such as reappropriating and auctioning portions of previously allocated spectrum.

Problems

1. Is an oil pipeline a simplex system, a half-duplex system, a full-duplex system, or none of the above? What about a river or a walkie-talkie-style communication?
2. What are the advantages of fiber optics over copper as a transmission medium? Is there any downside of using fiber optics over copper?
3. How much bandwidth is there in 0.1 microns of spectrum at a wavelength of 1 micron?
4. It is desired to send a sequence of computer screen images over an optical fiber. The screen is 3840 × 2160 pixels, each pixel being 24 bits. There are 60 screen images per second. What data rate is needed?
5. In **Fig. 2-5**, the left-hand band is narrower than the others. Why?
6. Imagine that the operations performed by digital computers, currently implemented using electrical signals, could be efficiently implemented using light beams. How would this affect digital communication? Why do modern computers not work this way?
7. Radio antennas often work best when the diameter of the antenna is equal to the wavelength of the radio wave. Reasonable antennas range from 1 cm to 1 meter in diameter. What frequency range does this cover?

8. Multipath fading is maximized when the two beams arrive 180 degrees out of phase. How much of a path difference is required to maximize the fading for a 100-km-long 1-GHz microwave link?
9. A laser beam 1 mm wide is aimed at a detector 1 mm wide 100 m away on the roof of a building. How much of an angular diversion (in degrees) does the laser have to have before it misses the detector?
10. Compute the Fourier coefficients for the function $f(t)=t\ (0 \le t \le 1)$.
11. A binary 5 GHz signal is sent over a channel with a signal-to-noise ratio of 40 dB. What is the lowest upper-bound on the maximum data rate? Explain your answer.
12. A noiseless 3-kHz channel is sampled every 1 msec. What is the maximum data rate? How does the maximum data rate change if the channel is noisy, with a signal-to-noise ratio of 30 dB?
13. Is the Nyquist theorem true for high-quality single-mode optical fiber or only for copper wire?
14. Television channels are 6 MHz wide. How many bits/sec can be sent if four-level digital signals are used? Assume a noiseless channel.
15. If a binary signal is sent over a 3-kHz channel whose signal-to-noise ratio is 20 dB, what is the maximum achievable data rate?
16. A channel using 4B/5B encoding sends data at a rate of 64 Mbps. What is the minimum bandwidth used by this channel?
17. In a constellation diagram, all points lie on the horizontal axis. What kind of modulation is being used?

41. What is the percent overhead on a T1 carrier? That is, what percent of the 1.544 Mbps are not delivered to the end user? How does it relate to the percent overhead in OC-1 or OC-768 lines?
42. SONET clocks have a drift rate of about 1 part in 109. How long does it take for the drift to equal the width of 1 bit? Do you see any practical implications of this calculation? If so, what?
43. In **Fig. 2-35**, the user data rate for OC-3 is stated to be 148.608 Mbps. Show how this number can be derived from the SONET OC-3 parameters. What will be the gross, SPE, and user data rates of an OC-3072 line?
44. To accommodate lower data rates than STS-1, SONET has a system of virtual tributaries (VTs). A VT is a partial payload that can be inserted into an STS-1 frame and combined with other partial payloads to fill the data frame. VT1.5 uses 3 columns, VT2 uses 4 columns, VT3 uses 6 columns, and VT6 uses 12 columns of an STS-1 frame. Which VT can accommodate
    a. A DS-1 service (1.544 Mbps)?
    b. European CEPT-1 service (2.048 Mbps)?
    c. A DS-2 service (6.312 Mbps)?
45. What is the available user bandwidth in an OC-12c connection?
46. What is the difference, if any, between the demodulator part of a modem and the coder part of a codec? (After all, both convert analog signals to digital ones.)
47. Three packet-switching networks each contain *n* nodes. The first network has a star topology with a central switch, the second is a (bidirectional) ring, and the third is fully

interconnected, with a wire from every node to every other node. What are the best-, average-, and worst-case transmission paths in hops?

48. Compare the delay in sending an *x*-bit message over a *k*-hop path in a circuit-switched network and in a (lightly loaded) packet-switched network. The circuit setup time is *s* sec, the propagation delay is *d* sec per hop, the packet size is *p* bits, and the data rate is *b* bps. Under what conditions does the packet network have a lower delay? Also, explain the conditions under which a packet-switched network is preferable to a circuit-switched network.
49. Suppose that *x* bits of user data are to be transmitted over a *k*-hop path in a packet-switched network as a series of packets, each containing *p* data bits and *h* header bits, with $x \gg p+h$. The bit rate of the lines is *b* bps and the propagation delay is negligible. What value of *p* minimizes the total delay?
50. In a typical mobile phone system with hexagonal cells, it is forbidden to reuse a frequency band in an adjacent cell. If 840 frequencies are available, how many can be used in a given cell?
51. The actual layout of cells is seldom as regular that as shown in **Fig. 2-39**. Even the shapes of individual cells are typically irregular. Give a possible reason why this might be. How do these irregular shapes affect frequency assignment to each cell?
52. Make a rough estimate of the number of PCS microcells 100 m in diameter it would take to cover San Francisco (120 square km).

53. Sometimes when a mobile user crosses the boundary from one cell to another, the current call is abruptly terminated, even though all transmitters and receivers are functioning perfectly. Why?
54. At the low end, the telephone system is star shaped, with all the local loops in a neighborhood converging on an end office. In contrast, cable television consists of a single long cable snaking its way past all the houses in the same neighborhood. Suppose that a future TV cable were 10-Gbps fiber instead of copper. Could it be used to simulate the telephone model of everybody having their own private line to the end office? If so, how many one-telephone houses could be hooked up to a single fiber?
55. A cable TV system has 100 commercial channels, all of them alternating programs with advertising. Is this more like TDM or like FDM?
56. A cable company decides to provide Internet access over cable in a neighborhood consisting of 5000 houses. The company uses a coaxial cable and spectrum allocation allowing 100 Mbps downstream bandwidth per cable. To attract customers, the company decides to guarantee at least 2 Mbps downstream bandwidth to each house at any time. Describe what the cable company needs to do to provide this guarantee.
57. Using the spectral allocation of **Fig. 2-46** and the information given in the text, how many Mbps does a cable system allocate to upstream and how many to downstream?
58. How fast can a cable user receive data if the network is otherwise idle? Assume that the user interface is