COMP 431 — INTERNET SERVICES & PROTOCOLS

Spring 2020

Homework 2, January 23

Due: 10:30 am, January 30

Note: Late solutions for this assignment ***cannot*** be accepted.

Note:

- Please typeset your answers.
- Please upload solution for each question separately on Gradescope (do not upload one document with answers to all questions).

1. [4+4+4+4+4 = 20 pts] An FTP server running at host A must transmit a file of length F bytes to host B over a network path consisting of N links (N–1 routers in the path). Assume the links all have the same transmission speed of R bits/second, the sum of propagation delays on all N links is D seconds, and that processing and queuing delays are all negligible relative to the transmission delays.
   a) Suppose the network operates as a *message-switched datagram* network and that a header of h bytes (combined headers for all protocol layers) is added to the entire message when it is being transmitted. How long does it take to send the file from A to B?
   b) Suppose the network operates as a *packet-switched datagram* network, the F bytes are segmented into M packets of P bytes each, and a header of h bytes is added to each packet when it is being transmitted. How long does it take to send the file from A to B?
   c) Suppose the network operates as a *packet-switched virtual-circuit* network, the F bytes are segmented into M packets of P bytes each, and a header of $h/2$ bytes is added to each packet when it is being transmitted. The virtual circuit set-up time is T_s. How long does it take to send the file from A to B?
   d) Suppose the network operates as a pure *circuit-switched* network with an end-to-end transmission speed of R bits/second once the circuit has been established. A header of $h/2$ bytes is added to the entire file when it is transmitted and the circuit set-up time is T_s. How long does it take to send the file from A to B?
   e) Under what conditions of circuit set-up time, T_s, does the packet-switched datagram network provide a faster transfer of file F from A to B than the circuit-switched network?

2. [2+1+3+4+3=13 pts] Suppose users share a 3 Mbps link. Also suppose each user requires 150 Kbps when transmitting, but each user transmits only 10 percent of the time.
   a) When circuit switching is used, how many users can be supported?
   b) For the remainder of this problem, suppose packet switching is used, Find the probability that a given user is transmitting.
   c) Suppose there are 120 users. Find the probability that at any given time, exactly n users are transmitting simultaneously.
   d) Find the probability that there are 21 or more users transmitting simultaneously.
   e) Suppose the routers connected to the shared link have buffers to help absorb simultaneous packet arrivals. However, the network administrator wants to run the shared link at no more than 70% average utilization, to avoid excessive queue build-ups. How may users can be supported?

3. [3+3+4+2+2= 14 pts] 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 send 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 1.27 illustrates the end-to-end transport of a message with and without message segmentation. Consider a message that is 8×10^6 bits long that is to be sent from source to destination in Figure 1.27. Suppose each link in the figure is 2 Mbps. Ignore propagation, queuing, and processing delays.
   a) Consider sending the message from source to destination without message segmentation. How long does it take to move the message from the source host to the first packet switch? Keeping in mind that each switch uses store-and-forward packet switching, what is the total time to move the message from source host to destination host?
   b) Now suppose that the message is segmented into 800 packets, with each packet being 10,000 bits long. How long does it take to move the first packet from source host to the first switch? When the first packet is being sent from the first switch to the second switch, the second packet is being sent from the source host to the first switch. At what time will the second packet be fully received at the first switch?
   c) How long does it take to move the file from source host to destination host when message segmentation is used? Compare this result with your answer in part (a) and comment.
   d) In addition to reducing delay, what are reasons to use message segmentation?
   e) Discuss the drawbacks of message segmentation.

4. [2+2+1+1+1+1+2 = 10 pts] This problem explores propagation delay and transmission delay, two central concepts in data networking. Consider two hosts, A and B, connected by a single link of rate R bps. Suppose that the two hosts are separated by m meters, and suppose the propagation speed along the link is s meters/sec. Host A is to send a packet of size L bits to Host B.
   a) Express the propagation delay, d_{prop}, in terms of m and s.
   b) Determine the transmission time of the packet, d_{trans}, in terms of L and R.
   c) Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.
   d) Suppose Host A begins to transmit the packet at time t=0. At time $t=d_{trans}$, where is the last bit of the packet?
   e) Suppose d_{prop} is greater than d_{trans}. At time $t= d_{trans}$, where is the first bit of the packet?
   f) Suppose d_{prop} is less than d_{trans}. At time $t= d_{trans}$, where is the first bit of the packet?
   g) Suppose $s = 2.5*10^8$, L = 120 bits, and R = 56 kbps. Find the distance m so that d_{prop} equals d_{trans}.

5. [2 + 5 = 7 pts] Consider the queuing delay in a router buffer. Let I denote traffic intensity; that is, I = La/R. Suppose that the queuing delay takes the form IL/(R(1-I)) for I < 1.
   a) Provide a formula for the total delay, that is, the queuing delay plus the transmission delay.
   b) Plot the total delay as a function of L/R. Discuss the plot.

6. [5 pts] Let a denote the rate of packets arriving at a link in packets/sec, and let μ denote the link's transmission rate in packets/sec. Based on the formula for the total delay (i.e., the queuing delay plus the transmission delay) derived in the previous problem (above), derive the total delay in terms of a and μ.

7. [4+4 = 8 pts] Consider Figure 1.19(b). Now suppose that there are M paths between the server and the client. No two paths share any link. Path k (k = 1, …, M) consists of N links with transmission rates $R^k_1, R^k_2, \ldots, R^k_N$. If the server can only use one path to send data to the client, what is the maximum throughput that the server can achieve? If the server can use all M paths to send data, what is the maximum throughput that the server can achieve?

8. [2+2+2+4+4+8 = 22 pts] The owner of an Internet backbone network has two routers, A and B, interconnected by a single transcontinental communications link in the US operating at T1 speeds (for this problem, assume T1 transmission speed, R, is exactly 1.5 Million bits/second (Mbps)). The physical length of this link is 5,000 kilometers and propagation speed over the link is 2.5×10^{8} meters/second.

   a) Calculate the one-way *bandwidth-delay product* for this link given by $R \times T_{\textbf{propagation}}$ ($T_{\textbf{propagation}}$ is the one-way propagation delay for the link).

   b) Router A has 450,000 bits that are to be sent to router B stored in its buffers. Suppose these bits are transmitted to B in a continuous stream at rate R. What is the maximum number of bits that will be in the link at any one time?

   c) Using the results from (*a*) and (*b*) give a brief discussion of what information is provided if one knows the bandwidth-delay product for a link.

   d) What is the total end-to-end delay for transmitting all 450,000 bits in a continuous stream from router A to router B?

   e) Suppose the 450,000 bits in buffers at router A are segmented into 50 frames of 9,000 bits each. Router A transmits the frames to B using a link-layer protocol that requires the sender to wait for an acknowledgement frame from the receiver (indicating that the sender's frame *n* was received correctly) before the sender can send frame *n*+1. Assume the acknowledgement frame is very small so its transmission time is negligible and all frames sent are received correctly. Assuming the link speeds are completely symmetric in both directions, what is the total-end-to-end delay for transmitting all 450,000 bits from A to B in frames (the end-to-end delay interval ends when the last frame arrives at the receiver, not when the last acknowledgement returns to the sender)?

   f) Suppose the link-layer protocol described in (*e*) is modified so the sender can send up to *m* frames of 9,000 bits each before it has to wait for an acknowledgement frame from the receiver (*i.e.*, the sender can have up to *m* unacknowledged frames "in flight" to the receiver at any point in time). Assume that the link is *full-duplex* (the nodes at both ends of the link can transmit frames at the same time) and the link speeds are completely symmetric in both directions. What is the largest value of *m* such that an acknowledgement for frame 1 will arrive while frame *m* is being transmitted by the sender (the sender can then send frame *m*+1 immediately after *m*)? How soon after beginning to send frame 1 will the sender be able to begin sending frame *m*+1? How soon after beginning to send frame 1 will the sender be able to begin sending frame *2m*? Assuming the sender can always maintain *m* frames "in-flight," what is the total end-to-end delay for transmitting all 450,000 bits from A to B in frames? (Assume the end-to-end delay interval ends when the last frame arrives at the receiver and not when the last acknowledgement returns to the sender.)

A Reminder on the Honor Code

It is acceptable for students to work together on this homework assignment. Acceptable collaboration on this assignment includes:

- Discussing the assigned problems to understand their meaning.
- Discussing possible approaches to assigned problems.

In all cases you must explicitly acknowledge any and all substantive help received from other individuals during the course of the preparation of your homework solution. That is, if you collaborate with other individuals then you must include an explicit acknowledgment in your homework solution of the persons from whom you received aid. Acknowledging others, if done properly, will not adversely affect your grade.

Unacceptable collaboration on written homework includes:

- Copying (verbatim use) of physical papers or computer files, and
- Submission of solutions that are jointly authored, or authored either wholly or in part by other individuals.

The general rule to be followed is that the strategy and approach of solutions may be developed jointly but all actual solutions (*i.e.*, the final solution) must be constructed and written up individually. Work done jointly should not be done in sufficient detail as to make it a final solution. For example, solutions may be sketched out jointly, however each student must construct the final form of their solution individually and write-up their own solution. No student should look at the written solution of another student.

Should questions arise during the course of working on a problem please feel free to contact the instructor. In principle, if you work with others in good faith and are honest and generous with your attributions of credit you will have no problems.