ECE/CS 438: Communication Networks **Spring 2023**

Homework 1

Handed Out: January 29^{th}, 2023 *Due: 11:59pm, February 5^{th}, 2023*

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- Homework assignments must be submitted online through GradeScope. Hard copies are not accepted. Please submit a pdf file to GradeScope (`https://www.gradescope.com`). You can either type your solution or scan a **legible** hand-written copy. We will not correct anything we do not understand. Contact the TAs via Campuswire if you face technical difficulties in submitting the assignment.
- Homework assignments can be done in groups of two, but only one person needs to submit on GradeScope. Remember to include your partners name in the solution and on GradeScope by editing "Group Members". It is your responsibility that your partner's name is included. For detailed instruction please refer to (`https://youtu.be/rue7p_kATLA`).
- You can use Campuswire to find a partner. We highly recommend working in groups. You will not get extra credit for working alone.
- Please use Campuswire and come to office hours if you have questions about the homework. Failure to understand the solutions will be the student's fault.
- While we encourage discussion within and outside of the class, cheating and copying is strictly prohibited. Copied solutions will result in the entire assignment being discarded from grading at the very least and a report filed in the FAIR system. It is also your responsibility to ensure that your partner obeys the academic integrity rules as well.

1 Delays - 20 points

For this part, consider two hosts, A and B, connected by a switch S. The link A↔S is 80 Mbps and has a propagation delay of 8 ms; the link B↔S is 16 Mbps and has a propagation delay of 80 ms. Assume 1 byte = 8 bit and 1k=1000 (not 1024). Also assume 1s=1000ms.

1. Suppose A sends a 100 kB packet to B. What is the total (end-to-end) delay before the packet is received by B in its entirety? Assume that S operates in a "store-and-forward" manner and that the processing delay is 0.
2. Suppose A is sending a sequence of 100 kB packets. How many packets will it have sent when the first packet arrives (completely) at B? (integer number of packets)
3. Let S have a 900 kB buffer for packets. Suppose A sends a sequence of 100 kB packets as fast as possible; how long will it be until the buffer is full?
4. What will be the queueing delay encountered by the last packet to enter the buffer?
5. Assume now that the buffer is infinite and each packet size is 100 kB. How long will it take (end-to-end) for a 100 MB file to be sent from A to B? What is the average throughput?

6. Suppose that, after B receives a packet, it sends a short (100 byte) acknowledgment packet to A. A waits for this acknowledgment before sending the next packet. How long will it take to send a 100 MB file in this setting? What is the average throughput?

Solution: (4+2+3+3+4+4 points)

Note: if you assume that packets are not sent out instantly, you will get different answers, which are also accepted

1. Total end-to-end delay is

$$L/R_{AS} + d_{prop\_AS} + L/R_{SB} + d_{prop\_SB}$$

$$= \frac{100 * 10^3 * 8}{80 * 10^6} s + 8ms + \frac{100 * 10^3 * 8}{16 * 10^6} s + 80ms$$
$$= 148ms$$

2. The transmit delay from $A \rightarrow S$ is $L/R_{AS} = 10ms$. So the number of packets sent is

$$148ms/10ms = 14$$

packets.

3. Once the first packet arrives at the buffer, the following packets will arrive seamlessly at an inflow rate of 80 Mbps. Additionally, once the first packet completely arrives at S, S starts sending out packets seamlessly at an outflow rate of 16 Mbps. Note that since the outflow rate is smaller than the inflow rate, S always has packets to send out from its buffer once the first packet arrives. Hence, the buffer will be filled up by the speed difference between the outflow rate and inflow rate. So the total time until the buffer fills up is

$$t_{total} = L/R_{AS} + d_{prop\_AS} + t_{fill\_up}$$
$$= 10ms + 8ms + \frac{(900 - 100) * 10^3 * 8}{(80 * 10^6 - 16 * 10^6)} s$$
$$= 118ms$$

The first two terms in the above expression account for the time it takes for the first packet to get to S.

4. The last packet in the buffer has to wait until all the previous packets in the buffer are sent over the link $S \rightarrow B$. That would be number of packets divided by the transmission delay. So the queueing delay is

$$d_{queue} = \frac{(900kB - 100kB)}{100kB} * (L/R_{SB})$$

$$= 8 * 50ms = 400ms$$

Note that queue delay ends as soon as the last packet starts transmitting, so the last packet will wait for 8 packets instead of 9 packets.

5. 100MB file = 1000 packets.

   At time $18ms$ S received the first packet ($L/R_{AS} + d_{prop\_AS}$). Note that the inflow rate of packets at S is higher than the outflow rate of packets. Hence once the first packet arrives at S, S will always have something to transmit from thereon. Hence S takes $L/R_{SB} * 1000$ time to transmit all packets on link $S \rightarrow B$. Finally, the last packet that S transmitted on $S \rightarrow B$ requires 80 ms to get to B. Therefore the total time can be calculated as

$$t_{firstpacketarriveatS} + L/R_{SB} * 1000 + d_{prop_SB} = 18 + 50 * 1000 + 80 = 50098ms$$

   Hence throughput is

$$\frac{100MB}{50098ms} = 1.996MBps$$

6. The time for one packet to go from A to B is 148 ms as shown in part 1. The time required for an ACK to get from B to A is -

$$t_{ack} = L_{ack}/R_{BS} + d_{prop\_BS} + L_{ack}/R_{SA} + d_{prop\_SA}$$

$$t_{ack} = \frac{100 * 8}{16 * 10^6}s + 80ms + \frac{100 * 8}{80 * 10^6}s + 8ms = 88.06$$

   Hence the total amount of time needed for one packet to go from A to B, and then for the ACK to get back to A is 148+88.06 = 236.06. Since this process repeats for each of the 1000 packets, the total time required for transmitting 100 MB is $236.06ms * 1000 =$ 236.06 sec.

   Average throughput is

$$100MB/236.06s = 0.4236MBps$$

   Deepak's note: Answer can be slightly different if the students don't account for the last ack.

2 Layering - 10 points

Give a real-world example of a system / set of protocols that can be explained using layering. Explain what the layers are (there should be at least 3), and what the interface between each pair of adjacent layers looks like.

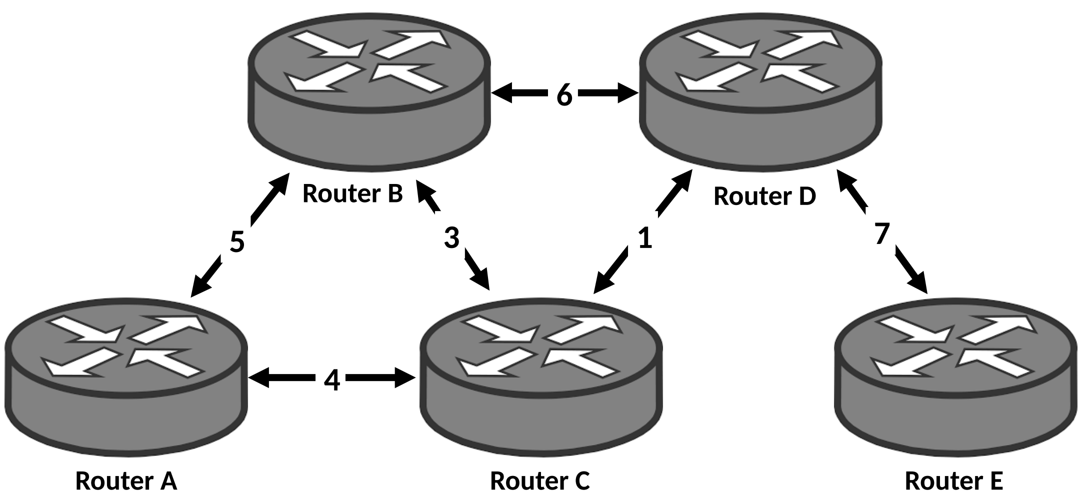
In the context of your example, what are some of the advantages of layering? What is a disadvantage?

Solution:

1. 2 point for reasonable real-world example
2. 4 points for explaining layers
3. 2 point for advantage
4. 2 point for disadvantage

3 Circuit Switching - 12 points

The diagram below shows a network of routers and the capacity of links (in Mbps) that are attached to each router.



1. If each circuit uses 1 Mbps, how many circuits can we simultaneously support between routers A and E? Which links would they use?
2. How many circuits can we simultaneously support between B and C? Which links would they use? For this part, assume that no other circuits are active.

3. For this part, consider establishing circuits simultaneously A↔D and B↔C. What is the maximum total number of circuits that this network configuration would support?

Solution:

1. The bottleneck is link $D \to E$. So the number of circuits they can support at the same time is

$$7/1 = 7$$

2. Bandwidth of link $B \to A \to C$ is 4Mbps.
   Bandwidth of link $B \to C$ is 3Mbps.
   Bandwidth of link $B \to D \to C$ is 1Mbps.
   So the number of circuits they can support at the same time is

$$(4 + 3 + 1)/1 = 8$$

3. In the network, link $A \leftrightarrow B, B \leftrightarrow C, C \leftrightarrow D$ are bottlenecks. So the total number of circuits that this network would support is

$$(5 + 3 + 1)/1 = 9$$

4 Packet Switching - 12 points

Suppose that you share your 600 Mbps connection with two roommates. The first roommate uses the link 50% of the time, and the second one uses the link 50% of the time. Assume that their internet access activity is independent from each other. Also assume that network use is distributed uniformly through the day.

1. What is the fraction of the time that you have the connection all to yourself?
2. What is the fraction of the time that you have to share the connection with both roommates simultaneously?
3. Assume that when two or more people use the connection, the bandwidth is divided fairly among them. What is the average bandwidth you will receive from the link?

Solution: (3+3+6 points)

1. The probability that both roommates are not online is $p = (1 - 0.5) * (1 - 0.5) = 0.25$
2. The probability that both roommates are online is $p = 0.5 * 0.5 = 0.25$
3. With probability 0.25, you have the bandwidth all to your self so the bandwidth assigned to you is 600Mbps. With probability 0.25, you share with 2 roommates and get bandwidth of $\frac{600}{3}$Mbps. With probability $(1 - 0.25 - 0.25)$, you share the bandwidth with 1 roommate, the bandwidth you get in this case is $\frac{600}{2} Mbps$.

$$B_{avg} = 0.25 * 600 + 0.25 * 600/3 + (1 - 0.25 - 0.25) * 600/2 = 350 Mbps$$

5 HTTP - 12 points

Suppose a webpage has nothing but 50 large images each of size 10 MB. A client wants to access the webpage and load the images in his browser. The RTT between the client and the server is 100 ms and the transmission rate at the server is 50 MB/s. How long will it take to load the webpage in each of the following cases:

1. Using Non-Persistent HTTP?
2. Using Persistent HTTP?
3. Using Pipelined Persistent HTTP?

(Note: the size of the object for indexing is negligible.)

Solution: (4+4+4 points)

Note: if you assume there should be a delay for closing the HTTP connection, or if you assume that it takes no time (RTT) to fetch the webpage itself, the answers are also accepted

1. It will take $2 \times RTT + (2 \times RTT + \frac{10MB}{50MB/s}) \times 50 = 200 + 400 \times 50 = 20200ms$
2. It will take $2 \times RTT + (RTT + 200\ ms) \times 50 = 200 + 300 \times 50 = 15200ms$
3. It will take $2 \times RTT + RTT + 200\ ms \times 50 = 300 + 200 \times 50 = 10300ms$

6 Wireshark - 10 points

Install Wireshark on your laptop and use it to monitor your Internet traffic. Record a session that includes you opening YouTube in your browser and watching a 30 second video. Answer the questions below.

1. How much data in total was received by your computer during this time?
2. What are the top 2 IPs that sent traffic to your computer (by number of bytes sent)
3. What ports were used to communicate with these two IPs? What protocol was it using (full name instead of acronym)?
4. Try to find out a bit about where these IPs are located and who owns them
5. List the full name of 2 other protocols?

Solution: (2+2+2+2+2 points)

1. I got 13.9 MB
2. 2607:f8b0:4009:816::2016 belongs to Google, and 2607:f8b0:4009:810::2001 belongs to UIUC

3. I saw traffic on ports 443 -> 50576/52817/62038/63498, User Datagram Protocol
4. See above, Google and UIUC.
5. Address Resolution Protocol, Domain Name System.

7 Traceroute - 12 points

In the next figures, you will see a series of results from running `traceroute` (with the `-q 1` option to send one probe per hop). For each of the results, please answer the following questions:

1. Which hop (if any) is the transoceanic link?
2. Based on the RTT to the last hop, what's the furthest away the corresponding server could possibly be located? (Note: use speed of packet propagation: $(2 \times 10^8)\ m/s$.)
3. Sometimes the RTT of a subsequent hop is *lower* than the RTT of a previous one. Give one reason why this might happen.

```
traceroute to www.google.com (216.58.192.132), 64 hops max, 52 byte packets
 1  0148-cslgeneral-net.gw.uiuc.edu (192.17.100.1)  0.958 ms
 2  t-core1-2.gw.uiuc.edu (172.20.101.29)  0.660 ms
 3  t-exiti1.gw.uiuc.edu (130.126.0.162)  0.321 ms
 4  t-fw1.gw.uiuc.edu (130.126.0.134)  0.716 ms
 5  t-exite1.gw.uiuc.edu (130.126.0.141)  1.067 ms
 6  t-dmzo.gw.uiuc.edu (130.126.0.202)  1.087 ms
 7  ur1rtr-uiuc.ex.ui-iccn.org (72.36.127.1)  1.100 ms
 8  t-ur2rtr.ix.ui-iccn.org (72.36.126.66)  1.413 ms
 9  r-equinix-isp-ae0-2244.wiscnet.net (216.56.50.49)  4.007 ms
10  74.125.49.37 (74.125.49.37)  4.113 ms
11  209.85.254.157 (209.85.254.157)  4.390 ms
12  216.239.42.149 (216.239.42.149)  4.459 ms
13  216.239.42.153 (216.239.42.153)  4.375 ms
14  ord36s01-in-f132.1e100.net (216.58.192.132)  4.414 ms
```

```
traceroute to www.auckland.ac.nz (130.216.159.127), 64 hops max, 52 byte packets
 1  0148-cslgeneral-net.gw.uiuc.edu (192.17.100.1)  0.967 ms
 2  t-core1-1.gw.uiuc.edu (172.20.101.25)  0.536 ms
 3  t-exit1.gw.uiuc.edu (130.126.0.242)  0.407 ms
 4  t-fw1.gw.uiuc.edu (130.126.0.134)  0.666 ms
 5  t-exite1.gw.uiuc.edu (130.126.0.141)  0.937 ms
 6  t-dmzo.gw.uiuc.edu (130.126.0.202)  12.626 ms
 7  ur1rtr-uiuc.ex.ui-iccn.org (72.36.127.1)  1.051 ms
 8  t-ur2rtr.ix.ui-iccn.org (72.36.126.66)  1.576 ms
 9  internet2-710rtr.ex.ui-iccn.org (72.36.127.158)  4.107 ms
10  et-7-1-0.4070.rtsw.kans.net.internet2.edu (198.71.45.15)  21.305 ms
11  et-4-1-0.4070.rtsw.salt.net.internet2.edu (198.71.45.19)  41.337 ms
12  et-4-1-0.4070.rtsw.salt.net.internet2.edu (198.71.45.19)  41.280 ms
```

```
13  aarnet-1-is-jmb-776.lsanca.pacificwave.net (207.231.241.149)  81.268 ms
14  et-1-2-1.pe1.a.koa.aarnet.net.au (113.197.15.86)  205.814 ms
15  et-1-2-1.pe1.a.koa.aarnet.net.au (113.197.15.86)  205.753 ms
16  et-1-0-0-202.and12-nsh.reannz.co.nz (182.255.119.201)  205.921 ms
17  br-cpf1-north.net.auckland.ac.nz (130.216.95.106)  206.111 ms
18  cxj-alfa-430.net.auckland.ac.nz (130.216.95.122)  208.200 ms
19  cxj-alfa-430.net.auckland.ac.nz (130.216.95.122)  207.881 ms
20  *
21  www.auckland.ac.nz (130.216.159.127)  206.567 ms
```

Solution: (4+4+4 points)

1. (a) No transoceanic link.

   (b) Transoceanic link is et-1-2-1.pe1.a.koa.aarnet.net.au

2. (a) RTT for last hop is 4.414 ms, and one side delay is 2.207 ms. If we take speed of packet propagation as (2×10^8), we have the maximum possible distance for the last hop router as $(2 \times 10^8)\ m/s \times (2.207 \times 10^{-3})\ s = 441\ km$. This is the maximum possible distance because the 2.207 ms also includes processing and queuing delays in addition to propagation delays.

   (b) $103.25 \times 10^{-3} \times 2 \times 10^8 = 20650\ km$

3. The RTT of a subsequent hop might be *lower* than the RTT of a previous one, because we are dealing with a real network which is very dynamic. Hence the various delays like queuing delays might vary over time, making it possible for subsequent RTTs to be smaller than the RTT of a previous hop.