Multiple Division Techniques

Introduction

- Multiple division techniques
  - Motivation: to have many traffic channels
  - Classifications
    - Frequency: FDMA (Frequency Division Multiple Access)
    - Time: TDMA (Time Division Multiple Access)
    - Code: CDMA (Code Division Multiple Access)
    - SDMA (Space Division Multiple Access)
- Reminder
  - Multiple radio access—dealing with control channels in cellular systems
  - Multiple division techniques—dealing with traffic channels in cellular systems

Models of Multiple Divisions (1/2)

- General model

  $$s(f,t,c) = s(f,t)c(t)$$

- General expression for the signal as a function of frequency and time

  $$s(f,t,c) = s(f,t)$$

Models of Multiple Divisions (2/2)

- Simultaneously two-way communications (duplex communications) [full duplex v.s. half duplex]
  - A forward (downlink) channel: transmissions from the BS to a MS
  - A reverse (uplink) channel: transmissions from a MS to the BS
- Two types of duplex
  - FDD (frequency division duplexing)
  - TDD (time division duplexing)
- FDMA mainly uses FDD, while TDMA and CDMA use either FDD or TDD

FDMA (1/2)

- Model
  - Let $s_i(f,t)$ and $s_j(f,t)$ be two signals being transmitted in the cell space
  - The orthogonality condition of two signals in FDMA is

$$\int_{\boxed{F}} s_i(f,t)s_j(f,t)df = \begin{cases} 1 & \text{for } i = j \\ 0 & \text{for } i \neq j \end{cases} \quad i,j = 1,2,..,k$$

- Concept

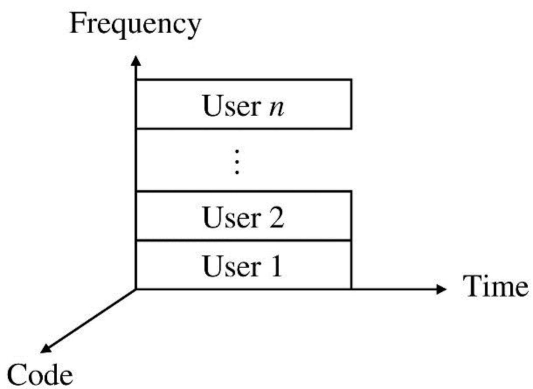


Figure 7.1 The concept of FDMA.

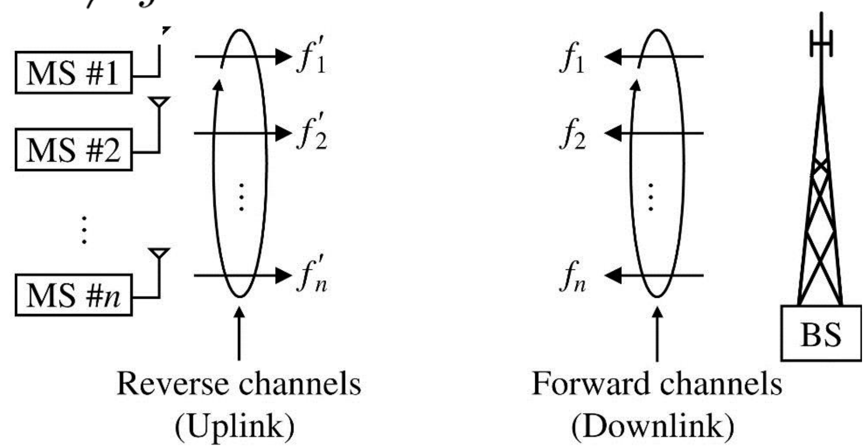


Figure 7.2 The basic structure of a FDMA system.

FDMA (2/2)

- Channel structure

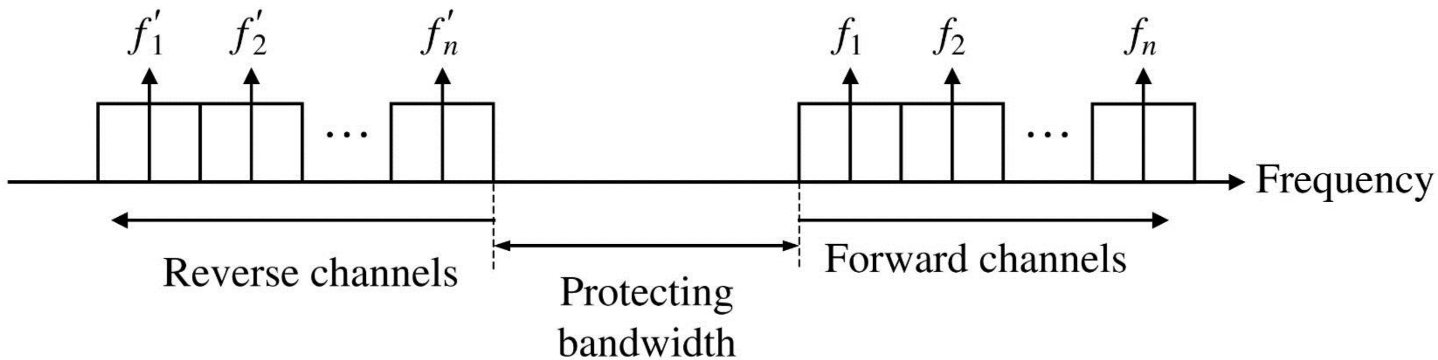


Figure 7.3 Structure of forward and reverse channels in FDMA.

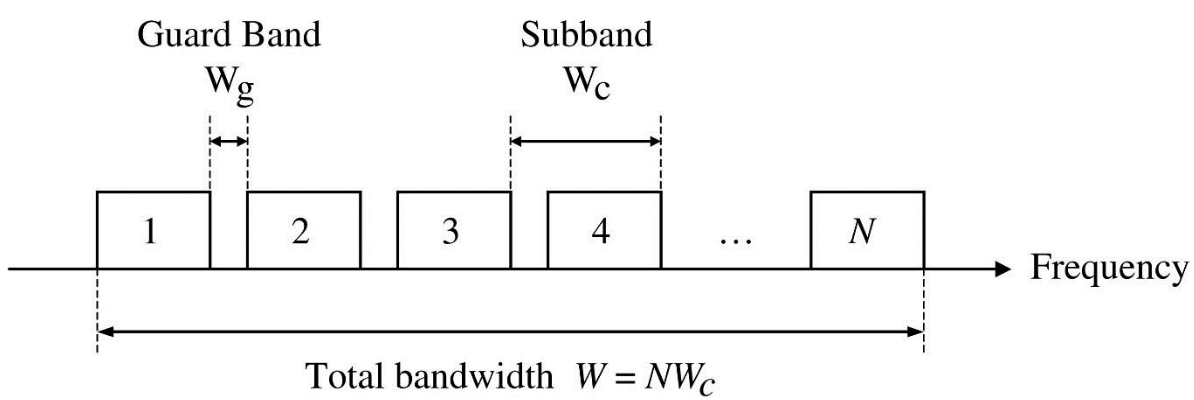


Figure 7.4 Guard band in FDMA.

TDMA (1/5)

- Model
  - Let $s_i(f,t)$ and $s_j(f,t)$ be two signals being transmitted in the cell space
  - The orthogonality condition of two signals in TDMA is

$$\int_{\boxed{T}} s_i(f,t)s_j(f,t)df = \begin{cases} 1 & \text{for } i = j \\ 0 & \text{for } i \neq j \end{cases} \quad i,j = 1,2,..,k$$

- Concept

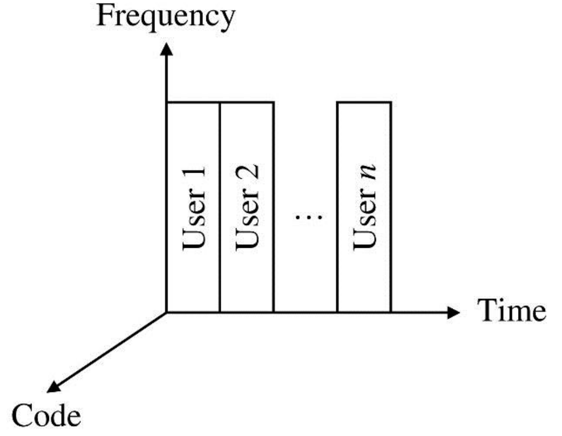


Figure 7.5 The concept of TDMA.

TDMA (2/5)

- Basic structure

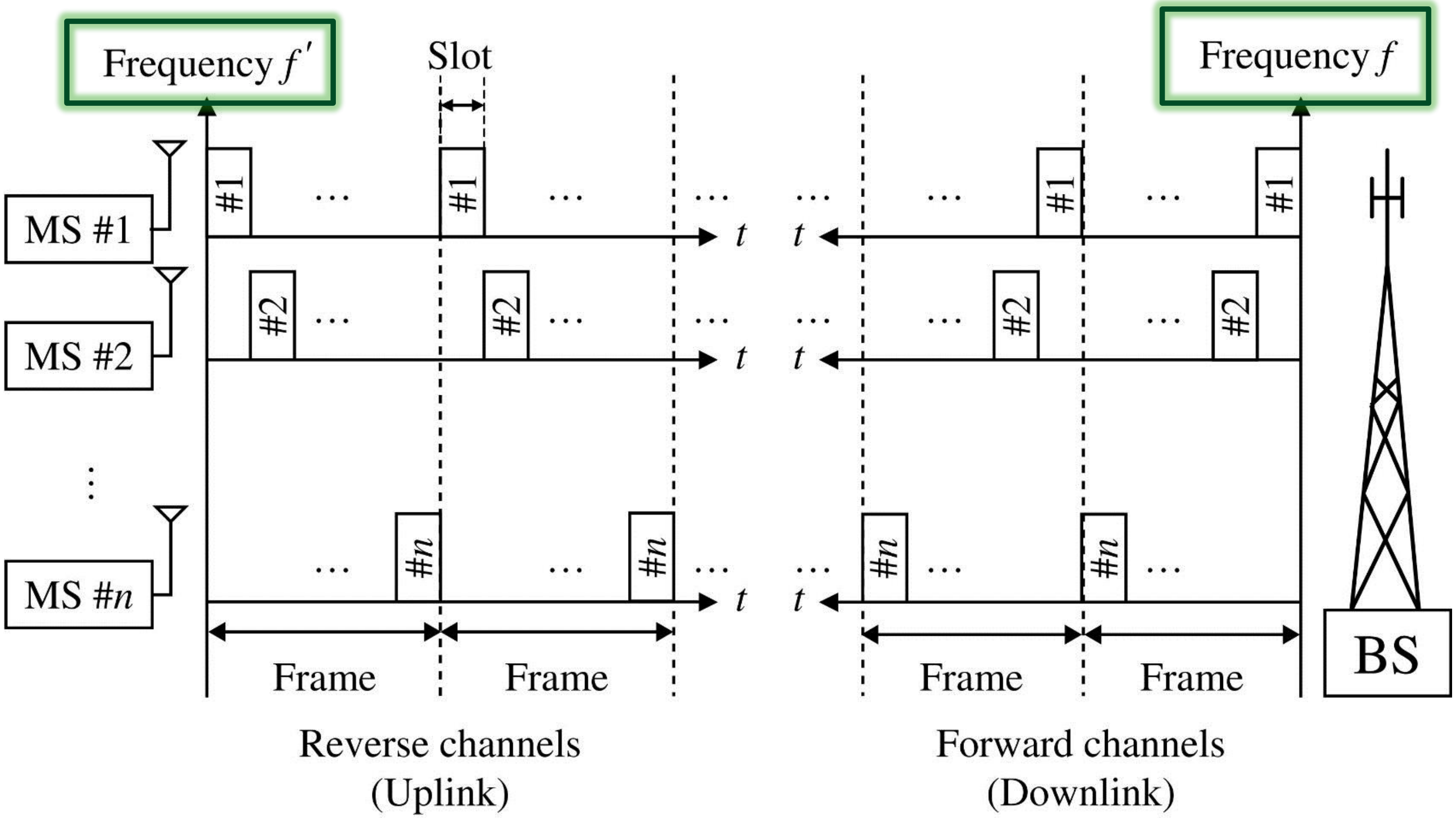


Figure 7.6 The basic structure of a TDMA system.

TDMA (3/5)

- Channel structure: TDMA/FDD

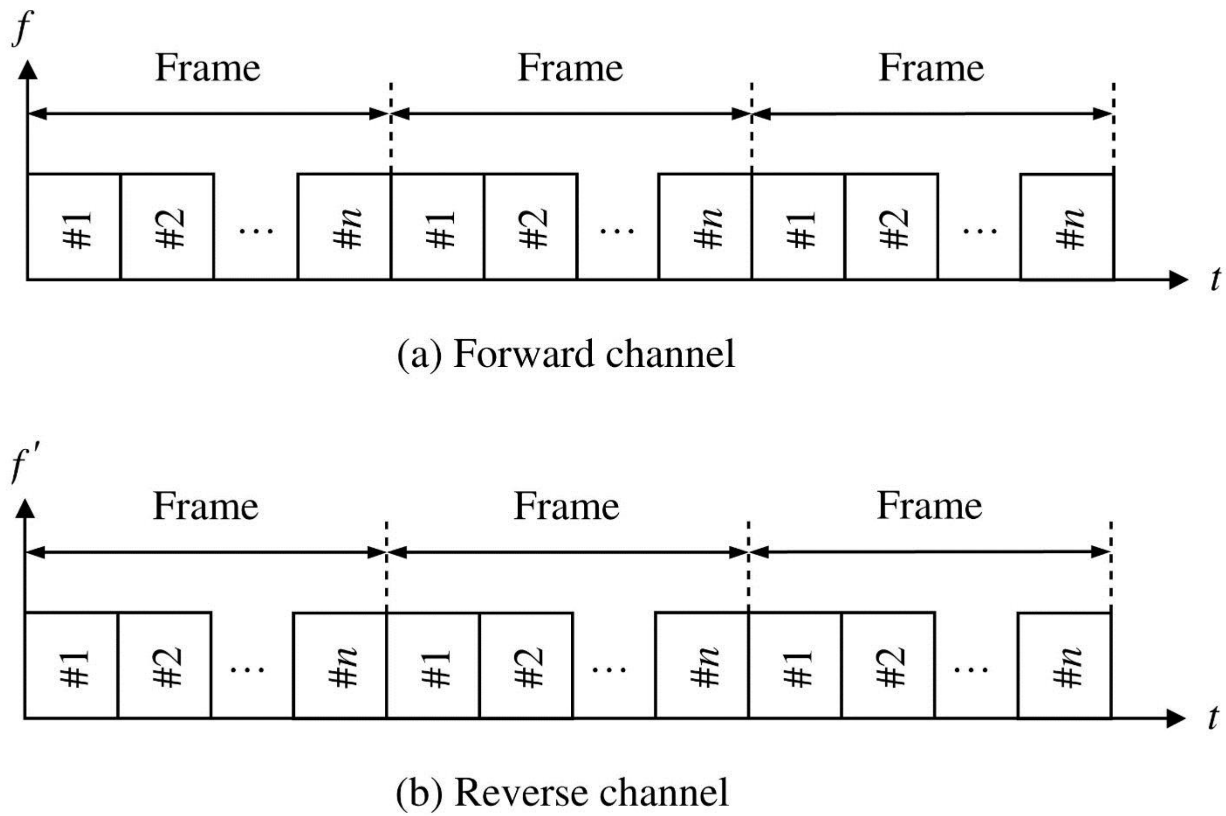


Figure 7.7 Structure of forward and reverse channels in a TDMA/FDD system.

TDMA (4/5)

- Channel structure: TDMA/TDD

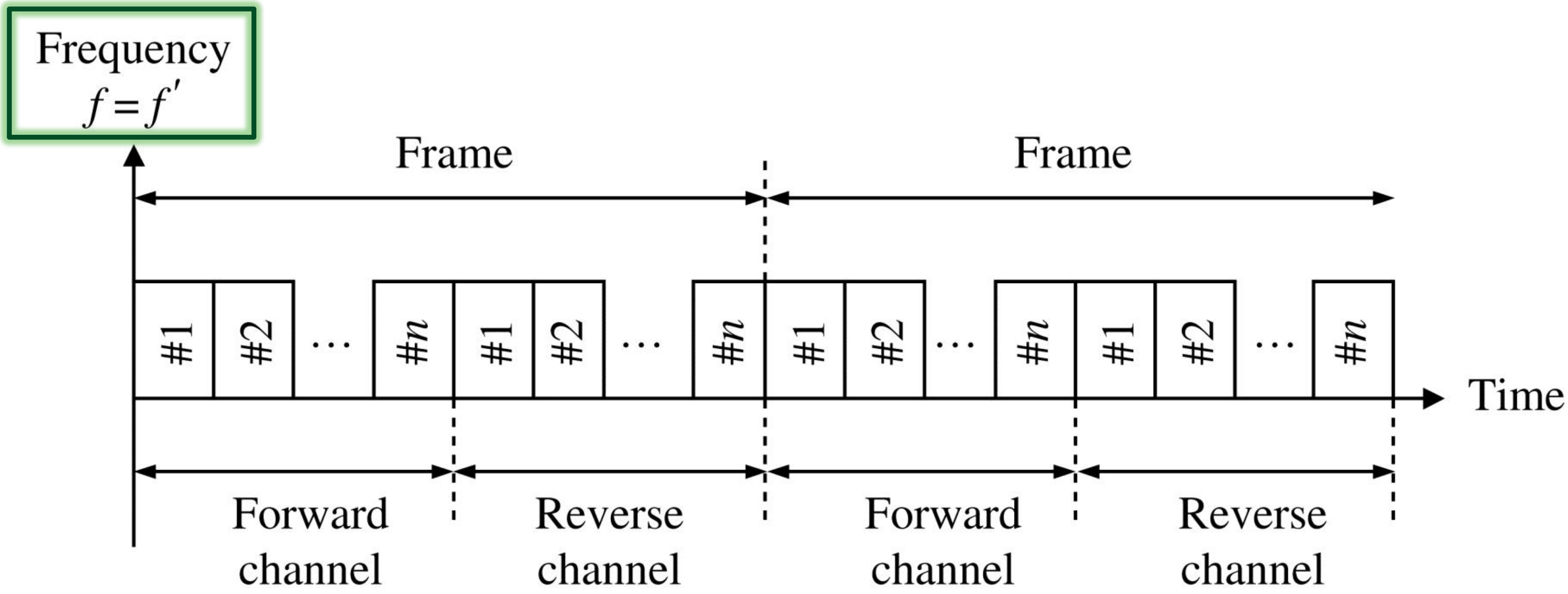


Figure 7.8 Structure of forward and reverse channels in a TDMA/TDD system.

TDMA (5/5)

- TDMA frame structure

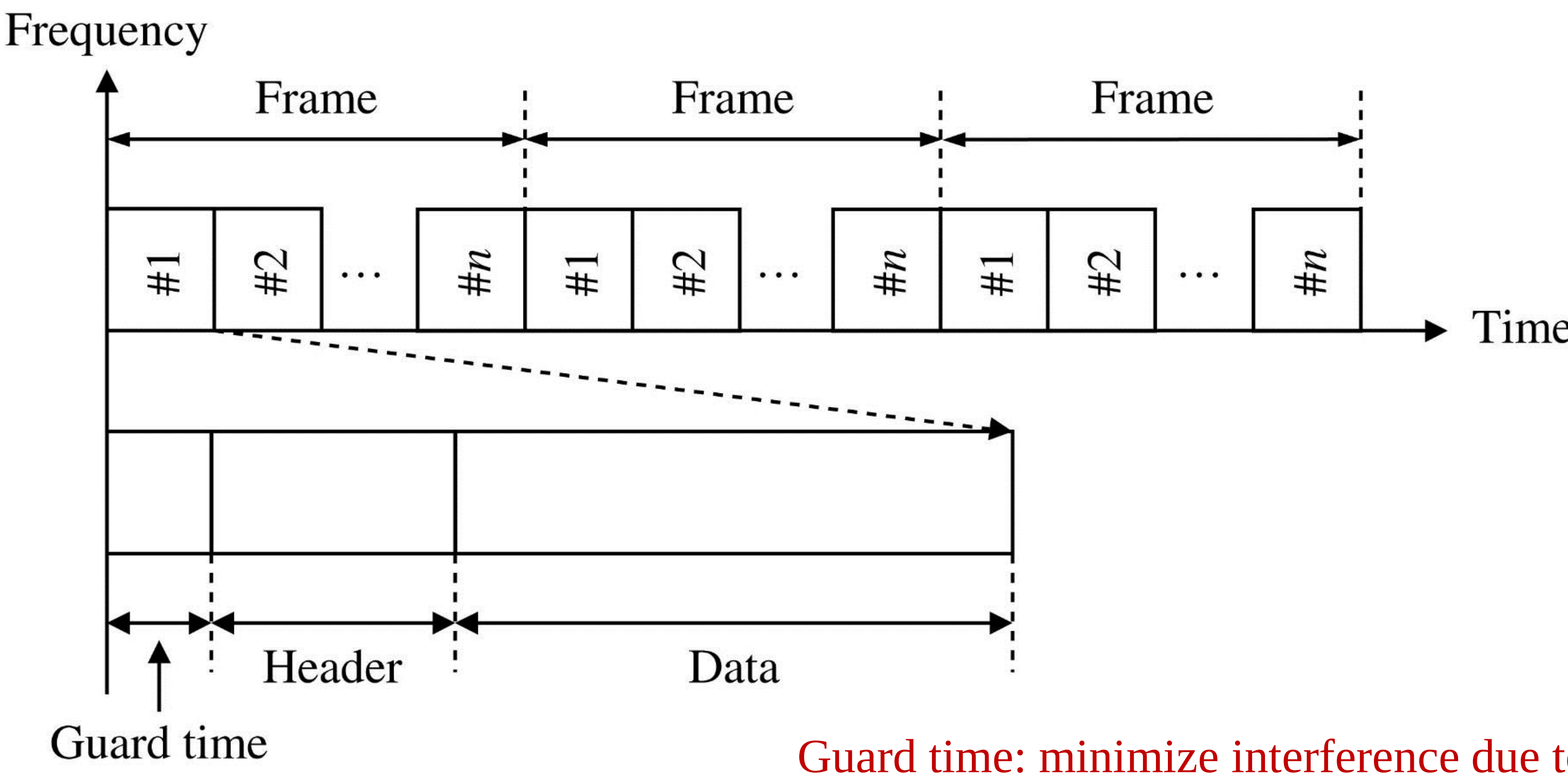


Figure 7.9 Frame structure of TDMA.

Guard time: minimize interference due to propagation delays along different paths

CDMA (1/13)

- Model
  - The orthogonality condition of two signals in CDMA is

$$\int_{\boxed{C}} s_i(t)s_j(t)df = \begin{cases} 1 & \text{for } i = j \\ 0 & \text{for } i \neq j \end{cases} \quad i, j = 1, 2, .., k$$

- Concept

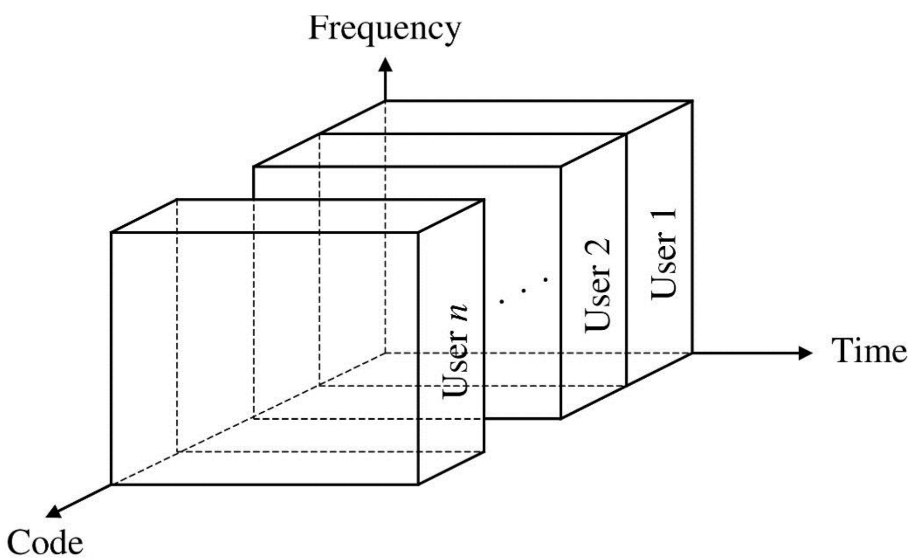


Figure 7.10 The concept of CDMA.

CDMA (2/13)

- Each user is assigned a unique spread-spectrum code
- CDMA is based on spectrum-spread technology
- Frequency efficiency is improved by utilizing power control
- 2 basic types of CDMA implementation methodologies: direct sequence (DS) and frequency hopping (FH)

CDMA (3/13)

- Spread spectrum is a transmission technique wherein data occupy a larger bandwidth than necessary
- Bandwidth spreading is accomplished before transmission through the use of a code being independent of the transmitted data
- The receiver uses the same code to do demodulation

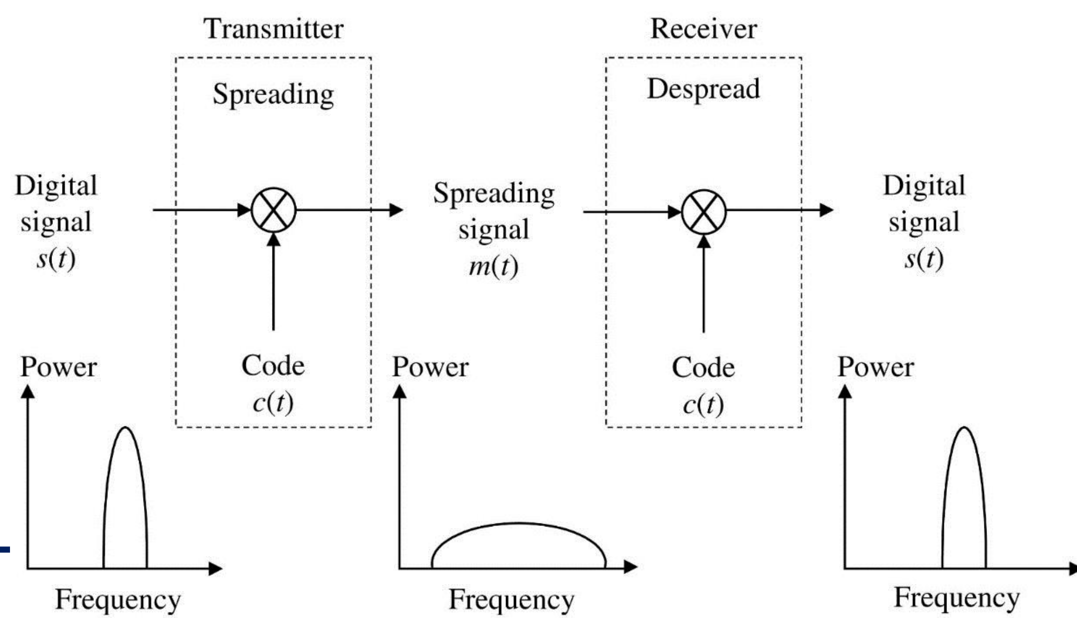


Figure 7.13 Concept of direct sequence spread spectrum.

CDMA (4/13)

- A pseudorandom sequence is used to change the radio signal frequency across a broad frequency band in a random fashion
- Fast hopping: multiple hops per data bit
- Slow hopping: multiple bits per hop

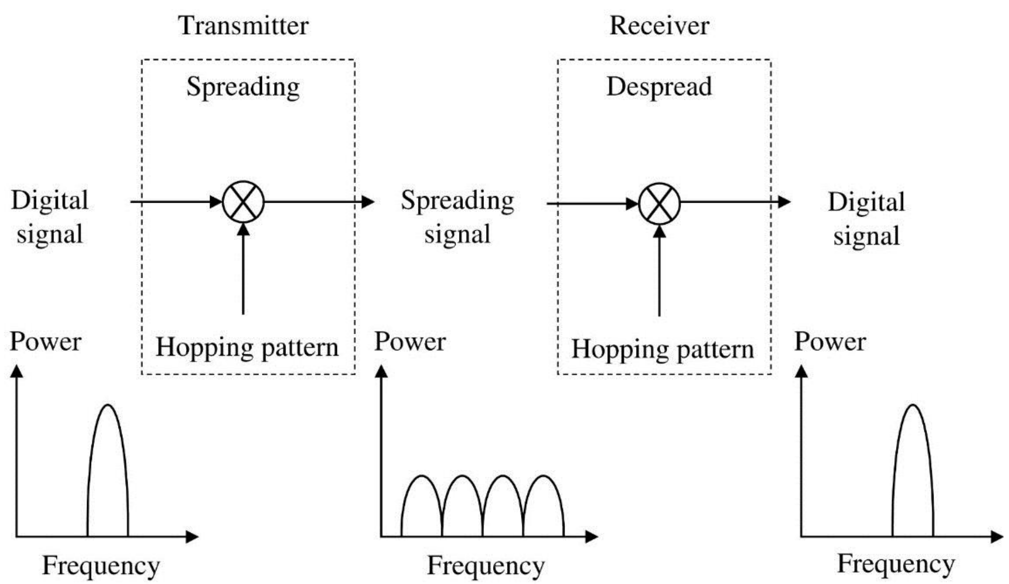
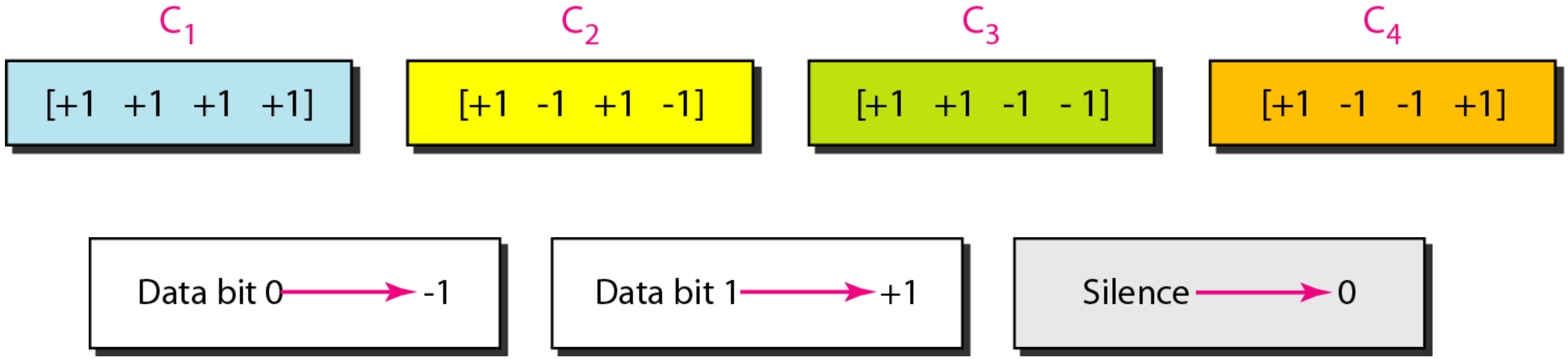


Figure 7.14 Concept of frequency hopping spread spectrum system.

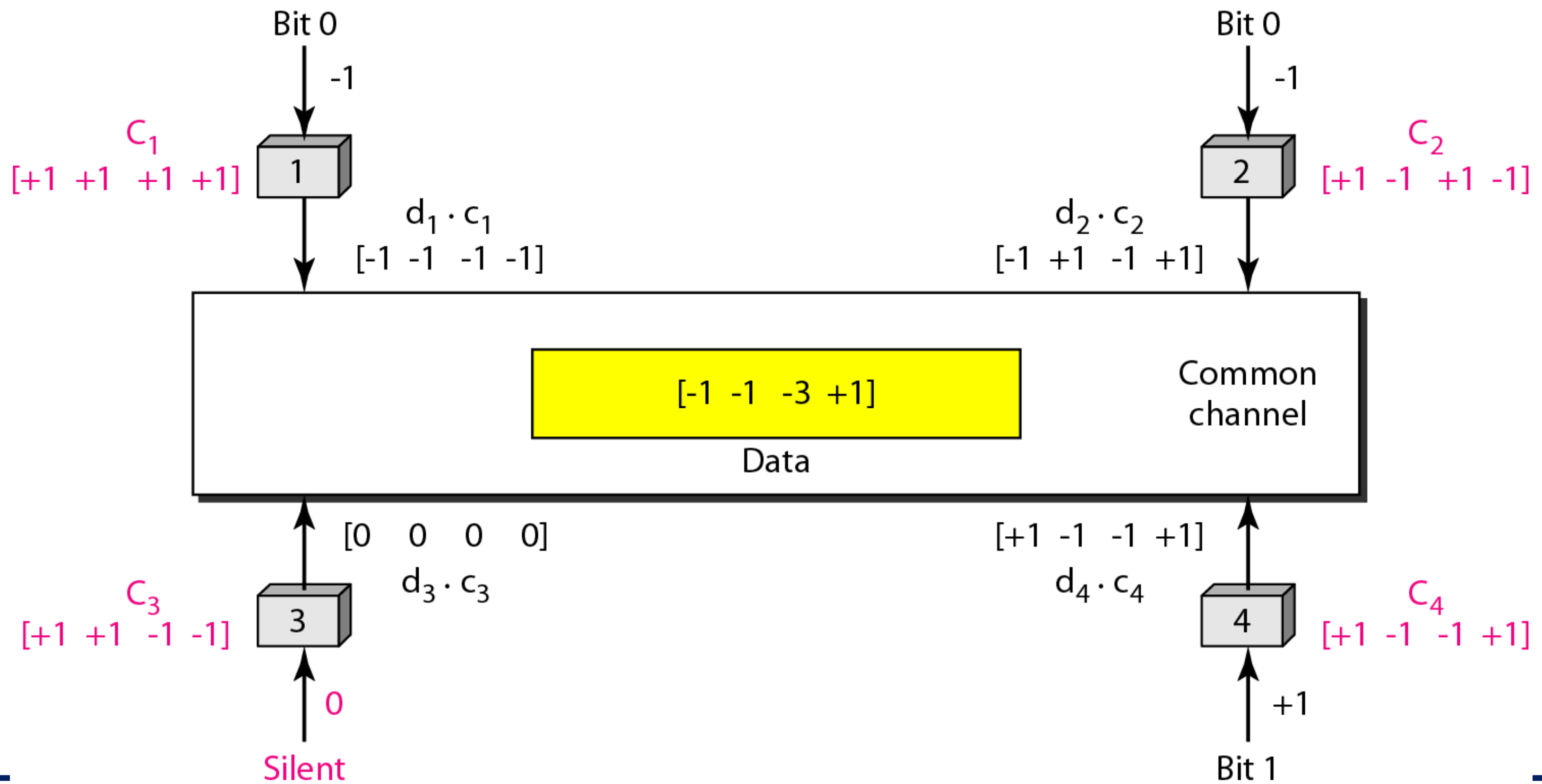
CDMA (5/13)

- An example
  - Encoding rules
  - Chip sequence



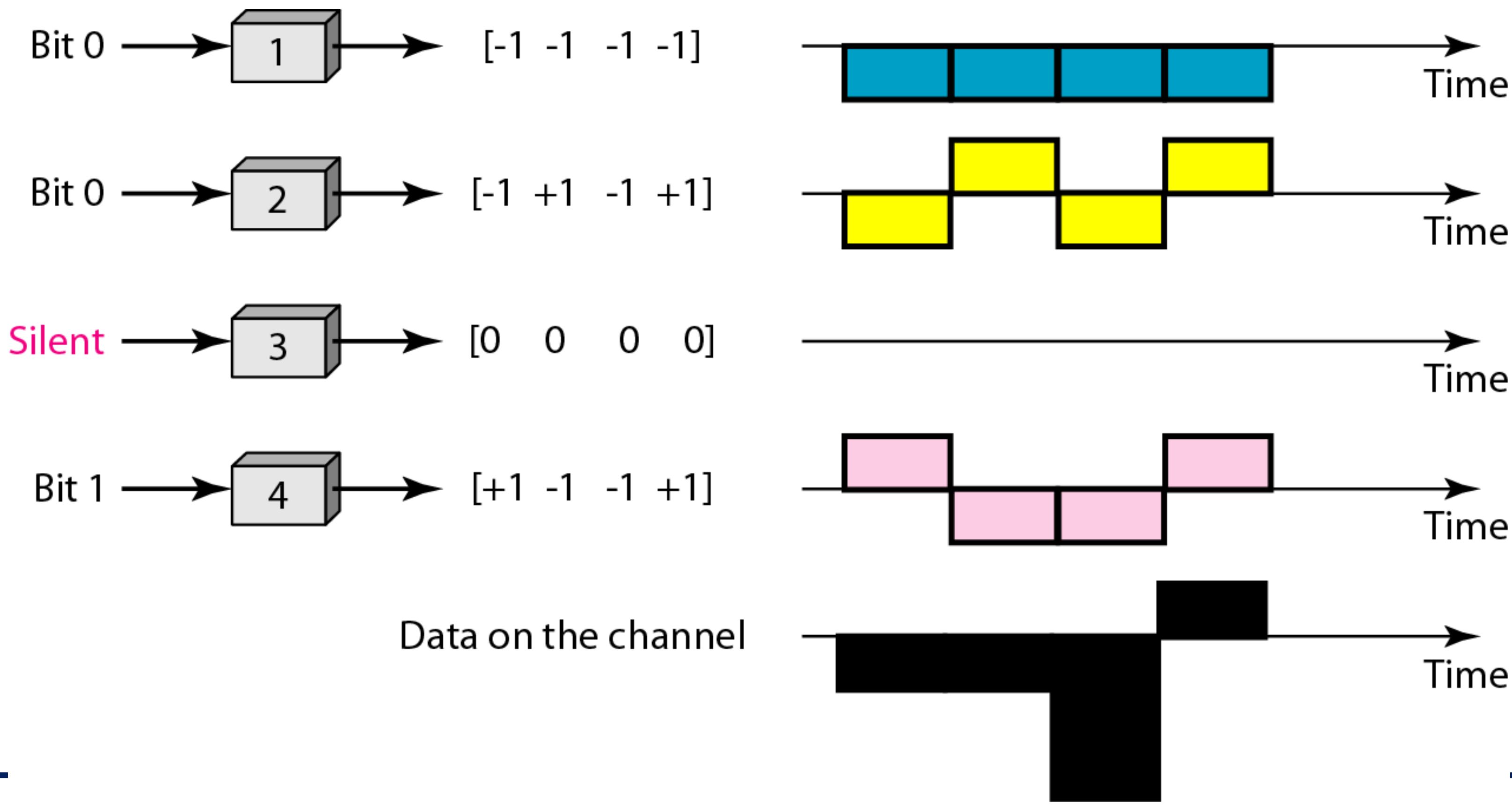
CDMA (6/13)

- Channel share



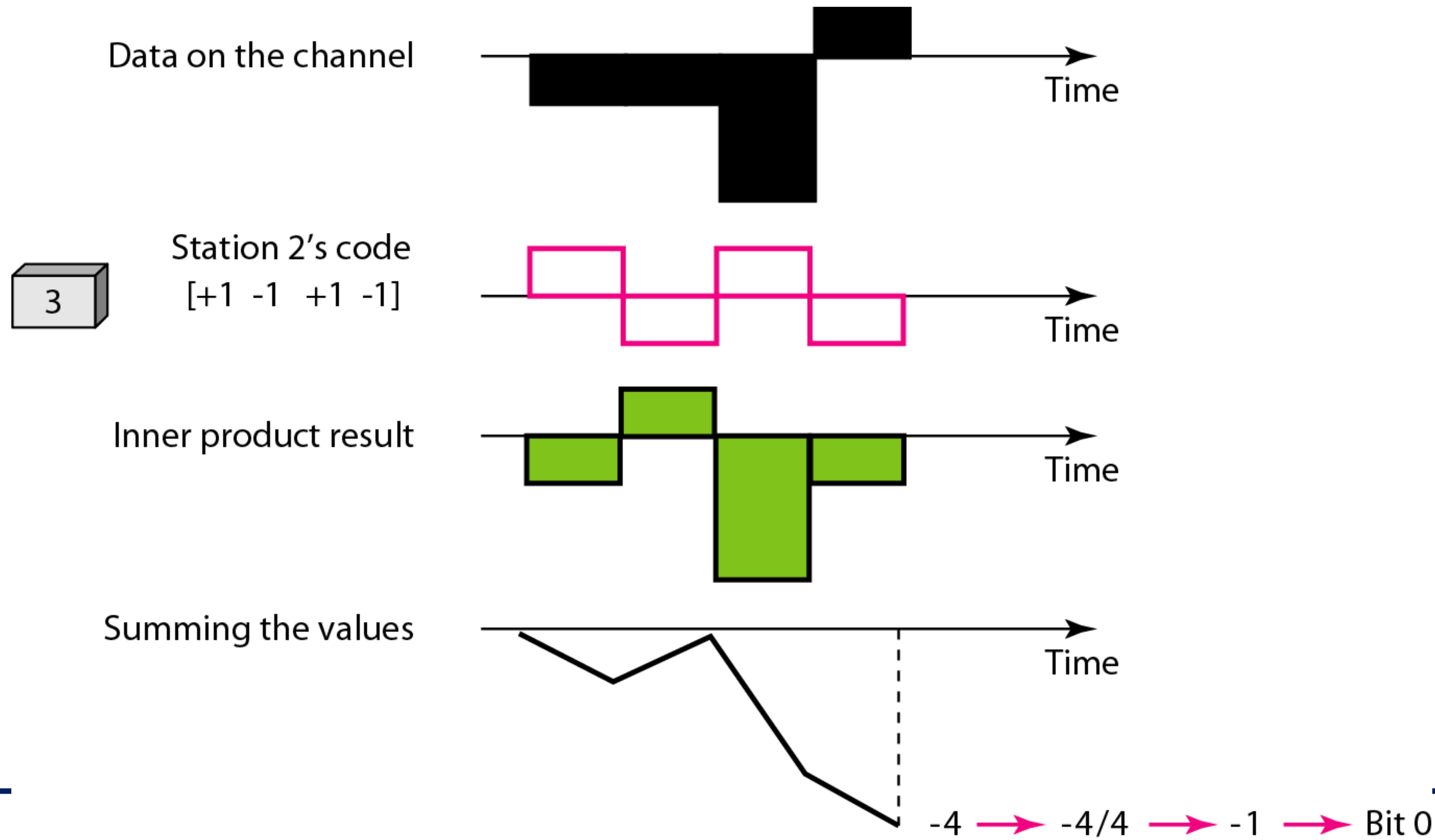
CDMA (7/13)

- Coding



CDMA (8/13)

- Decoding



CDMA (9/13)

- Sequence generation
  - Walsh table: a two-dimensional table with an equal number of rows and columns
  - Each row is a sequence of chips
  - We can create W_{2N} from W_N

CDMA (10/13)

$$W_1 = \begin{bmatrix} +1 \end{bmatrix} \qquad W_{2N} = \begin{bmatrix} W_N & W_N \\ W_N & \overline{W_N} \end{bmatrix}$$

a. Two basic rules

$$W_1 = \begin{bmatrix} +1 \end{bmatrix}$$

$$W_2 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \qquad W_4 = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix}$$

b. Generation of W_1, W_2, and W_4

CDMA (11/13)

- Walsh codes
  - Hadamard matrix: $H_n = \begin{bmatrix} H_{n-1} & H_{n-1} \\ H_{n-1} & \overline{H}_{n-1} \end{bmatrix}$
  - $H_0 = [1]$
  - $W(k, n)$ denotes Walsh code *k* in *n*-length Walsh matrix
    - ✓ $W(0, 1) = 1$
    - ✓ $W(0, 2) = 1, 1$
    - ✓ $W(1, 2) = 1, -1$
    - ✓ $W(0, 4) = 1, 1, 1, 1$
    - ✓ $W(1, 4) = 1, -1, 1, -1$
    - ✓ $W(2, 4) = 1, 1, -1, -1$
    - ✓ $W(3, 4) = 1, -1, -1, 1$

CDMA (12/13)

- **Near far problem**: both MS1 and MS2 are transmitting to the BS with equal transmit power. Since MS2 (MS1) is far from (close to) the BS, the SNR from MS1 is better than that from MS2, which makes the BS may not understand what MS2 sent
  - Solution: power control (i.e., MS1 transmits frames with lower power)
- What's auto gain control (AGC)?

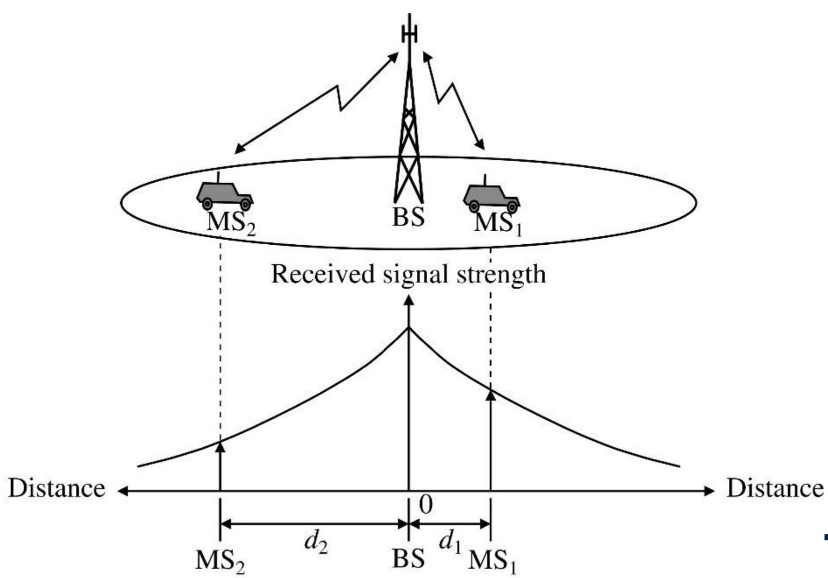
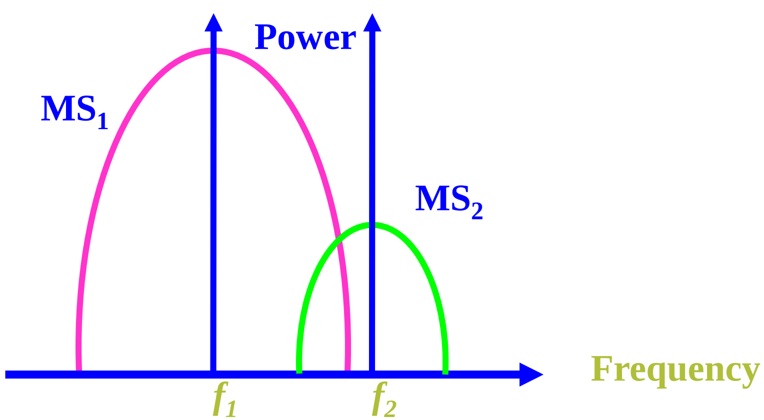


Figure 7.17 Near-far problem.



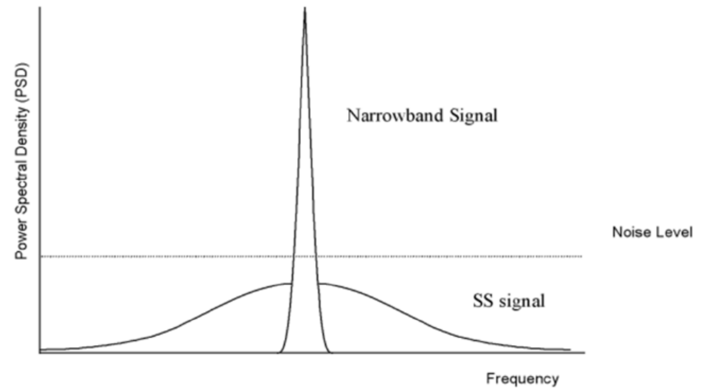
CDMA (13/13)

- **Power control**
  - In free space, the propagation path loss depends on the frequency of transmission *f*, and the distance between transmitter and receiver, *d*, i.e.,

$$\frac{P_r}{P_t} = \frac{1}{\left(\frac{4\pi df}{c}\right)^{\alpha}}$$

Spread Spectrum Modulation

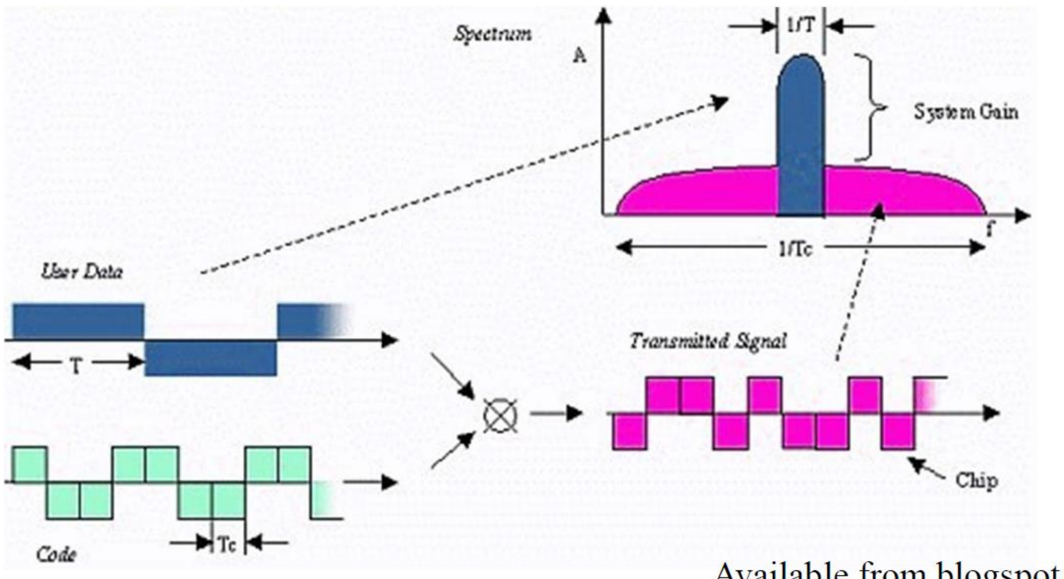
- What is spread spectrum modulation?
  - A means of transmission in which data sequences occupy a bandwidth (BW) in excess of the minimum necessary BW



- Why do we need spread spectrum modulation?
  - Interference rejection in multiple access channels
  - Secure communications in a hostile environment where a transmitter may attempt to jam the transmission

Spread Spectrum Modulation

- How do we do spread spectrum modulation?
  - A straightforward method is to multiply the message symbol by a wideband pseudo noise (PN) spreading sequence ⇨ Direct-Sequence spread spectrum (DSSS) modulation



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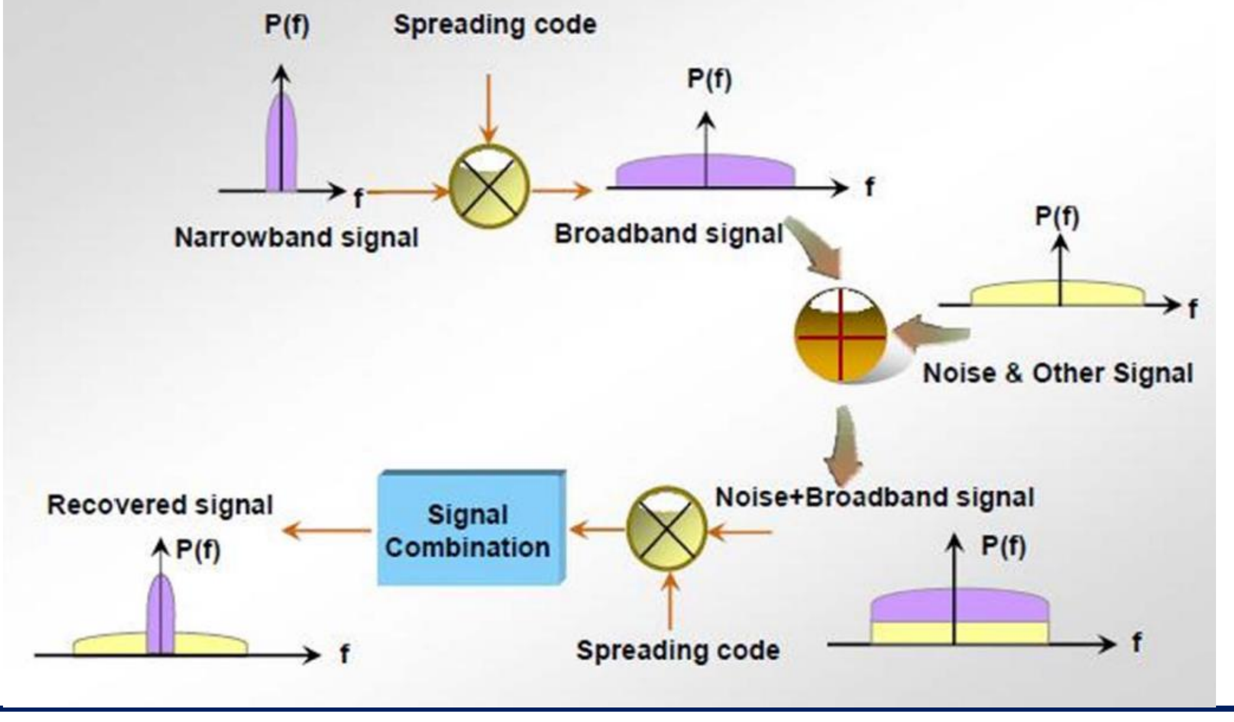
Spread Spectrum Modulation

- How do we do demodulation for DSSS?
  - The same PN spreading code is used in the receiver to de-spread the received signal



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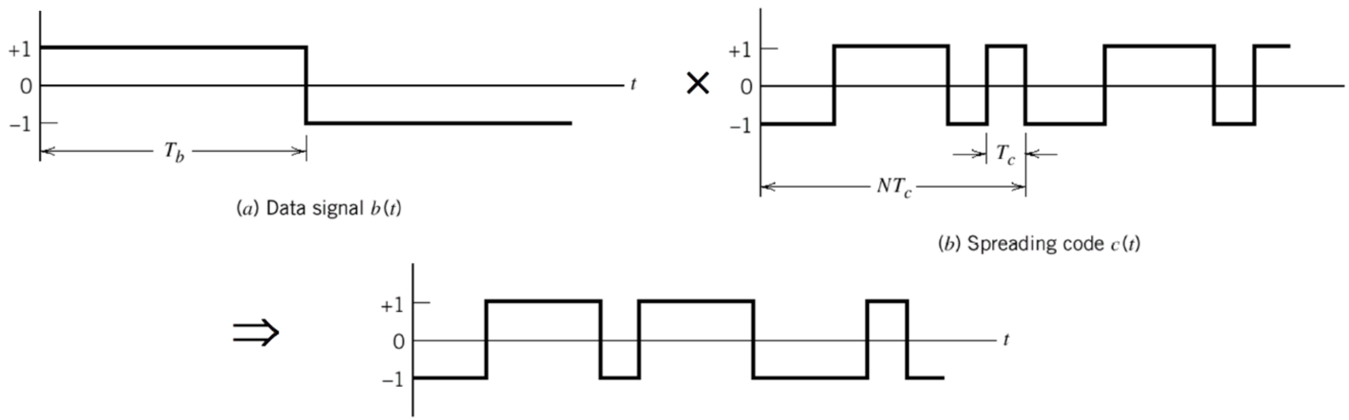
Spread Spectrum Modulation

- Denote the transmit DSSS signal by $m(t) = c(t) \otimes b(t)$
  - $c(t)$ stands for the wideband PN signal
  - $b(t)$ is the narrowband message signal



(a) Data signal $b(t)$

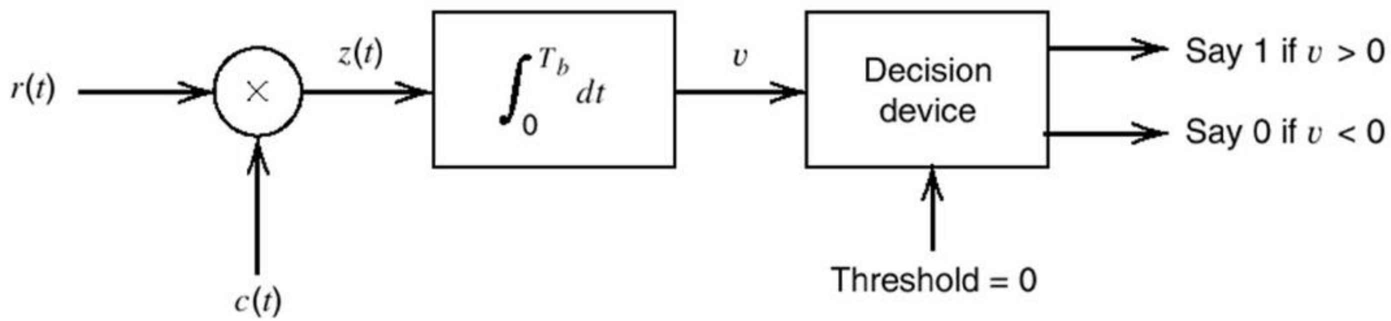
(b) Spreading code $c(t)$

(c) Product signal $m(t)$

- The received signal is $r(t) = m(t) + i(t) = c(t) \otimes b(t) + i(t)$
  - $i(t)$ is an additive interference

Spread Spectrum Modulation

- Suppose that the receiver operates in perfect synchronism with the transmitter
- The multiplier output $z(t) = c(t) \otimes r(t) = c^2(t)b(t) + c(t)i(t)$



  - Since $c^2(t) = 1$, we have $z(t) = b(t) + c(t)i(t)$
  - The spreading code $c(t)$ will affect the interference $i(t)$ just as it did to the original signal $b(t)$
- Applying $z(t)$ to a low-pass filter with a BW just large enough to accommodate $b(t)$, most of $c(t)i(t)$ is filtered out
- The low-pass filter action is performed by the integrator

DSSS (Direct-Sequence Spread Spectrum)

- In DSSS, the message signal is modulated with a bit sequence known as the Pseudo Noise (PN) code
- This PN code consists of pulses of a much shorter duration (larger bandwidth) than the pulse duration of the message signal
- Thus the modulation by the message signal has the effect of chopping up the pulses of the message signal and thereby resulting in a signal which has a bandwidth nearly as large as that of the PN sequence

FHSS (Frequency Hopping Spread Spectrum)

- FHSS transmits radio signals by rapidly switching a carrier among many frequency channels, using a pseudorandom sequence known to both transmitter and receiver
- Fast hopping: multiple hops per data bit
- Slow hopping: multiple data bits per hop
- Multiple simultaneous transmission from several users is possible
- Collision is possible

SDMA (Space Division Multiple Access)

- Need smart antennas
- BSs equip multiple antennas

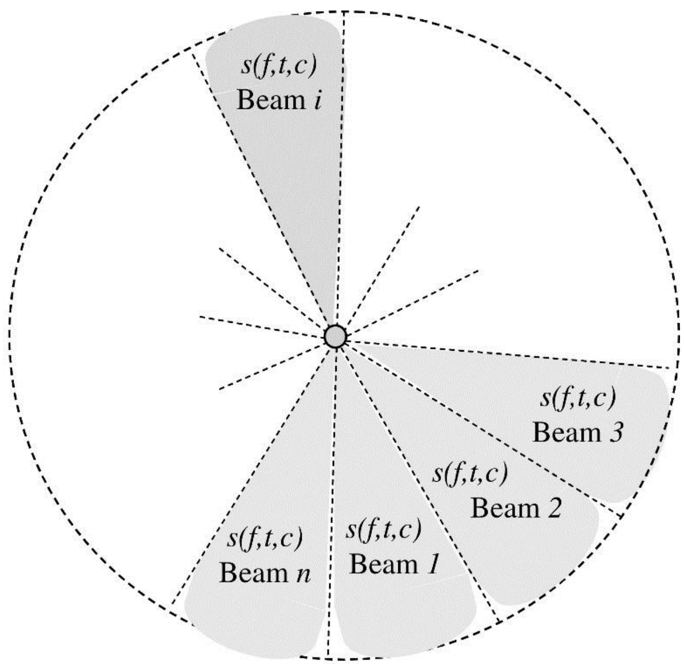


Figure 7.23 The concept of SDMA.

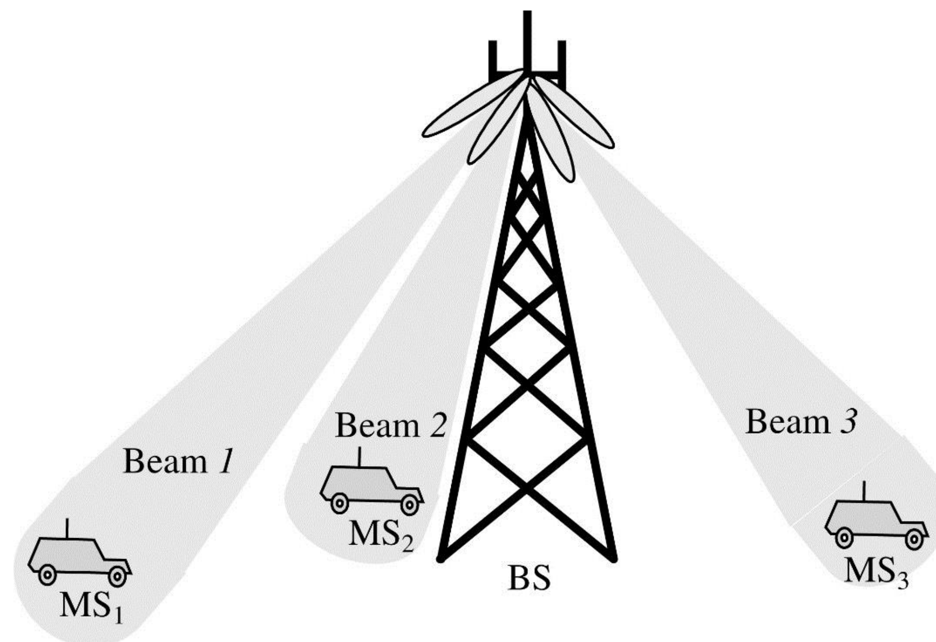


Figure 7.24 The basic structure of a SDMA system.

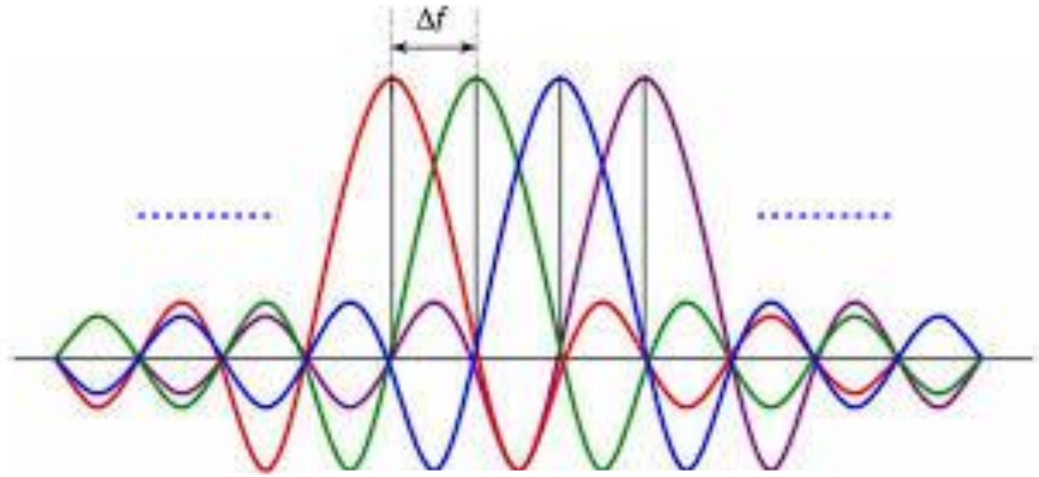
OFDM (1/3)

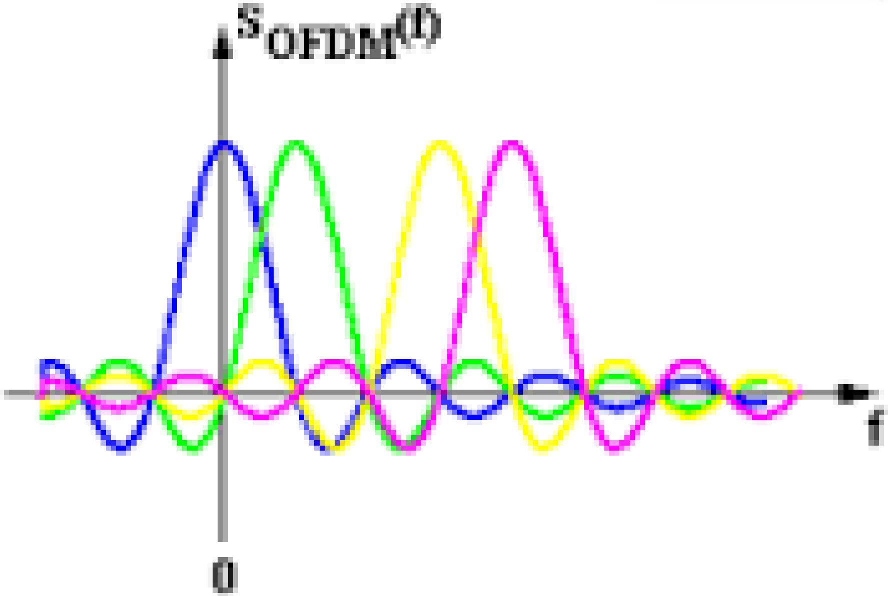
- OFDM = Orthogonal Frequency Division Multiplexing
- A digital multi-carrier modulation method
- A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels
- Each sub-carrier is modulated with a conventional modulation scheme (such as QAM or PSK) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth

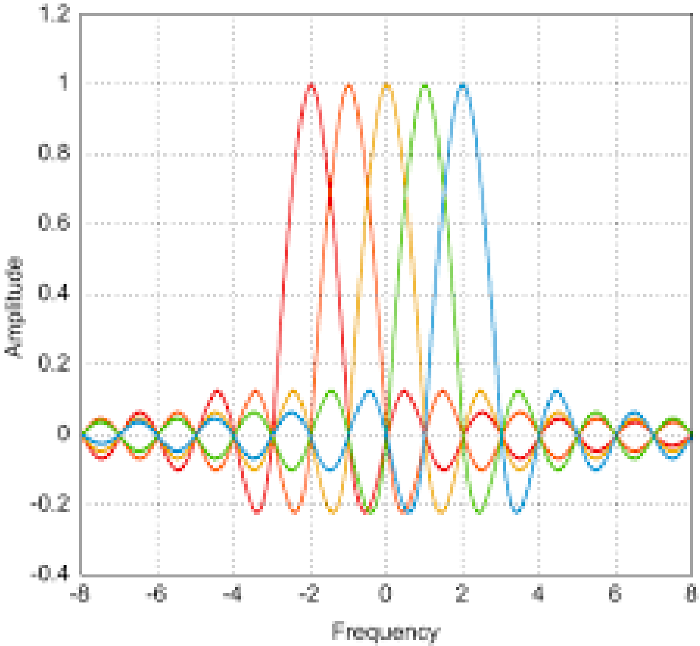
OFDM (2/3)

- The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions
- The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to eliminate ISI

OFDM (3/3)


Δf

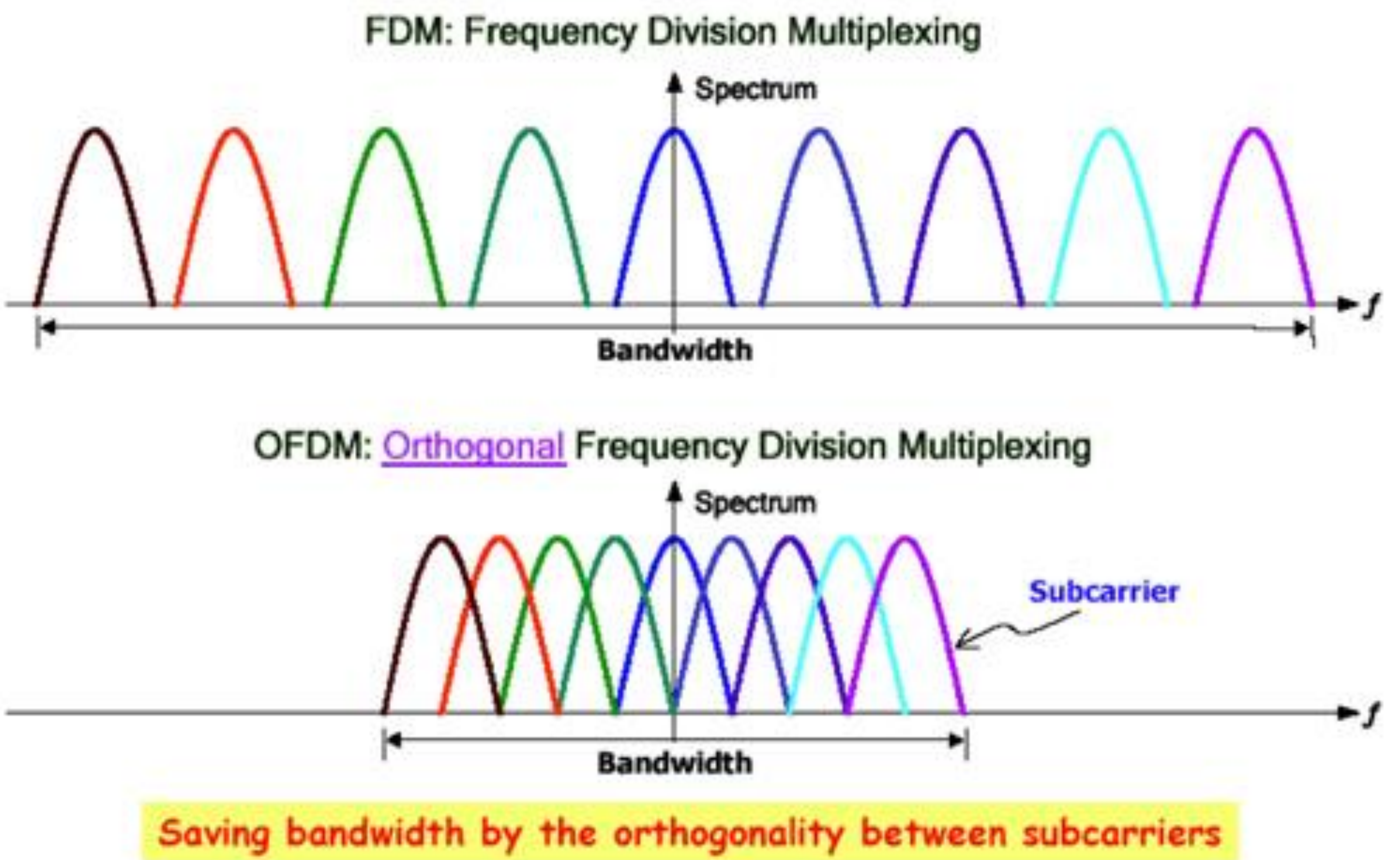

$S_{OFDM}(f)$
f
0


Amplitude
Frequency
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-8
-6
-4
-2
0
2
4
6
8

OFDMA

- Multi-user version of the OFDM digital modulation scheme
- Assigning subsets of subcarriers to individual users to allow simultaneous low data rate transmission from several users

Difference between FDM & OFDM (1/2)



Difference between FDM & OFDM (2/2)