

SMART ANTENNAS FOR WIRELESS COMMUNICATIONS:

IS-95 and Third Generation CDMA Applications



**JOSEPH C. LIBERTI, JR.
THEODORE S. RAPPAPORT**

Techniques and architectures
for uplink spatial processing
and downlink beamforming
in CDMA

Practical, hard-to-find
IS-95 engineering data
with link budget
examples

Tools for analyzing the
range and capacity of
CDMA wireless systems
with adaptive antenna
technology

Spatial channel
models for smart
antenna systems

Vital position location
and direction finding
algorithms for
implementing E-911
services

PRENTICE HALL COMMUNICATIONS ENGINEERING AND EMERGING TECHNOLOGIES SERIES
Theodore S. Rappaport, Series Editor

JOSEPH C. LIBERTI, JR. & THEODORE S. RAPPAPORT

SMART ANTENNAS FOR WIRELESS COMMUNICATIONS:

IS-95 and Third Generation CDMA Applications

SMART ANTENNAS FOR WIRELESS COMMUNICATIONS
IS-95 and Third Generation CDMA Applications

THE ONE-STOP SOURCE FOR ENGINEERING CDMA ADAPTIVE ANTENNAS



New adaptive ("smart") antenna arrays can enhance the performance of virtually any CDMA system, including IS-95, IMT-2000 and Wideband CDMA. *Smart Antennas for Wireless Communications* is the first book that brings together all the real-world data and expertise communications engineers need to develop smart antennas for CDMA.



Start out with a detailed overview of IS-95 PCS and Cellular CDMA, including uplink and downlink signal formats and link budgets. Next, understand the full range of smart antenna technology, from simple beamforming networks to advanced multi-user spatial processing systems. Learn how adaptive antenna systems can change patterns dynamically, adjusting to noise, interference, and multipath as they track mobile users.



Learn the key elements of smart antenna development, including vector channel impulse response, spatial signatures, spatial diversity, diversity combining, sectoring, and transmission beamforming. Understand important CDMA-related issues, including non-coherent and coherent CDMA spatial processors, dynamic re-sectoring, and the use of spatial filtering to increase range and capacity. Master all these fundamental design techniques:

- Characterization of spatio-temporal radio channels
- The geometrically-based single bounce elliptical model
- Optimal spatial filtering and adaptive algorithms
- Direction-Of-Arrival estimation algorithms



This book reflects the latest developments in CDMA and smart antennas, including the IS-95 and J-STD-008 CDMA standards, 14.4K vocoders, and techniques for designing RF location systems that meet the FCC's stringent E-911 requirements. Whether you're designing for today's CDMA systems or tomorrow's, you'll find it invaluable.



About the Authors

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Table 1-1 Evolution of Wireless Networks

	First Generation Systems	Second Generation Systems	Third Generation Systems
Time Frame	1984-1996	1996-2000	2000-2010
Services	Analog Mobile Telephony Voice Band Data	Digital voice, messaging	High speed data Broadband video Multimedia
Architecture	Macrocellular	Microcellular, Picocel- lular Wireless Local Loop	
Radio Technology	Analog FM, FDD- FDMA	Digital modulation, CDMA, TDMA using TDD and FDD	CDMA, possibly com- bined with TDMA, with TDD and FDD variants
Frequency Band	800 MHz	800+1900 MHz	2 GHz+
Examples	AMPS TACS ETACS NMT450/900 NTT JTACS/NTACS	cdmaOne (IS-95) GSM/DCS-1900 US TDMA IS-136 PACS PHS	cdma2000 WCDMA

is not simple to share an FDMA channel among multiple users or accommodate variable bandwidth signals. A fundamental result from communications theory is that the signals from multiple users may share a transmission medium if their signals can be made orthogonal [Proa89]. In FDMA systems, the signals are made orthogonal by separating channels into distinct frequency bands. The channels may alternatively be separated by making them mutually orthogonal based on some other characteristic, such as the time slot occupied by the channel, an underlying signal property, or even spatial position.

In Time Division Multiple Access (TDMA), the channels are made orthogonal by separating them in time, with all users using the same frequency band. The channels may also be made orthogonal by using a different underlying code sequence for each channel which is orthogonal to the code sequences used by other channels. This is called Code Division Multiple Access (CDMA). These multiple access strategies are illustrated conceptually in Figure 1-5.

In TDMA a time slot, which recurs once per frame, is assigned to each user. The users each transmit at a very high data rate during the brief time slot. For instance, if there are N time slots, each of which is T_s seconds long, then each user, producing data at some data rate R_d , must store data for NT_s seconds and transmit at a data rate NR_d during the T_s second time slot.

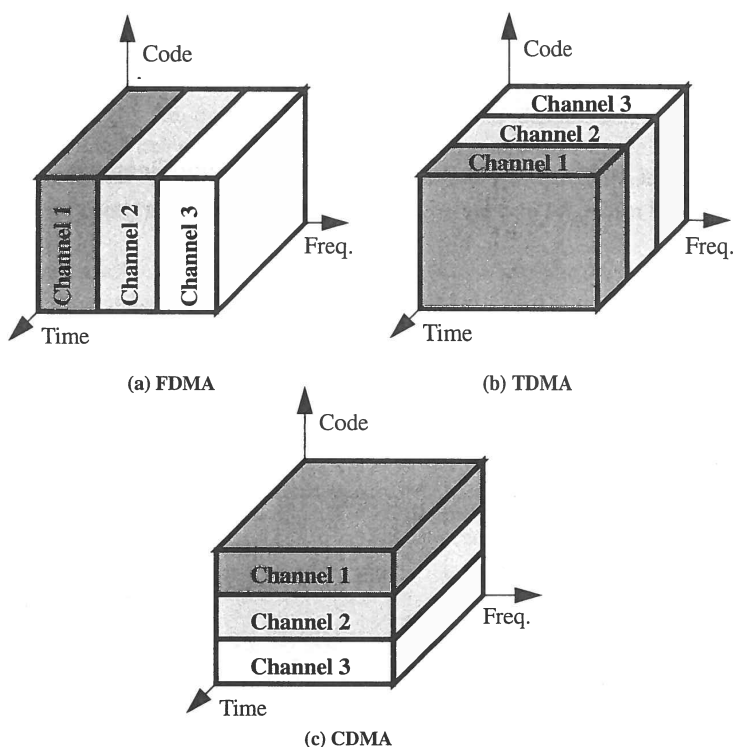


Figure 1-5 Three multiple access schemes: (a) Frequency Division Multiple Access (FDMA), in which different channels are assigned to different frequency bands; (b) Time Division Multiple Access (TDMA), where each channel occupies a cyclically repeating time slot; and (c) Code Division Multiple Access (CDMA), in which each channel is assigned a unique signature sequence code. A system could also combine all three of these multiple access strategies [Jer92].

High data rate users may be accommodated by assigning more than one time slot to a user. For instance, if M time slots are assigned to a user, then they can produce data at a rate MR_d bits per second at the expense of allowing fewer users on the system.

While TDMA users within a cell are separated by their separate time slots, different cells use different frequency channels. There may also be different frequency slots, or carriers within a cell, each of which may support several users. Examples of TDMA cellular systems are the Global System for Mobile Communications (GSM), Digital-AMPS (IS-136), the Personal Access Communications System (PACS), and the Personal Handyphone System (PHS).

Alternatively, in a Direct Sequence CDMA (DS-CDMA) system, all users transmit in the same frequency band at the same time. Different channels are distinguished by assigning a dif-

ferent underlying pseudo-noise (PN) sequence to each channel. The bandwidth of the PN-sequence is much larger than the bandwidth of the data sequence transmitted by the user. The method for despreading the signal at the receiver and the underlying concepts of direct sequence spread spectrum are discussed more fully in Section 1.3.

1.2.1 Key Terms and Concepts in Wireless Communications

To assist the reader, we now present a brief glossary of key terms which are the subject of this book.

Direct Sequence Code Division Multiple Access (DS-CDMA) - A wireless access technique, where signals from different users are assigned a unique *spreading code*. Signals from different users occupy the same spectrum at the same time. The receiver separates signals using their codewords, as shown in Figure 1-6.

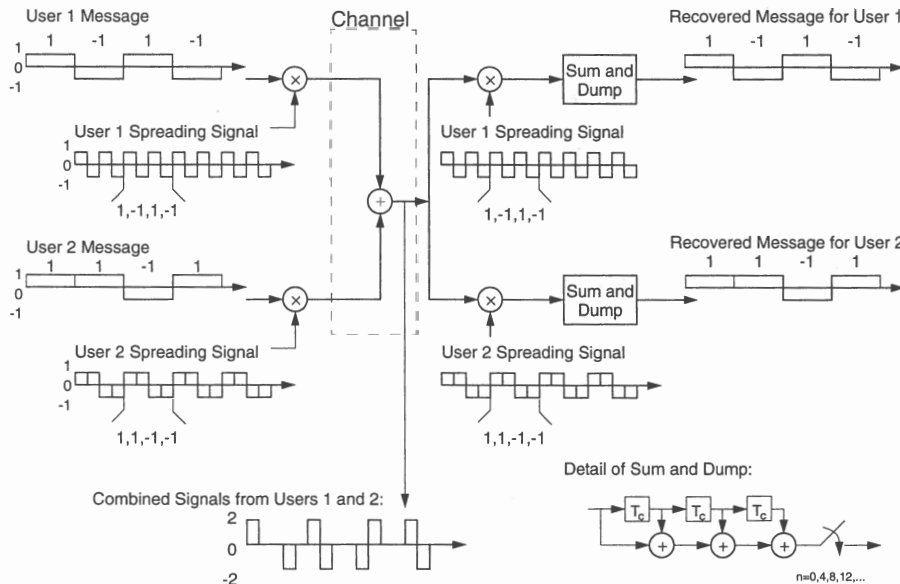


Figure 1-6 A simple Direct Sequence CDMA system. The signals from each user are spread by a spreading code, which is known at the transmitter and receiver. CDMA signals can occupy the same spectrum at the same time.

Adaptive Antenna - An array of antennas which is able to change its antenna pattern dynamically to adjust to noise, interference, and multipath. Adaptive array antennas can adjust their pattern to track portable users. Adaptive antennas are used to enhance received signals and may also be used to form beams for transmission.

Switched Beam Systems - Switched beam systems use a number of fixed beams at an antenna site. The receiver selects the beam that provides the greatest signal enhancement and interference reduction. Switched beam systems may not offer the degree of performance improvement offered by adaptive systems, but they are often much less complex and are easier to retro-fit to existing wireless technologies.

Smart Antennas - Smart antenna systems can include both adaptive antenna and switched beam technologies, as shown in Figure 1-7.

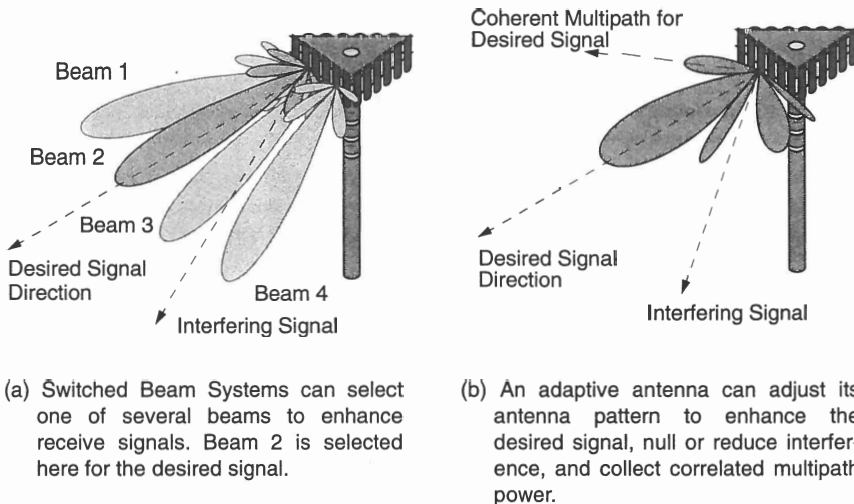


Figure 1-7 Two smart antenna technologies.

Macrocells - Large cells, covering several kilometers with each base station.

Microcells - Smaller cells, used to provide increased capacity with cell spacing of a few hundred meters to a kilometer.

Picocells - Very small cells, used to provide extremely high capacity indoors and in high-traffic pedestrian areas.

Low Tier Systems - Wireless systems using picocells and microcells to provide low power service to pedestrian users indoors and in pedestrian areas. Typically, low tier systems, such as Digital European Cordless Telephone (DECT) and Personal Access Communications System (PACS), are not as well suited for high vehicle speeds as High Tier systems, and are more susceptible to multipath. However, low tier systems are usually able to support higher voice quality. Because low tier systems do not have to contend with high time delay spread, base stations and subscriber units can be less expensive, and low power requirements allow very long

A frequency hopping system provides a level of security, especially when a large number of channels are used, since an unintended receiver that does not know the pseudo random sequence of frequency slots must constantly retune to search for the signal that it is attempting to intercept. FH systems also have the effect of randomizing interference which can be beneficial [Par89]. In today's emerging wireless CDMA technology, DS spread spectrum has been widely accepted, and the remainder of this text focuses on Direct Sequence rather than Frequency Hop Spread Spectrum.

1.4 Antenna Systems

In any wireless system, antennas are used at each end of the link. The antenna is a means of coupling radio frequency power from a transmission line into free space, allowing a transmitter to radiate, and a receiver to capture incident electromagnetic power. Antennas can be as simple as a piece of wire, or they can be complex systems with active electronics. Despite the range of technologies comprising antenna systems, there are a number of concepts which are common to all antenna systems.

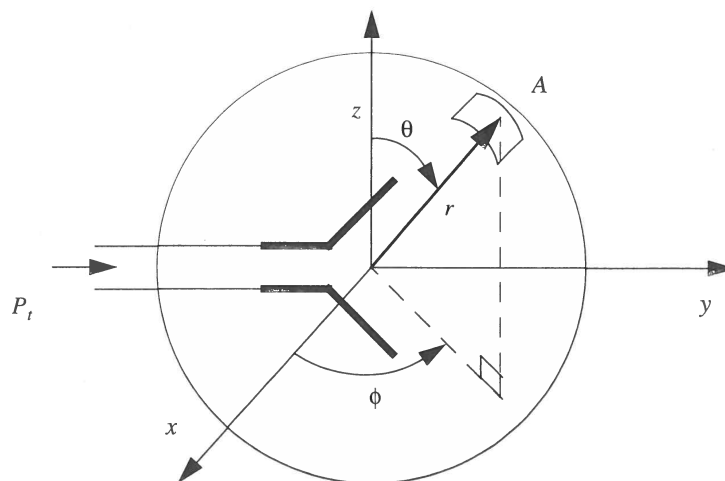


Figure 1-14 Geometry for analyzing antenna systems.

An antenna is illustrated in Figure 1-13. Here, a signal with time-average power of P_t is fed into the antenna. The antenna radiates this power in all directions. We define a direction using polar coordinates, θ and ϕ . If the vector $\mathbf{r}$ points in a particular direction, then ϕ is the angle between the x -axis and the projection of $\mathbf{r}$ into the x - y plane and θ is the angle between the z -axis and $\mathbf{r}$.