SOLUTIONS MANUAL

WIRELESS COMMUNICATIONS AND NETWORKS

SECOND EDITION

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NOTICE

This manual contains solutions to all of the review questions and homework problems in *Wireless Communications and Networks, Second Edition*. If you spot an error in a solution or in the wording of a problem, I would greatly appreciate it if you would forward the information via email to me at ws@shore.net. An errata sheet for this manual, if needed, is available at ftp://shell.shore.net/members/w/s/ws/S/

W.S.

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Chapter 2
Transmission Fundamentals

Answers to Questions

2.1 A continuous or analog signal is one in which the signal intensity varies in a smooth fashion over time while a discrete or digital signal is one in which the signal intensity maintains one of a finite number of constant levels for some period of time and then changes to another constant level.

2.2 Amplitude, frequency, and phase are three important characteristics of a periodic signal.

2.3 2π radians.

2.4 The relationship is $\lambda f = v$, where λ is the wavelength, f is the frequency, and v is the speed at which the signal is traveling.

2.5 The spectrum of a signal consists of the frequencies it contains; the bandwidth of a signal is the width of the spectrum.

2.6 Attenuation is the gradual weakening of a signal over distance.

2.7 The rate at which data can be transmitted over a given communication path, or channel, under given conditions, is referred to as the channel capacity.

2.8 Bandwidth, noise, and error rate affect channel capacity.

2.9 With guided media, the electromagnetic waves are guided along an enclosed physical path, whereas unguided media provide a means for transmitting electromagnetic waves through space, air, or water, but do not guide them.

2.10 Point-to-point microwave transmission has a high data rate and less attenuation than twisted pair or coaxial cable. It is affected by rainfall, however, especially above 10 GHz. It is also requires line of sight and is subject to interference from other microwave transmission, which can be intense in some places.

2.11 Direct broadcast transmission is a technique in which satellite video signals are transmitted directly to the home for continuous operation.

2.12 A satellite must use different uplink and downlink frequencies for continuous operation in order to avoid interference.

2.13 Broadcast is omnidirectional, does not require dish shaped antennas, and the antennas do not have to be rigidly mounted in precise alignment.

2.14 Multiplexing is cost-effective because the higher the data rate, the more cost-effective the transmission facility.

2.15 Interference is avoided under frequency division multiplexing by the use of guard bands, which are unused portions of the frequency spectrum between subchannels.

2.16 A synchronous time division multiplexer interleaves bits from each signal and takes turns transmitting bits from each of the signals in a round-robin fashion.

Answers to Problems

2.1 Period = 1/1000 = 0.001 s = 1 ms.

2.2 **a.** $\sin(2\pi ft - \pi) + \sin(2\pi ft + \pi) = 2\sin(2\pi ft + \pi)$ or $2\sin(2\pi ft - \pi)$ or $-2\sin(2\pi ft)$
b. $\sin(2\pi ft) + \sin(2\pi ft - \pi) = 0$.

2.3

N	C		D		E		F		G		A		B		C
F	264		297		330		352		396		440		495		528
D		33		33		22		44		44		55		33	
W	1.25		1.11		1		0.93		0.83		0.75		0.67		0.63

N = note; F = frequency (Hz); D = frequency difference; W = wavelength (m)

2.4 $2\sin(4\pi t + \pi)$; $A = 2$, $f = 2$, $\phi = \pi$

2.5 $(1 + 0.1\cos 5t)\cos 100t = \cos 100t + 0.1\cos 5t\cos 100t$. From the trigonometric identity $\cos a\cos b = (1/2)(\cos(a + b) + \cos(a - b))$, this equation can be rewritten as the linear combination of three sinusoids:
$\cos 100t + 0.05\cos 105t + 0.05\cos 95t$

2.6 We have $\cos^2 x = \cos x\cos x = (1/2)(\cos(2x) + \cos(0)) = (1/2)(\cos(2x) + 1)$. Then: $f(t) = (10\cos t)^2 = 100\cos^2 t = 50 + 50\cos(2t)$. The period of $\cos(2t)$ is π and therefore the period of $f(t)$ is π.

2.7 If $f_1(t)$ is periodic with period X, then $f_1(t) = f_1(t + X) = f_1(t + nX)$ where n is an integer and X is the smallest value such that $f_1(t) = f_1(t + X)$. Similarly, $f_2(t) = f_2(t + Y) = f_2(t + mY)$. We have $f(t) = f_1(t) + f_2(t)$. If $f(t)$ is periodic with period Z, then $f(t) = f(t + Z)$. Therefore $f_1(t) + f_2(t) = f_1(t + Z) + f_2(t + Z)$. This last equation is satisfied if $f_1(t) = f_1(t + Z)$ and $f_2(t) = f_2(t + Z)$. This leads to the condition $Z = nX = mY$ for some integers n and m. We can rewrite this last as $(n/m) = (Y/X)$. We can therefore conclude that if the ratio (Y/X) is a rational number, then $f(t)$ is periodic.

2.8 The signal would be a low-amplitude, rapidly changing waveform.

2.9 Using Shannon's equation: $C = B\log_2(1 + SNR)$
We have $W = 300$ Hz $\quad (SNR)_{dB} = 3$
Therefore, $SNR = 10^{0.3}$

$C = 300 \log_2 (1 + 10^{0.3}) = 300 \log_2 (2.995) = 474$ bps

2.10 Using Nyquist's equation: $C = 2B \log_2 M$

We have $C = 9600$ bps

a. $\log_2 M = 4$, because a signal element encodes a 4-bit word

Therefore, $C = 9600 = 2B \times 4$, and

$B = 1200$ Hz

b. $9600 = 2B \times 8$, and $B = 600$ Hz

2.11 Nyquist analyzed the theoretical capacity of a noiseless channel; therefore, in that case, the signaling rate is limited solely by channel bandwidth. Shannon addressed the question of what signaling rate can be achieved over a channel with a given bandwidth, a given signal power, and in the presence of noise.

2.12 **a.** Using Shannon's formula: $C = 3000 \log_2 (1+400000) = 56$ Kbps

b. Due to the fact there is a distortion level (as well as other potentially detrimental impacts to the rated capacity, the actual maximum will be somewhat degraded from the theoretical maximum. A discussion of these relevant impacts should be included and a qualitative value discussed.

2.13 $C = B \log_2 (1 + SNR)$

$20 \times 10^6 = 3 \times 10^6 \times \log_2(1 + SNR)$

$\log 2(1 + SNR) = 6.67$

$1 + SNR = 102$

$SNR = 101$

2.14 From Equation 2.1, we have $L_{dB} = 20 \log (4\pi d/\lambda) = 20 \log (4\pi df/v)$, where $\lambda f = v$ (see Question 2.4). If we double either d or f, we add a term 20 log(2), which is approximately 6 dB.

2.15

Decibels	1	2	3	4	5	6	7	8	9	10
Losses	0.8	0.63	0.5	0.4	0.32	0.25	0.2	0.16	0.125	0.1
Gains	1.25	1.6	2	2.5	3.2	4.0	5.0	6.3	8.0	10

2.16 For a voltage ratio, we have

$$N_{dB} = 30 = 20 \log(V_2/V_1)$$
$$V_2/V_1 = 10^{30/20} = 10^{1.5} = 31.6$$

2.17 Power (dBW) = 10 log (Power/1W) = 10 log20 = 13 dBW

CHAPTER 3
COMMUNICATION NETWORKS

ANSWERS TO QUESTIONS

3.1 Wide area networks (WANs) are used to connect stations over very large areas that may even be worldwide while local area networks (LANs) connect stations within a single building or cluster of buildings. Ordinarily, the network assets supporting a LAN belong to the organization using the LAN. For WANs, network assets of service providers are often used. LANs also generally support higher data rates than WANs.

3.2 It is advantageous to have more than one possible path through a network for each pair of stations to enhance reliability in case a particular path fails.

3.3 Telephone communications.

3.4 Static routing involves the use of a predefined route between any two end points, with possible backup routes to handle overflow. In alternate routing, multiple routes are defined between two end points and the choice can depend on time of day and traffic conditions.

3.5 This is a connection to another user set up by prior arrangement, and not requiring a call establishment protocol. It is equivalent to a leased line.

3.6 In the **datagram** approach, each packet is treated independently, with no reference to packets that have gone before. In the **virtual circuit** approach, a preplanned route is established before any packets are sent. Once the route is established, all the packets between a pair of communicating parties follow this same route through the network.

3.7 It is not efficient to use a circuit switched network for data since much of the time a typical terminal-to-host data communication line will be idle. Secondly, the connections provide for transactions at a constant data rate, which limits the utility of the network in interconnecting a variety of host computers and terminals.

3.8 A **virtual channel** is a logical connection similar to virtual circuit in X.25 or a logical channel in frame relay. In ATM, virtual channels that have the same endpoints can be grouped into **virtual paths**. All the circuits in virtual paths are switched together; this offers increased efficiency, architectural simplicity, and the ability to offer enhanced network services.

ANSWERS TO PROBLEMS

3.1 a. Circuit Switching

$T = C_1 + C_2$ where

C_1 = Call Setup Time

C_2 = Message Delivery Time
C_1 = $S = 0.2$
C_2 = Propagation Delay + Transmission Time
= $N \times D + L/B$
= $4 \times 0.001 + 3200/9600 = 0.337$
T = $0.2 + 0.337 = 0.537$ sec

Datagram Packet Switching

T = $D_1 + D_2 + D_3 + D_4$ where
D_1 = Time to Transmit and Deliver all packets through first hop
D_2 = Time to Deliver last packet across second hop
D_3 = Time to Deliver last packet across third hop
D_4 = Time to Deliver last packet across forth hop

There are $P - H = 1024 - 16 = 1008$ data bits per packet. A message of 3200 bits requires four packets (3200 bits/1008 bits/packet = 3.17 packets which we round up to 4 packets).

D_1 = $4 \times t + p$ where
t = transmission time for one packet
p = propagation delay for one hop
D_1 = $4 \times (P/B) + D$
= $4 \times (1024/9600) + 0.001$
= 0.428
D_2 = $D_3 = D_4 = t + p$
= $(P/B) + D$
= $(1024/9600) + 0.001 = 0.108$
T = $0.428 + 0.108 + 0.108 + 0.108$
= 0.752 sec

Virtual Circuit Packet Switching

T = $V_1 + V_2$ where
V_1 = Call Setup Time
V_2 = Datagram Packet Switching Time
T = $S + 0.752 = 0.2 + 0.752 = 0.952$ sec

b. Circuit Switching vs. Diagram Packet Switching

T_c = End-to-End Delay, Circuit Switching
T_c = $S + N \times D + L/B$
T_d = End-to-End Delay, Datagram Packet Switching
N_p = Number of packets = $\left\lceil \dfrac{L}{P - H} \right\rceil$
T_d = $D_1 + (N - 1)D_2$
D_1 = Time to Transmit and Deliver all packets through first hop
D_2 = Time to Deliver last packet through a hop
D_1 = $N_p(P/B) + D$
D_2 = $P/B + D$
T = $(N_p + N - 1)(P/B) + N \times D$

$$T = T_d$$
$$S + L/B = (N_p + N - 1)(P/B)$$

Circuit Switching vs. Virtual Circuit Packet Switching

T_V = End-to-End Delay, Virtual Circuit Packet Switching

$$T_V = S + T_d$$
$$T_C = T_V$$
$$L/B = (N_p + N - 1)(P/B)$$

Datagram vs. Virtual Circuit Packet Switching

$$T_d = T_V - S$$

3.2 From Problem 3.1, we have

$$T_d = (N_p + N - 1)(P/B) + N \times D$$

For maximum efficiency, we assume that $N_p = L/(P - H)$ is an integer. Also, it is assumed that $D = 0$. Thus

$$T_d = (L/(P - H) + N - 1)(P/B)$$

To minimize as a function of P, take the derivative:

$$0 = dT_d/(dP)$$
$$0 = (1/B)(L/(P - H) + N - 1) - (P/B)L/(P - H)^2$$
$$0 = L(P - H) + (N - 1)(P - H)^2 - LP$$
$$0 = -LH + (N - 1)(P - H)^2$$
$$(P - H)^2 = LH/(N - 1)$$
$$P = H + \sqrt{\frac{LH}{N-1}}$$

3.3 Each telephone makes 0.5 calls/hour at 6 minutes each. Thus a telephone occupies a circuit for 3 minutes per hour. Twenty telephones can share a circuit (although this 100% utilization implies long queuing delays). Since 10% of the calls are long distance, it takes 200 telephones to occupy a long distance (4 kHz) channel full time. The interoffice trunk has $10^6/(4 \times 10^3) = 250$ channels. With 200 telephones per channel, an end office can support $200 \times 250 = 50{,}000$ telephones.

3.4 The argument ignores the overhead of the initial circuit setup and the circuit teardown.

3.5 Yes. A large noise burst could create an undetected error in the packet. If such an error occurs and alters a destination address field or virtual circuit identifier field, the packet would be misdelivered.

3.6 The number of hops is one less than the number of nodes visited.

a. The fixed number of hops is 2.

b. The furthest distance from a station is halfway around the loop. On average, a station will send data half this distance. For an N-node network, the average number of hops is (N/4) – 1.

c. 1.

3.7 a. We reason as follows. A total of X octets are to be transmitted. This will require a total of $\left\lceil \frac{X}{L} \right\rceil$ cells. Each cell consists of (L + H) octets, where L is the number of data field octets and H is the number of header octets. Thus

$$N = \frac{X}{\left\lceil \frac{X}{L} \right\rceil (L + H)}$$

The efficiency is optimal for all values of X which are integer multiples of the cell information size. In the optimal case, the efficiency becomes

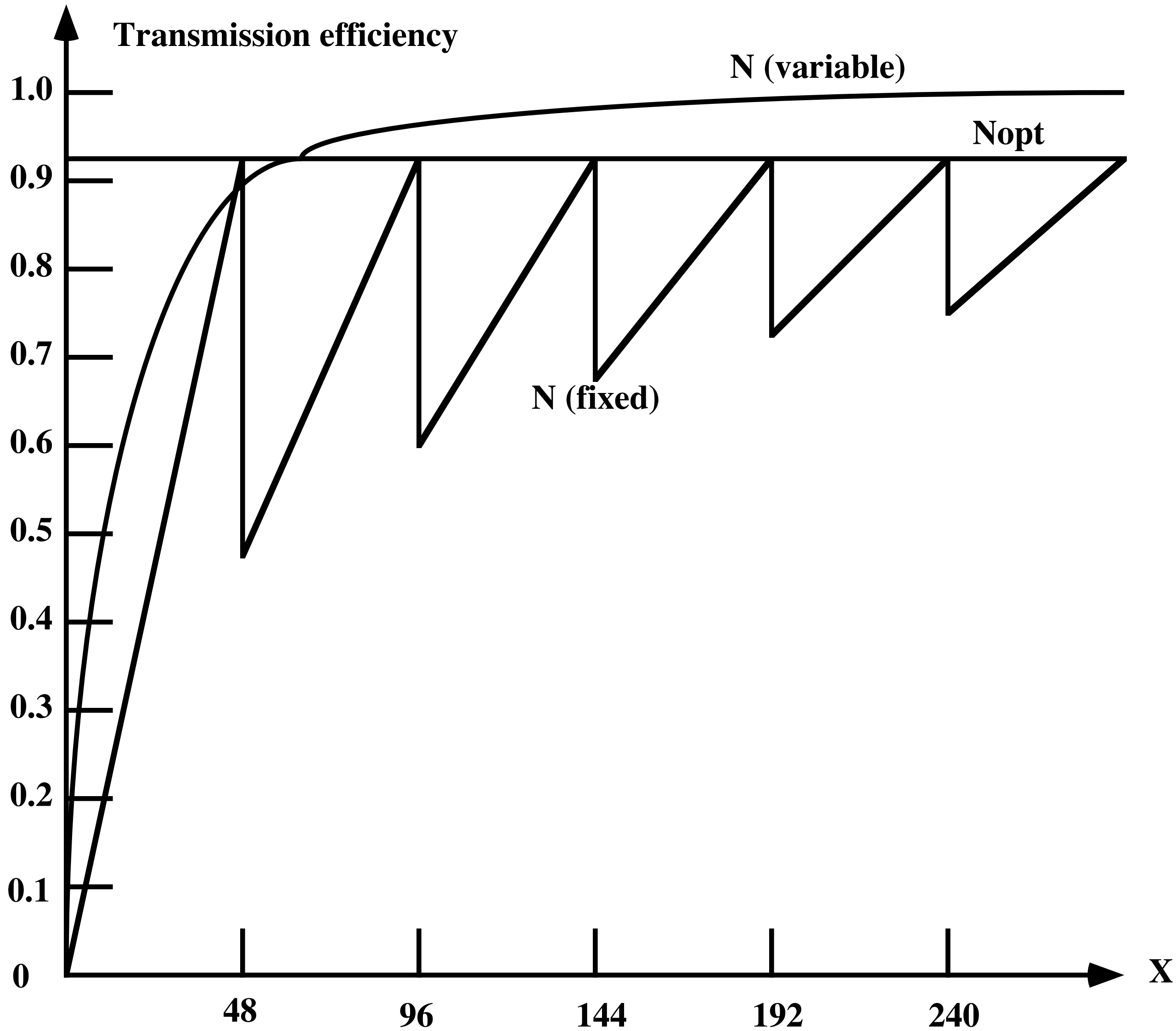
$$N_{\text{opt}} = \frac{X}{\frac{X}{L} + H} = \frac{L}{L + H}$$

For the case of ATM, with L = 48 and H = 5, we have $N_{\text{opt}} = 0.91$

b. Assume that the entire X octets to be transmitted can fit into a single variable-length cell. Then

$$N = \frac{X}{X + H + H_v}$$

c.



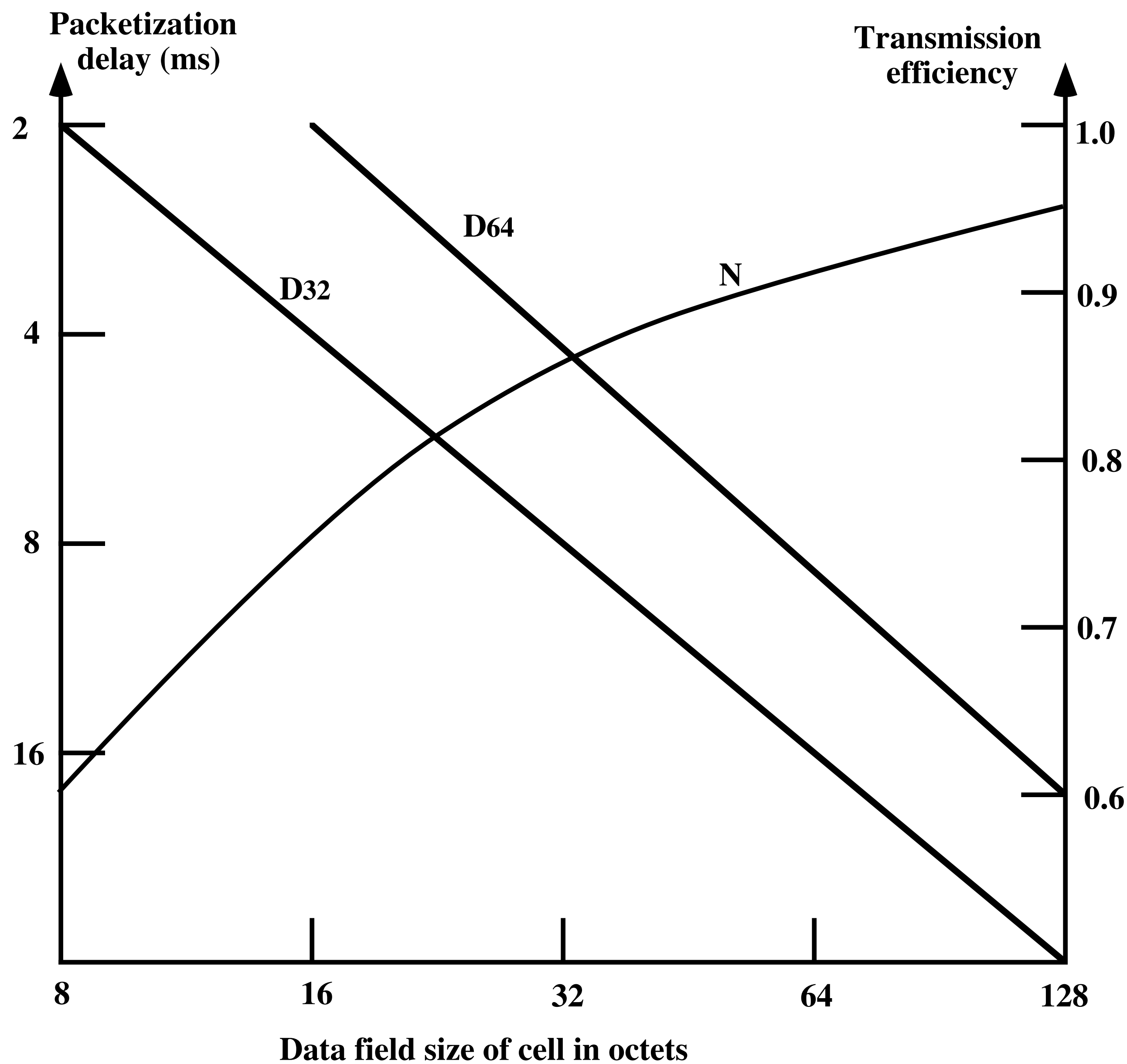
N for fixed-sized cells has a sawtooth shape. For long messages, the optimal achievable efficiency is approached. It is only for very short cells that efficiency is rather low. For variable-length cells, efficiency can be quite high, approaching 100% for large X. However, it does not provide significant gains over fixed-length cells for most values of X.

3.8 a. As we have already seen in Problem 3.7:

$$N = \frac{L}{L + H}$$

b. $D = \dfrac{8 \times L}{R}$

c.



A data field of 48 octets, which is what is used in ATM, seems to provide a reasonably good tradeoff between the requirements of low delay and high efficiency.

3.9 a. The transmission time for one cell through one switch is $t = (53 \times 8)/(43 \times 10^6) = 9.86\mu s$.

b. The maximum time from when a typical video cell arrives at the first switch (and possibly waits) until it is finished being transmitted by the 5th and last one is $2 \times 5 \times 9.86\mu s = 98.6\mu s$.

c. The average time from the input of the first switch to clearing the fifth is $(5 + 0.6 \times 5 \times 0.5) \times 9.86\mu s = 64.09\mu s$.

d. The transmission time is always incurred so the jitter is due only to the waiting for switches to clear. In the first case the maximum jitter is 49.3μs. In the second case the average jitter is $64.09 - 49.3 = 14.79\mu s$.

CHAPTER 4
PROTOCOLS AND THE TCP/IP SUITE

ANSWERS TO QUESTIONS

4.1 The network access layer is concerned with the exchange of data between a computer and the network to which it is attached.

4.2 The transport layer is concerned with data reliability and correct sequencing.

4.3 A protocol is the set of rules or conventions governing the way in which two entities cooperate to exchange data.

4.4 A PDU is the combination of data from the next higher communications layer and control information.

4.5 The software structure that implements the communications function. Typically, the protocol architecture consists of a layered set of protocols, with one or more protocols at each layer.

4.6 Transmission Control Protocol/Internet Protocol (TCP/IP) are two protocols originally designed to provide low level support for internetworking. The term is also used generically to refer to a more comprehensive collection of protocols developed by the U.S. Department of Defense and the Internet community.

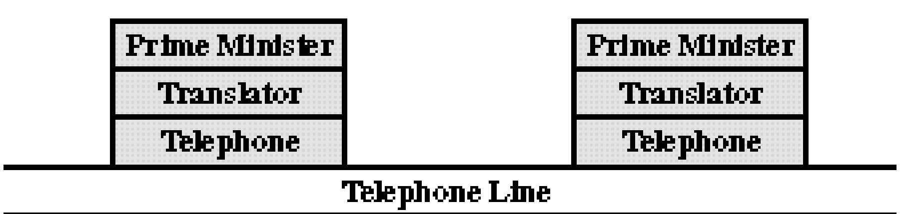
4.7 Layering decomposes the overall communications problem into a number of more manageable subproblems.

4.8 A router is a device that operates at the Network layer of the OSI model to connect dissimilar networks.

ANSWERS TO PROBLEMS

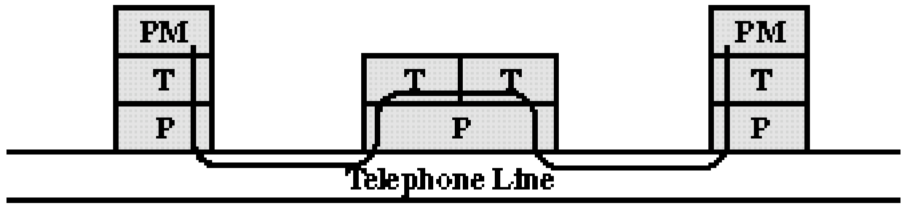
4.1 The guest effectively places the order with the cook. The host communicates this order to the clerk, who places the order with the cook. The phone system provides the physical means for the order to be transported from host to clerk. The cook gives the pizza to the clerk with the order form (acting as a "header" to the pizza). The clerk boxes the pizza with the delivery address, and the delivery van encloses all of the orders to be delivered. The road provides the physical path for delivery.

4.2 **a.**



The PMs speak as if they are speaking directly to each other. For example, when the French PM speaks, he addresses his remarks directly to the Chinese PM. However, the message is actually passed through two translators via the phone system. The French PM's translator translates his remarks into English and telephones these to the Chinese PM's translator, who translates these remarks into Chinese.

b.



An intermediate node serves to translate the message before passing it on.

4.3 Perhaps the major disadvantage is the processing and data overhead. There is processing overhead because as many as seven modules (OSI model) are invoked to move data from the application through the communications software. There is data overhead because of the appending of multiple headers to the data. Another possible disadvantage is that there must be at least one protocol standard per layer. With so many layers, it takes a long time to develop and promulgate the standards.

4.4 No. There is no way to be assured that the last message gets through, except by acknowledging it. Thus, either the acknowledgment process continues forever, or one army has to send the last message and then act with uncertainty.

4.5 A case could be made either way. **First**, look at the functions performed at the network layer to deal with the communications network (hiding the details from the upper layers). The network layer is responsible for routing data through the network, but with a broadcast network, routing is not needed. Other functions, such as sequencing, flow control, error control between end systems, can be accomplished at layer 2, because the link layer will be a protocol directly between the two end systems, with no intervening switches. So it would seem that a network layer is not needed. **Second**, consider the network layer from the point of view of the upper layer using it. The upper layer sees itself attached to an access point into a network supporting communication with multiple devices. The layer for assuring that data sent across a network is delivered to one of a number of other end systems is the network layer. This argues for inclusion of a network layer.

In fact, the OSI layer 2 is split into two sublayers. The lower sublayer is concerned with medium access control (MAC), assuring that only one end system at a time transmits; the MAC sublayer is also responsible for addressing other end systems across the LAN. The upper sublayer is called Logical Link Control (LLC). LLC performs traditional link control functions. With the MAC/LLC combination, no network layer is needed (but an internet layer may be needed).

4.6 The internet protocol can be defined as a separate layer. The functions performed by IP are clearly distinct from those performed at a network layer and those performed at a transport layer, so this would make good sense.

The session and transport layer both are involved in providing an end-to-end service to the OSI user, and could easily be combined. This has been done in TCP/IP, which provides a direct application interface to TCP.

4.7 **a.** No. This would violate the principle of separation of layers. To layer (N – 1), the N-level PDU is simply data. The (N – 1) entity does not know about the internal format of the N-level PDU. It breaks that PDU into fragments and reassembles them in the proper order.

b. Each N-level PDU must retain its own header, for the same reason given in (a).

4.8 Data plus transport header plus internet header equals 1820 bits. This data is delivered in a sequence of packets, each of which contains 24 bits of network header and up to 776 bits of higher-layer headers and/or data. Three network packets are needed. Total bits delivered = $1820 + 3 \times 24 = 1892$ bits.

4.9 UDP provides the source and destination port addresses and a checksum that covers the data field. These functions would not normally be performed by protocols above the transport layer. Thus UDP provides a useful, though limited, service.

4.10 In the case of IP and UDP, these are unreliable protocols that do not guarantee delivery, so they do not notify the source. TCP does guarantee delivery. However, the technique that is used is a timeout. If the source does not receive an acknowledgment to data within a given period of time, the source retransmits.

4.11 UDP has a fixed-sized header. The header in TCP is of variable length.

Chapter 5
Antennas and Propagation

Answers to Questions

5.1 The two functions of an antenna are: (1) For transmission of a signal, radio-frequency electrical energy from the transmitter is converted into electromagnetic energy by the antenna and radiated into the surrounding environment (atmosphere, space, water); (2) for reception of a signal, electromagnetic energy impinging on the antenna is converted into radio-frequency electrical energy and fed into the receiver.

5.2 An **isotropic antenna** is a point in space that radiates power in all directions equally.

5.3 A radiation pattern is a graphical representation of the radiation properties of an antenna as a function of space coordinates.

5.4 A parabolic antenna creates, in theory, a parallel beam without dispersion. In practice, there will be some beam spread. Nevertheless, it produces a highly focused, directional beam.

5.5 Effective area and wavelength.

5.6 Free space loss.

5.7 **Thermal noise** is due to thermal agitation of electrons. **Intermodulation noise** produces signals at a frequency that is the sum or difference of the two original frequencies or multiples of those frequencies. **Crosstalk** is the unwanted coupling between signal paths. **Impulse noise** is noncontinuous, consisting of irregular pulses or noise spikes of short duration and of relatively high amplitude.

5.8 Refraction is the bending of a radio beam caused by changes in the speed of propagation at a point of change in the medium.

5.9 The term *fading* refers to the time variation of received signal power caused by changes in the transmission medium or path(s).

5.10 **Diffraction** occurs at the edge of an impenetrable body that is large compared to the wavelength of the radio wave. The edge in effect become a source and waves radiate in different directions from the edge, allowing a beam to bend around an obstacle. If the size of an obstacle is on the order of the wavelength of the signal or less, **scattering** occurs. An incoming signal is scattered into several weaker outgoing signals in unpredictable directions.

5.11 **Fast fading** refers to changes in signal strength between a transmitter and receiver as the distance between the two changes by a small distance of about one-half a wavelength. **Slow fading** refers to changes in signal strength between a transmitter and receiver as the distance between the two changes by a larger distance, well in excess of a wavelength.

5.12 **Flat fading**, or nonselective fading, is that type of fading in which all frequency components of the received signal fluctuate in the same proportions simultaneously. **Selective fading** affects unequally the different spectral components of a radio signal.

5.13 **Space diversity** involves the physical transmission path and typical refers to the use of multiple transmitting or receiving antennas. With **frequency diversity**, the signal is spread out over a larger frequency bandwidth or carried on multiple frequency carriers. **Time diversity** techniques aim to spread the data out over time so that a noise burst affects fewer bits.

ANSWERS TO PROBLEMS

5.1

Distance (km)	Radio (dB)	Wire (dB)
1	–6	–3
2	–12	–6
4	–18	–12
8	–24	–24
16	–30	–48

5.2 The length of a half-wave dipole is one-half the wavelength of the signal that can be transmitted most efficiently. Therefore, the optimum wavelength in this case is λ = 20 m. The optimum free space frequency is $f = c/\lambda = (3 \times 10^8)/20 = 15$ MHz.

5.3 We have $\lambda f = c$; in this case $\lambda \times 30 = 3 \times 10^8$ m/sec, which yields a wavelength of 10,000 km. Half of that is 5,000 km which is comparable to the east-to-west dimension of the continental U.S. While an antenna this size is impractical, the U.S. Defense Department has considered using large parts of Wisconsin and Michigan to make an antenna many kilometers in diameter.

5.4 **a.** Using $\lambda f = c$, we have $\lambda = (3 \times 10^8$ m/sec$)/(300$ Hz$) = 1{,}000$ km, so that $\lambda/2 = 500$ km.
b. The carrier frequency corresponding to $\lambda/2 = 1$ m is given by: $f = c/\lambda = (3 \times 10^8$ m/sec$)/(2$ m$) = 150$ MHz.

5.5 $\lambda = 2 \times 2.5 \times 10^{-3}$ m $= 5 \times 10^{-3}$ m
$f = c/\lambda = (3 \times 10^8$ m/sec$)/(5 \times 10^{-3}$ m$) = 6 \times 10^{10}$ Hz $= 60$ GHz

5.6 **a.** First, take the derivative of both sides of the equation $y^2 = 2px$:

$$\frac{dy}{dx}y^2 = \frac{dy}{dx}(2px);\ \ 2y\frac{dy}{dx} = 2p;\ \ \frac{dy}{dx} = \frac{p}{y}$$

Therefore $\tan \beta = (p/y_1)$.

b. The slope of PF is $(y_1 - 0)/(x_1 - (p/2))$. Therefore:

$$\tan\alpha = \frac{\dfrac{y_1}{x_1 - \dfrac{p}{2}} - \dfrac{p}{y_1}}{1 + \dfrac{y_1}{x_1 - \dfrac{p}{2}}\dfrac{p}{y_1}} = \frac{y_1^2 - px_1 + \dfrac{1}{2}p^2}{x_1y_1 - \dfrac{1}{2}py_1 + py_1}$$

Because $y_1^2 = 2px_1$, this simplifies to $\tan\alpha = (p/y_1)$.

5.7

Antenna	λ = 30 cm		λ = 3 mm	
	Effective area (m^2)	**Gain**	**Effective area (m^2)**	**Gain**
Isotropic	0.007	1	7.2×10^{-7}	1
Infinitesimal dipole or loop	0.011	1.5	1.1×10^{-6}	1.5
Half-wave dipole	0.012	1.64	1.2×10^{-6}	1.64
Horn	2.54	349	2.54	3.5×10^{6}
Parabolic	1.76	244	1.76	2.4×10^{6}
Turnstile	0.008	1.15	8.2×10^{-7}	1.15

5.8 $L_{dB} = 20\log(f_{MHz}) + 120 + 20\log(d_{km}) + 60 - 147.56$
$= 20\log(f_{MHz}) + 20\log(d_{km}) + 32.44$

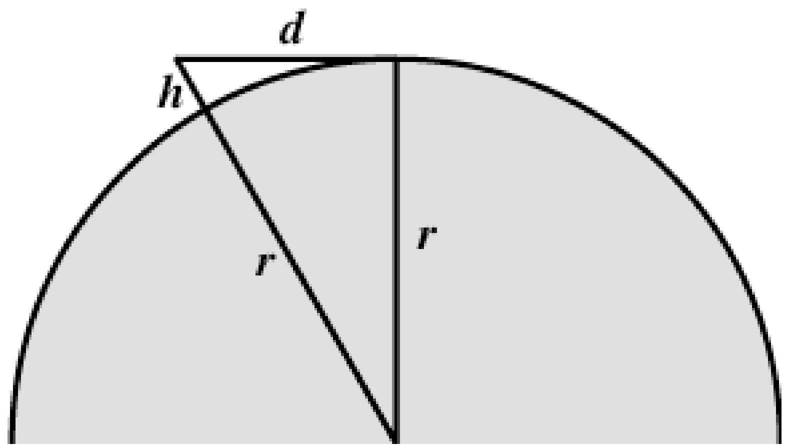
5.9 We have $P_r = [(P_t)(G_t)(G_r)(c)^2]/(4\pi fd)^2$
$= [(1)(2)(2)(3 \times 10^8)^2]/[(16)(\pi)^2(3 \times 10^8)^2(10^4)^2] = 0.76 \times 10^{-9}$ W
Source: [THUR00]

5.10 **a.** From Appendix 2A, $Power_{dBW} = 10\log(Power_W) = 10\log(50) = 17$ dBW
$Power_{dBm} = 10\log(Power_{mW}) = 10\log(50{,}000) = 47$ dBm
b. Using Equation (5.2),
$L_{dB} = 20\log(900 \times 10^6) + 20\log(100) - 147.56 = 120 + 59.08 + 40 - 147.56 = 71.52$
Therefore, received power in dBm = 47 – 71.52 = –24.52 dBm
c $L_{dB} = 120 + 59.08 + 80 - 147.56 = 111.52$; $P_{r,dBm} = 47 - 111.52 = -64.52$ dBm
d The antenna gain results in an increase of 3 dB, so that $P_{r,dBm} = -61.52$ dBm
Source: [RAPP02]

5.11 **a.** From Table 5.2, $G = 7A/\lambda^2 = 7Af^2/c^2 = (7\times\pi\times(0.6)^2\times(2\times10^9)^2]/(3\times10^8)^2 = 351.85$
$G_{dB} = 25.46$ dB
b. 0.1 W x 351.85 = 35.185 W
c. Use $L_{dB} = 20\log(4\pi) + 20\log(d) + 20\log(f) - 20\log(c) - 10\log(G_r) - 10\log(G_t)$
$L_{dB} = 21.98 + 87.6 + 186.02 - 169.54 - 25.46 - 25.46 = 75.14$ dB
The transmitter power, in dBm is 10 log (100) = 20.
The available received signal power is 20 – 75.14 = –55.14 dBm

5.12 From Equation 2.2, the ratio of transmitted power to received power is
$P_t/P_r = (4\pi d/\lambda)^2$
If we double the frequency, we halve λ, or if we double the distance, we double d, so the new ratio for either of these events is:
$P_t/P_{r2} = (8\pi d/\lambda)^2$
Therefore:
$10 \log (P_r/P_{r2}) = 10 \log (2^2) = 6$ dB

5.13



By the Pythagorean theorem: $d^2 + r^2 = (r + h)^2$
Or, $d^2 = 2rh + h^2$. The h^2 term is negligible with respect to $2rh$, so we use $d^2 = 2rh$.

Then, $d_{km} = \sqrt{2r_{km}h_{km}} = \sqrt{2r_{km}h_m/1000} = \sqrt{2 \times 6.37 \times h_m} = 3.57\sqrt{h_m}$

5.14 For radio line of sight, we use $d = 3.57\sqrt{Kh}$, with $K = 4/3$, we have $80^2 = (3.57)^2 \times 1.33 \times h$. Solving for h, we get h = 378 m.

5.15 $N = -228.6$ dBW $+ 10 \log T + 10 \log B$
We have $T = 273.15 + 50 = 323.15$ K, and B = 10,000
$N = -228.6$ dBW $+ 25.09 + 40 = -163.51$ dBW
Converting to watts, $N_W = 10^{N/10} = 4 \times 10^{-17}$ W

5.16 **a.** Output waveform:
$\sin (2\pi f_1 t) + 1/3 \sin (2\pi(3f_1)t) + 1/5 \sin (2\pi(5f_1)t) + 1/7 \sin (2\pi (7f_1)t)$
where $f_1 = 1/T = 1$ kHz
Output power = 1/2 (1 + 1/9 + 1/25 + 1/49) = 0.586 watt
b. Output noise power = 8 kHz × 0.1 μWatt/Hz = 0.8 mWatt
SNR = 0.586/0.0008 = 732.5 $(SNR)_{dB} = 28.65$

5.17 **(**E_b/N_0) = –151 dBW – 10 log 2400 – 10 log 1500 + 228.6 dBW = 12 dBW
Source: [FREE98a]

5.18 Let *RI* = refractive index, α = angle of incidence, β = angle of refraction

$(\sin \alpha)/\sin \beta) = RI_{air}/RI_{water} = 1.0003/(4/3) = 0.75$
$\sin \beta = 0.5/0.75 = 0.66; \quad \beta = 41.8°$

CHAPTER 6
SIGNAL ENCODING TECHNIQUES

ANSWERS TO QUESTIONS

6.1 In differential encoding, the signal is decoded by comparing the polarity of adjacent signal elements rather than determining the absolute value of a signal element.

6.2 A modem converts digital information into an analog signal, and conversely.

6.3 Cost, capacity utilization, and security and privacy are three major advantages enjoyed by digital transmission over analog transmission.

6.4 With amplitude-shift keying, binary values are represented by two different amplitudes of carrier frequencies. This approach is susceptible to sudden gain changes and is rather inefficient.

6.5 Non return-to-zero-level (NRZ-L) is a data encoding scheme in which a negative voltage is used to represent binary one and a positive voltage is used to represent binary zero. A disadvantage of NRZ transmission is that it is difficult to determine where one bit ends and the next bit begins.

6.6 The difference is that offset QPSK introduces a delay of one bit time in the Q stream

6.7 QAM takes advantage of the fact that it is possible to send two different signals simultaneously on the same carrier frequency, by using two copies of the carrier frequency, one shifted by 90° with respect to the other. For QAM, each carrier is ASK modulated.

6.8 The sampling rate must be higher than twice the highest signal frequency.

6.9 Frequency modulation (FM) and phase modulation (PM) are special cases of angle modulation. For PM, the phase is proportional to the modulating signal. For FM, the derivative of the phase is proportional to the modulating signal.

ANSWERS TO PROBLEMS

6.1 $s(t) = d_1(t)\cos w_c t + d_2(t)\sin w_c t$

Use the following identities: $\cos 2\alpha = 2\cos^2\alpha - 1$; $\sin 2\alpha = 2\sin\alpha \cos\alpha$

$$\begin{aligned} s(t)\cos w_c t &= d_1(t)\cos^2 w_c t + d_2(t)\sin w_c t \cos w_c t \\ &= (1/2)d_1(t) + (1/2)d_1(t)\cos 2w_c t + (1/2)d_2(t)\sin 2w_c t \end{aligned}$$

Use the following identities: $\cos 2\alpha = 1 - 2\sin^2\alpha$; $\sin 2\alpha = 2\sin\alpha \cos\alpha$

$$s(t)\sin w_c t = d_1(t)\cos w_c t \sin w_c t + d_2(t)\sin^2 w_c t$$
$$= (1/2)d_1(t)\sin 2w_c t + (1/2)d_2(t) - (1/2)d_2(t)\cos 2w_c t$$

All terms at $2w_c$ are filtered out by the low-pass filter, yielding:

$y_1(t) = (1/2)d_1(t)$; $y_2(t) = (1/2)d_2(t)$

6.2 T_s = signal element period; T_b = bit period; A = amplitude = 0.005

a. $T_s = T_b = 10^{-5}$ sec

$$P = \frac{1}{T_s}\int_0^{T_s} s^2(t) = \frac{A^2}{2}$$

$$E_b = P \times T_b = P \times T_s = \frac{A^2}{2} \times T_s; \quad N_0 = 2.5 \times 10^{-8} \times T_s$$

$$\frac{E_b}{N_0} = \frac{\left(A^2/2\right) \times T_s}{2.5 \times 10^{-8} \times T_s} = 500; \quad \left(E_b/N_0\right)_{\mathrm{dB}} = 10\log 500 = 27 \text{ dB}$$

b.

$$T_b = \frac{T_s}{2}; \; E_b = P \times \frac{T_s}{2}; \; N_0 = 2.5 \times 10^{-8} \times T_s$$

$$\left(E_b/N_0\right) = 250; \qquad \left(E_b/N_0\right)_{\mathrm{dB}} = 10\log 250 = 24\,\mathrm{dB}$$

6.3 Each signal element conveys two bits. First consider NRZ-L. It should be clear that in this case, D = R/2. For the remaining codes, one must first determine the average number of pulses per bit. For example, for Biphase-M, there is an average of 1.5 pulses per bit. We have pulse rate of P, which yields a data rate of

R = P/1.5

D = P/2 = (1.5 x R)/2 = 0.75 × R

6.4 $E_b/N_0 = (S/N)(B/R)$

$S/N = (R/B)(E_b/N_0) = 1 \times (E_b/N_0)$

$(S/N)_{dB} = (E_b/N_0)_{dB}$

For **FSK** and **ASK**, from Figure 4.10, $(E_b/N_0)_{dB} = 13.5$ dB

$(S/N)_{dB} = 13.5$ dB

For **PSK**, from Figure 4.10, $(E_b/N_0)_{dB} = 10.5$

$(S/N)_{dB} = 10.5$ dB

For **QPSK**, the effective bandwidth is halved, so that

$(R/B) = 2$

$(R/B)_{dB} = 3$

$(S/N)_{dB} = 3 + 10.5 = 13.5$ dB

6.5 For **ASK**, $B_T = (1 + r)R = (1.5)2400 = 3600$ Hz
For **FSK**, $B_T = 2\,\Delta F + (1 + r)R = 2(2.5 \times 10^3) + (1.5)2400 = 8600$ Hz

6.6 For multilevel signaling $B_T = [(1 + r)/\log_2 L]R$
For 2400 bps QPSK, $\log_2 L = \log_2 4 = 2$

$B_T = (2/2)2400 = 2400$ Hz, which just fits the available bandwidth

For 8-level 4800 bps signaling, $\log_2 L = \log_2 8 = 3$

$B_T = (2/3)(4800) = 3200$ Hz, which exceeds the available bandwidth

6.7 As was mentioned in the text, analog signals in the voice band that represent digital data have more high frequency components than analog voice signals. These higher components cause the signal to change more rapidly over time. Hence, DM will suffer from a high level of slope overload noise. PCM, on the other hand, does not estimate changes in signals, but rather the absolute value of the signal, and is less affected than DM.

6.8 No. The demodulator portion of a modem expects to receive a very specific type of waveform (e.g., ASK) and would not produce meaningful output with voice input. Thus, it would not function as the coder portion of a codec. The case against using a codec in place of a modem is less easily explained, but the following intuitive argument is offered. If the decoder portion of a codec is used in place of the modulator portion of a modem, it must accept an arbitrary bit pattern, interpret groups of bits as a sample, and produce an analog output. Some very wide value swings are to be expected, resulting in a strange-looking waveform. Given the effects of noise and attenuation, the digital output produced at the receiving end by the coder portion of the codec will probably contain many errors.

6.9 From the text, $(SNR)_{db} = 6.02\,n + 1.76$, where n is the number of bits used for quantization. In this case, $(SNR)_{db} = 60.2 + 1.76 = 61.96$ dB.

6.10 **a.** $(SNR)_{db} = 6.02\,n + 1.76 = 30$ dB
$n = (30 - 1.76)/6.02 = 4.69$
Rounded off, n = 5 bits
This yields $2^5 = 32$ quantization levels
b. R = 7000 samples/s × 5 bits/sample = 35 Kbps

6.11 The maximum slope that can be generated by a DM system is
$\delta/T_s = \delta f_s$
where T_s = period of sampling; f_s = frequency of sampling
Consider that the maximum frequency component of the signal is

$w(t) = A \sin 2\pi f_a t$

The slope of this component is

$dw(t)/dt = A 2\pi f_a \cos 2\pi f_a t$

and the maximum slope is $A2\pi f_a$. To avoid slope overload, we require that

$$\delta f_s > A2\pi f_a$$

or $$\delta > \frac{2\pi f_a A}{f_s}$$

Source: [COUC01]

6.12 **a.** A total of 2^8 quantization levels are possible, so the normalized step size is $2^{-8} = 0.003906$.

b. The actual step size, in volts, is:

$0.003906 \times 10\text{V} = 0.03906\text{V}$

c. The maximum normalized quantized voltage is $1 - 2^{-8} = 0.9961$. Thus the actual maximum quantized voltage is:

$0.9961 \times 10\text{V} = 9.961\text{V}$

d. The normalized step size is 2^{-8}. The maximum error that can occur is one-half the step size. Therefore, the normalized resolution is:

$\pm\ 1/2 \times 2^{-8} = 0.001953$

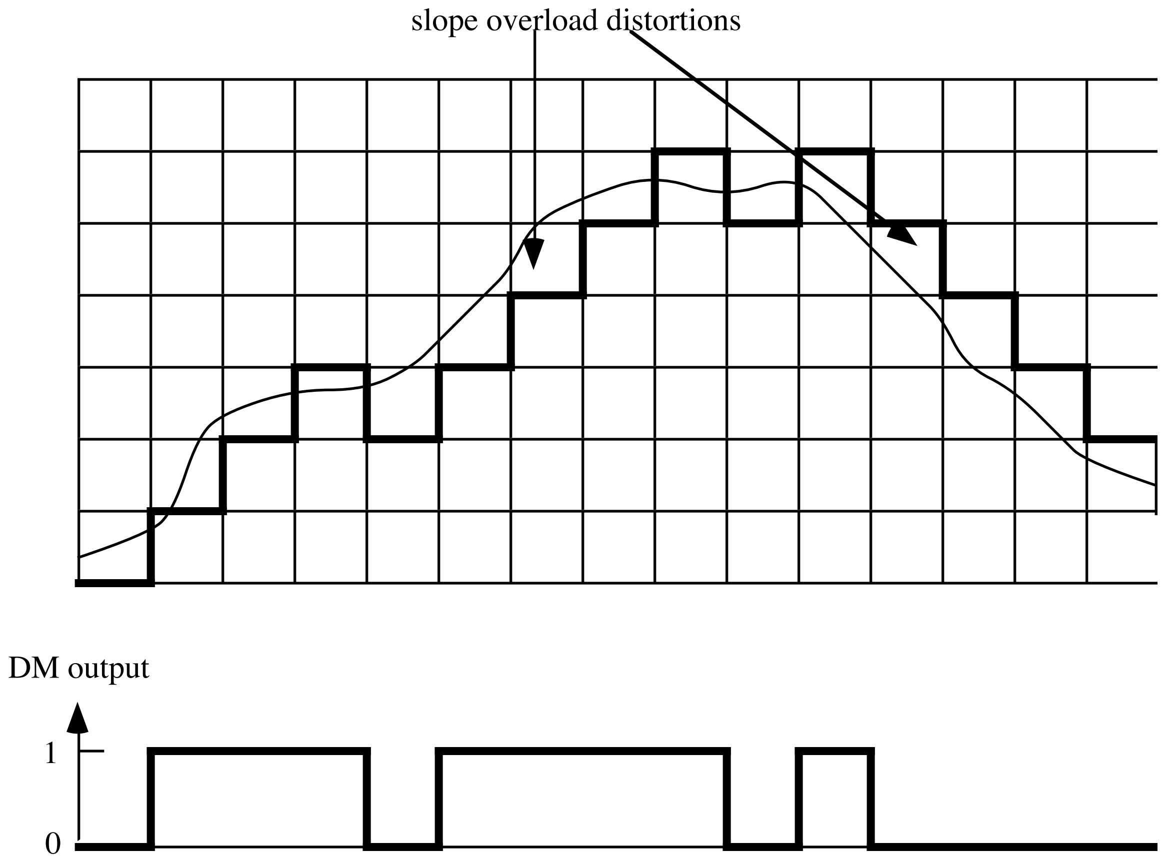
e. The actual resolution is

$\pm\ 0.001953 \times 10\text{V} = \pm\ 0.01953\text{V}$

f. The percentage resolution is

$\pm\ 0.001953 \times 100\% = \pm\ 0.1953\ \%$

6.13



6.14 $s(t) = A_c \cos[2\pi f_c t + \phi(t)] = 10 \cos[(10^8)\pi t + 5 \sin 2\pi(10^3)t]$
Therefore, $\phi(t) = 5 \sin 2\pi(10^3)t$, and the maximum phase deviation is 5 radians. For frequency deviation, recognize that the change in frequency is determined by the derivative of the phase:
$\phi'(t) = 5\,(2\pi)\,(10^3) \cos 2\pi(10^3)t$
which yields a frequency deviation of $\Delta f = (1/2\pi)[\,5\,(2\pi)\,(10^3)] = 5$ kHz

6.15 **a.** $s(t) = A_c \cos[2\pi f_c t + n_p m(t)] = 10 \cos[2\pi(10^6)t + 0.1 \sin(10^3)\pi t]$
$A_c = 10$; $f_c = 10^6$
$10\, m(t) = 0.1 \sin(10^3)\pi t$, so $m(t) = 0.01 \sin(10^3)\pi t$
b. $s(t) = A_c \cos[2\pi f_c t + \phi(t)] = 10 \cos[2\pi(10^6)t + 0.1 \sin(10^3)\pi t]$
$A_c = 10$; $f_c = 10^6$
$\phi(t) = 0.1 \sin(10^3)\pi t$, so $\phi'(t) = 100\pi \cos(10^3)\pi t = n_f m(t) = 10\, m(t)$
Therefore $m(t) = 10\pi \cos(10^3)\pi t$

6.16 **a.** For AM, $s(t) = [1 + m(t)] \cos(2\pi f_c t)$
$s_1(t) = [1 + m_1(t)] \cos(2\pi f_c t)$; $\qquad s_2(t) = [1 + m_2(t)] \cos(2\pi f_c t)$
For the combined signal $m_c(t) = m_1(t) + m_2(t)$,
$s_c(t) = [1 + m_1(t) + m_2(t)] \cos(2\pi f_c t) = s_1(t) + s_2(t) - 1$, which is a linear combination of $s_1(t)$ and $s_2(t)$.

b. For PM, $s(t) = A\cos(2\pi f_c t + n_p m(t))$
$s_1(t) = A\cos(2\pi f_c t + n_p m_1(t))$; $s_2(t) = A\cos(2\pi f_c t + n_p m_2(t))$
For the combined signal $m_c(t) = m_1(t) + m_2(t)$,
$s_c(t) = A\cos(2\pi f_c t + n_p[m_1(t) + m_2(t)])$, which is not a linear combination of $s_1(t)$ and $s_2(t)$.

CHAPTER 7
SPREAD SPECTRUM

ANSWERS TO QUESTIONS

7.1 The bandwidth is wider after the signal has been encoded using spread spectrum.

7.2 **(1)** We can gain immunity from various kinds of noise and multipath distortion. **(2)** It can also be used for hiding and encrypting signals. Only a recipient who knows the spreading code can recover the encoded information. **(3)** Several users can independently use the same higher bandwidth with very little interference, using code division multiple access (CDMA).

7.3 With frequency hopping spread spectrum (FHSS), the signal is broadcast over a seemingly random series of radio frequencies, hopping from frequency to frequency at fixed intervals. A receiver, hopping between frequencies in synchronization with the transmitter, picks up the message.

7.4 Slow FHSS = multiple signal elements per hop; fast FHSS = multiple hops per signal element.

7.5 With direct sequence spread spectrum (DSSS), each bit in the original signal is represented by multiple bits in the transmitted signal, using a spreading code.

7.6 For an *N*-bit spreading code, the bit rate after spreading (usually called the chip rate) is *N* times the original bit rate.

7.7 CDMA allows multiple users to transmit over the same wireless channel using spread spectrum. Each user uses a different spreading code. The receiver picks out one signal by matching the spreading code.

7.8 **Autocorrelation**, which is defined in Equation 7.10, is the correlation or comparison of a sequence with all phase shifts of itself. **Cross-correlation**, which is defined in Equation 7.11, is the comparison is made between two sequences from different sources rather than a shifted copy of a sequence with itself.

ANSWERS TO PROBLEMS

7.1 a. We have $C = B \log_2 (1 + \text{SNR})$. For SNR = 0.1, C = 0.41 MHz; For SNR = 0.01, C = 3.9 MHz; for SNR = 0.001, C = 38.84 MHz. Thus, to achieve the desired SNR, the signal must be spread so that 56 KHz is carried in very large bandwidths.

b. For 1 bps/Hz, the equation $C = B \log_2 (1 + \text{SNR})$ becomes $\log_2 (1 + \text{SNR}) = 1$. Solving for SNR, we have SNR = 1. Thus a far higher SNR is required without spread spectrum.

7.2 The total number of tones, or individual channels is:
$W_s / f_d = (400 \text{ MHz})/(100 \text{ Hz}) = 4 \times 10^6$.
The minimum number of PN bits = $\lceil \log_2 (4 \times 10^6) \rceil = 22$
where $\lceil x \rceil$ indicates the smallest integer value not less than x. Source: [SKLA01]

7.3 $W_s = 1000 f_d$; $W_d = 4 f_d$; Using Equation 7.3 , $G_p = W_s / W_d = 250 = 24$ dB

7.4 **a.** Period of the PN sequence is $2^4 - 1 = 15$
b. MFSK
c. $L = 2$
d. $M = 2^L = 4$
e. $k = 3$
f. slow FHSS
g. $2^k = 8$
h.

Time	0	1	2	3	4	5	6	7	8	9	10	11
Input data	0	1	1	1	1	1	1	0	0	0	1	0
Frequency	f_1		f_3		f_3		f_2		f_0		f_2	

Time	12	13	14	15	16	17	18	19
Input data	0	1	1	1	1	0	1	0
Frequency	f_1		f_3		f_2		f_2	

7.5 **a.** Period of the PN sequence is $2^4 - 1 = 15$
b. MFSK
c. $L = 2$
d. $M = 2^L = 4$
e. $k = 3$
f. fast FHSS
g. $2^k = 8$
h. Same as for Problem 7.4

7.6 **a.** This is from the example 6.1.

$f_1 =$ 75 kHz 000	$f_2 =$125 kHz 001	$f_3 =$ 175 kHz 010	$f_4 =$ 225 kHz 011
$f_5 =$ 275 kHz 100	$f_6 =$ 325 kHz 101	$f_7 =$ 375 kHz 110	$f_8 =$ 425 kHz 111

b. We need three more sets of 8 frequencies. The second set can start at 475 kHz, with 8 frequencies separated by 50 kHz each. The third set can start at 875 kHz, and the fourth set at 1275 kHz.

7.7 **a.** C0 = 1110010; C1 = 0111001; C2 = 1011100; C3 = 0101110; C4 = 0010111; C5 = 1001011; C6 = 1100101
b. C1 output = –7; bit value = 0
c. C2 output = +9; bit value = 1

7.8 It is –1 for each of the other 6 channels.

7.9 Let us start with an initial seed of 1. The first generator yields the sequence:

1, 6, 10, 8, 9, 2, 12, 7, 3, 5, 4, 11, 1, . . .

The second generator yields the sequence:

1, 7, 10, 5, 9, 11, 12, 6, 3, 8, 4, 2, 1, . . .

Because of the patterns evident in the second half of the latter sequence, most people would consider it to be less random than the first sequence.

7.10 When $m = 2^k$, the right-hand digits of X_n are much less random than the left-hand digits. See [KNUT98], page 13 for a discussion.

7.11 Many packages make use of a linear congruential generator with $m = 2^k$. As discussed in the answer to Problem 10, this leads to results in which the right-hand digits are much less random than the left-hand digits. Now, if we use a linear congruential generator of the following form:

$$X_{n+1} = (aX_n + c) \bmod m$$

then it is easy to see that the scheme will generate all even integers, all odd integers, or will alternate between even and odd integers, depending on the choice for a and c. Often, a and c are chosen to create a sequence of alternating even and odd integers. This has a tremendous impact on the simulation used for calculating π. The simulation depends on counting the number of pairs of integers whose greatest common divisor is 1. With truly random integers, one-fourth of the pairs should consist of two even integers, which of course have a gcd greater than 1. This never occurs with sequences that alternate between even and odd integers. To get the correct value of π using Cesaro's method, the number of pairs with a gcd of 1 should be approximately 60.8%. When pairs are used where one number is odd and the other even, this percentage comes out too high, around 80%, thus leading to the too small value of π. For a further discussion, see Danilowicz, R. "Demonstrating the Dangers of Pseudo-Random Numbers," *SIGCSE Bulletin*, June 1989.

7.12 a.

State	B_4	B_3	B_2	B_1	B_0	$B_0 \oplus B_3$	**output**
0	1	0	0	0	0	0	0
1	0	1	0	0	0	1	0
2	1	0	1	0	0	0	0
3	0	1	0	1	0	1	0
4	1	0	1	0	1	1	1
5	1	1	0	1	0	1	0
6	1	1	1	0	1	0	1
7	0	1	1	1	0	1	0
8	1	0	1	1	1	1	1
9	1	1	0	1	1	0	1
10	0	1	1	0	1	0	1
11	0	0	1	1	0	0	0
12	0	0	0	1	1	1	1
13	1	0	0	0	1	1	1
14	1	1	0	0	0	1	0
15	1	1	1	0	0	1	0
16	1	1	1	1	0	1	0
17	1	1	1	1	1	0	1
18	0	1	1	1	1	0	1
19	0	0	1	1	1	1	1
20	1	0	0	1	1	1	1
21	1	1	0	0	1	0	1
22	0	1	1	0	0	1	0
23	1	0	1	1	0	0	0
24	0	1	0	1	1	0	1
25	0	0	1	0	1	1	1
26	1	0	0	1	0	0	0
27	0	1	0	0	1	0	1
28	0	0	1	0	0	0	0
29	0	0	0	1	0	0	0
30	0	0	0	0	1	1	1
31=0	1	0	0	0	0	0	0

b.

State	B_4	B_3	B_2	B_1	B_0	$B_0 \oplus B_1 \oplus B_3 \oplus B_4$	**output**
0	1	0	0	0	0	1	0
1	1	1	0	0	0	0	0
2	0	1	1	0	0	1	0
3	1	0	1	1	0	0	0
4	0	1	0	1	1	1	1
5	1	0	1	0	1	0	1
6	0	1	0	1	0	0	0
7	0	0	1	0	1	1	1
8	1	0	0	1	0	0	0
9	0	1	0	0	1	0	1
10	0	0	1	0	0	0	0
11	0	0	0	1	0	1	0
12	1	0	0	0	1	0	1
13	0	1	0	0	0	1	0
14	1	0	1	0	0	1	0
15	1	1	0	1	0	1	0
16	1	1	1	0	1	1	1
17	1	1	1	1	0	1	0
18	1	1	1	1	1	0	1
19	0	1	1	1	1	1	1
20	1	0	1	1	1	1	1
21	1	1	0	1	1	0	1
22	0	1	1	0	1	0	1
23	0	0	1	1	0	1	0
24	1	0	0	1	1	1	1
25	1	1	0	0	1	1	1
26	1	1	1	0	0	0	0
27	0	1	1	1	0	0	0
28	0	0	1	1	1	0	1
29	0	0	0	1	1	0	1
30	0	0	0	0	1	1	1
31=0	1	0	0	0	0	1	0

7.13 Recall that to compute the cross-correlation, we replace 1 with +1 and 0 with –1. The 8-bit Walsh codes are:

–1	–1	–1	–1	–1	–1	–1	–1
–1	1	–1	1	–1	1	–1	1
–1	–1	1	1	–1	–1	1	1
–1	1	1	–1	–1	1	1	–1
–1	–1	–1	–1	1	1	1	1
–1	1	–1	1	1	–1	1	–1
–1	–1	1	1	1	1	–1	–1
–1	1	1	–1	1	–1	–1	1

It is easily seen that a bitwise multiplication of any two rows produces 0. For example, row 3 multiplied by row 4 equals 1 + (–1) + 1 + (–1) + 1 + (–1) + 1 + (–1) = 0.

7.14 a. 8

b. –8

c.

A output (data = 1)	–1	1	–1	1	–1	1	–1	1	
B output (data = 1)	–1	–1	1	1	–1	–1	1	1	
Received	–2	0	0	2	–2	0	0	2	
Receiver codeword	–1	1	–1	1	–1	1	–1	1	
Multiplication	2	0	0	2	2	0	0	2	=8

d.

A output (data = 0)	1	–1	1	–1	1	–1	1	–1	
B output (data = 1)	–1	–1	1	1	–1	–1	1	1	
Received	0	–2	2	0	0	–2	2	0	
Receiver codeword	–1	1	–1	1	–1	1	–1	1	
Multiplication	0	–2	–2	0	0	–2	–2	0	=–8

e.

A output (data = 1)	–1	1	–1	1	–1	1	–1	1	
B output (data = 0)	1	1	–1	–1	1	1	–1	–1	
Received	0	2	–2	0	0	2	–2	0	
Receiver codeword	–1	1	–1	1	–1	1	–1	1	
Multiplication	0	2	2	0	0	2	2	0	=8

f.

A output (data = 0)	1	–1	1	–1	1	–1	1	–1	
B output (data = 0)	1	1	–1	–1	1	1	–1	–1	
Received	2	0	0	–2	2	0	0	–2	
Receiver codeword	–1	1	–1	1	–1	1	–1	1	
Multiplication	–2	0	0	–2	–2	0	0	–2	=–8

g.

A output (data = 1)	–1	1	–1	1	–1	1	–1	1	
B output (data = 1)	–2	–2	2	2	–2	–2	2	2	
Received	–3	–1	1	3	–3	–1	1	3	
Receiver codeword	–1	1	–1	1	–1	1	–1	1	
Multiplication	3	–1	–1	3	3	–1	–1	3	=8

h.

A output (data = 0)	1	–1	1	–1	1	–1	1	–1	
B output (data = 1)	–2	–2	2	2	–2	–2	2	2	
Received	–1	–2	2	1	–1	–3	3	–1	
Receiver codeword	–1	1	–1	1	–1	1	–1	1	
Multiplication	1	–2	–2	1	1	–3	–3	–1	=–8

Source: [WEBB00]

CHAPTER 8
CODING AND ERROR CONTROL

ANSWERS TO QUESTIONS

8.1 A parity bit appended to an array of binary digits to make the sum of all the binary digits, including the parity bit, always odd (odd parity) or always even (even parity).

8.2 The CRC is an error detecting code in which the code is the remainder resulting from dividing the bits to be checked by a predetermined binary number.

8.3 The CRC has more bits and therefore provides more redundancy. That is, it provides more information that can be used to detect errors.

8.4 Modulo 2 arithmetic, polynomials, and digital logic.

8.5 It is possible. You could design a code in which all codewords are at least a distance of 3 from all other codewords, allowing all single-bit errors to be corrected. Suppose that some but not all codewords in this code are at least a distance of 5 from all other codewords. Then for those particular codewords, but not the others, a double-bit error could be corrected.

8.6 An (n, k) block code encodes k data bits into n-bit codewords.

8.7 An (n, k, K) code processes input data k bits at a time and produces an output of n bits for each incoming k bits. The current output of n bits is a function of the last $K \times k$ input bits.

8.8 A trellis is a diagram that shows the state transitions over time in a convolutional code.

8.9 Detection of errors and retransmission of frames that are received in error.

8.10 Go-back-N ARQ is a form of error control in which a destination station sends a negative acknowledgment (NAK) when it receives an error. The source station receiving the NAK will retransmit the frame in error plus all succeeding frames transmitted in the interim.

ANSWERS TO PROBLEMS

8.1 Any arithmetic scheme will work if applied in exactly the same way to the forward and reverse process. The modulo 2 scheme is easy to implement in circuitry. It also yields a remainder one bit smaller than binary arithmetic.

8.2 **a.** We have:

Pr [single bit in error] = 10^{-3}

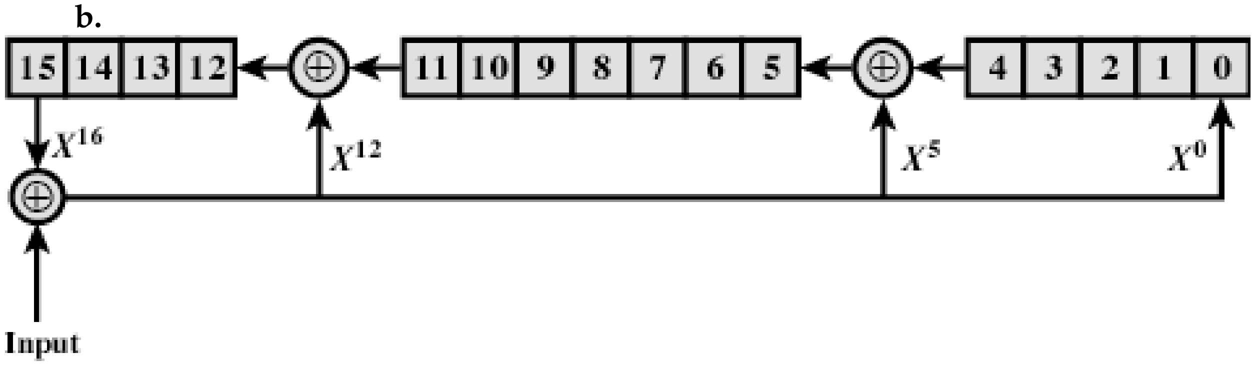
Pr [single bit not in error] = $1 - 10^{-3} = 0.999$
Pr [8 bits not in error] = $(1 - 10^{-3})^8 = (0.999)^8 = 0.992$
Pr [at least one error in frame] = $1 - (1 - 10^{-3})^8 = 0.008$

b. Pr [at least one error in frame] = $1 - (1 - 10^{-3})^{10} = 1 - (0.999)^{10} = 0.01$

8.3 a.

```
                                   1000100010011000
                   ________________________________
10001000000100001 / 10000000000000000000000000000000
                    10001000000100001
                        10000001000010000
                        10001000000100001
                            10010001100010000
                            10001000000100001
                               11001100110001000
                               10001000000100001
                                10001001101010010
                                10001000000100001
         remainder =                    0001101110011000
```

b.



Shift	Shift Register																Input
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	1
2	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0
3	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
4	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
5	0	0	0	1	0	0	1	0	0	0	1	1	0	0	0	1	0
6	0	0	1	0	0	1	0	0	0	1	1	0	0	0	1	0	0
7	0	1	0	0	1	0	0	0	1	1	0	0	0	1	0	0	0
8	1	0	0	1	0	0	0	1	1	0	0	0	1	0	0	0	0
9	0	0	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0
10	0	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	0
11	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	0	0
12	1	0	0	0	1	0	0	1	1	0	1	0	1	0	0	1	0
13	0	0	0	0	0	0	1	1	0	1	1	1	0	0	1	1	0
14	0	0	0	0	0	1	1	0	1	1	1	0	0	1	1	0	0
15	0	0	0	0	1	1	0	1	1	1	0	0	1	1	0	0	0
16	0	0	0	1	1	0	1	1	1	0	0	1	1	0	0	0	0

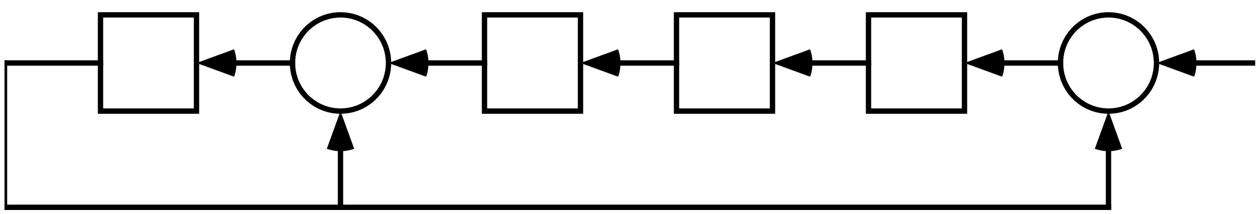
CRC

8.4 At the conclusion of the data transfer, just before the CRC pattern arrives, the shift register should contain the identical CRC result. Now, the bits of the incoming CRC are applied at point C_4 (Figure 8.3). Each 1 bit will merge with a 1 bit (exclusive-or) to produce a 0; each 0 bit will merge with a 0 bit to produce a zero.

8.5

```
               10110110
       110011/1110001100000
              110011
               101111
               110011
                111000
                110011
                  101100
                  110011
                   111110
                   110011
        CRC =       11010
```

8.6 **a.**



b. Data = 1 0 0 1 1 0 1 1 1 0 0

$M(X) = 1 + X^3 + X^4 + X^6 + X^7 + X^8$

$X^4M(X) = X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^4$

$$\frac{X^4M(X)}{P(X)} = X^{12} + X^{11} + X^{10} + X^8 + X^7 + \frac{X^2}{P(X)}$$

$R(X) = X^2$

$T(X) = X^4M(X) + R(X) = X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^4 + X^2$

Code = 0 0 1 0 1 0 0 1 1 0 1 1 1 0 0

c. Code = 0 0 1 0 1 0 0 0 1 0 1 1 1 0 0

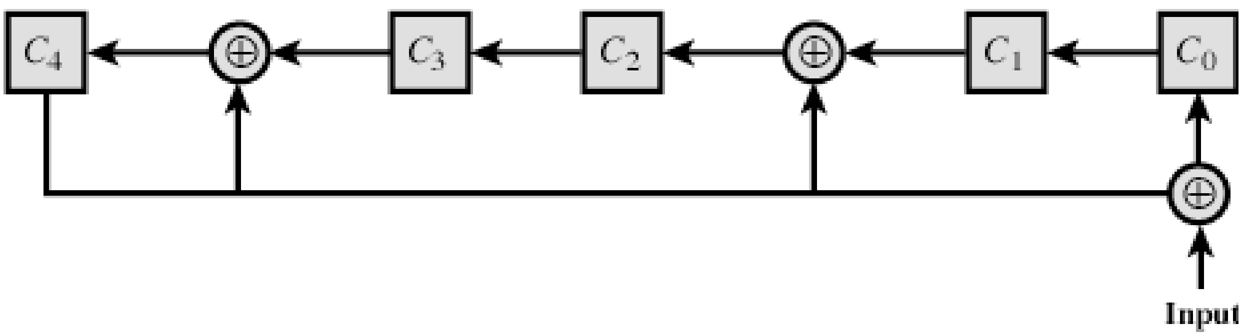
$\frac{T(X)}{P(X)}$ yields a nonzero remainder

8.7 **a.** The multiplication of M(X) by X^{16} corresponds to shifting M(X) 16 places and thus providing the space for a 16-bit FCS. The addition of $X^kL(X)$ to $X^{16}M(X)$ inverts the first 16 bits of G(X) (one's complements). The addition of L(X) to R(X) inverts all of the bits of R(X).

b. The HDLC standard provides the following explanation. The addition of $X^KL(X)$ corresponds to a value of all ones. This addition protects against the obliteration of leading flags, which may be non-detectable if the initial remainder is zero. The addition of L(X) to R(X) ensures that the received, error-free message will result in a unique, non-zero remainder at the receiver. The non-zero remainder protects against the potential non-detectability of the obliteration of trailing flags.

c. The implementation is the same as that shown in Solution 3b, with the following strategy. At both transmitter and receiver, the initial content of the register is preset to all ones. The final remainder, if there are no errors, will be 0001 1101 0000 1111.

8.8 **a.** For simplicity, we do not show the switches.



b.

C_4	C_3	C_2	C_1	C_0	$C_4 \oplus C_3$	$C_4 \oplus C_1$	$C_4 \oplus I$	Input
0	0	0	0	0	0	0	1	1
0	0	0	0	1	0	0	0	0
0	0	0	1	0	0	1	1	1
0	0	1	0	1	0	0	0	0
0	1	0	1	0	1	1	0	0
1	0	1	0	0	1	1	1	0
1	1	1	0	1	0	1	0	1
0	1	1	1	0	1	1	1	1
1	1	1	0	1	0	1	1	0
0	1	1	1	1	1	1	1	1
1	1	1	1	1	0	0	1	–
0	1	0	1	1	1	1	0	–
1	0	1	1	0	1	0	1	–
1	1	0	0	1	0	1	1	–
0	0	1	1	1	0	1	0	–
0	1	1	1	0				

c. The partial results from the long division show up in the shift register, as indicated by the shaded portions of the preceding table. Compare to long division example in Section 8.1.

d. Five additional steps are required to produce the result.

8.9 **a.**

	00000	10101	01010
00000	0	2	2
10101	3	0	5
01010	2	5	0

b.

	000000	010101	101010	110110
000000	0	3	3	4
010101	3	0	6	6
101010	3	6	0	3
110110	4	6	3	0

8.10 **a.** $p(\mathbf{v} \mid \mathbf{w}) = \beta^{d(w,v)}(1 - \beta)^{(n - d(w,v))}$

b. If we write $d_i = d(\mathbf{w}_i, \mathbf{v})$, then $\dfrac{\mathbf{p}(\mathbf{v} \mid \mathbf{w}_1)}{\mathbf{p}(\mathbf{v} \mid \mathbf{w}_2)} = \dfrac{\beta^{d_1}(1-\beta)^{n-d_1}}{\beta^{d_2}(1-\beta)^{n-d_2}} = \left(\dfrac{1-\beta}{\beta}\right)^{d_2 - d_1}$

c. If $0 < \beta < 0.5$, then $(1 - \beta)/\beta > 1$. Therefore, by the equation of part b, $p(\mathbf{v} \mid \mathbf{w}_1)/p(\mathbf{v} \mid \mathbf{w}_2) > 1$ if an only if $d_1 < d_2$.

8.11 Suppose that the minimum distance between codewords is at least $2t + 1$. 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**. For this to happen, at least $t + 1$ bits of **w** must be in error. Therefore all errors involving t or fewer digits are correctable.

8.12
$$
\begin{aligned}
C1 &= D1 \oplus D2 \oplus D4 \oplus D5 \oplus D7 \\
C2 &= D1 \oplus D3 \oplus D4 \oplus D6 \oplus D7 \\
C4 &= D2 \oplus D3 \oplus D4 \oplus D8 \\
C8 &= D5 \oplus D6 \oplus D7 \oplus D8
\end{aligned}
$$

8.13 The transmitted block and check bit calculation are shown in Table 8.2a and b. Now suppose that the only error is in C8. Then the received block results in the following table:

Position	12	11	10	9	8	7	6	5	4	3	2	1
Bits	D8	D7	D6	D5	C8	D4	D3	D2	C4	D1	C2	C1
Block	0	0	1	1	1	1	0	0	1	1	1	1
Codes			1010	1001		0111				0011		

The check bit calculation after reception:

Position	Code
Hamming	1111
10	1010
9	1001
7	0111
3	0011
XOR = syndrome	1000

The nonzero result detects and error and indicates that the error is in bit position 8, which is check bit C8.

8.14 Data bits with value 1 are in bit positions 12, 11, 5, 4, 2, and 1:

Position	12	11	10	9	8	7	6	5	4	3	2	1
Bit	D8	D7	D6	D5	C8	D4	D3	D2	C4	D1	C2	C1
Block	1	1	0	0		0	0	1		0		
Codes	1100	1011						0101				

Check bit calculation:

Position	**Code**
12	1100
11	1011
5	0101
XOR = C8 C4 C2 C1	0010

8.15 The Hamming Word initially calculated was:

bit number:

12	11	10	9	8	7	6	5	4	3	2	1
0	0	1	1	0	1	0	0	1	1	1	1

Doing an exclusive-OR of 0111 and 1101 yields 1010 indicating an error in bit 10 of the Hamming Word. Thus, the data word read from memory was 00011001.

8.16 Need $n - k$ check bits such that $2^{(n-k)} - 1 \geq 1024 + (n - k)$.
The minimum value of $n - k$ that satisfies this condition is 11.

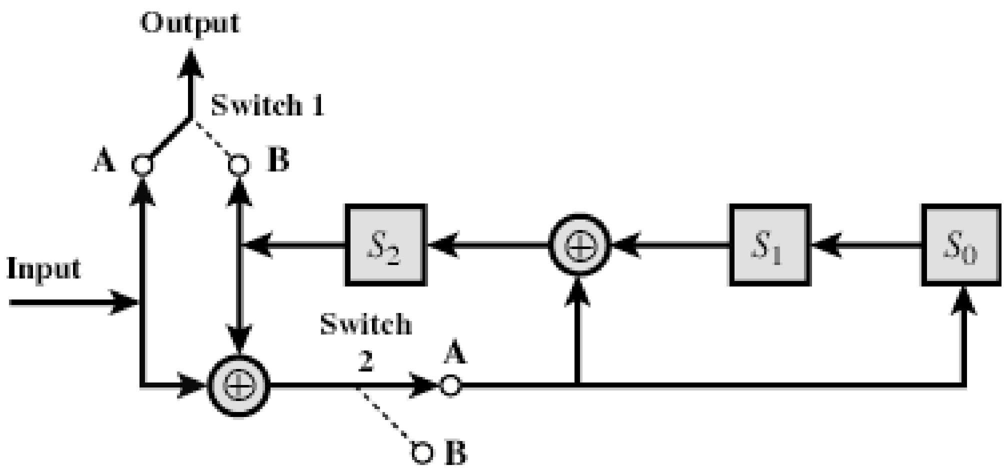
8.17 The calculation shows that g(X) divides f(X) with no remainder.

$$
\begin{array}{rl}
 & X^2 + X + 1 \\ \cline{2-2}
X^4 + X^3 + X + 1 \,\big) & X^6 + \qquad\qquad\qquad 1 \\
 & X^6 + X^5 + \quad X^3 + X^2 \\ \cline{2-2}
 & \quad X^5 + \quad X^3 + X^2 + \quad 1 \\
 & \quad X^5 + X^4 + \quad X^2 + X \\ \cline{2-2}
 & \qquad X^4 + X^3 \quad + X + 1 \\
 & \qquad X^4 + X^3 \quad + X + 1 \\ \cline{2-2}
 & \qquad\qquad\qquad\qquad 0
\end{array}
$$

This result is verified by multiplying the quotient by g(X) to get back f(X) exactly:

$$
\begin{array}{rrrrrrr}
 & & X^4 + & X^3 & & + X & + 1 \\
 & & & & X^2 & + X & + 1 \\
\hline
 & & X^4 + & X^3 & & + X & + 1 \\
 & X^5 + & X^4 + & & X^2 & + X & \\
X^6 + & X^5 & & + X^3 + & X^2 & & \\
\hline
X^6 + & & & & & & 1
\end{array}
$$

8.18 a.



b.

S_2	S_1	S_0	$S_2 \oplus S_1 \oplus I$	$S_2 \oplus I$	Input
0	0	0	1	1	1
1	0	1	1	1	0
1	1	1	1	0	1
1	1	0	0	1	0
0	0	1			

8.19

a.

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24

b.

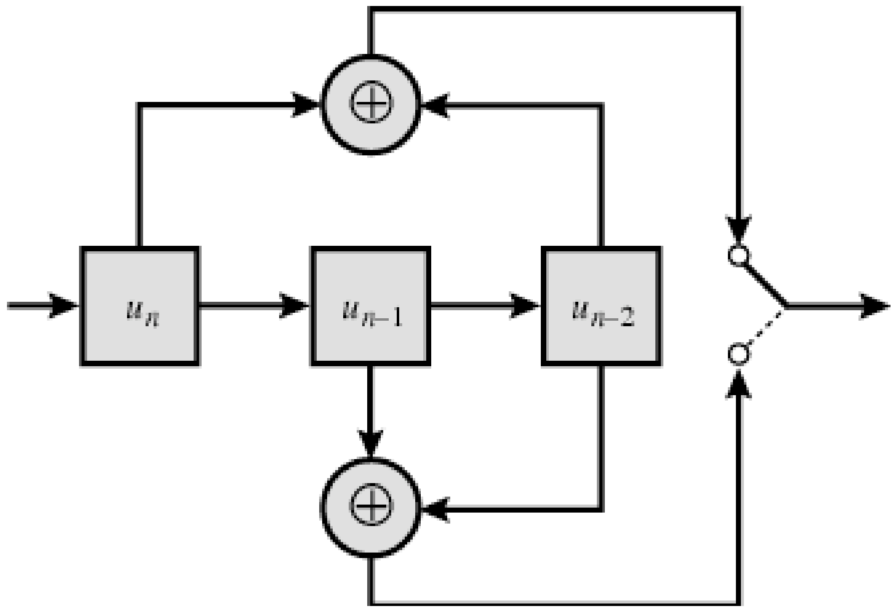
1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24

c.

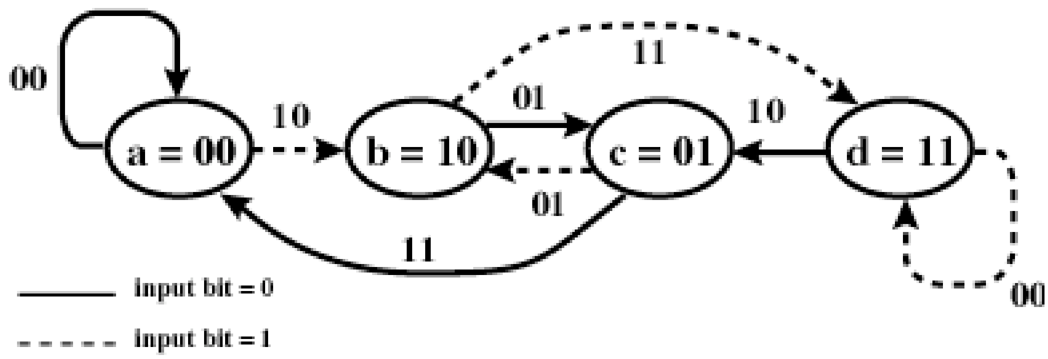
1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24

d. The first column is filled after 21 bits are read in. Similarly, 21 bits must arrive before deinterleaving. This confirms $2(n(m-1)+1) = 2(4(5)+1) = 42$.
Source: {SKLA01].

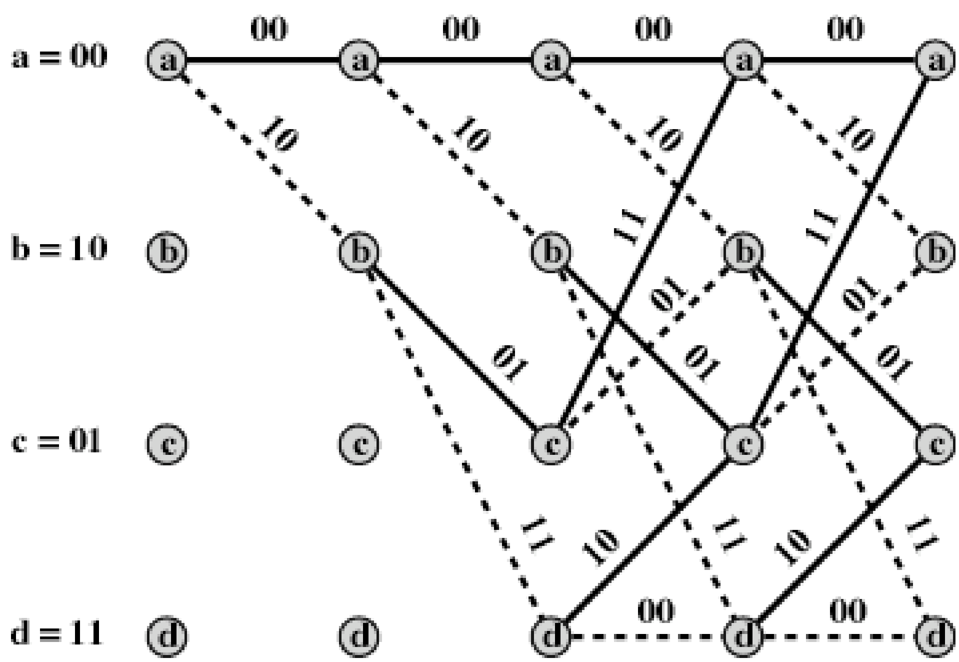
8.20 **a.**



b.



c.



8.21 **a.** This clears out the encoder, making it ready for use for the next transmission.

b. The encoder is in state a = 00 before transmission and after transmission of the last information bit two zero bits are transmitted. The sequence of states traversed is abdcbcbdcb. The output sequence is 10 11 10 01 01 01 11 10 01 00

8.22 a. Because only one frame can be sent at a time, and transmission must stop until an acknowledgment is received, there is little effect in increasing the size of the message if the frame size remains the same. All that this would affect is connect and disconnect time.

b. Increasing the number of frames would decrease frame size (number of bits/frame). This would lower line efficiency, because the propagation time is unchanged but more acknowledgments would be needed.

c. For a given message size, increasing the frame size decreases the number of frames. This is the reverse of (b).

8.23 A → B: Propagation time = 4000 × 5 μsec = 20 msec

$$\text{Transmission time per frame} = \frac{1000}{100 \times 10^3} = 10 \text{ msec}$$

B → C: Propagation time = 1000 × 5 μsec = 5 msec

Transmission time per frame = x = 1000/R

R = data rate between B and C (unknown)

A can transmit three frames to B and then must wait for the acknowledgment of the first frame before transmitting additional frames. The first frame takes 10 msec to transmit; the last bit of the first frame arrives at B 20 msec after it was transmitted, and therefore 30 msec after the frame transmission began. It will take an additional 20 msec for B's acknowledgment to return to A. Thus, A can transmit 3 frames in 50 msec.

B can transmit one frame to C at a time. It takes 5 + x msec for the frame to be received at C and an additional 5 msec for C's acknowledgment to return to A. Thus, B can transmit one frame every 10 + x msec, or 3 frames every 30 + 3x msec. Thus:

30 + 3x = 50

x = 6.66 msec

R = 1000/x = 150 kbps

8.24 Round trip propagation delay of the link = 2 × L × t

Time to transmit a frame = B/R

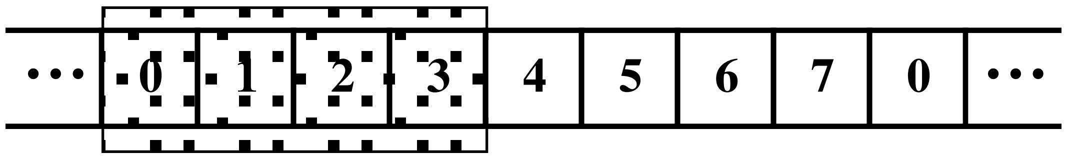
To reach 100% utilization, the transmitter should be able to transmit frames continuously during a round trip propagation time. Thus, the total number of frames transmitted without an ACK is:

$$N = \left\lceil \frac{2 \times L \times t}{B/R} + 1 \right\rceil, \quad \text{where } \lceil X \rceil \text{ is the smallest integer greater than or equal to X}$$

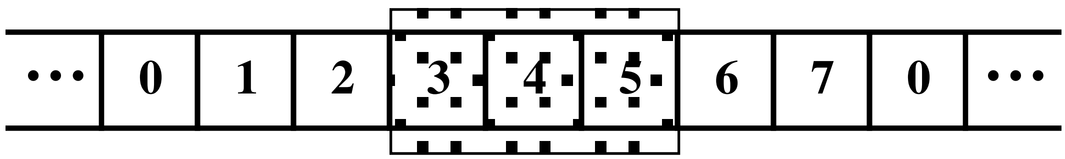
This number can be accommodated by an M-bit sequence number with:

$M = \lceil \log_2(N) \rceil$

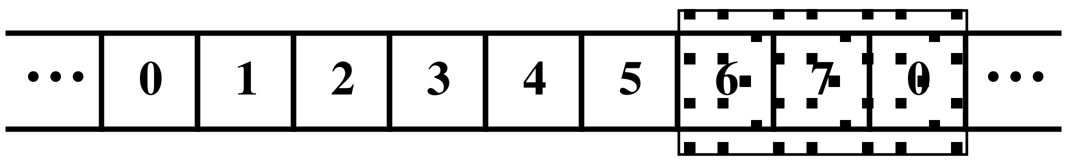
8.25 a.



b.



c.



8.26 Let t_1 = time to transmit a single frame

$$t_1 = \frac{1024 \text{ bits}}{10^6 \text{ bps}} = 1.024 \text{ msec}$$

The transmitting station can send 7 frames without an acknowledgment. From the beginning of the transmission of the first frame, the time to receive the acknowledgment of that frame is:

$$t_2 = 270 + t_1 + 270 = 541.024 \text{ msec}$$

During the time t_2, 7 frames are sent.

$$\text{Data per frame} = 1024 - 48 = 976$$

$$\text{Throughput} = \frac{7 \times 976 \text{ bits}}{541.024 \times 10^{-3} \text{ sec}} = 12.6 \text{ kbps}$$

CHAPTER 9
SATELLITE COMMUNICATIONS

ANSWERS TO QUESTIONS

9.1 **Coverage area:** global, regional, or national. The larger the area of coverage, the more satellites must be involved in a single networked system. **Service type:** fixed service satellite (FSS), broadcast service satellite (BSS), and mobile service satellite (MSS). This chapter is concerned with FSS and BSS types. **General usage:** commercial, military, amateur, experimental.

9.2 **(1)** The area of coverage of a satellite system far exceeds that of a terrestrial system. In the case of a geostationary satellite, a single antenna is visible to about one-fourth of the earth's surface. **(2)** Spacecraft power and allocated bandwidth are limited resources that call for careful tradeoffs in earth station/satellite design parameters. **(3)** Conditions between communicating satellites are more time invariant that those between satellite and earth station or between two terrestrial wireless antennas. Thus, satellite-to-satellite communication links can be designed with great precision. **(4)** Transmission cost is independent of distance, within the satellite's area of coverage. **(5)** Broadcast, multicast, and point-to-point applications are readily accommodated. **(6)** Very high bandwidths or data rates are available to the user. **(7)** Although satellite links are subject to short-term outages or degradations, the quality of transmission is normally extremely high. **(8)** For a geostationary satellite, there is an earth-satellite-earth propagation delay of about one-fourth of a second. **(9)** A transmitting earth station can in many cases receive its own transmission.

9.3 **(1)** The orbit may be circular, with the center of the circle at the center of the earth, or elliptical, with the earth's center at one of the two foci of the ellipse. **(2)** A satellite may orbit around the earth in different planes. An **equatorial orbit** is directly above the earth's equator. A **polar orbit** passes over both poles. Other orbits are referred to as **inclined orbits**. **(3)** The altitude of communications satellites is classified as geostationary orbit (GEO), medium earth orbit (MEO), and low earth orbit (LEO).

9.4 LEO, GEO and HEO stand for low earth orbit, geostationary (or geosynchronous) orbit, and highly elliptical orbit, respectively. The traditional GEO satellite is in a circular orbit in an equatorial plane such that the satellite rotates about the earth at the same angular velocity that the earth spins on its axis. To accomplish this the satellite must be approximately 35,838 km above the earth’s surface at the equator. LEO satellites are satellites with much lower orbits, on the order of 700 to 1,400 km high. Finally, HEO satellites are characterized by an orbit that is an ellipse with one axis very substantially larger than the other. The height of the orbit can vary; it is the **shape** of the orbit that characterizes this type of satellite.

Because of the high altitude of the GEO satellite the signal strength is relatively weak compared to LEOs. Frequency reuse is more difficult because the antenna beam (all other things being equal) covers a much greater area from a GEO than from a LEO. The propagation delay for a GEO satellite is about 1/4th of second; that of a LEO satellite is much less. Because the GEO satellite must be over the equator, the coverage near the north and south poles is inadequate. For these regions, better communication can be achieved by LEO or HEO satellites. HEO satellites have the additional advantage that they spend most of their time at the "high" part of their orbit so that you get the most coverage for the longest time for this type of satellite. On the other hand, tracking and handoff is not necessary for GEO satellites because they appear stationary relative to the earth. LEO satellites, since they are so low travel very much faster, and cover less area than GEO so that tracking is more difficulty and passing off is frequent. HEOs require tracking and handoffs, as well. However, if the HEOs have high orbits the handoff frequency can be much less and the tracking easier than for LEOs.

9.5 You would use GEOs when the earth stations are not near the poles, when there is a premium on not having to steer the earth station antennas, and when broad earth coverage is important, for television broadcasting for instance. HEOs are primarily of use when coverage of areas near one of the poles is essential, such as the use of the Molniya satellites to cover the northern parts of the former Soviet Union. LEOs are useful for point-to-point communication, and for extensive frequency reuse. Since LEOs have much less propagation delay they are useful for interactive data services. They also can cover polar regions. Finally, while you need many more LEOs for broad coverage, each satellite is much less expensive than a GEO.

9.6 **(1)** Distance between earth station antenna and satellite antenna. **(2)** In the case of the downlink, terrestrial distance between earth station antenna and the "aim point" of the satellite. **(1)** Atmospheric attenuation.

9.7 Oxygen and water.

9.8 Thermal noise, intermodulation noise, and crosstalk.

Answers to Problems

9.1 **a.** Rearranging the equation, we have $a^3 = T^2\mu/(4\pi^2)$.
One sidereal day is T = 86,164.1 s
$a^3 = (86{,}164.1)2 \times (3.986004418 \times 10^5)/(4\pi^2) = 7.496020251 \times 10^{13}$ km^3
a = 42,164 km
b. h = 35,794 km

9.2 **a.** a = 6378.14 + 250 = 6628.14 km
$T^2 = (4\pi^2 a^3)/\mu = (4\pi^2) \times (6628.14)^3/(3.986004418 \times 10^5) = 2.88401145 \times 107$ s^2
T = 5370.3 s = 89 min 30.3 s
b. The linear velocity is the circumference divided by the period
$(2\pi a)/T = (41645.83)/(5370.3) = 7.775$ km/s

9.3 The received signal is, essentially, the same. The received power will increase by a factor of 4

9.4 received_power = transmitted_power + transmitted_gain + received_gain – path_loss
From Equation (2.2):
path_loss = 20 log $(4\pi d/\lambda)$ = 20 log $[4\pi d/(c/f)]$

$= 20 \log [(4\pi \times 4 \times 10^7)/(2.727 \times 10^{-2}) = -205.3$ dB
received_power = 10 + 17 + 52.3 – 205.3 = –126 dBW

9.5 The total bandwidth is 500 MHz. The channel bandwidth is 12 × 36 = 432 MHz. So the overhead is ((500 - 432)/500) × 100% = 13.6%

9.6 **a.** The data rate R = 2 × QPSK baud rate = 120.272 Mbps
The frame duration T = 0.002 s
The number of frame bits $b_F = R \times T = 1.20272 \times 10^8 \times 2 \times 10^{-3} = 240544$ bits
Overhead calculation: Overhead bits $b_o = N_R b_R + N_T b_p + (N_R + N_T) b_G$
where
N_R = number of participating reference stations = 2
b_R = number of bits in reference burst = 576
N_T = number of participating traffic stations
b_p = number of preamble bits =560
b_G = number guard bits = 24
$b_o = (2)(576) + 560\ N_T + (2)(24) + 24\ N_T = 1200 + 584\ N_T$
$b_F - b_o = 240544 - (1200 + 584\ N_T) = 239344 - 584\ N_T$
$N_T = (b_F - b_o)/16512 = (239344 - 584\ N_T)/16512$
$(16512 + 584)\ N_T = 239344$
Therefore, NT = 14
b. $(b_F - b_o)/b_F = (239344 - 584 \times 14)/240544 = 0.96$
Source: [GLOV98]

9.7 **a.** The time, T_d, available in each station burst for transmission of data bits is

$$T_d = [T_{frame} - N(t_g + t_{pre})]/N$$

That is, take the frame time, subtract out all the guard and preamble times, and divide by the number of stations N.

$$T_d = [2000 - 5(5 + 20)]/5 = 375\ \mu s$$

A burst transmission rate of 30 Mbaud is 30 million signal elements per second and QPSK signal elements carry 2 bits, so the transmitted bit rate in each burst is R_b = 60 Mbps
The capacity of each earth station, C_b, is the number of data bits transmitted in one burst divided by the frame time:

$$C_b = (375 \times 60)/2000 = 11.25 \text{ Mbps}$$

The number of 64-kbps channels that can be carried is:

$$(11.25 \times 10^6)/(64{,}000) = 175$$

b. 11.25 Mbps
c. The total available capacity is 60 Mbps.

The total data transmission rate is $5 \times 11.25 = 56.25$ Mbps
Efficiency = $56.25/60 = 0.9375$

9.8 The transponder must carry a total data bit rate of $15 + 10 + 5 = 30$ Mbps. Thus, each frame carries 30 Mbps × 0.001 s = 30 kb The three preamble and guard times take up $3 \times (10 + 2) = 36$ μs in each frame, leaving $1000 - 36 = 964$ μs for transmission of the data. Therefore, the burst bit rate is

$$\text{Rbit} = 30 \text{ kb}/964\ \mu\text{s} = 31.12 \text{ Mbps}$$

For QPSK, the symbol rate is half the bit rate = 15.56 Mbaud

Chapter 10
Cellular Wireless Networks

Answers to Questions

10.1 Hexagon

10.2 For frequency reuse in a cellular system, the same set of frequencies are used in multiple cells, with these cells separated from one another by enough distance to avoid interference.

10.3 **Adding new channels:** Typically, when a system is set up in a region, not all of the channels are used, and growth and expansion can be managed in an orderly fashion by adding new channels. **Frequency borrowing:** In the simplest case, frequencies are taken from adjacent cells by congested cells. The frequencies can also be assigned to cells dynamically. **Cell splitting:** In practice, the distribution of traffic and topographic features is not uniform, and this presents opportunities of capacity increase. Cells in areas of high usage can be split into smaller cells. **Cell sectoring:** With cell sectoring, a cell is divided into a number of wedge-shaped sectors, each with its own set of channels, typically 3 or 6 sectors per cell. Each sector is assigned a separate subset of the cell's channels, and directional antennas at the base station are used to focus on each sector. **Microcells:** As cells become smaller, antennas move from the tops of tall buildings or hills, to the tops of small buildings or the sides of large buildings, and finally to lamp posts, where they form microcells. Each decrease in cell size is accompanied by a reduction in the radiated power levels from the base stations and the mobile units. Microcells are useful in city streets in congested areas, along highways, and inside large public buildings.

10.4 To complete a call to a mobile unit, the base stations in a number of cells will send out a page signal in an attempt to find the mobile unit and make the connection.

10.5 **Cell blocking probability:** the probability of a new call being blocked, due to heavy load on the BS traffic capacity. In this case, the mobile unit is handed off to a neighboring cell based not on signal quality but on traffic capacity. **Call dropping probability:** the probability that, due to a handoff, a call is terminated. **Call completion probability:** the probability that an admitted call is not dropped before it terminates. **Probability of unsuccessful handoff:** the probability that a handoff is executed while the reception conditions are inadequate. **Handoff blocking probability:** the probability that a handoff cannot be successfully completed. **Handoff probability:** the probability that a handoff occurs before call termination. **Rate of handoff:** the number of handoffs per unit time. **Interruption duration:** the duration of time during a handoff in which a mobile is not connected to either base station. **Handoff delay:** the distance the mobile moves from the point at which the handoff should occur to the point at which it does occur.

10.6 As the mobile unit moves away from the transmitter, the received power declines due to normal attenuation. In addition, the effects of reflection, diffraction, and scattering can cause rapid changes in received power levels over small distances. This is because the power level is the sum from signals coming from a number of different paths and the phases of those paths are random, sometimes adding and sometimes subtracting. As the mobile unit moves, the contributions along various paths change.

10.7 **Open-loop power control** depends solely on the mobile unit, with no feedback from the BS, and is used in some SS systems. **Closed loop power control** adjusts signal strength in the reverse (mobile to BS) channel based on some metric of performance in that reverse channel, such as received signal power level, received signal-to-noise ratio, or received bit error rate.

10.8 The **mean rate of calls** is the number of calls attempted in a unit time, so its dimensions are calls per second or a similar dimension. **Traffic intensity** is a normalized version of mean rate of calls, and equals the average number of calls arriving during the average holding period. Thus, traffic intensity is dimensionless.

10.9 **Digital traffic channels:** The most notable difference between the two generations is that first generation systems are almost purely analog, where as second generation systems are digital. In particular, the first generation systems are designed to support voice channels using FM; digital traffic is supported only by the use of a modem that converts the digital data into analog form. Second generation systems provide digital traffic channels. These readily support digital data; voice traffic is first encoded in digital form before transmitting. Of course, for second-generation systems, the user traffic (data or digitized voice) must be converted to an analog signal for transmission between the mobile unit and the base station. **Encryption:** Because all of the user traffic, as well as control traffic, is digitized in second-generation systems, it is a relatively simple matter to encrypt all of the traffic to prevent eavesdropping. All second-generation systems provide this capability, whereas first generation systems send user traffic in the clear, providing no security. **Error detection and correction:** The digital traffic stream of second-generation systems also lends itself to the use of error detection and correction techniques. The result can be very clear voice reception. **Channel access:** In first generation systems, each cell supports a number of channels. At any given time a channel is allocated to only one user. Second generation systems also provide multiple channels per cell, but each channel is dynamically shared by a number of users using time division multiple access (TDMA) or code division multiple access (CDMA).

10.10 **Frequency diversity:** Because the transmission is spread out over a larger bandwidth, frequency-dependent transmission impairments, such as noise bursts and selective fading, have less effect on the signal. **Multipath resistance:** The chipping codes used for CDMA not only exhibit low cross-correlation but also low autocorrelation. Therefore, a version of the signal that is delayed by more than one chip interval does not interfere with the dominant signal as much as in other multipath environments. **Privacy:** Because spread spectrum is obtained by the use of noise-like signals, where each user has a unique code, privacy is inherent. **Graceful degradation:** With FDMA or TDMA, a fixed number of users can simultaneously access the system. However, with CDMA, as more users simultaneously access the system, the noise level and hence the error rate increases; only gradually does the system degrade to the point of an unacceptable error rate.

10.11 **Self-jamming:** Unless all of the mobile users are perfectly synchronized, the arriving transmissions from multiple users will not be perfectly aligned on chip boundaries. Thus the spreading sequences of the different users are not orthogonal and there is some level of cross-correlation. This is distinct from either TDMA or FDMA, in which for reasonable time or frequency guardbands, respectively, the received signals are orthogonal or nearly so. **Near-far problem:** Signals closer to the receiver are received with less attenuation than signals farther away. Given the lack of complete orthogonality, the transmissions from the more remote mobile units may be more difficult to recover. Thus, power control techniques are very important in a CDMA system. **Soft handoff:** A smooth handoff from one cell to the next requires that the mobile acquire the new cell before it relinquishes the old. This is referred to as a soft handoff, and is more complex than the hard handoff used in FDMA and TDMA schemes.

10.12 **Hard handoff:** When the signal strength of a neighboring cell exceeds that of the current cell, plus a threshold, the mobile station is instructed to switch to a new frequency band that is within the allocation of the new cell. **Soft handoff**: a mobile station is temporarily connected to more than one base station simultaneously. A mobile unit may start out assigned to a single cell. If the unit enters a region in which the transmissions from two base stations are comparable (within some threshold of each other), the mobile unit enters the soft handoff state in which it is connected to the two base stations. The mobile unit remains in this state until one base station clearly predominates, at which time it is assigned exclusively to that cell.

10.13 Voice quality comparable to the public switched telephone network; 144 kbps data rate available to users in high-speed motor vehicles over large areas; 384 kbps available to pedestrians standing or moving slowly over small areas; Support (to be phased in) for 2.048 Mbps for office use; Symmetrical and asymmetrical data transmission rates; Support for both packet switched and circuit switched data services; An adaptive interface to the Internet to reflect efficiently the common asymmetry between inbound and outbound traffic; More efficient use of the available spectrum in general; Support for a wide variety of mobile equipment; Flexibility to allow the introduction of new services and technologies

Answers to Problems

10.1 **a.** We have the number of clusters $M = 16$; bandwidth assigned to cluster $B_{CL} = 40$ MHz; bandwidth required for each two-way channel $b_{ch} = 60$ kHz. The total number of simultaneous calls that can be supported by the system is $k_{SYS} = MB_{CL}/b_{ch} = 10{,}666$ channels

b. Total number of channels available is $K = B_{CL}/b_{ch} = 666$. For a frequency reuse factor N, each cell can use $k_{CE} = K/N$ channels.
For $N = 4$, $k_{CE} = 166$ channels
For $N = 7$, $k_{CE} = 95$ channels

For $N = 12$, $k_{CE} = 55$ channels

For $N = 19$, $k_{CE} = 35$ channels

c. For $N = 4$, area = 64 cells; For $N = 7$, area = 112 cells; For $N = 12$, area = 192 cells; For $N = 19$, area = 304 cells.

d. From part b, we know the number of channels that can be carried per cell for each system. The total number of channels available is just 100 times that number, for a result of 16600, 9500, 5500, 3500, respectively. Source: [CARN99]

10.2 a. Steps a and b are the same. The next step is placing the call over the ordinary public switched telephone network (PSTN) to the called subscriber. Steps d, e, and f are the same except that only the mobile unit can be involved in a handoff.

b. Instead of steps a, b, and c, the process starts with a call coming in from the PSTN to an MTSO. From there, steps c, d, e, and f are the same except that only the mobile unit can be involved in a handoff.

10.3 This causes additional interference to co-channel users.

10.4 Suppose that a thermostat on a heating system is set to 20° C. Suppose the temperature in the room is greater than 20° C and falling. The heating system may not click on until, say, 19° C. As the temperature in the room rises, the thermostat may cause the heater to remain on until room temperature reaches 21° C.

10.5 $A = \lambda h = 1 \times (23/60) = 0.383$ Erlangs

10.6 a. For a given traffic level (A) and given capacity (N), what is the probability of blocking (P)?

$(10.5 - 10.07)/(11.1 - 10.07) = (P - 0.002)/(0.005 - 0.002)$; $P = 0.00325$

b. What traffic level can be supported with a given capacity to achieve a given probability of blocking?

$(0.015 - 0.01)/(0.02 - 0.01) = (A - 12.03)/(13.19 - 12.03)$; $A = 12.61$

c. For a given traffic level, what capacity is needed to achieve a certain upper bound on the probability of blocking ?

$(6 - 3.96)/(11.1 - 3.96) = (N - 10)/(20 - 10)$; $N = 12.857$

10.7 a. The total number of available channels is K = 33000/50 = 660. For a frequency reuse factor N, each cell can use $k_{CE} = K/N$ channels.

For $N = 4$, $k_{CE} = 165$ channels

For $N = 7$, $k_{CE} = 94$ channels

For $N = 12$, $k_{CE} = 55$ channels

b. 32 MHz is available for voice channels for a total of 640 channels.

For $N = 4$, we can have 160 voice channels and one control channel per cell

For $N = 7$, we can have 4 cells with 91 voice channels and 3 cells with 92 voice channels, and one control channel per cell.

For $N = 12$, we can have 8 cells with 53 voice channels and 4 cells with 54 voice channels, and one control channel per cell. Source: [RAPP96]

10.8 a. Number of 30-kHz channels = 12500/30 = 416

Number of voice channels = 416 – 21 = 395

Number of voice channels per cell = 395/7 = 56

b. $(56 - 40)/(70 - 40) = (A - 31)/(59.13 - 31)$; $A = 46$ Erlangs/cell
c. Number of calls/hour/cell = 46/(100/3600) = 1656
Number of calls/hour/km^2 = 1656/8 = 207
d. Number of users/hour/cell = 1656/1.2 = 1380
Number of users/hour/channel = 1380/56 = 24.6
e. The total number of cells is 4000/8 = 500
η = (46 Erlangs/cell × 500 cells)/(12.5 MHz × 4000 km^2)
= 0.46 Erlangs/MHz/km^2 Source: [GARG96]

10.9 $(12.5 \times 10^6 - 2(10 \times 10^3)/(30 \times 10^3) = 416$

10.10 $(25 \times 10^6)/((200 \times 10^3)/8) = 1000$ Source: [RAPP96]

10.11 **a.** From Figure 10.14, we have 156.25 bits in 0.577 ms. Thus, bit duration is: $(0.577 \times 10^{-3})/156.25 = 3.6928$ μs
b. The delay is the duration of 1 frame, which is 4.615 ms

10.12 Total bits in one timeslot = 156.25. Data bits = 114.
Overhead = (156.25 – 114)/156.25 = 0.27

10.13 Slow FHSS = multiple signal elements per hop. In GSM, the frequency is changed one per frame, which is many bits, so GSM uses slow frequency hopping.

10.14 **a.** The amount of bandwidth allocated to voice channels (B_cN_t) must be no greater than the total bandwidth (B_w). Therefore $\eta_a \leq 1$.
b. $x = (30 \times 10^3 \times 395)/(12.5 \times 10^6) = 0.948$

10.15 **a.** Number of subscribers = Traffic/0.03

Cell number	1	2	3	4	5	6	7
Subscribers	1026.7	2223.3	1620.0	1106.7	1273.3	1260.0	1086.7

b. Number of calls per hour per subscriber = $\lambda = A/h = 0.03/(120/3600) = 0.9$
c. Multiply results of part (a) by 0.9

Cell number	1	2	3	4	5	6	7
Calls per hour	924	2001	1458	996	1146	1134	978

d. The table in the problem statement gives the value of A. Use $P = 0.02$. Find N.

Cell number	1	2	3	4	5	6	7
Channels	40	78	59	43	48	48	42

e. Total number of subscribers = the sum of the values from part (a) = 9597
f. From (d), the total number of channels required = 358
Average number of subscribers per channel = 9597/358 = 26.8
g. Subscriber density = 9597/3100 = 3.1 subscribers per km^2
h. Total traffic = the sum of the values from table in the problem statement = 287.9
i. Erlangs per km^2 = 287.9/3100 = 0.09

j. The area of a hexagon of radius R is $A = 1.5R^2\sqrt{3}$. For A = 3100/7 = 442.86 km^2 we have R = 13 km

Source: [GARG96]

CHAPTER 11
CORDLESS SYSTEMS AND WIRELESS LOCAL LOOP

ANSWERS TO QUESTIONS

11.1 Standardized cordless systems can support multiple users from the same base station, which could include either multiple telephone handsets or both voice and data devices (e.g., fax or printer). Standardized cordless systems can operate in a number of environment.

11.2 With TDD data are transmitted in one direction at a time, with transmission alternating between the two directions. TDM is a multiplexing technique that allows multiple data sources to transmit over the same channel by taking turns. With full-duplex TDM, data are transmitted in both directions simultaneously.

11.3 The **Q channel** is used to broadcast general system information from the base station to all terminals. The **P channel** provides paging from the base station to the terminals. In response to a page and at the time of handoff, a terminal uses the two-way **M channel** to exchange medium access control messages with the base station. Once a connection is established, the **N channel** provides a handshaking protocol. The **C channel** provides call management for active connections.

11.4 **Cost:** Wireless systems are less expensive than wired systems. **Installation time:** WLL systems typically can be installed rapidly. **Selective installation:** Radio units are installed only for those subscribers who want the service at a given time.

11.5 **(1)** There are wide unused frequency bands available above 25 GHz. (2)At these high frequencies, wide channel bandwidths can be used, providing high data rates. **(3)** Small size transceivers and adaptive antenna arrays can be used.

11.6 **(1)** Free space loss increases with the square of the frequency (Equation 5.2), thus losses are much higher in this range than in the ranges used for traditional microwave systems. **(2)** Generally, below 10 GHz, we can ignore attenuation due to rainfall and atmospheric or gaseous absorption. Above 10 GHz, these attenuation effects are large. **(3)** Multipath losses can be quite high. As was pointed out in Chapter 5, Reflection occurs when an electromagnetic signal encounters a surface that is large relative to the wavelength of the signal; scattering occurs if the size of an obstacle is on the order of the wavelength of the signal or less; diffraction occurs when the wavefront encounters the edge of an obstacle that is large compared to the wavelength.

11.7 First, frequency selective fading only affects some subchannels and not the whole signal. If the data stream is protected by a forward error-correcting code, this type of fading is easily handled. More importantly, OFDM overcome intersymbol interference (ISI) in a multipath environment.

11.8 **(1)** MMDS signals have larger wavelengths (greater than 10 cm) and can travel farther without losing significant power. Hence MMDS can operate in considerably larger cells, thereby lowering base station equipment costs. **(2)** Equipment at lower frequencies is less expensive, yielding cost savings at both the subscriber and base station. **(3)** MMDS signals don't get blocked as easily by objects and are less susceptible to rain absorption.

11.9 802.16.1 is targeted at the 10 to 66 GHz spectrum and is considered a millimeter wave system. It is designed to support data rates above 2 Mbps. The target market is small and medium size businesses. 802.16.2 is concerned with coexistence of multiple systems in the same area. 802.16.3 is targeted at the 2 to 11 GHz spectrum and is a microwave system. It is designed for data rates below 2 Mbps. The target market is residential and small business.

Answers to Problems

11.1 A straightforward way to do this is to double the bandwidth of each individual channel (using half as many channels), double the data rate, and use TDD on each channel. So, the channel bandwidth becomes 400 kHz with a bit rate of 541.6 kbps. Total number of TDD channels = 125.

11.2 **a.** First, we need the attenuation from rain. We use Equation 11.3, namely $A = aR^b$. From Table 11.8, we get R = 32 mm/hr. For the parameters a and b, we use Table 11.7 and interpolate for a_h and b_h at 38 GHz, yielding a = 0.3152 and b = 0.955. With these parameters A = 0.3152 x $(32)^{0.955}$ = 8.63 dB/km.
Total attenuation = 8.63 x 12 = 103.56 dB

b. At 99.9%, R = 10 mm/hr. A = 0.3152 x $(10)^{0.955}$ = 2.84 dB/km
Total attenuation = 2.84 x 12 = 34.08 dB
At 99%, R = 2 mm/hr. A = 0.3152 x $(2)^{0.955}$ = 0.61 dB/km
Total attenuation = 0.61 x 12 = 7.32 dB
The 99.99% requirement would be difficult to meet.
Source: [FREE98]

Chapter 12
Mobile IP and Wireless Application Protocol

Answers to Questions

12.1 A **mobile user** is connected to one or more applications across the Internet such that the user's point of attachment changes dynamically, and that all connections are automatically maintained despite the change. For a **nomadic user**, the user's Internet connection is terminated each time the user moves and a new connection is initiated when the user dials back in.

12.2 Tunneling is a process in which an IP datagram is encapsulated with an outer IP header so as to be transmitted across the Internet using the destination address and parameters of the outer header.

12.3 **Discovery:** A mobile node uses a discovery procedure to identify prospective home agents and foreign agents. **Registration:** A mobile node uses an authenticated registration procedure to inform its home agent of its care-of address. **Tunneling:** Tunneling is used to forward IP datagrams from a home address to a care-of address.

12.4 Discovery makes use of the existing ICMP (Internet control message protocol) by adding the appropriate extensions to the ICMP header.

12.5 The destination care-of address can either be that of a foreign agent, or it can be a co-located address that is associated physically with the node.

12.6 The foreign agent address is used when there is a foreign agent present and available on the foreign network. The co-located address is used if there is no foreign agent or all foreign agents on the foreign network are busy.

12.7 An HTML filter translates the HTML content into WML content. It may or may not be collocated with the WAP proxy. The proxy converts the WML to a more compact form known as binary WML and delivers it to the mobile user over a wireless network using the WAP protocol stack.

12.8 Deck structure, content, formatting, user input, variables, timers, tasks, task/event bindings.

12.9 **Text and image support:** Formatting and layout commands are provided for text and limited image capability. **Deck/card organizational metaphor:** WML documents are subdivided into small, well-defined units of user interaction called *cards*. Users navigate by moving back and forth between cards. A card specifies one or more units of interaction (a menu, a screen of text, or a text-entry field). A WML deck is similar to an HTML page in that it is identified by a Web address (URL) and is the unit of content transmission. **Support for navigation among**

cards and decks: WML includes provisions for event handling, which is used for navigation or executing scripts.

12.10 **Class 0** provides an unreliable datagram service, which can be used for an unreliable push operation. **Class 1** provides a reliable datagram service, which can be used for a reliable push operation. **Class 2** provides a request/response transaction service and supports the execution of multiple transactions during one WSP session.

12.11 **Data integrity:** Ensures that data sent between the client and the gateway are not modified, using message authentication. **Privacy:** Uses encryption to ensure that a third party cannot read the data. **Authentication:** Establishes the authentication of the two parties, using digital certificates. **Denial-of-service protection:** Detects and rejects messages that are replayed or not successfully verified.

Answers to Problems

12.1 **a.**

MAC-H DA = MACDA(E-Z)	LLC-H DSAP = DSAP (E)	IP-H DA = IPDA(HA-E)	TCP-H	Data

b. MAC frame leaving D:

MAC-H DA = MACDA(R3-Z)	LLC-H DSAP = DSAP (R3)	IP-H DA = IPDA(HA-E)	TCP-H	Data

IP datagram leaving R3 (using header formats of Figure 12.7a):

IP-H DA = IPDA(CA-E)	IP-H DA = IPDA(HA-E)	TCP-H	Data

c. IP datagram leaving R3 (using header formats of Figure 12.7b):

IP-H DA = IPDA(CA-E)	IP-H DA = IPDA(HA-E)	TCP-H	Data

Legend: MAC-H = MAC header; LLC-H = LLC header; IP-H = IP header; TCP-H = TCP header; MACDA(E-Z) = MAC destination address of E on LAN Z; DSAP(E) = LLC DSAP for E; IPDA(HA-E) = E's home IP address; IPDA(CA-E) = E's care-of IP address.

12.2 **a.** IP datagram arriving at R1 from Internet (using header formats of Figure 12.7a):

IP-H DA = IPDA(R1)	IP-H DA = IPDA(HA-A)	TCP-H	Data

MAC frame leaving R1 onto LAN X:

MAC-H DA = MACDA(A-X)	LLC-H DSAP = DSAP (A)	IP-H DA = IPDA(HA-A)	TCP-H	Data

b. IP datagram arriving at R1 from Internet (using header formats of Figure 12.7b):

IP-H DA = IPDA(R1)	IP-H DA = IPDA(HA-A)	TCP-H	Data

MAC frame leaving R1 onto LAN X:

MAC-H DA = MACDA(A-X)	LLC-H DSAP = DSAP (A)	IP-H DA = IPDA(HA-A)	TCP-H	Data

c. IP datagram arriving at R1 from Internet (using header formats of Figure 12.7a):

IP-H DA = IPDA(A-X)	IP-H DA = IPDA(HA-A)	TCP-H	Data

MAC frame leaving R1 onto LAN X:

MAC-H DA = MACDA(A-X)	LLC-H DSAP = DSAP (A)	IP-H DA = IPDA(A-X)	IP-H DA = IPDA(HA-A)	TCP-H	Data

d. IP datagram arriving at R1 from Internet (using header formats of Figure 12.7b):

IP-H DA = IPDA(A-X)	IP-H DA = IPDA(HA-A)	TCP-H	Data

MAC frame leaving R1 onto LAN X:

MAC-H DA = MACDA(A-X)	LLC-H DSAP = DSAP (A)	IP-H DA = IPDA(A-X)	IP-H DA = IPDA(HA-A)	TCP-H	Data

12.3 Home address, care-of address, lifetime.

12.4 Home address, home agent address, MAC address, lifetime.

12.5 The change cipher spec protocol exists to signal transitions in ciphering strategies, and can be sent independently of the complete handshake protocol exchange.

CHAPTER 13
WIRELESS LAN TECHNOLOGY

ANSWERS TO QUESTIONS

13.1 **LAN extension:** a wireless LAN integrated with a wired LAN to extend the coverage area of the LAN complex; **cross-building interconnect:** wireless point-to-point link two LANs; **nomadic access:** provides a wireless link between a LAN hub and a mobile data terminal equipped with an antenna, such as a laptop computer or notepad computer; **ad hoc network:** a peer-to-peer network (no centralized server) set up temporarily to meet some immediate need.

13.2 **Throughput:** The medium access control protocol should make as efficient use as possible of the wireless medium to maximize capacity. **Number of nodes:** Wireless LANs may need to support hundreds of nodes across multiple cells. **Connection to backbone LAN:** In most cases, interconnection with stations on a wired backbone LAN is required. For infrastructure wireless LANs, this is easily accomplished through the use of control modules that connect to both types of LANs. There may also need to be accommodation for mobile users and ad hoc wireless networks. **Service area:** A typical coverage area for a wireless LAN has a diameter of 100 to 300 m. **Battery power consumption:** Mobile workers use battery-powered workstations that need to have a long battery life when used with wireless adapters. This suggests that a MAC protocol that requires mobile nodes to monitor access points constantly or engage in frequent handshakes with a base station is inappropriate. Typical wireless LAN implementations have features to reduce power consumption while not using the network, such as a sleep mode. **Transmission robustness and security:** Unless properly designed, a wireless LAN may be interference prone and easily eavesdropped. The design of a wireless LAN must permit reliable transmission even in a noisy environment and should provide some level of security from eavesdropping. **Collocated network operation:** As wireless LANs become more popular, it is quite likely for two or more wireless LANs to operate in the same area or in some area where interference between the LANs is possible. Such interference may thwart the normal operation of a MAC algorithm and may allow unauthorized access to a particular LAN. **License-free operation:** Users would prefer to buy and operate wireless LAN products without having to secure a license for the frequency band used by the LAN. **Handoff/roaming:** The MAC protocol used in the wireless LAN should enable mobile stations to move from one cell to another. **Dynamic configuration:** The MAC addressing and network management aspects of the LAN should permit dynamic and automated addition, deletion, and relocation of end systems without disruption to other users.

13.3 **Single-cell wireless LAN**: all of the wireless end systems are within range of a single control module. **Multiple-cell wireless LAN**: there are multiple control modules interconnected by a wired LAN; each control module supports a number of wireless end systems within its transmission range.

13.4 A Kiviat graph provides a pictorial means of comparing systems along multiple variables. The variables are laid out at equal angular intervals. A given system is defined by one point on each variable; these points are connected to yield a shape that is characteristic of that system.

13.5 **(1)** The spectrum for infrared is virtually unlimited, which presents the possibility of achieving extremely high data rates. **(2)** The infrared spectrum is unregulated worldwide, which is not true of some portions of the microwave spectrum. **(3)** Infrared light is diffusely reflected by light-colored objects; thus it is possible to use ceiling reflection to achieve coverage of an entire room. **(4)** Infrared light does not penetrate walls or other opaque objects. This has two advantages: First, infrared communications can be more easily secured against eavesdropping than microwave; and second, a separate infrared installation can be operated in every room in a building without interference, enabling the construction of very large infrared LANs. **(5)** Another strength of infrared is that the equipment is relatively inexpensive and simple.

13.6 **(1)** Many indoor environments experience rather intense infrared background radiation, from sunlight and indoor lighting. This ambient radiation appears as noise in an infrared receiver, requiring the use of transmitters of higher power than would otherwise be required and also limiting the range. **(2)** Increases in transmitter power are limited by concerns of eye safety and excessive power consumption.

13.7 The transmitted signal can be focused and aimed (as in a remote TV control); it can be radiated omnidirectionally; or it can be reflected from a light-colored ceiling.

Answers to Problems

13.6 Wired LANs become part of a location's infrastructure and are therefore less flexible in maintenance and modification, however, the physical nature of the wired LAN makes it inherently more controllable. Wireless LANs are more flexible in implementation and modification, but require more complex maintenance mechanisms because of their more fluid characteristics. Unique concerns for wireless LAN designers include: device power consumption, quality and security of transmission medium, licensing and other concerns related to the mobile nature of the technology.

13.7 FCC OET-65 (Bulletin on Evaluating RF Exposure Compliance) and ANSI/IEEE C95.1-1999 (Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz). Both documents characterize safety concerns associated with wireless media. Concerns primarily involve the levels of radiation exposure from wireless devices and the operation of these devices in proximity to explosive devices and where it may interfere with other vital electronic traffic. Specific references to these documents are provided on the web at:
http://www.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet65/oet65.pdf
http://www.rfsafetysolutions.com/IEEE_standard.htm

CHAPTER 14
WI-FI AND THE IEEE 802.11 WIRELESS LAN STANDARD

ANSWERS TO QUESTIONS

14.1 **Logical link control (LLC):** provides an interface to higher layers and perform flow and error control; **medium access control (MAC):** provides addressing for physical attachment points to the LAN and provides medium access; **physical:** defines the topology, transmission medium, and signaling.

14.2 A **MAC address** defines a physical point of attachment to the LAN. An **LLC address** identifies a particular LLC user (next higher layer above LLC).

14.3 **Unacknowledged connectionless service:** This service is a datagram-style service. It is a very simple service that does not involve any of the flow- and error-control mechanisms. Thus, the delivery of data is not guaranteed. **Connection-mode service:** This service is similar to that offered by HDLC. A logical connection is set up between two users exchanging data, and flow control and error control are provided. **Acknowledged connectionless service:** This is a cross between the previous two services. It provides that datagrams are to be acknowledged, but no prior logical connection is set up.

14.4 An **access point** functions as a bridge to enable the linking of multiple separate 802.11 wireless LANs. A **portal** provides an interconnection point between an 802.11 wireless LAN and a wired LAN.

14.5 It may or may not be.

14.6 **Association:** Establishes an initial association between a station and an AP. **Authentication:** Used to establish the identity of stations to each other. **Deauthentication:** This service is invoked whenever an existing authentication is to be terminated. **Disassociation:** A notification from either a station or an AP that an existing association is terminated. A station should give this notification before leaving an ESS or shutting down. **Distribution:** used by stations to exchange MAC frames when the frame must traverse the DS to get from a station in one BSS to a station in another BSS. **Integration:** enables transfer of data between a station on an IEEE 802.11 LAN and a station on an integrated IEEE 802.x LAN. **MSDU delivery:** delivery of MAC service data units. **Privacy:** Used to prevent the contents of messages from being read by other than the intended recipient. **Reassocation:** Enables an established association to be transferred from one AP to another, allowing a mobile station to move from one BSS to another.

14.7 **Mobility** refers to the types of physical transitions that can be made by a mobile node within an 802.11 environment (no transition, movement from one BSS to another within an ESS, movement from one ESS to another). **Association** is a service that allows a mobile node that has made a transition to identify itself to the

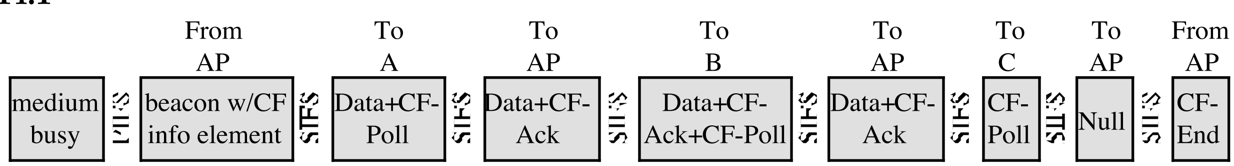
AP within a BSS so that the node can participate in data exchanges with other mobile nodes.

14.8 **(1)** In order to transmit over a wired LAN, a station must be physically connected to the LAN. On the other hand, with a wireless LAN, any station within radio range of the other devices on the LAN can transmit. In a sense, there is a form of authentication with a wired LAN, in that it requires some positive and presumably observable action to connect a station to a wired LAN. **(2)** Similarly, in order to receive a transmission from a station that is part of a wired LAN, the receiving station must also be attached to the wired LAN. On the other hand, with a wireless LAN, any station within radio range can receive. Thus, a wired LAN provides a degree of privacy, limiting reception of data to stations connected to the LAN.

14.9 Shared key authentication is more secure because it requires the use of a secret key shared only by the two sides. Open system authentication is simply a protocol for agreeing to communicate and provides no security features.

Answers to Problems

14.1



Source: [ROSH04]

14.2 The equation is $R(\tau) = \frac{1}{N}\sum_{k=1}^{N} B_k B_{k-\tau}$, and the Barker sequence is (+ – + + – + + + – – –).

For R(0), we multiply the sequence with itself:

+	–	+	+	–	+	+	+	–	–	–
+	–	+	+	–	+	+	+	–	–	–
+	+	+	+	+	+	+	+	+	+	+

The net result is +11, which divided by N = 11 yields R(0) = 1. For all other values of τ from 1 through 10, the value is R(τ) = –1/11. We show, as an example R(3). For this result, the sequence is circular-shifted by 3 and then multiplied by the original sequence:

+	–	+	+	–	+	+	+	–	–	–
–	–	–	+	–	+	+	–	+	+	+
–	+	–	+	+	+	+	–	–	–	–

The net result is 5 – 6 = –1, which divided by N yields R(3) = –1/11.

14.3 **a1.** The 16-PPM scheme is for the 1-Mbps data rate. Therefore, the period for bit transmission is 10^{-6} = 1 μs.

a2. One 16-PPM symbol represents 4 bits. Therefore, the period for symbol transmission is 4 μs. There is one pulse in each symbol, so the average time between pulses is 4 μs.

a3. Each symbol consists of 16 pulse positions, with only one pulse present. If the adjacent symbols are 0000000000000001 and 1000000000000000, then the time between pulses is $4/16 = 0.25$ μs.

a4. If the adjacent symbols are 1000000000000000 and 0000000000000001, then the time between pulses is $31 \times 0.25 = 7.75$ μs

b1. The 4-PPM scheme is for the 2-Mbps data rate. Therefore, the period for bit transmission is $1/(2 \times 10^6) = 0.5$ μs.

b2. One 4-PPM symbol represents 2 bits. Therefore, the period for symbol transmission is 1 μs. There is one pulse in each symbol, so the average time between pulses is 1 μs.

b3. Each symbol consists of 4 pulse positions, with only one pulse present. If the adjacent symbols are 0001 and 1000, then the time between pulses is $1/4 = 0.25$ μs.

b4. If the adjacent symbols are 1000 0001, then the time between pulses is $7 \times 0.25 = 1.75$ μs

14.4 Each subcarrier can operate at 250 kbaud, that is, 0.25×10^6 signal elements per second. For the first row in Figure 14.6d, BPSK is used, which corresponds to one bit per signal element. With a code rate of 1/2, each data bit is encoded as 2 code bits. Thus, the effective data rate on each subcarrier is 125 kbps. With 48 subcarriers, this results in a data rate of 48×125 kbps = 6 Mbps.

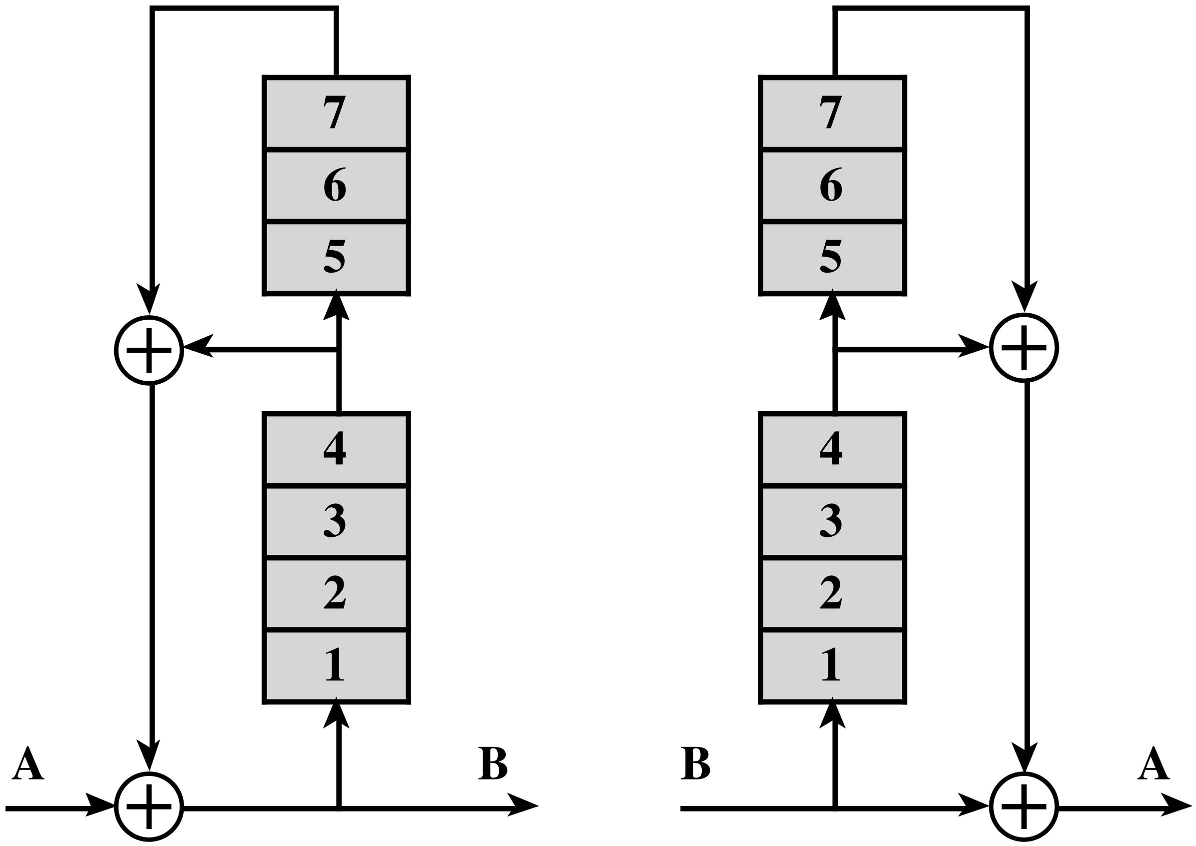
For the second row in Figure 14.6d, a code rate of 3/4 is used, meaning 3 data bits are coded as 4 code bits. Thus, the effective data rate on each subcarrier is $0.75 \times 250 = 187.5$ kbps. The overall data rate is $48 \times 187.5 = 9$ Mbps.

For the third row, the use of QPSK allows two bits per signal element, so that the 250-kbaud rate per subcarrier becomes 500 kbps. Using the same reasoning as for the first row in the table, this results in a data rate of 12 Mbps.

The remaining rows can be easily calculated.

14.5 a. $B_m = A_m \oplus B_{m-4} \oplus B_{m-7}$

b.



Scrambler **Descrambler**

CHAPTER 15
BLUETOOTH AND IEEE 802.15

ANSWERS TO QUESTIONS

15.1 **Data and voice access points:** Bluetooth facilitates real-time voice and data transmissions by providing effortless wireless connection of portable and stationary communications devices. **Cable replacement:** Bluetooth eliminates the need for numerous, often proprietary, cable attachments for connection of practically any kind of communication device. Connections are instant and are maintained even when devices are not within line of sight. The range of each radio is approximately 10 m, but can be extended to 100 m with an optional amplifier. **Ad hoc networking:** A device equipped with a Bluetooth radio can establish instant connection to another Bluetooth radio as soon as it comes into range.

15.2 The **core specifications** describe the details of the various layers of the Bluetooth protocol architecture, from the radio interface to link control. The **profile specifications** are concerned with the use of Bluetooth technology to support various applications.

15.3 A set of protocols that implement a particular Bluetooth-based application.

15.4 The radio designated as the master makes the determination of the channel (frequency hopping sequence) and phase (timing offset, i.e., when to transmit) that shall be used by all devices on this piconet. The radio designated as master makes this determination using its own device address as a parameter, while the slave devices must tune to the same channel and phase. A slave may only communicate with the master and may only communicate when granted permission by the master.

15.5 A frequency hopping defines a logical channel. This channel can be shared using TDD.

15.6 In FH-CDMA, the spreading sequence defines the sequence of frequencies to be used for frequency hopping. In DS-CDMA, the spreading sequence is used to map one data bit into multiple transmitted bits.

15.7 **Synchronous connection-oriented (SCO):** Allocates a fixed bandwidth between a point-to-point connection involving the master and a single slave. The master maintains the SCO link by using reserved slots at regular intervals. The basic unit of reservation is two consecutive slots (one in each transmission direction). The master can support up to three simultaneous SCO links while a slave can support two or three SCO links. SCO packets are never retransmitted **Asynchronous connectionless (ACL):** A point-to-multipoint link between the master and all the slaves in the piconet. In slots not reserved for SCO links, the master can exchange packets with any slave on a per-slot basis, including a slave already engaged in an SCO link. Only a single ACL link can exist. For most ACL packets, packet retransmission is applied.

15.8 1/3 rate FEC (forward error correction); 2/3 rate FEC; ARQ (automatic repeat request).

15.9 **Link control (LC):** Used to manage the flow of packets over the link interface. The LC control channel is mapped onto the packet header. This channel carries low-level link control information like ARQ, flow control, and payload characterization. The LC channel is carried in every packet except in the ID packet, which has no packet header. **Link manager (LM):** Transports link management information between participating stations. This logical channel supports LMP traffic and can be carried over either an SCO or ACL link. **User asynchronous (UA):** Carries asynchronous user data. This channel is normally carried over the ACL link, but may be carried in a DV packet on the SCO link. **User isochronous (UI):** Carries isochronous user data. This channel is normally carried over the ACL link, but may be carried in a DV packet on the SCO link. At the baseband level, the UI channel is treated the same way as a UA channel. Timing to provide isochronous properties is provided at a higher layer. **User synchronous (US):** Carries synchronous user data. This channel is carried over the SCO link.

15.10 Authentication; encryption (privacy); key management and usage.

15.11 **Connectionless:** Supports the connectionless service. Each channel is unidirectional. This channel type is typically used for broadcast from the master to multiple slaves. **Connection-oriented:** Supports the connection-oriented service. Each channel is bidirectional (full-duplex). A quality of service (QoS) flow specification is assigned in each direction. **Signaling:** Provides for the exchange of signaling messages between L2CAP entities.

15.12 A **flow specification** is a set of parameters that indicate a performance level that the transmitter will attempt to achieve.

Answers to Problems

15.1
1. The master sends message A to slave 1.
2. Slave 1 sends message F to the master, piggybacking the acknowledgement to A.
3. The master sends message B to slave 1, but it contains an error.
4. Slave 1 sends message G back, saying that the last message received contained errors.
5. The master retransmits message B, using the same SEQN bit, and acknowledges G.
6. Slave 1 sends message H, piggybacking the acknowledgement to B.
7. The master sends message X to slave 2.
8. Slave 2 sends message Z, piggybacking the acknowledgement to X. Message Z contains an error.
9. The master sends message C to slave 1, piggybacking the acknowledgement to H.
10. Slave 1 acknowledges C, but has no message to send.
11. The master sends a NAK to slave 2, indicating that its last message contained errors.
12. Slave 2 retransmits message Z.

15.2 The equation is $R(\tau) = \frac{1}{N}\sum_{k=1}^{N} B_k B_{k-\tau}$, and the Barker sequence is (+ + + – – + –).

For R(0), we multiply the sequence with itself:

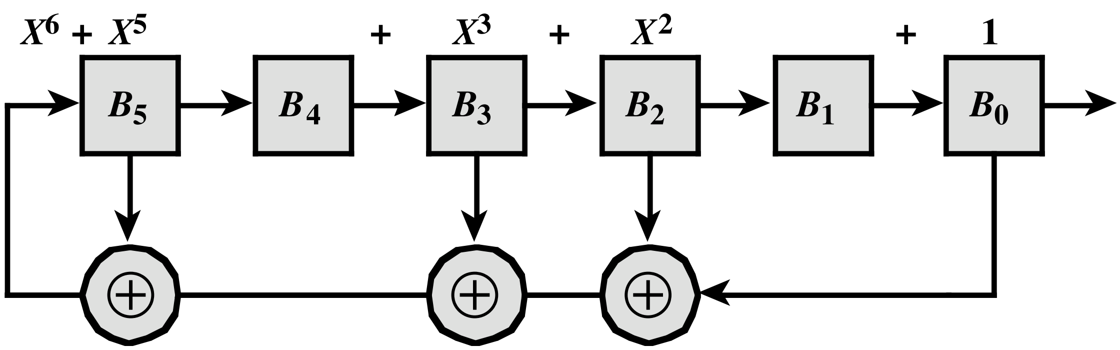
```
+ + + – – + –
+ + + – – + –
-------------
+ + + + + + +t
```

The net result is +7, which divided by N = 7 yields R(0) = 1. For all other values of τ from 1 through 6, the value is R(τ) = 1/7. We show, as an example R(3). For this result, the sequence is circular-shifted by 3 and then multiplied by the original sequence:

```
+ + + – – + –
– + – + + + –
-------------
– + – – – + +
```

The net result is 3 – 4 = –1, which divided by N yields R(3) = –1/7.

15.3 **a.**



b.

B_5	B_4	B_3	B_2	B_1	B_0
0	0	0	0	0	1
1	0	0	0	0	0
1	1	0	0	0	0
1	1	1	0	0	0
0	1	1	1	0	0
0	0	1	1	1	0
0	0	0	1	1	1
0	0	0	0	1	1

The final column is the output. Hence the first 8 bits of output are 10000011.

15.4 a.

$$b(k) = 1 \qquad \textit{because} \;\; x(k) - \hat{x}(k-1) \geq 0$$
$$\delta(k) = \min[10 + 30, 1280] = 40$$
$$\hat{y}(k) = 990 + (1 \times 40) = 1030$$
$$y(k-1) = \min\left[1030, \left(2^{15} - 1\right)\right] = 1030$$
$$\hat{x}(k-1) = 1030 \times 0.96875 = 998$$

b.

$$b(k) = 1 \qquad \textit{because} \;\; x(k) - \hat{x}(k-1) \geq 0$$
$$\delta(k) = \max[(0.999 \times 30), 10] = 29.97$$
$$\hat{y}(k) = 990 + (1 \times 29.97) = 1019.97$$
$$y(k-1) = \min\left[1019.97, \left(2^{15} - 1\right)\right] = 1019.97$$
$$\hat{x}(k-1) = 1019.97 \times 0.96875 = 988$$

15.5 a. During a bust of S seconds, a total of MS octets are transmitted. A burst empties the bucket (b octets) and, during the burst, tokens for an additional rS octets are generated, for a total burst size of (b + rS). Thus,
b + rS = MS
S = b/(M – r)

b. S = (250 × 10^3)/(23 × 10^6) ≈ 11 msec

15.6 a. $b_2(n) = a_1(n)$; $b_1(n) = a_0(n) \oplus a_0(n-2)$; $b_0(n) = a_0(n-1)$

b.

$a_0(n-2)$	$a_0(n-1)$	$a_0(n)$	$a_1(n)$	$b_2(n)$	$b_1(n)$	$b_0(n)$
0	0	0	0	0	0	0
0	0	0	1	1	0	0
0	0	1	0	0	1	0
0	0	1	1	1	1	0
0	1	0	0	0	0	1
0	1	0	1	1	0	1
0	1	1	0	0	1	1
0	1	1	1	1	1	1
1	0	0	0	0	1	0
1	0	0	1	1	1	0
1	0	1	0	0	0	0
1	0	1	1	1	0	0
1	1	0	0	0	1	1
1	1	0	1	1	1	1
1	1	1	0	0	0	1
1	1	1	1	1	0	1

c. $(01) \rightarrow (00)$: 00/010 (90º) and 10/110 (270º)
$(01) \rightarrow (10)$: 01/000 (0º) and 11/100 (180º)
$(11) \rightarrow (01)$: 00/010 (135º) and 10/111 (315º)
$(11) \rightarrow (11)$: 01/000 (45º) and 11/101 (225º)