RF and Microwave Wireless Systems. Kai Chang

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CHAPTER TEN

Multiple-Access Techniques

10.1 INTRODUCTION

Three commonly used techniques for accommodating multiple users in wireless communications are frequency division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA). Frequency division multiple access and TDMA are old technologies and have been used for quite a while. Code division multiple access is the emerging technology for many new cellular phone systems. This chapter will briefly discuss these techniques.

10.2 FREQUENCY DIVISION MULTIPLE ACCESS AND FREQUENCY DIVISION MULTIPLEXING

For the FDMA and frequency division multiplexing (FDM) systems, the available frequency band is split into a specific number of channels, and the bandwidth of each channel depends on the type of information to be transmitted. To transmit a number of channels over the same system, the signals must be kept apart so that they do not interfere with each other.

Figure 10.1 shows an example of the FDM transmitter system with simultaneous transmission of 10 signals from 10 users. Each signal contains video information from 0 to 6 MHz with a guard band of 4 MHz. A double side band (DSB) modulator is used. The guard band is placed between two adjacent signals to avoid interference. A multiplexer is used to combine the signals, and the combined signals are then upconverted and amplified.

In the receiver, the signals are separated by a multiplexer that consists of many filters. The information is recovered after the demodulator. Figure 10.2 shows a receiver block diagram. The advantage of FDMA is that no network timing

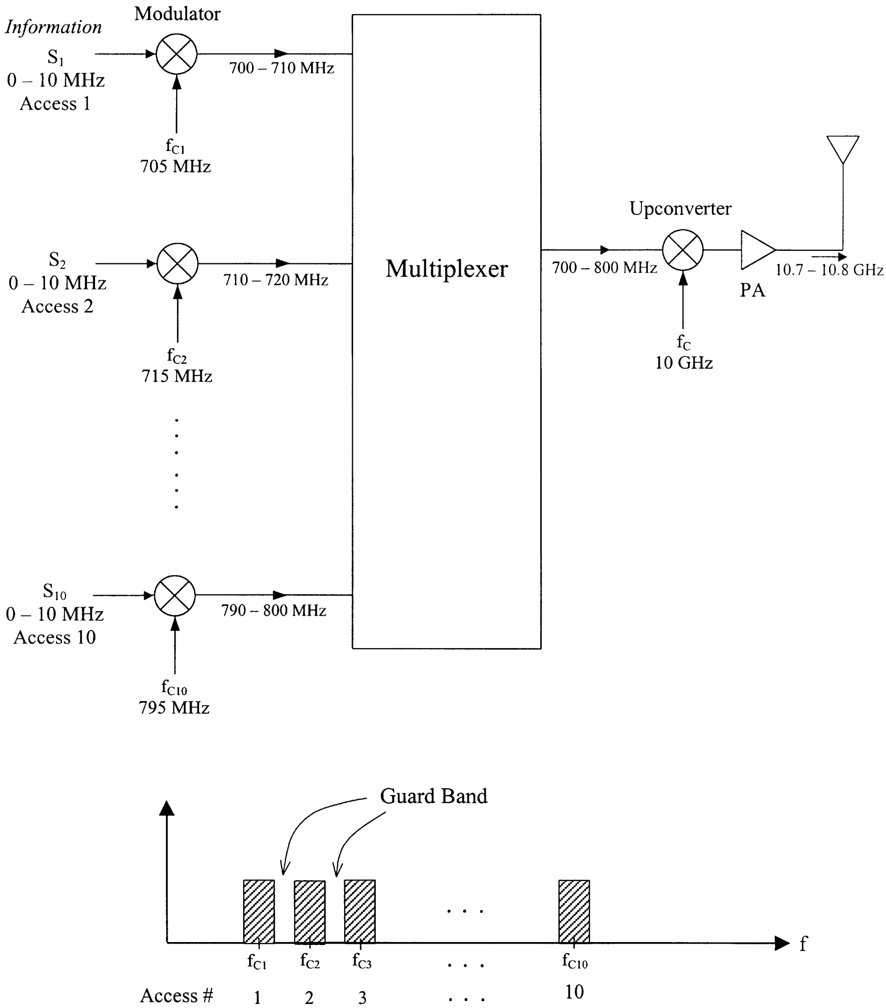

FIGURE 10.1 FDM system and frequency spectrums.

is required, and the major disadvantages include required power control, a wide frequency band, and interference caused by intermodulation and sideband distortion.

10.3 TIME DIVISION MULTIPLE ACCESS AND TIME DIVISION MULTIPLEXING

A TDMA or time division multiplexing (TDM) system uses a single frequency band to simultaneously transmit many signals (channels) in allocated time slots. These different channels time-share the same frequency band without interfering with each

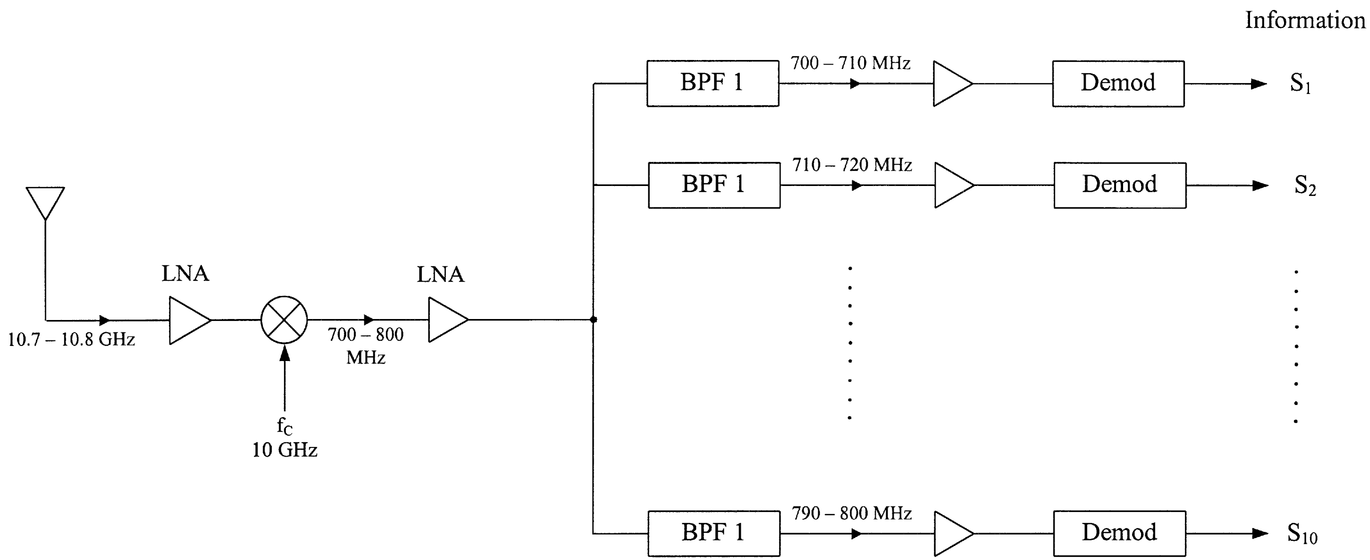

FIGURE 10.2 Receiver block diagram for an FDM system.

other. The advantages of TDMA as compared to FDMA are the requirement of a narrower frequency bandwidth, invulnerability to interchannel crosstalk and imperfect channel filtering, no power control required, and high efficiency. The disadvantage is the requirement of network timing.

Figure 10.3*a* shows a block diagram of a TDMA transmitting system. The samples are interleaved, and the composite signal consists of all of the interleaved pulses. A commutator or switch circuit is normally used to accomplish the data interleaving. Figure 10.3*b* shows an example of TDM of two signals. Figure 10.3*c* shows the data slot allocation for *N* signals. Each data slot could consist of a group

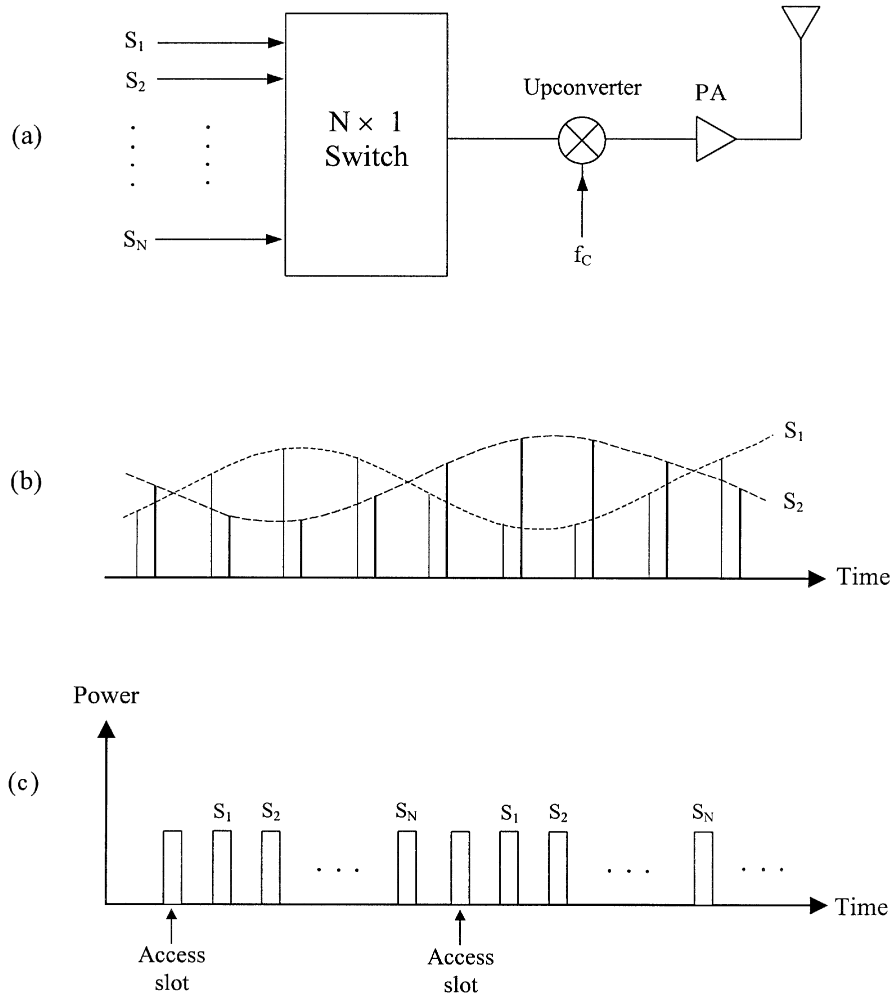

FIGURE 10.3 TDMA or TDM system: (*a*) a transmitter; (*b*) TDM of two signals; (*c*) data slot allocation for *N* signals.

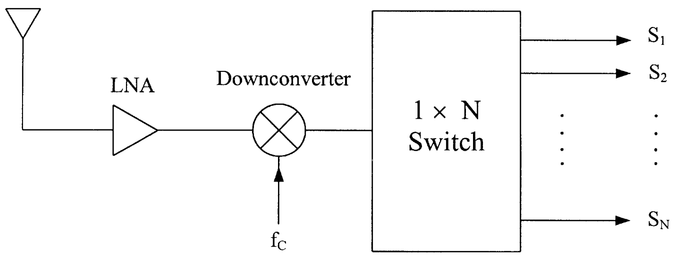

FIGURE 10.4 TDMA receiver.

of PCM codes. All samples are transmitted sequentially. At the receiver, the composite signal is demultiplexed by using a $1 \times N$ switch or commutator (Fig. 10.4).

10.4 SPREAD SPECTRUM AND CODE DIVISION MULTIPLE ACCESS

Spread spectrum (SS) is broadly defined as a technique by which the transmitted signal bandwidth is much greater than the baseband information signal bandwidth. The technique was initially developed by the military since it provided the desirable advantage of having a low probability of detection and thus made for secure communications. Because today's cellular and mobile communication systems suffer from severe spectrum congestion, especially in urban areas, spread spectrum techniques are used to increase system capacity in order to relieve congestion.

Spread spectrum has the following features and advantages:

1. It improves the interference rejection.
2. Because each user needs a special code to get access to the data stream, it has applications for secure communications and code division multiple access.
3. It has good antijamming capability.
4. The capacity and spectral efficiency can be increased by the use of spread spectrum techniques. Many users can use the same frequency band with different codes.
5. It has a nice feature of graceful degradation as the number of users increases.
6. Low-cost IC components can be used for implementation.

In the implementation of the spread spectrum technique, a modulated signal is modulated (spread) a second time to generate an expanded-bandwidth wide-band signal that does not interfere with other signals. The second modulation can be accomplished by one of the following methods [1]:

1. Direct-sequence spread spectrum (DSSS)
2. Frequency-hopping spread spectrum (FHSS)

3. Time hopping
4. Chirp

Figure 10.5*a* shows an example of a transmitter for the DSSS system [2]. The digital binary information is first used to modulate the IF carrier. The modulated signal is

$$s(t) = A\cos(\omega_{\rm IF}t + \phi) \tag{10.1}$$

where $\phi = 0^\circ$ and $\phi = 180^\circ$ for a BPSK modulator when the data are 1 and 0. The modulated IF carrier is modulated again by a spreading signal function $g(t)$, where $g(t)$ could be a pseudonoise (PN) signal or a code signal. Each user is assigned a special code. The output signal is equal to

$$v(t) = g(t)s(t) = Ag(t)\cos(\omega_{\rm IF}t + \phi) \tag{10.2}$$

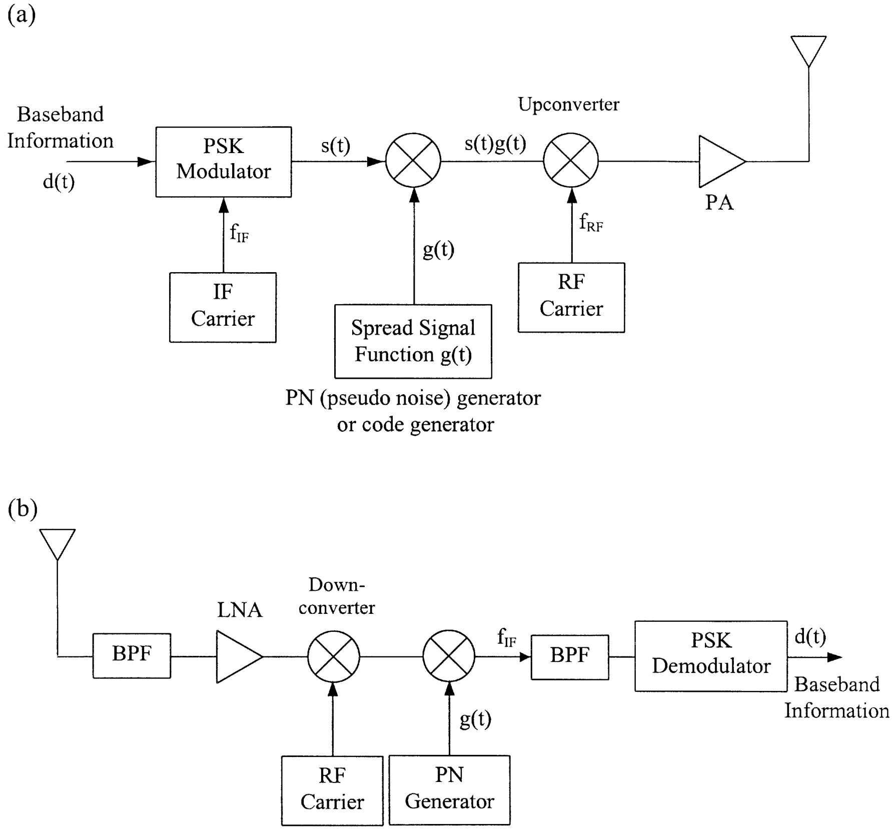

FIGURE 10.5 Direct-sequence spread spectrum system: (*a*) transmitter; (*b*) receiver.

This signal is upconverted by an RF carrier obtained from a phase-locked source or a frequency synthesizer. The signal is finally amplified and transmitted through an antenna. At the receiver end (Fig. 10.5*b*), the intended user will have a synchronized $g(t)$ that despreads the received signal and has the same PN sequence as that of the corresponding transmitter. The despreading or decoded signal is PSK demodulated to recover the information. Although the BPSK is assumed here for the first modulation, other digital modulation techniques described in Chapter 9 can be used.

The FHSS is similar to the direct-sequence spread spectrum system. The difference is that the PN sequence generator is used to control a frequency synthesizer to hop to one of the many available frequencies chosen by the PN sequence generator. As shown in Fig. 10.6, the output frequencies from the synthesizer hop pseudorandomly over a frequency range covering $f_1, f_2, \ldots, f_N$. Since N could be several thousand or more, the spectrum is spread over a wide frequency range. These output frequencies are the RF carrier frequencies coupled to the upconverter. The system is called a fast frequency hopping spread spectrum (FFHSS) system if the hopping rate is higher than the data bit rate. If the hopping rate is slower than the data rate, the system is called a slow frequency hopping spread spectrum (SFHSS) system. In the receiver, a PN generator with the same sequence (code) is used to generate the same frequency hopping sequence. These frequencies are used to downconvert the received signal. The IF signal is then demodulated to recover the data.

An important component in the spread spectrum (SS)-CDMA system is the PN sequence (or PN code) generator. The major functions of the PN code generator are as follows:

1. Spread the bandwidth of the modulated signal to the larger transmission bandwidth.
2. Distinguish between the different user signals utilizing the same transmission bandwidth in a multiple-access scheme.

The PN code is the "key" of each user to access his or her intended signal in the receiver. Two commonly used sequences are the maximal-length sequences and Gold sequences. The maximal-length sequences (m-sequences) use cascaded flip-flops to generate the random codes. As shown in Fig. 10.7, each flip-flop can generate a logic output of 1 or 0. If N is the total number of flip-flops, the sequence length L in bits is given by

$$L = 2^N - 1 \tag{10.3}$$

As examples, if $N = 3$, $L = 2^3 - 1 = 7$. If $N = 15$, $L = 2^{15} - 1 = 32{,}767$. The subtraction of 1 in Eq. (10.3) is to exclude the code with all zeroes. Here, L represents the maximum number of users with different codes.

Gold sequences were invented by R. Gold in 1967 [3]. Gold sequences are generated by combining two m-sequences clocked by the same chip-clock, as shown

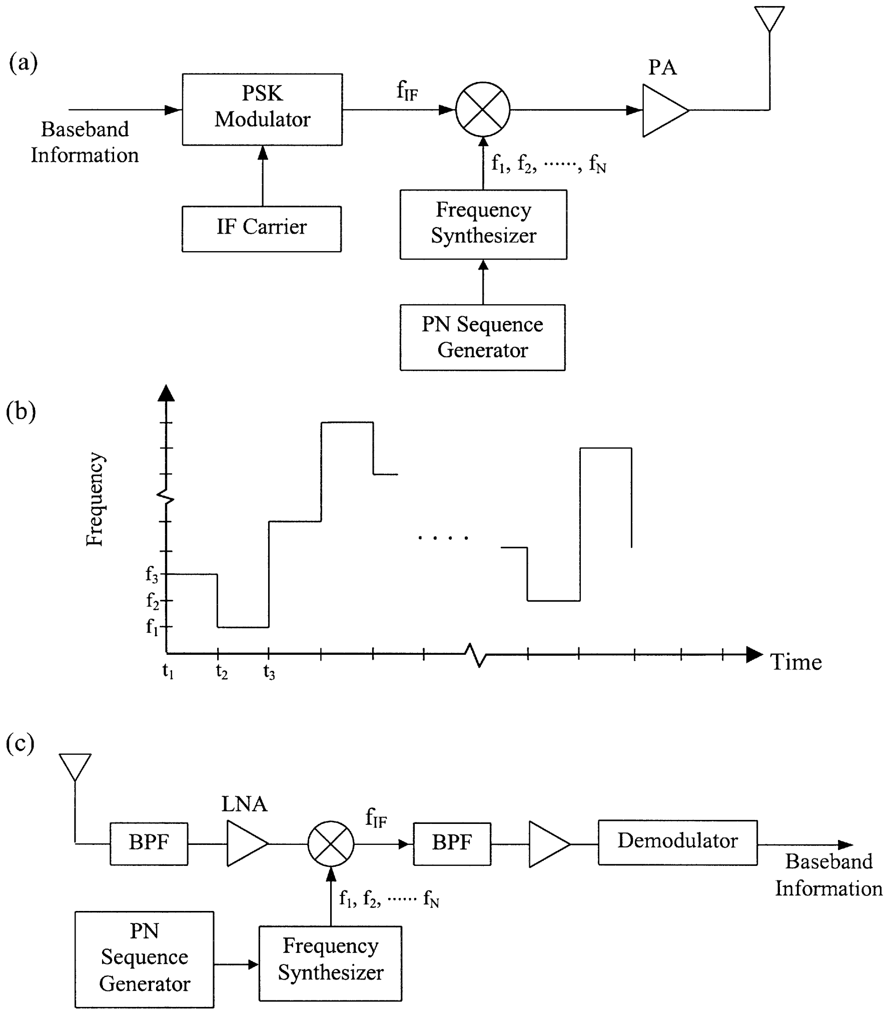

FIGURE 10.6 Frequency hopping spread spectrum system: (*a*) transmitter block diagram; (*b*) frequency hopping output; (*c*) receiver block diagram.

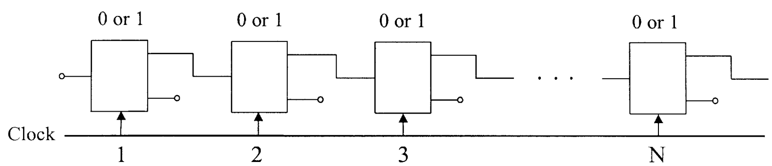

FIGURE 10.7 An m-sequence generator.

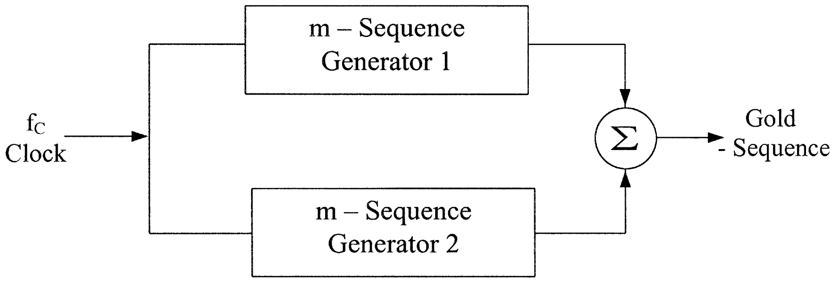

FIGURE 10.8 Gold sequence generator.

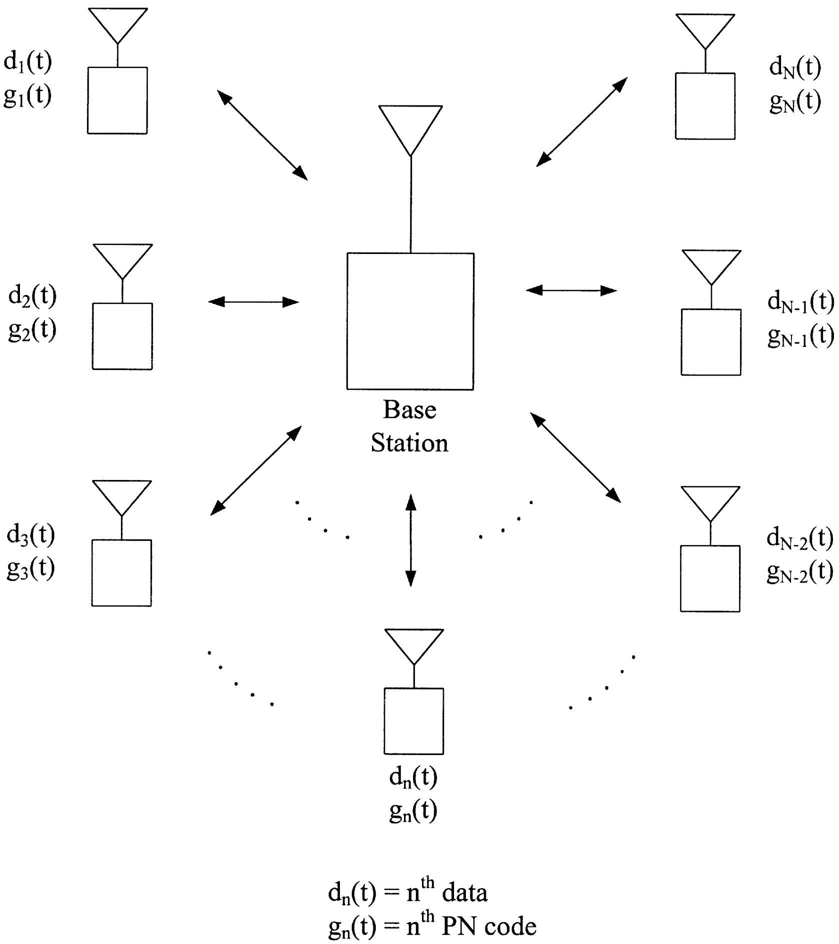

FIGURE 10.9 Many users share the same frequency band in the same mobile cellular cell using CDMA techniques.

in Fig. 10.8. The Gold sequences offer good cross-correlation between the single sequences.

In summary, SS-CDMA received widespread interest because it allows many users to occupy the same frequency band without causing interference. In military applications, it offers secure communications and immunity to jamming. In wireless mobile communications, it allows many users to simultaneously occupy the same frequency. Each user is assigned a unique code. All signals from all users are received by each user, but each receiver is designed to listen to and recognize only one specific sequence. Figure 10.9 shows many users communicating simultaneously with the base station operating at the same frequency band. Compared to TDMA systems, CDMA has the following advantages: (1) It is relatively easy to add new users. (2) It has the potential for higher capacity. (3) The system is more tolerant to multipath fading and more immune to interference. (4) Network synchronization is not required. Because of these advantages, many new communications will use CDMA techniques.

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