CSC645/745 COMPUTER NETWORKS

Homework 1 Solution

1. What advantage does a circuit-switched network have over a packet-switched network? Consider an application that transmits data at a steady rate. Also, when such an application starts, it will continue running for a relatively long period of time. Would a packet-switched network or a circuit-switched network be more appropriate for this application? Why? (10 Points)

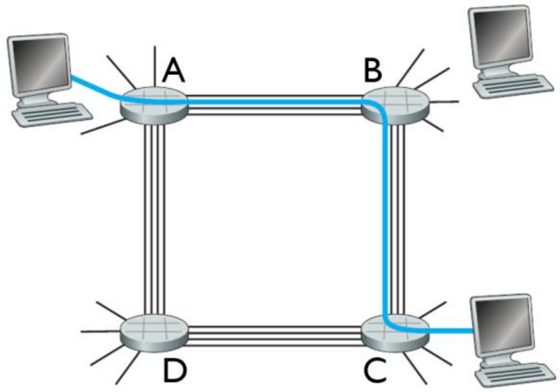
   Sol:
   A circuit-switched network can guarantee a certain amount of end-to-end bandwidth for the duration of a call. Most packet-switched networks today (including the Internet) cannot make any end-to-end guarantees for bandwidth.
   A circuit-switched network would be well suited to the application, because the application involves long sessions with predictable smooth bandwidth requirements. Since the transmission rate is known and not bursty, bandwidth can be reserved for each application session without significant waste.

2. What are the five layers in the Internet protocol stack? What are the principal responsibilities of each of these layers? (10 Points)

   Sol:
   The five layers in the Internet protocol stack are – from top to bottom – the application layer, the transport layer, the network layer, the link layer, and the physical layer.
   The application layer is where network applications and their application-layer protocols reside. The transport layer transports application-layer messages between application endpoints. The network layer is responsible for moving network-layer packets from one host to another. The link layer moves a packet from one node (host or router) to the next node in the route. The physical layer moves the individual bits from one node to the next.

3. Consider the following circuit-switched network. There are 4 circuits on each link.
   a. What is the maximum number of simultaneous connections that can be in progress at any one time in this network? (5 Points)
   b. Suppose that all connections are between switches A and C. What is the maximum number of simultaneous connections that can be in progress? (5 Points)
   c. Suppose we want to make four connections between switches A and C, and another four connections between switches B and D. Can we route these calls

through the four links to accommodate all eight connections? (5 Points)



Sol:

a. Between the switch in the upper left and the switch in the upper right we can have 4 connections. Similarly we can have four connections between each of the 3 other pairs of adjacent switches. Thus, this network can support up to 16 connections.

b. We can 4 connections passing through the switch in the upper-right-hand corner and another 4 connections passing through the switch in the lower-left-hand corner, giving a total of 8 connections.
c. Yes. For the connections between A and C, we route two connections through B and two connections through D. For the connections between B and D, we route two connections through A and two connections through C. In this manner, there are at most 4 connections passing through any link.

4. 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. (3 Points)
   b. Determine the transmission time of the packet, d_{trans}, in terms of L and R. (3 Points)
   c. Ignoring processing and queuing delays, obtain an expression for the end-to-end delay. (3 Points)
   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? (3 Points)
   e. Suppose d_{prop} is greater than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet? (3 Points)
   f. Suppose d_{prop} is less than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet? (3 Points)

Sol:

a. $d_{prop} = m/s$ seconds.

b. $d_{trans} = L/R$ seconds.
c. $d_{end\text{-}to\text{-}end} = (m/s + L/R)$ seconds.
d. The bit is just leaving Host A.
e. The first bit is in the link and has not reached Host B.
f. The first bit has reached Host B.

5. Suppose Host A wants to send a large file to Host B. The path from Host A to Host B has three links, of rates R_1 = 500 kbps, R_2 = 2 Mbps, and R_3 = 1 Mbps.
   a. Assuming no other traffic in the network, what is the throughput for the file transfer? (3 Points)
   b. Suppose the file is 4 million bytes. Dividing the file size by the throughput, roughly how long will it take to transfer the file to Host B? (3 Points)
   c. Repeat (a) and (b), but now with R_2 reduced to 100 kbps. (6 Points)

   Sol:
   a. 500 kbps
   b. 64 seconds
   c. 100kbps; 320 seconds

6. Consider a packet of length L which 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}. 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? Suppose now 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? (10 Points)

   Sol:
   The first end system requires L/R_1 to transmit the packet onto the first link; the packet propagates over the first link in d_1/s_1; the packet switch adds a processing delay of d_{proc}; after receiving the entire packet, the packet switch connecting the first and the second link requires L/R_2 to transmit the packet onto the second link; the packet propagates over the second link in d_2/s_2. Similarly, we can find the delay caused by the second switch and the third link: L/R_3, d_{proc}, and d_3/s_3.
   Adding these five delays gives
   $d_{end\text{-}end} = L/R_1 + L/R_2 + L/R_3 + d_1/s_1 + d_2/s_2 + d_3/s_3 + d_{proc} + d_{proc}$

To answer the second question, we simply plug the values into the equation to get 6 + 6 + 6 + 20+16 + 4 + 3 + 3 = 64 msec.

7. Suppose you would like to urgently deliver 40 terabytes (1 terabyte = 10^{12} bytes) 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 overnight delivery? Explain. (5 Points)

   Sol:
   40 terabytes = $40\times10^{12}\times8$ bits. So, if using the dedicated link, it will take $40\times10^{12}\times8/(100\times10^{6})$ =3200000 seconds = 37 days. But with FedEx overnight delivery, you can guarantee the data arrives in one day, and it should cost less than $100.

8. 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 8×10^{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.
   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? (8 Points)
   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? (8 Points)
   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. (4 Points)

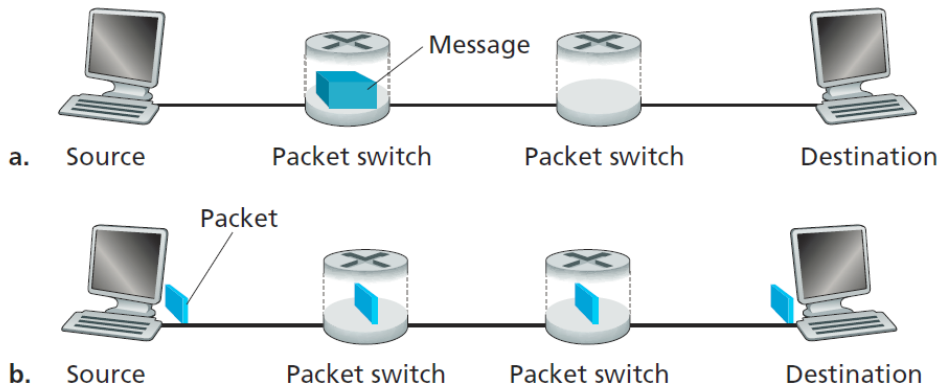


Figure 1.27 ♦ End-to-end message transport: (a) without message segmentation; (b) with message segmentation

Sol:

a. Time to send message from source host to first packet switch = $\frac{8\times10^6}{2\times10^6}$ sec = 4 sec. With store-and-forward switching, the total time to move message from source host to destination host = 4 sec × 3 = 12 sec.
b. Time to send 1st packet from source host to first packet switch = $\frac{1\times10^4}{2\times10^6}$ sec = 5 msec. Time at which 2nd packet is received at the first switch = time at which 1st packet is received at the second switch = 5 msec × 2 = 10 msec.
c. Time at which 1st packet is received at the destination host = 5 msec × 3 = 15 msec. After this, every 5 msec one packet will be received; thus time at which last (800th) packet is received = 15 msec + 799 × 5 msec = 4.01 sec. It can be seen that delay in using message segmentation is significantly less (almost 1/3).

Bonus Question

In class, we know that the end-to-end delay of sending one packet of length L over N links of transmission rate R from source host to destination host is $N \cdot L/R$. What is the end-to-end delay for sending P such packets back-to-back over the N links? (5 Points)

Sol:

At time $N\times(L/R)$ the first packet has reached the destination, the second packet is stored in the last router, the third packet is stored in the next-to-last router, etc. At time $N\times(L/R) + L/R$, the second packet has reached the destination, the third packet is stored in the last router, etc. Continuing with this logic, we see that at time $N\times(L/R) + (P-1)\times(L/R) = (N+P-1)\times(L/R)$ all packets have reached the destination.