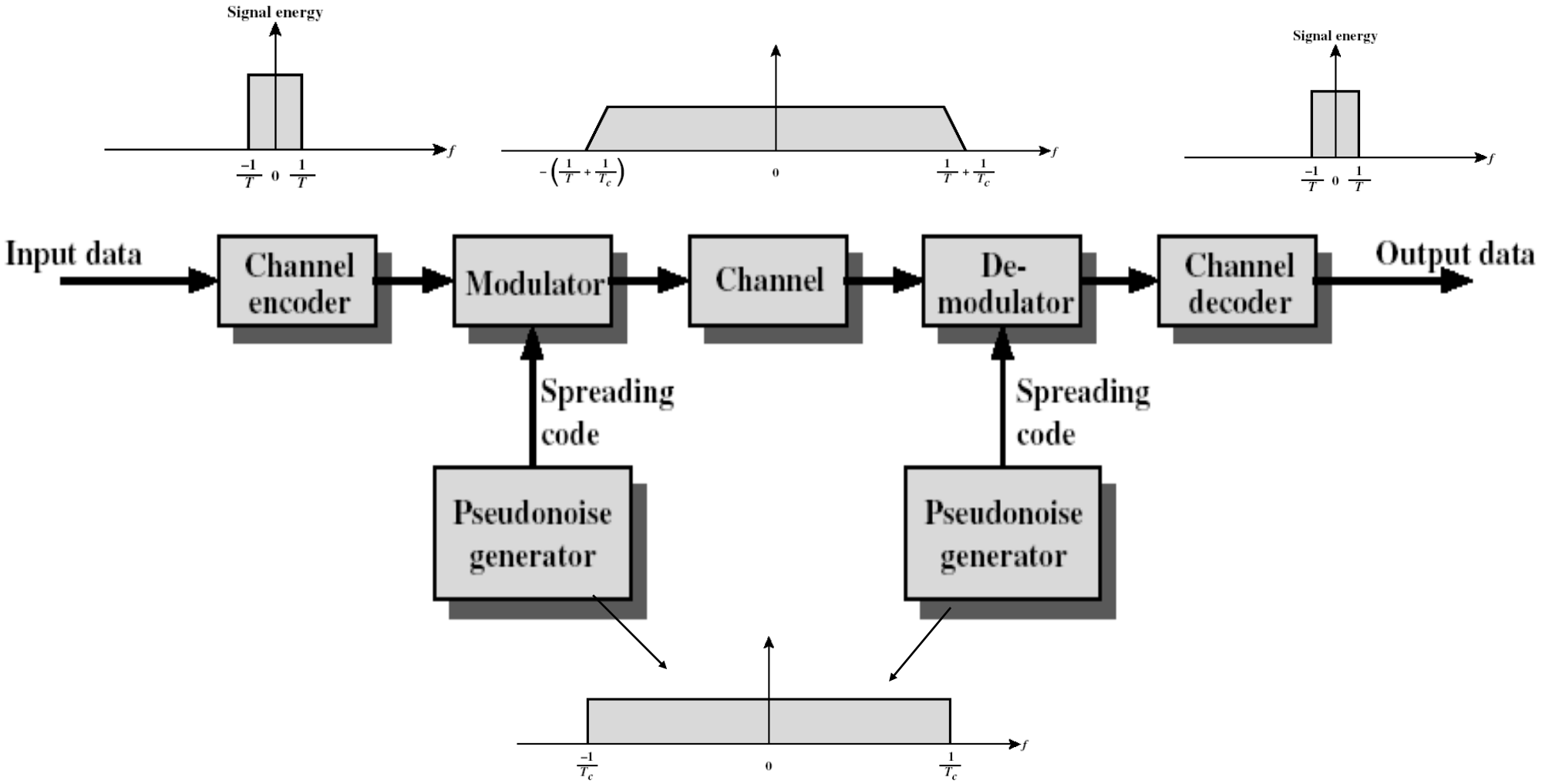
Spread Spectrum and Multiple Access

- **Concept of spread spectrum (WS: 7.1)**
  - **Direct sequence (WS:7.3)**
  - **Frequency-hopping (WS: 7.2)**
- **Multiple Access Techniques**
  - **CDMA (WS: 7.4)**
  - **Random Access (PK:4.3)**

Spread Spectrum Model



Spread Spectrum

- **Input is fed into a modulator**
  - **Produces analog signal with narrow bandwidth**
- **Signal is further modulated using sequence of digits**
  - **Spreading code or spreading sequence**
  - **Generated by pseudonoise, or pseudo-random number generator**
- **Effect of modulation is to increase bandwidth of signal to be transmitted**
- **On receiving end, digit sequence is used to demodulate the spread spectrum signal**
- **Signal is fed into a channel decoder to recover data**

Advantages of Spread Spectrum

- **What can be gained from apparent waste of spectrum?**
  - **Immunity from various kinds of noise and multipath distortion – reduce SNR margin!**

    Shannon formula: $C = B*\log(1+ S/N)$

    for the same Capacity C, when B increases, S/N can be decreased.

  - **Can be used for hiding and encrypting signals – Security!**
  - **Several users can independently use the same higher bandwidth with very little interference – CDMA!**

Direct Sequence Spread Spectrum (DSSS)

- **Each bit in original signal is represented by multiple bits in the transmitted signal**
- **Spreading code spreads signal across a wider frequency band**
  - **Spread is in direct proportion to number of bits used**
- **One technique combines digital information stream with the spreading code bit stream using exclusive-OR (Figure 7.6)**

Direct Sequence Spread Spectrum (DSSS)

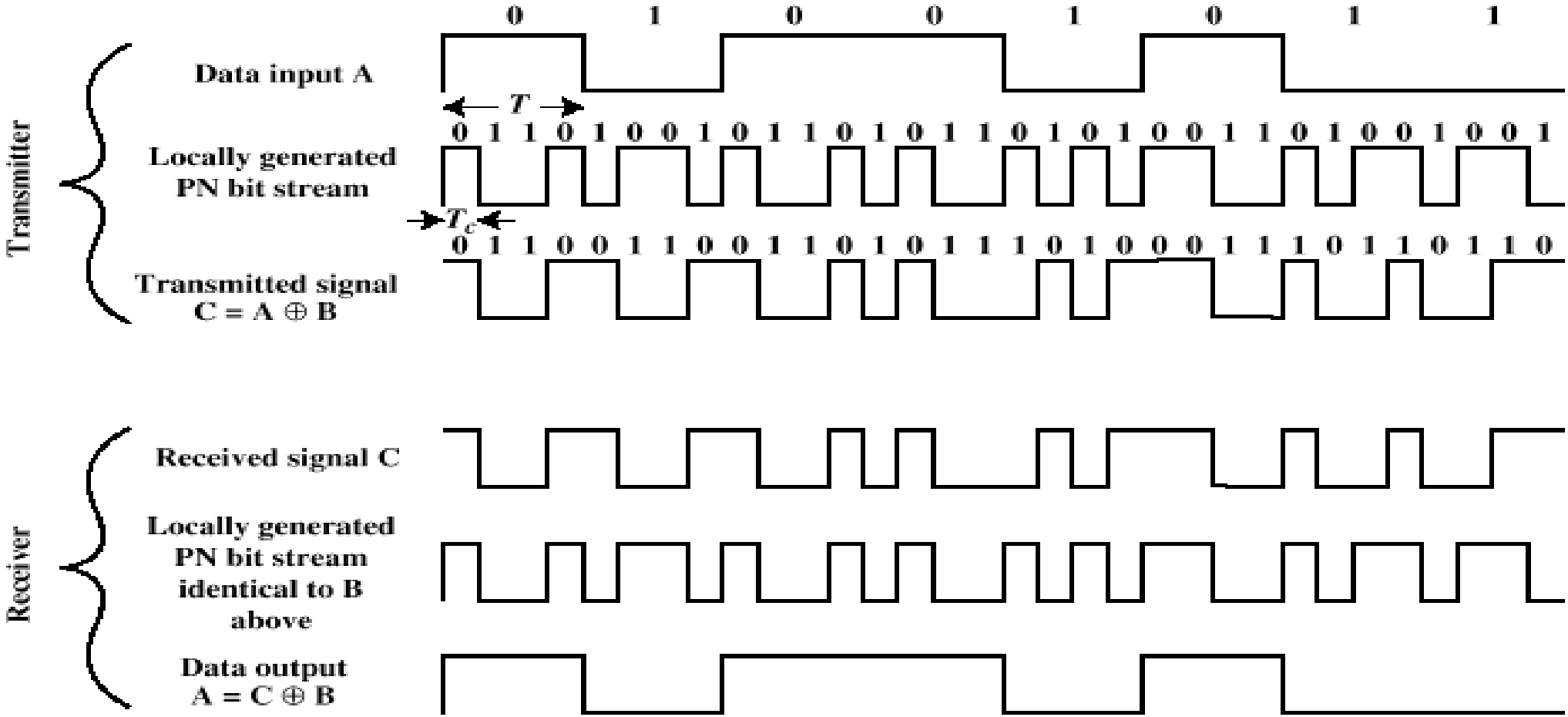
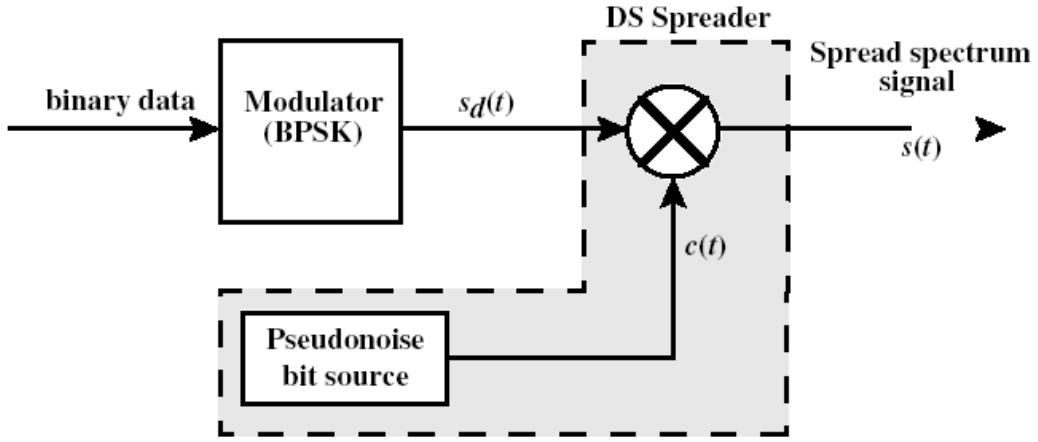
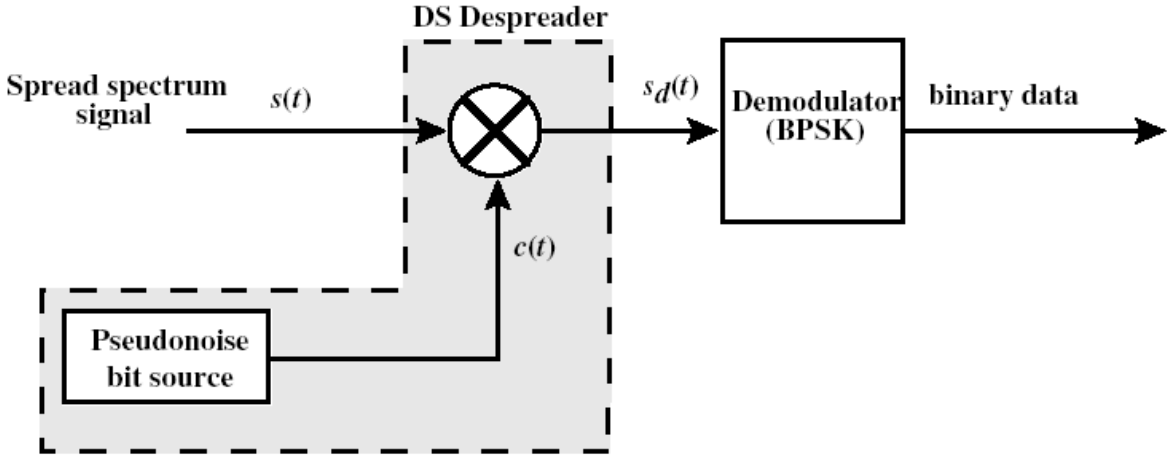


Figure 7.6 Example of Direct Sequence Spread Spectrum

DSSS System

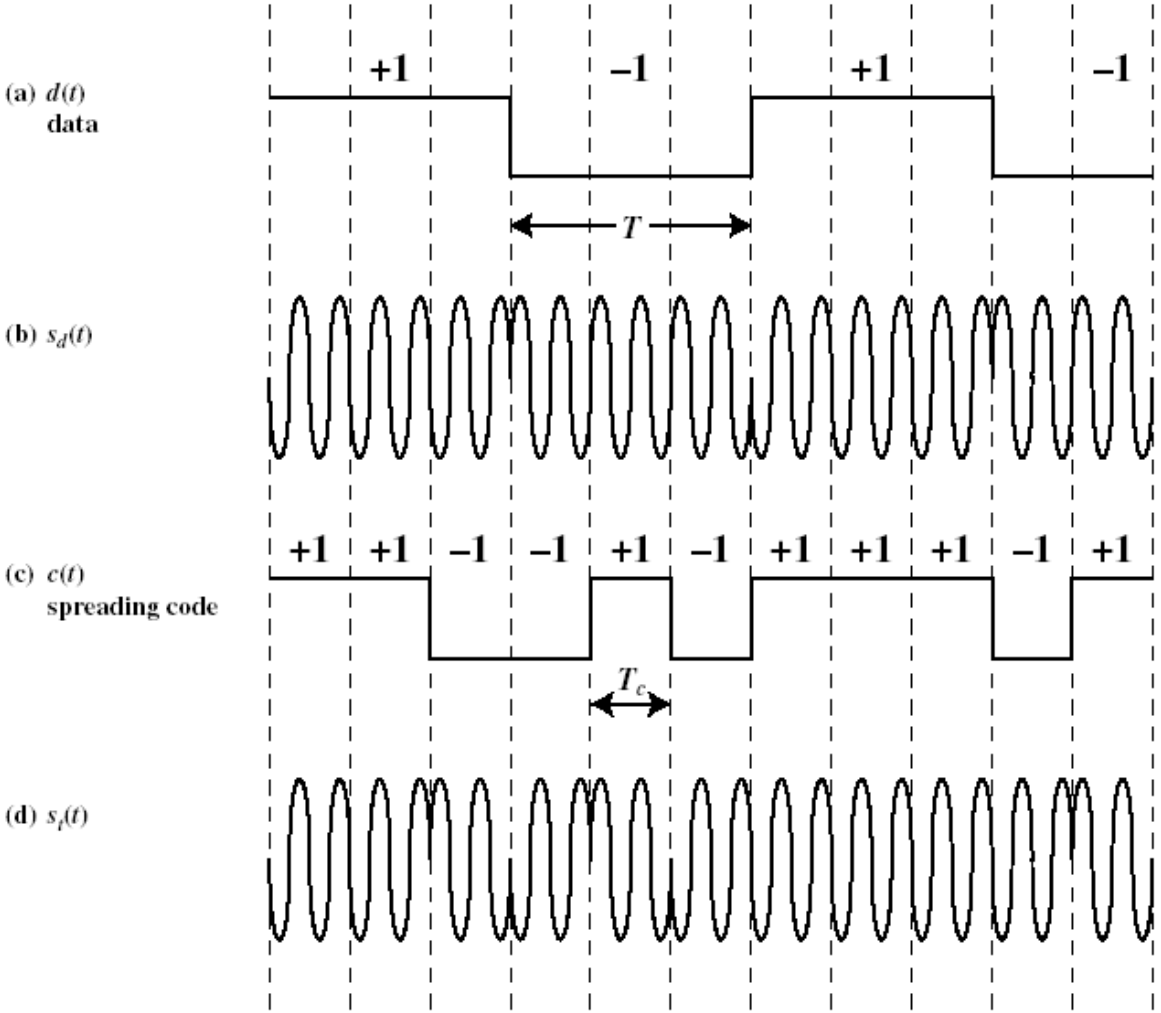


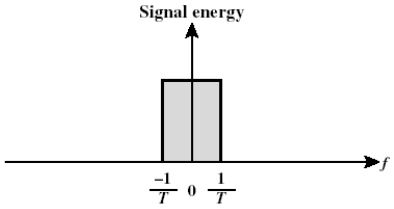
(a) Transmitter



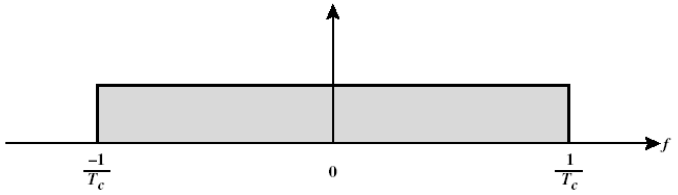
(b) Receiver

DSSS Using BPSK

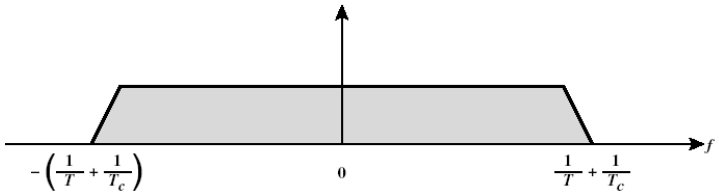




(a) Spectrum of data signal



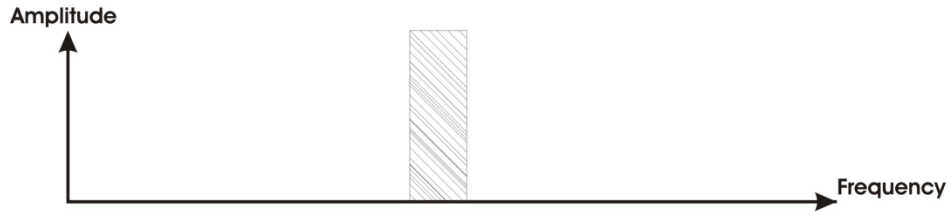
(b) Spectrum of pseudonoise signal



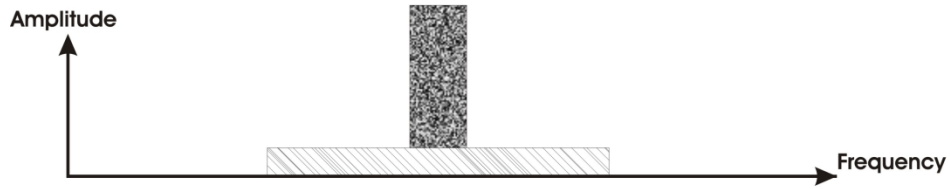
Performance of DSSS

- The carrier power is spread over a bandwidth of ~ $2/T_c$.
- After the demodulation, including a bandpass filter, the data recovered with bandwidth 2/T.
- The most jamming power is filtered, reducing by a factor, **Processing gain**:

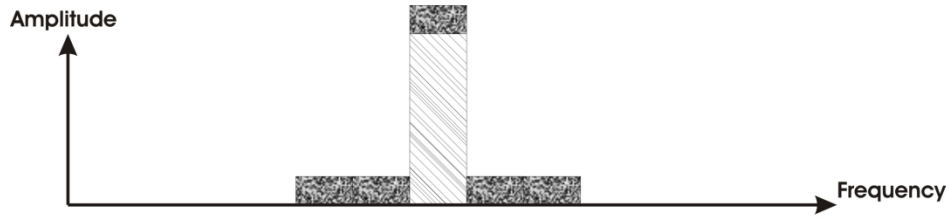
$$G = T / T_c = W_s / W_d$$



Step 1: The original, narrowband information signal.



Step 2: The information signal is spread over a wide frequency range with the spreading code and narrowband noise is added by the channel.



Step 3: The received signal is multiplied with the spreading code, causing the narrowband noise to be spread, and the wideband information signal to be despread.

Frequency Hoping Spread Spectrum (FHSS)

- **Signal is broadcast over seemingly random series of radio frequencies**
  - **A number of channels allocated for the FH signal**
  - **Width of each channel corresponds to bandwidth of input signal**
- **Signal hops from frequency to frequency at fixed intervals**
  - **Transmitter operates in one channel at a time**
  - **Bits are transmitted using some encoding scheme**
  - **At each successive interval, a new carrier frequency is selected**

Frequency Hoping Spread Spectrum

- **Channel sequence dictated by spreading code**
- **Receiver, hopping between frequencies in synchronization with transmitter, picks up message**
- **Advantages**
  - **Eavesdroppers hear only unintelligible blips**
  - **Attempts to jam signal on one frequency succeed only at knocking out a few bits**

Frequency Hoping Spread Spectrum

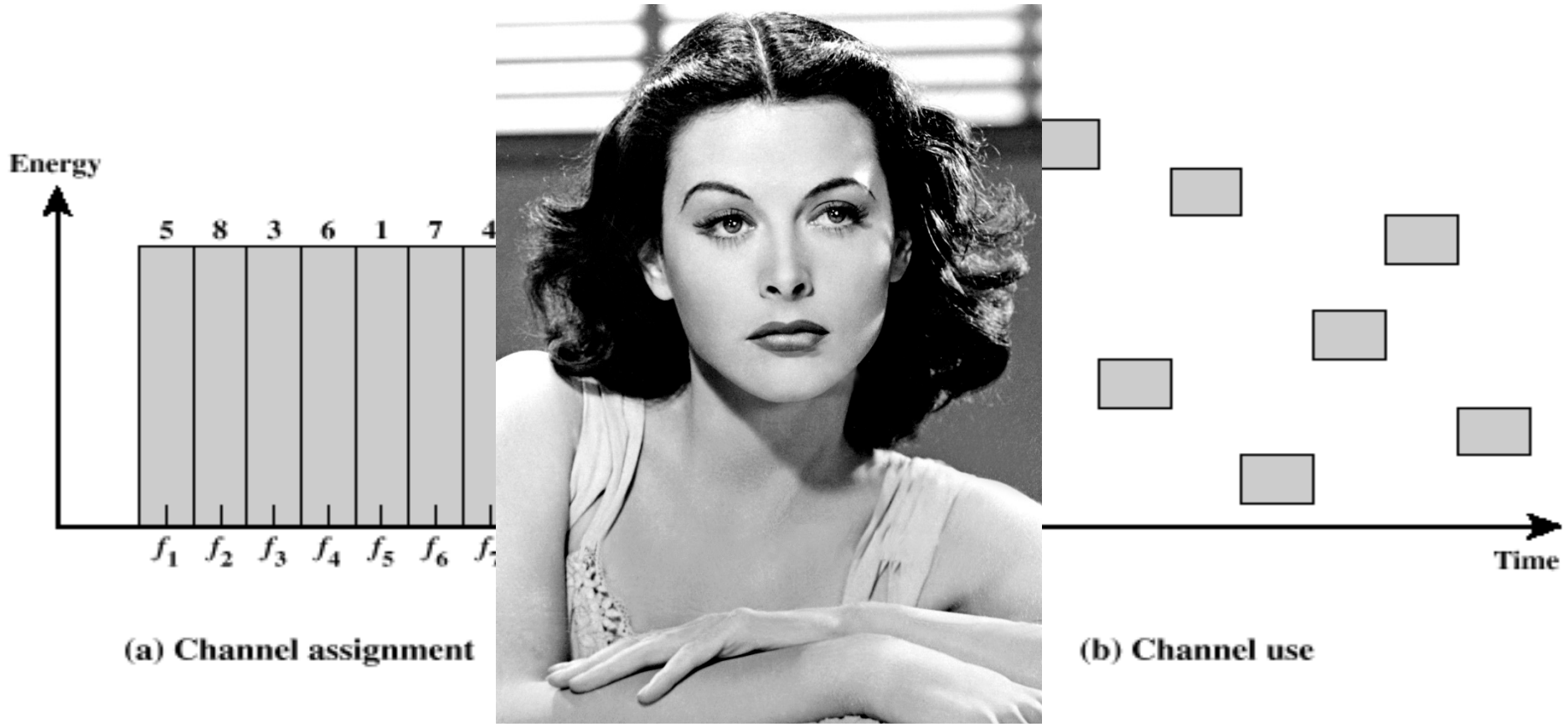


Figure 7.2 Frequency Hopping Example

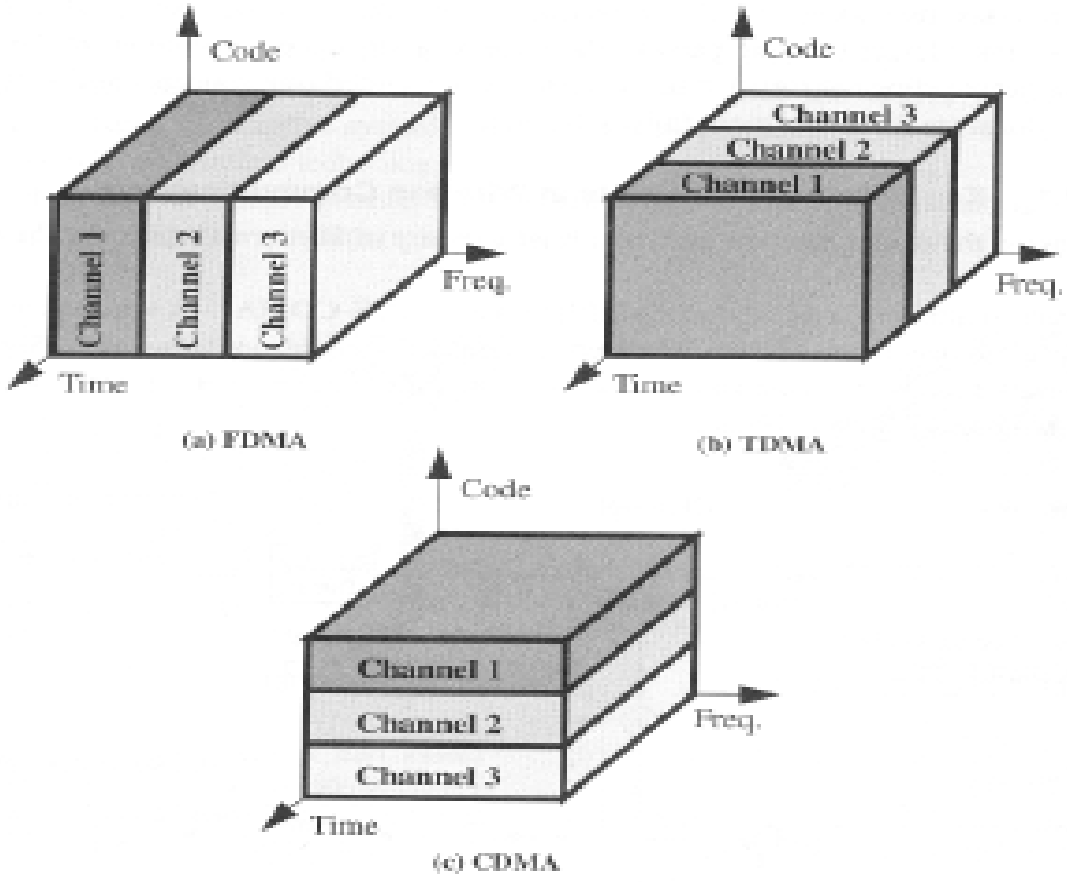
FHSS Performance Considerations

- **Large number of frequencies used**
- **Results in a system that is quite resistant to jamming**
  - **Jammer must jam all frequencies**
  - **With fixed power, this reduces the jamming power in any one frequency band by a factor of 2^k.**

- **Processing gain: use $4 = 2^k$ FHSS scheme,**

$$G_p = 2^k = W_S / W_d$$

Fixed Assignment Multiple Access

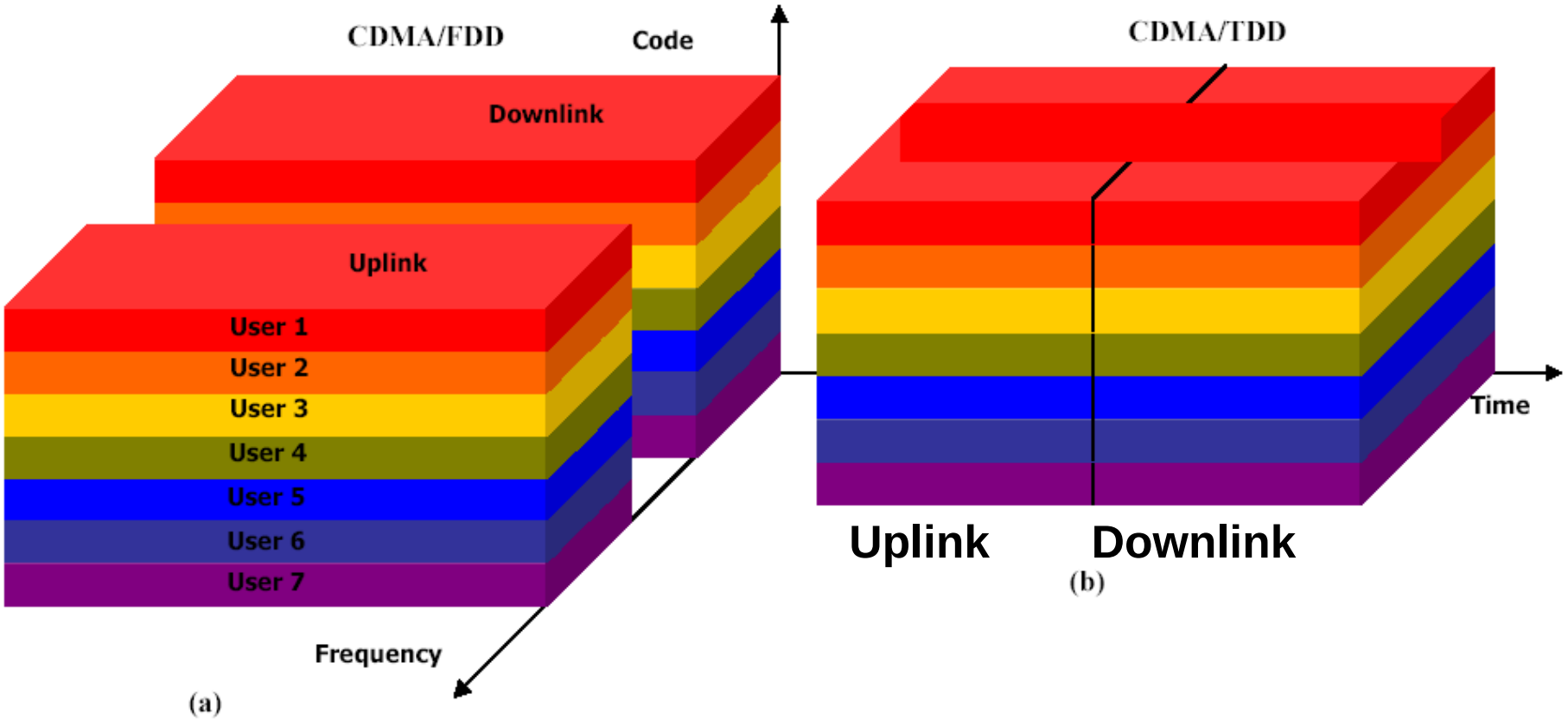


Frequency Division Multiple Access (FDMA), in which different channels are assigned to different frequency bands (users).

Time Division Multiple Access (TDMA), where each channel occupies a cyclically repeating time slot.

Code Division Multiple Access (CDMA), in which each channel is assigned a unique signature sequence code.

CDMA/FDD or TDD



IS-95 and 3G Systems

Code-Division Multiple Access (CDMA)

- **Basic Principles of CDMA**
  - ***D* = rate of data signal**
  - **Break each bit into *k chips***
    - » **Chips are a user-specific fixed pattern**
  - **Chip data rate of new channel = *kD***

Simple illustration of CDMA

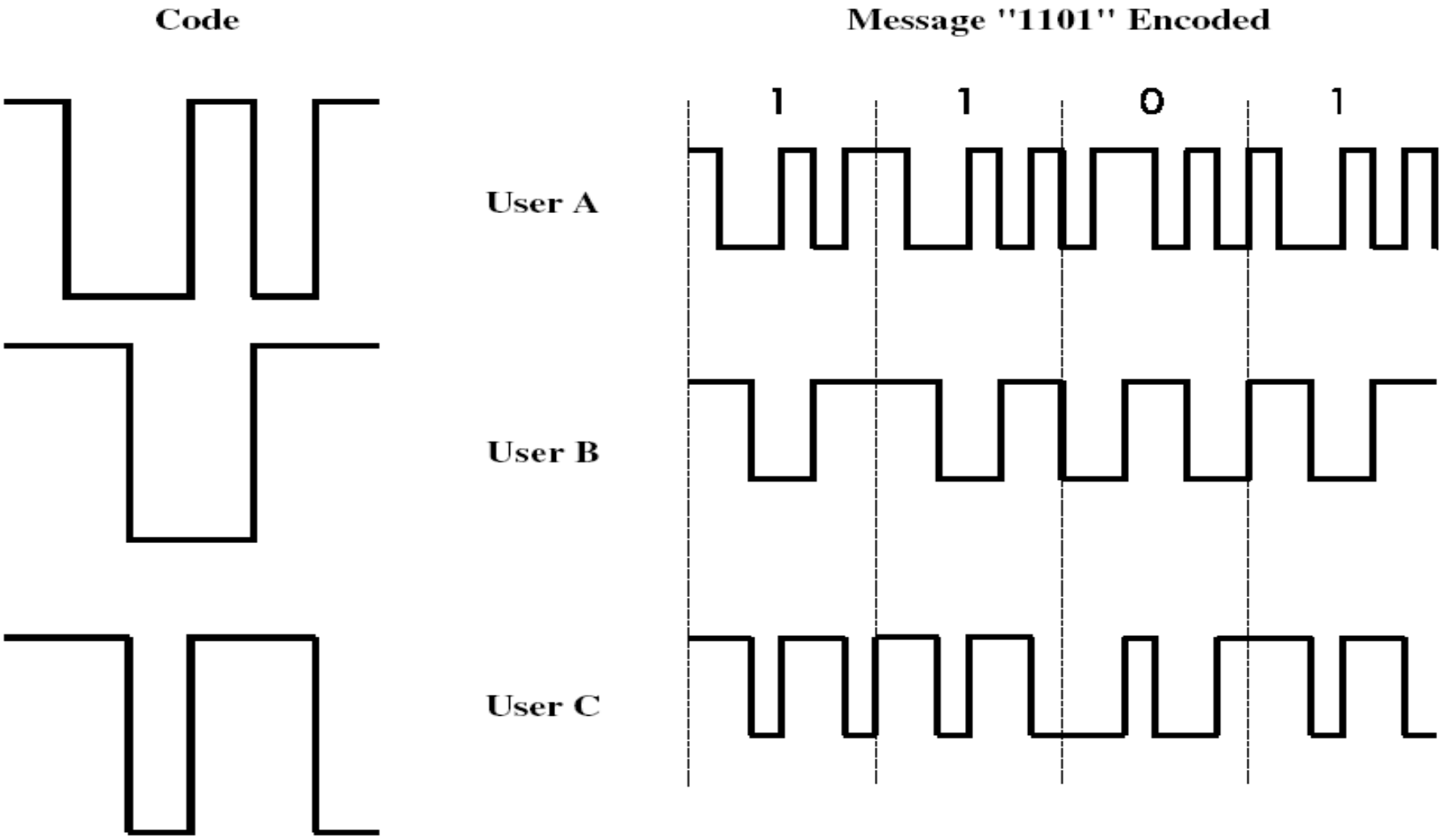


Figure 7.10 CDMA Example

CDMA in DSSS

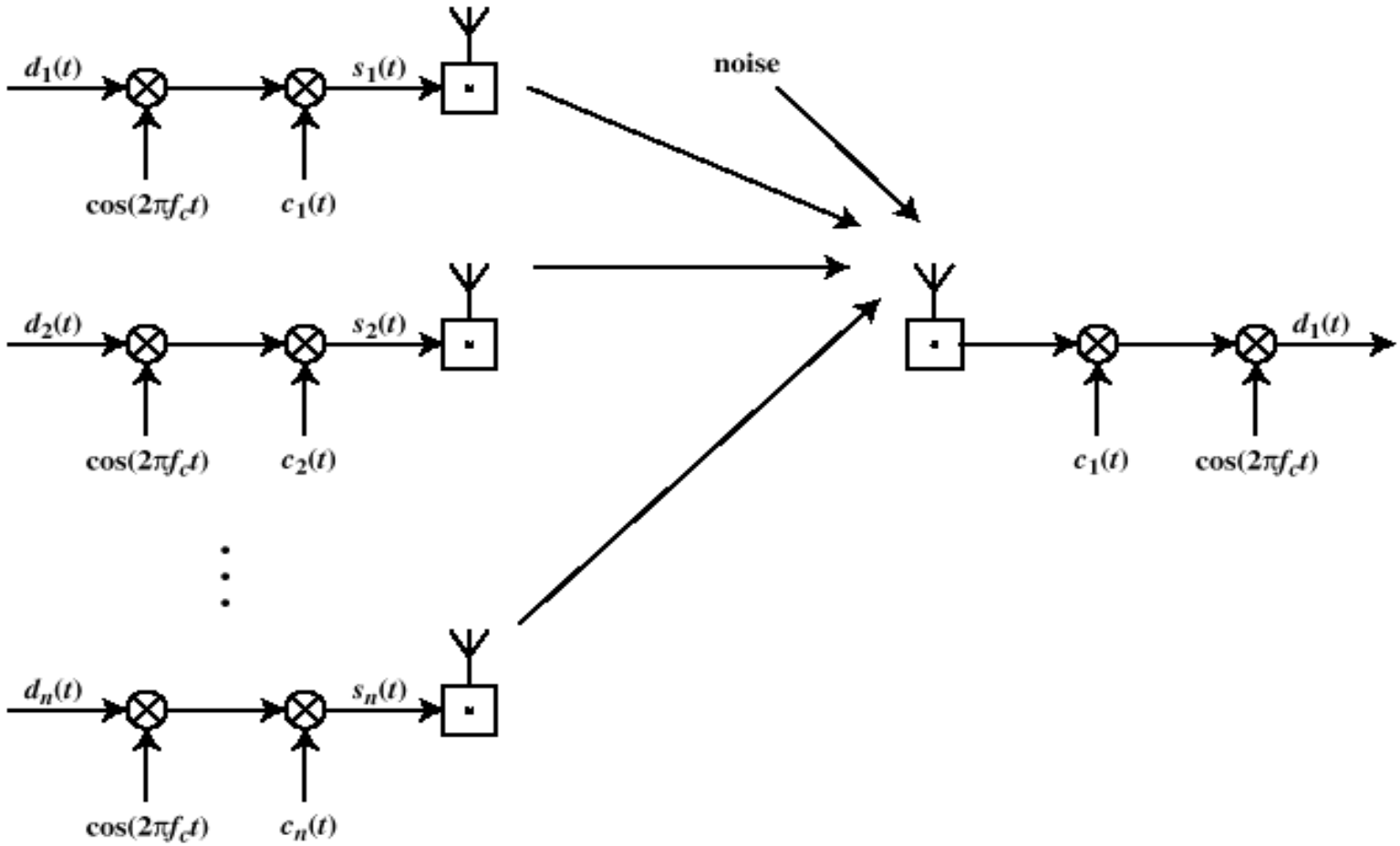


Figure 7.11 CDMA in a DSSS Environment

Random Access Methods

Fixed access techniques (FDMA,TDMA and CDMA) are inefficient in transmitting bursty data!

The random access techniques are used in mobile data networks, which can be divided into two groups:

- **ALOHA based access methods:**
  - **The mobile terminals transmit their contention packet without any coordination between them.**
- **CSMA (Carrier-Sense Multiple Access):**
  - **The mobile terminals senses the availability of the channel before it transmits its packets.**

ALOHA

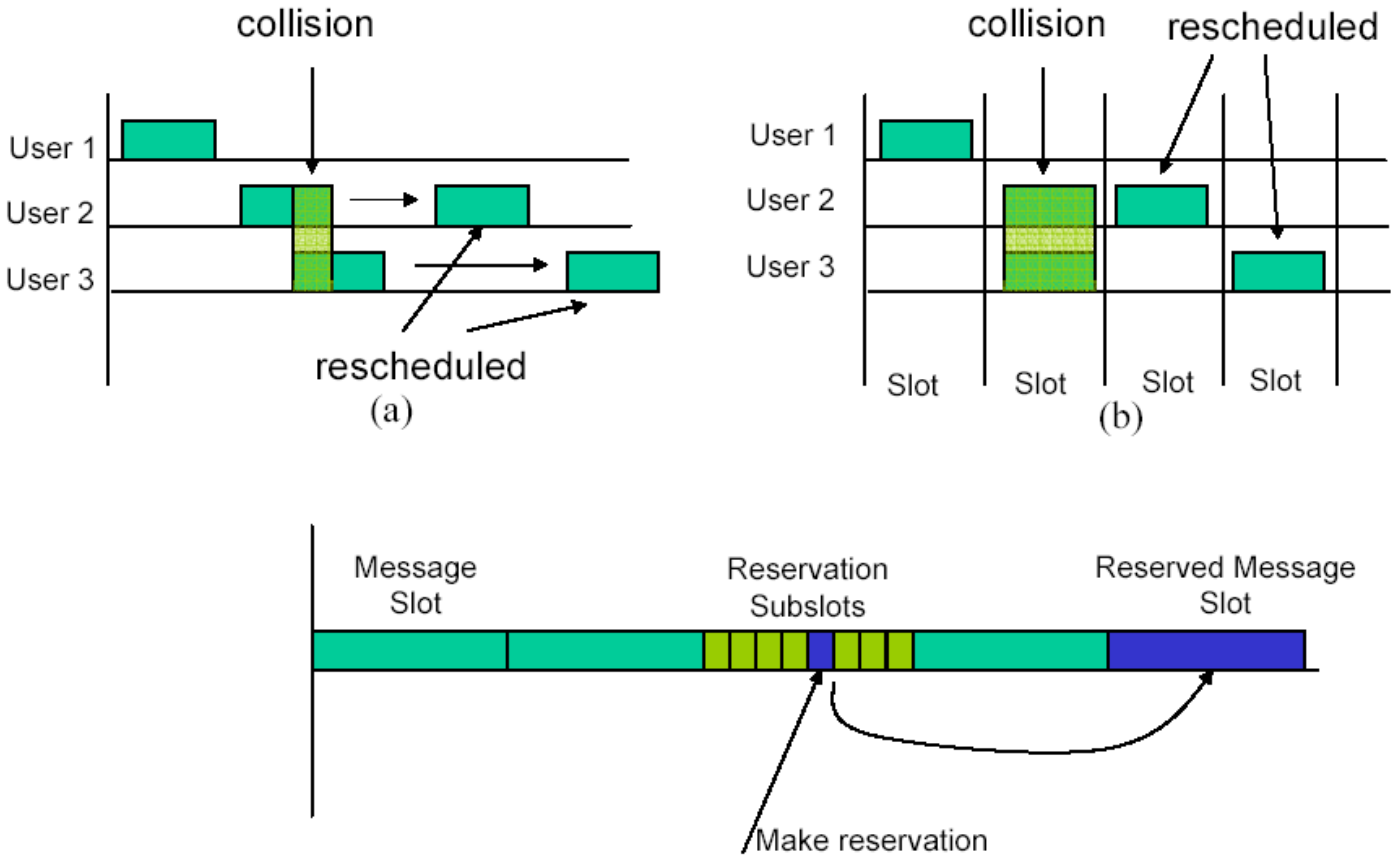
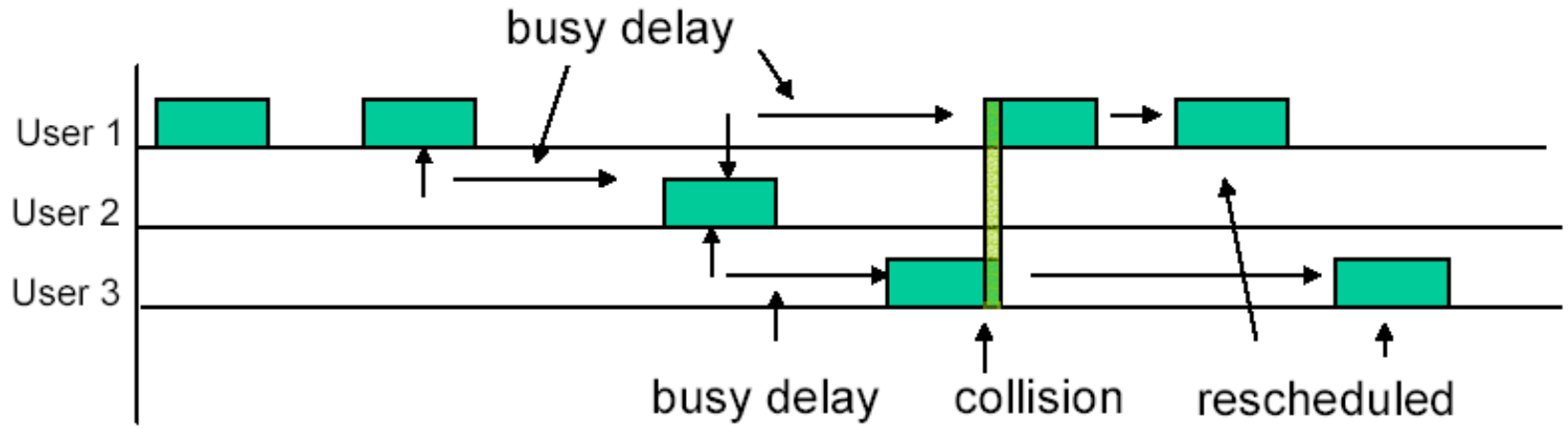


Figure 10: (a) Pure ALOHA protocol (b) Slotted ALOHA protocol (c) Reservation ALOHA

CSMA

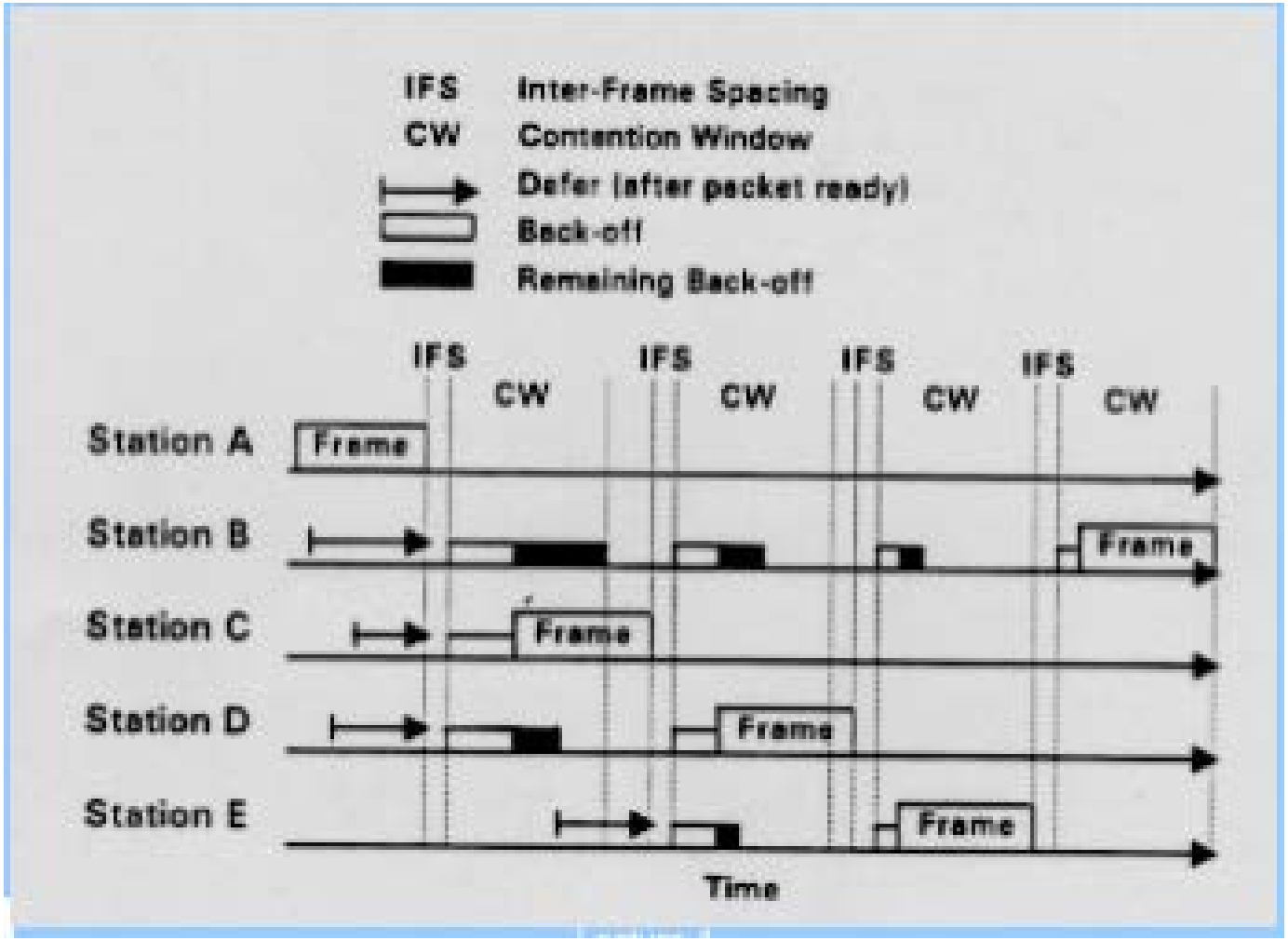
- **CSMA or Listen-before-talk protocol**

- **Basic operation of CSMA Protocol :**

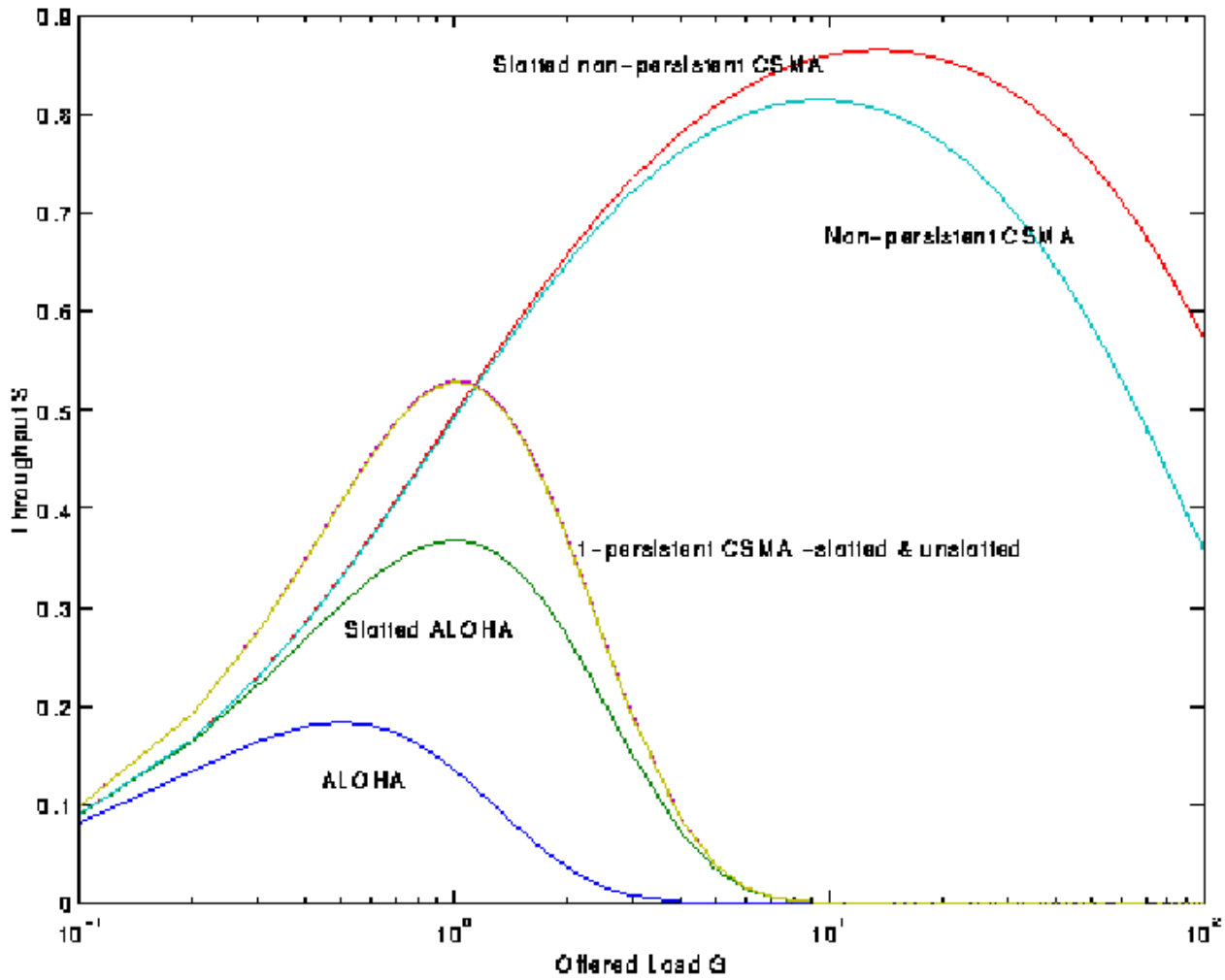


CSMA/CA

Collision Avoidance (CSMA/CA) used in IEEE802.11. Example:



Performance of Random Access Methods



Class Quizzes

- What are the two types of spread spectrum techniques?
- How does CDMA work?
- What are the slotted ALOHA and CSMA/CA schemes, respectively?

Reading References

- **References:**
  - **(PK): K. Pahlavan and P. Krishnamurthy, Principles of Wireless Networks: A Unified Approach, Prentice Hall, 2002 (new version coming)**
  - **(WS): William Stallings, Wireless Communications and Networks, 2/e , Prentice Hall, 2005**
  - **T.S. Rappaport, Wireless Communications: Principles and practice, Second Edition, Prentice Hall, 2002.**