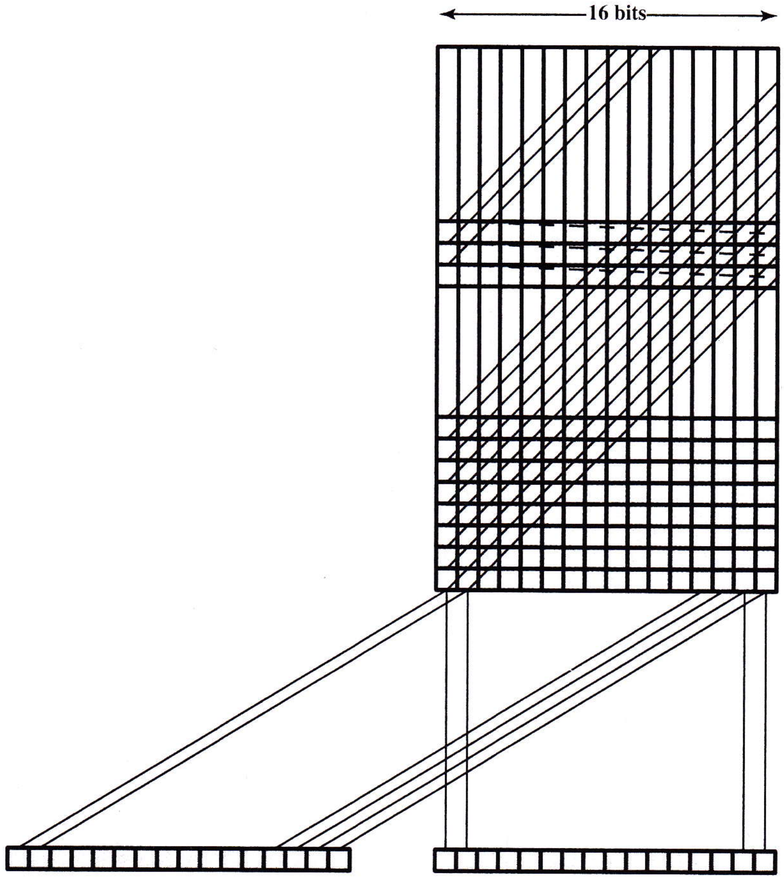

Figure 6.10 The XTP Checksum Scheme

RXOR are illustrated in Figure 6.10. The XOR function calculates the column parity. RXOR is a diagonal parity check, achieved by rotating each successive 16-bit word in the data block one bit and then performing a bitwise XOR.

a. Will this checksum detect all errors caused by an odd number of error bits? Explain.
b. Will this checksum detect all errors caused by an even number of error bits? If not, characterize the error patterns that will cause the checksum to fail.

6.9 What is the purpose of using modulo 2 arithmetic rather than binary arithmetic in computing an FCS?

6.10 Using the CRC-CCITT polynomial, generate the 16-bit CRC code for a message consisting of a 1 followed by 15 0s.
a. Use long division.
b. Use the shift-register mechanism shown in Figure 6.4.

6.11 Explain in words why the shift-register implementation of CRC will result in all 0s at the receiver if there are no errors. Demonstrate by example.

6.12 For $P = 110011$ and $M = 11100011$, find the CRC.

6.13 A CRC is constructed to generate a 4-bit FCS for an 11-bit message. The generator polynomial is $X^4 + X^3 + 1$.

a. Draw the shift-register circuit that would perform this task (see Figure 6.4).
b. Encode the data bit sequence 10011011100 (leftmost bit is the least significant) using the generator polynomial and give the codeword.
c. Now assume that bit 7 (counting from the LSB) in the codeword is in error and show that the detection algorithm detects the error.

6.14 **a.** In a CRC error-detecting scheme, choose $P(X) = X^4 + X + 1$. Encode the bits 10010011011.
b. Suppose the channel introduces an error pattern 100010000000000 (i.e., a flip from 1 to 0 or from 0 to 1 in position 1 and 5). What is received? Can the error be detected?
c. Repeat part (b) with error pattern 100110000000000.

6.15 A modified CRC procedure is commonly used in communications standards. It is defined as follows:

$$\frac{X^{16}D(X) + X^kL(X)}{P(X)} = Q + \frac{R(X)}{P(X)}$$

$$\text{FCS} = L(X) + R(X)$$

where

$$L(X) = X^{15} + X^{14} + X^{13} + \cdots + X + 1$$

and k is the number of bits being checked (address, control, and information fields).
a. Describe in words the effect of this procedure.
b. Explain the potential benefits.
c. Show a shift-register implementation for $P(X) = X^{16} + X^{12} + X^5 + 1$.

6.16 Calculate the Hamming pairwise distances among the following codewords:
a. 00000, 10101, 01010
b. 000000, 010101, 101010, 110110

6.17 Section 6.6 discusses block error-correcting codes that make a decision on the basis of minimum distance. That is, given a code consisting of s equally likely codewords of length n, for each received sequence **v**, the receiver selects the codeword **w** for which the distance $d(\mathbf{w}, \mathbf{v})$ is a minimum. We would like to prove that this scheme is "ideal" in the sense that the receiver always selects the codeword for which the probability of **w** given **v**, $p(\mathbf{w}|\mathbf{v})$, is a maximum. Because all codewords are assumed equally likely, the codeword that maximizes $p(\mathbf{w}|\mathbf{v})$ is the same as the codeword that maximizes $p(\mathbf{v}|\mathbf{w})$.
a. In order that **w** be received as **v**, there must be exactly $d(\mathbf{w}, \mathbf{v})$ errors in transmission, and these errors must occur in those bits where **w** and **v** disagree. Let β be the probability that a given bit is transmitted incorrectly and n be the length of a codeword. Write an expression for $p(\mathbf{v}|\mathbf{w})$ as a function of β, $d(\mathbf{w}, \mathbf{v})$, and n. *Hint:* The number of bits in error is $d(\mathbf{w}, \mathbf{v})$ and the number of bits not in error is $n - d(\mathbf{w}, \mathbf{v})$.
b. Now compare $p(\mathbf{v}|\mathbf{w}_1)$ and $p(\mathbf{v}|\mathbf{w}_2)$ for two different codewords $\mathbf{w}_1$ and $\mathbf{w}_2$ by calculating $p(\mathbf{v}|\mathbf{w}_1)/p(\mathbf{v}|\mathbf{w}_2)$.
c. Assume that $0 < \beta < 0.5$ and show that $p(\mathbf{v}|\mathbf{w}_1) > p(\mathbf{v}|\mathbf{w}_2)$ if and only if $d(\mathbf{v},\mathbf{w}_1) < d(\mathbf{v},\mathbf{w}_2)$. This proves that the codeword **w** that gives the largest value of $p(\mathbf{v}|\mathbf{w})$ is that word whose distance from **v** is a minimum.

6.18 Section 6.6 states that for a given positive integer t, if a code satisfies $d_{\min} \geq 2t + 1$, then the code can correct all bit errors up to and including errors of t bits. Prove this assertion. *Hint:* Start by observing that for a codeword **w** to be decoded as another codeword **w**′, the received sequence must be at least as close to **w**′ as to **w**.

6.19 A common technique for implementing CRC is to use a table lookup algorithm. The document site at box.com/dcc10e contains several papers describing this approach. Write a short paper that summarizes the general approach to implementing CRC using table lookup.

7.7 What is piggybacking?
7.8 Define *error control.*
7.9 List common ingredients for error control for a link control protocol.
7.10 Describe automatic repeat request (ARQ).
7.11 List and briefly define three versions of ARQ.
7.12 What are the station types supported by HDLC? Describe each.
7.13 What are the transfer modes supported by HDLC? Describe each.
7.14 What is the purpose of the flag field?
7.15 Define *data transparency*.
7.16 What are the three frame types supported by HDLC? Describe each.

Problems

7.1 Consider a half-duplex point-to-point link using a stop-and-wait scheme, in which a series of messages is sent, with each message segmented into a number of frames. Ignore errors and frame overhead.

a. What is the effect on line utilization of increasing the message size so that fewer messages will be required? Other factors remain constant.

b. What is the effect on line utilization of increasing the number of frames for a constant message size?

c. What is the effect on line utilization of increasing frame size?

7.2 The number of bits on a transmission line that are in the process of actively being transmitted (i.e., the number of bits that have been transmitted but have not yet been received) is referred to as the *bit length* of the line. Plot the line distance versus the transmission speed for a bit length of 1000 bits. Assume a propagation velocity of 2×10^8 m/s.

7.3 In Figure 7.10 frames are generated at node A and sent to node C through node B. Determine the minimum data rate required between nodes B and C so that the buffers of node B are not flooded, based on the following:

- The data rate between A and B is 100 kbps.
- The propagation delay is 5 μs/km for both lines.
- There are full-duplex lines between the nodes.
- All data frames are 1000 bits long; ACK frames are separate frames of negligible length.
- Between A and B, a sliding-window protocol with a window size of 3 is used.
- Between B and C, stop-and-wait is used.
- There are no errors.

Hint: In order not to flood the buffers of B, the average number of frames entering and leaving B must be the same over a long interval.

7.4 A channel has a data rate of R bps and a propagation delay of t s/km. The distance between the sending and receiving nodes is L kilometers. Nodes exchange fixed-size frames of B bits. Find a formula that gives the minimum sequence field size of the frame as a function of R, t, B, and L (considering maximum utilization). Assume that ACK frames are negligible in size and the processing at the nodes is instantaneous.

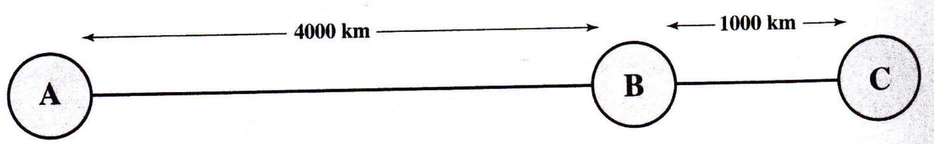

Figure 7.10 Configuration for Problem 7.3

8.6 Why is a statistical time-division multiplexer more efficient than a synchronous time-division multiplexer?

8.7 Using Table 8.3 as a guide, indicate the major difference between North American and international TDM carrier standards.

Problems

8.1 The information in four analog signals is to be multiplexed and transmitted over a telephone channel that has a 400- to 3100-Hz bandpass. Each of the analog baseband signals is bandlimited to 500 Hz. Design a communication system (block diagram) that will allow the transmission of these four sources over the telephone channel using

a. Frequency-division multiplexing with SSB (single sideband) subcarriers
b. Time-division multiplexing using PCM; assume 4-bit samples

Show the block diagrams of the complete system, including the transmission, channel, and reception portions. Include the bandwidths of the signals at the various points in the systems.

8.2 To paraphrase Lincoln: "...all of the channel some of the time, some of the channel all of the time...." Refer to Figure 8.2 and relate the preceding to the figure.

8.3 Consider a transmission system using frequency-division multiplexing. What cost factors are involved in adding one more pair of stations to the system?

8.4 In synchronous TDM, it is possible to interleave bits, one bit from each channel participating in a cycle. If the channel is using a self-clocking code to assist synchronization, might this bit interleaving introduce problems because there is not a continuous stream of bits from one source?

8.5 Why is it that the start and stop bits can be eliminated when character interleaving is used in synchronous TDM?

8.6 Explain in terms of data link control and physical layer concepts how error and flow control are accomplished in synchronous time-division multiplexing.

8.7 One of the 193 bits in the DS-1 transmission format is used for frame synchronization. Explain its use.

8.8 In the DS-1 format, what is the control signal data rate for each voice channel?

8.9 Twenty-four voice signals are to be multiplexed and transmitted over twisted pair. What is the bandwidth required for FDM? Assuming a bandwidth efficiency (ratio of data rate to transmission bandwidth, as explained in Chapter 5) of 1 bps/Hz, what is the bandwidth required for TDM using PCM?

8.10 Draw a block diagram similar to Figure 8.8 for a TDM PCM system that will accommodate four 300-bps, synchronous, digital inputs and one analog input with a bandwidth of 500 Hz. Assume that the analog samples will be encoded into 4-bit PCM words.

8.11 A character-interleaved time-division multiplexer is used to combine the data streams of a number of 110-bps asynchronous terminals for data transmission over a 2400-bps digital line. Each terminal sends asynchronous characters consisting of 7 data bits, 1 parity bit, 1 start bit, and 2 stop bits. Assume that one synchronization character is sent every 19 data characters and, in addition, at least 3% of the line capacity is reserved for pulse stuffing to accommodate speed variations from the various terminals.

a. Determine the number of bits per character.
b. Determine the number of terminals that can be accommodated by the multiplexer.
c. Sketch a possible framing pattern for the multiplexer.

8.12 Find the number of the following devices that could be accommodated by a T1-type TDM line if 1% of the T1 line capacity is reserved for synchronization purposes.

a. 110-bps teleprinter terminals
b. 300-bps computer terminals

BARA02 Baran, P. "The Beginnings of Packet Switching: Some Underlying Concepts." *IEEE Communications Magazine*, July 2002.

BELL00 Bellamy, J. *Digital Telephony*. New York: Wiley, 2000.

BERT92 Bertsekas, D., and Gallager, R. *Data Networks*. Englewood Cliffs, NJ: Prentice Hall, 1992.

FREE04 Freeman, R. *Telecommunication System Engineering*. New York: Wiley, 2004.

HEGG84 Heggestad, H. "An Overview of Packet Switching Communications." *IEEE Communications Magazine*, April 1984.

IBM95 IBM International Technical Support Organization. *Asynchronous Transfer Mode (ATM) Technical Overview*. IBM Redbook SG24-4625-00, 1995. www.redbooks.ibm.com

ROBE78 Roberts, L. "The Evolution of Packet Switching." *Proceedings of the IEEE*, November 1978.

[BERT92] is a good treatment of this subject.

9.8 KEY TERMS, REVIEW QUESTIONS, AND PROBLEMS

Key Terms

asynchronous transfer mode (ATM)	header error control (HEC)	time-division switching
cell	internal virtual circuit	time-multiplexed switching (TMS)
circuit switching	local loop	time-slot interchange (TSI)
circuit-switching network	media gateway controller (MGC)	trunk
crossbar matrix	packet switching	virtual channel connection (VCC)
datagram	softswitch	virtual circuit
digital switch	space division switching	virtual path connection (VPC)
exchange	subscriber	
external virtual circuit	subscriber line	
generic flow control (GFC)	subscriber loop	

Review Questions

9.1 Why is it useful to have more than one possible path through a network for each pair of stations?

9.2 What are the four generic architectural components of a public communications network? Define each term.

9.3 What is the principal application that has driven the design of circuit-switching networks?

9.4 What are the advantages of packet switching compared to circuit switching?

9.5 Explain the difference between datagram and virtual circuit operation.

9.6 What is the significance of packet size in a packet-switching network?

9.7 What types of delay are significant in assessing the performance of a packet-switching network?

9.8 What are the characteristics of a virtual channel connection?

9.9 What are the characteristics of a virtual path connection?

9.10 List and briefly explain the fields in an ATM cell.

Problems

9.1 Consider a simple telephone network consisting of two end offices and one intermediate switch with a 1-MHz full-duplex trunk between each end office and the intermediate switch. Assume a 4-kHz channel for each voice call. The average telephone is used to make four calls per 8-hour workday, with a mean call duration of six minutes. Ten percent of the calls are long distance. What is the maximum number of telephones an end office can support?

9.2 a. If a crossbar matrix has n input lines and m output lines, how many crosspoints are required?
 b. How many crosspoints would be required if there were no distinction between input and output lines (i.e., if any line could be interconnected to any other line serviced by the crossbar)?
 c. Show the minimum configuration.

9.3 Consider a three-stage switch such as in Figure 9.6. Assume that there are a total of N input lines and N output lines for the overall three-stage switch. If n is the number of input lines to a stage 1 crossbar and the number of output lines to a stage 3 crossbar, then there are N/n stage 1 crossbars and N/n stage 3 crossbars. Assume each stage 1 crossbar has one output line going to each stage 2 crossbar, and each stage 2 crossbar has one output line going to each stage 3 crossbar. For such a configuration it can be shown that, for the switch to be nonblocking, the number of stage 2 crossbar matrices must equal $2n - 1$.
 a. What is the total number of crosspoints among all the crossbar switches?
 b. For a given value of N, the total number of crosspoints depends on the value of n. That is, the value depends on how many crossbars are used in the first stage to handle the total number of input lines. Assuming a large number of input lines to each crossbar (large value of n), what is the minimum number of crosspoints for a nonblocking configuration as a function of n?
 c. For a range of N from 10^2 to 10^6, plot the number of crosspoints for a single-stage $N \times N$ switch and an optimum three-stage crossbar switch.

9.4 Consider a TSI system with a TDM input of 8000 frames per second. The TSI requires one memory read and one memory write operation per slot. What is the maximum number of slots per frame that can be handled, as a function of the memory cycle time?

9.5 Consider a TDM system with 8 I/O lines, and connections 1-2, 3-7, and 5-8. Draw several frames of the input to the TSI unit and output from the TSI unit, indicating the movement of data from input time slots to output time slots.

9.6 Explain the flaw in the following reasoning: Packet switching requires control and address bits to be added to each packet. This introduces considerable overhead in packet switching. In circuit switching, a transparent circuit is established. No extra bits are needed. Therefore, there is no overhead in circuit switching. Because there is no overhead in circuit switching, line utilization must be more efficient than in packet switching.

9.7 Define the following parameters for a switching network:

N = number of hops between two given end systems
L = message length in bits
B = data rate, in bits per second (bps), on all links
P = fixed packet size, in bits

H = overhead (header) bits per packet
S = call setup time (circuit switching or virtual circuit) in seconds
D = propagation delay per hop in seconds

a. For $N = 4$, $L = 3200$, $B = 9600$, $P = 1024$, $H = 16$, $S = 0.2$, $D = 0.001$, compute the end-to-end delay for circuit switching, virtual circuit packet switching, and datagram packet switching. Assume that there are no acknowledgments. Ignore processing delay at the nodes.
b. Derive general expressions for the three techniques of part (a), taken two at a time (three expressions in all), showing the conditions under which the delays are equal.

9.8 What value of P, as a function of N, L, and H, results in minimum end-to-end delay on a datagram network? Assume that L is much larger than P, and D is zero.

9.9 Assuming no malfunction in any of the stations or nodes of a network, is it possible for a packet to be delivered to the wrong destination?

9.10 Although ATM does not include any end-to-end error detection and control functions on the user data, it is provided with a HEC field to detect and correct header errors. Let us consider the value of this feature. Suppose that the bit error rate of the transmission system is B. If errors are uniformly distributed, then the probability of an error in the header is

$$\frac{h}{h + i} \times B$$

and the probability of error in the data field is

$$\frac{i}{h + i} \times B$$

where h is the number of bits in the header and i is the number of bits in the data field.

a. Suppose that errors in the header are not detected and not corrected. In that case, a header error may result in a misrouting of the cell to the wrong destination; therefore, i bits will arrive at an incorrect destination, and i bits will not arrive at the correct destination. What is the overall bit error rate $B1$? Find an expression for the multiplication effect on the bit error rate: $M1 = B1/B$.
b. Now suppose that header errors are detected but not corrected. In that case, i bits will not arrive at the correct destination. What is the overall bit error rate $B2$? Find an expression for the multiplication effect on the bit error rate: $M2 = B2/B$.
c. Now suppose that header errors are detected and corrected. What is the overall bit error rate $B3$? Find an expression for the multiplication effect on the bit error rate: $M3 = B3/B$.
d. Plot $M1$, $M2$, and $M3$ as a function of header length, for $i = 48 \times 8 = 384$ bits. Comment on the results.

9.11 One key design decision for ATM was whether to use fixed- or variable-length cells. Let us consider this decision from the point of view of efficiency. We can define transmission efficiency as

$$N = \frac{\text{Number of information octets}}{\text{Number of information octets} + \text{Number of overhead octets}}$$

a. Consider the use of fixed-length packets. In this case the overhead consists of the header octets. Define

L = Data field size of the cell in octets
H = Header size of the cell in octets
X = Number of information octets to be transmitted as a single message

for base station transmission. A duplex circuit consists of one 30-kHz channel in each direction. The systems are distinguished by the reuse factor, which is 4, 7, 12, and 19, respectively.

a. Suppose that in each of the systems, the cluster of cells (4, 7, 12, 19) is duplicated 16 times. Find the number of simultaneous communications that can be supported by each system.

b. Find the number of simultaneous communications that can be supported by a single cell in each system.

c. What is the area covered, in cells, by each system?

d. Suppose the cell size is the same in all four systems and a fixed area of 100 cells is covered by each system. Find the number of simultaneous communications that can be supported by each system.

10.3 Describe a sequence of events similar to that of Figure10.6 for

a. a call from a mobile unit to a fixed subscriber

b. a call from a fixed subscriber to a mobile unit

10.4 An analog cellular system has a total of 33 MHz of bandwidth and uses two 25-kHz simplex (one-way) channels to provide full-duplex voice and control channels.

a. What is the number of channels available per cell for a frequency reuse factor of (1) 4 cells, (2) 7 cells, and (3) 12 cells?

b. Assume that 1 MHz is dedicated to control channels but that only one control channel is needed per cell. Determine a reasonable distribution of control channels and voice channels in each cell for the three frequency reuse factors of part (a).

10.5 A cellular system uses FDMA with a spectrum allocation of 12.5 MHz in each direction, a guard band at the edge of the allocated spectrum of 10 kHz, and a channel bandwidth of 30 kHz. What is the number of available channels?

10.6 For a cellular system, FDMA spectral efficiency is defined as $\eta_a = \frac{B_c N_T}{B_w}$ where

B_c = channel bandwidth
B_w = total bandwidth in one direction
N_T = total number of voice channels in the covered area

What is an upper bound on η_a?

1. $D = 1$ km, $B = 1$ Mbps, $P = 256$ bits
2. $D = 1$ km, $B = 10$ Mbps, $P = 256$ bits
3. $D = 10$ km, $B = 1$ Mbps, $P = 256$ bits
4. $D = 1$ km, $B = 50$ Mbps, $P = 10{,}000$ bits

11.4 Consider a baseband bus with a number of equally spaced stations with a data rate of 10 Mbps and a bus length of 1 km.

a. What is the mean time to send a frame of 1000 bits to another station, measured from the beginning of transmission to the end of reception? Assume a propagation speed of 200 m/μs.

b. If two stations begin to transmit at exactly the same time, their packets will interfere with each other. If each transmitting station monitors the bus during transmission, how long before it notices an interference, in seconds? In bit times?

11.5 Repeat Problem 15.4 for a data rate of 100 Mbps.

11.6 Draw figures similar to Figure 11.7 for a configuration in which

a. Two LANs are connected via two bridges that are connected by a point-to-point link.

b. Two LANs are connected via two bridges that are connected by an ATM packet-switching network.

11.7 For the configuration of Figure 11.8, show the central routing matrix and the routing tables at each bridge.

11.8 Develop a spanning tree for the configuration of Figure 11.15.

11.9 A station on a LAN that includes an attached bridge sends out a frame to a device that is not present on any of the segments of the total network. What does the bridge do with this frame?

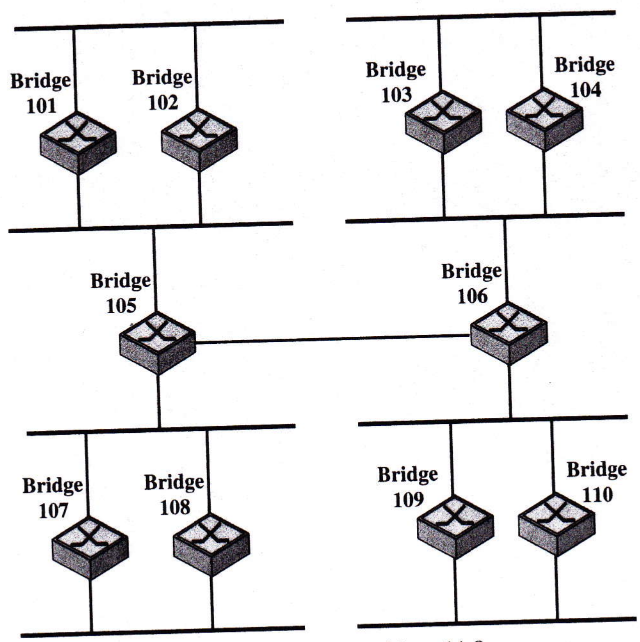

Figure 11.15 Configuration of Problem 11.8

12.4 Explain binary exponential backoff.
12.5 What are the transmission medium options for Fast Ethernet?
12.6 How does Fast Ethernet differ from 10BASE-T, other than the data rate?
12.7 In the context of Ethernet, what is full-duplex operation?

Problems

12.1 A disadvantage of the contention approach for LANs, such as CSMA/CD, is the capacity wasted due to multiple stations attempting to access the channel at the same time. Suppose that time is divided into discrete slots, with each of N stations attempting to transmit with probability p during each slot. What fraction of slots are wasted due to multiple simultaneous transmission attempts?

12.2 For p-persistent CSMA, consider the following situation. A station is ready to transmit and is listening to the current transmission. No other station is ready to transmit, and there will be no other transmission for an indefinite period. If the time unit used in the protocol is T, show that the average number of iterations of step 1 of the protocol is $1/p$ and that therefore the expected time that the station will have to wait after the current transmission is $T\left(\frac{1}{P} - 1\right)$. *Hint:* Use the equality $\sum_{i=1}^{\infty} iX^{i-1} = \frac{1}{(1 - X)^2}$.

12.3 The binary exponential backoff algorithm is defined by IEEE 802 as follows:

> The delay is an integral multiple of slot time. The number of slot times to delay before the nth retransmission attempt is chosen as a uniformly distributed random integer r in the range $0 \le r < 2^K$, where $K = \min(n,10)$.

Slot time is, roughly, twice the round-trip propagation delay. Assume that two stations always have a frame to send. After a collision, what is the mean number of retransmission attempts before one station successfully retransmits? What is the answer if three stations always have frames to send?

12.4 Describe the signal pattern produced on the medium by the Manchester-encoded preamble of the IEEE 802.3 MAC frame.

12.5 Analyze the advantages of having the FCS field of IEEE 802.3 frames in the trailer of the frame rather than in the header of the frame.

12.6 With 8B6T coding, the effective data rate on a single channel is 33 Mbps with a signaling rate of 25 Mbaud. If a pure ternary scheme were used, what is the effective data rate for a signaling rate of 25 Mbaud?

12.7 With 8B6T coding, the DC algorithm sometimes negates all of the ternary symbols in a code group. How does the receiver recognize this condition? How does the receiver discriminate between a negated code group and one that has not been negated? For example, the code group for data byte 00 is $+ - 0 0 + -$ and the code group for data byte 38 is the negation of that, namely, $- + 0 0 - +$.

12.8 Draw the MLT decoder state diagram that corresponds to the encoder state diagram of Figure 12.12.

12.9 For the bit stream 0101110, sketch the waveforms for NRZ-L, NRZI, Manchester, and differential Manchester, and MLT-3.

12.10 **a.** Verify that the division illustrated in Figure 12.18a corresponds to the implementation of Figure 12.17a by calculating the result step by step using Equation (12.1).
b. Verify that the multiplication illustrated in Figure 12.18b corresponds to the implementation of Figure 12.17b by calculating the result step by step using Equation (12.2).

12.11 Draw a figure similar to Figure 12.16 for the MLT-3 scrambler and descrambler.

Review Questions

13.1 List and briefly define key requirements for WLANs.
13.2 What is the difference between a single-cell and a multiple-cell WLAN?
13.3 What is the difference between an access point and a portal?
13.4 Is a distribution system a wireless network?
13.5 List and briefly define IEEE 802.11 services.
13.6 How is the concept of an association related to that of mobility?

Problems

13.1 Consider the sequence of actions within a BSS depicted in Figure 13.14. Draw a timeline, beginning with a period during which the medium is busy and ending with a period in which the CF-End is broadcast from the AP. Show the transmission periods and the gaps.

13.2 For IEEE 802.11a, show how the modulation technique and coding rate determine the data rate.

13.3 The 802.11a and 802.11b physical layers make use of data scrambling (see Appendix 12B). For 802.11, the scrambling equation is

$$P(X) = 1 + X^4 + X^7$$

In this case the shift register consists of seven elements, used in the same manner as the five-element register in Figure 12.17. For the 802.11 scrambler and descrambler,

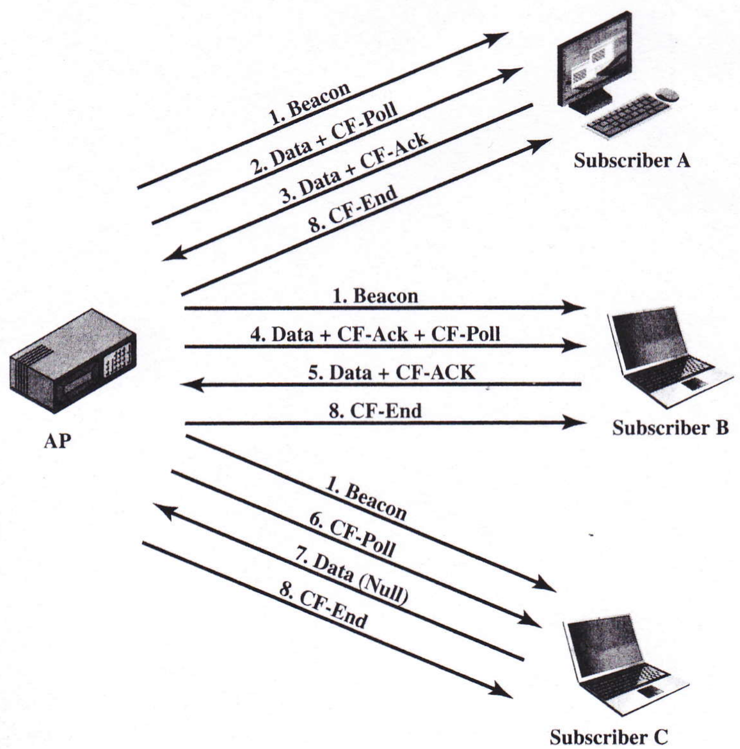

Figure 13.14 Configuration for Problem 13.1