Chapter 7

Multiple Division Techniques

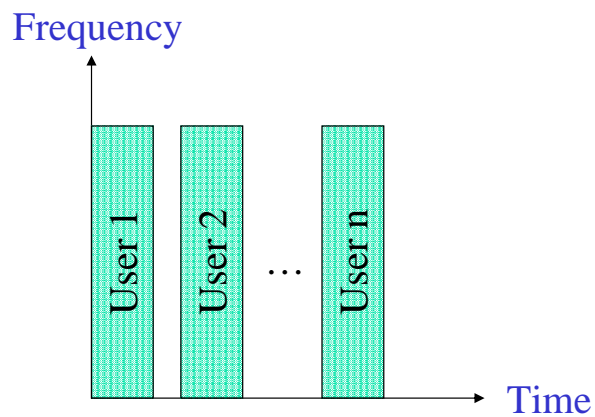# Outline

Frequency Division Multiple Access (FDMA)

Frequency

User n

⋮

User 2

User 1
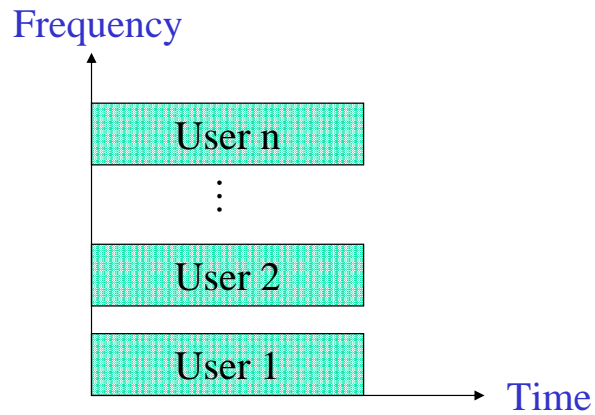
Time

- Single channel per carrier

- All first generation systems use FDMA

Time Division Multiple Access (TDMA)

Frequency

User 1   User 2   …   User n

Time

- Multiple channels per carrier

- Most of second generation systems use TDMA

Code Division Multiple Access (CDMA)

Frequency

User n · · · User 2 User 1

Time
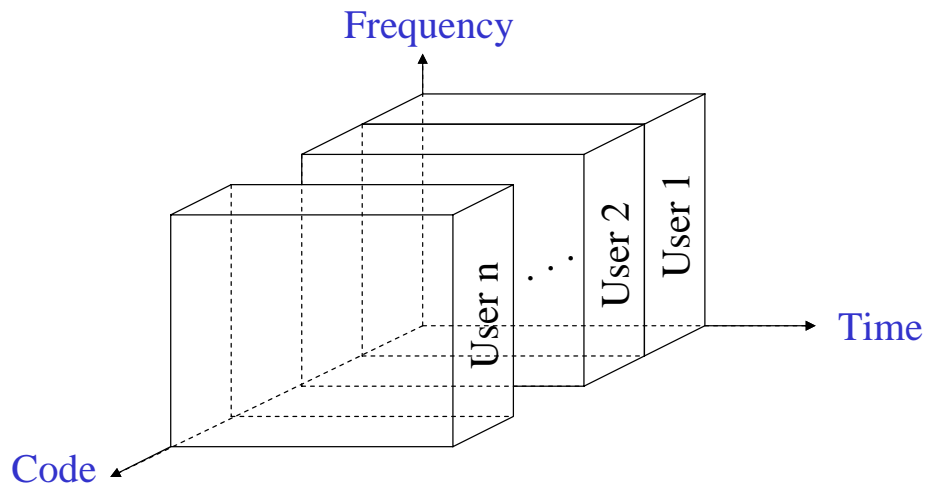
Code

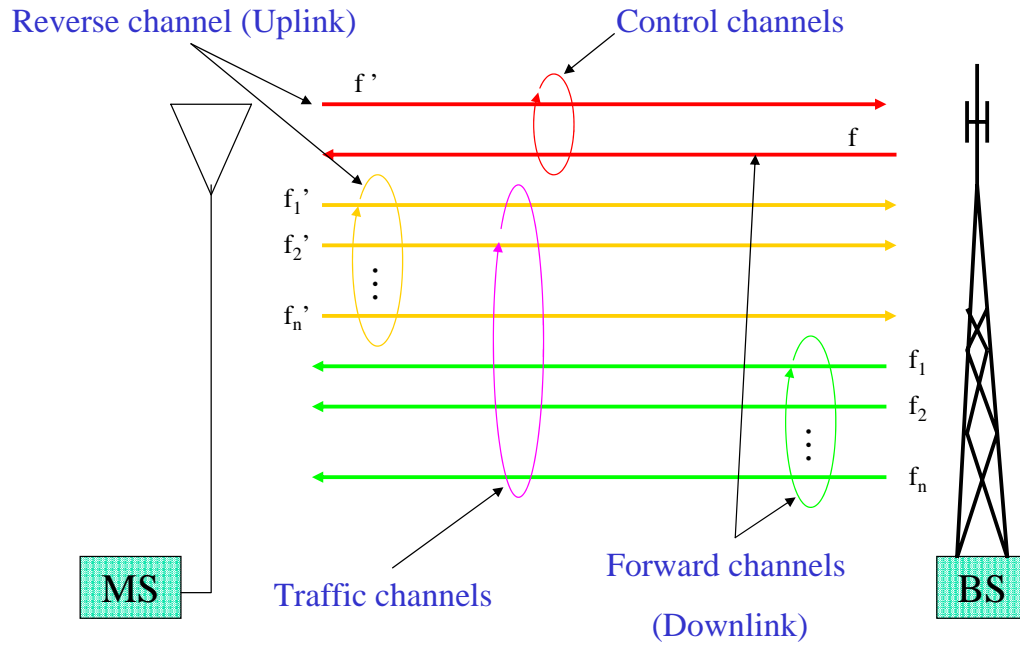- Users share bandwidth by using code sequences that are orthogonal to each other
- Some second generation systems use CDMA
- Most of third generation systems use CDMA

Types of Channels

- Control channel
  - Forward (Downlink) control channel
  - Reverse (Uplink) control channel
- Traffic channel
  - Forward traffic (traffic or information) channel
  - Reverse traffic (traffic or information) channel

Types of Channels (Cont'd)

Reverse channel (Uplink)

Control channels

f '

f

f$_1$'

f$_2$'

$\vdots$

f$_n$'

f$_1$

f$_2$

$\vdots$

f$_n$

MS

Traffic channels

Forward channels

(Downlink)

BS

FDMA

MS #1

MS #2

$\vdots$

MS #n

f$_1$'

f$_2$'

$\vdots$

f$_n$'

f$_1$

f$_2$

$\vdots$

f$_n$

BS

Reverse channels

(Uplink)

Forward channels

(Downlink)

FDMA: Channel Structure

Guard Band W$_g$　　Sub Band W$_c$

| 1 | | 2 | 3 | 4 | ··· | N |

Frequency

Total Bandwidth W=NW$_c$

f$_1$'　f$_2$'　　f$_n$'　　　　f$_1$　f$_2$　　f$_n$

··· 　　　　　　···

Frequency

Reverse channels　　　　　　Forward channels

Protecting bandwidth

TDMA

Frequency f '　　**Slot**　　　　　　　　　　　　**Frequency f**

MS #1

#1　···　#1　···　···　→ t

MS #2

#2　···　#2　···　···　→ t

⋮

MS #n

···　#n　　···　#n　···　→ t

t ←　···　#1　···　#1

t ←　···　#2　···　#2

t ←　#n　···　#n　···

Frame　Frame　　　　　Frame　Frame

Reverse channels　　　　　　Forward channels

(Uplink)　　　　　　　(Downlink)
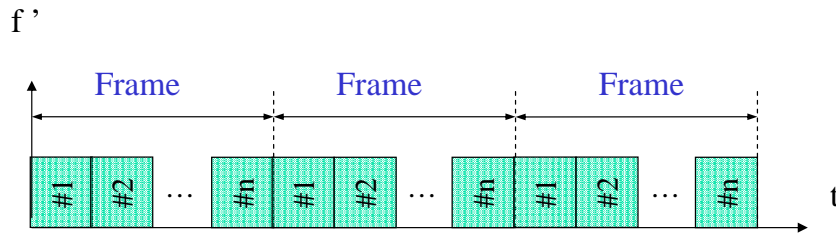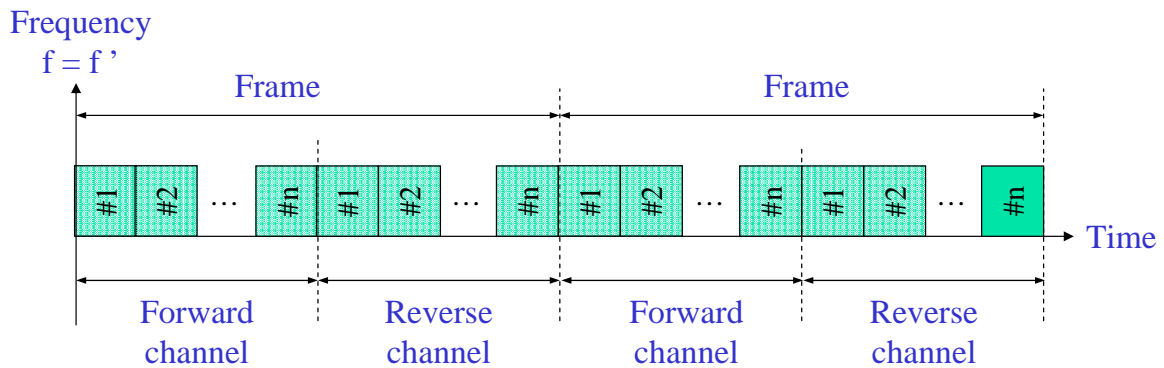
BS

TDMA: Channel Structure

(a). Forward channel

(b). Reverse channel

TDMA: Frame Structure (Cont'd)

Channels in Simplex Mode

TDMA: Frame Structure (Cont'd)

Frequency

Frame   Frame   Frame

#1 #2 ... #n #1 #2 ... #n #1 #2 ... #n

Time

Guard time   Head   Data

Code Division Multiple Access (CDMA)

Frequency f '   Frequency f

MS #1 C_1' C_1

MS #2 C_2' C_2

MS #n C_n' C_n

BS

Reverse channels   Forward channels

(Uplink)   (Downlink)
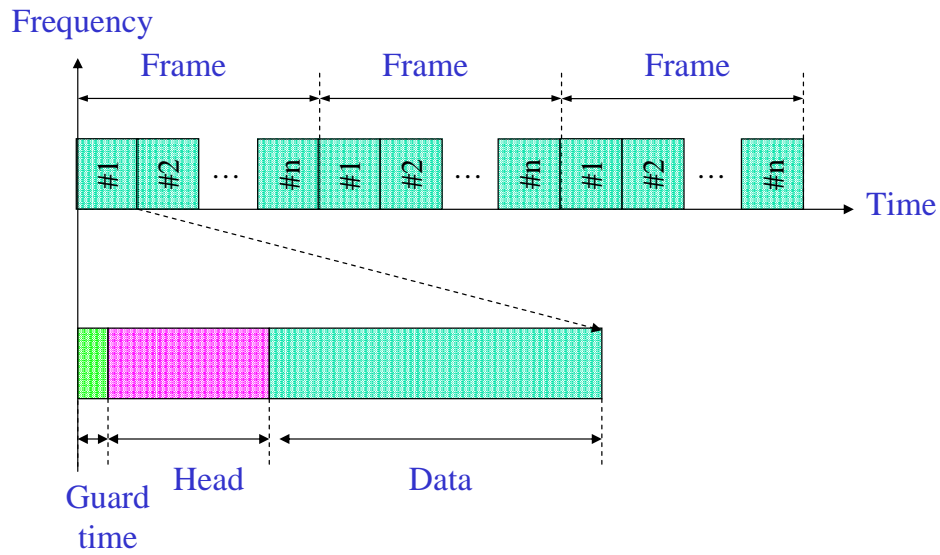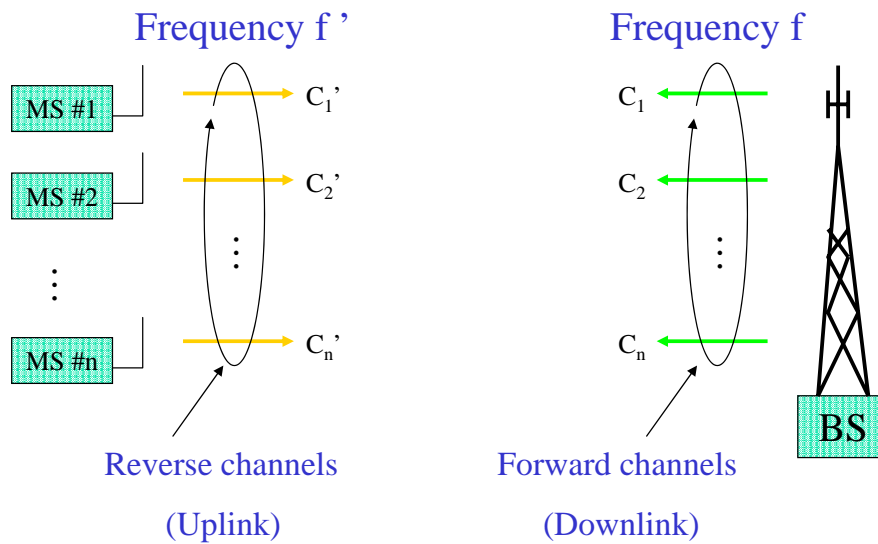
Note: C_i' x C_j' = 0, i.e., C_i' and C_j' are orthogonal codes,
      C_i x C_j = 0, i.e., C_i and C_j are orthogonal codes

Comparisons of FDMA, TDMA, and CDMA
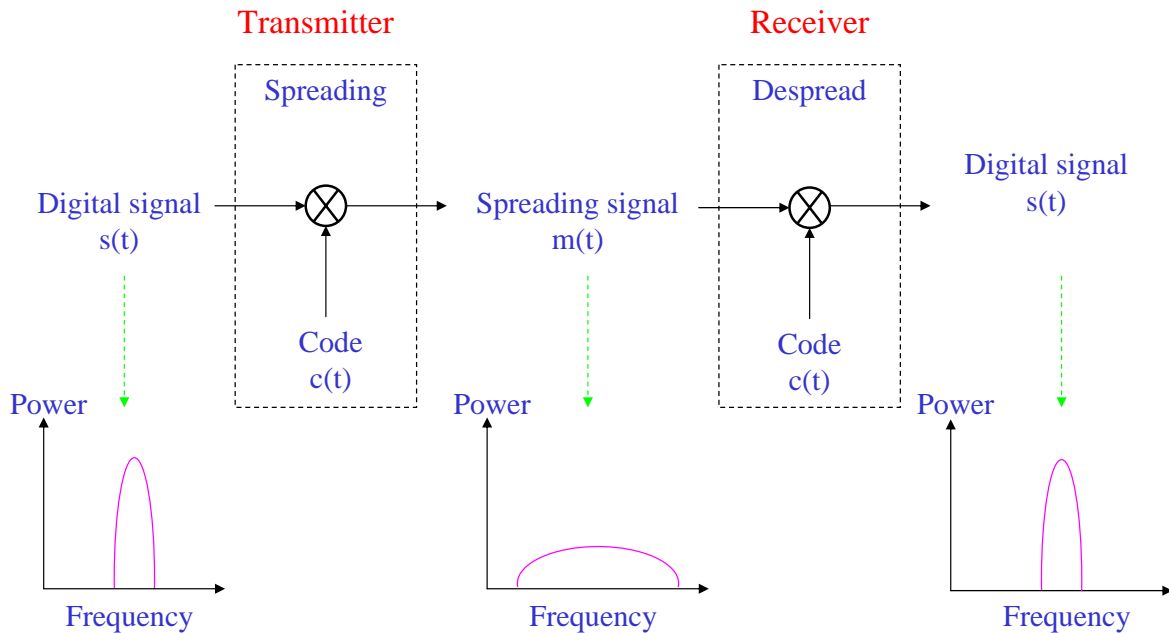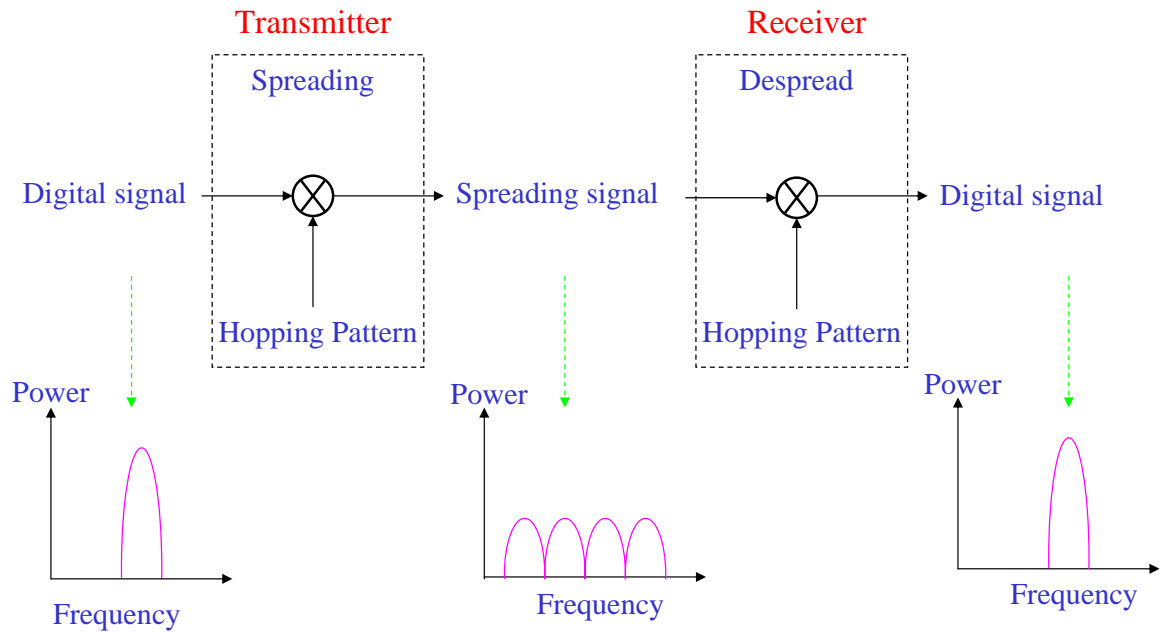## (Example)

Operation	FDMA	TDMA	CDMA
Allocated Bandwidth	12.5 MHz	12.5 MHz	12.5 MHz
Frequency reuse	7	7	1
Required channel BW	0.03 MHz	0.03 MHz	1.25 MHz
No. of RF channels	12.5/0.03=416	12.5/0.03=416	12.5/1.25=10
Channels/cell	416/7=59	416/7=59	12.5/1.25=10
Control channels/cell	2	2	2
Usable channels/cell	57	57	8
Calls per RF channel	1	4*	40**
Voice channels/cell	57x1=57	57x4=228	8x40=320
Sectors/cell	3	3	3
Voice calls/sector	57/3=19	228/3=76	320
Capacity vs FDMA	1	4	16.8
Delay	?	?	?

* Depends on the number of slots   ** Depends on the number of codes

Direct Sequence Spread Spectrum for CDMA

Concept of Frequency Hopping Spread Spectrum

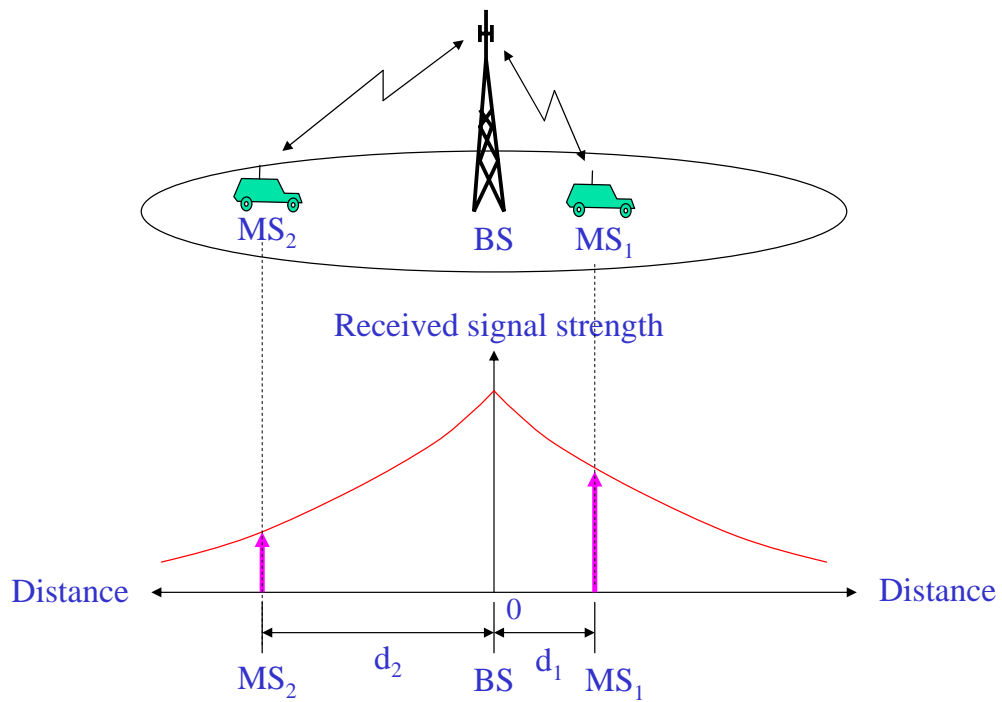Transmitter

Receiver

Spreading

Despread

Digital signal → ⊗ → Spreading signal → ⊗ → Digital signal

Hopping Pattern

Hopping Pattern

Power

Frequency

Power

Frequency

Power

Frequency

An Example of Frequency Hopping Pattern

Frequency

Time
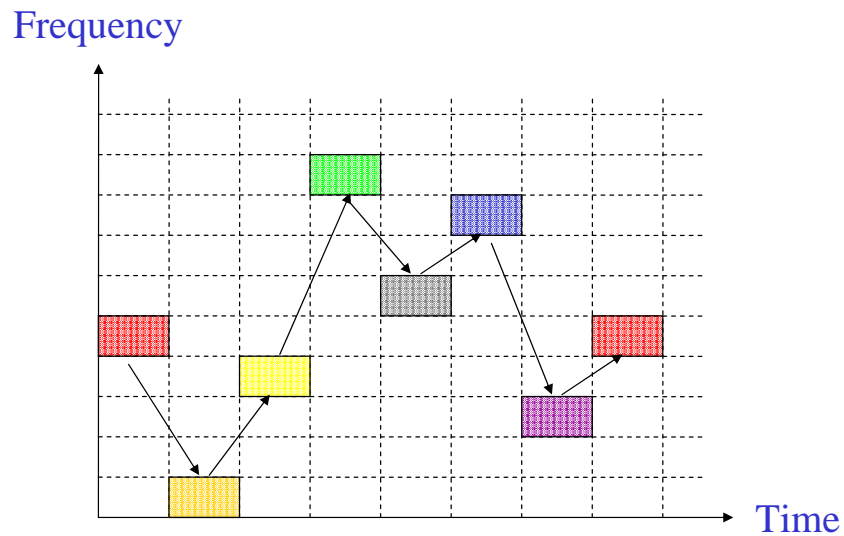
Walsh Codes (Orthogonal Codes)

Wal (0, t)　　　　　　　　　　　　　　t

Wal (1, t)　　　　　　　　　　　　　　t

Wal (2, t)　　　　　　　　　　　　　　t

Wal (3, t)　　　　　　　　　　　　　　t

Wal (4, t)　　　　　　　　　　　　　　t

Wal (5, t)　　　　　　　　　　　　　　t

Wal (6, t)　　　　　　　　　　　　　　t

Wal (7, t)　　　　　　　　　　　　　　t

Near-far Problem

MS_2　　　　BS　　MS_1

Received signal strength

Distance　　　　　　　　　　　　　　Distance

0

MS_2　　d_2　　BS　d_1　MS_1
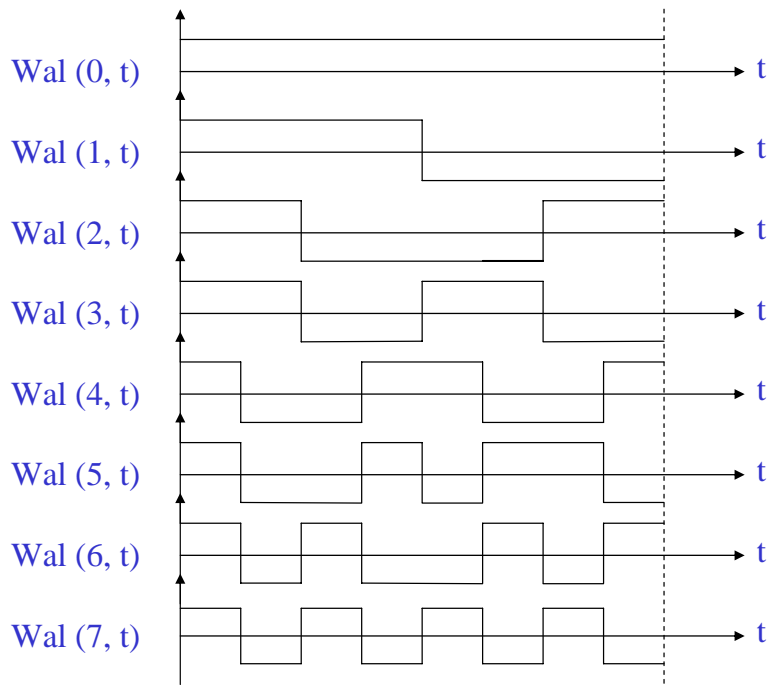
Types of Interference in CDMA

Interference baseband signals

Baseband signal

Spreading signal

Despread signal

Interference signals

Frequency

Frequency

Frequency
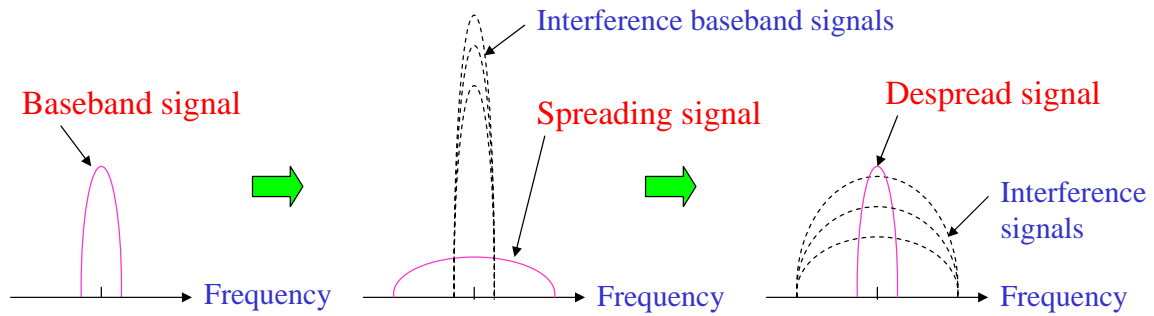
Interference in spread spectrum system in CDMA

Adjacent Channel Interference in CDMA

$Channel_1$

$Channel_2$

Power

Frequency

f_1

f_2
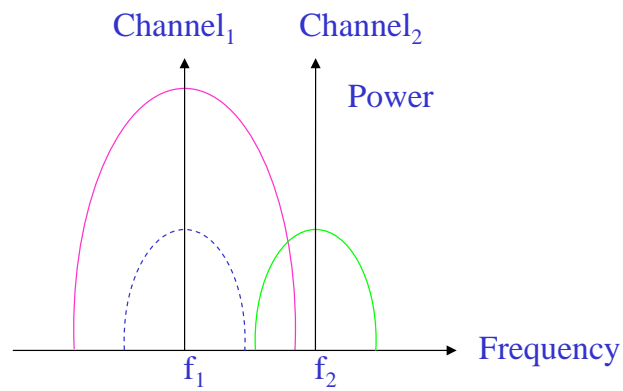
Power Control in CDMA

Controlling transmitted power affects the CIR

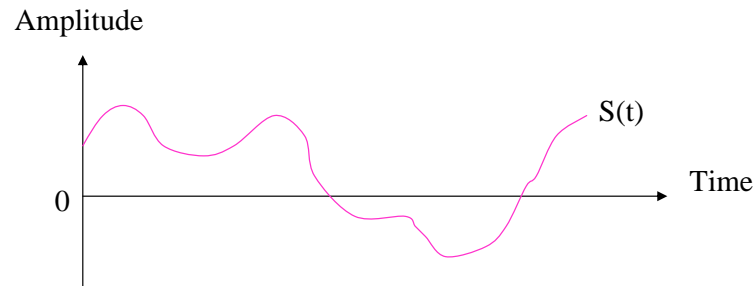$$\frac{P_r}{P_t} = \frac{1}{\left(\dfrac{4\pi df}{c}\right)^{\alpha}}$$

$P_t =$ Transmitted power
$P_r =$ Received power in free space
$d \ =$ Distance between receiver and transmitter
$f \ =$ Frequency of transmission
$c \ =$ Speed of light
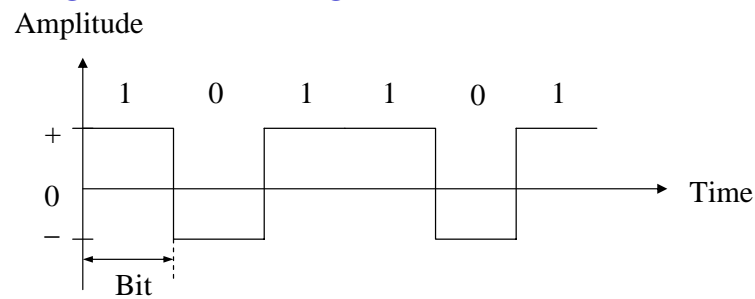$\alpha =$ Attenuation constant (2 to 4)

Modulation

- Why need modulation?
  - Small antenna size

    Antenna size is inversely proportional to frequency

    e.g., 3 kHz → 50 *km* antenna

          3 GHz → 5 *cm* antenna
  - Limits noise and interference,
    e.g., FM (Frequency Modulation)
  - Multiplexing techniques,
    e.g., FDM, TDM, CDMA
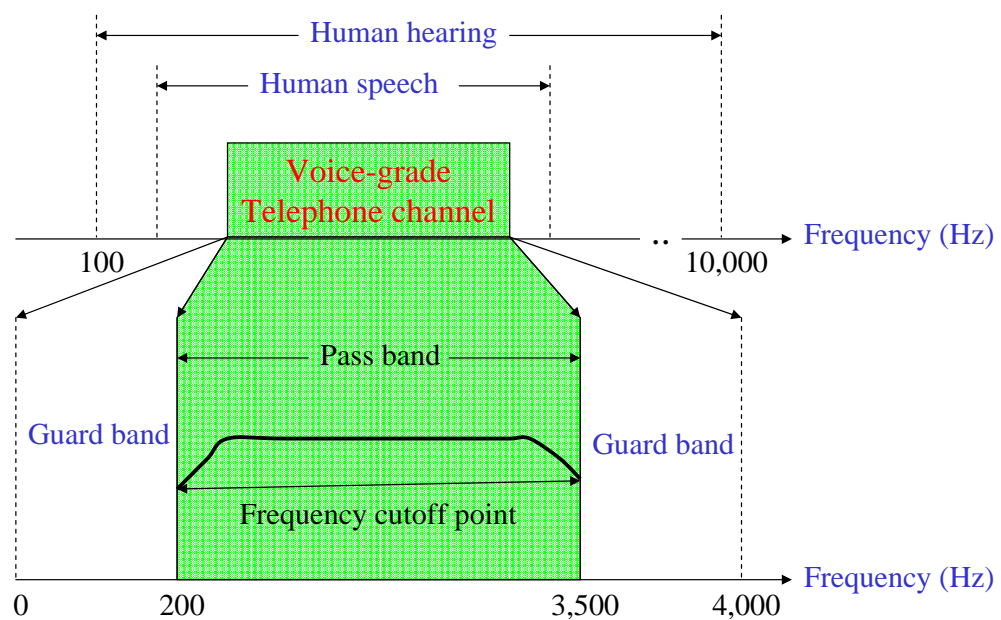
Analog and Digital Signals

- Analog Signal (Continuous signal)

Amplitude

S(t)

0

Time

- Digital Signal (Discrete signal)

Amplitude

1   0   1   1   0   1

+

0

Time

−

Bit

Hearing, Speech, and Voice-band Channels

Human hearing

Human speech

Voice-grade
Telephone channel

100

..

10,000

Frequency (Hz)

Pass band

Guard band

Guard band

Frequency cutoff point

0

200

3,500

4,000

Frequency (Hz)

Amplitude Modulation (AM)

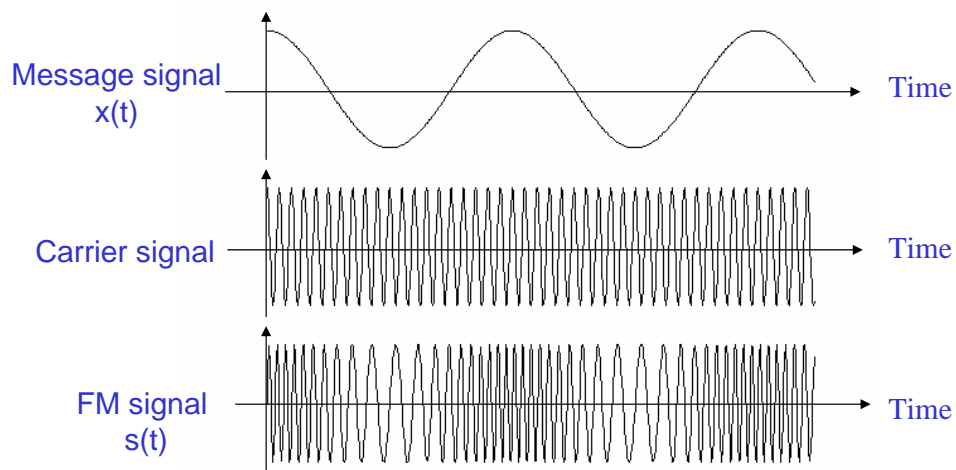Message signal
x(t) — Time

Carrier signal — Time
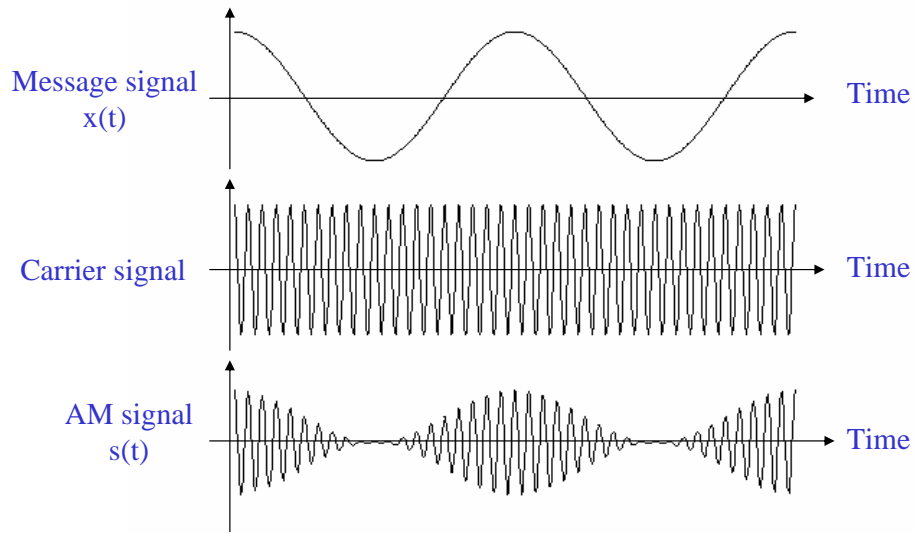
AM signal
s(t) — Time

Amplitude of carrier signal is varied as the message signal to be transmitted.

Frequency of carrier signal is kept constant.

Frequency Modulation (FM)
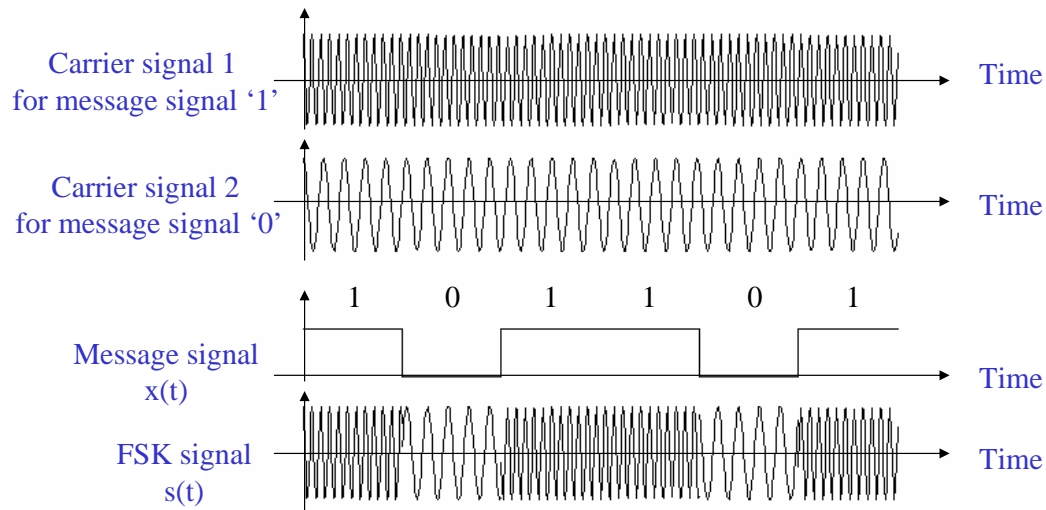
Message signal
x(t) — Time

Carrier signal — Time

FM signal
s(t) — Time

FM integrates message signal with carrier signal by varying the instantaneous frequency. Amplitude of carrier signal is kept constant.

Frequency Shift Keying (FSK)

• 1/0 represented by two different frequencies slightly offset from carrier frequency
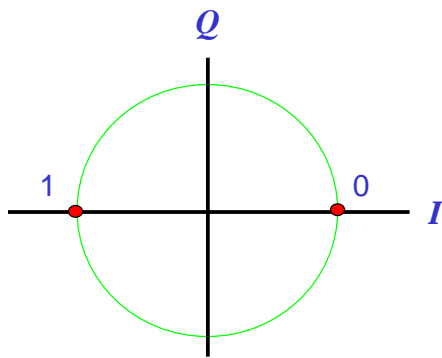
Carrier signal 1
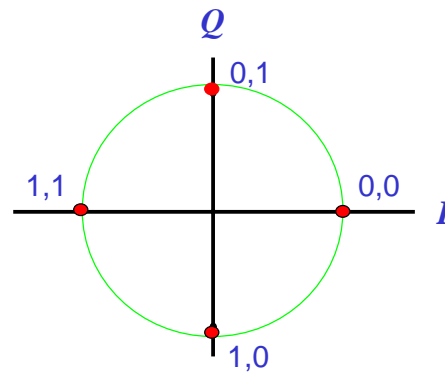for message signal '1'   Time

Carrier signal 2
for message signal '0'   Time

    1   0   1   1   0   1

Message signal
x(t)   Time

FSK signal
s(t)   Time

Phase Shift Keying (PSK)

• Use alternative sine wave phase to encode bits

Carrier signal
$\sin(2\pi f_c t)$ Time

Carrier signal
$\sin(2\pi f_c t + \pi)$ Time

    1   0   1   1   0   1

Message signal
x(t)   Time
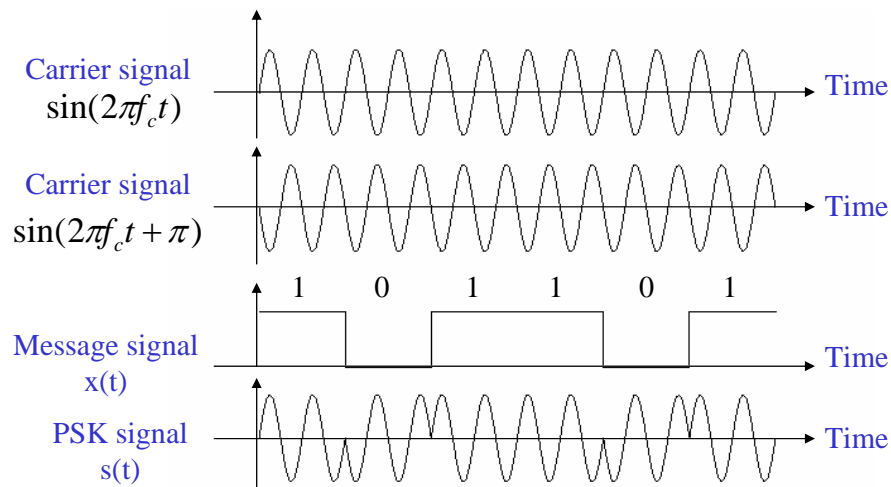
PSK signal
s(t)   Time
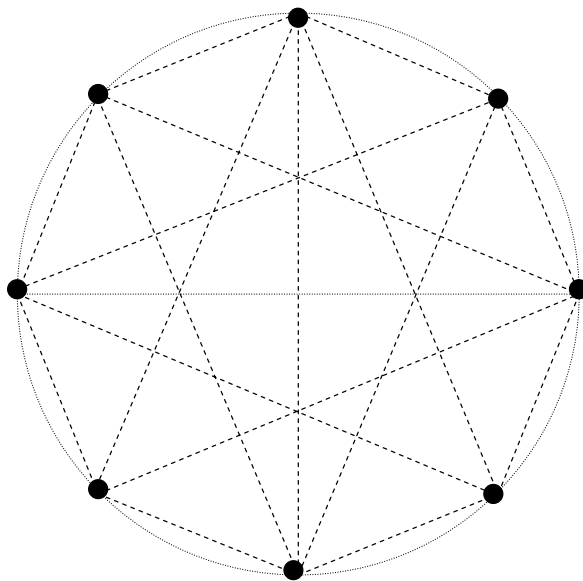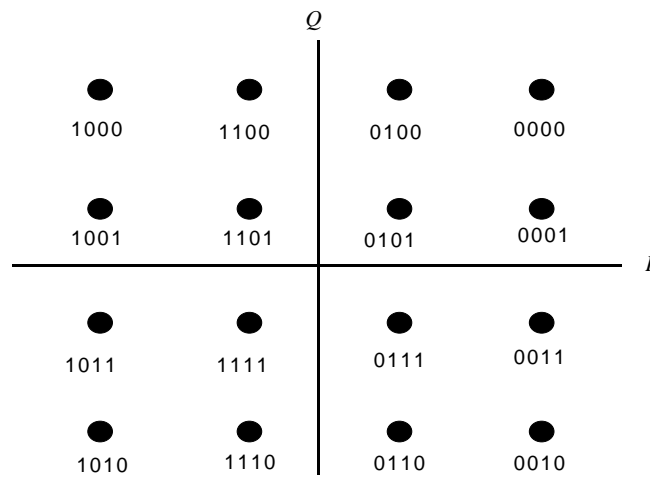
QPSK Signal Constellation

(a) BPSK

(b) QPSK

All Possible State Transitions in π/4 QPSK

Quadrature Amplitude Modulation (QAM)

Combination of AM and PSK

Two carriers out of phase by 90 deg are amplitude modulated

Rectangular constellation of 16QAM