$= 3000$ kbps

P8. 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? $\dfrac{3000 \text{ kbps}}{150 \text{ kbps/user}} = 20$ users

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

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

c. $X \sim \text{Binomial}(120, 0.1)$

$$P(X=n) = \binom{120}{n} (0.1)^n (0.9)^{120-n}$$

d. $$P(X \geq 21) = 1 - P(X \leq 20)$$
$$= 1 - \sum_{n=0}^{20} \binom{120}{n} p^n (1-p)^{120-n}$$

$p = 0.1$

$\mu = 120 \times 0.1 = 12$

$\sigma^2 = 120 \times 0.1 \times (1-0.1)$

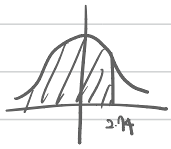
$= 120 \times 0.1 \times 0.9$

$= 10.8$

$\sigma = \sqrt{10.8} \approx 3.28$.

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

$Z = \dfrac{X-\mu}{\sigma} = \dfrac{21-12}{3.28} = \dfrac{9}{3.28} \approx 2.74$



$P(X \leq 20) \approx P(Z \leq 2.74)$.

$P(X \geq 21) = 1 - P(Z \leq 2.74)$

$= 1 - 0.997$

$= 0.003$

$\therefore 0.003$, 0.3%

P14. 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.

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

a. queuing delay $= \frac{IL}{R(1-L)}$

Transmission delay $= \frac{L}{R}$

$\rightarrow$ total delay $= \frac{IL}{R(1-I)} + \frac{L}{R} = \frac{L}{R}\left(\frac{I}{1-I}+1\right)$

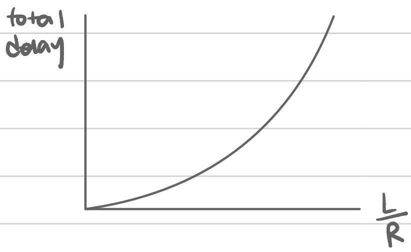
$= \frac{L}{R}\left(\frac{\cancel{I}+1-\cancel{I}}{1-I}\right) = \frac{L}{R}\left(\frac{1}{1-I}\right)$

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

b. total delay $= \frac{L}{R} \cdot \frac{1}{1-\frac{La}{R}}$

$\frac{L}{R} = x \rightarrow \frac{x}{1-ax}$

x approches $\frac{1}{a}$



P18. Perform a Traceroute between source and destination on the same continent at three different hours of the day.

VideoNote

Using Traceroute to discover network paths and measure network delay

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.

```
:\Users\easy1>tracert www.targethost.com

대 30홉 이상의
ww.targethost.com [104.21.80.1](으)로 가는 경로 추적:

 1   209 ms     3 ms     1 ms  10.50.35.254
 2     *        *        *     요청 시간이 만료되었습니다.
 3     6 ms     2 ms     1 ms  10.1.0.2
 4     5 ms     3 ms     6 ms  203.246.85.254
 5     3 ms     3 ms     8 ms  115.92.253.185
 6     2 ms     2 ms     3 ms  10.243.48.181
 7    33 ms    11 ms    13 ms  1.208.180.5
 8     *       14 ms    10 ms  1.208.107.189
 9     *        *        *     요청 시간이 만료되었습니다.
10     7 ms     4 ms     5 ms  1.208.165.9
11    38 ms    39 ms    38 ms  61.43.235.130
12    60 ms    60 ms    81 ms  100.67.30.98
13    40 ms    44 ms    79 ms  13335.hkg.equinix.com [36.255.56.48]
14    40 ms    43 ms    41 ms  103.22.203.71
15    40 ms    40 ms    40 ms  104.21.80.1

적을 완료했습니다.
```

a. $\text{Mean} = \dfrac{209+3+1+6+2+1+5+3+6+3+3+8+2+2+3+33+11+13+7+4+5+38+39+38+60+60+81+40+44+79+40+43+41+40+40+40}{36}$

$= 29.25$ ms

Standard deviation 38.17 ms

b. total hops : 15

c. four and more ISPs were involved.

Major ISPs

- Domestic 203.246.85.254, 115.92.253.185
- International 61.43.235.130
- Equinix data center (Hong kong)
- cloud flare (104.21.80.1. Final destination)

Significant delay increase after Hop 7

Notable RTT rise at Hop 12 .

Equinix data center Hop 13 stabilizes the RTT

RTT increase significantly at ISP peering points

The most significant delays occur at international ISP handovers, which is expected in cross - border connection.

d. Intra - Continent traceroute

- Hop count : 5-10
- Average RTT : 20-30 ms
- Peering delays : minimal

Inter Continent Traceroute.

(Korea → Hong kong → USA)

Hop count 15

Average RTT : 40-80ms

Peering delays : Significant at internation ISP transitions (Hop 7, 12)

P25. 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 2.5·108 meters/sec.

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

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?

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

d. What is the width (in meters) of a bit in the link? Is it 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*.

$m = 20000 \times 10^3 m = 2.0 \times 10^7$

$R = 2Mbps = 2 \times 10^6 bps$

$s = 2.5 \times 10^8 \ m/sec$

a. $d_{prop} = \frac{m}{s} = \frac{2.0 \times 10^{\cancel{7}}}{2.5 \times 10^{\cancel{8}}} = \frac{4}{5} \times \frac{1}{10} = \frac{8}{100} = 0.08 \ sec$

$R \cdot d_{prop} = 2 \times 10^6 \times 0.08 = 160000$ bits

b. 160,000 bits

c. The bandwidth-delay product represents the maximum number of bits can be transit within the link

d. Bit width $= \frac{s}{R} = \frac{2.5 \times 10^8 \ m/s}{2 \times 10^6 \ bps} = 125$ meters.

one bit in this link is longer than football field.

e. $\frac{s}{R}$

P31. 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 8·106 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.

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?

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?

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.

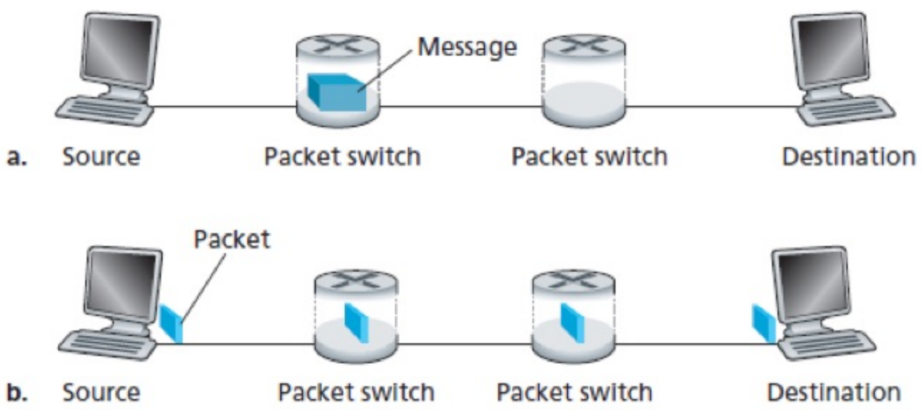


Figure 1.27 End-to-end message transport: (a) without message segmentation; (b) with message segmentation

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

e. Discuss the drawbacks of message segmentation.

a. Transmission time $= \dfrac{\text{Message size}}{\text{Transmission Rate}} = \dfrac{8 \times 10^6 \text{ bits.}}{2 \times 10^6 \text{ bps}}$

$= 4$ sec

source → 1st switch → 2nd Switch → destination

4 4 4

4sec × 3 = 12sec

∴ 12 seconds

b. Transmission time per packet $= \dfrac{\text{Packet size}}{\text{Transmission Rate}} = \dfrac{10000 \text{ bits}}{2 \times 10^6 \text{ bps}} = \dfrac{1}{200} = 0.005$

$0.005 \times 2 = 0.01$

∴ 0.01 seconds

c. first packet to reach the destination : $3 \times 0.005 = 0.015$

time for last packet to arrive : $(800 - 1) \times 0.05 = 3.995$

$3.995 + 0.015 = 4.01$.sec

d. for efficient error handling

for better network resource management.

e. Since packets may arrive out of order, the destination must sort and reassemble them correctly.

Each packet includes a header, and segmenting a message into many packets means more total header bytes reducing useful data transmission efficiency.

P33. 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.

Transmission time per link $= \frac{L}{R} = \frac{S+80}{R}$

file has F/s packets → total delay $\frac{F}{S} \times \frac{S+80}{R} \times 3 = \frac{3F(S+80)}{SR}$.

$\frac{F}{S} \times \frac{S+80}{R}$ at this time first packet arrived at destination

$\frac{F}{S}-1$th packet arrived at Second Router

Last packet arrived at first Router

last packet should go to first router → Second router → destination so

$\frac{S+80}{R} \times 2$

so whole file delay is $\frac{S+80}{R} \times \left(\frac{F}{S}+2\right)$

to calculate the value of S. which leads to the minimum delay,

$\frac{d}{dS}\left(\frac{S+80}{R} \times \left(\frac{F}{S}+2\right)\right) = 0$

$\frac{F}{R} \times \left(\frac{S+80}{S}\right)$

$\frac{F}{R} \times \left(0 - \frac{80}{S^2}\right) = -\frac{80F}{S^2R}$ $\qquad \frac{d}{dS}\left(\frac{2S}{R}\right) = \frac{2}{R}$

$-\frac{80F}{S^2R} + \frac{2}{R} = 0$ $\qquad -\frac{80F}{S^2} + 2 = 0$ $\qquad S^2 = 40F$ $\qquad S = \sqrt{40F}$