Networks HW1

Shane Cincotta

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1 Chapter 1, Problem 5

a. Suppose the caravan travels 150 km, beginning in front of one tollbooth, passing through a second tollbooth, and finishing just after a third tollbooth. What is the end-to-end delay?

Propagation delay = $\frac{Distance}{Speed}$ = 1.5 hours

Transmission delay = $\frac{BoothTime}{Car} * Cars * Booths = 12 * 10 * 3 = 6$ minutes

Processing delay = 0 seconds

End-to-end delay = N(Processing Delay + Propagation Delay + Transmission Delay) = 0 + 90 minutes + 6 minutes = 96 minutes

b. Repeat (a), now assuming that there are eight cars in the caravan instead of ten.

New Transmission delay = $96 * 3$ seconds = 4 mins 48 seconds

End-to-end delay = N(Processing Delay + Propagation Delay + New Transmission Delay) = 0 + 90 minutes + 4 minutes 48 seconds = 94 minutes 48 seconds

2 Chapter 1, Problem 6

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.

$d_{prop} = \frac{Distance}{Speed} = m/s$

b. Determine the transmission time, d_{trans}, of the packet, in terms of L and R.

$d_{trans} = \frac{Size}{Rate} = \frac{L}{R}$

c. Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.

End-to-end delay = $d_{trans} + d_{prop} = \frac{L}{R} + \frac{m}{s}$ seconds

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?

At $t = d_{trans}$, the last bit of the packet is transmitted/pushed onto the link. It is just leaving Host A.

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

At $t = d_{trans}$, the first bit is in the link but has not reached Host B.

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

At $t = d_{trans}$, the first bit of the packet has reached Host B.

g. Suppose s $= 2.5 * 10^8, L = 120$ bits, and $R = 56$ kbps. Find the distance m so that $d_{prop} = d_{trans}$

$m = \frac{L}{R} * s = \frac{120}{56*10^3}(2.5 * 10^8) = 535.714$ km

3 Chapter 1, Problem 8

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?

Max users $= \frac{3Mbps}{120Kbps} = 20$ users.

b. For the remainder of this problem, suppose packet switching is used. Find the probability that a given user is transmitting.

Transmission rate per user = 10 percent. Thus the probability of transmission of a packet by a user is 0.1.

c. Suppose there are 120 users. Find the probability that at any given time, exactly n users are transmitting simultaneously.

Total users (N) = 120.

Number of users transmitting = n.

X = Binom(N = 120, p = 0.1)

P(X=N) $= C_n^N(p)^n(1-p)^{N-n}$

$= C_n^{120}(p)^n(1-p)^{120-n}$

$= C_n^{120}(0.1)^n(0.9)^{120-n}$

d. Find the probability that there are 21 or more users transmitting simultaneously.

P(X=N) $= C_n^{120}(0.1)^n(0.9)^{120-n}$

P(X$\geq$21) = 1-P(X$\leq$20)

$= 1 - \sum_{n=0}^{20}$ P(X=x)

$= 1 - \sum_{n=0}^{20} C_n^{120} (0.1)^n (0.9)^{120-n}$

$= 0.992059$

4 Chapter 1, Problem 9

a. What is N, the maximum number of users that can be supported simultaneously under circuit switching?

Total transmission rate = 1Gbps.

Data generation rate per user = 100 Kbps.

Max possible users = 1Gbps/100Kbps = 10000.

b. Now consider packet switching and a user population of M users. Give a formula (in terms of p, M, N) for the probability that more than N users are sending data.

Total users = M.

Users transmitting = N.

Probability, P, of data generation per user = 0.1.

Probability that more than N users are transmitting = $\sum_{n=N+1}^{M} M_c p^n (1-p)^{M-n}$

5 Chapter 1, Problem 10

Consider a packet of length L that begins at end system A and travels over three links to a destination end system. These three links are connected by two packet switches. Let d_i, s_i, and 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?

End-to-end delay = $\frac{L}{R_1} + \frac{d_1}{s_1} + d_{proc}(s_1) + \frac{L}{R_2} + \frac{d_2}{s_2} + d_{proc}(s_2) + \frac{L}{R_3} + \frac{d_3}{s_3}$

b. Suppose now the packet is 1,500 bytes, the propagation speed on all three links is 2.510^8 m/s, the transmission rates of all three links are 2 Mbps, the packet switch processing delay is 3 msec, the length of the first link is 5,000 km, the length of the second link is 4,000 km, and the length of the last link is 1,000 km. For these values, what is the end-to-end delay?

End-to-end delay = $\frac{L}{R_1} + \frac{d_1}{s_1} + d_{proc}(s_1) + \frac{L}{R_2} + \frac{d_2}{s_2} + d_{proc}(s_2) + \frac{L}{R_3} + \frac{d_3}{s_3}$

$d_{proc} = 0.003$ seconds.

$L/R_1 = \frac{1500*8}{2*10^6} = 0.006$ seconds.

$\frac{d1}{s1} = \frac{5000*10^3}{2.5*10^8} = 0.02$ seconds.

$\frac{L}{R_2} = \frac{1500*8}{2*10^6} = 0.006$ seconds.

$\frac{d_2}{s_2} = \frac{4000*10^3}{2.5*10^8} = 0.016$ seconds.

$\frac{L}{R_3} = \frac{1500*8}{2.5*10^6} = 0.006$ seconds.

$\frac{d_3}{s_3} = \frac{1000*10^3}{2.5*10^8} = 0.004$ seconds.

End-to-end delay $= 0.006 + 0.02 + 0.003 + 0.006 + 0.016 + 0.003 + 0.006 + 0.004 = 0.064$ seconds.

6 Chapter 1, Problem 13

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.

a. What is the average queuing delay for the N packets?

The queuing delay for the first packet is 0 because it's first in the queue. The queuing delay for the second packet is L/R, the third packet is 2L/R ... $\frac{(N-1)L}{R}$. Thus the average queuing delay is $\frac{\frac{L}{R}+\frac{2L}{R}+\ldots\frac{(N-1)L}{R}}{N} =$

$= \frac{L(N-1)}{2R}$

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

The queue is filled when a batch of N packets arrive. Thus the average delay of a packet in a batch is equal to the average delay of a packet in all the batches.

Average queuing delay $= \frac{1}{N}\sum_{k=0}^{N}\frac{L(N-1)}{R}$

$= \frac{L}{R} * \frac{1}{N}\sum_{k=0}^{N-1} N$

$= \frac{L}{R} * \frac{1}{N}\sum_{k=0}^{N-1}\frac{N(N-1)}{2}$

$= \frac{L(N-1)}{2R}$

7 Chapter 1, 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.

Hour 1 Intra-continental 11:30 AM

Router Num	Address of the Router	Round-trip delay1	Round-trip delay2	Round-trip delay3
1	192.168.1.1	1.962	1.780	2.121
2	100.41.23.86	7.159	3.931	4.920
3	140.222.1.61	7.661	9.079	7.361
4	152.179.72.42	9.315	9.937	8.237
5	129.250.6.116	11.664	9.215	9.546
6	129.250.3.85	12.301	11.388	11.656
7	129.250.2.87	31.887	31.010	31.702
8	129.250.3.142	35.843	35.062	33.262
9	129.250.3.41	38.004	35.754	37.186
10	157.238.179.114	34.601	35.849	32.709
11	66.216.1.27	38.018	37.254	36.374

Average = 19.807

Standard deviation = 13.859

Hour 2 Intra-continental 1:18 PM

Router Num	Address of the Router	Round-trip delay1	Round-trip delay2	Round-trip delay3
1	192.168.1.1	1.987	1.878	1.765
2	100.41.23.84	6.952	6.333	6.033
3	140.222.1.61	8.570	8.227	7.370
4	152.179.72.42	9.459	9.758	8.963
5	129.250.6.116	21.366	20.149	12.320
6	129.250.3.85	11.690	11.095	11.238
7	129.250.2.87	35.441	36.068	35.402
8	129.250.3.142	32.395	43.954	31.420
9	129.250.3.41	37.255	36.524	36.702
10	157.238.179.114	37.472	36.401	39.470
11	66.216.1.27	39.271	38.893	38.916

Average = 21.840

Standard deviation = 14.521

Hour 3 Intra-continental 3:20 PM

Router Num	Address of the Router	Round-trip delay1	Round-trip delay2	Round-trip delay3
1	192.168.1.1	2.015	5.268	2.329
2	100.41.23.86	6.570	3.928	4.844
3	140.222.1.61	8.554	8.767	8.680
4	152.179.72.42	10.020	9.602	8.756
5	129.250.6.116	15.521	18.819	16.899
6	129.250.3.85	12.073	13.425	11.236
7	129.250.2.87	34.844	48.204	36.617
8	129.250.3.142	41.994	36.975	39.745
9	129.250.3.41	41.280	38.441	42.049
10	157.238.179.114	35.028	36.015	33.852
11	66.216.1.27	37.857	38.830	36.929

Average = 22.605

Standard deviation = 15.173

b. Find the number of routers in the path at each of the three hours. Did the paths change during any of the hours?

The number of routers remains constant at 11, however, some of the IP addresses change.

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?

During the first hour, there appeared to be 6 ISP networks.

During the second hour, there appeared to be 6 ISP networks.

During the third hour, there appeared to be 6 ISP networks.

In almost all of my experiments, the largest delays occur at peering interfaces between adjacent ISPs.

d. Repeat the above for a source and destination on different continents. Compare the Intra-continental and inter-continent results.

The other continent used was Europe.

Hour 1 Inter-continental 11:30 AM

Router Num	Address of the Router	Round-trip delay1	Round-trip delay2	Round-trip delay3
1	192.168.1.1	2.508	1.763	1.725
2	100.41.23.84	9.809	13.874	6.421
3	140.222.234.107	7.601	6.705	7.105

Average = 6.390

Standard deviation = 3.771
Hour 2 Inter-continental 1:55 PM

Router Num	Address of the Router	Round-trip delay1	Round-trip delay2	Round-trip delay3
1	192.168.1.1	1.982	1.820	1.812
2	100.41.23.84	9.156	4.240	4.231
3	140.222.3.85	11.686	11.602	10.473

Average = 6.334

Standard deviation = 4.083
Hour 3 Inter-continental 3:30 PM

Router Num	Address of the Router	Round-trip delay1	Round-trip delay2	Round-trip delay3
1	192.168.1.1	2.302	2.394	3.800
2	100.41.23.84	8.000	5.406	4.389
3	140.222.234.105	9.528	8.046	24.871

Average = 7.637

Standard deviation = 6.558

During the first hour, there appeared to be 3 ISP networks.

During the second hour, there appeared to be 3 ISP networks.

During the third hour, there appeared to be 3 ISP networks.

In almost all of my experiments, the largest delays occur at peering interfaces between adjacent ISPs.

By comparing the round-trip delays between inter-continental travel are greater than that of intra-continental travel.

8 Chapter 1, Problem 24

Suppose you would like to urgently deliver 40 terabytes data from Boston to Los Angeles. You have available a 100 Mbps dedicated link for data transfer. Would you prefer to transmit the data via this link or instead use FedEx over-night delivery? Explain.

40 TB $= 3.2 * 10^8$ bits.

$\frac{3.2*10^8}{100} = 3.2 * 10^6$ seconds.

$\frac{3.2*10^6}{60*60*24} = 37$ days.

Given the fact that it would take over 37 days to transmit the data via the dedicated link, I think I would just overnight the HDDs.

9 Chapter 1, Problem 25

Suppose two hosts, A and B, are separated by 20,000 kilometers and are connected by a direct link of R=2 Mbps. Suppose the propagation speed over the link is $2.5 * 10^8$ meters/sec.

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

$d_{prop} = \frac{D}{S} = \frac{2*10^7}{2.5*10^8} = 0.08$ seconds.

$R * d_{prop} = 2 * 10^6 * 0.08 = 160,000$ bits.

b. Consider sending a file of 800,000 bits from Host A to Host B. Suppose the file is sent continuously as one large message. What is the maximum number of bits that will be in the link at any given time?

The bandwidth-delay product is the product of a data link's capacity. Thus the maximum number of bits that will be in the system is the value calculated in a. (160 Kb).

c. Provide an interpretation of the bandwidth-delay product.

As stated above, in data communications, the bandwidth-delay product is the product of a data link's capacity and its round-trip delay time.

d. What is the width (in meters) of a bit in the link? Is it longer than a football field?

Length of 1 bit = $\frac{S}{R}$ where S is the value of d_{prop} as calculated in a, and R is the transmission rate.

$\frac{S}{R} = \frac{2.5*10^8}{2*10^6} = 125$ meter/bit.

Thus the length of a bit is longer than a football field.

e. Derive a general expression for the width of a bit in terms of the propagation speed s, the transmission rate R, and the length of the link m.

The width of a bit is independent of the link length. The expression is equal to the ratio of propagation speed and transmission rate. That is, width = $\frac{S}{R}$.

10 Chapter 1, Problem 26

Referring to problem P25, suppose we can modify R. For what value of R is the width of a bit as long as the length of the link?

The width of a bit is independent of link length, it is dependent on the propagation speed and the transmission rate ($m = \frac{S}{R}$).

Rearrange terms to solve for R, $R = \frac{S}{m}$

$= \frac{2.5*10^8}{2*10^7} = 12.5$ bps.

11 Chapter 1, Problem 31

Consider a message that is $8 * 10^6$ bits long that is to be sent from source to destination. 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?

Without segmentation, the packet size (p_s) is equal to the message size (8000) Kbits. The transmission time (T_l) = $\frac{p_s}{R} = \frac{8000}{2000} = 4$ seconds.

The total time, T, required to transmit from source to destination = number of links$*T_l$.

Thus T = $3 * 4 = 12$ seconds.

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?

$p_s = 10$ Kbits

$T_l = \frac{p_s}{R} = \frac{10}{2000} = 5$ msec.

The second packet is completely received by the first switch when the first packet is completely received by the second switch. That is, the time required for the first packet to reach the second switch is equal to the time required for the second packet to reach the first switch.

Total time, T, required to transmit the first packet to the second switch = number of hops * $T_l = 2 * 5 = 10$ msec.

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.

Total time, T, required to transmit the first packet to the destination = number of hops $*T_l = 3 * 5 =$ 15 msec.

After the first packet arrives at the destination, another packet (total of 799) will arrive every 5 msec. Thus the total time = 15 msec + 799 * 5 msec = 4.01 seconds.

d. In addition to reducing delay, what are reasons to use message segmentation?

If a packet is lost, only the lost packet will be sent, reducing the time needed to restart sending the message.

Also, each packet has the possibility of taking different paths, thus the transmission time of a particular network will not be saturated as easily.

e. Discuss the drawbacks of message segmentation.

When the packets arrive at the destination, they need to be reassembled. This takes processing power and time.

The size of a message header increases as the number of packets increase. This leads to higher overhead and a need for more bandwidth.

If just one packet is lost, the whole message needs to be resent.