2025 Computer Networks
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Chapter 1 Problems

Problem 08. 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. (See the discussion of packet switching versus circuit switching in **Section 1.3** .)

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

$$\frac{3\times10^{6}\ \text{bps}}{1.5\times10^{5}\ \text{bps}} = 20\ \text{users}.$$

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

$$p = 0.1$$

c. Suppose there are 120 users. Find the probability that at any given time, exactly *n* users are transmitting simultaneously. (*Hint*: Use the binomial distribution.)

$$_{120}C_{n}\cdot(0.1)^{n}(0.9)^{120-n}$$

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

$$P(X\geq 21) = 1 - P(X\leq 20)$$
$$= 1 - \sum_{n=0}^{20} {}_{120}C_{n}\,(0.1)^{n}(0.9)^{120-n}$$
$$\simeq 0.008$$

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

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

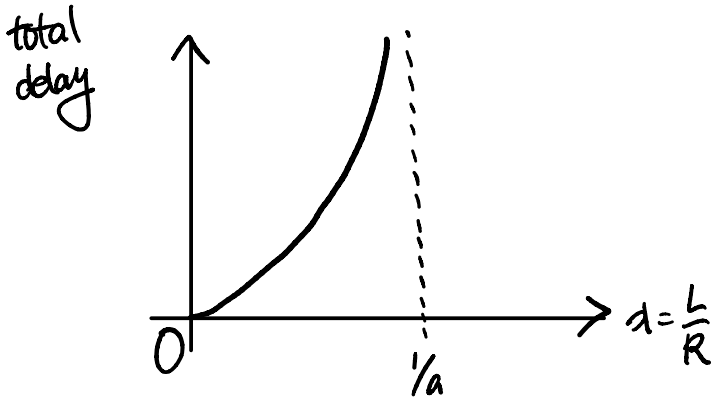
total delay = queuing delay + trans delay

$$= \frac{I \cdot L}{R(1-I)} + \frac{L}{R} = \frac{L}{R}\left(\frac{1}{1-I}\right)$$

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

$L/R = \lambda$, $I = a\lambda$

then total delay = $\frac{\lambda}{1-a\lambda}$



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.
[Answer]

1) Mean: 1.84ms, SD: 2.83ms

```
❯ traceroute naver.com
traceroute to naver.com (223.130.192.248), 30 hops max, 60 byte packets
 1  DESKTOP.mshome.net (172.17.144.1)  0.221 ms  0.207 ms  0.199 ms
 2  210.108.124.1 (210.108.124.1)  0.613 ms  0.799 ms *
 3  118.130.102.249 (118.130.102.249)  0.856 ms *  0.557 ms
 4  10.243.48.213 (10.243.48.213)  0.550 ms 10.243.48.209 (10.243.48.209)  0.544 ms  0.492 ms
 5  1.208.180.5 (1.208.180.5)  0.915 ms  0.908 ms 100.75.12.37 (100.75.12.37)  1.287 ms
 6  * * *
 7  61.43.224.62 (61.43.224.62)  1.484 ms 1.208.174.10 (1.208.174.10)  2.500 ms 1.208.174.90 (1.208.174.90)  1.269 ms
 8  61-111-40-250.kidc.net (61.111.40.250)  16.071 ms 61-111-34-174.kidc.net (61.111.34.174)  2.006 ms 61-111-61-66.kidc.net (61.111.61.66)  1.907 ms
 9  100.68.87.18 (100.68.87.18)  1.703 ms  1.726 ms 100.68.87.34 (100.68.87.34)  2.005 ms
10  211.233.33.14 (211.233.33.14)  1.827 ms  1.785 ms 211.233.33.10 (211.233.33.10)  2.036 ms
11  10.22.80.170 (10.22.80.170)  2.117 ms 10.22.80.166 (10.22.80.166)  2.570 ms 10.22.80.210 (10.22.80.210)  2.232 ms
12  * * *
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2) Mean: 2.63ms, SD: 3.19ms

```
❯ traceroute naver.com
traceroute to naver.com (223.130.200.236), 30 hops max, 60 byte packets
 1  DESKTOP.mshome.net (172.17.144.1)  0.155 ms  0.138 ms  0.128 ms
 2  210.108.124.1 (210.108.124.1)  0.824 ms  1.007 ms  0.620 ms
 3  118.130.102.249 (118.130.102.249)  0.992 ms  0.831 ms  0.736 ms
 4  10.243.48.213 (10.243.48.213)  0.554 ms  0.514 ms 10.243.48.209 (10.243.48.209)  0.507 ms
 5  1.213.143.9 (1.213.143.9)  14.672 ms 1.208.180.13 (1.208.180.13)  5.475 ms 1.208.180.5 (1.208.180.5)  5.449 ms
 6  1.213.114.165 (1.213.114.165)  1.376 ms 1.208.107.189 (1.208.107.189)  1.394 ms 1.213.114.165 (1.213.114.165)  1.383 ms
 7  1.213.153.14 (1.213.153.14)  1.343 ms 1.213.146.134 (1.213.146.134)  1.348 ms 1.213.153.14 (1.213.153.14)  1.301 ms
 8  182.162.152.114 (182.162.152.114)  1.304 ms 117.52.240.106 (117.52.240.106)  1.501 ms 117.52.240.118 (117.52.240.118)  1.459 ms
 9  117.52.1.154 (117.52.1.154)  12.333 ms  5.284 ms  5.233 ms
10  10.22.67.242 (10.22.67.242)  3.388 ms 10.22.67.254 (10.22.67.254)  2.847 ms 10.22.67.246 (10.22.67.246)  3.003 ms
11  10.118.1.82 (10.118.1.82)  3.027 ms 10.118.1.58 (10.118.1.58)  3.109 ms 10.118.1.118 (10.118.1.118)  3.614 ms
12  * * *
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3) Mean: 1.52ms, SD: 0.96ms

```
❯ traceroute naver.com
traceroute to naver.com (223.130.200.219), 30 hops max, 60 byte packets
 1  DESKTOP.mshome.net (172.17.144.1)  0.261 ms  0.268 ms  0.240 ms
 2  210.108.124.1 (210.108.124.1)  0.621 ms  0.843 ms  0.960 ms
 3  118.130.102.249 (118.130.102.249)  0.644 ms  1.052 ms  0.749 ms
 4  10.243.48.209 (10.243.48.209)  0.539 ms 10.243.48.213 (10.243.48.213)  0.658 ms  0.609 ms
 5  1.208.180.13 (1.208.180.13)  1.252 ms 1.208.180.9 (1.208.180.9)  1.194 ms 100.75.12.33 (100.75.12.33)  1.288 ms
 6  * * *
 7  1.213.147.130 (1.213.147.130)  1.277 ms 1.213.146.130 (1.213.146.130)  1.937 ms 1.208.104.22 (1.208.104.22)  2.006 ms
 8  117.52.240.174 (117.52.240.174)  1.430 ms 117.52.240.106 (117.52.240.106)  1.424 ms 182.162.152.126 (182.162.152.126)  1.418 ms
 9  211.233.33.6 (211.233.33.6)  2.166 ms 117.52.1.158 (117.52.1.158)  2.101 ms 117.52.1.154 (117.52.1.154)  2.107 ms
10  10.22.67.242 (10.22.67.242)  3.445 ms 10.22.67.254 (10.22.67.254)  2.787 ms 10.22.67.246 (10.22.67.246)  3.161 ms
11  10.118.1.146 (10.118.1.146)  2.984 ms 10.118.1.126 (10.118.1.126)  3.184 ms 10.118.1.82 (10.118.1.82)  3.116 ms
12  * * *
```

b. Find the number of routers in the path at each of the three hours. Did the paths change during any of the hours?
[Answer]
11 routers were in the path for all trials. Some routers send nothing to source. However, the specific path of each Traceroute execution is changed.

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?
[Answer]
I found three ISP during the hops. It was possible to observe a significant change in round-trip delay when the IP address changed significantly, that is, when IPS changed.

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

[Answer]

```
traceroute to google.com (142.250.207.46), 30 hops max, 60 byte packets
 1  DESKTOP.mshome.net (172.17.144.1)  0.259 ms  0.246 ms  0.239 ms
 2  210.108.124.1 (210.108.124.1)  2.671 ms  2.705 ms  2.644 ms
 3  118.130.102.249 (118.130.102.249)  0.622 ms  0.751 ms  0.905 ms
 4  10.243.48.213 (10.243.48.213)  0.559 ms 10.243.48.209 (10.243.48.209)  0.576 ms 10.243.48.213 (10.243.48.213)  0.550 ms
 5  1.208.180.13 (1.208.180.13)  1.060 ms 1.213.143.5 (1.213.143.5)  1.422 ms 1.208.180.5 (1.208.180.5)  1.064 ms
 6  1.213.115.73 (1.213.115.73)  1.255 ms anyg12br4-pos2-0.rt.bora.net (210.120.244.21)  1.222 ms 1.208.107.189 (1.208.107.189)  1.318 ms
 7  * * *
 8  100.65.51.5 (100.65.51.5)  6.306 ms 1.213.113.41 (1.213.113.41)  1.730 ms 1.208.114.5 (1.208.114.5)  2.072 ms
 9  61.42.202.94 (61.42.202.94)  33.239 ms 1.208.106.18 (1.208.106.18)  33.179 ms 61.43.235.130 (61.43.235.130)  54.164 ms
10  61.43.220.22 (61.43.220.22)  33.233 ms 203.233.45.98 (203.233.45.98)  32.887 ms 100.67.30.110 (100.67.30.110)  33.463 ms
11  142.250.168.244 (142.250.168.244)  76.473 ms  55.299 ms  55.280 ms
12  * * *
13  142.251.245.22 (142.251.245.22)  55.239 ms 66.249.95.128 (66.249.95.128)  33.318 ms 66.249.95.170 (66.249.95.170)  33.933 ms
14  172.253.69.246 (172.253.69.246)  33.944 ms 74.125.245.4 (74.125.245.4)  69.795 ms  68.985 ms
15  209.85.250.119 (209.85.250.119)  56.545 ms  56.813 ms 209.85.142.203 (209.85.142.203)  35.022 ms
16  142.251.66.223 (142.251.66.223)  75.245 ms * *
17  142.250.213.103 (142.250.213.103)  77.544 ms  98.302 ms  77.272 ms
18  209.85.244.36 (209.85.244.36)  98.482 ms 72.14.234.66 (72.14.234.66)  96.972 ms 142.251.254.136 (142.251.254.136)  97.969 ms
19  142.251.252.95 (142.251.252.95)  76.517 ms 192.178.86.165 (192.178.86.165)  76.764 ms 108.170.248.189 (108.170.248.189)  76.936 ms
20  142.250.62.47 (142.250.62.47)  99.180 ms 216.239.57.163 (216.239.57.163)  76.449 ms 142.250.62.47 (142.250.62.47)  98.370 ms
21  nrt13s55-in-f14.1e100.net (142.250.207.46)  75.977 ms  75.480 ms  75.712 ms
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traceroute to google.com (172.217.31.174), 30 hops max, 60 byte packets
 1  DESKTOP.mshome.net (172.17.144.1)  0.170 ms  0.154 ms  0.147 ms
 2  210.108.124.1 (210.108.124.1)  0.567 ms  0.880 ms  0.734 ms
 3  118.130.102.249 (118.130.102.249)  1.560 ms  0.566 ms  0.682 ms
 4  10.243.48.213 (10.243.48.213)  0.471 ms  0.444 ms 10.243.48.209 (10.243.48.209)  0.540 ms
 5  1.213.143.13 (1.213.143.13)  0.597 ms 1.208.180.13 (1.208.180.13)  0.722 ms 1.208.180.5 (1.208.180.5)  0.693 ms
 6  * * *
 7  1.208.144.177 (1.208.144.177)  1.027 ms 1.213.112.137 (1.213.112.137)  1.658 ms 100.65.16.9 (100.65.16.9)  1.470 ms
 8  1.208.150.253 (1.208.150.253)  1.435 ms * *
 9  100.67.30.2 (100.67.30.2)  33.267 ms 100.67.30.38 (100.67.30.38)  54.060 ms 61.42.202.94 (61.42.202.94)  33.432 ms
10  210.107.126.38 (210.107.126.38)  33.632 ms 61.42.0.26 (61.42.0.26)  55.569 ms  55.564 ms
11  142.250.168.244 (142.250.168.244)  55.559 ms  55.272 ms  76.577 ms
12  * * *
13  74.125.253.92 (74.125.253.92)  33.668 ms 216.239.43.60 (216.239.43.60)  54.922 ms 66.249.95.128 (66.249.95.128)  54.632 ms
14  142.251.240.102 (142.251.240.102)  54.788 ms 172.253.69.246 (172.253.69.246)  34.030 ms 142.250.59.28 (142.250.59.28)  55.087 ms
15  216.239.35.151 (216.239.35.151)  34.224 ms 209.85.142.26 (209.85.142.26)  33.933 ms 74.125.251.3 (74.125.251.3)  33.932 ms
16  142.251.49.205 (142.251.49.205)  74.574 ms * 142.251.66.223 (142.251.66.223)  96.718 ms
17  * 142.250.213.15 (142.250.213.15)  77.485 ms 142.250.226.151 (142.250.226.151)  97.763 ms
18  142.251.254.82 (142.251.254.82)  117.709 ms 209.85.249.240 (209.85.249.240)  118.645 ms 209.85.246.82 (209.85.246.82)  99.825 ms
19  108.170.252.9 (108.170.252.9)  118.076 ms 108.170.241.109 (108.170.241.109)  97.621 ms  97.704 ms
20  209.85.253.109 (209.85.253.109)  97.979 ms 209.85.248.113 (209.85.248.113)  77.302 ms  76.907 ms
21  nrt12s22-in-f14.1e100.net (172.217.31.174)  97.567 ms  76.640 ms  76.469 ms
```

```
traceroute to google.com (172.217.175.110), 30 hops max, 60 byte packets
 1  DESKTOP.mshome.net (172.17.144.1)  0.264 ms  0.251 ms  0.245 ms
 2  210.108.124.1 (210.108.124.1)  0.834 ms  0.670 ms  0.972 ms
 3  118.130.102.249 (118.130.102.249)  0.581 ms  0.995 ms  0.686 ms
 4  10.243.48.213 (10.243.48.213)  0.506 ms  0.515 ms  0.493 ms
 5  1.213.143.1 (1.213.143.1)  1.846 ms 1.213.143.13 (1.213.143.13)  0.767 ms 1.208.180.5 (1.208.180.5)  3.858 ms
 6  1.213.115.73 (1.213.115.73)  1.293 ms  1.125 ms 1.213.107.97 (1.213.107.97)  0.976 ms
 7  * * *
 8  100.66.52.5 (100.66.52.5)  1.615 ms 1.213.113.5 (1.213.113.5)  3.728 ms 100.65.51.5 (100.65.51.5)  2.089 ms
 9  1.208.113.78 (1.208.113.78)  54.433 ms 61.42.202.94 (61.42.202.94)  33.246 ms 1.208.113.78 (1.208.113.78)  54.404 ms
10  203.233.45.98 (203.233.45.98)  32.992 ms 1.208.179.94 (1.208.179.94)  33.188 ms  33.182 ms
11  142.250.168.244 (142.250.168.244)  76.926 ms  55.090 ms  76.913 ms
12  * * *
13  108.170.233.30 (108.170.233.30)  33.514 ms 66.249.94.222 (66.249.94.222)  33.896 ms 72.14.234.198 (72.14.234.198)  54.574 ms
14  172.253.69.246 (172.253.69.246)  33.736 ms  34.003 ms  33.430 ms
15  74.125.251.11 (74.125.251.11)  56.307 ms 74.125.251.3 (74.125.251.3)  54.618 ms 216.239.62.165 (216.239.62.165)  55.338 ms
16  142.251.49.205 (142.251.49.205)  74.793 ms 74.125.37.11 (74.125.37.11)  74.884 ms 142.251.66.223 (142.251.66.223)  75.670 ms
17  142.250.213.103 (142.250.213.103)  77.249 ms  98.214 ms 142.250.213.15 (142.250.213.15)  77.558 ms
18  142.251.254.82 (142.251.254.82)  98.663 ms 209.85.246.82 (209.85.246.82)  121.150 ms 209.85.249.240 (209.85.249.240)  120.187 ms
19  108.170.248.191 (108.170.248.191)  76.701 ms 192.178.86.57 (192.178.86.57)  77.516 ms 142.251.252.95 (142.251.252.95)  76.390 ms
20  108.170.233.191 (108.170.233.191)  97.817 ms  77.385 ms 108.170.235.103 (108.170.235.103)  76.728 ms
21  nrt20s21-in-f14.1e100.net (172.217.175.110)  75.244 ms  76.155 ms  75.882 ms
```

Number of routers: 21, but 2 routers send nothing.

Mean: 42.33421052631579, 41.72894736842105, 39.54468421052631

SD: 36.73835388796919, 40.66046548822699, 35.261463789261555

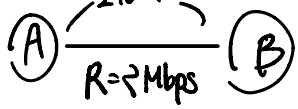
Compared to intra-continent, it can be seen that in the case of an inter-continent connection, the number of routers passing through is large, and the delay occurs very large in a specific section. It is estimated that it is a point of change in ISP or a section using an undersea cable.

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 $2.5 \cdot 10^8$ meters/sec.

a. Calculate the bandwidth-delay product R·dprop.

$R = 2 \cdot 10^6$ bps, $d_{prop} = d/s = 2 \cdot 10^4 / 2.5 \cdot 10^8 = \frac{2 \cdot 10^{11}}{2.5 \cdot 10^8} = \frac{2}{2.5 \times 10}$ sec

$R \cdot d_{prop} = 2 \cdot 10^6 \times \frac{2}{2.5 \times 10} = \frac{4 \cdot 10^5}{2.5} = 160000$ 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?

160000 bits

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

bandwidth = data link capacity. bit/sec
x
delay = round-trip delay time. sec
||
product = max amount of data on the network circuit at any given time.

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

width of a bit = m/bit ... $\frac{2.5 \times 10^8 \text{ m/s}}{2 \times 10^6 \text{ bit/s}} = 125$ meter/bit

width of a bit (125m) > football field (110m)

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.

width of a bit = $\frac{m}{R \cdot d_{prop}} = \frac{s}{R}$

Problem 31. In modern packet-switched networks, including the Internet, the source host segments long, application-layer messages (for example, an image or a music file) into smaller packets and sends the packets into the network. The receiver then reassembles the packets back into the original message. We refer to this process as *message segmentation*. **Figure 1.27** illustrates the end-to-end transport of a message with and without message segmentation. Consider a message that is $8 \cdot 10^6$ bits long that is to be sent from source to destination in **Figure 1.27** .

Suppose each link in the figure is 2 Mbps. Ignore propagation, queuing, and processing delays.

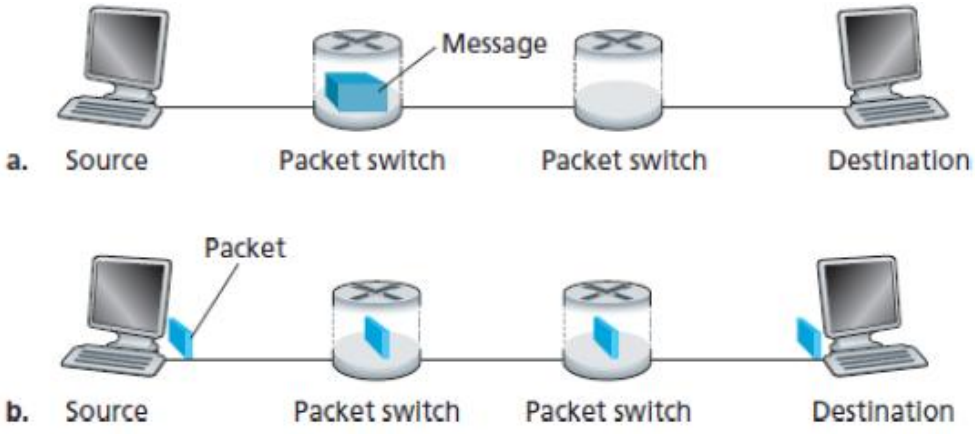


Figure 1.27 End-to-end message transport: (a) without message segmentation; (b) with message segmentation

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?

$\frac{8 \times 10^6 \text{ bits}}{2 \cdot 10^6 \text{ bps}} = 4 \text{ sec}$ (src → 1st swith)

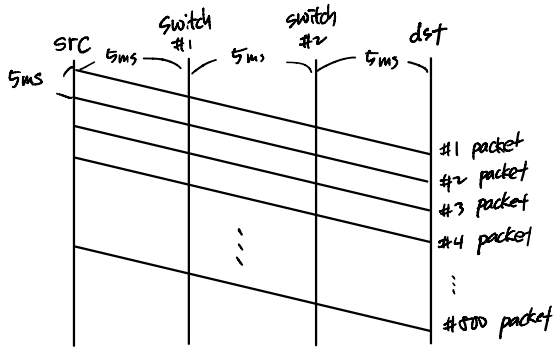
$4 \text{ sec} \times 3 = 12 \text{ sec}$ (src → dst)

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?

$\frac{10^4 \text{ bits}}{2 \cdot 10^6 \text{ bps}} = 0.005 \text{ sec}$ (1st packet src → 1st switch)
5ms

0.005 sec + 0.005 sec = 0.01 sec (2nd packet src → 1st switch)
1st packet to switch; 2nd packet to switch; 10ms

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.



transmission delay = 5ms + 5ms + 5ms = 15ms

time to move whole file
= total time for #800 packet to arrive at dst
= 15ms + 5ms × (800 − 1) = 7.01 sec ≪ 12 sec (non-seg)
∴ message segmentation is (efficient / fast) method to transfer data.

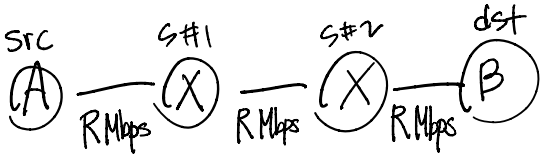
d. In addition to reducing delay, what are reasons to use message segmentation?

Using message segmentation can achieve error control and job scheduling for data transferring with reliability and efficiency.

e. Discuss the drawbacks of message segmentation.

The packets can be lost / delayed during transmission process.
The sequence of packet arrival is unordered
these can increase cost for retransmission and reassembly.

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 Host B. Disregard propagation delay.



F bits into S+80 bits packets, $S \neq 0$

$\frac{S+80}{R} \times 3$ sec per a packet (src → dst) $R \neq 0$

F/S packets in total

$$f = \frac{S+80}{R} \times 3 + \frac{S+80}{R}\left(\frac{F}{S}-1\right) = \frac{S+80}{R}\left(2+\frac{F}{S}\right)$$

$$f' = \frac{d}{dS}\left(\frac{S+80}{R}\left(2+\frac{F}{S}\right)\right) = \frac{1}{R}\left(2+\frac{F}{S}\right) + \frac{S+80}{R}\left(-\frac{F}{S^2}\right) = 0$$

$$\frac{1}{R}\left(2+\frac{F}{S}\right) = \frac{S+80}{R}\left(\frac{F}{S^2}\right),$$

$$\frac{F}{S}\left(2\frac{S}{F}+1\right) = \frac{F}{S}\left(\frac{1}{S}\right)(S+80)$$

$$\frac{2S}{F}+1 = 1+\frac{80}{S}$$

$$2S^2 = 80F$$

$$\therefore S = \sqrt{40F}$$