

EXHIBIT I

WIRELESS

communications

Principles & Practice

Theodore S. Rappaport

PRENTICE HALL COMMUNICATIONS ENGINEERING AND
EMERGING TECHNOLOGIES SERIES
THEODORE S. RAPPAPORT, SERIES EDITOR

Wireless Communications

Principles and Practice

Theodore S. Rappaport

For book and bookstore information



<http://www.prenhall.com>

*Prentice Hall PTR
Upper Saddle River, New Jersey 07458*

Editorial/production manager: *Camille Trentacoste*
Cover design director: *Jerry Votta*
Cover designer: *Anthony Gemmellaro*
Manufacturing manager: *Alexis R. Heydt*
Acquisitions editor: *Karen Gettman*
Editorial assistant: *Barbara Alfieri*

© 1996 by Prentice Hall, PTR
Prentice Hall, Inc.
Upper Saddle River, NJ 07458

The publisher offers discounts on this book when ordered in bulk quantities. For more information, contact Corporate Sales Department, Prentice Hall PTR, One Lake Street, Upper Saddle River, NJ 07458. Phone: 800-382-3419; FAX: 201-236-7141. E-mail: corpsales@prenhall.com

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.

All product names mentioned herein are the trademarks of their respective owners.

Printed in the United States of America
20 19 18 17 16 15 14 13

ISBN 0-13-375536-3

Reprinted with corrections July, 1999

Prentice-Hall International (UK) Limited, *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Prentice-Hall of Canada, Inc., *Toronto*
Prentice-Hall Hispanoamericana, S. A., *Mexico*
Prentice-Hall of India Private Limited, *New Delhi*
Prentice-Hall of Japan, Inc., *Tokyo*
Prentice-Hall Asia Pte. Ltd., *Singapore*
Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*

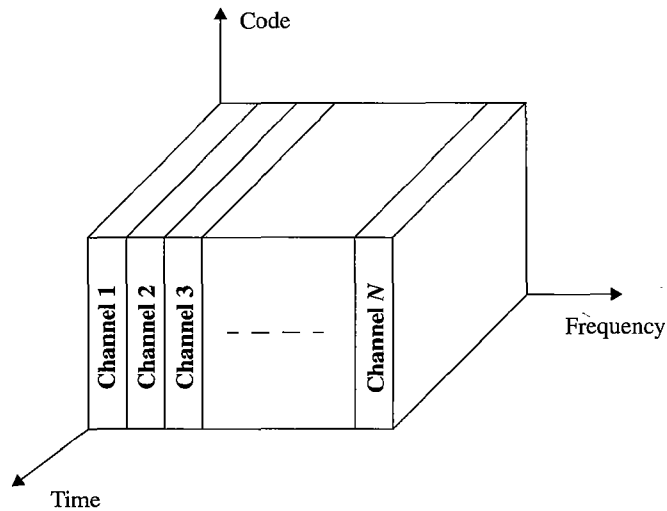


Figure 8.2
FDMA where different channels are assigned different frequency bands.

Example 8.2

If B_t is 12.5 MHz, B_{guard} is 10 kHz, and B_c is 30 kHz, find the number of channels available in an FDMA system.

Solution to Example 8.2

The number of channels available in the FDMA system is given as

$$N = \frac{12.5 \times 10^6 - 2(10 \times 10^3)}{30 \times 10^3} = 416$$

In the U.S., each cellular carrier is allocated 416 channels.

8.3 Time Division Multiple Access (TDMA)

Time division multiple access (TDMA) systems divide the radio spectrum into time slots, and in each slot only one user is allowed to either transmit or receive. It can be seen from Figure 8.3 that each user occupies a cyclically repeating time slot, so a channel may be thought of as particular time slot that reoccurs every frame, where N time slots comprise a frame. TDMA systems transmit data in a buffer-and-burst method, thus the transmission for any user is noncontinuous. This implies that, unlike in FDMA systems which accommodate analog FM, digital data and digital modulation must be used with TDMA. The transmission from various users is interlaced into a repeating frame structure as shown in Figure 8.4. It can be seen that a frame consists of a number of slots. Each frame is made up of a preamble, an information message, and tail bits. In TDMA/TDD, half of the time slots in the frame information message would be used for

the forward link channels and half would be used for reverse link channels. In TDMA/FDD systems, an identical or similar frame structure would be used solely for either forward or reverse transmission, but the carrier frequencies would be different for the forward and reverse links. In general, TDMA/FDD systems intentionally induce several time slots of delay between the forward and reverse time slots of a particular user, so that duplexers are not required in the subscriber unit.

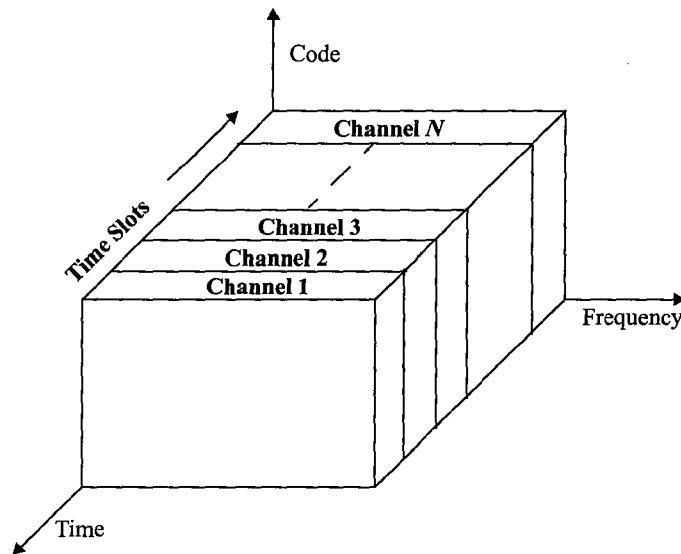


Figure 8.3
TDMA scheme where each channel occupies a cyclically repeating time slot.

In a TDMA frame, the preamble contains the address and synchronization information that both the base station and the subscribers use to identify each other. Guard times are utilized to allow synchronization of the receivers between different slots and frames. Different TDMA wireless standards have different TDMA frame structures, and some are described in Chapter 10. The features of TDMA include the following:

- TDMA shares a single carrier frequency with several users, where each user makes use of nonoverlapping time slots. The number of time slots per frame depends on several factors, such as modulation technique, available bandwidth, etc.
- Data transmission for users of a TDMA system is not continuous, but occurs in bursts. This results in low battery consumption, since the subscriber transmitter can be turned off when not in use (which is most of the time).
- Because of discontinuous transmissions in TDMA, the handoff process is much simpler for a subscriber unit, since it is able to listen for other base stations during idle time slots. An enhanced link control, such as that provided by *mobile assisted handoff* (MAHO) can be carried out by a subscriber

by listening on an idle slot in the TDMA frame.

- TDMA uses different time slots for transmission and reception, thus duplexers are not required. Even if FDD is used, a switch rather than a duplexer inside the subscriber unit is all that is required to switch between transmitter and receiver using TDMA.
- Adaptive equalization is usually necessary in TDMA systems, since the transmission rates are generally very high as compared to FDMA channels.
- In TDMA, the guard time should be minimized. If the transmitted signal at the edges of a time slot are suppressed sharply in order to shorten the guard time, the transmitted spectrum will expand and cause interference to adjacent channels.
- High synchronization overhead is required in TDMA systems because of burst transmissions. TDMA transmissions are slotted, and this requires the receivers to be synchronized for each data burst. In addition, guard slots are necessary to separate users, and this results in the TDMA systems having larger overheads as compared to FDMA.
- TDMA has an advantage in that it is possible to allocate different numbers of time slots per frame to different users. Thus bandwidth can be supplied on demand to different users by concatenating or reassigning time slots based on priority.

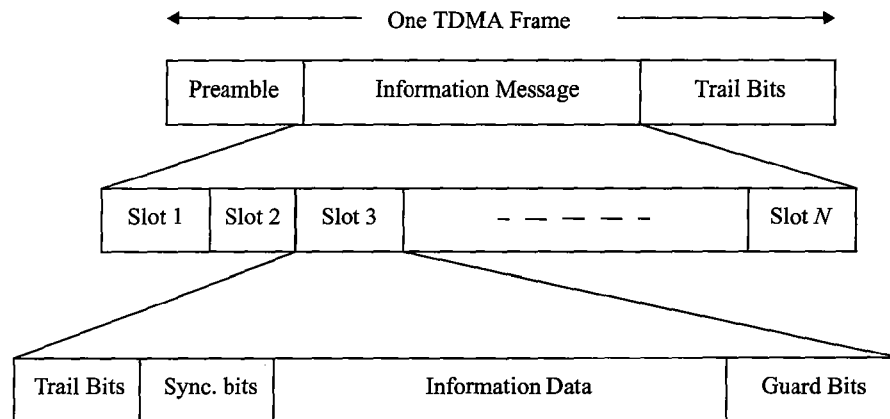


Figure 8.4
TDMA frame structure.

Efficiency of TDMA — The efficiency of a TDMA system is a measure of the percentage of transmitted data that contains information as opposed to providing overhead for the access scheme. The frame efficiency, η_f , is the percentage of bits per frame which contain transmitted data. Note that the transmitted data may include source and channel coding bits, so the raw end-user efficiency of a system is generally less than η_f . The frame efficiency can be found as follows.

The number of overhead bits per frame is [Zie92],

$$b_{OH} = N_r b_r + N_t b_p + N_t b_g + N_r b_g \quad (8.2)$$

where, N_r is the number of reference bursts per frame, N_t is the number of traffic bursts per frame, b_r is the number of overhead bits per reference burst, b_p is the number of overhead bits per preamble in each slot, and b_g is the number of equivalent bits in each guard time interval. The total number of bits per frame, b_T , is

$$b_T = T_f R \quad (8.3)$$

where T_f is the frame duration, and R is the channel bit rate. The frame efficiency η_f is thus given as

$$\eta_f = \left(1 - \frac{b_{OH}}{b_T}\right) \times 100\% \quad (8.4)$$

Number of channels in TDMA system — The number of TDMA channel slots that can be provided in a TDMA system is found by multiplying the number of TDMA slots per channel by the number of channels available and is given by

$$N = \frac{m (B_{tot} - 2B_{guard})}{B_c} \quad (8.5)$$

where m is the maximum number of TDMA users supported on each radio channel. Note that two guard bands, one at the low end of the allocated frequency band and one at the high end, are required to ensure that users at the edge of the band do not "bleed over" into an adjacent radio service.

Example 8.3

Consider Global System for Mobile, which is a TDMA/FDD system that uses 25 MHz for the forward link, which is broken into radio channels of 200 kHz. If 8 speech channels are supported on a single radio channel, and if no guard band is assumed, find the number of simultaneous users that can be accommodated in GSM.

Solution to Example 8.3

The number of simultaneous users that can be accommodated in GSM is given as

$$N = \frac{25 \text{ MHz}}{(200 \text{ kHz})/8} = 1000$$

Thus, GSM can accommodate 1000 simultaneous users.

Example 8.4

If GSM uses a frame structure where each frame consists of 8 time slots, and each time slot contains 156.25 bits, and data is transmitted at 270.833 kbps in the channel, find (a) the time duration of a bit, (b) the time duration of a slot, (c) the time duration of a frame, and (d) how long must a user occupying a single time slot must wait between two simultaneous transmissions.

Solution to Example 8.4

- (a) The time duration of a bit, $T_b = \frac{1}{270.833 \text{ kbps}} = 3.692 \text{ } \mu\text{s}$.
- (b) The time duration of a slot, $T_{slot} = 156.25 \times T_b = 0.577 \text{ ms}$.
- (c) The time duration of a frame, $T_f = 8 \times T_{slot} = 4.615 \text{ ms}$.
- (d) A user has to wait 4.615 ms, the arrival time of a new frame, for its next transmission.

Example 8.5

If a normal GSM time slot consists of 6 trailing bits, 8.25 guard bits, 26 training bits, and 2 traffic bursts of 58 bits of data, find the frame efficiency.

Solution to Example 8.5

A time slot has $6 + 8.25 + 26 + 2(58) = 156.25$ bits.

A frame has $8 \times 156.25 = 1250$ bits/frame.

The number of overhead bits per frame is given by

$$b_{OH} = 8(6) + 8(8.25) + 8(26) = 322 \text{ bits}$$

Thus, the frame efficiency

$$\eta_f = \left[1 - \frac{322}{1250} \right] \times 100 = 74.24 \%$$

8.4 Spread Spectrum Multiple Access

Spread spectrum multiple access (SSMA) uses signals which have a transmission bandwidth that is several orders of magnitude greater than the minimum required RF bandwidth. A pseudo-noise (PN) sequence (discussed in Chapter 5) converts a narrowband signal to a wideband noise-like signal before transmission. SSMA also provides immunity to multipath interference and robust multiple access capability. SSMA is not very bandwidth efficient when used by a single user. However, since many users can share the same spread spectrum bandwidth without interfering with one another, spread spectrum systems become bandwidth efficient in a multiple user environment. It is exactly this situation that is of interest to wireless system designers. There are two main types of spread spectrum multiple access techniques; *frequency hopped multiple access* (FH) and *direct sequence multiple access* (DS). Direct sequence multiple access is also called *code division multiple access* (CDMA).

8.4.1 Frequency Hopped Multiple Access (FHMA)

Frequency hopped multiple access (FHMA) is a digital multiple access system in which the carrier frequencies of the individual users are varied in a pseudorandom fashion within a wideband channel. The digital data is broken into uniform sized bursts which are transmitted on different carrier frequencies. The