Computer Networks and the Internet

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1 Design and describe an application-level protocol to be used between an ATM and a bank's centralized computer. It should allow a user's card and password to be verified, the account balance to be queried, and an account withdrawal to be made.

ATM: [$card_number, $password]
COMP: ["APPROVED", $account_balance, $code] or ["REJECTED"]

if ("APPROVED" and $withdraw_requested and $amount ≤ $balance):
ATM: [$code, $amount]

2 Generalize the formula for end-to-end delay for sending P packets of length L over N links of transmission rate R.

The first packet reaches the destination at time $N * L/R$, and each subsequent packet adds an additional L/R delay. The Pth packet therefore reaches the destination at time $N * L/R + (P - 1) * L/R$ or $(N + P - 1) * L/R$.

3 Consider an application that transmits data at a steady rate and once started, continues for a long time.

3.0.1 Would a packet-switched network or a circuit-switched network be more appropriate for this application? Why?

One of the usual downsides of using a circuit-switched network, the wasted resources during silent periods, doesn't apply since the data is transmitted at a steady rate. Another, the inital costs of establishing the connection, is amortized over the long runtime. If the amount of bandwidth reserved for the application is proportionate to the data transmission rate, a circuit-switched network is more appropriate.

3.1 Suppose that a packet-switched network is used and the only traffic comes from the application. 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?

No. Congestion control is only needed if the total data rate exceeds the capacity of at least one of the links.

4 Consider the given circuit-switched network with four switches and four circuits on each link.

4.1 What is the maximum number of simultaneous connections that can be in progress at any one time in this network?

Sixteen. If each switch is connected only to adjacent switches, each link represents exactly one connection,

4.2 Suppose that all connections are between switches A and C. What is the maximum number of simultaneous connections that can be in progress?

Eight. Each connection requires two links, either A-B-C or A-D-C.

4.3 Suppose we want four connections between A and C and another four between B and D. Is that possible?

Yes. It will be a perfectly symmetrical system where each set of four links between two nodes has two links connecting A and C and the other two connecting B and D.

5 Review the car-caravan analogy and assume a propagation speed of 100 km/hour.

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

The tollbooth can service one car every twelve seconds, so it takes ten cars two minutes to pass through each tollbooth. The first car can't pass through the second tollbooth until the last has arrived, so the delay between the last car being serviced by the first tollbooth and the first car passing through the second tollbooth is equal to the time it takes for the last car to drive the 75 kilometers between them. Therefore, the total delay equals T(ten cars through booth #1) + T(one car drives 75 km) + T(ten cars through booth #2) + T(one car drives 75 km) + T(ten cars through booth #3). The time through each tollbooth is two minutes and the time for a car to drive 75 kilometers is 45 minutes, so the total is 2+45+2+45+2 = 96 minutes.

5.2 Now assume there are eight cars in the caravan instead of ten. What is the end-to-end delay?

The only difference is that the time through each tollbooth is 96 seconds instead of two minutes. This reduces the total time by 72 seconds to 94 minutes and 48 seconds.

6 Consider two hosts, A and B, connected by a single link of rate R bps. Suppose the two hosts are m meters apart and the propagation speed along the link is s meters/second. Host A sends an L bit packet to Host B.

6.1 Express the propagation delay in terms of m and s.

$d_{prop} = m/s$

6.2 Determine the transmission time of the packet in terms of L and R.

$d_{trans} = L/R$

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

$d_{total} = d_{prop} + d_{trans}$

6.4 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?

The last bit has just left Host A.

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

Somewhere between Host A and Host B.

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

It has arrived at Host B.

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

$m = 5.36 * 10^5$ meters or 536 kilometers

7 Host A converts analog voice to a digital 64 kbps bit stream, groups the bits into 56-byte packets, and sends them to Host B over a link with a transmission rate of 2 Mbps and a propagation delay of 10 msec. How much time elapses from the time a bit is created at Host A until it is decoded at Host B?

Before the first bit can be created, enough data for a 56 byte packet must be gathered. A 56 byte packet has $56 * 8 = 448$ bits, and the analog voice is converted to a stream with a data density of 64 kbps. $448/64,000 = .007$

seconds, or 7 milliseconds. The transmission time of a 448 bit packet on a link with a transmission rate of 2 Mbps is 448/2000000 = .000224 seconds, 2.24 milliseconds. The propagation delay is 10 milliseconds. The sum, or total delay, is $7 + .224 + 10 = 17.224$ milliseconds.

8 Suppose users share a 3 Mbps link and that each user requires 150 kbps when transmitting, but only transmits 10% of the time.

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

$(3 * 10^6)/(150 * 10^3) = 20$

8.2 For the remainder, suppose packet switching is used. Find the probability that a given user is transmitting.

10%

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

Probability(n users transmitting when there are 120 users)
$P(x = n, 120, .1) = \binom{120}{n}(.1)^k(1 - .1)^{120-n}$
$P(x = n, 120, .1) = \frac{120!}{n!(120-n)!}(.1)^n(.9)^{120-n}$

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

$P(x >= 21, 120, .1) = 1 - P(x < 21, 120, .1)$
$P(x >= 21, 120, .1) = 1 - \sum_{n=0}^{20} \frac{120!}{n!(120-n)!}(.1)^n(.9)^{120-n}$
$P(x >= 21, 120, .1) = 0.00794$

9 Suppose that users are generating data at a rate of 100 kbps when busy, but only busy 10% of the time, and that they are using a 1 Gbps link.

9.1 What is the maximum number of users that can be supported simultaneously under circuit switching?

1 Gbps = 10^9 bps, 100 kbps = 10^5 bps. $10^9/10^5 = 10^4 = 10,000$ users

9.2 Give a formula for the probability that more than N out of M users are sending data.

$P(x > N, M, p) = 1 - P(x <= N, M, p)$
$P(x > N, M, p) = 1 - \sum_{n=0}^{N} \frac{M!}{n!(M-n)!} p^n (1-p)^{M-n}$

10 Consider a packet of length L that begins at end system A and travels over three links to a destination end system with two packet switches in between. Let d_i, s_i, R_i denote the length, propagation speed, and transmission rate of each link $i \in 1, 2, 3$. The packet switches delay each packet by d_proc.

10.1 Assuming no queuing delays, what is the total end-to-end delay for the packet?

The total delay is the sum of the transmission delay and propagation delay on each of the three links plus the sum of the processing delay at each of the two packet switches.
$L/R_1 + L/R_2 + L/R_3 + d_1/s_1 + d_2/s_2 + d_3/s_3 + 2d_{proc}$

10.2 Suppose the packet is 1,500 bytes, the propagation speed on all three links is $2.5 * 10^8$ 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?

Transmission delay, converting bytes to bits and seconds to milliseconds:
$L/R = (1500 * 8)/(2 * 10^6) * 10^3 = 6$ milliseconds

Propagation delay, converting kilometers to meters and seconds to milliseconds:
$d_1/s_1 = (5000 * 10^3)/(2.5 * 10^8 * 10^3) = 20$ milliseconds
$d_2/s_2 = (4000 * 10^3)/(2.5 * 10^8 * 10^3) = 16$ milliseconds
$d_3/s_3 = (1000 * 10^3)/(2.5 * 10^8 * 10^3) = 4$ milliseconds

$L/R_1 + L/R_2 + L/R_3 + d_1/s_1 + d_2/s_2 + d_3/s_3 + 2d_{proc}$
$3 * 6 + 20 + 16 + 4 + 2 * 3$
64 milliseconds

11 Repeat the previous problem for $R1 = R2 = R3 = R$, $d_{proc} = 0$, and supposing that the packet switches don't store-and-forward packets but instead immediately transmit each bit.

Only the first node causes a transmission delay, the the propagation delay is the same, and there is no processing delay.

Transmission delay: $(1500 * 8)/(2 * 10^6) * 10^3 = 6$ milliseconds
Propagation delay: $(5000 * 10^3)/(2.5 * 10^8 * 10^3) + (4000 * 10^3)/(2.5 * 10^8 * 10^3) + (1000 * 10^3)/(2.5 * 10^8 * 10^3) = 40$ milliseconds

Total delay: 46 milliseconds

12 Consider a packet switch that receives packets that are all 1,500 bytes and whose link rate is 2 Mbps.

12.1 When a packet arrives at a packet switch, one other packet is halfway done being transmitted on the same outbound link and four other packets are waiting to be transmitted. If the packets are transmitted in the same order they are received, what is the queuing delay for the arriving packet?

The queuing delay is the delay for a single packet, converting bytes to bits and seconds to milliseconds, times the four and a half packets ahead of the arriving one.
$4.5 * ((1500 * 8)/(2 * 10^6)) * 10^3 = 27$ milliseconds

12.2 More generally, what is the queuing delay when all packets have length L, the transmission rate is R, x bits of the currently-being-transmitted packet have been transmitted, and n packets are already in the queue?

$(n * L + (L - x))/R$

13

13.1 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?

$(N - 1)/2 * L/R$

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

Since it takes N packets NL/R seconds to be transmitted, there is no buildup of they arrive at a rate of N packets every LN/R seconds. If the packets arrive in bursts of N batches at a time, the answer is the same as the one to the previous question: $(N - 1)/2 * L/R$.

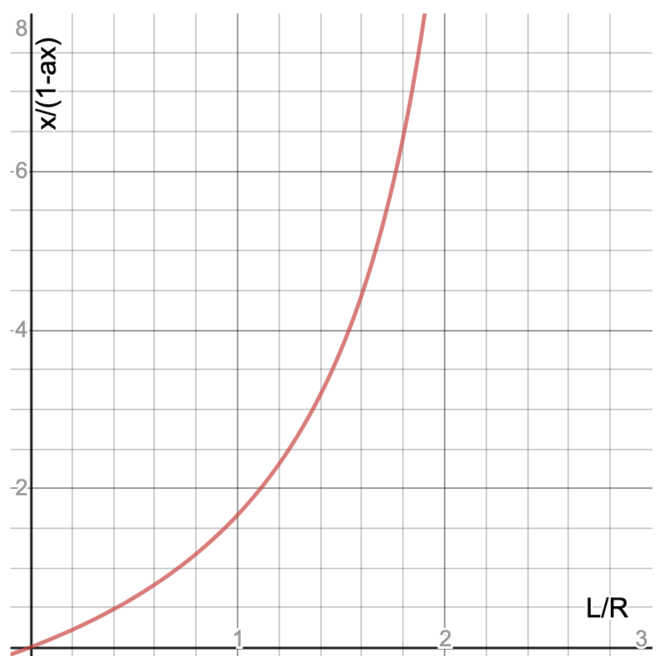
14 Consider the queuing delay in a router buffer. Let I denote traffic intensity such that $I = La/R$. Suppose the queuing delay takes the form $IL/(R(1-I))$ for $I < 1$.

14.1 Provide a formula for the total delay, that is, the queuing delay plus the transmission delay.

Queuing delay: $IL/(R(1-I))$
Transmission delay: L/R
Total delay: $L/R + IL/(R(1-I)) = (L - IL + IL)/(R(1-I)) = L/(R(1-I))$

14.2 Plot the total delay as a function of L/R.

Let $x = L/R$. Since $I = La/R$, the total delay is $L/(R(1-(La/R)) = (L/R)/(1 - a * L/R) = x/(1-ax)$. Since $0 < I < 1$, $0 < xa < 1$. The slope varies based on the value of a, starting at 1 when $a = 0$ and quickly approaching infinity as a grows larger. Pictured is $a = 0.4$.



15 Let a denote the rate of packets arriving at a link in packets per second, and let μ denote the link's transmission rate in packets per second. Based on the formula for the total delay, derive a formula for the total delay in terms of a and μ.

The total delay equals the queuing delay plus the transmission delay, which is the multiplicative inverse of the transmission rate, or R/L. This gives $\mu = R/L$.
$L/(R(1-I)) \quad I = La/R \quad \mu = R/L$
$(L/R)/(1-a(L/R)) = (1/\mu)/(1-a/\mu)$
$1/(\mu - a)$

16 Consider a router buffer preceding an outbound link. 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, queuing plus transmission, experienced by a packet. Use Little's formula: $N = a * d$ to calculate the average packet arrival rate, assuming no packet loss, when the buffer contains an average of 10 packets, the link's transmission rate is 100 packets per second, and the average packet queuing delay is 10 msec.

If there are an average of 10 packets in the buffer at a time, $N = 11$ to include the packet being transmitted. The average packet queuing delay is 10 milliseconds and if the transmission rate is 100 packets per second, each packet is delayed by .01 seconds during transmission, or 10 milliseconds. Applying Little's formula, $11 = a(10 + 10)$, $a = 11/20 = .55$ packets per millisecond, which equals 550 packets per second.

17

17.1 Generalize $d_{end-end} = N(d_{proc} + d_{trans} + d_{prop})$ for heterogenous processing rates, transmission rates, and propagation delays.

$d_{end-to-end} = \sum_{i=1}^{N}(d_{proc}(i) + d_{trans}(i) + d_{prop}(i))$

17.2 Repeat with the assumption that there is an average queuing delay of d_{queue} at each node.

$d_{end-to-end} = \sum_{i=1}^{N}(d_{proc}(i) + d_{trans}(i) + d_{prop}(i) + d_{queue}(i))$

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

18.1 Find the average and standard deviation of the round-trip delays at each of the three hours.

Of the three traceroutes from Luxembourg to my address in Turkey, none made it all the way here. Each time, at least one attempt made it to my province within around 63 milliseconds.

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

At 8am and 1pm, the traceroutes noted eight routers before they lost track. The one at 3:30pm was slightly different, with two hops in Brussels and one in Vienna instead of the other way around and it only noted two hops in Antalya instead of the three in the other two.

18.3 Try to identify the number of ISP networks that the Traceroute packets pass through from source to destination. Do the largest delays occur at the peering interfaces between adjacent ISPs?

I count five ISP networks in each traceroute, and the largest delays do seem to be when the packets move between ISP networks, not when they move within them.

18.4 Repeat the above for a source and destination on different continents. Compare the intra-continent and inter-continent results.

Again, the traceroutes were unable to track the entire route. There was slightly more variation between total times, which is to be expected since the total time was almost five times as long. Surprisingly, the routes were even more similar than the ones from the closer source. Each passed through six ISP networks, but some of the largest jumps occurred within ISP networks. I chose Brazil, which is a practically continent sized country, so it may not be that surprising that one ISP networked spanned so much territory.

19

19.1 Use traceroute.org to perform traceroutes from two different cities in France to the same destination host in the United States. How many links are the same in the two traceroutes? Is the transatlantic link the same?

The two routes converge before leaving France and the last four links are the same.

19.2 Repeat, but choose once city in France and another city in Germany.

These also seem to converge before leaving Europe.

19.3 Pick a city in the United States and perform traceroutes to two hosts, each in a different city in China. How many links are in common in the two traceroutes? Do the two traceroutes diverge before reaching China?

Oddly, one seemed to send the packet across the Pacific, the other across the Atlantic. Clearly, they diverged quickly, after only two hops.

20 **Consider the throughput example and suppose that there are M client-server pairs. Denote R_s, R_c, and R for the rates of server links, client links, and network link. Assume all other links have abundant capacity and that there is no other traffic in the network. Derive a general expression for throughput in terms of R_s, R_c, R, and M.**

Throughput $= min\{R_s, R_c, R/M\}$

21 **Now suppose there are M paths between the server and the client. No two paths share any link. Each path k consists of N links with transmission rates $R1_k, R2_k, ..., RN_k$. If the server can only use one path to send data to the client, what is the maximum throughput the server can achieve? If the server can use all M paths to send data, what is the maximum throughput the server can achieve?**

Let $T_k = min\{R1_k, R2_k, ...R3_k\}$. Then if the server can only use one path, its maximum throughput is $max\{T_1, T_2, ...T_M\}$. If it can use all of the paths, its maximum throughput is $\sum_{k=1}^{M} T_k$.

22 Suppose that each link between the server and the client has a packet loss probability p and the packet loss probabilities for these links are independent. What is the probability that a packet sent by the server is successfully received by the receiver? If a packet is lost, the server will re-transmit the packet. On average, how many times will the server re-transmit the packet in order for the client to successfully receive it?

The probability of a sent packet being received after passing through N links with a probability p of being lost at each one is $(1-p)^N$. On average, the packet will need to be sent $1/(1-p)^N$ times for it to be received, so it will need to be re-transmitted $1/(1-p)^N - 1$ times.

23 Assume that the bottleneck link along the path from a server to a client is the first link with rate R_s bits per second. Suppose a pair of packets are sent back to back from the server to a client and that there is no other traffic on this path. Assume each packet has L bits and both links have propagation delay d_{prop}.

23.1 How much time elapses from when the last bit of the first packet arrives until the last bit of the second packet arrives?

L/R_s

23.2 Now assume that the second link is the bottleneck. Is it possible that the second packet queues at the input queue of the second link?

Yes. The time for the first packet to leave the router is $L/R_s + d_{prop} + L/R_c$. The time for the second packet to arrive at the router is $2 * L/R_s + d_{prop}$. Since

$L/R_c > L/R_s$, the second packet will arrive at the router before the first has left.

23.3 Suppose the server sends the second packet T seconds after sending the first packet. How large must T be to ensure no queuing before the second link?

T must be large enough to make up the difference between L/R_c and L/R_s, so $T \geq L/R_c - L/R_s$.

24 Suppose you need 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 for over-night delivery.

$40TB * \frac{10^{12}\ bytes}{TB} * \frac{8\ bits}{byte} * \frac{1Mb}{10^6\ bits} * \frac{1\ sec}{100\ Mb} * \frac{1\ hour}{3600\ sec} * \frac{1\ day}{24\ hours} = 37$ days.
Clearly, FedEx wins.

25 Suppose Host A and Host 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 per second.

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

$d_{prop} = 20,000\ km * \frac{1000\ m}{km} * \frac{1\ sec}{2.5*10^8\ m} = .08$ seconds
$R * d_{prop} = 2\ Mbps * .08\ seconds = .16$ Mb, or 160,000 bits

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

160,000

25.3 Provide an interpretation of the bandwidth-delay product.

The bandwidth-delay product is a measurement of the size of a link in terms of how many bits it can hold. The fatter and longer the link, the higher the bandwidth-delay product.

25.4 What is the width in meters of a bit in the link? Is it longer than a football field?

20,000 km/160,000 bits = 125 meters, which is longer than a football field

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

s/R The width of a bit, or meters per bit, is the inverse of the bandwidth-delay product, whose units are bits per meter.

26 Refer to P25. For what value of R is the width of a bit as long as the length of the link?

To make $s/R = m$, where m is the length of the link,
$R = s/m = \frac{2.5*10^8\ m}{sec} * \frac{km}{1000\ m} * \frac{1\ bit}{20{,}000\ km} = 12.5$ bits per second.

27 Refer to P25. Let $R = 1$ Gbps.

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

As before, $d_{prop} = .08$ seconds.
$R * d_{prop} = 1\ Gbps * .08\ sec = .08$ Gb, or 80,000,000 bits

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

800,000 if the file is the only traffic on the link, 80,000,000 otherwise.

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

20,000km/80,000,000 bits = .25 meters

28 Refer to P25.

28.1 How long does it take to send the file, assuming it is sent continuously?

Transmission delay: $800,000\ bits\ * \frac{Mb}{10^6\ bits} * \frac{1\ sec}{2\ Mb} = .4$ seconds
Propagation delay: $20,000\ km * \frac{1000\ m}{km} * \frac{sec}{2.5*10^8\ m} = .08$ seconds
Total delay: $.4 + .08 = .48$ seconds or 480 milliseconds

28.2 Suppose the file is broken up into 20 packets of 40,000 bits and that each packet can only be sent after the previous one is received. How long does it take to send the file?

Transmission delay: $40,000\ bits\ * \frac{Mb}{10^6\ bits} * \frac{1\ sec}{2\ Mb} = .02$ seconds
Propagation delay: .08 seconds
Total delay: $20 * (.02 + .08) = 2$ seconds

28.3 Compare the time to send the entire file at once versus breaking it up.

Breaking the file up and sending it in pieces takes over four times as long as sending it all at once.

29 Suppose there is a 10 Mbps microwave link between a geostationary satellite and its base station on Earth. Every minute the satellite takes a digital photo and sends it to the base station. Assume a propagation speed of $2.4 * 10^8$ meters per second.

29.1 What is the propagation delay of the link?

Geostationary satellites orbit at 36,000 kilometers above the Earth's surface, so the propagation delay is $36,000\ km\ * \frac{1000\ m}{km} * \frac{sec}{2.4*10^8\ m} = .15$ seconds or 150 milliseconds

29.2 What is the bandwidth-delay product, $R * d_{prop}$?

$\frac{10\ Mb}{sec} * .15\ sec = 1.5$ Mb, or 1,500,000 bits

29.3 Let x denote the size of the photo. What is the minimum value of x for the microwave link to be continuously transmitting?

$\frac{10\ Mb}{sec} * \frac{60\ sec}{min} = 600$ Mb or 600,000,000 bits

30 Consider the airline travel analogy of layering and the addition of headers to protocol data units as they flow down the protocol stack. Is there an equivalent notion of header information that is added to passengers and baggage as they move down the airline protocol stack?

Yes, passengers receive boarding passes and baggage is tagged.

31 Consider the process of message segmentation and a message that is $8 * 10^6$ bits long sent on a series of 2 Mbps links, ignoring propagation, queuing, and processing delays.

31.1 Consider sending the message without message segmentation. How long does it take to move the message from the source host to the first packet switch? What is the total time to move the message from source host to destination when each switch uses store-and-forward packet switching?

Transmission delay: $8 * 10^6\ bits * \frac{1\ Mb}{10^6\ bits} * \frac{sec}{2\ Mb} = 4$ seconds
From the source host to the first packet switch takes 4 seconds. To get all the way to the destination host with two packet switches in between takes $4 * 3 = 12$ seconds.

31.2 Now suppose the message is segmented into 800 packets, with each packet 10,000 bits long. How long does it take to move the first packet from the source host to the first switch? At what time will the second packet be fully received at the first switch?

Transmission delay: $10,000\ bits * \frac{1\ Mb}{10^6\ bits} * \frac{sec}{2\ Mb} = .005$ seconds, or 5 milliseconds
It takes 5 milliseconds for the first packet to get to the first switch, and 5 more, or 10 total, for the second packet to be fully received.

31.3 How long does it take to move the file from the source host to the destination host when message segmentation is used? Compare this to the time required without message segmentation.

The first packet takes 15 milliseconds, the second an additional 5 milliseconds, the third an additional 5 and so on. The nth packet takes $15 + 5 * (n - 1)$ milliseconds. Since there are 800 packets, the 800th packet will arrive after $15 + 5 * (799) = 4010$ milliseconds, or 4.01 seconds. This is almost three times faster than sending the file monolithically.

31.4 In addition to reducing delay, what are the reasons to use message segmentation?

If there is an error, only a few packets will need to be resent instead of the entire file. Also, on a packet switched network, other packets will be able to slip through instead of waiting for the entire file to be sent, which is a more fair policy.

31.5 Discuss the drawbacks of message segmentation.

There is more overhead in splitting up the message and reassembling it, both in time and in data. Each smaller packet needs its own headers, as well as information about how it fits into the larger file.

32 Experiment with the Message Segmentation applet. Do the delays in the applet correspond with the delays in the previous problem? How do link propagation delays affect the overall end-to-end delay for packet switching with message segmentation and for message switching?

Yes. Queuing and processing delays are not included, only the transmission delay and (optionally) a propagation delay. Even the maximum propagation delay is relatively small compared to the transmission delay. Propagation delays slow down message segmented packet switched links as much as message switched links in absolute terms, although they affect message switched links less as a percentage because those links are already slower.

33 Consider sending a large file of F bits from Host A to Host B. There are three links between A and B, and the links are uncongested. Host A segments the file into segments of S bits each and adds 80 bits of header to each segment. 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 Host B.

Number of packets: F/S
Size of each packet: $S + 80$
Delay of each packet at each link: $D = (S + 80)/R$
Total delay for nth packet: $3 * D + D(n - 1)$
Total delay for last packet, F/S: $3 * D + D(F/S - 1)$

Total delay:
$3 * D + D(F/S - 1)$
$3 * (S + 80)/R + ((S + 80)/R)(F/S - 1)$
$(3S + 240 + (S + 80)(F/S - 1))/R$
$(3S + 240 + F + 80F/S - S - 80)/R$
$(2S + 80F/S + F + 160)/R$

Take the derivative with respect to S:
$((2S + 80F/S + F + 160)/R)dS$
$2 - 80F/S^2$

Set it equal to zero and solve for S to find critical point:
$2 - 80F/S^2 = 0$
$2 = 80F/S^2$
$S^2 = 40F$
$S = \sqrt{40F}$

34 Skype allows you to make a phone call from a PC to an ordinary phone. This means that the voice call must pass through both the Internet and through a telephone network. Discuss how this might be done.

This requires establishing some sort of connection between ordinary phone lines and the internet as well as converting an analog voice stream to digital packets and vice versa. Since Skype is offering this service, they must have established themselves at the intersection, possibly in a similar way to how Google established their own content provider network, linking in to local ISPs, except with telephone networks.