Homework 1

All conversions in this assignment are 1 TB=1024 GB, 1 GB=1024 MB, etc.

0. Academic integrity

I have read and understood the course academic integrity policy.

Chapter 1

1. **Circuit/packet switching** – Suppose users share an 8 Mbps link. Also suppose each user requires a constant bitrate of 2 Mbps when transmitting, but each user transmits only 25% of the time.

   a) When circuit switching is used, how many users can be supported?

   Total Bandwidth available $= 8 \ Mbps$.
   One user requirement $= 2 \ Mbps$.

   So total users that can be supported $= \frac{8 \ Mbps}{2 \ Mbps} = 4$ Users.

   b) For the remainder of the question, suppose packet switching is used. Will there be any queuing delay before the link if $\leqslant$4 users transmit simultaneously?

   There will not be any queuing delay.

   c) Find the probability that a given user is transmitting.

   Probability that a given user is transmitting $= 0.25$.

   d) Suppose threre are 5 users. Find the probability that at any given time, all 5 users are transmitting simultaneously. Find the fraction of time during which the queue grows.

   Probability $= \binom{5}{5} p^5 (1-p)^{5-5} = 0.000977$.

   Since the queue grows when all the users are transmitting, the fraction of time during which the queue grows is 0.000977.

2. **Transmission delay and propagation delay** – Consider two hosts, A and B, directly connected by a link of 2, 500 km, propagation speed 2.5 * 10^8 m/s, and transmission rate 8 Mbps, Assume zero queuing delay.

a) How long does it take to move a packet of length 1000 bytes from one A to B?

$$d_{end-to-end} = d_{trans} + d_{prop} = \frac{L}{R} + \frac{m}{s}$$
$$= \frac{0.0001192\ Mb}{8\ Mbps} + \frac{2500\ km}{250000\ km/s}$$
$$d_{end-to-end} = 0.0000149\ s + 0.01\ s = 0.0100149\ s$$

b) Assume the transmission time of the packet is d_{trans} and the propagation delay d_{prop}. Suppose that host A begins to transmit a packet at time $t = 0$. At time $t = d_{trans}$ where is the last bit of the packet?

The last bit is just leaving Host A.

c) Suppose d_{prop} is greater than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?

The first bit is in the link and has not reached Host B.

d) Suppose d_{prop} is less than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?

The first bit has reached Host B.

e) You want to urgently deliver 40 terabytes of data from Buffalo to San Francisco. You have available a 100 Mbps dedicated link for the data transfer. Would you transmit the data over this link or use FedEx overnight delivery instead? Explain (write down any assumptions).

According to Google, distance from Buffalo to San Francisco is 4256 km. So if we use the link to transmit the data:

$$d_{end-to-end} = d_{trans} + d_{prop} = \frac{L}{R} + \frac{m}{s}$$
$$= \frac{41943040\ Mb}{100\ Mbps} + \frac{4256\ km}{250000\ km/s}$$
$$d_{end-to-end} = 419430.4\ s + 0.017\ s = 419430.417\ s\ =\ 116.5\ h$$

At this situation, we prefer to use FedEx overnight delivery.

3. **Bandwidth-delay product** – Suppose two hosts, A and B, are separated by 30, 000 km and are connected by a direct link of R = 3 Mbps. Suppose the propagation speed over the link is $2.5 * 10^8$ m/s.

   a) Calculate the bandwidth-delay product $R * d_{prop}$.

$$R * d_{prop} = 3\ Mbps * \frac{30000\ km}{250000\ km/s} = 0.36\ Mb$$

b) Consider sending a file of 1, 200, 000 bits from host A to host B. Suppose the file is sent continuously as a large message. What is the maximum number of bits that will be in the link at any time?

The maximum number of bits that will be in the link at any time

$$= 0.36\ Mb = 377487\ bits$$

c) What is the width (in meters) of a bit in the link?

$\text{The width of a bit} = \text{length of link / bandwidth} - \text{delay product} =$

$\frac{30000000\ m}{377487\ bits} = 79.473\ m/bit$

d) Repeat (a), (b) and (c) but now with a link of 3 Gbps.

$$R * d_{prop} = 3\ Gbps * \frac{30000\ km}{250000\ km/s} = 0.36\ Gb$$

Since 0.36 Gb > 1200000 bits, the maximum number of bits = 1200000 bits.

$\text{The width of a bit} = \frac{30000000\ m}{386547057\ bits} = 0.0776\ m/bit$

4. **Store-and-forward** – Consider a packet of length *L* which begins at Host A and travels over 3 links to Host B. These 3 links are connected by two store-and-forward packet switches. Let d_i, s_i, R_i denote the length, propagation speed, and the transmission rate of link *i*, for *i* = 1, 2, 3. The packet switch delays each packet by d_{proc}.

a) Assuming no queuing delays, in terms of d_i, s_i, R_i (*i* = 1, 2, 3), and *L*, what is the total end-to-end delay for the packet?

$$d_{end-to-end} = \frac{L}{R_1} + \frac{L}{R_2} + \frac{L}{R_3} + \frac{d_1}{S_1} + \frac{d_2}{S_2} + \frac{d_3}{S_3} + d_{proc} + d_{proc}$$

b) Now suppose $R_1 = R_2 = R_3 = R$ and $d_{proc} = 0$. Further suppose the packet switches do not store-and-forward but instead immediately transmit each bit they receive before waiting for the entire packet to arrive. What is the end-to-end delay?

$$d_{end-to-end} = \frac{L}{R} + \frac{d_1}{S_1} + \frac{d_2}{S_2} + \frac{d_3}{S_3}$$

Chapter 2

5. **HTTP performance** – Here, we consider the performance of HTTP, comparing non-persistent HTTP with persistent HTTP. Suppose the page you browser wants to download is 100 Kbits long, and contains 5 embedded images, each of which is 100 Kbits long. The page and the 5 images are stored on the same server, which has 300 msec roundtrip time (RTT) from your browser. We'll abstract the network path between your browser and the Web server as a 100 Mbps link. You can assume that the time it takes to transmit the base file and the embedded objects into the "link". **This means that the server-to-client "link" has both a 150 msec one-way propagation delay, as well as a transmission delay associated with it, similar to the examples in class.** In your answers, be sure to account for the time needed to set up a TCP connection (1 RTT).

   a) Assuming non-persistent HTTP (and assuming no parallel connections are open between the browser and the server), how long is the respponse time – the time from when the user requests the URL to the time when the page and its embedded images are displayed? Be sure to describe the various components that contribute to this delay.

      The transmission time of the 100 Kbits object (original page and embedded images) $= \frac{L}{R} = \frac{100\ Kbits}{100\ Mbps} = 0.976\ ms$

      The total delays $= 2 \times RTT \times 6 + transmission\ time = (12 \times 300 + 6 \times 0.976)\ ms = 3605.9\ ms$

   b) Again, assume non-persistent HTTP, but now assume that the browser can open as many parallel TCP connections to the server as it wants. What is the response time in this case?

      Time saving in transferring embeded images due to parallel operation.
      The total delays $= 2 \times RTT + 2 \times RTT + transmission\ time = (4 \times 300 + 6 \times 0.976)\ ms = 1205.9\ ms$

   c) Now assume persistent HTTP (HTTP 1.1). What is the response time assuming no pipelining?

      The total delays $= 2 \times RTT + 5 \times RTT + transmission\ time = (7 \times 300 + 6 \times 0.976)\ ms = 2105.9\ ms$

   d) Now assume persistent HTTP with pipelining is used. What is the response time?

The total delays $= 2 \times RTT + 1 \times RTT + transmission\ time = (3 \times 300 + 6 \times 0.976)\ ms = 905.9\ ms$

6. **BitTorrent** – Suppose Bob joins a BitTorrent torrent, but he does not want to upload any data to other peers (also called free-riding).

   a) Can Bob receive a complete copy of the file that is shared by the swarm? Why or why not?
   Yes, he can. Through optimistic un-choking, he can receive a complete copy if peers in swarm remain for plenty of time.

   b) Bob claims that he can make his "free-riding" more efficient by using a collection of multiple computers with distinct IP addresses in the computer lab in his department. How can he do that?

   He can assign a client to each host of his lab and have those clients free-ride. Then all he has to do is to merge the chunks collected by each client into a file.

Bonus problem – Consider a short, 10-meter link, over which a sender can transmit at a rate of 150 bits/sec in both directions. Suppose that packets containing data are 100, 000 bits long, and packets containing only control (e.g., ACKs, hand-shaking, HTTP GET requests) are 200 bits long. Assume that N parallel connections each gets 1/N of the link bandwidth. Now consider the HTTP protocol and assume each downloaded object is 100 Kbits long, and that the initial downloaded object contains 10 referenced objects from the same sender.

a) Would parallel downloads via parallel instances of non-persistent HTTP make sense in this case?

$$d_{end-to-end}^{non-persistent} = d_{trans} + d_{prop}^{total} = d_{trans}^{first} + d_{prop}^{first} + d_{trans}^{referenced} + d_{prop}^{referenced}$$

$$= (\frac{200}{150} \times 3 + 3d_{prop}^{first} + \frac{100000}{150} + d_{prop}^{first}) + (\frac{200}{15} \times 3 + 3d_{prop}^{referenced} + \frac{100000}{15} + d_{prop}^{referenced}) = 7377 + 8d_{prop}$$

b) Now consider persistent HTTP without pipelining. Do you expect significant gains over the non-persistent case? Justify and explain your answer.

$$d_{end-to-end}^{persistent} = d_{trans} + d_{prop}^{total} = d_{trans}^{first} + d_{prop}^{first} + d_{trans}^{referenced} + d_{prop}^{referenced}$$

$$= (\frac{200}{150} \times 3 + 3d_{prop}^{first} + \frac{100000}{150} + d_{prop}^{first}) + 10 \times (\frac{200}{150} + d_{prop}^{referenced} + \frac{100000}{150} + d_{prop}^{referenced}) = 7351 + 24d_{prop}$$

Since d_{prop} is too small to be considered, there are no significant gains over the non-persistent case.