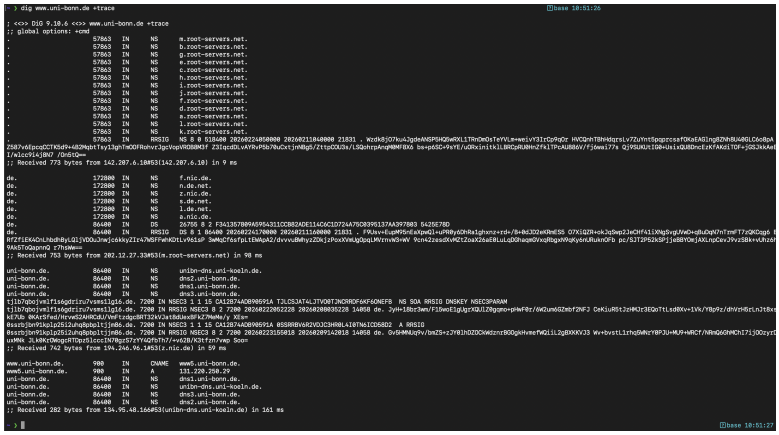


Figure 7: Dig trace for University of Bonn webserver

Figure 7 shows the delegation chain:

- **Root DNS Server**: `m.root-servers.net` with IP address 202.12.27.33
- **TLD DNS Server**: `z.nic.de` with IP address 194.246.96.1
- **Authoritative DNS Server**: `unibn-dns.uni-koeln.de` with IP address 134.95.48.166

References

[1] H. Nielsen et al., *Hypertext Transfer Protocol – HTTP/1.1*, RFC 2616, Jun. 1999. DOI: 10.17487/RFC2616. [Online]. Available: https://www.rfc-editor.org/info/rfc2616.

[2] Cloudflare, *What is HTTPS?* https://www.cloudflare.com/learning/ssl/what-is-https/, Accessed: 2026-02-11, 2026.