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Wireless Networks

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    - Dr. Sandra Wahid (S023)
    - Dr. Hoda Baraka (Before S2022)

Agenda

- Channel Capacity
  - How much can a channel handle?
- Modulation
  - How do we send the waves (with specific characteristic, for example: on a certain frequency)?

Channel Capacity

There are four concepts here that we are trying to relate to one another:

- **Data rate**: This is the rate, in bits per second (bps), at which data can be communicated.
- **Bandwidth**: This is the bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium, expressed in cycles per second, or Hertz.
- **Noise**: the average level of noise over the communications path.
- **Error rate**: This is the rate at which errors occur, where an error is the reception of a 1 when a 0 was transmitted or the reception of a 0 when a 1 was transmitted.

Nyquist Theorem (Noise-Free Channel)

- Signaling speed:
  - The number of times per second the signal changes its value/voltage
  - Also known as *symbol rate and* Measured in <u>*baud*</u>
  - For example, if the signal has 4 voltage levels 0,1,2,3,
    - each level can carry 2 bits 00, 01, 10, 11
    - if the signal changes its value 4 times per second
      - Its baud rate is 4 → Its bit rate is 8
- Nyquist rate

$$C \text{ (bit rate)} = 2B \log_2 L \text{ bits/sec}$$

  - B = channel bandwidth in Hz
  - L = Number of discrete signal/voltage levels

Given a bandwidth of B, the highest signal rate that can be carried is 2B. This limitation is due to the effect of inter-symbol interference, such as is produced by delay distortion.

Shannon Theorem

- Signal to noise ratio SNR measured in decibel (dB)
  - It is ratio of Signal Power (S) to Noise power (N)
  - $SNR_{db} = 10 \log_{10} \dfrac{\text{Signal Power}}{\text{Noise Power}}$
- Maximum channel capacity C in bits/sec

$$\mathbf{C = B \log_2 (1+SNR)}$$

Example

If Phone wire bandwidth = 3100 Hz and SNR is 30db, calculate the max. channel capacity and the maximum number of signaling levels

$30\text{ dB} = 10\ \text{Log}_{10}\ \text{SNR}$

$3 = \text{Log}_{10}\ \text{SNR}$

$\text{SNR} = 10^3 = 1000$

$\text{Capacity} = 3100\ \log_2(1+1000) = 30{,}894\ \text{bps}$

Based on Nyquist:

$C=2B\ \log_2 L$

$30894 = 2 * 3100 * \log_2 L$

$\log_2 L = 4.98$

$L = 31.5 = 31\ \text{levels}$

Modulation

- Modulation
  - is to convert **data** (digital or analog) into an **EM wave**
  - alters certain properties of a radio wave, called **carrier wave**, whose frequency is the same as the center frequency of the wireless channel used for transmission.

- Allocated radio spectrum is a precious resource so it has to be used efficiently.

- Types:
  - Analog modulation (for analog signals)
  - Digital modulation (for digital signals)

Modulation Techniques

Analog Modulation:

>>transmits continuous signals

- Amplitude Modulation (AM)
- Frequency Modulation (FM)
- Phase Modulation (PM)

Digital Modulation:

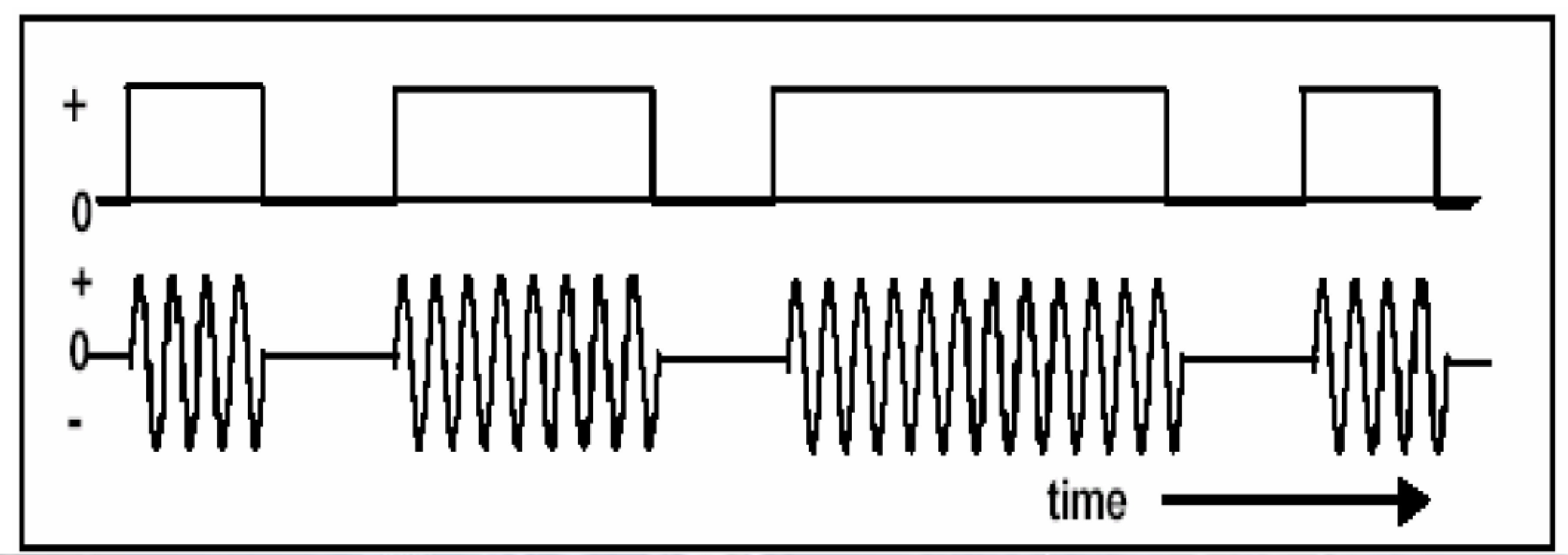
>>transmits digital signals that consist of a sequence of 0 and 1 bits

- Amplitude Shift Keying (ASK)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)

Amplitude Shift Keying (ASK)

- Also known as "OOK" On-Off Keying

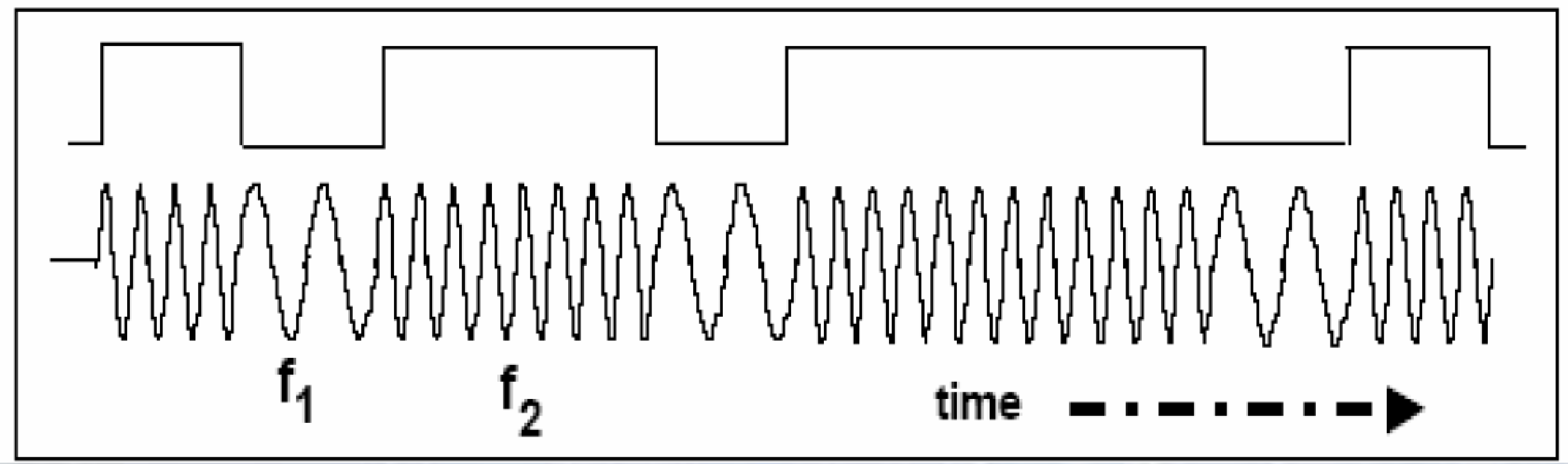
- A **binary 1** is represented by the **presence** of the signal.
- A **binary 0** is represented by the **absence** of the signal.



- Issue: No signal or zero bit.

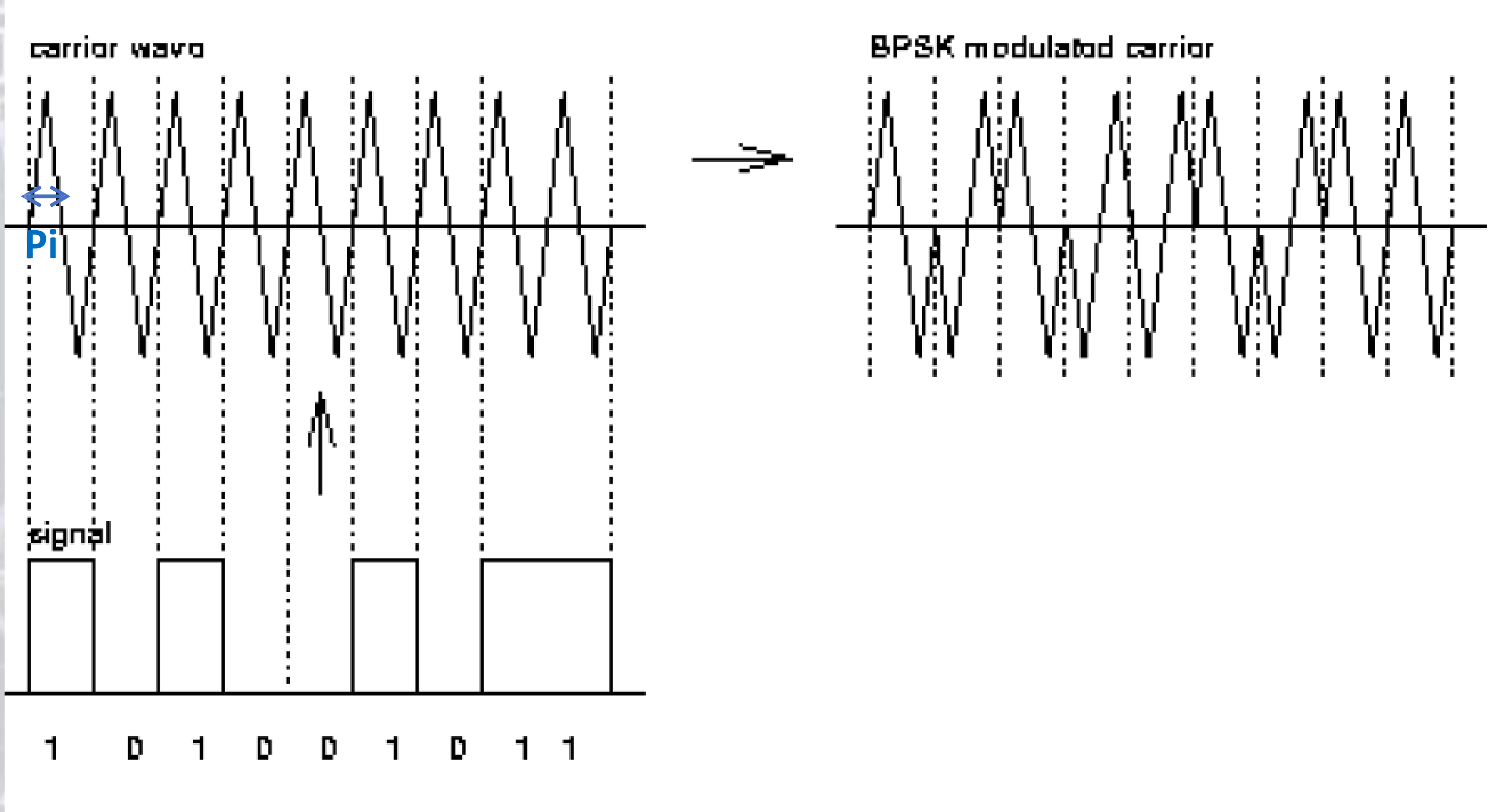
Frequency Shift Keying (FSK)

- BFSK →Binary FSK (only **two frequencies** used to represent single bits)



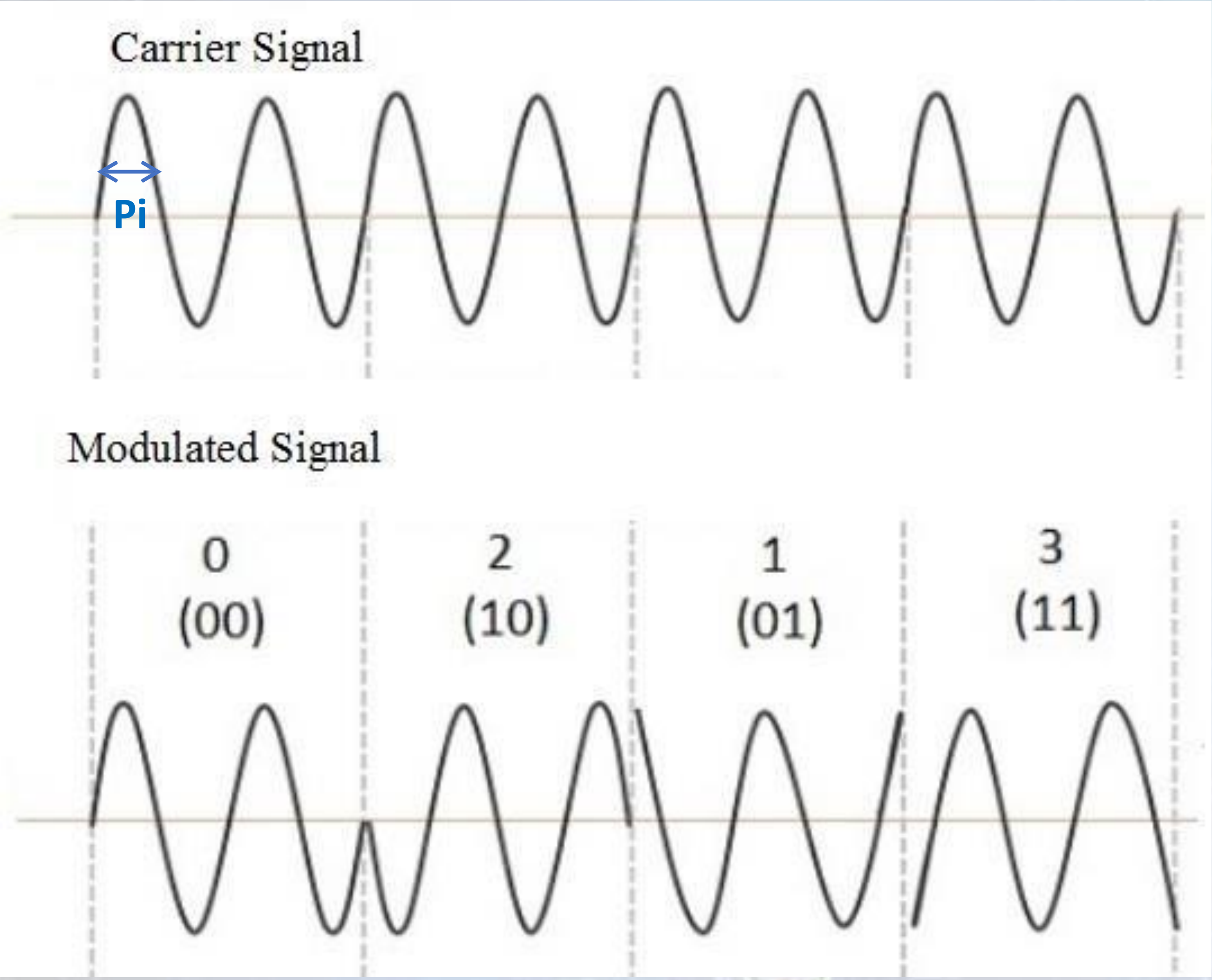
Phase Shift Keying (PSK)

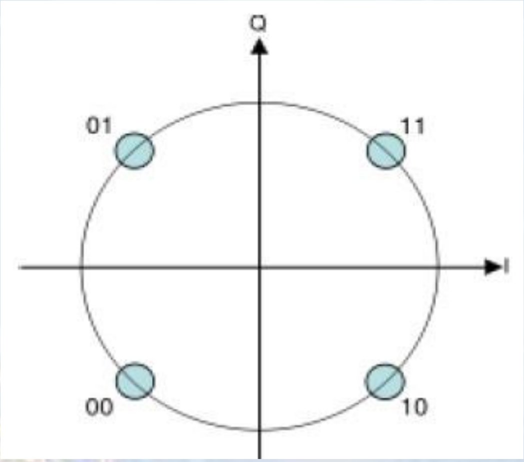
- BPSK →Binary PSK
  - Binary 1 is represented by the presence of a carrier signal with a **phase difference Pi** radians from Binary 0's signal.



Quadrature Phase Shift Keying (QPSK)

- Uses four phases each separated by **Pi/2 radians** (90 degrees)





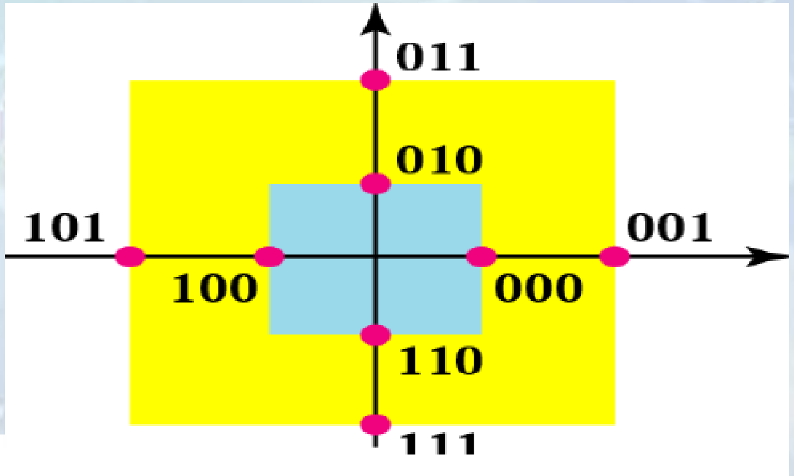
- **Symbol duration** in this modulation is ***twice*** the bit duration.

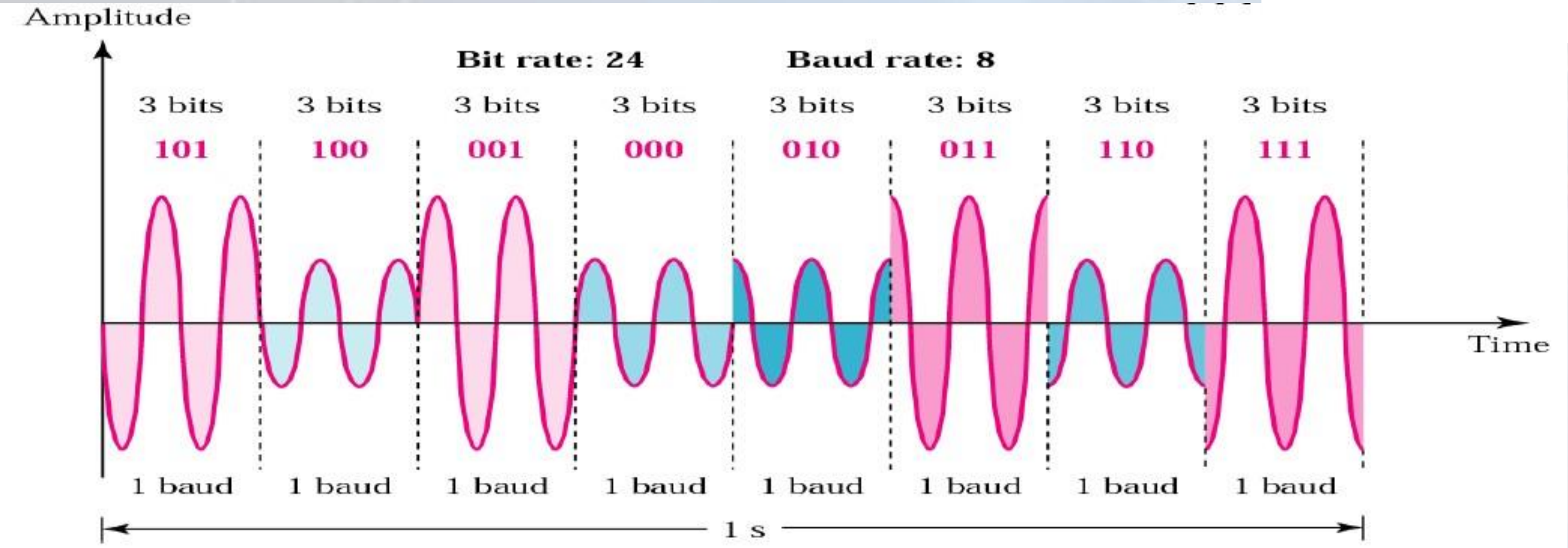
Quadrature Amplitude Modulation (QAM)

- Amplitude and phase modulation of 2 orthogonal carriers (phase difference Pi/2)
- <u>Example:</u>

  2 Amplitudes (distance from center), 4 Phases

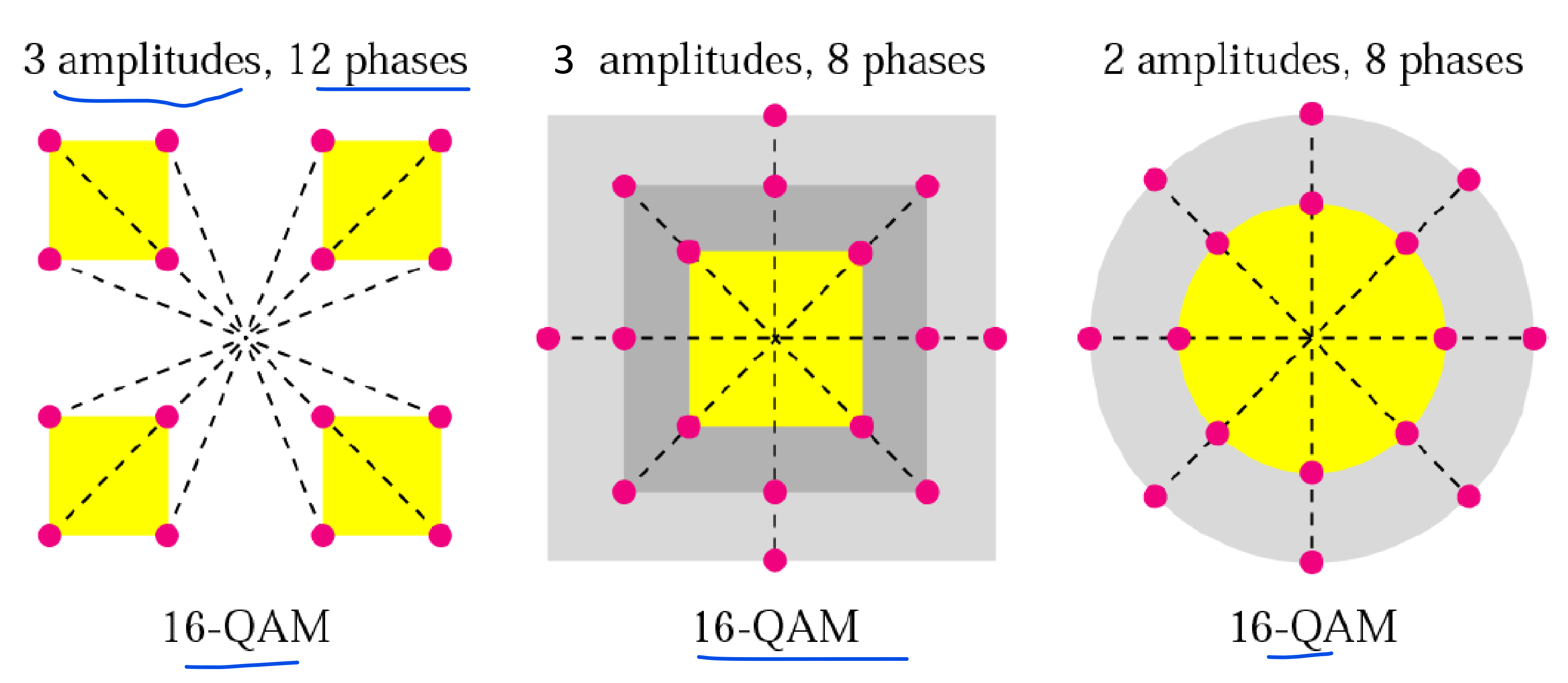
  - 8 symbols → 8-QAM
  - 1 symbol=3 bits





- Baud rate=symbol rate→ how many symbols/second

Quadrature Amplitude Modulation (QAM)



- **Drawback:** as the number of symbols increases, system becomes more complex and susceptible to errors.

Multiple Access Techniques

- Transmission Medium in wireless networks is broadcast in nature → thus a node can't just transmit whenever it wants to.

- Multiple access techniques are used to control access to the **Shared Medium**

- Examples:
  - ❑ Frequency Division Multiple Access (FDMA)
  - ❑ Time Division Multiple Access (TDMA)
  - ❑ Code Division Multiple Access (CDMA)
  - ❑ Space Division Multiple Access (SDMA)

Frequency Division Multiple Access (FDMA)

- BW is divided into multiple **frequency channels/bands** separated by guard bands (to eliminated interchannel interference)
- Tradeoff: efficiency versus interference.
- A Tx/Rx uses a single dedicated frequency channel.
- Example:
  - Cellular networks: the base station (BS) dynamically allocates a different carrier frequency to each mobile station (MS)
  - Each node is allocated two frequencies:
    - UL: uplink → BS receive, node transmit
    - DL: downlink → BS transmit, node receive
    - called **FDD** (Frequency Division Duplex)

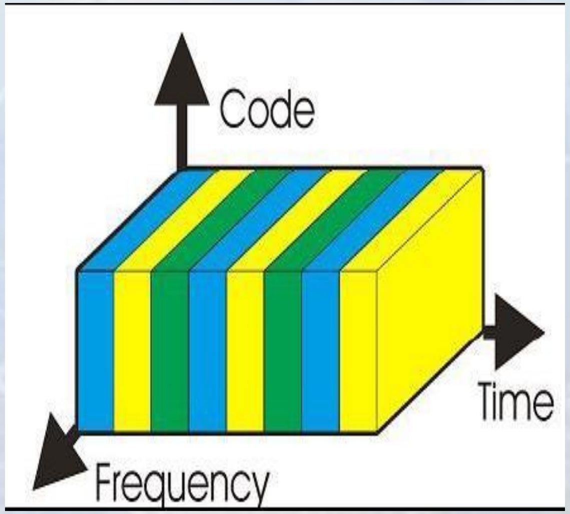
Time Division Multiple Access (TDMA)

- Each frequency band is divided into **several time slots** (channels) that repeat over time.

- The set of periodically repeating time slots is called a **TDMA frame**.

- A Tx/Rx is assigned one or more time slots in each frame.

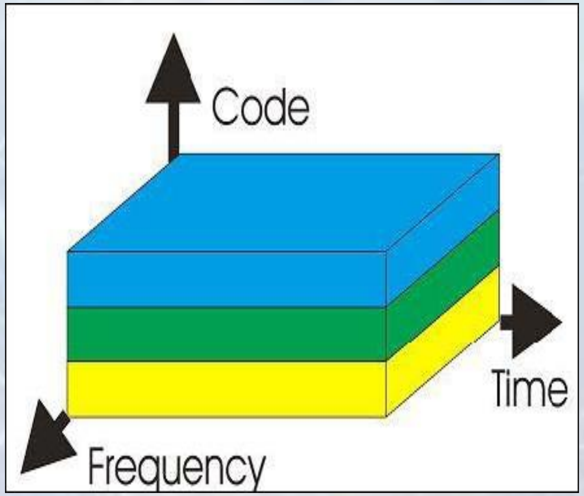
→The node transmits only on those slots.



- For two-way communication:
  - UL and DL time slots are allocated
    - Can be on the same band (TDD-TDMA: Time Division Duplex-TDMA)
    - Can be on different bands (FDD-TDMA: Frequency Division Duplex-TDMA)

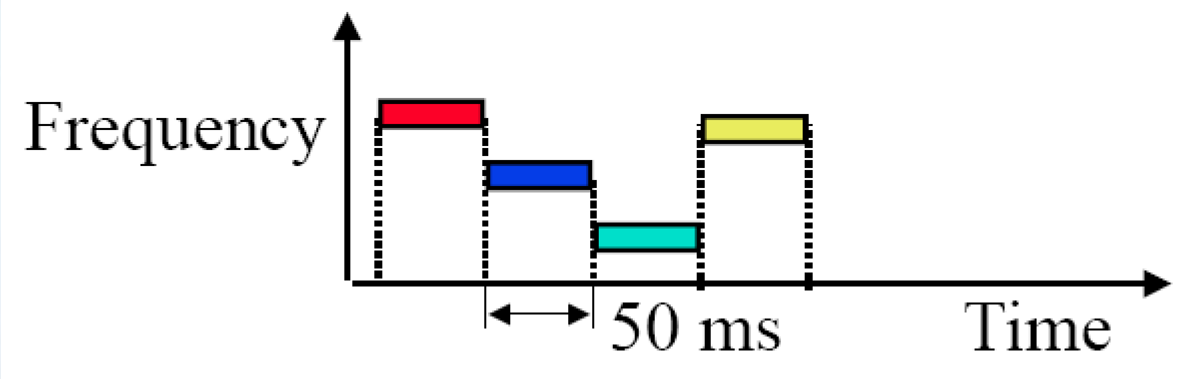
Code Division Multiple Access (CDMA)

- Every channel uses the entire spectrum.
- Each channel transmission is encoded with pseudo-random digital sequence.
- A **unique code** is assigned to each user.
- Codes are orthogonal.
- Types:
  - Frequency Hopping Spread Spectrum (FHSS)
  - Direct Sequence Spread Spectrum (DSSS)



Frequency Hopping Spread Spectrum (FHSS)

- A simple technique in which the transmission **switches across multiple narrow-band frequencies** in a pseudo-random manner.
- The sequence of transmission frequencies is known to Tx-Rx pair and appears random to other nodes.



- Frequency Hopping: is the process of switching from one channel to the other.
  - For example, a frequency was allotted to sender 1 for a particular period of time. Now, after a while, sender 1 hops to the other frequency and sender 2 uses the first frequency, which was previously used by sender 1. This is called **frequency reuse**.
- Dwell time: the amount of time spent on each frequency hop.
- FHSS is used to **avoid interference** (because the signal hops to a different frequency band) and to **prevent eavesdropping** (frequency-hopping pattern is not known to others).

Direct Sequence Spread Spectrum (DSSS)

- Each node assigned an n-bit code, called **chipping-code**.
- n is the **chipping-rate**.

✓

- All codes are ***orthogonal*** to each other, i.e. the dot product of the vector representations of any two codes is zero.

- For a binary 1, the sender transmits its code.
- For a binary 0, the sender transmits the complement of the code.

- Example: codes v1=(1,-1) and v2=(1,1)→ dot product=0
  - For a binary 1, the sender transmits its code
  - If the user is using v1, then it would transmit the code v1=(1,-1)
  - For a binary 0, the sender transmits the complement of the code.
  - If the user is using v1, then it would transmit the code **-v1**=(-1,1)

DSSS Example

- Assume we have two users that use orthogonal codes v1=(1,-1) and v2=(1,1)
- what is the chipping rate in this case? →2
- User 1 wants to transmit (1,0,1,1)
- User 2 wants to transmit (0,0,1,1)
- Encoding of user1 = [(1,–1),(–1,1),(1,–1),(1,–1)]
  - Resulting signal is [1,–1,–1,1,1,–1,1,–1]
- Encoding of user2 = [(–1,–1),(–1,–1),(1,1),(1,1)]
  - Resulting signal is [–1,–1,–1,–1,1,1,1,1]
- Composite transmitted signal is

(1,–1,–1,1,1,–1,1,–1) + (–1,–1,–1,–1,1,1,1,1) = (0,–2,–2,0,2,0,2,0)

DSSS Example

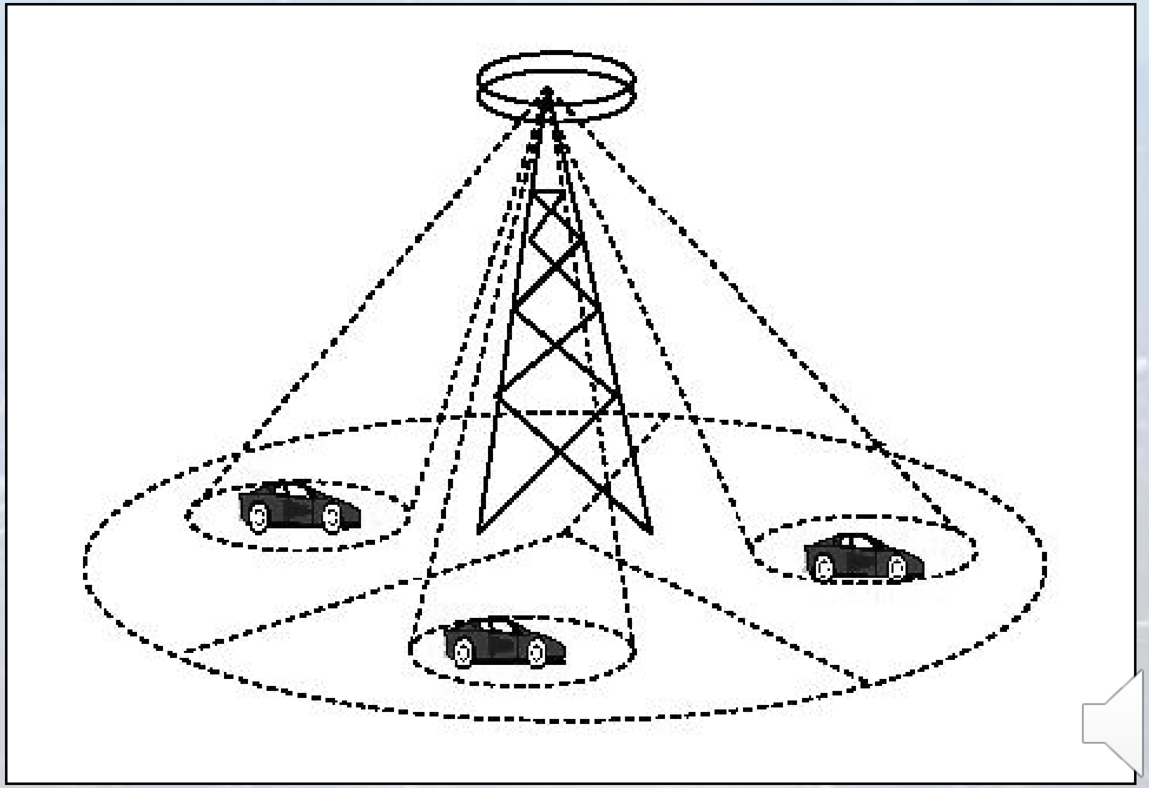
- Received Composite signal: C = (0,–2,–2,0,2,0,2,0)
- We know that the chipping rate is 2, hence C = [(0,–2),(–2,0),(2,0),(2,0)]
- To decode:
  - User1 = C.v1
  - User2 = C.v2
  - User 1 = [(0,–2),(–2,0),(2,0),(2,0)].(1,-1)= ((0+2),(–2+0),(2+0),(2+0)) = (2,-2,2,2)
  - User 2 = [(0,–2),(–2,0),(2,0),(2,0)].(1,1) = ((0–2),(–2+0),(2+0),(2+0)) = (-2,-2,2,2)
- Above zero →1
- Below Zero →0

Why this works??

- Hence the received bits are:
  - User 1 = (1,0,1,1)
  - User 2 = (0,0,1,1)

Space Division Multiple Access (SDMA)

- Space dimension.
- Uses directional tx antennas to cover angular regions.
- Same frequency is used for each space.



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Thank You