HW#1 Solution

Problem 3

Consider an application that transmits data at a steady rate (for example, the sender g enerates an N-bit unit of data every k time units, where k is small and fixed). Also, when such an application starts, it will continue running for a relatively long period of time. Answer the following questions, briefly justifying your answer:

a. Would a packet-switched network or a circuit-switched network be more appropriate for this application? Why?
b. Suppose that a packet-switched network is used and the only traffic in this network comes from such applications as described above. Furthermore, assume that the sum of the application data rates is less than the capacities of each and every link. Is some form of congestion control needed? Why?

Answer

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 required by the application 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.

b) In the worst case, all the applications simultaneously transmit over one or more network links. However, since each link has sufficient bandwidth to handle the sum of all of the applications' data rates, no congestion (very little queuing) will occur. Given such generous link capacities, the network does not need congestion control mechanisms.

Problem 6

This elementary problem begins to explore 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 meter/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 $= d_{trans}$, 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}.

Answer:

a) $d_{prop} = m/s$ seconds.

b) $d_{trans} = L/R$ seconds.

c) $d_{end-to-end} = (m/s + L/R)$ seconds.

d) The last bit is just leaving Host A after being encoded into the corresponding signal element.

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

f) The first bit has reached Host B and is stored into the incoming buffer of Host B.

g) From d_{prop}=d_{trans}, we have

$m = \frac{L}{R} s = \frac{120}{56 \times 10^3} \left(2.5 \times 10^8\right) = 536$ km.

Problem 13

a. Suppose *N* packets arrive simultaneously to a link at which no packets are currently being transmitted or queued. Each packet is of length *L* and the link has transmission rate *R*. what is the average queuing delay for the *N* packets?

b. Now suppose that *N* such packets arrive to the link every *LN/R* seconds. What is the average queuing delay of a packet?

Answer:

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 queuing delay $d_{avg\_queuing}$ for the *N* packets is:

$d_{avg\_queuing}$ = (L/R + 2L/R + ... + (N-1)L/R)/N

= L/(RN) * (1 + 2 + ... + (N-1))

= L/(RN) * N(N-1)/2

= LN(N-1)/(2RN)

= (N-1)L/(2R)

Note that here we used the well-known fact: *1 + 2 + ... + N = N(N+1)/2*

b) It takes LN/R seconds to transmit the N packets. Thus, the buffer is empty when 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*.

Problem 16

Consider a router buffer preceding an outbound link. In this problem, you will use Little's formula, a famous formula from queuing theory. Let *N* denote the average number of packets in the buffer plus the packet being transmitted. Let *a* denote the rate of packets arriving at the link. Let *d* denote the average total delay (i.e., the queuing delay plus the transmission delay) experienced by a packet. Little's formula is *N*= *a***d*. Suppose that on average, the buffer contains 10 packets, and the average packet queuing delay is 10 msec. The link's transmission rate is 100 packet/sec. Using Little's formula, what is the average packet arrival rate, assuming there is no packet loss?

Answer:
The total number of packets in the system includes those in the buffer and the packet that is being transmitted. So, $N=10+1$. Because $N = a \cdot d$, so (10+1)=a*(queuing delay + transmission delay). That is, 11=a*(0.01+1/100)=a*(0.01+0.01). Thus, a=550 packets/sec.

Problem 18

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

a. Find the average and standard deviation of the round-trip delays at each of the three hours.
b. Find the number of routers in the path at each of the three hours. Did the paths change during any of the hours?
c. Try to identify the number of ISP networks that the Traceroute packets pass through from source to destination. Routers with similar names and/or similar IP addresses should be considered as part of the same ISP. In your experiments, do the largest delays occur at the peering interfaces between adjacent ISPs?
d. Repeat the above for a source and destination on different continents. Compare the intra-continent and inter-continent results.

Answer:
On linux, you can use the command `traceroute www.targethost.com` and in the Windows command prompt `tracert www.targethost.com`.

```
traceroute to www.poly.edu (128.238.24.40), 30 hops max, 40 byte packets
 1  thunder.sdsc.edu (132.249.20.5)  2.802 ms  0.645 ms  0.484 ms
 2  dolphin.sdsc.edu (132.249.31.17)  0.227 ms  0.248 ms  0.239 ms
 3  dc-sdg-agg1--sdsc-1.cenic.net (137.164.23.129)  0.360 ms  0.260 ms  0.240 ms
 4  dc-riv-core1--sdg-agg1-10ge-2.cenic.net (137.164.47.14)  8.847 ms  8.497 ms  8.230 ms
 5  dc-lax-core1--lax-core2-10ge-2.cenic.net (137.164.46.64)  9.969 ms  9.920 ms  9.846 ms
 6  dc-lax-px1--lax-core1-10ge-2.cenic.net (137.164.46.151)  9.845 ms  9.729 ms  9.724 ms
 7  hurricane--lax-px1-ge.cenic.net (198.32.251.86)  9.971 ms  16.981 ms  9.850 ms
 8  10gigabitethernet4-3.core1.nyc4.he.net (72.52.92.225)  72.796 ms  80.278 ms  72.346 ms
 9  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  71.126 ms  71.442 ms  73.623 ms
10  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  70.924 ms  70.959 ms  71.072 ms
11  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  70.870 ms  71.089 ms  70.957 ms
12  72.22.188.102 (72.22.188.102)  71.242 ms  71.228 ms  71.102 ms
```

```
traceroute to www.poly.edu (128.238.24.40), 30 hops max, 40 byte packets
 1  thunder.sdsc.edu (132.249.20.5)  0.478 ms  0.353 ms  0.308 ms
 2  dolphin.sdsc.edu (132.249.31.17)  0.212 ms  0.251 ms  0.238 ms
 3  dc-sdg-agg1--sdsc-1.cenic.net (137.164.23.129)  0.237 ms  0.246 ms  0.240 ms
 4  dc-riv-core1--sdg-agg1-10ge-2.cenic.net (137.164.47.14)  8.628 ms  8.348 ms  8.357 ms
 5  dc-lax-core1--lax-core2-10ge-2.cenic.net (137.164.46.64)  9.934 ms  9.963 ms  9.852 ms
 6  dc-lax-px1--lax-core1-10ge-2.cenic.net (137.164.46.151)  9.831 ms  9.814 ms  9.676 ms
 7  hurricane--lax-px1-ge.cenic.net (198.32.251.86)  10.194 ms  10.012 ms  16.722 ms
 8  10gigabitethernet4-3.core1.nyc4.he.net (72.52.92.225)  73.856 ms  73.196 ms  73.979 ms
 9  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  71.247 ms  71.199 ms  71.646 ms
10  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  70.987 ms  71.073 ms  70.985 ms
11  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  71.075 ms  71.042 ms  71.328 ms
12  72.22.188.102 (72.22.188.102)  71.626 ms  71.299 ms  72.236 ms
```

```
 1  thunder.sdsc.edu (132.249.20.5)  0.403 ms  0.347 ms  0.358 ms
 2  dolphin.sdsc.edu (132.249.31.17)  0.225 ms  0.244 ms  0.237 ms
 3  dc-sdg-agg1--sdsc-1.cenic.net (137.164.23.129)  0.362 ms  0.256 ms  0.239 ms
 4  dc-riv-core1--sdg-agg1-10ge-2.cenic.net (137.164.47.14)  8.850 ms  8.358 ms  8.227 ms
 5  dc-lax-core1--lax-core2-10ge-2.cenic.net (137.164.46.64)  10.096 ms  9.869 ms  10.351 ms
 6  dc-lax-px1--lax-core1-10ge-2.cenic.net (137.164.46.151)  9.721 ms  9.621 ms  9.725 ms
 7  hurricane--lax-px1-ge.cenic.net (198.32.251.86)  11.345 ms  10.048 ms  13.844 ms
 8  10gigabitethernet4-3.core1.nyc4.he.net (72.52.92.225)  71.920 ms  72.977 ms  77.264 ms
 9  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  71.273 ms  71.247 ms  71.291 ms
10  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  71.114 ms  82.516 ms  71.136 ms
11  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  71.232 ms  71.071 ms  71.039 ms
12  72.22.188.102 (72.22.188.102)  71.585 ms  71.608 ms  71.493 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) Traceroute packets passed through four ISP networks (sdsc.edu, cenic.net, he.net, and lightower.net) from source to destination. Yes, in this experiment the largest delays occurred at peering interfaces between adjacent ISPs, namely between cenic.net and he.net.

```
traceroute to www.poly.edu (128.238.24.40), 30 hops max, 60 byte packets
 1  62-193-36-1.stella-net.net (62.193.36.1)  0.500 ms  0.415 ms  0.440 ms
 2  62.193.33.29 (62.193.33.29)  0.910 ms  1.065 ms  1.026 ms
 3  bg1.stella-net.net (62.193.32.254)  0.972 ms  1.026 ms  1.078 ms
 4  62.193.32.66 (62.193.32.66)  1.021 ms  0.988 ms  0.947 ms
 5  10gigabitethernet-2-2.par2.he.net (195.42.144.104)  1.537 ms  1.752 ms  1.714 ms
 6  10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93)  80.273 ms  80.103 ms  79.971 ms
 7  10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85)  86.494 ms  85.872 ms  86.223 ms
 8  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  85.248 ms  85.424 ms  85.388 ms
 9  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  86.194 ms  85.864 ms  86.116 ms
10  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  85.796 ms  85.823 ms  85.766 ms
11  72.22.188.102 (72.22.188.102)  87.717 ms  86.817 ms  86.774 ms
```

```
traceroute to www.poly.edu (128.238.24.40), 30 hops max, 60 byte packets
 1  62-193-36-1.stella-net.net (62.193.36.1)  0.375 ms  0.397 ms  0.355 ms
 2  62.193.33.29 (62.193.33.29)  0.810 ms  0.877 ms  0.836 ms
 3  bg1.stella-net.net (62.193.32.254)  1.098 ms  0.991 ms  1.055 ms
 4  62.193.32.66 (62.193.32.66)  0.994 ms  0.960 ms  1.157 ms
 5  10gigabitethernet-2-2.par2.he.net (195.42.144.104)  1.679 ms  1.816 ms  1.768 ms
 6  10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93)  80.416 ms  90.573 ms  90.659 ms
 7  10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85)  85.933 ms  95.987 ms  96.087 ms
 8  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  90.268 ms  90.229 ms  90.030 ms
 9  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  85.833 ms  85.448 ms  85.418 ms
10  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  87.067 ms  86.025 ms  85.962 ms
11  72.22.188.102 (72.22.188.102)  86.542 ms  86.369 ms  86.170 ms
```

```
traceroute to 128.238.24.40 (128.238.24.40), 30 hops max, 60 byte packets
 1  62-193-36-1.stella-net.net (62.193.36.1)  0.396 ms  0.284 ms  0.239 ms
 2  62.193.33.29 (62.193.33.29)  0.817 ms  0.786 ms  0.848 ms
 3  bg1.stella-net.net (62.193.32.254)  1.150 ms  1.216 ms  1.265 ms
 4  62.193.32.66 (62.193.32.66)  1.002 ms  0.963 ms  0.923 ms
 5  10gigabitethernet-2-2.par2.he.net (195.42.144.104)  1.573 ms  1.534 ms  1.643 ms
 6  10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93)  88.738 ms  82.866 ms  82.783 ms
 7  10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85)  94.888 ms  90.936 ms  90.877 ms
 8  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  90.498 ms  90.543 ms  90.482 ms
 9  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  85.716 ms  85.408 ms  85.637 ms
10  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  85.779 ms  85.290 ms  85.252 ms
11  72.22.188.102 (72.22.188.102)  86.217 ms  86.652 ms  86.588 ms
```

Traceroutes from www.stella-net.net (France) to www.poly.edu (USA).

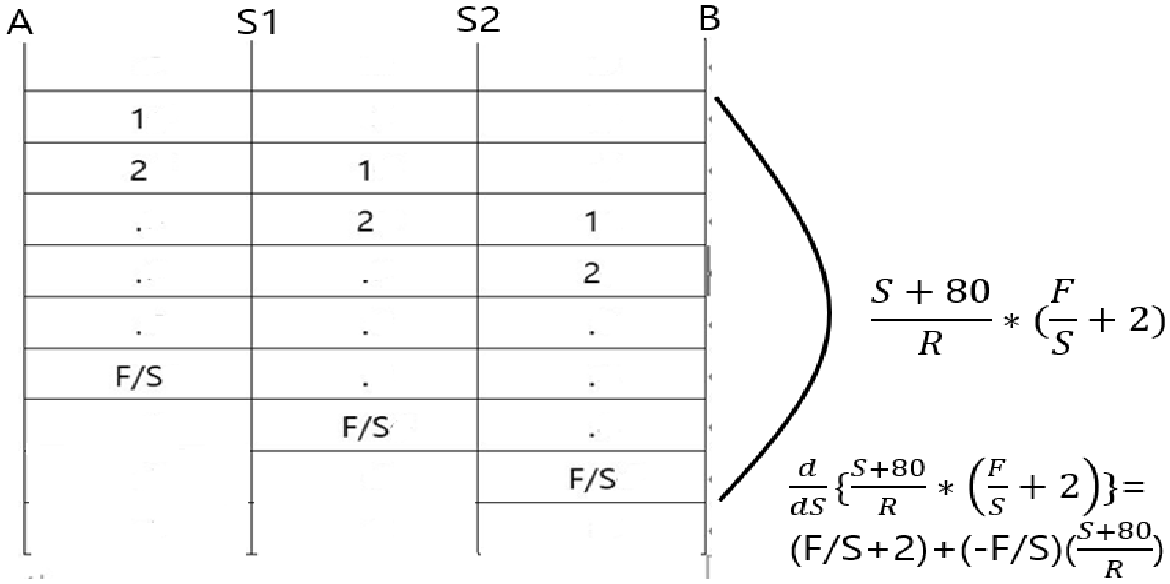
d) The average round-trip delays at each of the three hours are 87.09 ms, 86.35 ms and 86.48 ms, respectively. The standard deviations are 0.53 ms, 0.18 ms, 0.23 ms, respectively. In this example, there are 11 routers in the path at each of the three hours. No, the paths didn't change during any of the hours. Traceroute packets passed three ISP networks (stella-net.net, he.net, and lighttower.net) from source to destination. No, in this experiment the largest delays did not occur at peering interfaces between adjacent ISPs but over a link inside he.net.

Problem 33

Consider sending a large file of F bits from Host A to Host B. There are three links (and two switches) between A and B, and the links are uncongested (that is, no queuing delays). Host A segments the file into segments of S bits each and adds 80 bits of header to each segment, forming packets of L = 80 + S bits. Each link has a transmission rate of R bps. Find the value of S that minimizes the delay of moving the file from Host A to B. Disregard propagation delay.

Answer:

There are ceil(F/S) (or (F+S-1)/S for round-up) packets to deliver since the number of packets is an integer. But for the sake of convenience of computation, we use F/S since the answer for the packet size of minimizing the delay does not change. Each packet's size is S+80 bits. Time at which the last packet is received at the first router is $\frac{S+80}{R} \times \frac{F}{S}$ sec. For graphical explanation, please look at the below time-distance diagram to see how each packet arrives at each node A, S1, S2, B. At this time, the first F/S-2 packets are at the destination, and the (F/S-1)-th packet is at the second router. The last packet must then be transmitted by the first router and the second router, with each transmission taking $\frac{S+80}{R}$ sec. Thus delay in sending the whole file is $delay = \frac{S+80}{R} \times (\frac{F}{S} + 2)$. To calculate the value of S which leads to the minimum delay, we need to get S value to satisfy $\frac{d}{dS} delay = 0 \Rightarrow S = \sqrt{40F}$



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