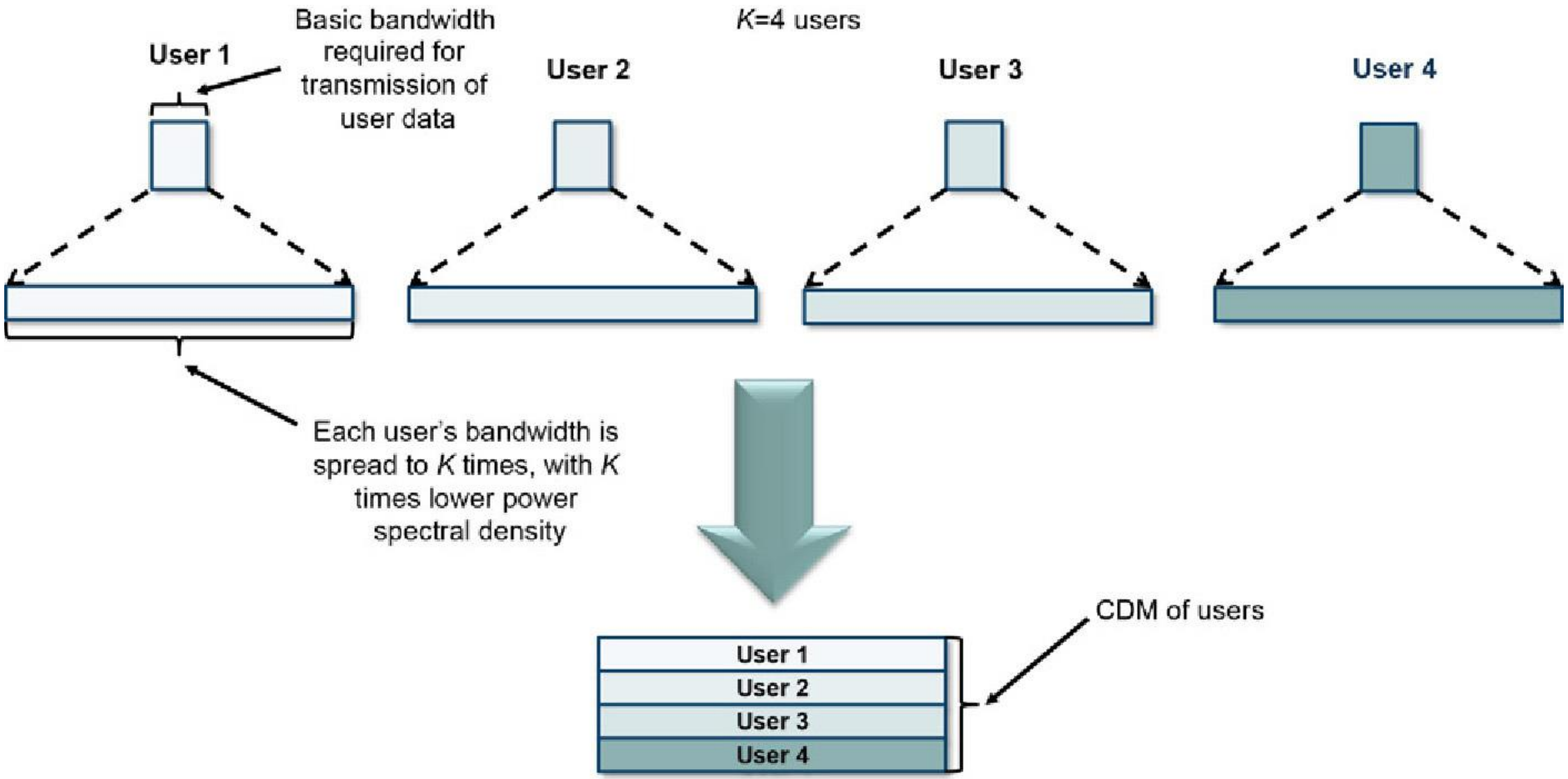
Spread Spectrum

- In a digital communication system the primary resources are Bandwidth and Power.
- The study of digital communication system deals with efficient utilization of these two resources, but there are situations where it is necessary to sacrifice their efficient utilization in order to meet certain other design objectives.

- Multiplexing combines signals from several sources to achieve bandwidth efficiency; the available bandwidth of a link is divided between the sources.
- In spread spectrum we also combine signals from different sources to fit into a larger bandwidth, and the goals are somewhat different.
- Spread spectrum is designed to be used in wireless applications (LANs and WANs). In these types of applications, we have some concerns that outweigh bandwidth efficiency.
- In wireless applications, all stations use air (or a vacuum) as the medium for communication. Stations must be able to share this medium without interception by an eavesdropper and without being subject to jamming from a malicious intruder

- A spread spectrum communications system is one that is built upon the principle of transmitting information signals over a much wider bandwidth than is strictly necessary for transferring the information.
- By transmitting over a larger bandwidth, robustness against external narrowband interference is increased, since the wider the bandwidth of any transmitted signal the lower will be the relative influence of interference over a small part of the bandwidth.
- Although from a single-link point of view, spread spectrum transmission may seem like very inefficient use of spectrum, this is not the case on a system level as spread spectrum techniques allow for simultaneous multiplexing of multiple transmissions in the same bandwidth.

The principle of spread spectrum based user multiplexing.



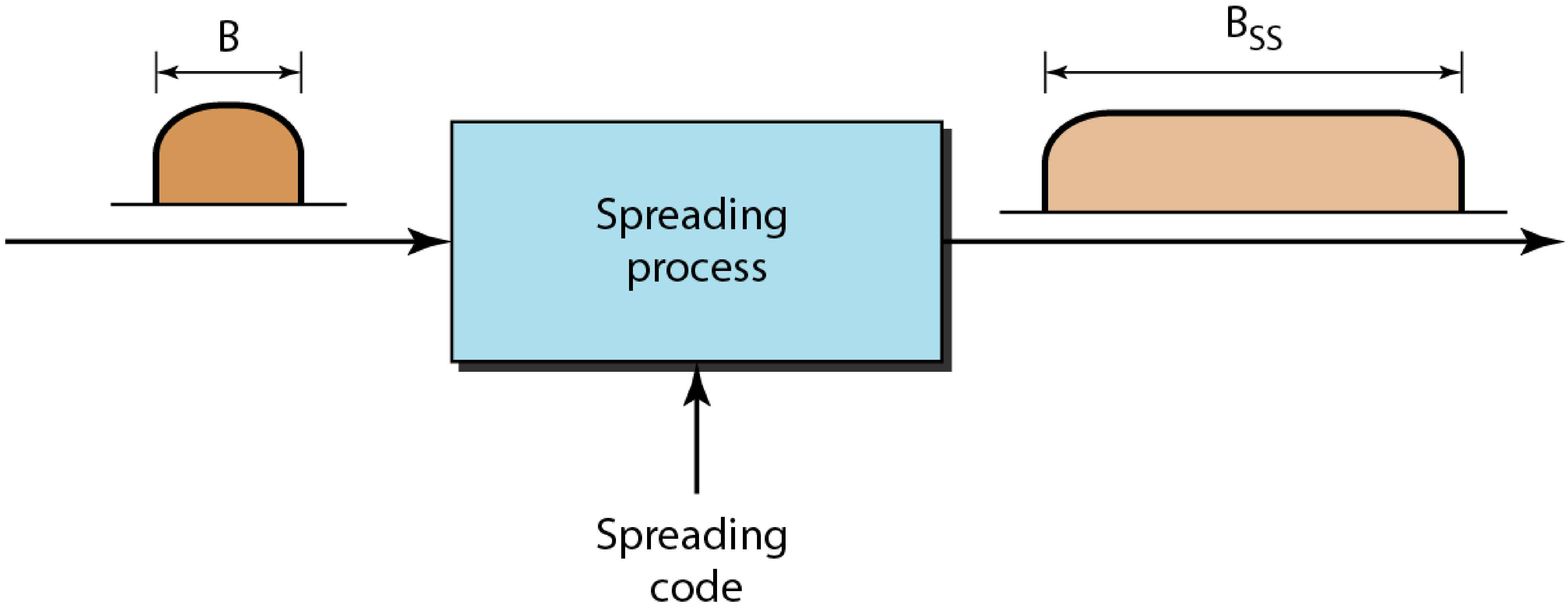
Spread spectrum achieves its goals through two principles:

1. The bandwidth allocated to each station needs to be, by far, larger than what is needed. This allows redundancy. If the required bandwidth for each station is *B,* spread spectrum expands it to Bss' such that Bss » *B.* The expanded bandwidth allows the source to wrap its message in a protective envelope for a more secure transmission.

2. The expanding of the original bandwidth *B* to the bandwidth Bss must be done by a process that is independent of the original signal. In other words, the spreading process occurs after the signal is created by the source.

After the signal is created by the source, the spreading process uses a spreading code and spreads the bandwidth.

The figure shows the original bandwidth *B* and the spreaded bandwidth *Bss.* The spreading code is a series of numbers that look random, but are actually a pattern.


B
B_SS
Spreading process
Spreading code

Spread Spectrum

- A signal that occupies a bandwidth of B, is spread out to occupy a bandwidth of B_{ss}
- All signals are spread to occupy the same bandwidth B_{ss}
- Signals are spread with different codes so that they can be separated at the receivers.
- Signals can be spread in the frequency domain or in the time domain.

Spread Spectrum

- Input is fed into a channel encoder
  - 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

Spread Spectrum

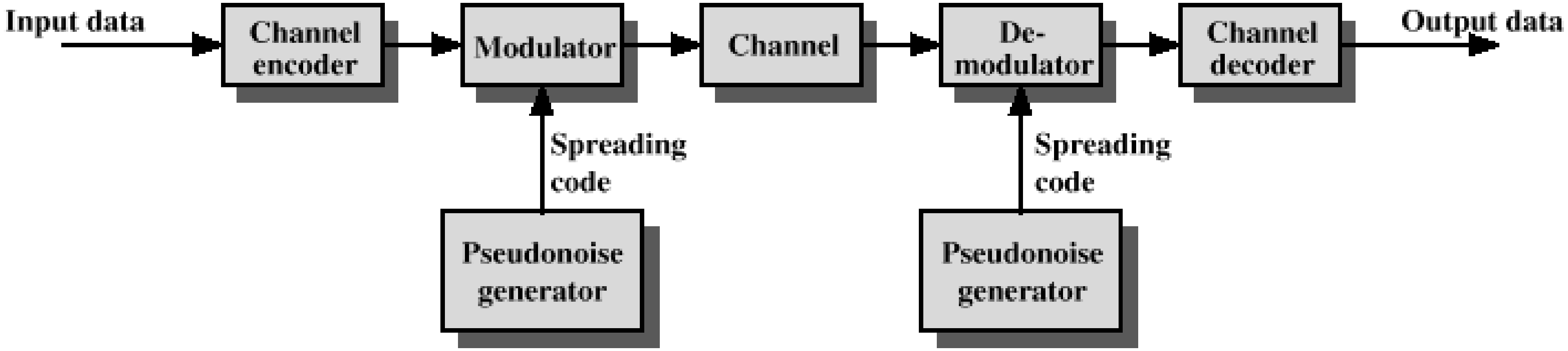


Figure 7.1 General Model of Spread Spectrum Digital Communication System

- In telecommunication and radio communication, **spread-spectrum** techniques are methods by which a signal (e.g., an electrical, electromagnetic, or acoustic signal) generated with a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth.
- These techniques are used for a variety of reasons, including the establishment of secure communications, increasing resistance to natural interference, noise, and jamming, to prevent detection, to limit power flux density (e.g., in satellite downlinks), and to enable multiple-access communications.

- Spread spectrum generally makes use of a sequential noise-like signal structure to spread the normally narrowband information signal over a relatively wideband (radio) band of frequencies.
- The receiver correlates the received signals to retrieve the original information signal.
- Originally there were two motivations: either to resist enemy efforts to jam the communications (anti-jam, or AJ), or to hide the fact that communication was even taking place, sometimes called low probability of intercept (LPI)

Spread Spectrum

- What can be gained from apparent waste of spectrum?
  - Immunity from various kinds of noise and multipath distortion
  - Can be used for hiding and encrypting signals
  - Several users can independently use the same higher bandwidth with very little interference

Types

- Frequency-hopping spread spectrum (FHSS),
- direct-sequence spread spectrum (DSSS),
- time-hopping spread spectrum (THSS),
- chirp spread spectrum (CSS), and combinations of these techniques are forms of spread spectrum.
- The first two of these techniques employ pseudorandom number sequences—created using pseudorandom number generators—to determine and control the spreading pattern of the signal across the allocated bandwidth.
- Wireless standard IEEE 802.11 uses either FHSS or DSSS in its radio interface.

- **Frequency-hopping spread spectrum** (**FHSS**) is a method of transmitting radio signals by rapidly changing the carrier frequency among many distinct frequencies occupying a large spectral band. The changes are controlled by a code known to both transmitter and receiver.
- FHSS is used to avoid interference, to prevent eavesdropping, and to enable code-division multiple access (CDMA) communications.
- The available frequency band is divided into smaller sub-bands. Signals rapidly change ("hop") their carrier frequencies among the center frequencies of these sub-bands in a predetermined order.
- Interference at a specific frequency will only affect the signal during a short interval

Direct-sequence spread spectrum (**DSSS**) is a spread spectrum modulation technique primarily used to reduce overall signal interference.

- The direct-sequence modulation makes the transmitted signal wider in bandwidth than the information bandwidth.
- After the de-spreading or removal of the direct-sequence modulation in the receiver, the information bandwidth is restored, while the unintentional and intentional interference is substantially reduced

- **Time-hopping** (**TH**) is a communications signal technique which can be used to achieve anti-jamming (AJ) or low probability of intercept (LPI).
- It can also refer to pulse-position modulation, which in its simplest form employs 2^k discrete pulses (referring to the unique positions of the pulse within the transmission window) to transmit k bit(s) per pulse.

- **Chirp spread spectrum** (**CSS**) is a spread spectrum technique that uses wideband linear frequency modulated chirp pulses to encode information.
- A chirp is a sinusoidal signal whose frequency increases or decreases over time (often with a polynomial expression for the relationship between time and frequency).

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 Hopping Spread Spectrum
- Another basic spread spectrum technique is frequency hopping. In a frequency hopping (FH) system, the frequency is constant in each time chip; instead it changes from chip to chip.

- Frequency hopping systems can be divided into fast-hop or slow-hop.
- A fast-hop FH system is the kind in which hopping rate is greater than the message bit rate and in the slow-hop system the hopping rate is smaller than the message bit rate.
- This differentiation is due to the fact that there is a considerable difference between these two FH types. The FH receiver is usually non-coherent.

- The incoming signal is multiplied by the signal from the PN generator identical to the one at the transmitter.
- Resulting signal from the mixer is a binary FSK, which is then demodulated in a "regular" way.
- Error correction is then applied in order to recover the original signal.
- The timing synchronization is accomplished through the use of early-late gates, which control the clock frequency

Frequency Hoping Spread Spectrum

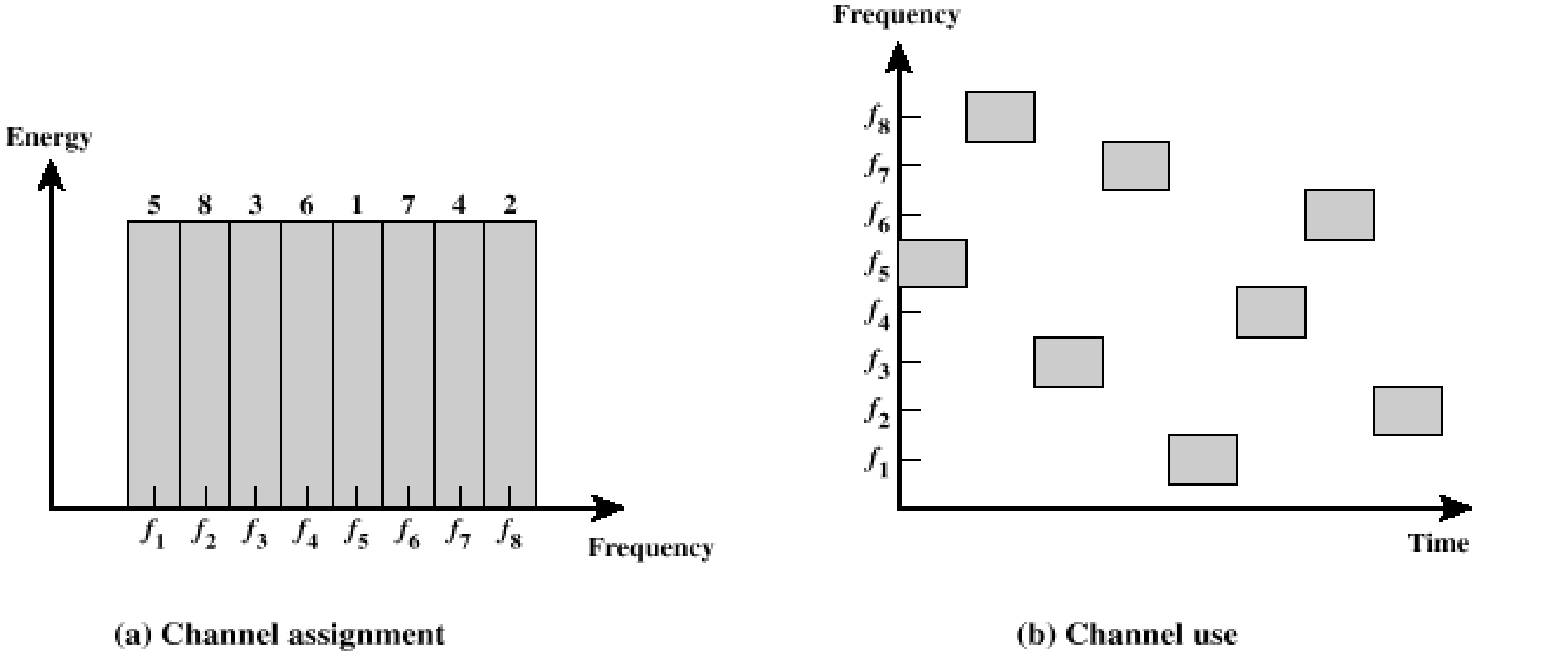


Figure 7.2 Frequency Hopping Example

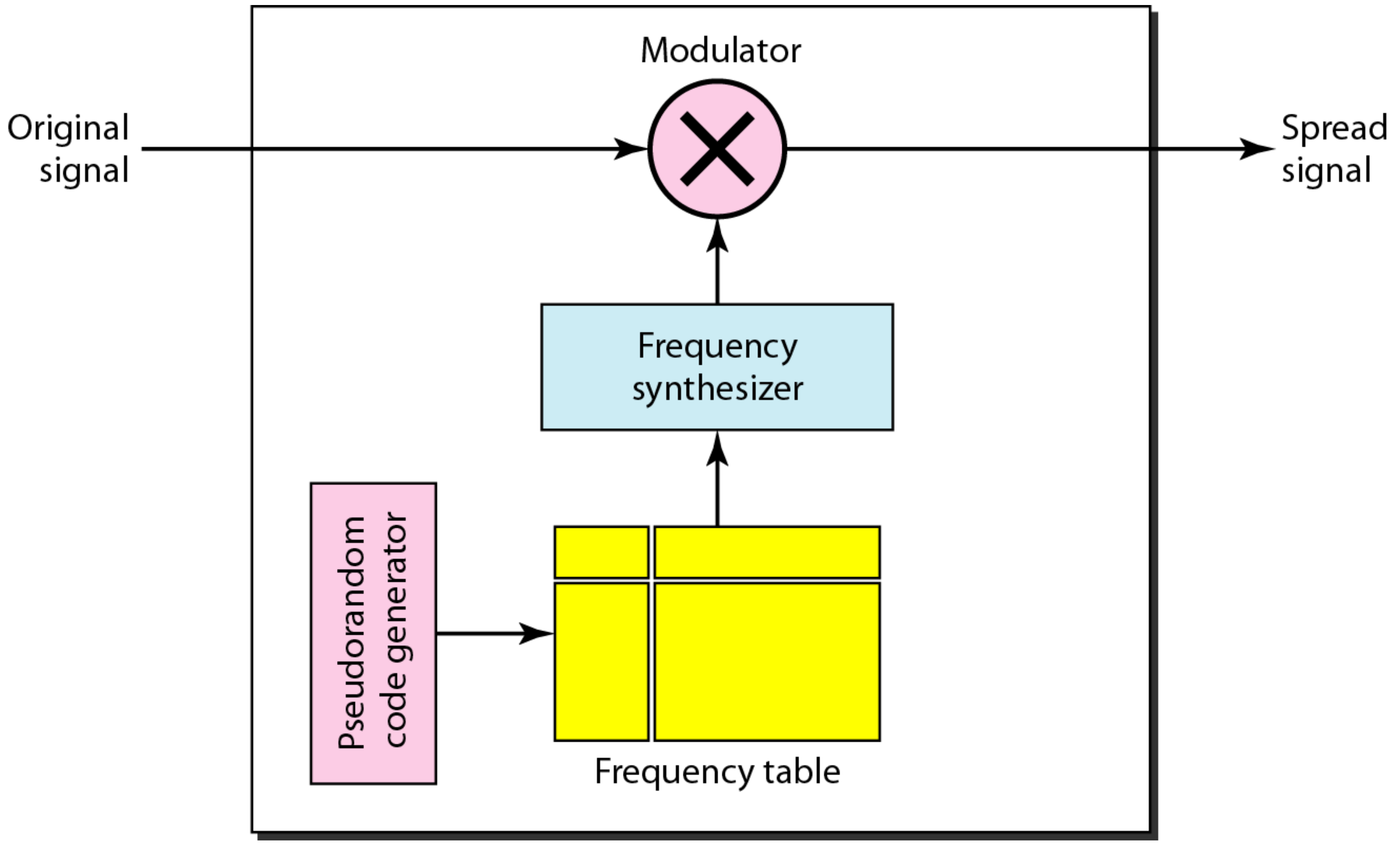
FHSS Using MFSK

- MFSK signal is translated to a new frequency every T_c seconds by modulating the MFSK signal with the FHSS carrier signal
- For data rate of R:
  - duration of a bit: $T = 1/R$ seconds
  - duration of signal element: $T_s = LT$ seconds
- $T_c \geq T_s$ - slow-frequency-hop spread spectrum
- $T_c < T_s$ - fast-frequency-hop spread spectrum

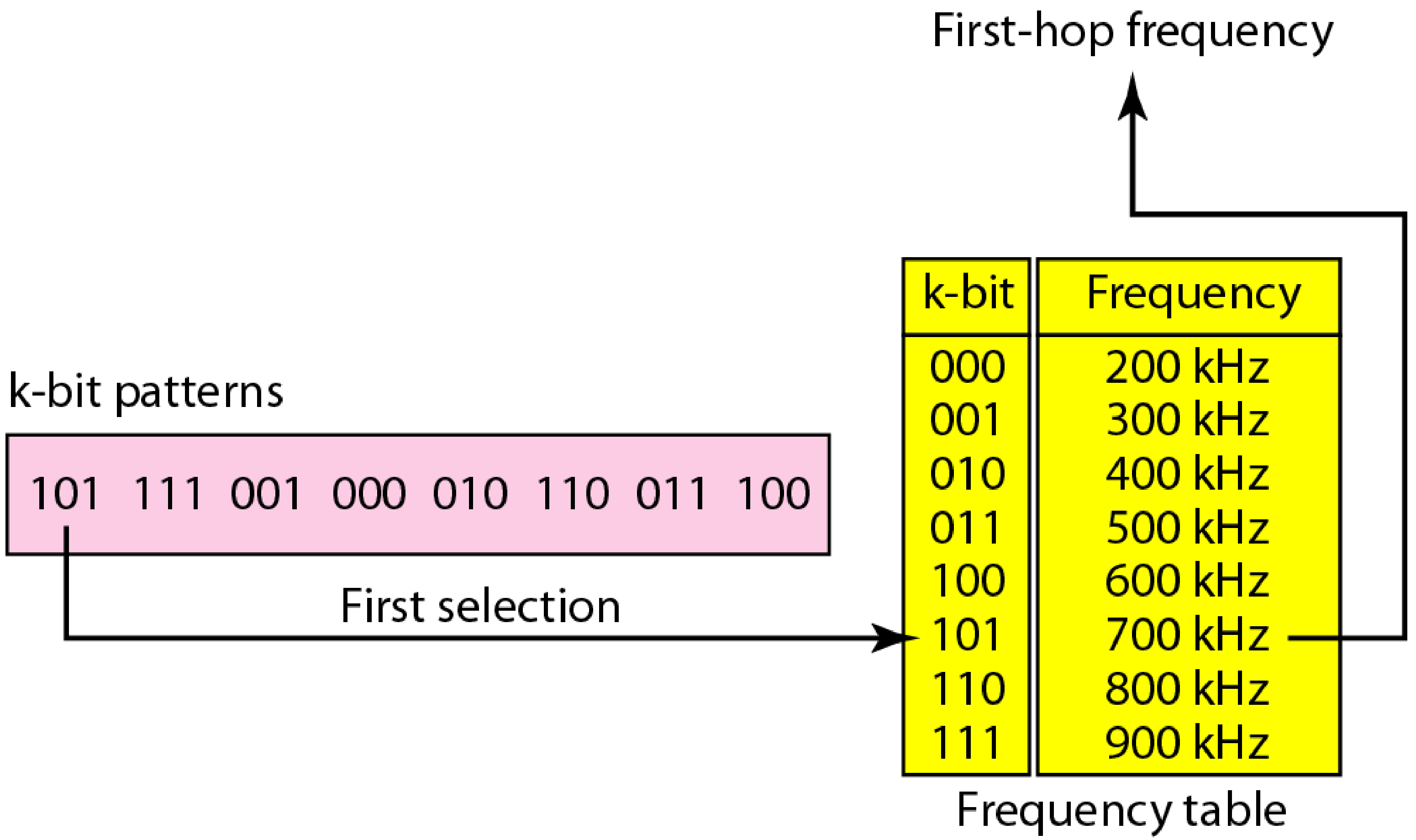
FHSS Performance Considerations

- 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

Frequency hopping spread spectrum (FHSS)



Frequency selection in FHSS



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

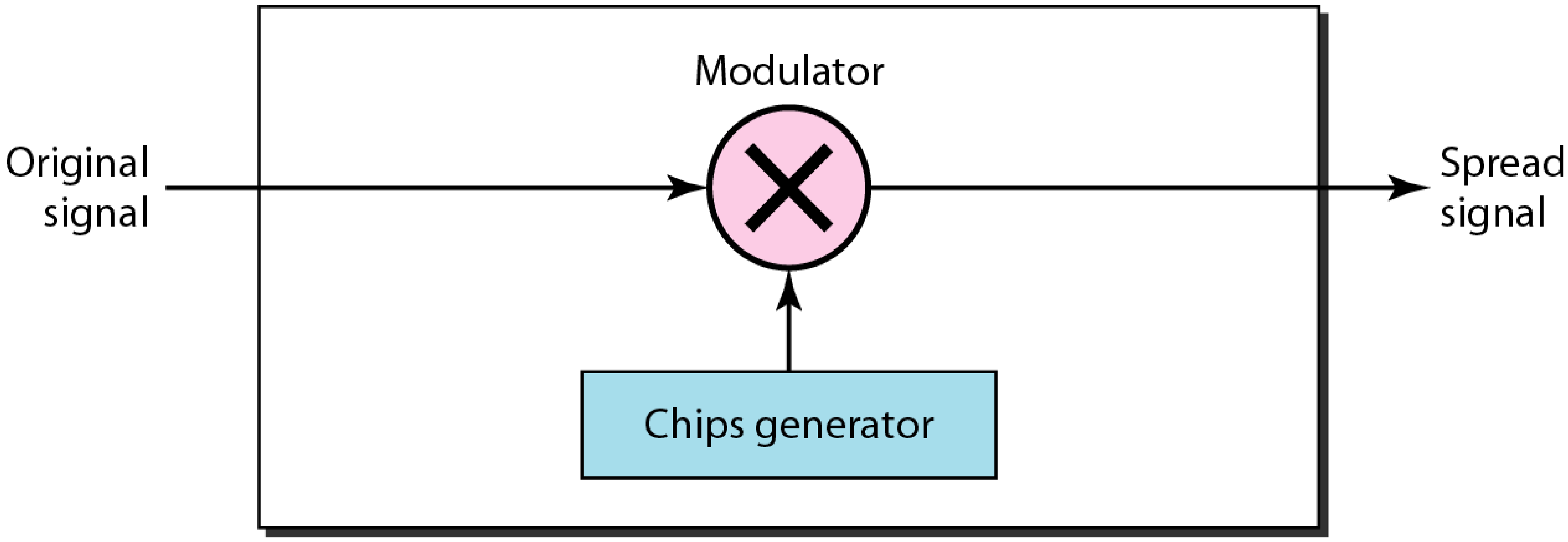
Direct Sequence (DS) Spread Spectrum System (DSSS)

- The information signal in DSSS transmission is spread at baseband and then the spread signal is modulated by a carrier in a second stage. Following this approach, the process of modulation is separate from the spreading operation.
- An important feature of DSSS system is its ability to operate in presence of strong co-channel interference.
- A popular definition of the processing gain (PG) of a DSSS system is the ratio of the signal bandwidth to the message bandwidth.

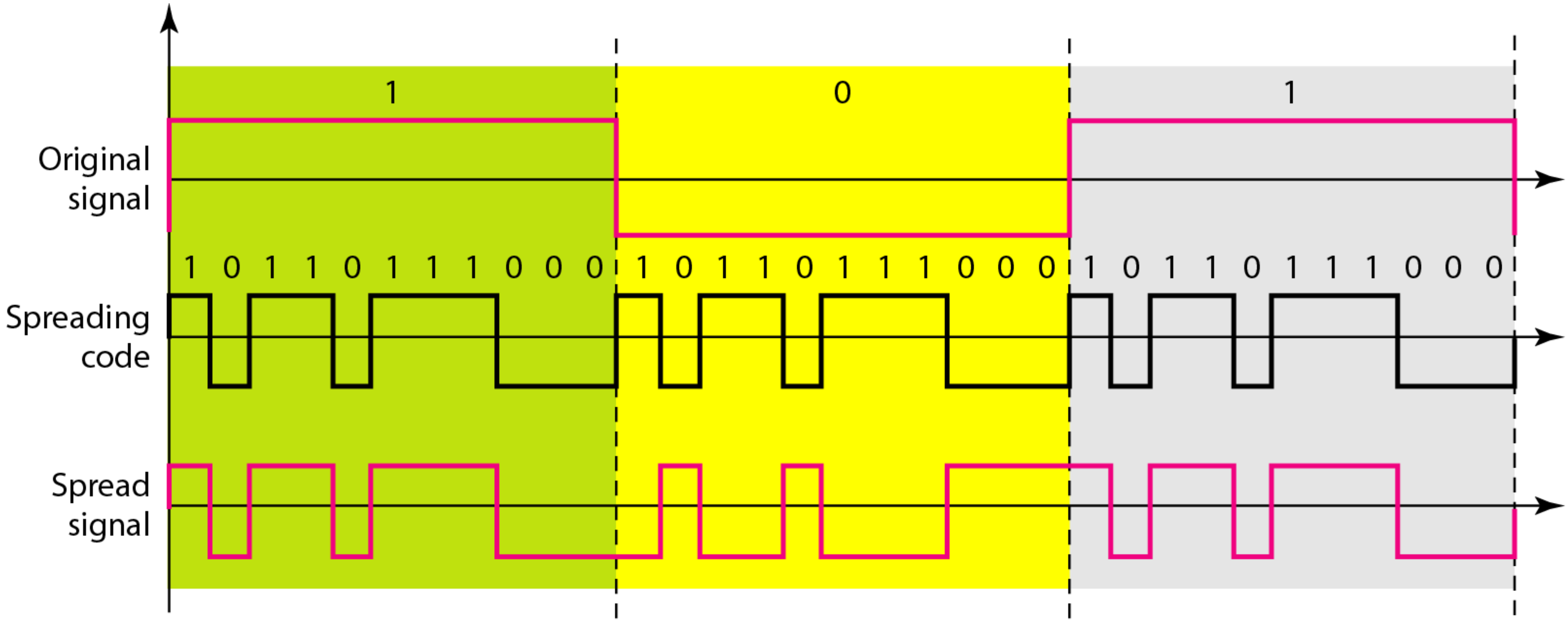
- A DSSS system can reduce the effects of interference on the transmitted information.
- An interfering signal may be reduced by a factor which may be as high as the processing gain.
- That is, a DSSS transmitter can withstand more interference if the length of the PN sequence is increased.
- The output signal to noise ratio of a DSSS receiver may be expressed as: (SNR)o = PG. (SNR)I, where (SNR)I is the signal to noise ratio before the dispreading operation is carried out.
- A major disadvantage of a DSSS system is the 'Near-Far effect',

- This effect is prominent when an interfering transmitter is close to the receiver than the intended transmitter.
- Although the cross-correlation between codes A and B is low, the correlation between the received signal from the interfering transmitter and code A can be higher than the correlation between the received signal from the intended transmitter and code A. So, detection of proper data becomes difficult.

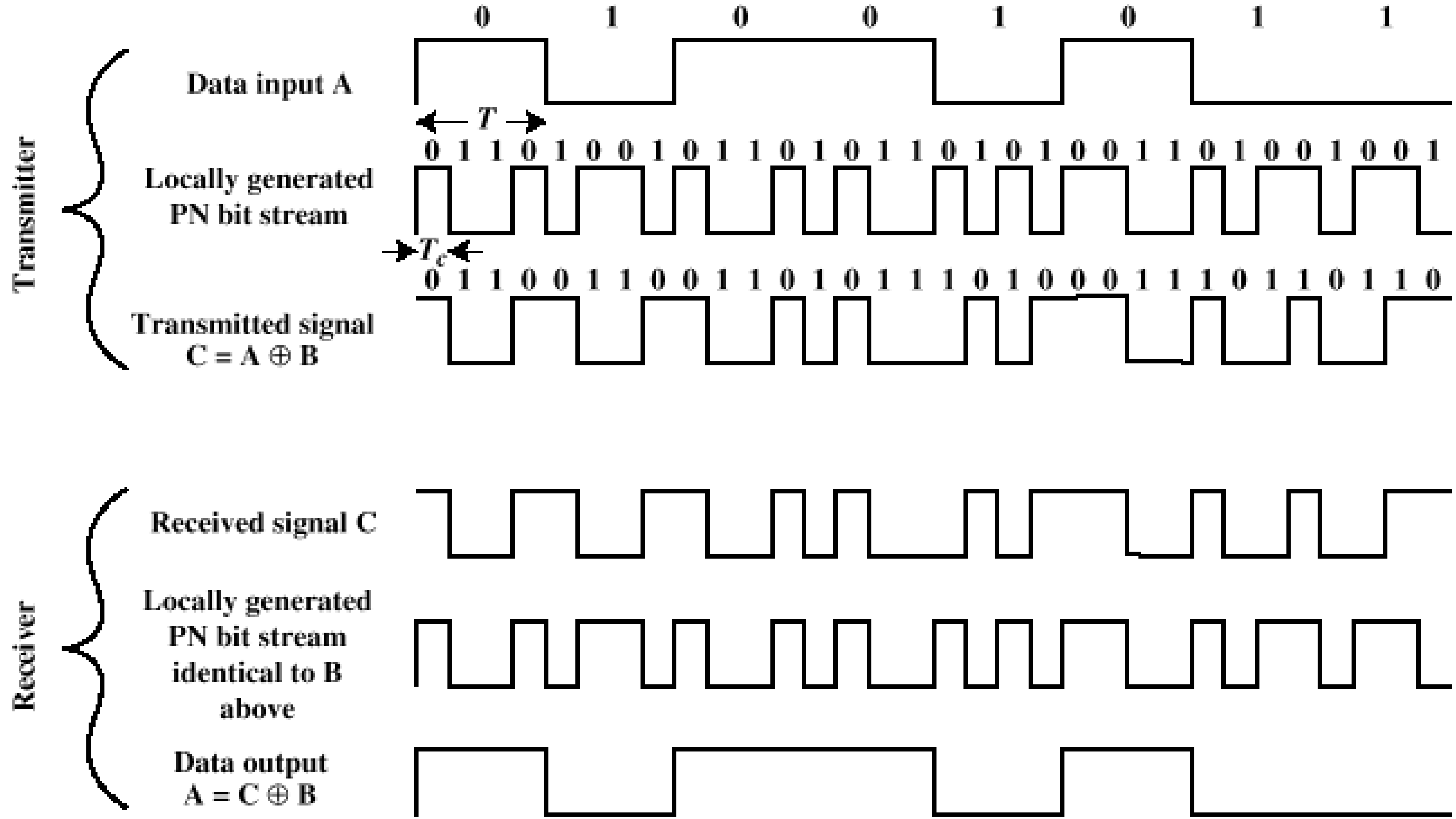
DSSS



DSSS example



Direct Sequence Spread Spectrum (DSSS)



DSSS Using BPSK

- Multiply BPSK signal,

$$s_d(t) = A\, d(t) \cos(2\pi\, f_c t)$$

  by $c(t)$ [takes values +1, -1] to get

$$s(t) = A\, d(t) c(t) \cos(2\pi\, f_c t)$$

    - A = amplitude of signal
    - f_c = carrier frequency
    - d(t) = discrete function [+1, -1]
- At receiver, incoming signal multiplied by $c(t)$
  - Since, $c(t)$ x $c(t)$ = 1, incoming signal is recovered

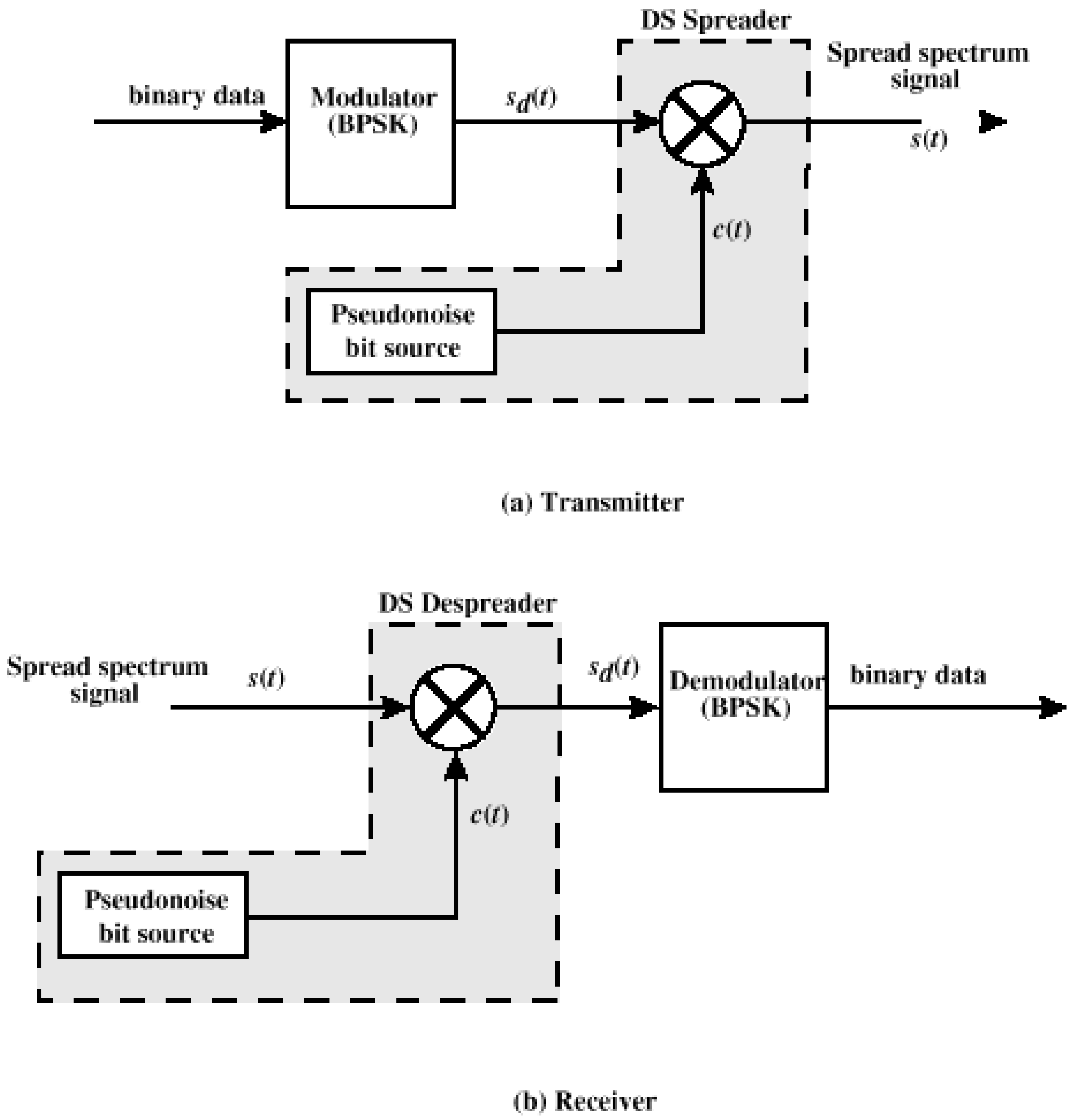


Figure 7.7 Direct Sequence Spread Spectrum System

- Resistance to jamming (interference). Direct sequence (DS) is good at resisting continuous-time narrowband jamming, while frequency hopping (FH) is better at resisting pulse jamming.
- In DS systems, narrowband jamming affects detection performance about as much as if the amount of jamming power is spread over the whole signal bandwidth, where it will often not be much stronger than background noise.
- By contrast, in narrowband systems where the signal bandwidth is low, the received signal quality will be severely lowered if the jamming power happens to be concentrated on the signal bandwidth.

- Resistance to eavesdropping.
- The spreading sequence (in DS systems) or the frequency-hopping pattern (in FH systems) is often unknown by anyone for whom the signal is unintended, in which case it obscures the signal and reduces the chance of an adversary making sense of it.
- Moreover, for a given noise power spectral density (PSD), spread-spectrum systems require the same amount of energy per bit before spreading as narrowband systems and therefore the same amount of power if the bitrate before spreading is the same, but since the signal power is spread over a large bandwidth, the signal PSD is much lower — often significantly lower than the noise PSD — so that the adversary may be unable to determine whether the signal exists at all.

- Resistance to fading. The high bandwidth occupied by spread-spectrum signals offer some frequency diversity; i.e., it is unlikely that the signal will encounter severe multipath fading over its whole bandwidth. In direct-sequence systems, the signal can be detected by using a rake receiver.
- Multiple access capability, known as code-division multiple access (CDMA) or code-division multiplexing (CDM). Multiple users can transmit simultaneously in the same frequency band as long as they use different spreading sequences.