بسم الله الرحمن الرحيم

# Mobile Networking

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FHSS, IR, and Data Modulations

# MORE ON 802.11B PHY LAYER

# Contents

- IEEE 802.11b with FHSS
- IEEE 802.11b with IR
- Available Modulations and their Performance
  - DBPSK
  - DQPSK
  - CCK: Complementary Code Keying
  - PBCC: Packet Binary Convolutional Code

Frame format, Regulations, …

# FHSS IN 802.11B

# Why Frequency Hopping?

- Frequency Hopping enables coexistence of multiple networks (or other devices) in same area
- FCC recognizes FH as one of the techniques withstanding Fairness requirements for unlicensed operation in the ISM bands.
- 802.11 Frequency Hopping PHY uses <u>79 nonoverlapping</u> frequency channels with <u>1 MHz</u> channel spacing.
- FH enables operation of up to <u>26 collocated networks</u>, enabling therefore high aggregate throughput.
- Frequency Hopping <u>is resistant to multipath fading</u> through the inherent frequency diversity mechanism

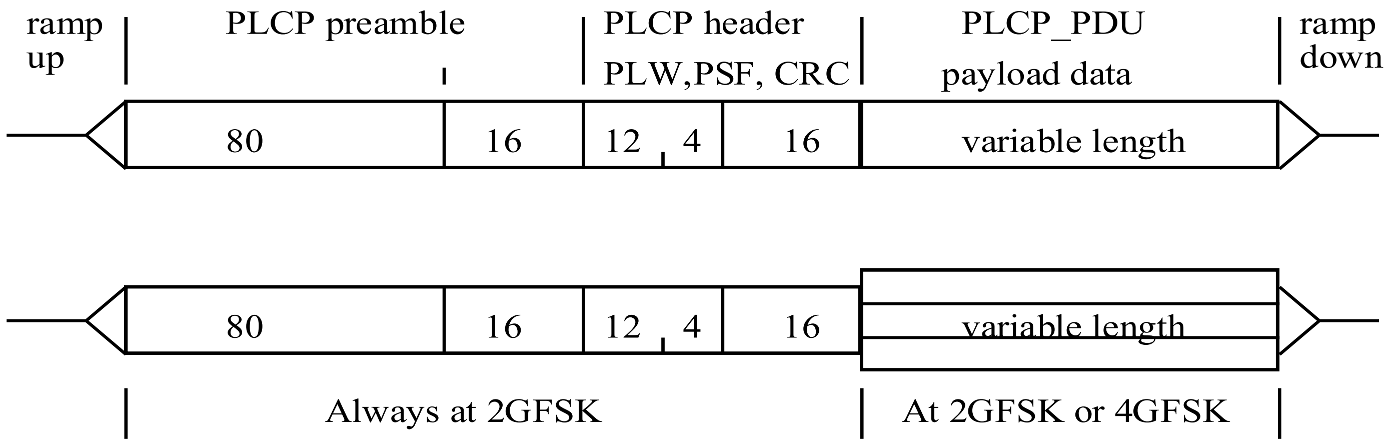
# Regulatory Requirements for FH

- **North America** (CFR47, Parts 15.247, 15.205, 15.209):
  - Frequency band: 2400-2483.5 MHz
  - At most 1 MHz bandwidth
  - At least 75 hopping channels, pseudorandom hopping pattern
  - At most 1 W transmit power and 4 W EIRP (including antenna)
- **Europe** (ETS 300-328, ETS 300-339):
  - Frequency band: 2400-2483.5 MHz
  - At least 20 hopping channels
  - At most 100 mW EIRP
- **Japan** (RCR STD-33A):
  - Frequency band: 2471-2497 MHz
  - At least 10 hopping channels

# 802.11 FH PHY vs. Regulations

- 1 MHz Bandwidth
- 79 hopping channels in **North America and Europe**; pseudorandom hopping pattern. (2.402-2.480GHz)
- 23 hopping channels in **Japan** (2.473-2.495GHz)
- At most 1 W power; devices capable of more than 100 mW have to support at least one power level not exceeding 100 mW.

# 802.11 FHSS Frame Format




- PHY header indicates payload rate and length; CRC16 protected
- Data is whitened by a synchronous scrambler and formatted to limit DC offset variations
- Preamble and Header always at 1 Mbit/sec; Data at 1 or 2 Mbit/sec

# PLCP Preamble

- PLCP preamble starts with **80 bits**
  - **0101** sync pattern
  - detect presence of signal
  - to resolve antenna diversity
  - to acquire symbol timing
- Follows **16 bit Start Frame Delimiter (SFD)**
  - **h0CBD**
  - the SFD provides symbol-level frame synchronization
  - the SFD pattern is balanced

# PLCP Header

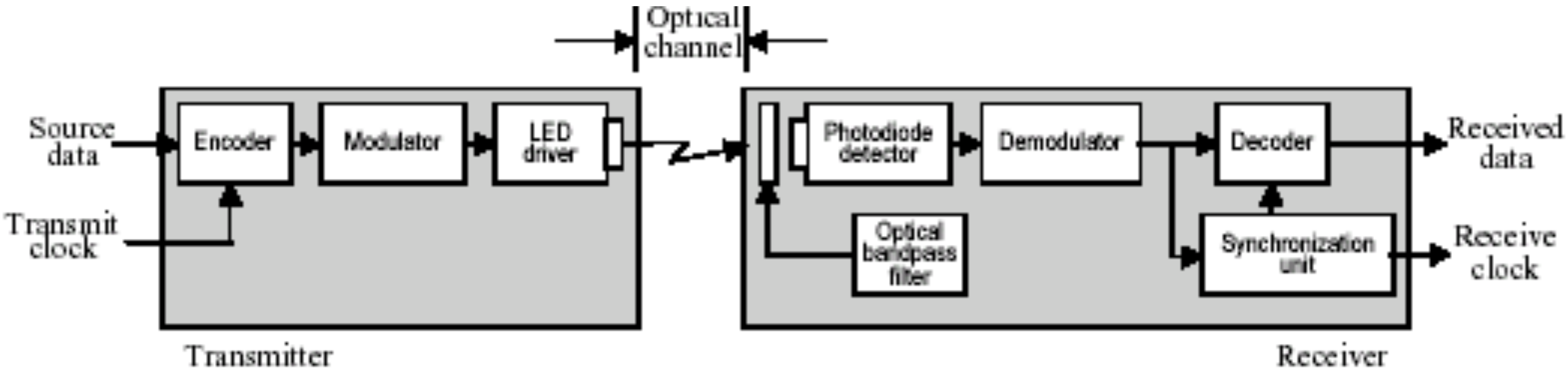
- A 32 bit PLCP header consists of
  - **PLW** (PLCP_PDU Length Word) is 12 bits field
    - indicating the length of PLCP_PDU in octets, including the 32 bit CRC at the PLCP_PDU end, in the range 0 .. 4095
  - **PSF** (PLCP Signaling Field) is 4 bit field,
    - Bit 0 is reserved
    - Bits 1-3 indicates the PLCP_PDU data rate
      - (1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5 Mbit/s)
  - **HEC** is a 16 bit CRC

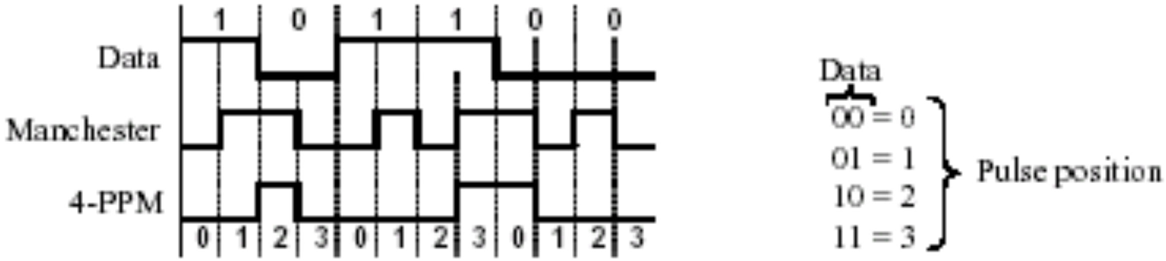
# PLCP_PDU Formatting

- Dividing serial bit stream into symbols:
  - at 1 Mbps, each bit is converted into 2FSK (Frequency-Shift Keying) symbol
  - at 2 Mbps, each 2 bits are encoded into 4FSK symbol using Gray mapping

# Baseband Infrared (IR) in 802.11b: PPM Modulation

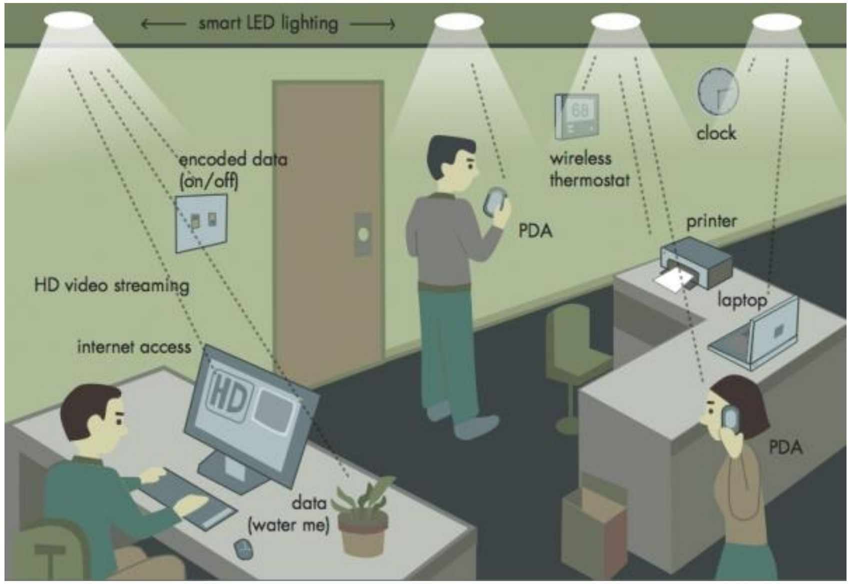
- OOKPPM :
  - Reduce the optical power



# LiFi: Visible Light Communications (IEEE 802.15.7)

- Defined by Prof. Harald Haas (University of Edinburgh in the UK)
- High speed and fully networked wireless communications, like Wi-Fi, using visible light
- (VLC) works by switching bulbs on and off within nanoseconds



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- Available Modulations and their Performance
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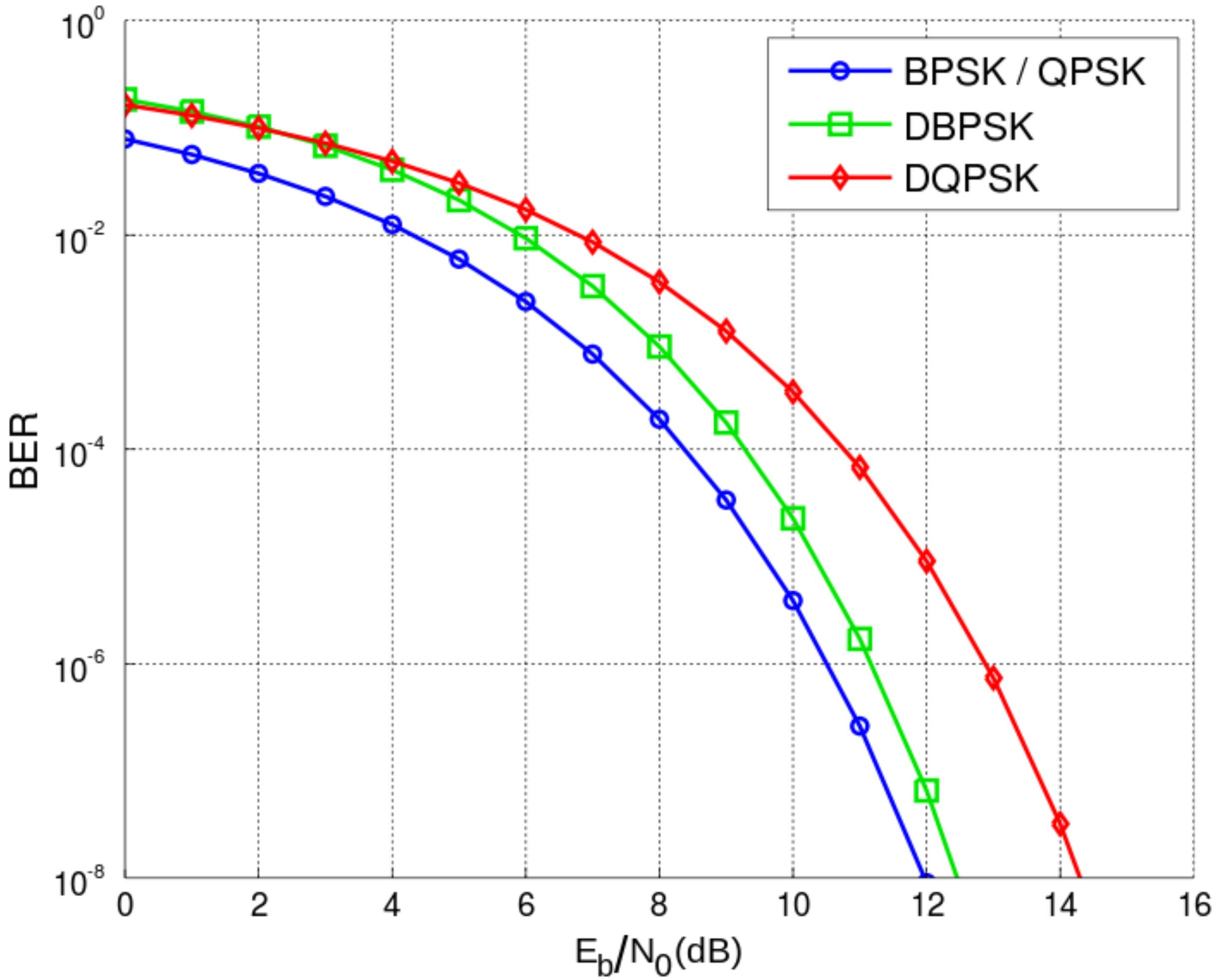
  – DQPSK
  – CCK: Complementary Code Keying
  – PBCC: Packet Binary Convolutional Code

# 1 Mbps DBPSK Modulation Encoding Table

| Bit input | Phase change (+jω) |
|---|---|
| 0 | 0 |
| 1 | π |

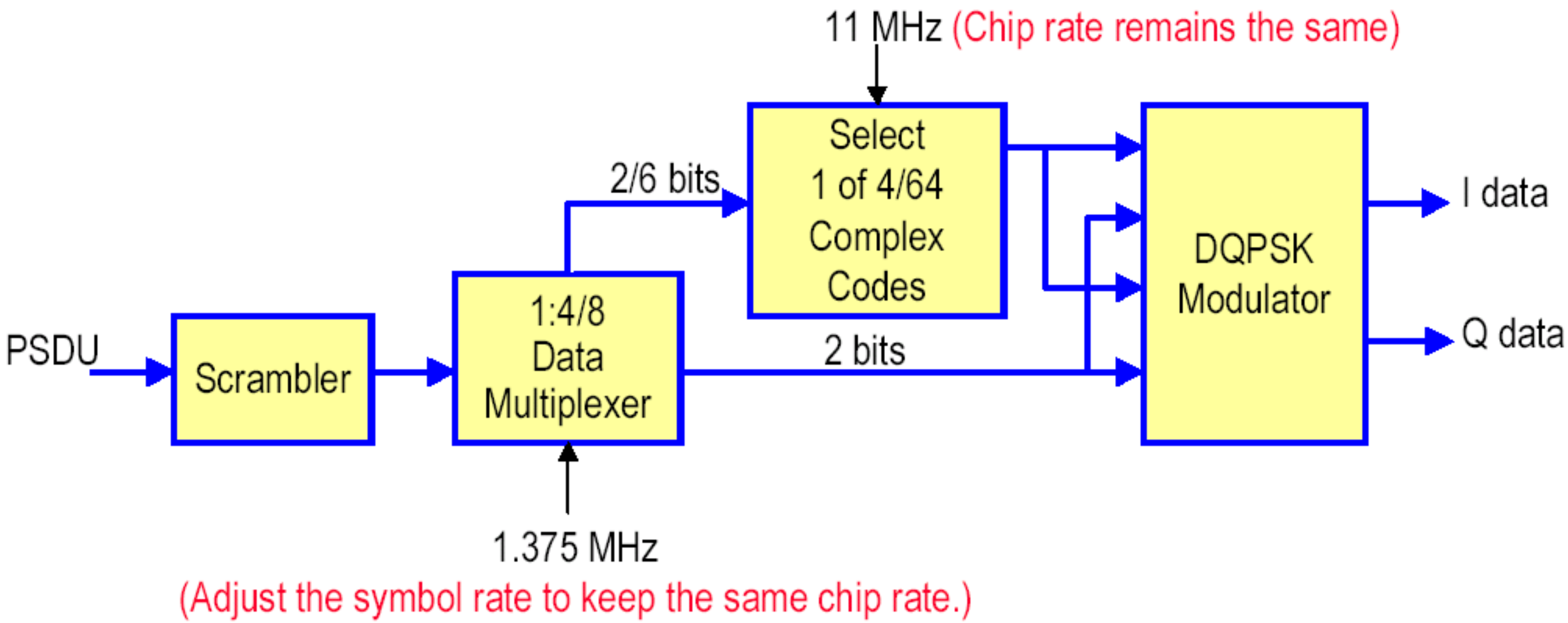
# 2 Mbps DQPSK Modulation Encoding Table

| Dibit pattern (d0,d1)<br>d0 is first in time | Phase change (+jω) |
|---|---|
| 00 | 0 |
| 01 | $\pi/2$ |
| 11 | $\pi$ |
| 10 | $3\pi/2$ ($-\pi/2$) |


BPSK / QPSK
DBPSK
DQPSK
BER
$E_b/N_0$(dB)
$10^0$
$10^{-2}$
$10^{-4}$
$10^{-6}$
$10^{-8}$
0
2
4
6
8
10
12
14
16

# Complementary Code Keying (CCK)

- HR/DSSS adopts 8-chip CCK as the modulation scheme with 11MHz chipping rate




8-chip*1.375MHz = 11MHz chipping rate

# Complementary Code Keying (CCK)

- Spreading code length = 8, c={c0-c7} and

$$c = \{e^{j(\varphi_1+\varphi_2+\varphi_3+\varphi_4)}, e^{j(\varphi_1+\varphi_3+\varphi_4)}, e^{j(\varphi_1+\varphi_2+\varphi_4)},$$

$$-e^{j(\varphi_1+\varphi_4)}, e^{j(\varphi_1+\varphi_2+\varphi_3)}, e^{j(\varphi_1+\varphi_3)}, -e^{j(\varphi_1+\varphi_2)}, e^{j\varphi_1}\}$$

where $\varphi_1$ is added to all code chips,

$\varphi_2$ is added to all odd code chips,

$\varphi_3$ is added to all odd pairs of code chips, and

$\varphi_4$ is added to all odd quads of code chips.

Cover code : c4 and c7 chips are rotated 180° (with -) by a cover sequence to optimize the sequence correlation properties and minimize dc offsets in the codes.

# Complementary Code Keying (CCK) 5.5Mbps

- At 5.5Mbps CCK, 4 data bits (d0,d1,d2,d3) are transmitted per symbol
  - (d0,d1) is DQPSK modulated to yield $\varphi 1$, which the information is bear on the "phase change" between two adjacent symbols
  - (11/8)*(4 data bits per symbol)*1Mbps = 5.5Mbps

| Dibit pattern (d0, d1) (d0 is first in time) | Even symbols phase change (+jω) | Odd symbols phase change (+jω) |
|---|---|---|
| 00 | 0 | $\pi$ |
| 01 | $\pi/2$ | $3\pi/2$ ($-\pi/2$) |
| 11 | $\pi$ | 0 |
| 10 | $3\pi/2$ ($-\pi/2$) | $\pi/2$ |

# Complementary Code Keying (CCK) 5.5Mbps

- (d2,d3) encodes the basic symbol, where

$$\begin{cases} \varphi_2 = d_2 \times \pi + \pi / 2; \\ \phi_3 = 0; \\ \phi_4 = d_3 \times \pi; \end{cases}$$

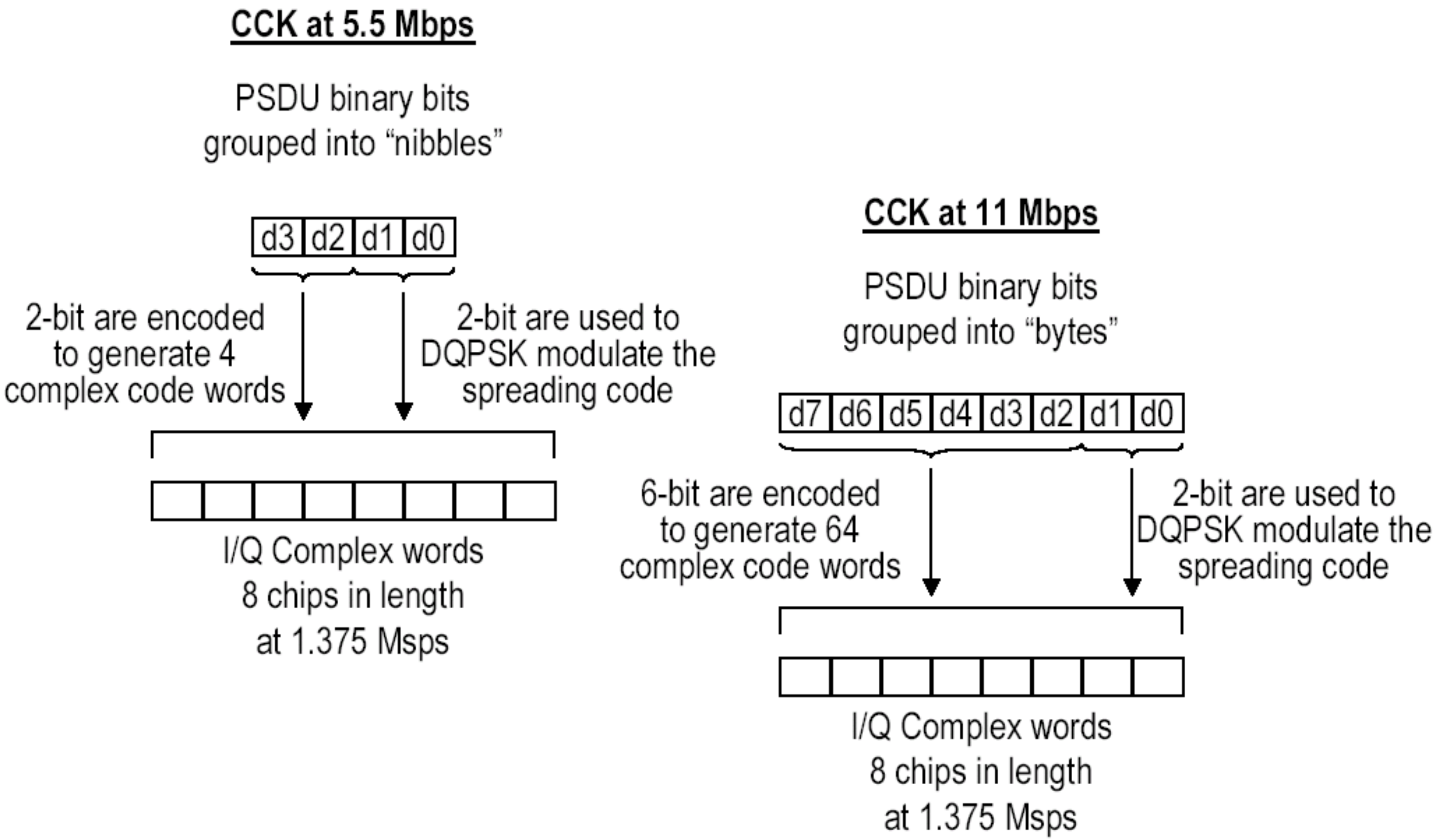
| d2, d3 | c1 | c2 | c3 | c4 | c5 | c6 | c7 | c8 |
|---|---|---|---|---|---|---|---|---|
| 00 | 1j | 1 | 1j | –1 | 1j | 1 | –1j | 1 |
| 01 | –1j | –1 | –1j | 1 | 1j | 1 | –1j | 1 |
| 10 | –1j | 1 | –1j | –1 | –1j | 1 | 1j | 1 |
| 11 | 1j | –1 | 1j | 1 | –1j | 1 | 1j | 1 |

# Complementary Code Keying (CCK) 11Mbps

- At 11Mbps CCK, 8 data bits (d0-d7) are transmitted per symbol
  - (d0,d1) is DQPSK modulated to yield $\varphi 1$, which the information is bear on the "phase change" between two adjacent symbols
  - (d2,d3),(d4,d5),(d6,d7) encode $\varphi 2$, $\varphi 3$, $\varphi 4$, respectively, based on QPSK
  - (11/8)*(8 data bits per symbol)*1Mbps = 11Mbps

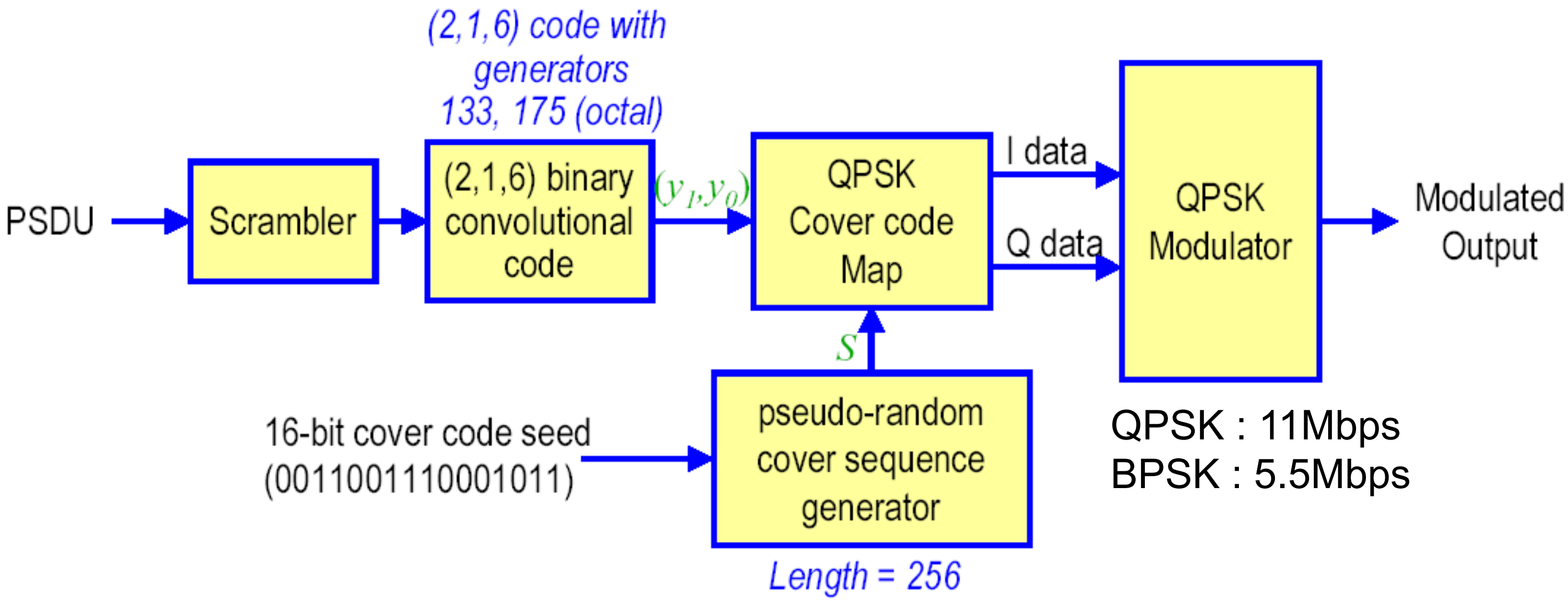
| **Dibit pattern [di, d(i+1)] (di is first in time)** | **Phase** |
|---|---|
| 00 | 0 |
| 01 | $\pi/2$ |
| 10 | $\pi$ |
| 11 | $3\pi/2$ ($-\pi/2$) |

# Complementary Code Keying (CCK)



# Packet Binary Convolutional Code (PBCC)

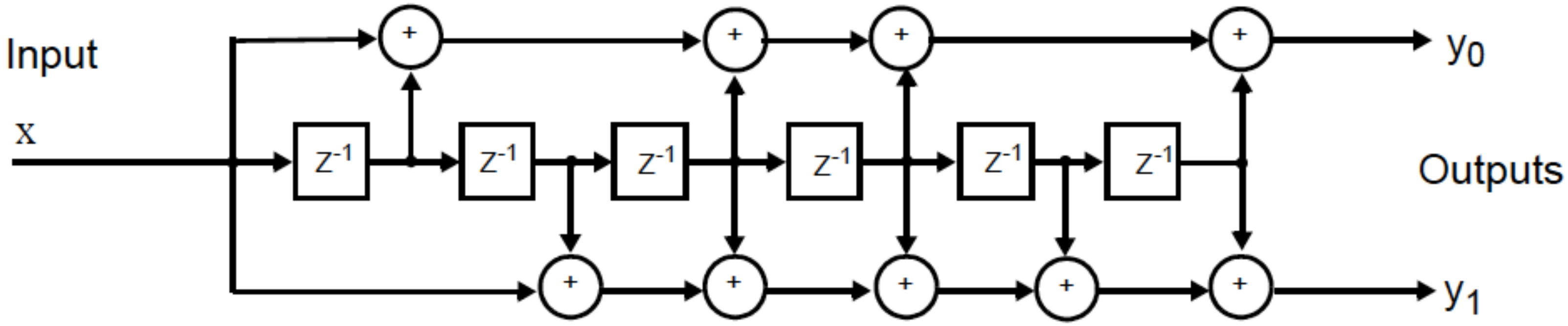
- 64-state BCC




QPSK : 11Mbps
BPSK : 5.5Mbps

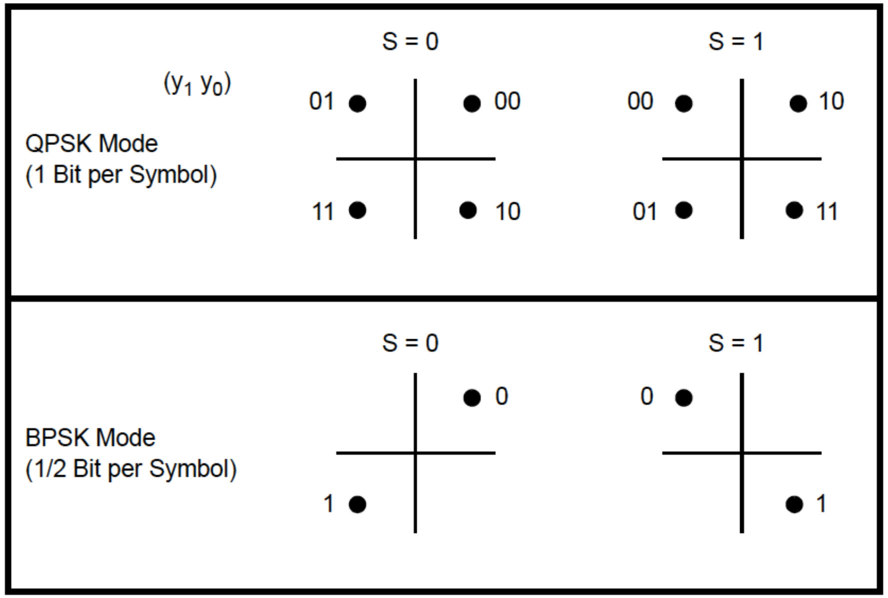
# Packet Binary Convolutional Code (PBCC)

- PBCC convolutional encoder
  - Provide encoder the "known state"
    - 6 memory elements are needed and
    - one octet containing all zeros is appended to the end of the PPDU prior to transmission
      - One more octet than CCK
  - For every data bit input, two output bits are generated



# Packet Binary Convolutional Code (PBCC)

- For 11Mbps, two output bits (y0,y1) produce one symbol via QPSK
  - one data bit per symbol
- For 5.5Mbps, each output bit (y0 or y1) produces two symbols via BPSK
  - One-half a bit per symbol



# Packet Binary Convolutional Code (PBCC)

- Pseudo-random cover sequence
  - use 16-bit seed sequence (0011001110001011)
  - to generate 256-bit pseudo-random cover sequence

c0 c1 c2 c3 c4 c5 c6 c7 c8 c9 c10 c11 c12 c13 c14 c15
c3 c4 c5 c6 c7 c8 c9 c10 c11 c12 c13 c14 c15 c0 c1 c2
c6 c7 c8 c9 c10 c11 c12 c13 c14 c15 c0 c1 c2 c3 c4 c5
c9 c10 c11 c12 c13 c14 c15 c0 c1 c2 c3 c4 c5 c6 c7 c8
c12 c13 c14 c15 c0 c1 c2 c3 c4 c5 c6 c7 c8 c9 c10 c11
c15 c0 c1 c2 c3 c4 c5 c6 c7 c8 c9 c10 c11 c12 c13 c14
c2 c3 c4 c5 c6 c7 c8 c9 c10 c11 c12 c13 c14 c15 c0 c1
c5 c6 c7 c8 c9 c10 c11 c12 c13 c14 c15 c0 c1 c2 c3 c4
c8 c9 c10 c11 c12 c13 c14 c15 c0 c1 c2 c3 c4 c5 c6 c7
c11 c12 c13 c14 c15 c0 c1 c2 c3 c4 c5 c6 c7 c8 c9 c10
c14 c15 c0 c1 c2 c3 c4 c5 c6 c7 c8 c9 c10 c11 c12 c13
c1 c2 c3 c4 c5 c6 c7 c8 c9 c10 c11 c12 c13 c14 c15 c0
c4 c5 c6 c7 c8 c9 c10 c11 c12 c13 c14 c15 c0 c1 c2 c3
c7 c8 c9 c10 c11 c12 c13 c14 c15 c0 c1 c2 c3 c4 c5 c6
c10 c11 c12c13 c14 c15 c0 c1 c2 c3 c4 c5 c6 c7 c8 c9
c13 c14 c15 c0 c1 c2 c3 c4 c5 c6 c7 c8 c9 c10 c11 c12