

P1

- of length  $L$  over  $N$  links of transmission rate  $R$  by sending  $P$  such packets back-to-back over the  $N$  links.
- P3. Consider an application that transmits data at a steady rate (for example, the sender generates 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:
- Would a packet-switched network or a circuit-switched network be more appropriate for this application? Why?
  - 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?

P6

- P6. 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  $s$  meters/sec. Host A is to send a packet of size  $L$  bits to Host B.
- Express the propagation delay,  $d_{\text{prop}}$ , in terms of  $m$  and  $s$ .
  - Determine the transmission time of the packet,  $d_{\text{trans}}$ , in terms of  $L$  and  $R$ .
  - Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.
  - Suppose Host A begins to transmit the packet at time  $t = 0$ . At time  $t = d_{\text{trans}}$ , where is the last bit of the packet?
  - Suppose  $d_{\text{prop}}$  is greater than  $d_{\text{trans}}$ . At time  $t = d_{\text{trans}}$ , where is the first bit of the packet?
  - Suppose  $d_{\text{prop}}$  is less than  $d_{\text{trans}}$ . At time  $t = d_{\text{trans}}$ , where is the first bit of the packet?
  - Suppose  $s = 2.5 \cdot 10^8$ ,  $L = 120$  bits, and  $R = 56$  kbps. Find the distance  $m$  so that  $d_{\text{prop}}$  equals  $d_{\text{trans}}$ .

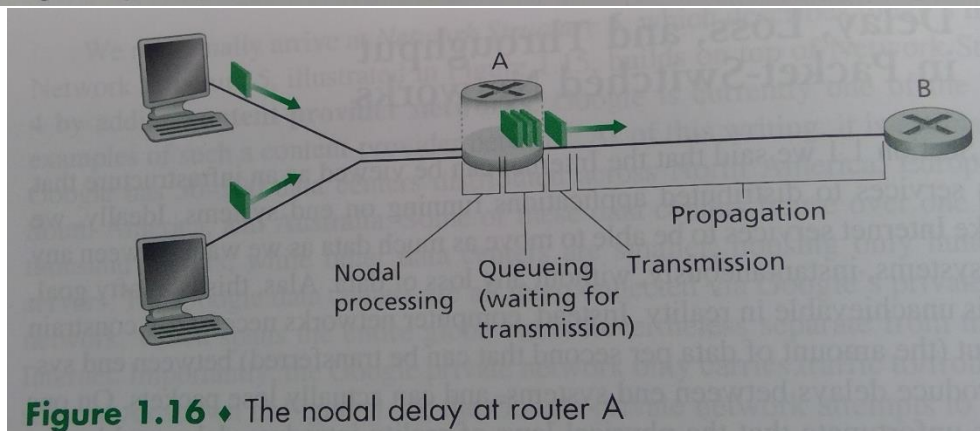
P8

- 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.)
- When circuit switching is used, how many users can be supported?
  - For the remainder of this problem, suppose packet switching is used. Find the probability that a given user is transmitting.

- Suppose there are 120 users. Find the probability that at any given time, exactly  $n$  users are transmitting simultaneously. (*Hint: Use the binomial distribution.*)
- Find the probability that there are 21 or more users transmitting simultaneously.

P11

- are sending data.
- P10. Consider the network illustrated in Figure 1.16. Assume the two hosts on the left of the figure start transmitting packets of 1500 bytes at the same time towards Router B. Suppose the link rates between the hosts and Router A is 4-Mbps. One link has a 6-ms propagation delay and the other has a 2-ms propagation delay. Will queuing delay occur at Router A?
- P11. Consider the scenario in Problem P10 again, but now assume the links between the hosts and Router A have different rates  $R_1$  and  $R_2$  byte/s in addition to different propagation delays  $d_1$  and  $d_2$ . Assume the packet lengths for the two hosts are of  $L$  bytes. For what values of the propagation delay will no queuing delay occur at Router A?



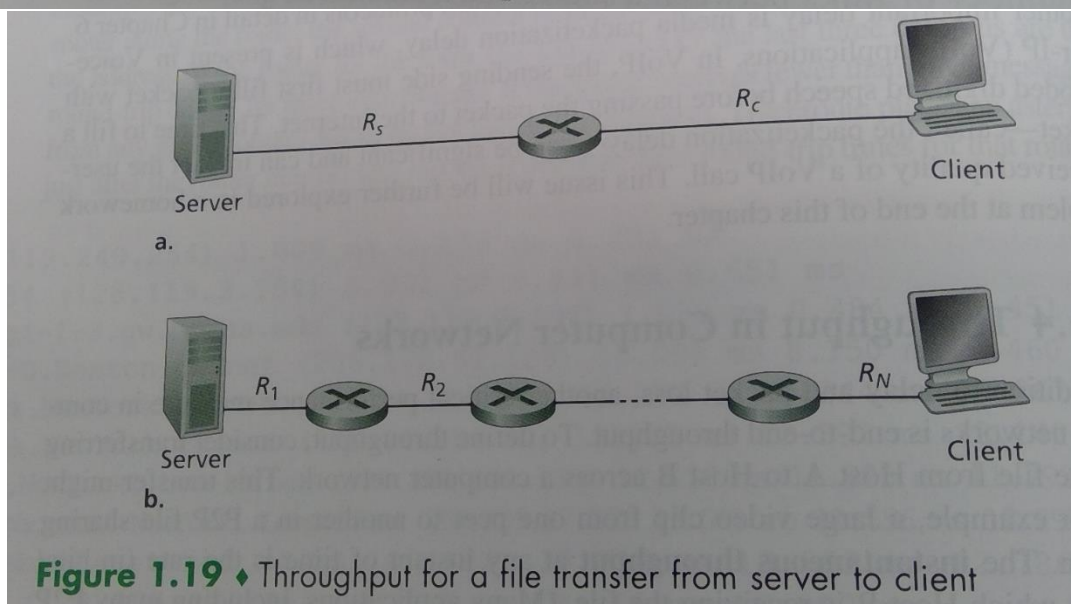


P18

- P18. Perform a Traceroute between source and destination on the same continent at three different hours of the day.
- Find the average and standard deviation of the round-trip delays at each of the three hours.
  - Find the number of routers in the path at each of the three hours. Did the paths change during any of the hours?
  - 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?
  - Repeat the above for a source and destination on different continents. Compare the intra-continent and inter-continent results.

P22

- will network (a) have a higher throughput?
- P22. Consider Figure 1.19(b). 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 in the path from the server to the client, then 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 the packet?



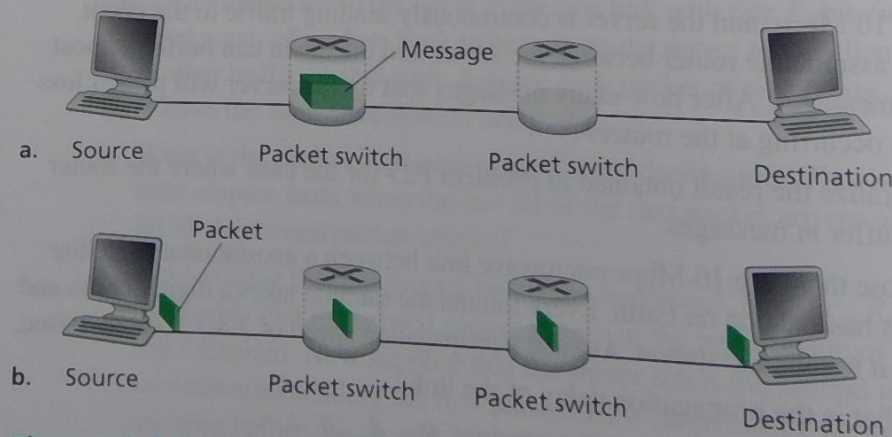
P25

- 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  $2.5 \cdot 10^8$  meters/sec.
- Calculate the bandwidth-delay product,  $R \cdot d_{\text{prop}}$ .
  - 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?
  - Provide an interpretation of the bandwidth-delay product.
  - What is the width (in meters) of a bit in the link? Is it longer than a football field?
  - 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  $m$ .

passengers and baggage as they move.

✓ 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 this process as *message segmentation*. Consider a transport of a message with and without message segmentation. Suppose each link in the figure is 2 Mbps. Ignore propagation, queuing, and processing delays.

- 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?
- 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?
- 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

- In addition to reducing delay, what are reasons to use message segmentation?
- Discuss the drawbacks of message segmentation.