Homework 1 solutions

R11. At time $t_0$, the sending host begins to transmit. At time $t_1 = L/R_1$, the sending host completes transmission and the entire packet is received at the router (no propagation delay). Because the router has the entire packet at time $t_1$, it can begin to transmit the packet to the receiving host at time $t_1$. At time $t_2 = t_1 + L/R_2$, the router completes transmission and the entire packet is received at the receiving host (again, no propagation delay). Thus, the end-to-end delay is $L/R_1 + L/R_2$.

R13.

a) 2 users can be supported because each user requires half of the link bandwidth.

b) Since each user requires 1Mbps when transmitting, if two or fewer users transmit simultaneously, a maximum of 2Mbps will be required. Since the available bandwidth of the shared link is 2Mbps, there will be no queuing delay before the link. Whereas, if three users transmit simultaneously, the bandwidth required will be 3Mbps which is more than the available bandwidth of the shared link. In this case, there will be queuing delay before the link.

c) Probability that a given user is transmitting = 0.2

d) Probability that all three users are transmitting simultaneously = $\binom{3}{3} p^3 (1-p)^{3-3} = (0.2)^3 = 0.008$. Since the queue grows when all the users are transmitting, the fraction of time during which the queue grows (which is equal to the probability that all three users are transmitting simultaneously) is 0.008.

R19.

a) 500 kbps
b) 64 seconds
c) 100kbps; 320 seconds

P3.

a) A circuit-switched network would be well suited to the application, because the application involves long sessions with predictable smooth bandwidth requirements. Since the transmission rate is known and not bursty, bandwidth can be reserved for each application session without significant waste. In addition, the overhead costs of setting up and tearing down connections are amortized over the lengthy duration of a typical application session.

P5.

Tollbooths are 75 km apart, and the cars propagate at 100km/hr. A tollbooth services a car at a rate of one car every 12 seconds.
a) There are ten cars. It takes 120 seconds, or 2 minutes, for the first tollbooth to service the 10 cars. Each of these cars has a propagation delay of 45 minutes (travel 75 km) before arriving at the second tollbooth. Thus, all the cars are lined up before the second tollbooth after 47 minutes. The whole process repeats itself for traveling between the second and third tollbooths. It also takes 2 minutes for the third tollbooth to service the 10 cars. Thus the total delay is 96 minutes.

P8.

a) 20 users can be supported.

b) \( p = 0.1 \).

c) \( \left( \frac{120}{n} \right) p^n (1-p)^{120-n} \).

d) \( 1 - \sum_{n=0}^{20} \left( \frac{120}{n} \right) p^n (1-p)^{120-n} \).

We use the central limit theorem to approximate this probability. Let \( X_j \) be independent random variables such that \( P(X_j = 1) = p \).

\[
P\left( \text{"21 or more users"} \right) = 1 - P\left( \sum_{j=1}^{120} X_j \leq 21 \right)
\]

\[
P\left( \sum_{j=1}^{120} X_j \leq 21 \right) = P\left( \frac{\sum_{j=1}^{120} X_j - 12}{\sqrt{120 \cdot 0.1 \cdot 0.9}} \leq \frac{9}{\sqrt{120 \cdot 0.1 \cdot 0.9}} \right)
\]

\[
\approx P\left( Z \leq \frac{9}{3.286} \right) = P(Z \leq 2.74)
\]

\[
= 0.997
\]

when \( Z \) is a standard normal r.v. Thus \( P\left( \text{"21 or more users"} \right) \approx 0.003 \).

P13.

a) The queuing delay is 0 for the first transmitted packet, \( L/R \) for the second transmitted packet, and generally, \((n-1)L/R \) for the \( n^{th} \) transmitted packet. Thus, the average delay for the \( N \) packets is:

\[
(L/R + 2L/R + \ldots + (N-1)L/R)/N
\]

\[
= L/(RN) \cdot (1 + 2 + \ldots + (N-1))
\]

\[
= L/(RN) \cdot N(N-1)/2
\]
\[ LN(N-1)/(2RN) = (N-1)L/(2R) \]

Note that here we used the well-known fact:

\[ 1 + 2 + \ldots + N = \frac{N(N+1)}{2} \]

b) It takes \( LN / R \) seconds to transmit the \( N \) packets. Thus, the buffer is empty when a each batch of \( N \) packets arrive. Thus, the average delay of a packet across all batches is the average delay within one batch, i.e., \( (N-1)L/2R \).

P18.
On linux you can use the command

```
traceroute www.targethost.com
```

and in the Windows command prompt you can use

```
tracert www.targethost.com
```

In either case, you will get three delay measurements. For those three measurements you can calculate the mean and standard deviation. Repeat the experiment at different times of the day and comment on any changes.

Here is an example solution:

```
traceroute to www.poly.edu (128.238.24.40), 30 hops max, 40 byte packets
1 thunder.sdsu.edu (132.249.20.5) 2.802 ms 0.644 ms 0.484 ms
2 dolphin.sdsu.edu (132.249.31.17) 0.227 ms 0.210 ms 0.239 ms
3 dc-sdg-agpl-sdc-1.cenic.net (137.164.23.129) 0.360 ms 0.260 ms 0.240 ms
4 dc-riv-corel-sdg-agpl-10ge-2.cenic.net (137.164.47.14) 8.847 ms 8.497 ms 8.230 ms
5 dc-lax-corel-lax-core2-10ge-2.cenic.net (137.164.46.61) 9.869 ms 9.920 ms 9.846 ms
6 dc-lax-pal-lax-corel-10ge-2.cenic.net (137.164.46.191) 9.865 ms 9.729 ms 9.724 ms
7 hurricane--lax-pal-ge.cenic.net (198.32.251.86) 9.971 ms 14.981 ms 9.850 ms
8 10gigabitethernet3-4.corel.nyc4.he.net (72.52.91.225) 72.796 ms 80.278 ms 72.346 ms
9 10gigabitethernet3-4.corel.nyc5.he.net (194.105.213.213) 71.126 ms 71.442 ms 73.623 ms
10 lightower-fiber-networks.10gigabitethernet3-3.corel.nyc5.he.net (216.66.56.106) 70.824 ms 70.959 ms 71.072 ms
11 ae0.nycmyzrz91.lightower.net (72.22.160.156) 70.870 ms 71.089 ms 70.937 ms
12 72.22.188.102 (72.22.188.102) 71.242 ms 71.224 ms 71.102 ms
```
Traceroutes between San Diego Super Computer Center and www.poly.edu

a) The average (mean) of the round-trip delays at each of the three hours is 71.18 ms, 71.38 ms and 71.55 ms, respectively. The standard deviations are 0.075 ms, 0.21 ms, 0.05 ms, respectively.

b) In this example, the traceroutes have 12 routers in the path at each of the three hours. No, the paths didn’t change during any of the hours.

c) Not assigned
Traceroutes from www.stella-net.net (France) to www.poly.edu (USA).

d) The average round-trip delays at each of the three hours are 87.09 ms, 86.35 ms and 86.48 ms, respectively. The standard deviations are 0.53 ms, 0.18 ms, 0.23 ms, respectively. In this example, there are 11 routers in the path at each of the three hours. No, the paths didn’t change during any of the hours. Traceroute packets passed three ISP networks from source to
destination. Yes, in this experiment the largest delays occurred at peering interfaces between adjacent ISPs.

P24.
40 terabytes = 40 * 10^{12} * 8 bits. So, if using the dedicated link, it will take 40 * 10^{12} * 8 / (100 * 10^6) = 3200000 seconds = 37 days. But with FedEx overnight delivery, you can guarantee the data arrives in one day, and it should cost less than $100.

P25.
a) 160,000 bits
b) 160,000 bits
c) Not assigned
d) Not assigned
e) s/R

P28.
a) t_{trans} + t_{prop} = 400 msec + 80 msec = 480 msec.
b) 20 * (t_{trans} + 2 t_{prop}) = 20*(20 msec + 2 * 80 msec) = 3.6 sec.
Breaking up a file takes longer to transmit because each data packet and its corresponding acknowledgement packet add their own propagation delays.