



WIRELESS COMMUNICATIONS AND NETWORKS

SECOND EDITION

William Stallings



Upper Saddle River, NJ 07458

Library of Congress Cataloging-in-Publication Data on file

Vice President and Editorial Director, ECS:
Marcia J. Horton
Publisher: *Alan Apt*
Associate Editor: *Toni D. Holm*
Editorial Assistant: *Patrick Lindner*
Vice President and Director of Production and
Manufacturing, ESM: *David W. Riccardi*
Executive Managing Editor: *Vince O'Brien*
Managing Editor: *Camille Trentacoste*
Production Editor: *Rose Keman*
Cover Photo: *Brand X Pictures*

Director of Creative Services: *Paul Belfanti*
Art Director: *Heather Scott*
Cover Designer: *Tamara Newnam*
Managing Editor, AV Management
and Production: *Patricia Burns*
Art Editor: *Gregory Dulles*
Manufacturing Manager: *Trudy Piscioti*
Manufacturing Buyer: *Lynda Castillo*
Marketing Manager: *Pamela Hersperger*
Marketing Assistant: *Barrie Reinhold*



© 2005, 2002 Pearson Education, Inc.
Pearson Prentice Hall
Pearson Education, Inc.
Upper Saddle River, NJ 07458

All rights reserved. No part of this book may be reproduced, in any form or by any means, without permission in writing from the publisher.

Pearson Prentice Hall® is a trademark of Pearson Education, Inc.

The author and publisher of this book have used their best efforts in preparing this book. These efforts include the development, research, and testing of the theories and programs to determine their effectiveness. The author and publisher make no warranty of any kind, expressed or implied, with regard to these programs or the documentation contained in this book. The author and publisher shall not be liable in any event for incidental or consequential damages in connection with, or arising out of, the furnishing, performance, or use of these programs.

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

ISBN: 0-13-191835-4

Pearson Education Ltd., *London*
Pearson Education Australia Pty. Ltd., *Sydney*
Pearson Education Singapore, Pte. Ltd.
Pearson Education North Asia Ltd., *Hong Kong*
Pearson Education Canada, Inc., *Toronto*
Pearson Educación de México, S.A. de C.V.
Pearson Education—Japan, *Tokyo*
Pearson Education Malaysia, Pte. Ltd.
Pearson Education Inc., *Upper Saddle River, New Jersey*

- **Cost and complexity:** Although digital logic continues to drop in price, this factor should not be ignored. In particular, the higher the signaling rate to achieve a given data rate, the greater the cost. We will see that some codes require a signaling rate that is in fact greater than the actual data rate.

We now turn to a discussion of various techniques.

6.2 DIGITAL DATA, ANALOG SIGNALS

We start with the case of transmitting digital data using analog signals. The most familiar use of this transformation is for transmitting digital data through the public telephone network. The telephone network was designed to receive, switch, and transmit analog signals in the voice-frequency range of about 300 to 3400 Hz. It is not at present suitable for handling digital signals from the subscriber locations (although this is beginning to change). Thus digital devices are attached to the network via a modem (modulator-demodulator), which converts digital data to analog signals, and vice versa.

For the telephone network, modems are used that produce signals in the voice-frequency range. The same basic techniques are used for modems that produce signals at higher frequencies (e.g., microwave). This section introduces these techniques and provides a brief discussion of the performance characteristics of the alternative approaches.

We mentioned that modulation involves operation on one or more of the three characteristics of a carrier signal: amplitude, frequency, and phase. Accordingly, there are three basic encoding or modulation techniques for transforming digital data into analog signals, as illustrated in Figure 6.2: amplitude-shift keying (ASK),

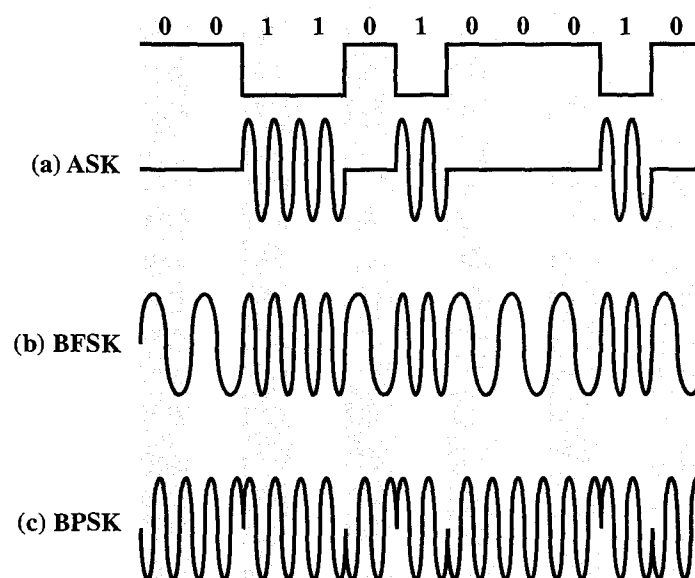


Figure 6.2 Modulation of Analog Signals for Digital Data

frequency-shift keying (FSK), and phase-shift keying (PSK). In all these cases, the resulting signal occupies a bandwidth centered on the carrier frequency.

Amplitude-Shift Keying

In ASK, the two binary values are represented by two different amplitudes of the carrier frequency. Commonly, one of the amplitudes is zero; that is, one binary digit is represented by the presence, at constant amplitude, of the carrier, the other by the absence of the carrier (Figure 6.2a). The resulting transmitted signal for one bit time is

$$\text{ASK} \quad s(t) = \begin{cases} A \cos(2\pi f_c t) & \text{binary 1} \\ 0 & \text{binary 0} \end{cases} \quad (6.1)$$

where the carrier signal is $A \cos(2\pi f_c t)$. ASK is susceptible to sudden gain changes and is a rather inefficient modulation technique. On voice-grade lines, it is typically used only up to 1200 bps.

The ASK technique is used to transmit digital data over optical fiber. For LED (light-emitting diode) transmitters, Equation (6.1) is valid. That is, one signal element is represented by a light pulse while the other signal element is represented by the absence of light. Laser transmitters normally have a fixed “bias” current that causes the device to emit a low light level. This low level represents one signal element, while a higher-amplitude lightwave represents another signal element.

Frequency-Shift Keying

The most common form of FSK is binary FSK (BFSK), in which the two binary values are represented by two different frequencies near the carrier frequency (Figure 6.2b). The resulting transmitted signal for one bit time is:

$$\text{BFSK} \quad s(t) = \begin{cases} A \cos(2\pi f_1 t) & \text{binary 1} \\ A \cos(2\pi f_2 t) & \text{binary 0} \end{cases} \quad (6.2)$$

where f_1 and f_2 are typically offset from the carrier frequency f_c by equal but opposite amounts.

Figure 6.3 shows an example of the use of BFSK for full-duplex operation over a voice-grade line. The figure is a specification for the Bell System 108 series modems. A voice-grade line will pass frequencies in the approximate range 300 to 3400 Hz. *Full duplex* means that signals are transmitted in both directions at the same time. To achieve full-duplex transmission, this bandwidth is split. In one direction (transmit or receive), the frequencies used to represent 1 and 0 are centered on 1170 Hz, with a shift of 100 Hz on either side. The effect of alternating between those two frequencies is to produce a signal whose spectrum is indicated as the shaded area on the left in Figure 6.3. Similarly, for the other direction (receive or transmit) the modem uses frequencies shifted 100 Hz to each side of a center frequency of 2125 Hz. This signal is indicated by the shaded area on the right in Figure 6.3. Note that there is little overlap and thus little interference.

BFSK is less susceptible to error than ASK. On voice-grade lines, it is typically used up to 1200 bps. It is also commonly used for high-frequency (3 to 30 MHz)

Table 10.1 Typical Parameters for Macrocells and Microcells [ANDE95]

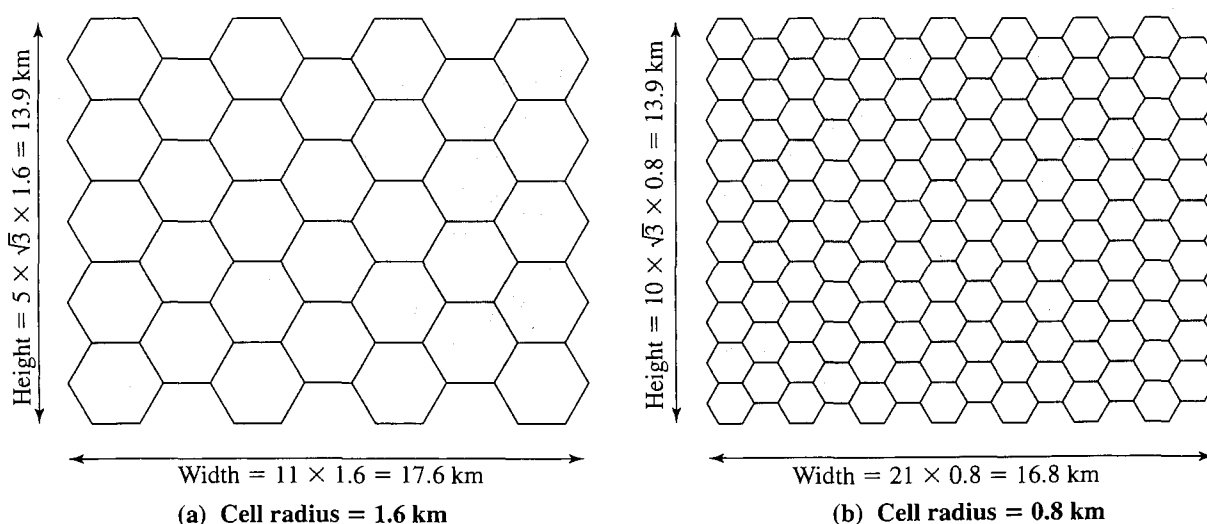
	Macrocell	Microcell
Cell radius	1 to 20 km	0.1 to 1 km
Transmission power	1 to 10 W	0.1 to 1 W
Average delay spread	0.1 to 10 μ s	10 to 100 ns
Maximum bit rate	0.3 Mbps	1 Mbps

Example 10.1 [HAAS00]. Assume a system of 32 cells with a cell radius of 1.6 km, a total of 32 cells, a total frequency bandwidth that supports 336 traffic channels, and a reuse factor of $N = 7$. If there are 32 total cells, what geographic area is covered, how many channels are there per cell, and what is the total number of concurrent calls that can be handled? Repeat for a cell radius of 0.8 km and 128 cells.

Figure 10.4a shows an approximately square pattern. The area of a hexagon of radius R is $1.5R^2\sqrt{3}$. A hexagon of radius 1.6 km has an area of 6.65 km^2 , and the total area covered is $6.65 \times 32 = 213 \text{ km}^2$. For $N = 7$, the number of channels per cell is $336/7 = 48$, for a total channel capacity of $48 \times 32 = 1536$ channels. For the layout of Figure 10.4b, the area covered is $1.66 \times 128 = 213 \text{ km}^2$. The number of channels per cell is $336/7 = 48$, for a total channel capacity of $48 \times 128 = 6144$ channels.

Operation of Cellular Systems

Figure 10.5 shows the principal elements of a cellular system. In the approximate center of each cell is a base station (BS). The BS includes an antenna, a controller, and a number of transceivers, for communicating on the channels assigned to that cell. The controller is used to handle the call process between the mobile unit and the rest of the network. At any time, a number of mobile units may be active and moving about within a cell, communicating with the BS. Each BS is connected to a mobile telecommunications switching office (MTSO), with one MTSO serving

**Figure 10.4** Frequency Reuse Example

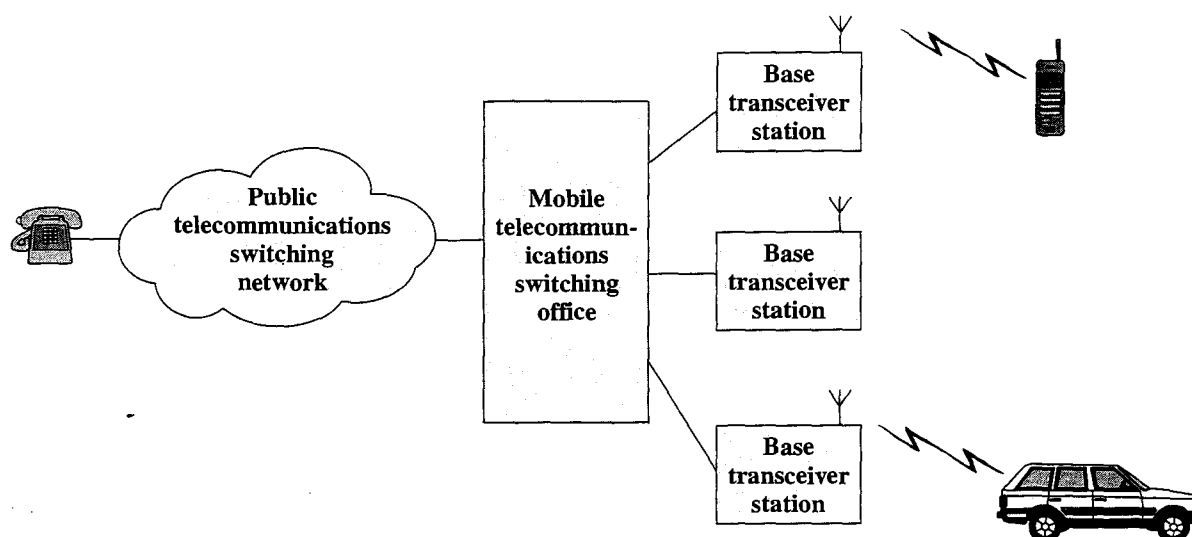


Figure 10.5 Overview of Cellular System

multiple BSs. Typically, the link between an MTSO and a BS is by a wire line, although a wireless link is also possible. The MTSO connects calls between mobile units. The MTSO is also connected to the public telephone or telecommunications network and can make a connection between a fixed subscriber to the public network and a mobile subscriber to the cellular network. The MTSO assigns the voice channel to each call, performs handoffs (discussed subsequently), and monitors the call for billing information.

The use of a cellular system is fully automated and requires no action on the part of the user other than placing or answering a call. Two types of channels are available between the mobile unit and the base station (BS): control channels and traffic channels. **Control channels** are used to exchange information having to do with setting up and maintaining calls and with establishing a relationship between a mobile unit and the nearest BS. **Traffic channels** carry a voice or data connection between users. Figure 10.6 illustrates the steps in a typical call between two mobile users within an area controlled by a single MTSO:

- **Mobile unit initialization:** When the mobile unit is turned on, it scans and selects the strongest setup control channel used for this system (Figure 10.6a). Cells with different frequency bands repetitively broadcast on different setup channels. The receiver selects the strongest setup channel and monitors that channel. The effect of this procedure is that the mobile unit has automatically selected the BS antenna of the cell within which it will operate.² Then a handshake takes place between the mobile unit and the MTSO controlling this cell, through the BS in this cell. The handshake is used to identify the user and register its location. As long as the mobile unit is on, this scanning procedure is repeated periodically to account for the motion of the unit. If the unit

²Usually, but not always, the antenna and therefore the base station selected is the closest one to the mobile unit. However, because of propagation anomalies, this is not always the case.

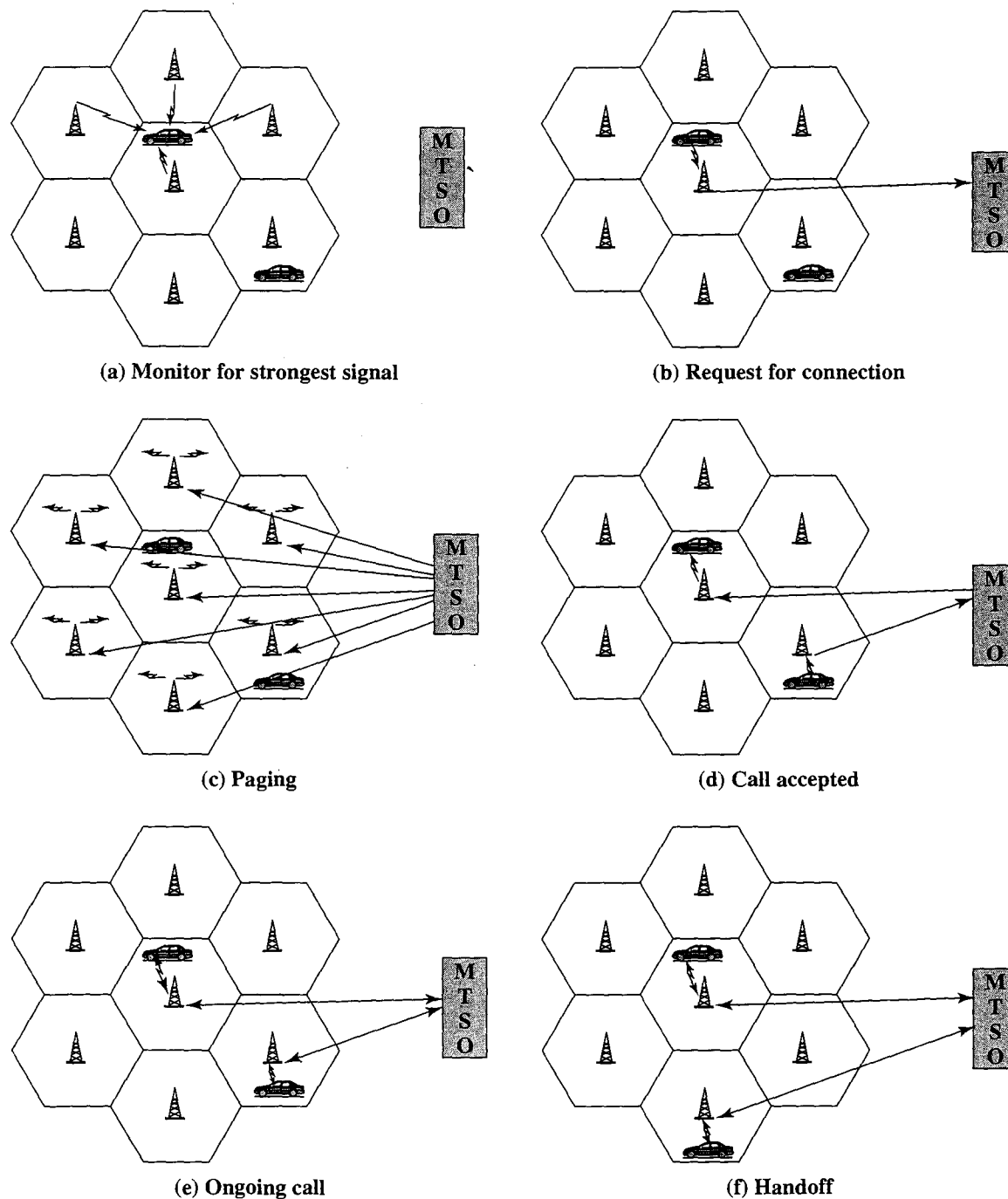


Figure 10.6 Example of Mobile Cellular Call

enters a new cell, then a new BS is selected. In addition, the mobile unit is monitoring for pages, discussed subsequently.

- **Mobile-originated call:** A mobile unit originates a call by sending the number of the called unit on the preselected setup channel (Figure 10.6b). The receiver at the mobile unit first checks that the setup channel is idle by examining information in the forward (from the BS) channel. When an idle is detected, the mobile unit may transmit on the corresponding reverse (to BS) channel. The BS sends the request to the MTSO.

- **Paging:** The MTSO then attempts to complete the connection to the called unit. The MTSO sends a paging message to certain BSs depending on the called mobile unit number (Figure 10.6c). Each BS transmits the paging signal on its own assigned setup channel.
- **Call accepted:** The called mobile unit recognizes its number on the setup channel being monitored and responds to that BS, which sends the response to the MTSO. The MTSO sets up a circuit between the calling and called BSs. At the same time, the MTSO selects an available traffic channel within each BS's cell and notifies each BS, which in turn notifies its mobile unit (Figure 10.6d). The two mobile units tune to their respective assigned channels.
- **Ongoing call:** While the connection is maintained, the two mobile units exchange voice or data signals, going through their respective BSs and the MTSO (Figure 10.6e).
- **Handoff:** If a mobile unit moves out of range of one cell and into the range of another during a connection, the traffic channel has to change to one assigned to the BS in the new cell (Figure 10.6f). The system makes this change without either interrupting the call or alerting the user.

Other functions performed by the system but not illustrated in Figure 10.6 include the following:

- **Call blocking:** During the mobile-initiated call stage, if all the traffic channels assigned to the nearest BS are busy, then the mobile unit makes a preconfigured number of repeated attempts. After a certain number of failed tries, a busy tone is returned to the user.
- **Call termination:** When one of the two users hangs up, the MTSO is informed and the traffic channels at the two BSs are released.
- **Call drop:** During a connection, because of interference or weak signal spots in certain areas, if the BS cannot maintain the minimum required signal strength for a certain period of time, the traffic channel to the user is dropped and the MTSO is informed.
- **Calls to/from fixed and remote mobile subscriber:** The MTSO connects to the public switched telephone network. Thus, the MTSO can set up a connection between a mobile user in its area and a fixed subscriber via the telephone network. Further, the MTSO can connect to a remote MTSO via the telephone network or via dedicated lines and set up a connection between a mobile user in its area and a remote mobile user.

Mobile Radio Propagation Effects

Mobile radio communication introduces complexities not found in wire communication or in fixed wireless communication. Two general areas of concern are signal strength and signal propagation effects.

- **Signal strength:** The strength of the signal between the base station and the mobile unit must be strong enough to maintain signal quality at the receiver but not so strong as to create too much cochannel interference with channels