MODULE 4. SPREAD SPECTRUM TECHNIQUES

1

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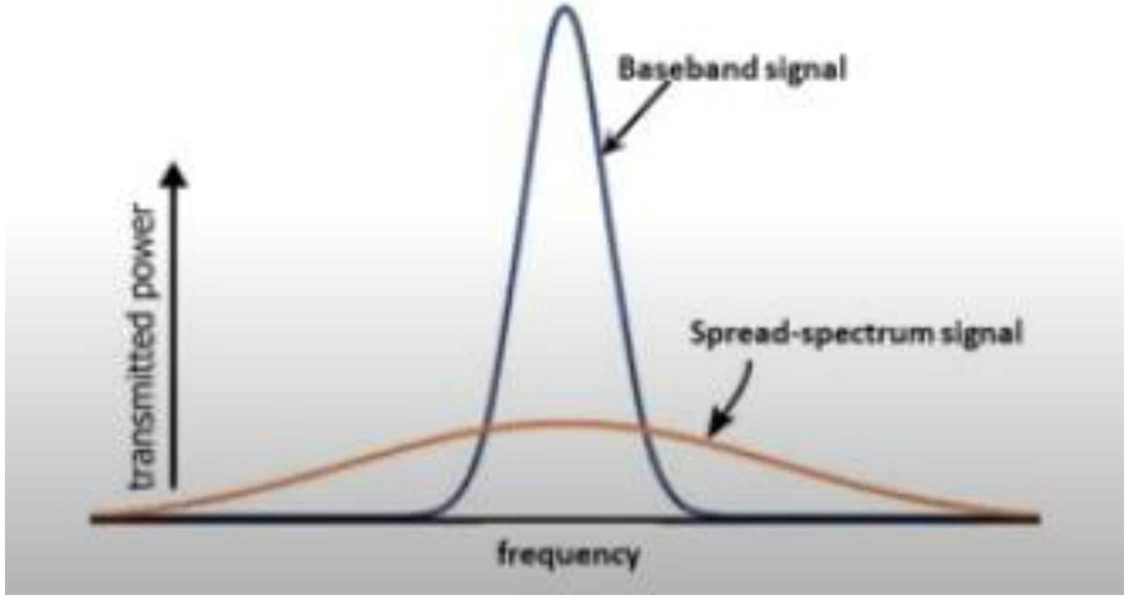
INTRODUCTION

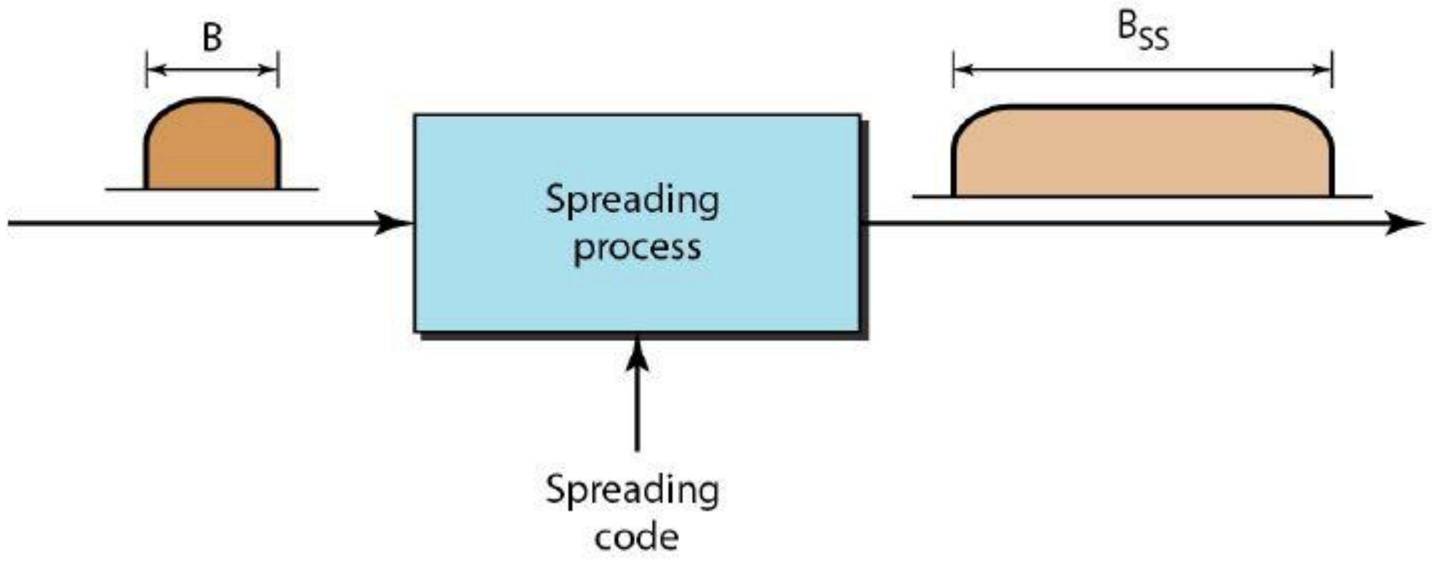
- **The Communication Systems we have discussed so far, our aim is to minimize the amount of bandwidth consumed by the modulated signal during transmission.**
- **Focus on achieving spectral efficiency and conserve bandwidth resource.**
- **The narrowband communication systems have two major drawbacks:**
  - **Interception by unintended users.**
  - **More susceptible to jamming.**

- One possible solution is spread spectrum.
- It was initially developed for military and intelligence requirement.
- The use of spread spectrum makes jamming and interception more difficult and provides improved reception.
- The basic idea was to expand each user signal to occupy a much broader spectrum than the necessary.
- For fixed transmission power, a broader spectrum means both lower signal power level and higher spectral redundancy.



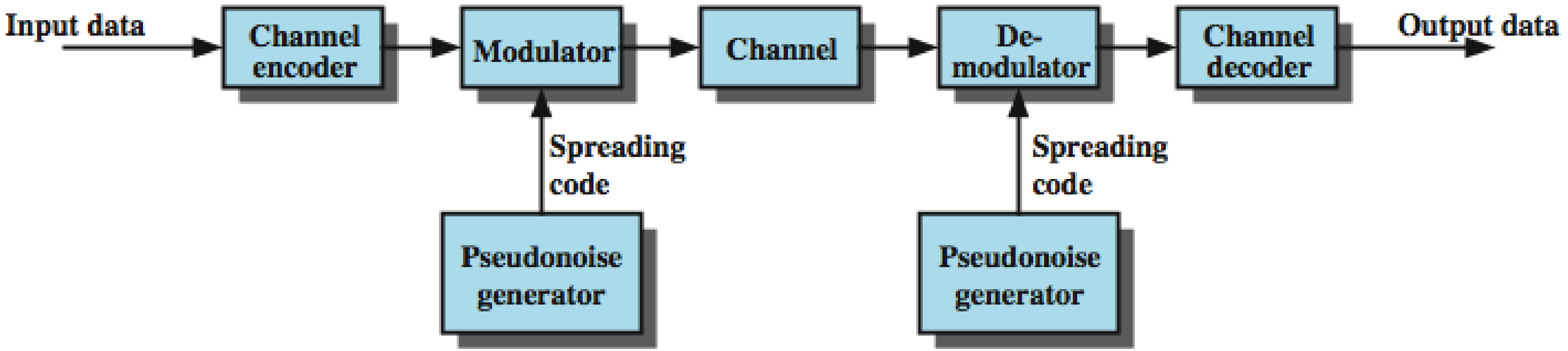
Spread Spectrum Modulation spreads the spectrum of transmitted signals into wider range.

The spreading code is used to spread the spectrum of transmitted signals.



- **Spread Spectrum is an important form of encoding for wireless Communications which can be used to transmit either analog or digital data, using an analog signal.**
- **Two approaches have been used in spread spectrum modulation:**
  - **Frequency Hopping**
  - **Direct Sequence**

GENERAL MODEL OF SPREAD SPECTRUM SYSTEM



- 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 which are 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 finally fed into a channel decoder to recover the original massage signal data

Pseudorandom Numbers

Generated by a deterministic algorithm

- not actually random
- but if algorithm good, results pass reasonable tests of randomness

- Starting from an initial seed
- One may Need to know algorithm and seed to predict sequence
- Hence only receiver can decode signal

Pseudorandom Numbers

These numbers are generated by an algorithm using some initial value called the seed. The algorithm is deterministic and therefore produces sequences of numbers that are not statistically random. However, if the algorithm is good, the resulting sequences will pass many reasonable tests of randomness. Such numbers are often referred to as pseudorandom numbers. The important point is that unless you know the algorithm and the seed, it is impractical to predict the sequence. Hence, only a receiver that shares this information with a transmitter will be able to decode the signal successfully.

Characteristics of Spread Spectrum Signals

They are difficult to intercept

They are easily hidden

They are resistant to jamming

They provide the immunity to distortion due to multi-path propagation.

They have Asynchronous multiple access capability

FREQUENCY HOPPING SPREAD SPECTRUM (FHSS)

With frequency-hopping spread spectrum (FHSS), the signal is broadcast over a seemingly random series of radio frequencies, hopping from frequency to frequency at fixed intervals

A receiver, hopping between frequencies in synchronization with the transmitter, picks up the message

Would-be eavesdroppers hear only unintelligible blips

Attempts to jamming the signal on one frequency succeed only at knocking out a few bits of it

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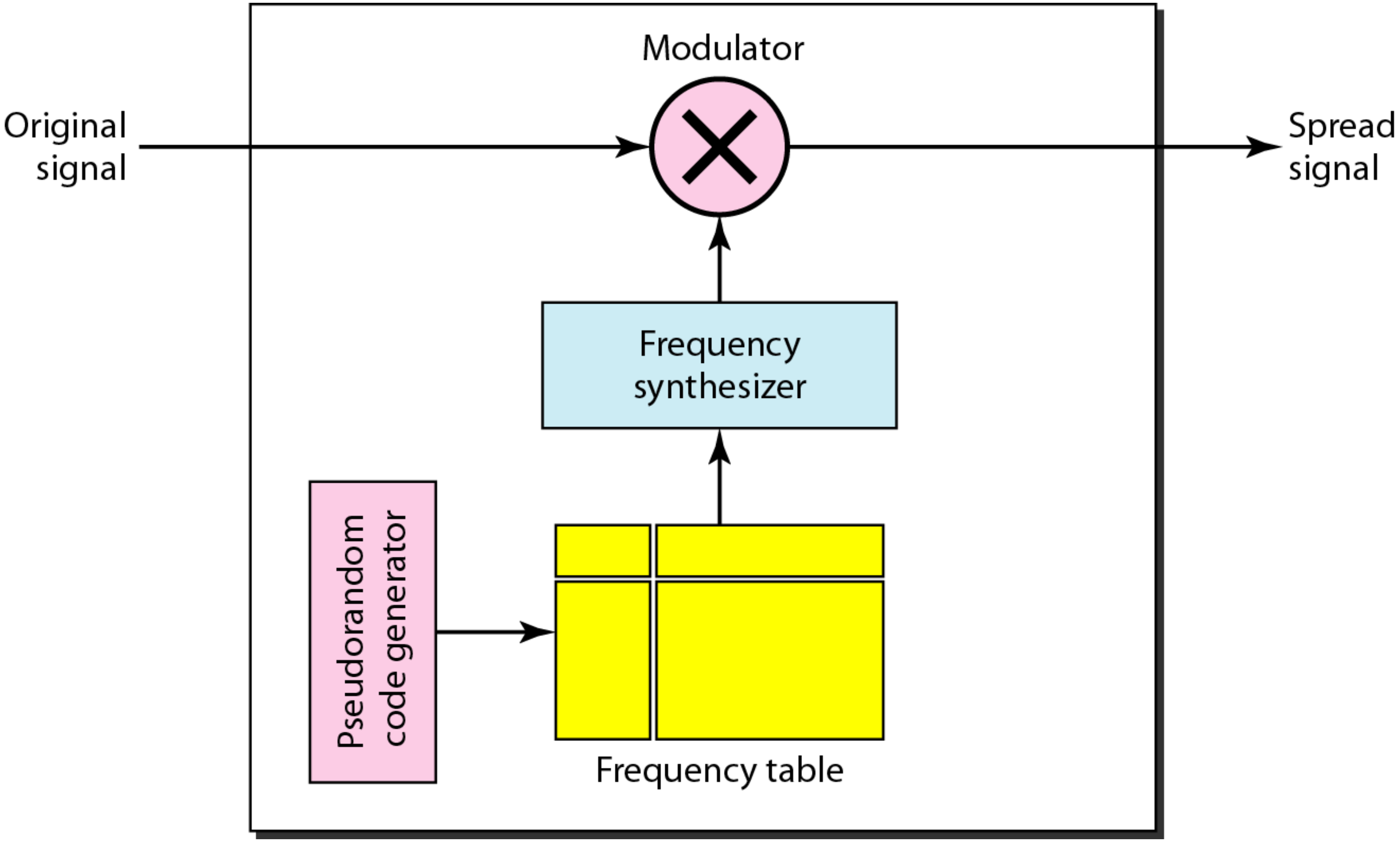
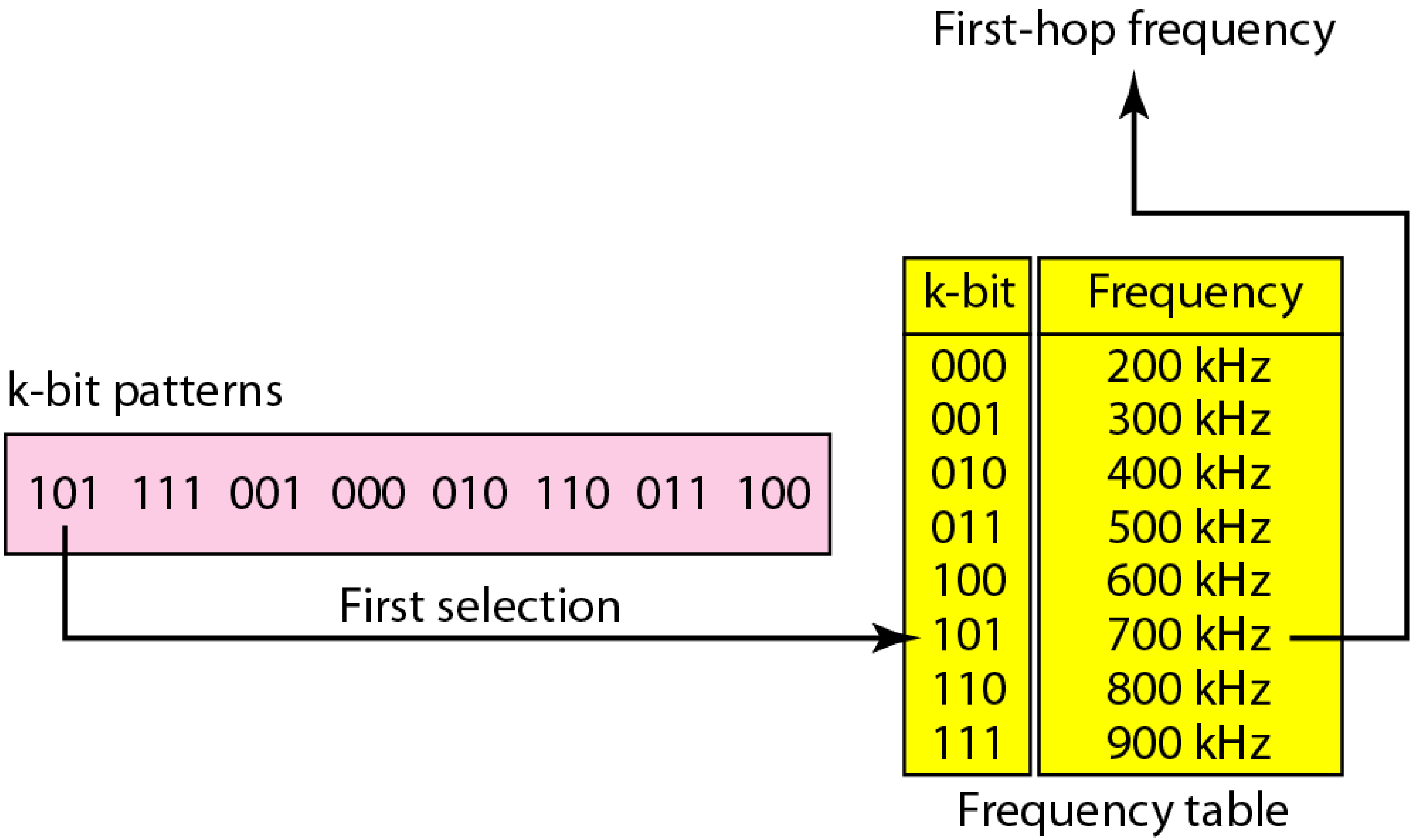
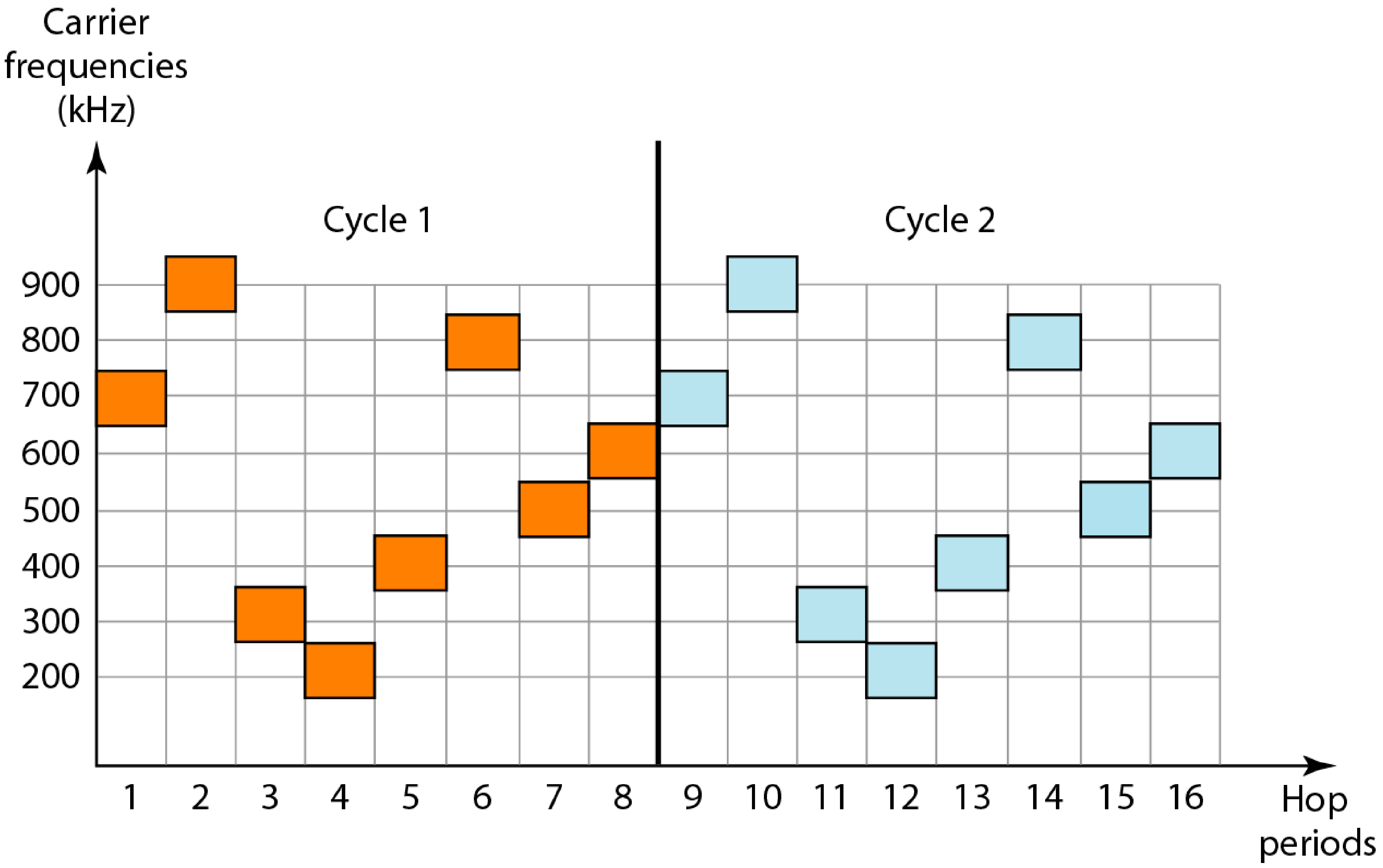
FREQUENCY HOPPING SPREAD SPECTRUM (FHSS)



FREQUENCY SELECTION IN FHSS

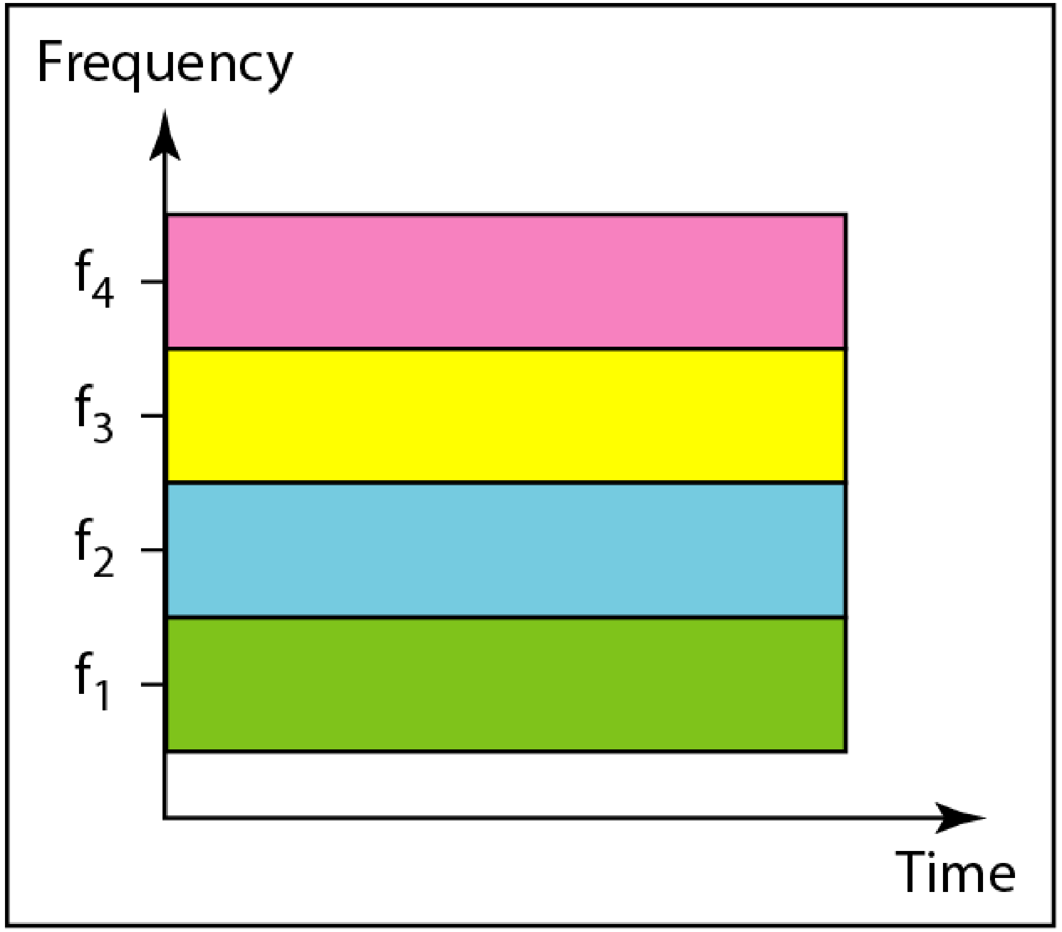


FHSS CYCLES

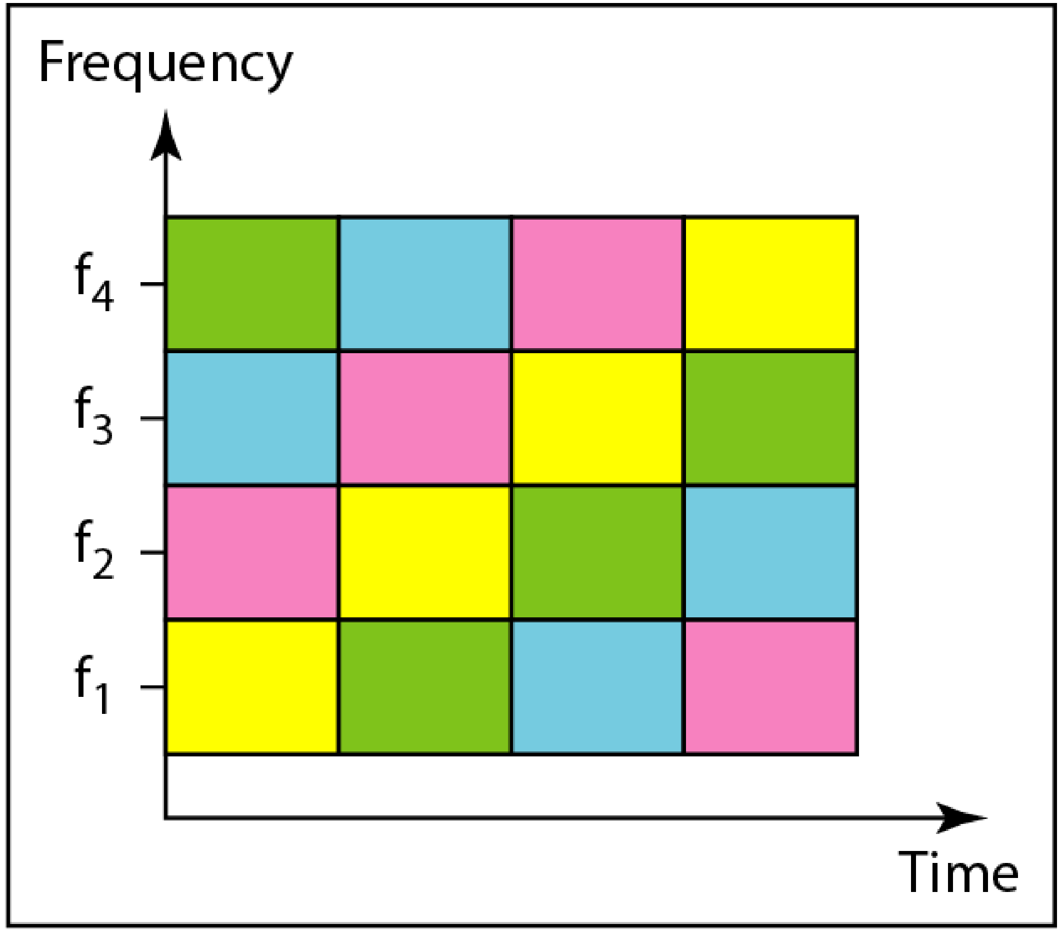


Carrier frequencies (kHz)
Cycle 1
Cycle 2
900
800
700
600
500
400
300
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Hop periods

BANDWIDTH SHARING

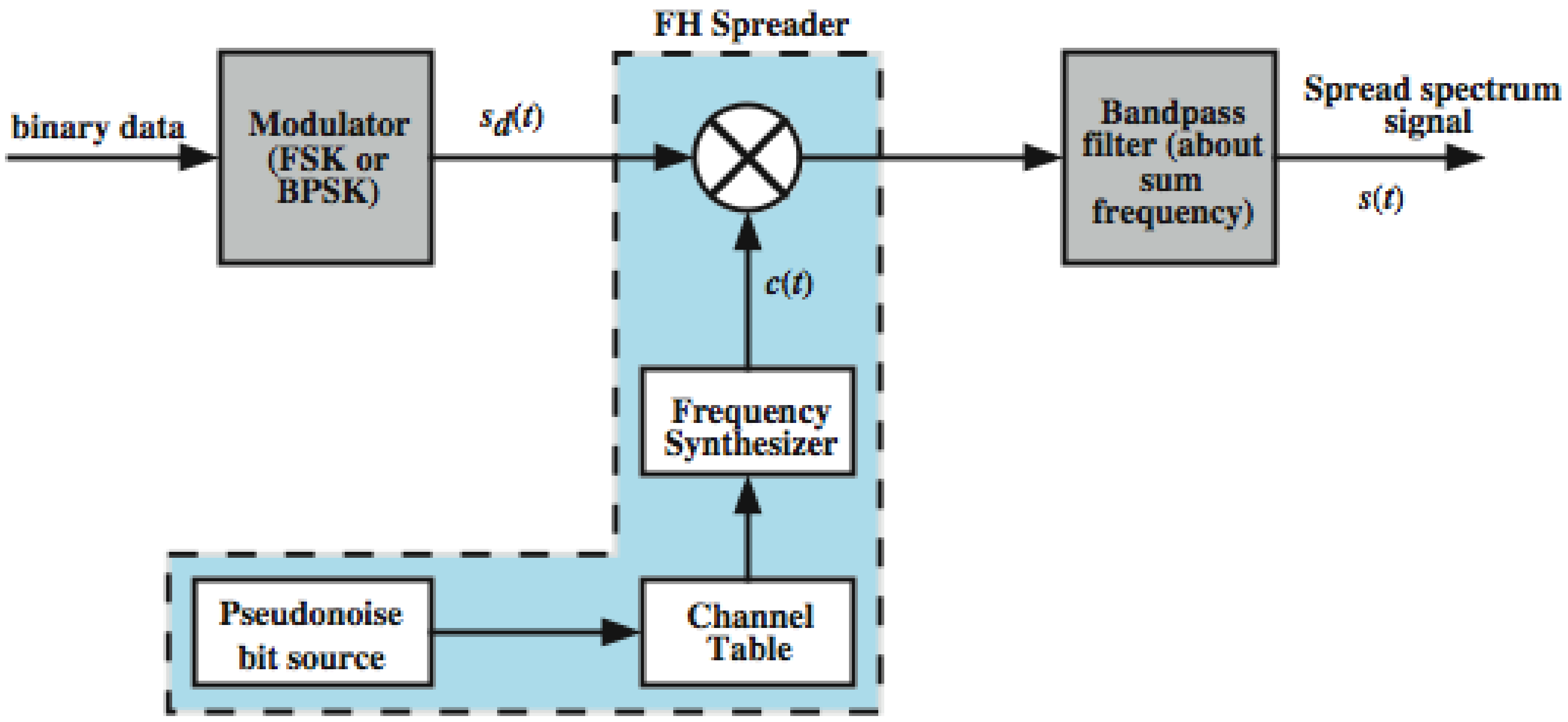


a. FDM



b. FHSS

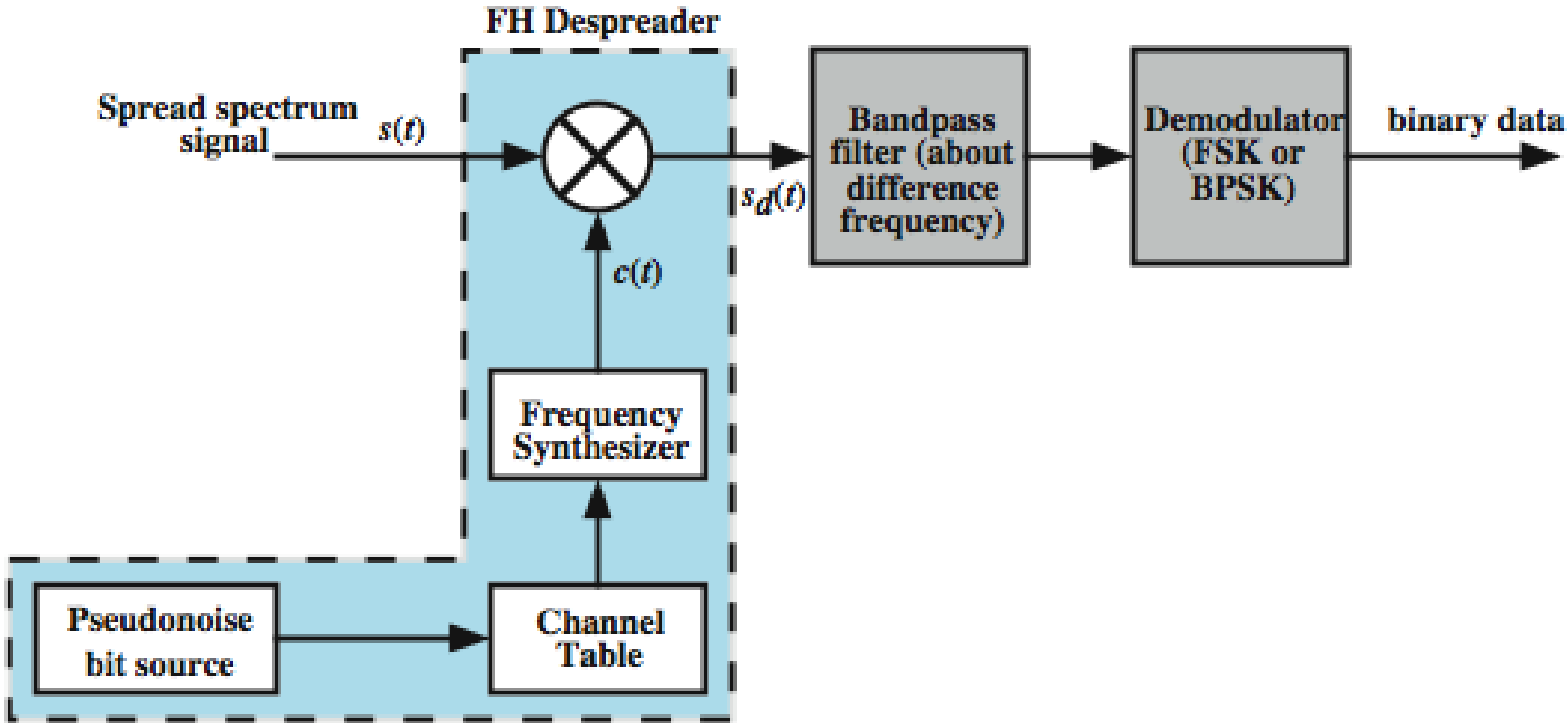
FHSS (TRANSMITTER)



(a) Transmitter

- **For transmission, binary data are fed into a modulator using some digital-to-analog encoding scheme, such as frequency shift keying (FSK) or binary phase shift keying (BPSK).**
- **The resulting signal sd(t) is centered on some base frequency. A pseudonoise (PN), or pseudorandom number, source serves as an index into a table of frequencies. This is the spreading code referred to previously.**
- **Each k bits of the PN source specifies one of the 2^k carrier frequencies. At each successive interval (each k PN bits), a new carrier frequency is selected**
- **The frequency synthesizer generates a constant-frequency tone whose frequency hops among a set of 2^k frequencies,**
- **with the hopping pattern determined by k bits from the PN sequence.**
- **This is known as the spreading or chipping signal c(t). This is then modulated by the signal produced from the initial modulator to produce a new signal with the same shape but now centered on the selected carrier frequency.**
- **A bandpass filter is used to block the difference frequency and pass the sum frequency, yielding the final FHSS signal s(t).**

FREQUENCY HOPPING SPREAD SPECTRUM SYSTEM (RECEIVER)



(b) Receiver

- the spread spectrum signal is demodulated using the same sequence of PN-derived frequencies and then demodulated to produce the output data.
- At the receiver, a signal of the form s(t) defined on the previous slide, will be received.
- This is multiplied by a replica of the spreading signal to yield a product signal.
- A bandpass filter is used to block the sum frequency and pass the difference frequency, which is then demodulated to recover the binary data.

FHSS ADVANTAGES

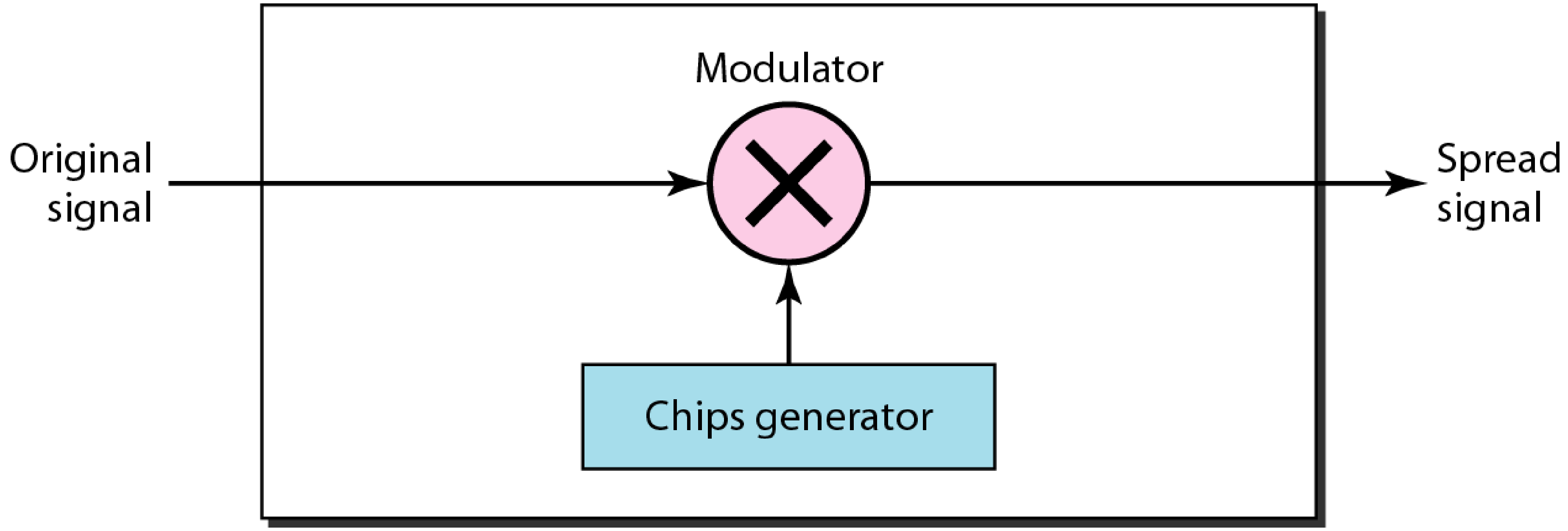
- It is quite difficult to intercept the FHSS modulated signal . A third party can only intercept the receiver if they have the same chipping/spreading code as at the transmitting side.
- With FHSS modulation, the same frequency channel can be shared among different users with little interference. This is an efficient use of BW.
- FHSS modulated signals appear as noise to unknown receiver, because the signal is hopped between different frequencies.
- FHSS modulation makes the jamming more difficult.

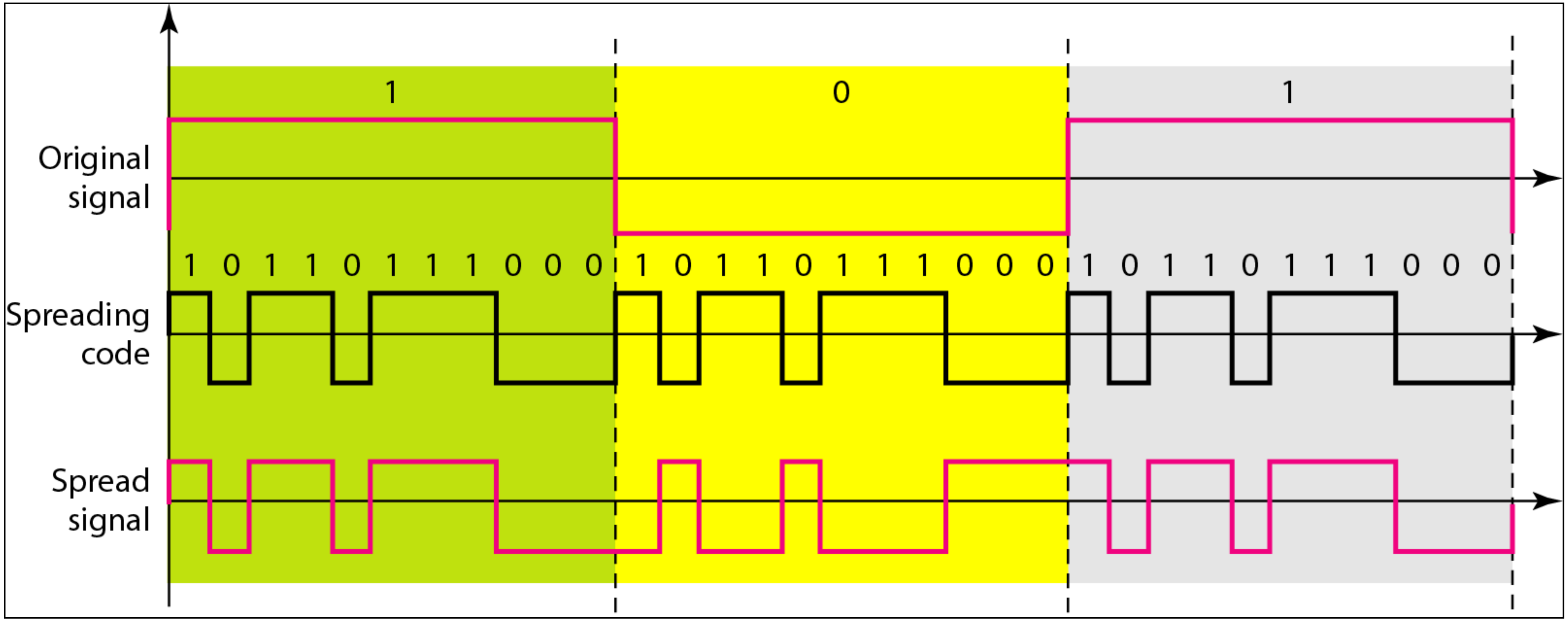
FHSS APPLICATIONS

- **FHSS modulation technique is used for military purposes. Cryptographic algorithms are used to generate the chipping/spreading code, which is shared between the sender and receiver.**
- **FHSS modulation is used in wireless LANs (WLAN).**
- **FHSS modulation is used in Global Positioning System (GPS). GPS has three segments; control segment (CS), space segment (SS) and user segment (US). There is wireless communication between control CS and SS and then SS and US.**
- **FHSS modulation is also used in Bluetooth technologies.**

DIRECT SEQUENCE SPREAD SPECTRUM (DSSS)

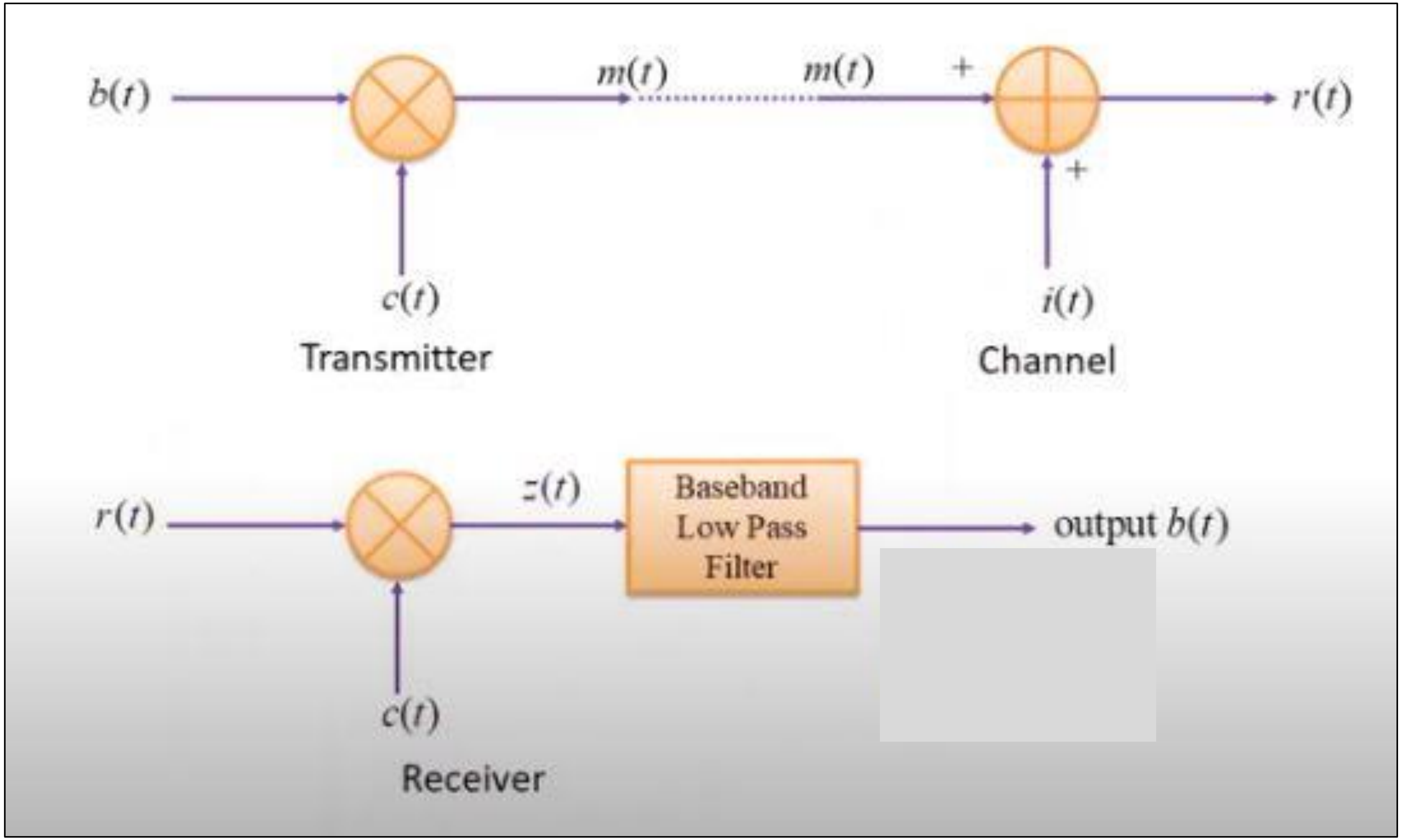
- **Each bit is represented by multiple bits using a spreading code.**
- **This spreads signal across a wider frequency band in direct proportion to the number of bits used.**
- **Has performance similar to FHSS**



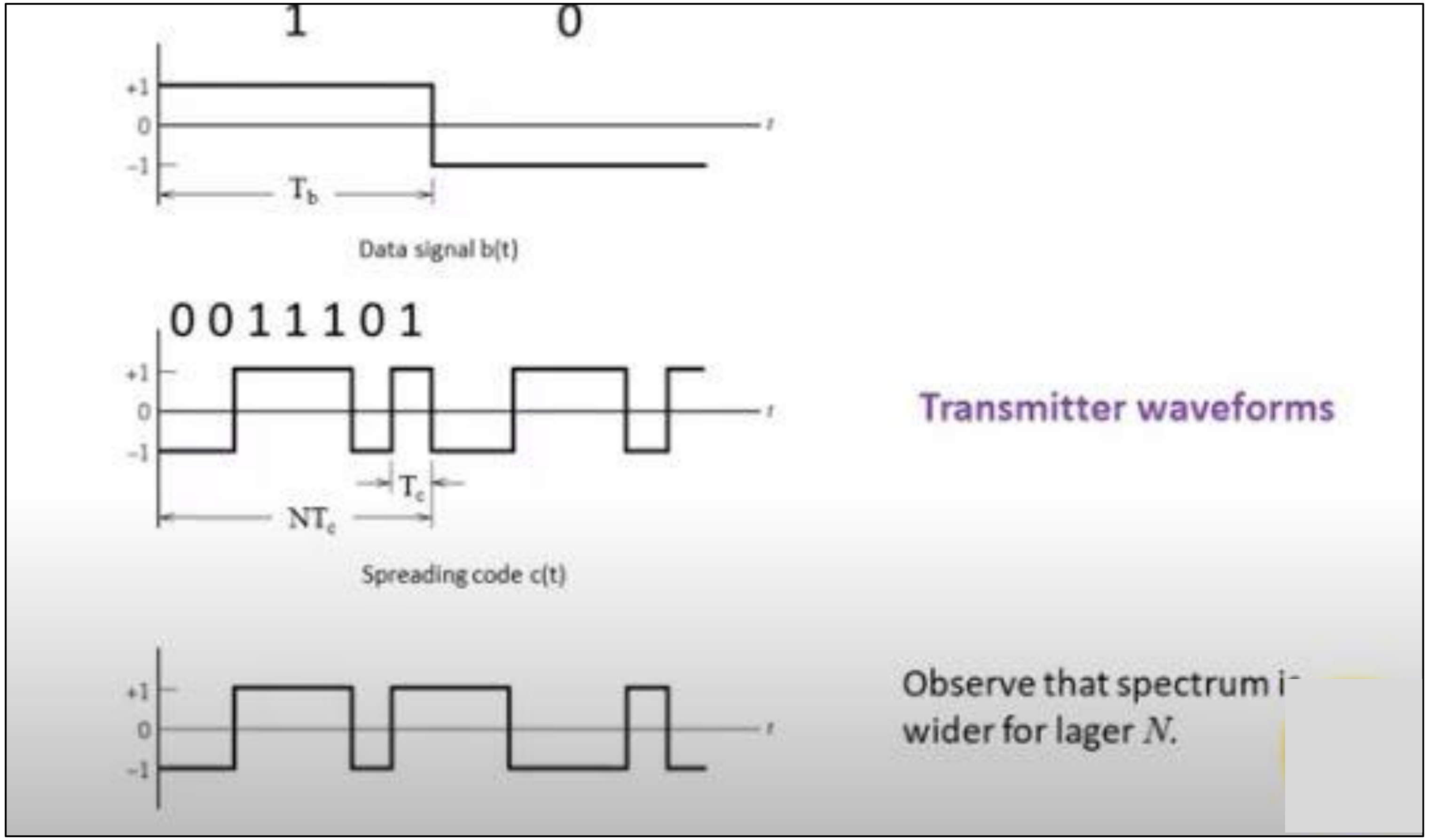


- Information bit is multiplied with chipping Sequence.
- Each bit is represented by multiple bits using a spreading code.
- This spreads the signal wider frequency band in direct proportion to the number of chip-bits used.

BASE BAND MODEL OF DSSS



- **Let {bk} be the binary data sequence**
- **Let {Ck} be the PN sequence.**
- **Both sequences are represented by polar NRZ are written as b(t) and c(t).**
- **Lt m(t) is the modulated signal by multiplying b(t) and c(t) together or m(t)=b(t).c(t)**



- **The transmitted signal is disturbed by interference i(t).**

Received signal $r(t) = m(t)+i(t)$

Assume that receiver has perfect synchronization.

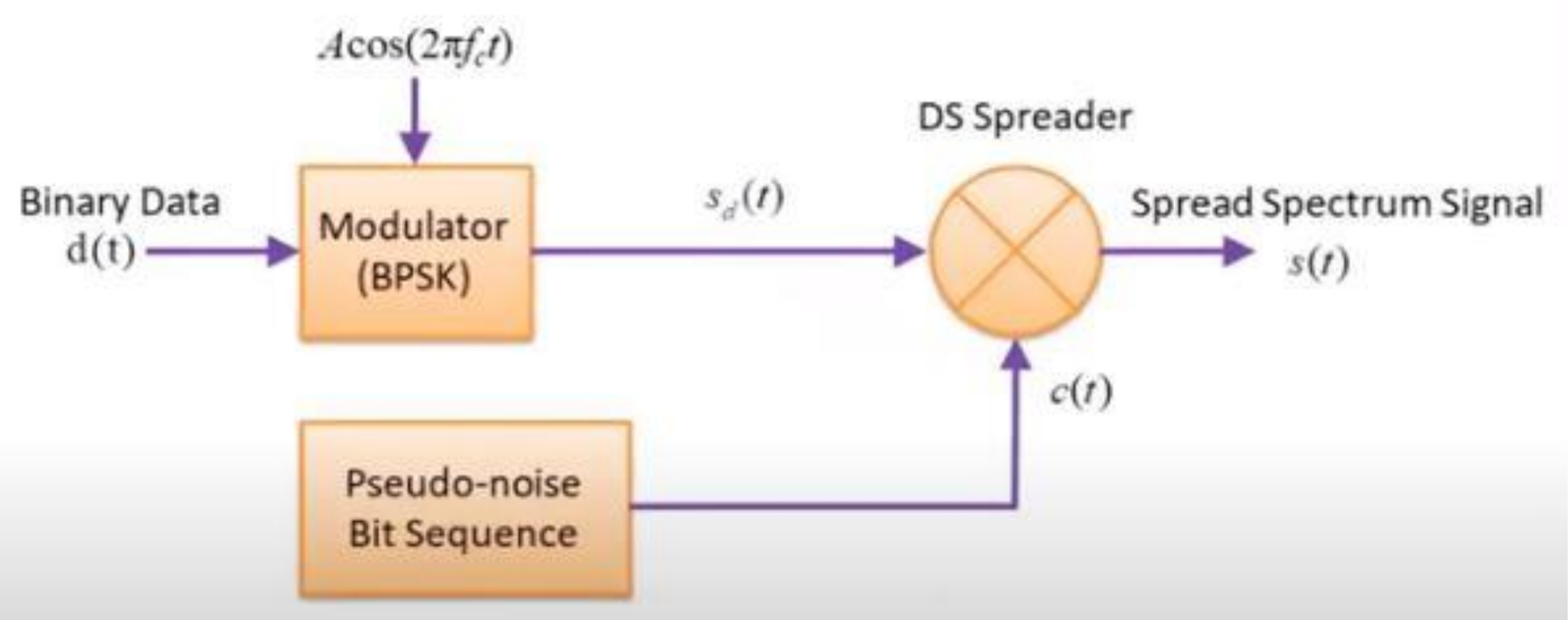
We multiply $r(t)$ with $c(t)$ again

$$z(t) = c(t)r(t) = c(t)m(t)+c(t)i(t) = c^2(t)b(t)+c(t)i(t)$$

Since $c^2(t) = 1$, we have $z(t) = b(t) + c(t)i(t)$.

C(t).i(t) has a wide spectrum. Hence LPF can remove most of the power of i(t).

DS-BPSK TRANSMITTER

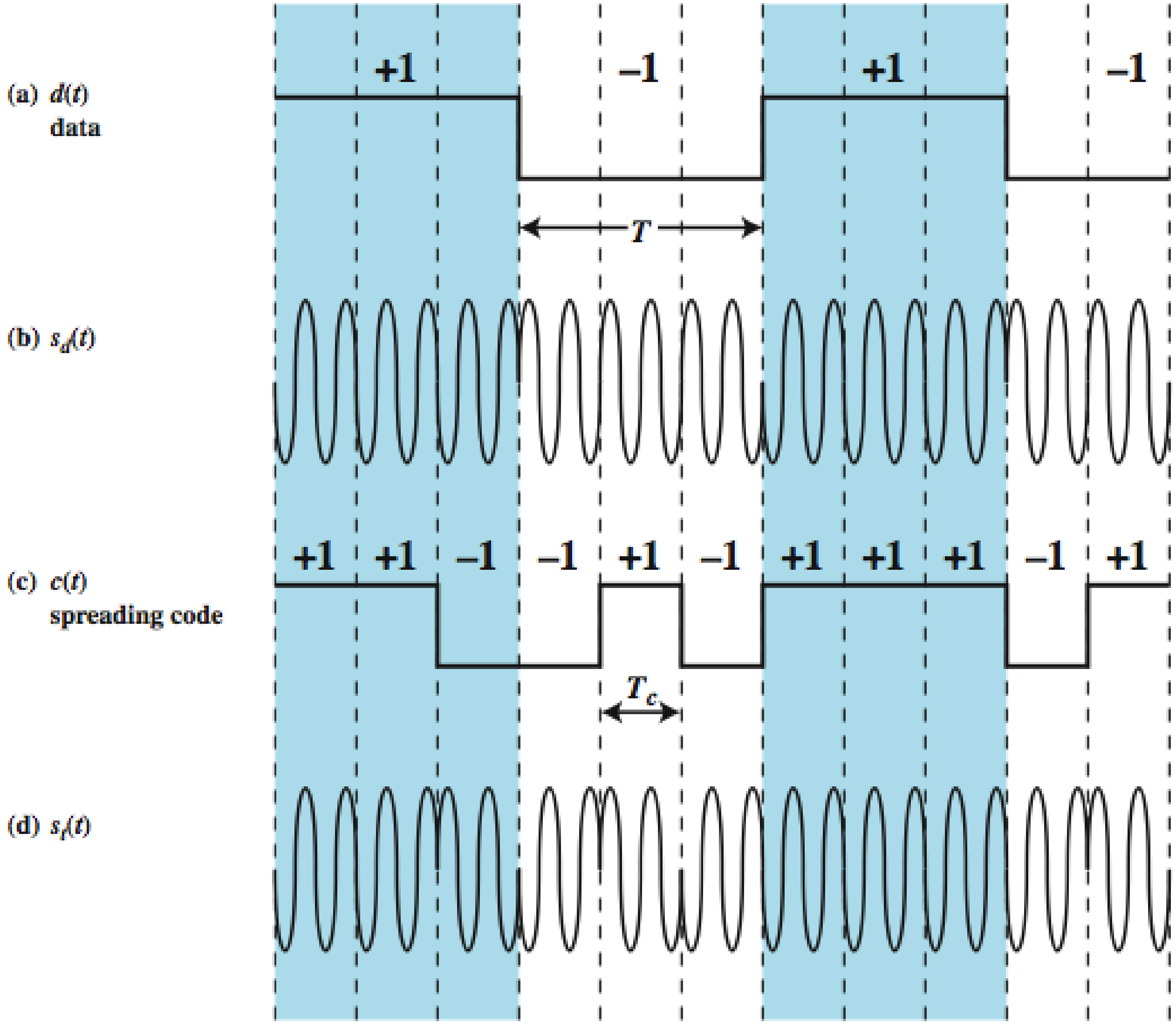


DS-BPSK Transmitter

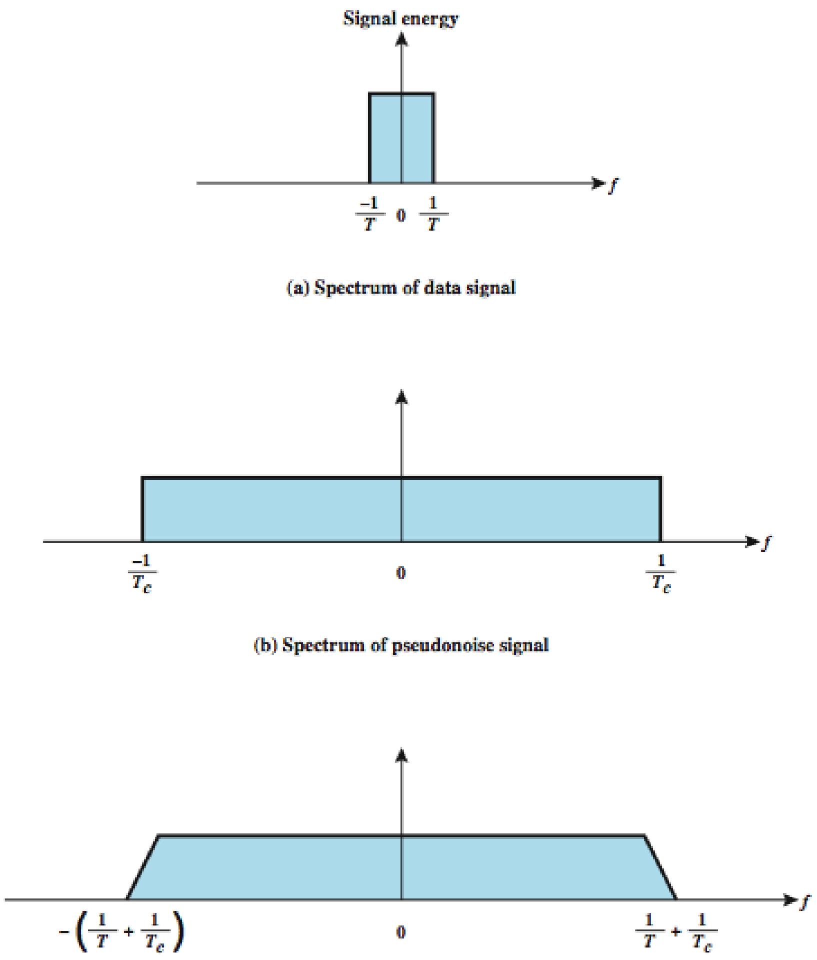
- **BPSK modulation scheme is used.**
- **Rather than represent binary data with 1 and 0, it is more convenient for our purposes to use +1 and -1 to represent two binary digits.**
- **To produce the DSSS Signal, we multiply the BPSK signal C9t0, which is the PN Sequence taking on values of +1 and -1.**

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

DS-BPSK WAVE FORMS



APPROXIMATE SPECTRUM OF DSSS SIGNAL



(c) Spectrum of combined signal

- **The information signal has a bit width of T, which is equivalent to a data rate of 1/T. In that case, the spectrum of the signal, depending on the encoding technique, is roughly 2/T.**
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APPLICATIONS OF DSSS

- Cordless Phones: Several manufacturers implement Spread Spectrum in Cordless phones. The advantages of using spread spectrum in cordless phone include the following:
  - Security: Inherently, a ss communication is coded.
  - Immunity to Noise: SS modulation is immune to noise when compared with other modulation schemes such as AM and FM.
  - Longer Range: Due to noise immunity, it is possible to achieve a longer range of communications, for a very small transmitted power.

- Long-range wireless phones for home and industry

- Cellular base stations interconnection

ADVANTAGES OF DSSS

- **Jam-resistant communication systems**
- **CDMA radios:** It is useful in multiple access communications wherein many users communicate over a shared channel. Here the assignment of a unique spread spectrum sequence to each user allows him to simultaneously transmit over a common channel with minimal mutual interference. Such access technique often simplifies the network control requirements considerably.
- **High Resolution Ranging:** SS Communications is often used in high resolution ranging. It is possible to locate an object with good accuracy using SS techniques. One example where it could be used is Global Positioning System (GPS). Here an object can use signals from several satellites transmitting SS signals according to a predefined format to determine its own position accurately on the globe.

CDMA – CODE DIVISION MULTIPLE ACCESS

- Code Division Multiple Access system is **very different** from **time and frequency** multiplexing.
- In this system, a **user has access to the whole bandwidth** for the entire duration. The basic principle is that **different CDMA codes** (pseudo-noise code sequence) are used to distinguish among the different users.
- Here, a signal is generated which extends over a wide bandwidth. A code called **spreading code** is used to perform this action.

- Using a group of codes, which are orthogonal to each other, it is possible to select a signal with a given code in the presence of many other signals with different orthogonal codes.

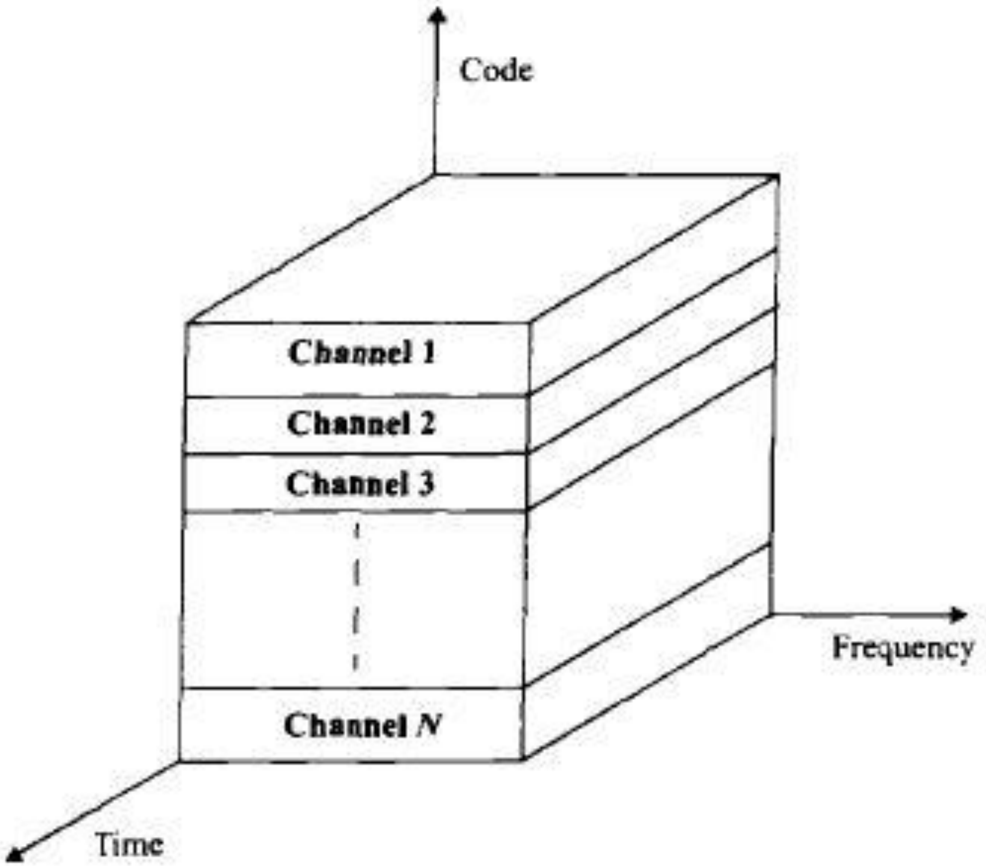
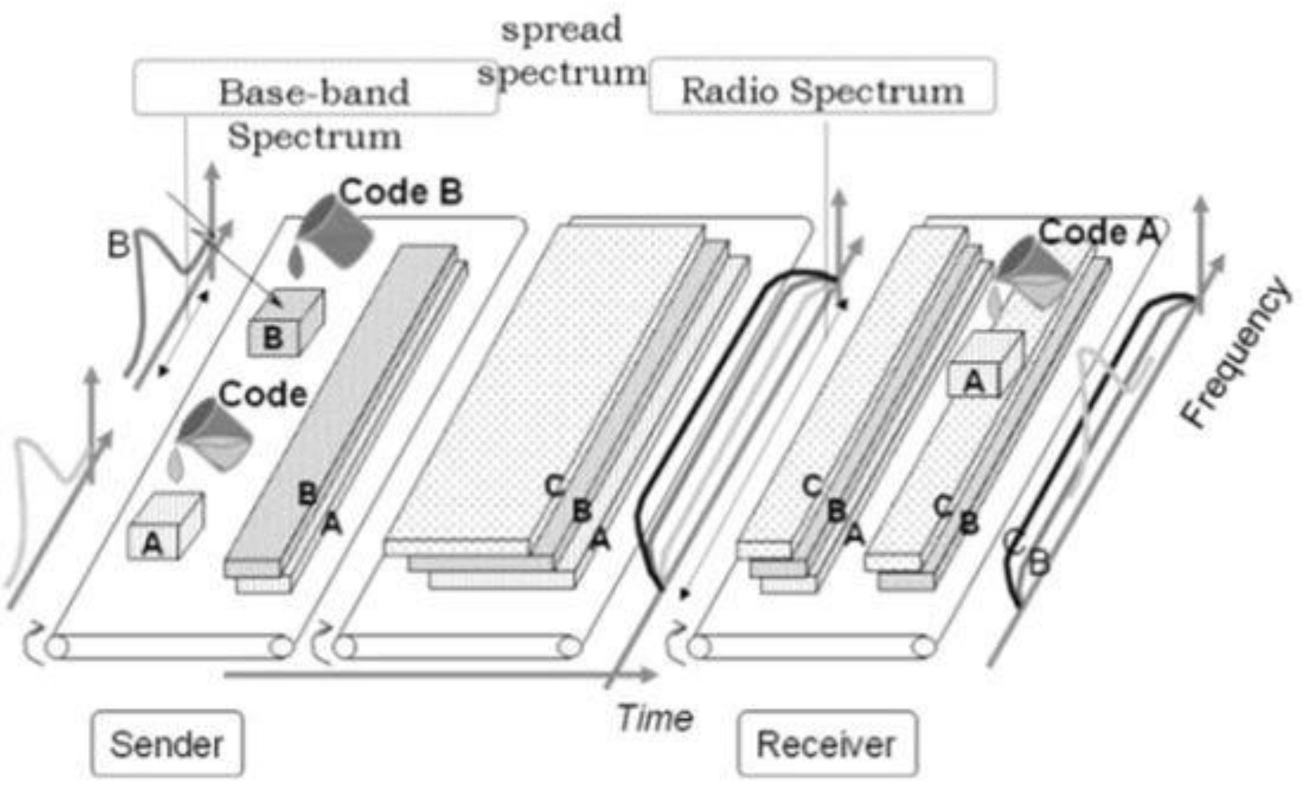


Figure 8.5
CDMA in which each channel is assigned a unique PN code which is orthogonal to PN codes used by other users.

HOW DOES CDMA WORK?

- In fact, many different "signals" baseband with **different spreading codes can be modulated on the same carrier** to allow many different users to be supported.
- Using different orthogonal codes, interference between the signals is minimal.
- By proving **different users with different spreading codes**, the different users are able to **utilize the same frequency channel**, whilst still being able to individually communicate with the base station.
- Conversely, when signals are received from several mobile stations, the base station is capable of isolating each as they **have different orthogonal spreading codes.**
- The use of **CDMA has been likened** to being in a room where there are many people speaking different languages, and being **able to understand someone speaking in your language** despite the high level of noise.

- The following figure shows the technicality of the CDMA system



- During the propagation, we mixed the signals of all users.
- but by that you use the **same code** as the code that was used at the time of sending the receiving side. You can take out only the signal of each user.

- **CDMA has a number of distinguishing features that are key to spread spectrum transmission technologies:**
- ***Use of wide bandwidth:*** CDMA, like other spread spectrum technologies uses a wider bandwidth than would otherwise be needed for the transmission of the data. This results in a number of advantages including an increased immunity to interference or jamming, and multiple user access.
- ***Spreading codes used:*** In order to achieve the increased bandwidth, the data is spread by use of a code which is independent of the data.
- ***Level of security:*** In order to receive the data, the receiver must have a knowledge of the spreading code, without this it is not possible to decipher the transmitted data, and this gives a measure of security.
- ***Multiple access:*** The use of the spreading codes which are independent for each user along with synchronous reception allow multiple users to access the same channel simultaneously.

Benefits or advantages of CDMA

Following are the benefits or **advantages of CDMA**:

➨In CDMA, signal to be transmitted **spread across the wide bandwidth** due to spreading. Hence CDMA is robust against fading and noisy environment.

➨As the transmitted information is below the noise floor, it is **difficult to intrude** the CDMA spectrum. Moreover it is **difficult for hackers to decipher the CDMA code** used over traffic channel. Hence CDMA is more secure system.

➨CDMA allows use of **entire bandwidth simultaneously** and hence there is no limit on number of subscribers per cell unlike TDMA and FDMA access schemes. This depends on number of codes **supported by the CDMA compliant base station**. Moreover it is easy to add users.

➨During the handover between the cells, due to **soft handoff** feature initially connection is being established with new cell and hence it minimizes chances of call drop or disconnection.

➨CDMA networks can interoperate with other cellular networks such as GSM/LTE. Hence nationwide roaming is possible without any issues.

Drawbacks or disadvantages of CDMA

Following are the **disadvantages of CDMA**:

➨In CDMA, orthogonal codes are **used by mobile subscribers**. Orthogonality **between the codes need to be maintained** in order to recover the data. The subscribers which are **farthest from BS will incur more attenuation and hence will lose the orthogonality** and hence it will be difficult to recover the data.

➨CDMA uses soft handoff. In this type of handoff, mobile needs to establish connection with the new target cell before disconnecting itself from serving cell. This procedure it more complex compare to the **hard handoff type**.

➨Precision code synchronization is needed to recover the original baseband signal.

Note : Two **codes are said to be orthogonal** if when they are multiplied together the result is added over a period of time they **sum to zero.** For example a codes 1 -1 -1 1 and 1 -1 1 -1 when multiplied together give 1 1 -1 -1 which gives the sum zero.

➡Increase in number of users will decrease the overall QoS.

➡Near far problem is encountered in CDMA system. This requires close control of transmit powers of CDMA handsets. This helps **farthest CDMA Phone to transmit at higher power** compare to CDMA phone which is closer in order to maintain good SNR at BS (Base station).

➡Self Jamming is observed in CDMA system **due to loss of orthogonality of PN codes or spreading sequences** of different subscribers.

Note : The **near–far problem** is the effect of a **strong signal from a near signal source** in making it hard for a **receiver to hear a weaker signal from a further source.**

Applications of CDMA

- Due to inherent advantages of CDMA over TDMA and FDMA such as user capacity, soft hand offs and security, etc., CDMA emerges as a winner in the battle of wireless technology and services. CDMA allows far greater development and the use of broad band devices **such as wireless laptop modems, GPS system units and other innovative devices**.
- For business purpose, CDMA supports in providing high speed push to talk and push to email services. **Push to talk gives mobile an ability to be used as a walky-talky device.** These services are exempted from the service charges imposed by the operators making CDMA cost effective.
- CDMA is considered as the highest mode of wireless communications, and is responsible for gibing fast and safe mode of data exchange such as 3G. Recently, CDMA has merged with the GSM technology to give a high-speed 4G or LTE internet services.

CDMA Capacity

Single cell case

- We now consider the capacity of a CDMA system in the simplest case of interference due to **mobile users within a single cell only.**

- Assume that there are ***K*** **users within the cell**. Hence each user has **(K – 1) interfering users**.

- Consider the uplink (**mobile to base station)** since this is the one in which **communication is most difficult to control**.

- All users in this **cell are assumed** to be power controlled to have the same power, **PR received at the base station.**

- In the case of mobile wireless communication, **noise is usually small or even negligible.**
- **Interference is the dominant issue** and therefore we use the **signal bit energy to interference noise power spectral density** as a measure of signal detectability.
- The power due to the (K – 1) interfering users, is given by (K – 1)*PR.

- The **power spectral density I_0** of the interference is given by:

$$I_0 = (K - 1)^* P_R / W$$

Where : *W* - Transmission bandwidth

- Also the received signal bit energy (Eb) is given by:

$$E_b = P_R / R$$

Where : R - information bit rate

- Therefore, signal bit-energy-to-noise spectral density can be written as:

$$\frac{E_b}{I_0} = \frac{P_R/R}{(K-1)P_R/W} = \frac{W/R}{(K-1)}$$

Where : *W* - Transmission bandwidth

- From above expression we see that the **larger the spreading gain *W/R***, the **more users *K* can be accommodated.**

Example

- In a CDMA system, If $\boldsymbol{E_b/I_0}$ **= 5 dB,** with the information bit rate $\boldsymbol{R}$ **= 10 kbps** and the transmission bandwidth W = 1.25 MHz.
- Find out the **Maximum Numbers of users** per Cell?

CDMA Power Control

- In CDMA, the system capacity is improved if each mobile transmitter power level is controlled.

- If the signal powers of the users **within an area covered by a cell site are controlled**, then the **total received power at the cell site will be equal** to the **average received power times** the number of mobiles operating in the coverage area.

- If a mobile signal arrives at the cell site with a signal that is **too weak**, most of the time the **weak signal will be dropped**.

- If the power of a **user is very high**, it will **add in undesirable interference power to the other uses.**

CDMA Near-Far Problem

- A **CDMA receiver cannot decode** signals in an interference environment.

- In order for the far transmitter to be heard, **a transmitter close to the receiver should transmit at a lower power**.

- Mobile devices should transmit at such power levels **such that received power levels are equal at base station**.

HYBRID SPREAD SPECTRUM TECHNIQUES

- In addition to the frequency hopped and direct sequence, spread spectrum multiple access techniques, there are certain other **hybrid combinations** that provide certain advantages.

Hybrid FDMA/CDMA (FCDMA)

- Below Figure shows the spectrum of this hybrid scheme.

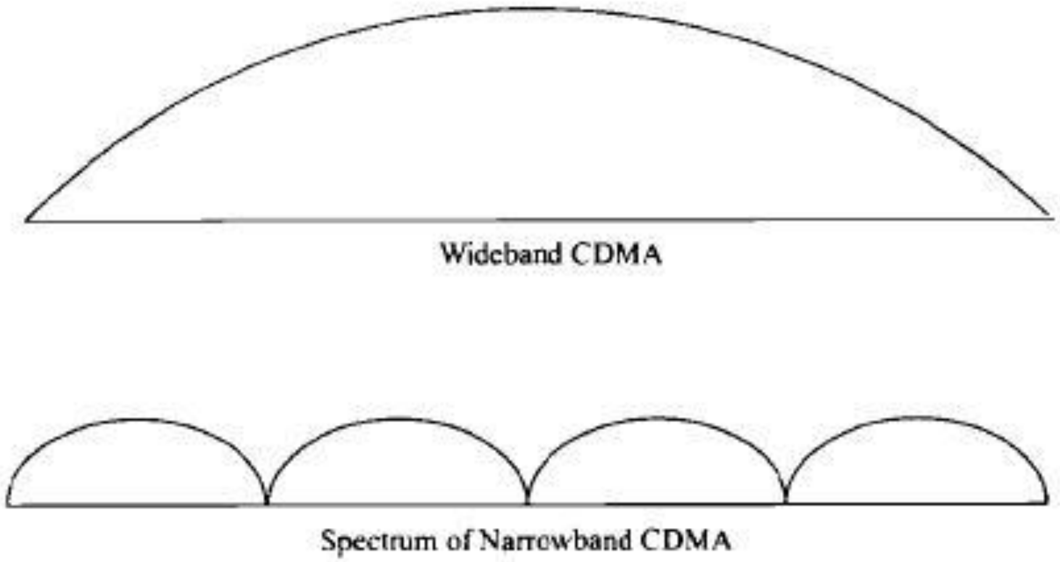


Figure 8.6
Spectrum of wideband CDMA compared to the spectrum of a hybrid, frequency division, direct sequence multiple access.

- The available wideband spectrum is divided **into a number of subspectras with smaller bandwidths**.
- Each of these smaller subchannels **becomes a narrowband CDMA system** having processing gain lower than the original CDMA system.
- This hybrid system **has an advantage** in that the required **bandwidth need not be contiguous** and different user**s can be allotted different subspectrum bandwidths** depending on their requirements.
- The capacity of this FDMA/CDMA technique is calculated as the sum of the capacities of a system operating in the subspectra.

TIME DIVISION CDMA (TCDMA)

- In a TCDMA (also called TDMA/CDMA) system, **different spreading codes are assigned to different cells.**
- Within each cell, **only one user per cell is allotted a particular time slot.** Thus at any time, only one **CDMA user is transmitting in each cell.**
- When a handoff takes place, the **spreading code of the user is changed to that of the new cell**.
- Using TCDMA has an advantage in that it avoids the **near-far effect since only one user transmits at a time within a cell.**

HYBRID DIRECT SEQUENCE/FREQUENCY HOPPED MULTIPLE ACCESS (DS/FHMA)

- This technique consists of a **direct sequence modulated signal** whose **center frequency is made to hop periodically** in a pseudorandom fashion.

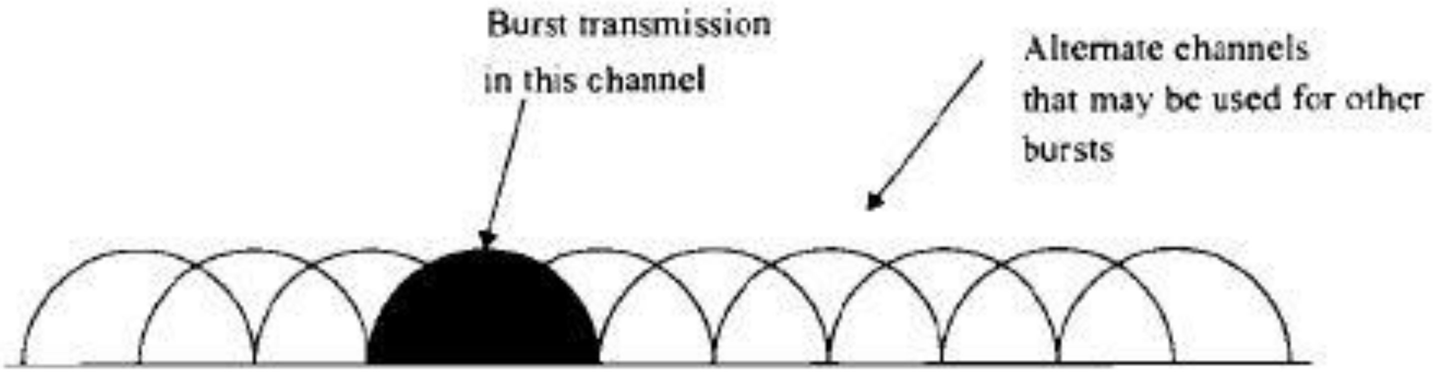


Figure 8.7
Frequency spectrum of a hybrid FH/DS system.

- Direct sequence, frequency hopped systems have an advantage in that they **avoid the near-far effect**. However, **frequency hopped CDMA systems are not adaptable to the soft handoff process** since it is difficult to **synchronize the frequency hopped base station receiver** to the multiple hopped signals.

TIME DIVISION FREQUENCY HOPPING (TDFH)

- This multiple access technique has an advantage, **in severe multipath or when severe co-channel interference occurs**.
- The subscriber **can hop to a new frequency at the start of a new TDMA frame,** thus avoiding a severe **fade or erasure event** on a particular channel.
- This technique has been **adopted for the GSM standard**, where the **hopping sequence is predefined** and the subscriber **is allowed to hop only on certain frequencies which are assigned to a cell**.
- This scheme also avoids **co-channel interference** problems between neighboring cells, if **two interfering base station transmitters** are made to transmit on different frequencies at different times.
- The use of TDFH can increase the capacity of GSM.