Chapter 7
Multiple Division (Access) Techniques

Adapted from class notes by
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Most slides based on publisher’s slides for 1st and 2nd edition of:
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Outline

- 7.1. Introduction
- 7.2. Concept and Models for Multiple Access
  - 7.2.1. Frequency Division Multiple Access (FDMA)
  - 7.2.2. Time Division Multiple Access (TDMA)
  - 7.2.3. Code Division Multiple Access (CDMA)
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    - 2) Spread Spectrum
    - 3) Direct Sequence Spread Spectrum (DSSS)
    - 4) Frequency Hopping Spread Spectrum (HFSS)
    - 5) Walsh Codes
    - 6) Near-far Problem
    - 7) Power Control
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- 7.3. Modulation Techniques
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  - 7.3.4. PSK (Phase Shift Keying)
  - 7.3.5. QPSK (Quadrature Phase Shift Keying)
  - 7.3.6. π/4 QPSK
  - 7.3.7. QAM (Quadrature Amplitude Modulation)
  - 7.3.8. 16QAM
Multiple access

Multiple Access Medium

MS 1

MS 2

MS 3

MS 4

MS n

Classification of Multiple Access Protocols

Random access protocols – upon collision, retransmit after a random delay

Collision resolution protocols – upon collision, retransmit according to a more sophisticated method

Random access

Collision resolution

ALOHA

CSMA

BTMA, ISMA etc.

FDMA

TDMA

CDMA

Token Bus

DQDB etc.

ALOHA and CSMA protocols will be discussed in this section.
7.1. Introduction

- Large # of traffic channels on each BS
  - Bec. traffic channels used by 1 MS exclusively for call duration

- Small # of control channels on each BS
  - Bec. control channels shared by many MSs for short periods
    - Too expensive/inefficient to assign control channel for call duration

- MS gets a traffic channel assigned for call duration
  - Once assigned, no need to compete for access to traffic channels
Types of Channels (Cont’d)

- **Reverse channel (Uplink)**
- **Control channels**
  - $f_1' \rightarrow f \rightarrow f_2' \rightarrow \ldots \rightarrow f_n'$
- **Traffic channels**
- **Forward channels (Downlink)**
  - $f_1 \rightarrow f_2 \rightarrow \ldots \rightarrow f_n$

For **control channels** — we used **contention-based protocols**
- Many MS’s competing for the same control channel

For **traffic channels** — we use now **contention-free protocols**
- Dedicated channel for each MS (not shared with other MSs)
  - Allocated by BS
  - When “this” MS requests

- Allocated thanks to exchange of control messages over control channels using **contention-based protocols**
7.2. Concept and Models for Multiple Access (Multiple Division)

- **Q**: Why “multiple access”?
- **A**: Multiple MSs can share a radio channel (without interference)
  
  => we can have **multiple access** to the same channel

- **Multiple traffic channels used simultaneously**
  
  - MS attached to a transmitter/receiver
  - **Transmission** from any MS is received by all MSs within its radio range

  MS communicates with its BS via a **traffic channel**
  - **Dedicated** traffic channel not shared by other MSs

---

**MS** must **distinguish** its own traffic from any other traffic

- Ignore traffic from its **own BSs** to other MSs
- Ignore traffic from “foreign” BSs
- Ignore traffic from other MSs
  
  - Like a person picking up his conversation partner’s speech when many people have many independent conversations in a room
7.2. Concept and Models for Multiple Division – cont. 1

- Also BS must distinguish traffic from different MSs
- MS or BS can distinguish thanks to orthogonization (正交性) of signals on different traffic channels

![Diagram](image)

7.2. Concept and Models for Multiple Division – cont. 2

- **Duplex communications** = simultaneous 2-way communications (Full Duplex)
- **Duplex communications requires**
  - Forward (downlink) channel
  - Reverse (uplink) channel

![Diagram](image)

Page 19 (頁19) Fig. 1.20
Frequency Division Duplex (FDD)

UL band separated from DL band

Time Division Duplex (TDD)

UL band same as DL band
7.2.1. **Frequency Division Multiple Access (FDMA)**

- Separate (unique) carrier frequency per user
- All 1G (first-generation) systems use FDMA
FDMA

- 將每個通話分配上、下行各一個固定的頻帶

Basic Structure of a FDMA System (FDD)

- 1 BS and n MSs
- $f'_i$ and $f_i$ – for MS #i

p. 145 (頁164) Fig. 7.2
FDMA Channel Structure (FDD)

reverse channels
Reverse channels

Protecting bandwidth
Protecting bandwidth

forward channels
Forward channels

Subband \( W_c \)
Subband \( W_c \)

Guard Band \( W_g \)
Guard Band \( W_g \)

Total bandwidth \( W = N \ast W_c \)
Total bandwidth \( W = N \ast W_c \)

(for reverse channels or for forward channels)
(for reverse channels or for forward channels)

p. 146 (頁164) Fig. 7.3 & 7.4
p. 146 (頁164) Fig. 7.3 & 7.4

\( f_i \)
\( f_i \)

\( f_{i+1} \)
\( f_{i+1} \)

p. 156 (頁174) Fig. 7.20(a)

p. 156 (頁174) Fig. 7.20(a)
7.2.2. **Time Division Multiple Access (TDMA)**

- Separate (unique) *time slot* per user
  - The same carrier (frequency) split into *time slots*
  - Each frequency efficiently utilized by *multiple users*
- Most of 2G systems use **TDMA**

**TDMA (GSM)**

- 為將頻譜更有效率的利用
- 一個Frame分割成8個*Time Slots*, 可分配給不同使用者
- 固定位置重複出現的Time Slot構成一個Physical Channel
- 毎一載波頻率最多有8 physical channels

**Fig. 7.5**

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>0</th>
</tr>
</thead>
</table>

200kHz

Frame (4.615ms)

Source: 本頁，無線傳訊網絡概論  文魁
TDMA(一般性)

- TDMA Frame與Physical Channel
- 接收與發射端須做到精確的同步(Synchronization)

GSM以TDMA及FDMA將頻譜切割成許多載波與TDMA Frame

(FDD)
Basic Structure of TDMA

Reverse channels (Uplink)  (FDD)  Forward channels (Downlink)

a) Channel Structure in TDMA/FDD System

(a) All forward channels on frequency $f$

(a) All reverse channels on different frequency $f'$
b) Channel Structure in TDMA/TDD System

對稱性 TDD

(a) All forward and all reverse channels on the same frequency $f$

(1st half of each frame used for forward channels, 2nd half – for reverse channels)

p. 148 (頁166) Fig. 7.8

TDMA Frame Structure

Notice Guard time between Time slots
- Minimize interference due to propagation delays

p. 148 (頁167) Fig. 7.9
7.2.3. Code Division Multiple Access (CDMA)

Outline:
1) Introduction to CDMA
2) Spread Spectrum
3) Direct Sequence Spread Spectrum (DSSS)
4) Frequency Hopping Spread Spectrum (FHSS)
5) Walsh Codes
6) Near-far Problem
7) Power Control

CDMA

不同手機傳送無線訊號賦予不同的特別編碼，經接收後再予以解碼還原的多重存取方法
所有手機可使用相同頻帶(展頻之特性)
展頻: Spread Spectrum
7.2.3. Code Division Multiple Access (CDMA) – cont.

1) Introduction

- Separate (unique) code per user
- Code sequences are orthogonal
  => different users can use same frequency simultaneously (see Fig above)
- Some 2G systems use CDMA / Most of 3G systems use CDMA

Do not confuse CDMA (conflict-free) with CSMA (contention-based)
CSMA = carrier sense multiple access

Structure of a CDMA System (with FDD)

Frequency $f'$

- Reverse channels (Uplink)
- $C_1'$, $C_2'$, ..., $C_n'$

Frequency $f$

- Forward channels (Downlink)
- $C_1$, $C_2$, ..., $C_n$

Notes:
1) FDD (frequency division duplex) since $f$ for all forward channels, and $f'$ for all reverse channels
2) $C_i = i$-the code
3) $C_i' \times C_j' = 0$, i.e., $C_i'$ and $C_j'$ are orthogonal codes on $f'$
   $C_i \times C_j = 0$, i.e., $C_i$ and $C_j$ are orthogonal codes on $f$
Two Implementation Methodologies for CDMA

- Two implementation methodologies for CDMA
  
a) DS = direct sequence
     - next slide
  
b) FH = frequency hopping
     - same frequency for all forward and all reverse channels

2) Spread Spectrum for CDMA

- Concept of spread spectrum:
  - Pseudorandom sequence $c(t)$ phase-modulates data-modulated carrier of $s(t)$, producing $m(t)$
  - $m(t)$ occupies broader bandwidth and has lower peak power than $s(t)$

  where:
  - $s(t)$ - original signal / $m(t)$ – xmitted signal derived fr. $s(t)$ by spreading
  - $c(t)$ – code signal (a parameter for spreading)

- Results in better resistance to interference

p. 150 (頁169)
Fig. 7.12
直接序列展頻

將窄頻寬、高能量的位元訊號與展頻碼做運算，將原本訊號延展為數倍頻寬，並將訊號能量降低，再把訊號傳送出去：

![Diagram of Direct Sequence Spread Spectrum](image)

直序展頻

**Direct Sequence Spread Spectrum**

若取平均值 → 完美的 1 和 0

<table>
<thead>
<tr>
<th>Code</th>
<th>Message “1101”</th>
</tr>
</thead>
<tbody>
<tr>
<td>100101</td>
<td>+1 -1 +1 +1</td>
</tr>
<tr>
<td>+1 +1 -1 +1</td>
<td>User A</td>
</tr>
<tr>
<td>Chip sequence</td>
<td>111111 111111 000000 111111</td>
</tr>
</tbody>
</table>

Encoded bit stream: 100101 100101 011010 100101
直接序列展頻

- 將窄頻寬、高能量的位元訊號與展頻碼做運算，將原本訊號展延為數倍頻寬，並將訊號能量降低，再把訊號傳送出去：

接收端收到訊號後，會用同樣的展頻碼再做一次運算，將訊號還原成所需的資料：

![展頻和解展頻的圖示](image-url)
3) Direct Sequence Spread Spectrum

- Concept of DSSS for CDMA
- Pseudorandom sequence $c(t)$ phase-modulates data-modulated carrier of $s(t)$, producing $m(t)$
  - $m(t)$ occupies broader bandwidth & has lower peak power than $s(t)$

---

直序展頻

Direct Sequence Spread Spectrum

<table>
<thead>
<tr>
<th>Chip sequence</th>
<th>Code</th>
<th>bit</th>
<th>Message “1101” Encoded</th>
</tr>
</thead>
<tbody>
<tr>
<td>User A</td>
<td>+1</td>
<td>1</td>
<td>101101</td>
</tr>
<tr>
<td>User B</td>
<td>-1</td>
<td>1</td>
<td>101101 101010 101101</td>
</tr>
<tr>
<td>User C</td>
<td>-1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Source: 吳銘華, 無線通信網路概論, 信友
5) Walsh Codes

- Each user in CDMA assigned ≥ 1 orthogonal waveforms derived from 1 orthogonal code
- Walsh Codes are an important set of orthogonal codes

p. 153 (頁171)
Fig. 7.16
Correlation (cont.)

Orthogonal property:

Cross-correlation:
To multiply any other orthogonal code and apply summation will yield zero.

Auto-correlation:
Multiplying by code-self and Σ will yield maximum value.

CDMA (cont.)

Ideal code group, but according to the Welch bound … Because time shift will destroy the orthogonal properties!
CDMA (cont.)

Practical auto-correlation

Practical cross-correlation

In a well performed Power Control

Adjacent Channel Interference in Spread Spectrum System in CDMA

- Adjacent channel interference can be especially serious when spread spectrum technique used
- Simple solution: power control (next slide)

p. 154 (頁173) Fig. 7.19
6) Near-far Problem

Assume 1:
- Transmission power of MS1 = transmission power of MS2
  =>
- RSS of MS1 at BS > RSS of MS2 at BS

Assume 2:
- MS1 & MS2 use adjacent channels
  =>
- Out-of-band radiation of MS1's signal interferes with MS2's signal in the adjacent channel (cf. next slide)

Adjacent Channel Interference in CDMA

- Adjacent channel interference can be serious
  => must keep out-of-band radiation small
### 7) Power Control in CDMA

Two alternatives:

a) Control transmit power $P_t$ of MS2 (調高)

$\Rightarrow$ received power $P_r$ of adjacent channel interference from MS2

is controlled

$\Rightarrow$ CCIR is controlled

(CCIR = cochannel interference ratio)

OR:

b) Control transmit power $P_t$ of MS1 (降低)

$\Rightarrow$ received power $P_r$ of MS1 is controlled (kept strong enough)
### 7.2.6. Comparisons of FDMA, TDMA, and CDMA (Example) p. 158 (頁177) Table 7.1

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

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

### Multiple Access Classification

- **FDMA (分頻)**
  - e.g. AMPS
  - 30KHz
  - 1G
  - 1G
- **TDMA (分頻分時)**
  - e.g. GSM
  - 200KHz
  - 2G
- **CDMA (分頻分碼)**
  - e.g. IS-95
  - 1.25MHz
  - 2G
  - Cdma2000: 3.75MHz (美)
  - WCDMA: 5MHz (歐日)

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3G WCDMA (cont.)

ITU 3G Approvals

cdma2000:
3.75MHz (US)

WCDMA:
(Europe, Japan)
5MHz (TDD)
10MHz (FDD)

TD-SCDMA:
1.6MHz (China)

4) Frequency Hopping Spread Spectrum

- **Concept of FHSS for CDMA**
  - Pseudo random *hopping pattern* sequence changes freq. of digital radio signal across broad freq. band in random way
    - Radio *xmitter* freq. hops fr. channel to channel in predetermined pseudorandom way *(cf. next slide)*
    - \( m(t) \) occupies broader bandwidth & has lower peak power than \( s(t) \)

---

**Fig. 7.14**

- Transmitter **Spreading**
  - Original digital signal
  - Power
  - Frequency
  - Hopping pattern

- Receiver **Despreading**
  - Xmit spread signal
  - Power
  - Frequency
  - Hopping pattern

- Recreated (“dehopped”) digital signal
  - Power
  - Frequency

---

- p.151(頁170)
- Fig. 7.14

---

- Normal Slots
  - Per Frame

---

**TDD/CDMA** *(分頻分時分碼)*

- e.g. TD-SCDMA
  - 1.6MHz *(中國)*
  - 3G

To achieve the optimum performance
An Example of Frequency Hopping Pattern

FHSS

p. 152 (頁171) Fig. 7.15

e.g., Bluetooth

Wii 的設計

By 中興大學物理學系 紀凱容
http://www.nintendo.tw
（羅炫嘉&蔡余慶&彭健倫製作）
Multiple Access Classification

FDMA (分頻)
e.g. AMPS
30KHz
1G

TDMA (分頻分時)
e.g. GSM
200KHz
2G

CDMA (分頻分碼)
e.g. IS-95
1.25MHz
2G

Cdma2000: 3.75MHz (美)
WCDMA: 5MHz (歐日)

7.2.4. OFDM

OFDMA Resource Management

Mobile Station

Base Station

4G LTE

Variable rate for multimedia transmission
(E.g., OFDM subcarriers)

Picture source: Compaq
電磁波頻譜資源有限，如何提升利用率？

這個方法如何？
OFDMA divides each carrier to several subcarriers.

(a) Single OFDM subchannel

(b) An OFDM signal with multiple subchannels

*Figure 7.20* The frequency spectrum of an OFDM signal.
Recall: FDMA

Reverse channels

Guard Band $W_g$

Protecting bandwidth

Forward channels

Total bandwidth $W = N \cdot W_c$
(for reverse channels or for forward channels)

Time and Frequency Domain

a. Time domain

b. Frequency domain
Examples

Time domain

Frequency domain

a. 1 second

b. 1 second

c. 1 second

Frequency domain

Examples (cont.): Fast Fourier Transform (FFT)

Frequency domain

(QAM symbols in FD)

IFFT

FFT

Baseband signal

OFDMA (cont.): Fast Fourier Transform (FFT)
OFDMA (cont.)

Figure 3. The block structure of the 3G TDD uplink.
OFDMA (cont.)

- **High spectral efficiency:**
  - Time domain waveforms of the subcarriers are orthogonal; spectra overlap in frequency.

- **Robust to typical multipath fading channels:**
  - Minimizing the effects of multipath delay spread (by cyclic prefix).

- **High speeds:** e.g., 300 km/h.

- **Simple implementation:**
  - Using highly efficient DSP based on FFT.

- **Low receiver and multiple access complexity.**
- **Flexible to assign subcarriers to users.**
**LTE Resource Structure**

(One frame = 10 subframes)

Fig. 1. Basic time-frequency resource structure of LTE (normal cyclic prefix case) [2]

**LTE-A Resource Blocks**

7 symbols

12 subcarriers

One slot

Fig. 2. The LTE-Advanced UL physical resource blocks.
OFDM + MIMO (Multiple Input Multiple Output)

Figure 1. The system structure of B3G TDD.

MIMO (Multiple Input Multiple Output)

http://www.zdnet.com

https://www.mgraves.org/

www.techbang.com
7.2.5. **SDMA**

![Figure 7.23](image)  
*The concept of SDMA.*

![Figure 7.24](image)  
*The basic structure of a SDMA system.*
7.3. Modulation Techniques

- Why need modulation?
  - “Transferring” from signal freq. to carrier frequency allows to use small antenna size
  - Antenna size is inversely proportional to frequency
    - E.g., $3 \text{ kHz} \rightarrow 50 \text{ km}$ antenna ($=\lambda/2$, bec. $c = \lambda f$)
    $3 \text{ GHz} \rightarrow 5 \text{ cm}$ antenna
  - Limits noise and interference
    - E.g., FM (Frequency Modulation)
  - Spectrum license

For example, GSM

![Diagram of modulation process]

Source: [禹帆, 無線通訊網路概論, 文魁](http://thumbnail.image.rakuten.co.jp)
Modulation + OFDMA

Figure 3. The block structure of the 3G TDD uplink.

Analog and Digital Signals

- **Analog signal** (continuous signal)

  ![Analog Signal](image)

- **Digital signal** (discrete signal)

  ![Digital Signal](image)
7.3.1. **AM (Amplitude Modulation)**

**(Analog Modulation)**

- Amplitude of carrier signal is varied as the message signal to be transmitted
- Frequency of carrier signal is kept constant

---

Fig. 7.25

- Message signal
- Carrier signal
- AM signal

p. 159 (頁178)

**Fig.7.25 Amplitude of carrier signal is varied as the message signal to be transmitted**

**Frequency of carrier signal is kept constant**
Amplitude Modulation

Modulating signal (audio)

Carrier frequency

AM signal

AM 調幅收音機

http://thumbnail.image.rakuten.co.jp
7.3.2. FM (Frequency Modulation) (Analog Modulation)

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

FM signal is represented as a modulated carrier wave. The message signal modulates the frequency of the carrier, resulting in a FM signal. The relationship between the message signal, carrier signal, and FM signal is shown in the diagram.

Frequency Modulation

The diagram illustrates the process of frequency modulation. The modulating signal (audio) modulates the carrier frequency, resulting in an FM signal. The amplitude of the carrier frequency varies according to the modulating signal.
(a) A binary signal. (b) Amplitude shift keying. (c) Frequency shift keying. (d) Phase shift keying.

Amplitude shift keying (ASK)

- 振幅偏移調変

(a) Amplitude-shift keying
振幅偏移調變 (ASK)

Bit rate: 5  Baud rate: 5

1 bit 1 bit 1 bit 1 bit 1 bit
0  1  0  1  0

1 baud 1 baud 1 baud 1 baud 1 baud

1 second
7.3.3. FSK (Frequency Shift Keying) (Digital Modulation)

- 1/0 represented by two different frequencies slightly offset from carrier frequency

Frequency shift keying (FSK)

- 頻率偏移調變

\[
\begin{align*}
0 & 0 1 1 0 1 0 0 0 1 0 \\
\end{align*}
\]

(b) Frequency-shift keying

\[
\begin{align*}
\text{freq.} & \quad \text{freq.} \\
f_{c1} & \quad f_{c2} \\
\end{align*}
\]

7.3.3. FSK (Frequency Shift Keying) (Digital Modulation)

- 1/0 represented by two different frequencies slightly offset from carrier frequency

Message signal \( x(t) \)

FSK signal \( s(t) \)
Phase (相位)

Frequency: 1 Period/Sec = 1 Hertz
### 7.3.4. PSK (Phase Shift Keying) (Digital Modulation)

- Use alternative sine wave phase to encode bits

<table>
<thead>
<tr>
<th>Carrier signal 1</th>
<th>Carrier signal 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sin(2\pi f_1 t)$</td>
<td>$\sin(2\pi f_2 (t + \pi))$</td>
</tr>
</tbody>
</table>

**Message signal**

| 1 | 0 | 1 | 1 | 0 | 1 |

**PSK signal**

The diagram illustrates the relationship between the carrier signals, message signal, and PSK signal over time. The bit rate is 5 baud. The baud rate is also 5.

---

**Diagram Notes**

- **Phase Shift Keying (PSK)**
- **Bit rate:** 5
- **Baud rate:** 5
- **Carrier signals:**
  - Carrier signal 1: $\sin(2\pi f c t)$
  - Carrier signal 2: $\sin(2\pi f c (t + \pi))$
- **Message signal:** $x(t)$
- **PSK signal:** $s(t)$

---

**Figure 7.28**

The figure shows the time domain representation of the PSK signals, with one baud per second. The message signal is represented by the sequence of bits: 1 0 1 1 0 1.
7.3.5. QPSK (4-PSK) (Quadrature Phase Shift Keying)

- **Signal constellation**

  p. 163 (頁182) Fig. 7.29

\[ \text{(BPSK) (QPSK)} \]

- **BPSK** = binary phase shift keying
QPSK (4-PSK)

Bit rate: 10  Baud rate: 5

(BPSK)

(BPSK) Modulation
1 bit / symbol

(QPSK)

QPSK Modulation
2 bits / symbol

Source: http://www.magnadesignnet.com/en/booth/technote/ofdm/OFDM_fig2_s.gif
### 4-PSK (QPSK) Characteristics

<table>
<thead>
<tr>
<th>Dibit</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>0</td>
</tr>
<tr>
<td>01</td>
<td>90</td>
</tr>
<tr>
<td>10</td>
<td>180</td>
</tr>
<tr>
<td>11</td>
<td>270</td>
</tr>
</tbody>
</table>

Dibit (2 bits)  
Constellation diagram

---

### 8-PSK Characteristics

<table>
<thead>
<tr>
<th>Tribit</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>0</td>
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<tr>
<td>001</td>
<td>45</td>
</tr>
<tr>
<td>010</td>
<td>90</td>
</tr>
<tr>
<td>011</td>
<td>135</td>
</tr>
<tr>
<td>100</td>
<td>180</td>
</tr>
<tr>
<td>101</td>
<td>225</td>
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<tr>
<td>110</td>
<td>270</td>
</tr>
<tr>
<td>111</td>
<td>315</td>
</tr>
</tbody>
</table>

Tribits (3 bits)  
Constellation diagram
7.3.6. $\pi/4$ QPSK

- All possible state transitions in $\pi/4$ QPSK

(A kind of 8PSK)

p. 164 (頁183) Fig. 7.30

切切切切切切蛋糕  ---- No!

http://amourcake.pixnet.net/blog/post/47253280-切蛋糕的小撇步
7.3.7. **QAM (正交調幅調變)**

*(Quadrature Amplitude Modulation)*

A combination of AM and PSK

Two carriers out of phase by 90 deg are amplitude modulated

\[ 8\text{QAM} = 2 \times 4 \]

<table>
<thead>
<tr>
<th>Bit sequence represented</th>
<th>Amplitude</th>
<th>Phase shift</th>
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<tbody>
<tr>
<td>000</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>001</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>010</td>
<td>1</td>
<td>( \pi/2 )</td>
</tr>
<tr>
<td>011</td>
<td>2</td>
<td>( \pi/2 )</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>( \pi )</td>
</tr>
<tr>
<td>101</td>
<td>2</td>
<td>( \pi )</td>
</tr>
<tr>
<td>110</td>
<td>1</td>
<td>( 3\pi/2 )</td>
</tr>
<tr>
<td>111</td>
<td>2</td>
<td>( 3\pi/2 )</td>
</tr>
</tbody>
</table>
7.3.8. **16QAM (QAM-16)**

Splitting signal into 12 different phases and 3 different amplitudes – the total of 16 different possible values

- 4 bits

![Rectangular constellation of 16QAM](image)

**QAM (cont.)**

- 2 bits
- 4 bits
- 6 bits

(a) QPSK.
(b) QAM-16. (Quadrature Amplitude Modulation)
(c) QAM-64.
(a) V.32 for 9600 bps.
(b) V32 bis for 14,400 bps.
<table>
<thead>
<tr>
<th>Band</th>
<th></th>
<th>稱呼</th>
<th>調變技術</th>
<th>DL</th>
<th>UL</th>
<th>天線技術</th>
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<td>10/2</td>
<td>台灣電信</td>
<td>256QAM</td>
<td>64QAM</td>
<td>2x2 MIMO</td>
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<td>10/2</td>
<td>鴻海電信</td>
<td>256QAM</td>
<td>64QAM</td>
<td>2x2 MIMO</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>5/2</td>
<td>亞太電信</td>
<td>256QAM</td>
<td>64QAM</td>
<td>2x2 MIMO</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>20/2</td>
<td>台灣大哥大</td>
<td>256QAM</td>
<td>64QAM</td>
<td>2x2 MIMO</td>
<td>當規劃或設備問題</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10/2</td>
<td>合勤之星</td>
<td>256QAM</td>
<td>64QAM</td>
<td>2x2 MIMO</td>
<td>目前256QAM只有部分區域</td>
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<td>64QAM</td>
<td>2x2 MIMO</td>
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<tr>
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<td>亞太電信</td>
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<td>64QAM</td>
<td>2x2 MIMO</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>15/2</td>
<td>台灣大哥大</td>
<td>256QAM</td>
<td>64QAM</td>
<td>2x2 MIMO</td>
<td>目前4X4 MIMO僅建設極少數</td>
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<td></td>
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<td>10/2</td>
<td>中華電信</td>
<td>256QAM</td>
<td>64QAM</td>
<td>2x2 MIMO</td>
<td>區域與熱區</td>
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<tr>
<td></td>
<td></td>
<td>20/2</td>
<td>亞太電信</td>
<td>256QAM</td>
<td>64QAM</td>
<td>2x2 MIMO</td>
<td>(大多數為2X2 MIMO)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20/2</td>
<td>中華電信</td>
<td>256QAM</td>
<td>64QAM</td>
<td>2x2 MIMO</td>
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<tr>
<td></td>
<td></td>
<td>10/2</td>
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<tr>
<td>B1 2100MHz</td>
<td>FDD</td>
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<td>64QAM</td>
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<td>已確認開通</td>
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<tr>
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<td></td>
<td>5/2</td>
<td>合勤之星</td>
<td>256QAM</td>
<td>64QAM</td>
<td>4G未開發</td>
<td>(待確認)</td>
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<td></td>
<td>20/2</td>
<td>台灣大哥大</td>
<td>256QAM</td>
<td>64QAM</td>
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<td>已確認開通</td>
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<td>64QAM</td>
<td>未知(待更新)</td>
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<td>目前256QAM只有部分區域</td>
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<td>64QAM</td>
<td>2x2 MIMO</td>
<td>(大多數為2X2 MIMO)</td>
</tr>
</tbody>
</table>

The End of Chapter 7