

**Problem-1:**

Consider the circuit-switched network in Figure 1.13. Recall that there are 4 circuits on each link. Label the four switches A, B, C and D, going in the clockwise direction.

- What is the maximum number of simultaneous connections that can be in progress at any one time in this network?
- Suppose that all connections are between switches A and C. What is the maximum number of simultaneous connections that can be in progress?
- 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?

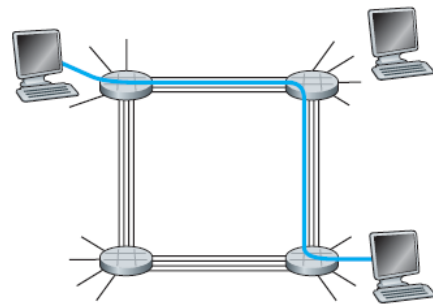


Figure 1.13 ♦ A simple circuit-switched network consisting of four switches and four links

**Solution:**

- 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.
- 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.
- 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.

**Problem-2:**

Consider the discussion in Section 1.3 of packet switching versus circuit switching in which an example is provided with a 1 Mbps link. Users are generating data at a rate of 100 kbps when busy, but are busy generating data only with probability  $p = 0.1$ . Suppose that the 1 Mbps link is replaced by a 1 Gbps link.

- What is  $N$ , the maximum number of users that can be supported simultaneously under circuit switching?
- Now consider packet switching and a user population of  $M$  users. Give a formula (in terms of  $p$ ,  $M$ ,  $N$ ) for the probability that more than  $N$  users are sending data.

It's referring to section 1.3 of the textbook.

**Solution:**

- 10,000
- $\sum_{n=N+1}^M \binom{M}{n} p^n (1-p)^{M-n}$

**Problem-3:**

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  $2.5 \cdot 10^8$  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?

**Solution:**

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

$$d_{end-end} = L/R_1 + L/R_2 + L/R_3 + d_1/s_1 + d_2/s_2 + d_3/s_3 + d_{proc} + d_{proc}$$

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.

**Problem-4:**

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  $m$ .

**Solution:**

- 160,000 bits
- 160,000 bits
- The bandwidth-delay product of a link is the maximum number of bits that can be in the link.
- the width of a bit = length of link / bandwidth-delay product, so 1 bit is 125 meters long, which is longer than a football field
- $s/R$

**Problem-5:**

Referring to the problem on last page:

- a. How long does it take to send the file, assuming it is sent continuously?
- b. Suppose now the file is broken up into 20 packets with each packet containing 40,000 bits. Suppose that each packet is acknowledged by the receiver and the transmission time of an acknowledgment packet is negligible. Finally, assume that the sender cannot send a packet until the preceding one is acknowledged. How long does it take to send the file?
- c. Compare the results from (a) and (b).

**Solution:**

- a)  $t_{trans} + t_{prop} = 400 \text{ msec} + 80 \text{ msec} = 480 \text{ msec}$ .
- b)  $20 * (t_{trans} + 2 t_{prop}) = 20 * (20 \text{ msec} + 80 \text{ msec}) = 2 \text{ sec}$ .
- c) Breaking up a file takes longer to transmit because each data packet and its corresponding acknowledgement packet add their own propagation delays.