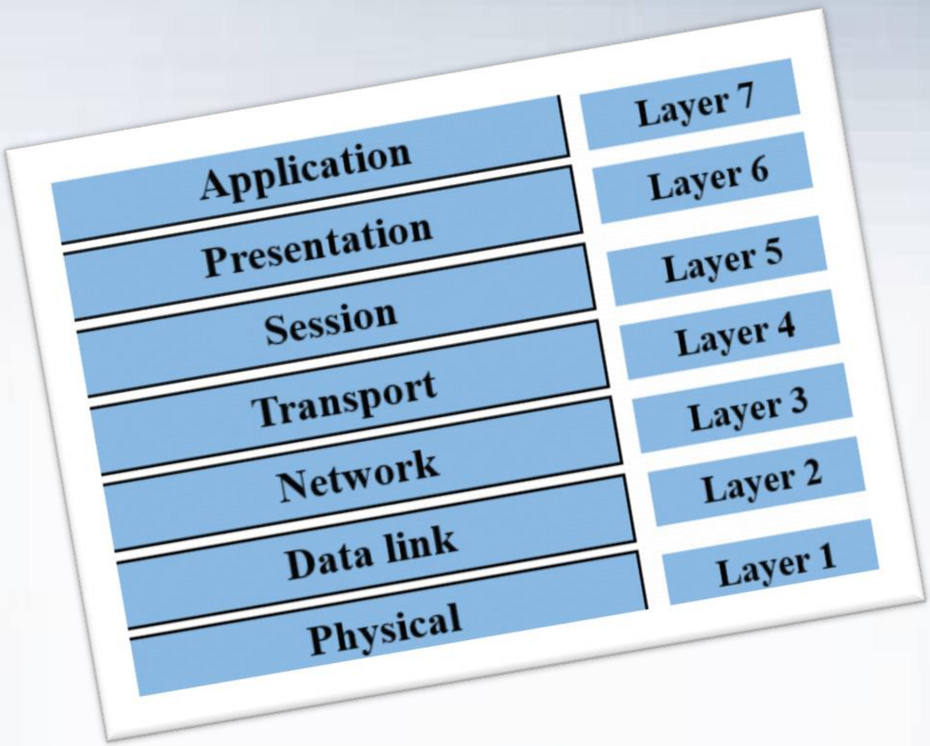
# CWNA Guide to Wireless LANs, Third Edition




*Chapter 5: Physical Layer Standards*

# Objectives

- List and describe the wireless modulation technologies
- Explain the features in the 802.11b Physical Layer Standards
- Describe the technologies found in the 802.11a PHY standards
- Explain how the 802.11g Physical Layer Standards are different from the other standards
- List the features in the 802.11n PHY standards

# Introduction

- Open Systems Interconnection (OSI) reference model: seven-layer model that conceptually illustrates the steps of networking (how dissimilar computers could be connected through a network)
  - Created by the International Organization for Standardization (ISO) in 1978
  - Within each layer, different networking tasks are performed by hardware and/or software
  - Revised in 1983
- This chapter deals with WLAN functions at the Physical Layer of the OSI model

# OSI Model

| Layer | Name | Function |
|---|---|---|
| 7 | Application | Interacts with software applications to provide the interface for network services. |
| 6 | Presentation | Handles how the data is represented and formatted for the user. |
| 5 | Session | Permits the devices on the network to hold ongoing communications across the network. Handles session setup, data or message exchanges, and tear-down when the session ends. |
| 4 | Transport | Ensures that error-free data is given to the user. It handles the setup and tear-down of connections. |
| 3 | Network | Picks the route packets take and handles addressing of packets for delivery. |
| 2 | Data Link | Provides the means to transfer data between network entities and detect and correct errors. |
| 1 | Physical | Sends signals to the network or receives signals from the network. |



Table 5-1: OSI layers and functions

# Physical Layer Functions

**Establishment and termination of a connection to a communication medium**

**Process for effective use of communication resources**

**Conversion between representation of digital data**

**Physical characteristics of interfaces and media**

**Representation of bits, transmission rate, synchronization of bits**

**Link configuration**

**Physical topology, and transmission mode**

# Data Link Layer Functions

**Provides functional and procedural means to transfer data between network entities**

**Responds to service requests from the network layer and issues requests to the physical layer**

**Concerned with:**

- **Framing**
- **Physical addressing**
- **Flow Control**
- **Error Control**
- **Access Control**

# Network Layer Functions

**Provides for transfer of variable length sequences from source to destination via one or more networks**

**Responds to service requests from the transport layer and issues requests to the data link layer**

**Concerned with:**

- **Logical addressing**
- **Routing**

# Transport Layer Functions

- **Provides transparent data transfer between end users**
- **Responds to service requests from the session layer and issues requests to the network layer**
- **Concerned with:**
  - **Service-point addressing**
  - **Segmentation and reassembly**
  - **Connection control; Flow Control**
  - **Error Control**

# Session Layer Functions

Provides mechanism for managing a dialogue between end-user application processes

Responds to service requests from the presentation layer and issues requests to the transport layer

Supports duplex or half- duplex operations

Concerned with:

- Dialogue control
- Synchronization

# Presentation Layer Functions

**Relieves application layer from concern regarding syntactical differences in data representation with end-user systems**

**Responds to service requests from the application layer and issues requests to the session layer**

**Concerned with:**

- **Translation**
- **Encryption**
- **Compression**

# Application Layer Functions

**Interfaces directly to and performs common application services for application processes**

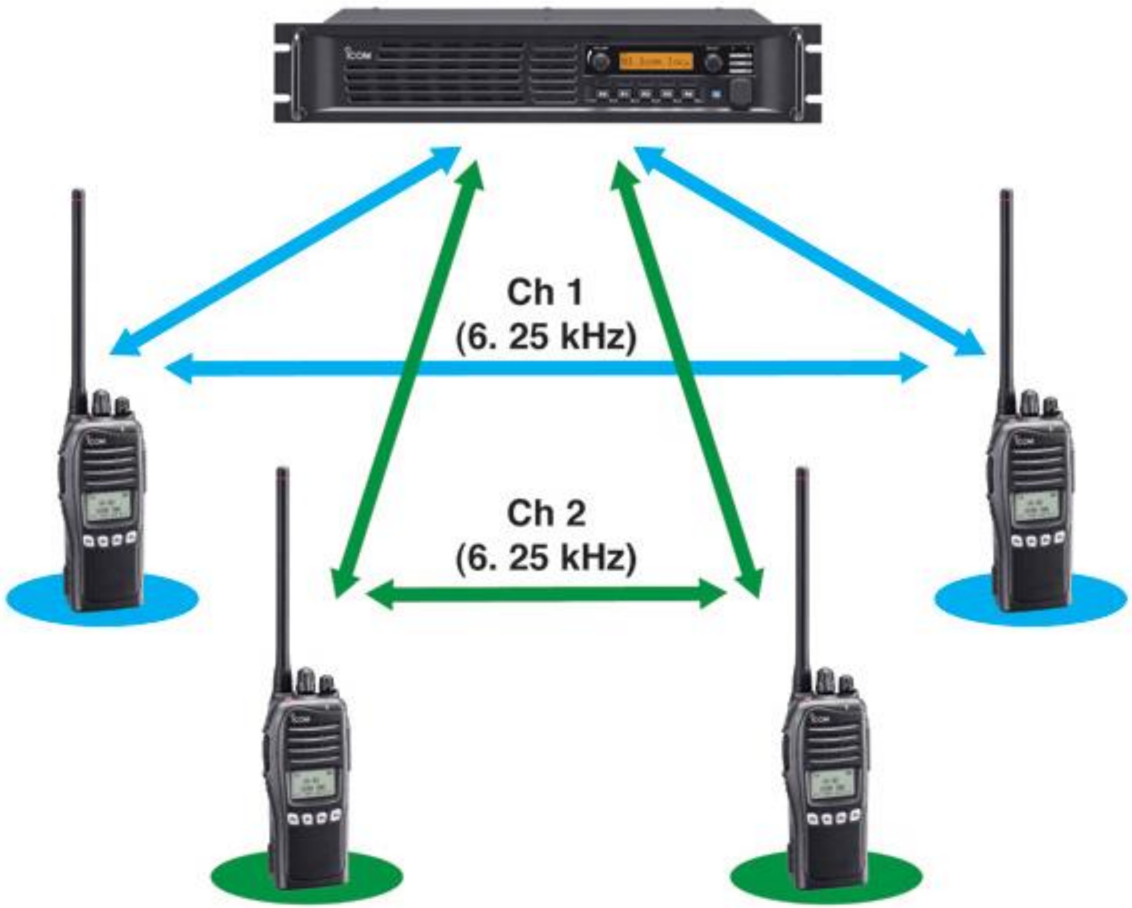
**Issues service requests to the Presentation layer**

**Specific services provided:**

- **Network virtual terminal**
- **File transfer, access and management**
- **Mail services**
- **Directory services**

# Multiple Access Principles-TDMA

# Multiple Access Principles-TDMA



# Multiple Access Principles

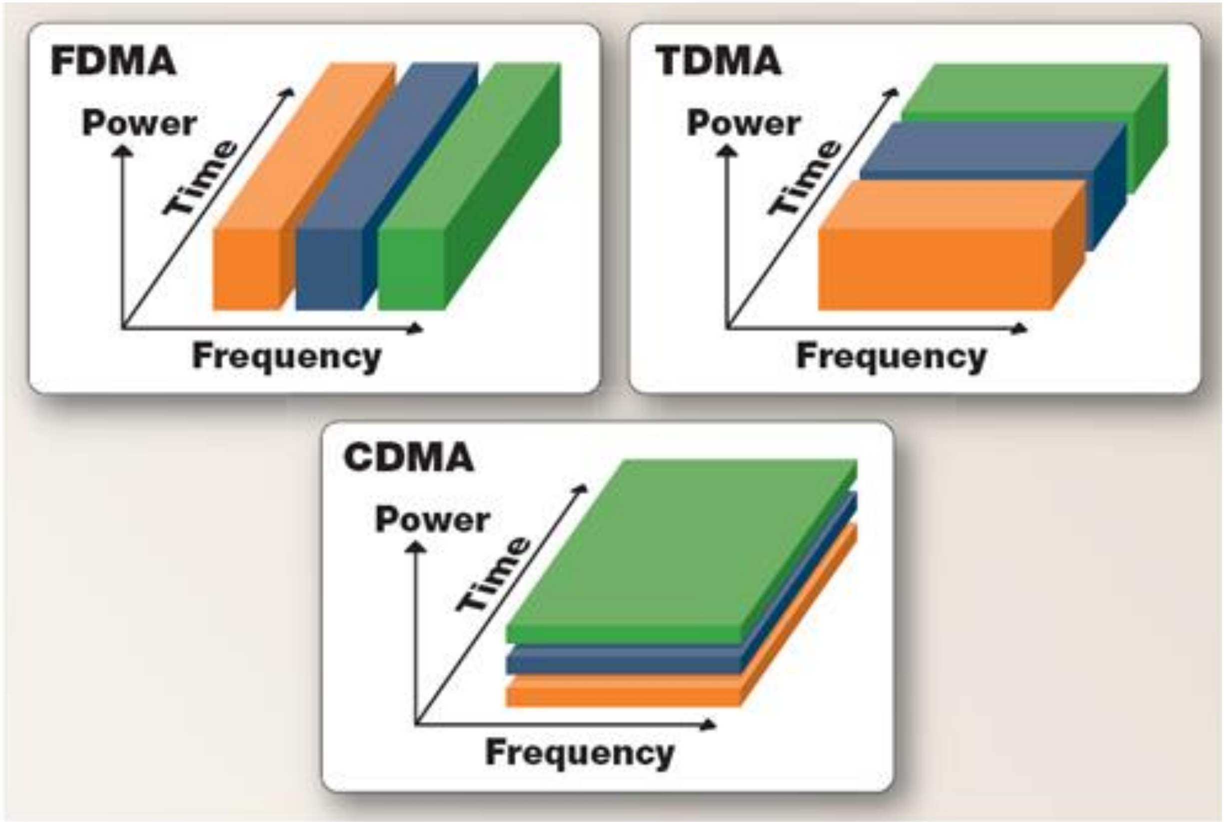
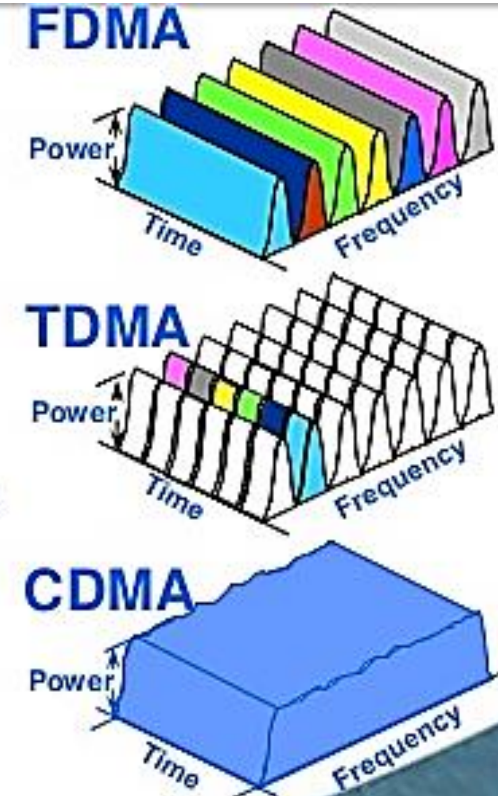



*Figure 4. Multiple Access principles – FDMA, TDMA and CDMA*

# Multiple Access Principles

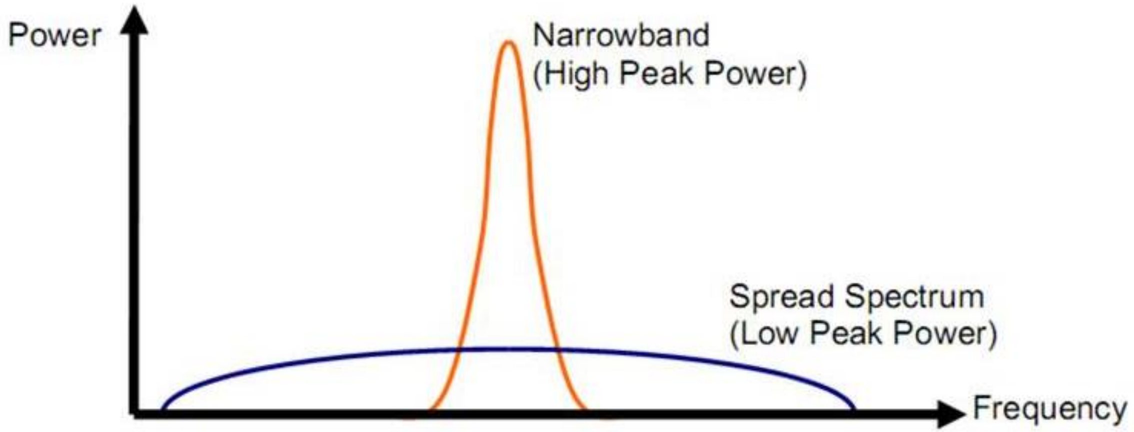
- *FDMA Frequency Division Multiple Access*
  - Each user on a different frequency
  - A channel is a frequency
- *TDMA Time Division Multiple Access*
  - Each user on a different window period in time ("time slot")
  - A channel is a specific time slot on a specific frequency
- *CDMA Code Division Multiple Access*
  - A channel is a unique code pattern
  - Each user uses the same frequency all the time, but mixed with different distinguishing code patterns



# Wireless Modulation Technologies

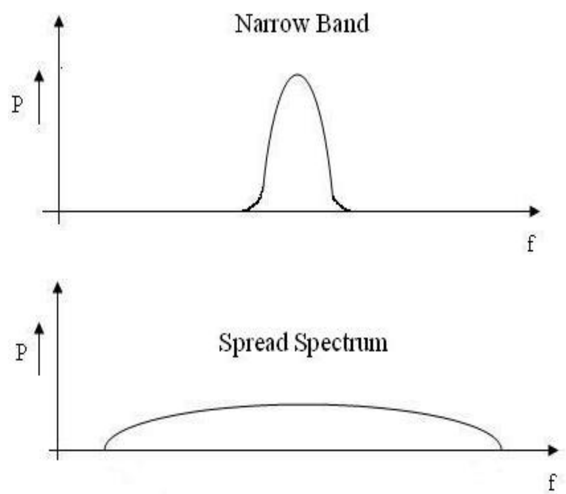
- Two primary wireless modulation techniques:
  - Narrowband transmission
  - Spread spectrum

- Narrowband transmission used primarily by radio stations



# Narrowband Transmission

- Radio signals by nature transmit on only one radio frequency or a narrow portion of frequencies
- Require more power for the signal to be transmitted
  - Signal must exceed **noise level**
    - Total amount of outside interference
- Vulnerable to interference from another radio signal at or near same frequency
- IEEE 802.11 standards do not use narrowband transmissions



# Narrowband Transmission

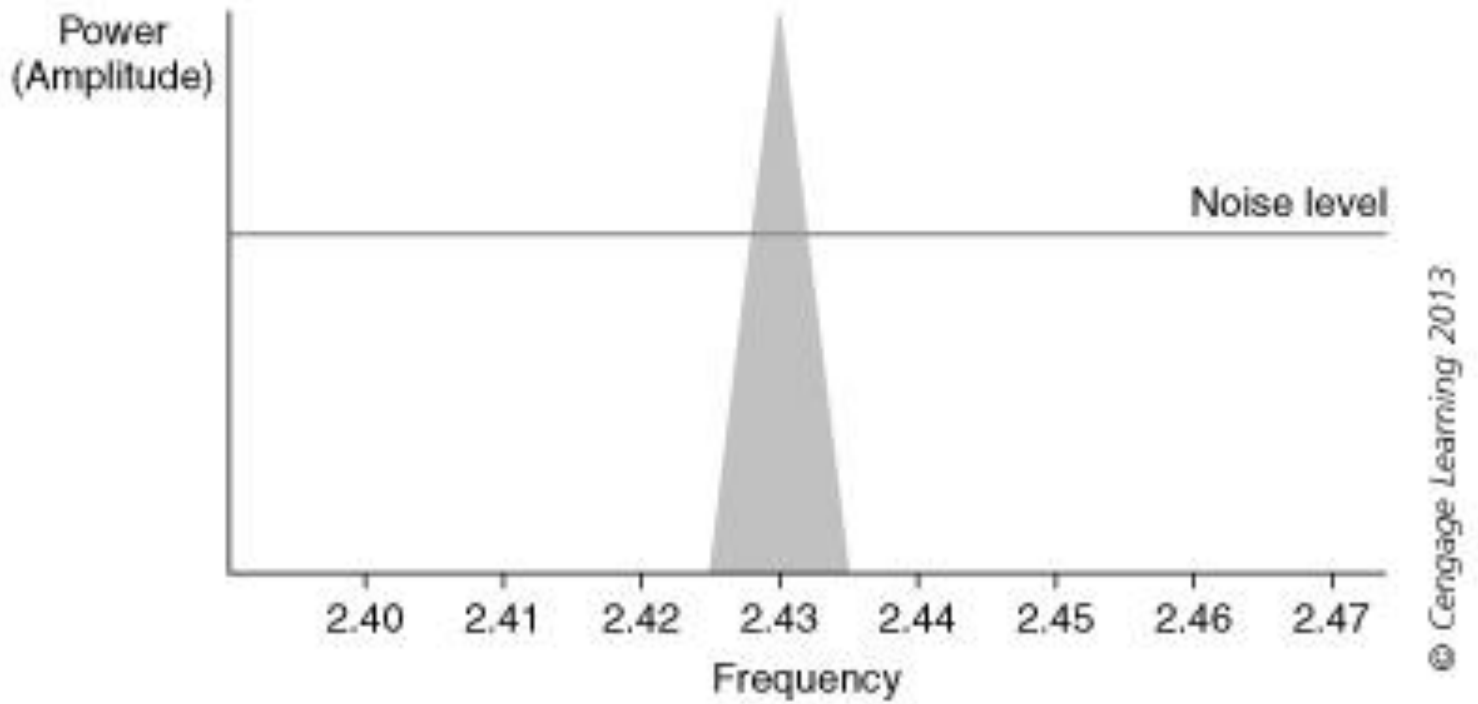
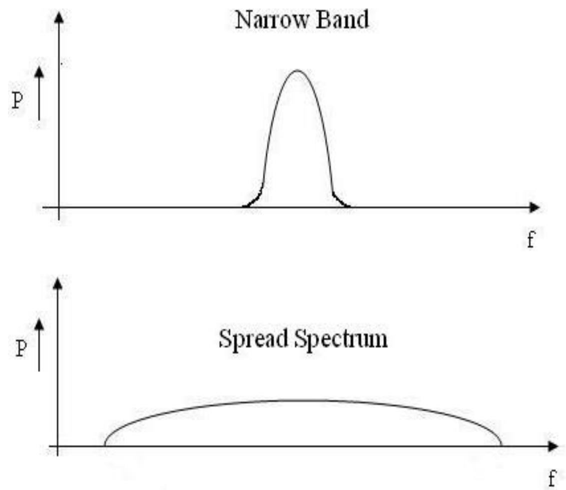



Figure 5-1 Narrowband transmission

# Spread-Spectrum Transmissions

- Spread-spectrum transmits a weaker signal across a broader portion of the RF band

- Advantages over narrowband:
  - Resistance to narrowband interference
  - Resistance to spread-spectrum interference
  - Lower power requirements
  - Less interference on other systems
  - More information transmitted
  - Increased security
  - Resistance to multipath distortion



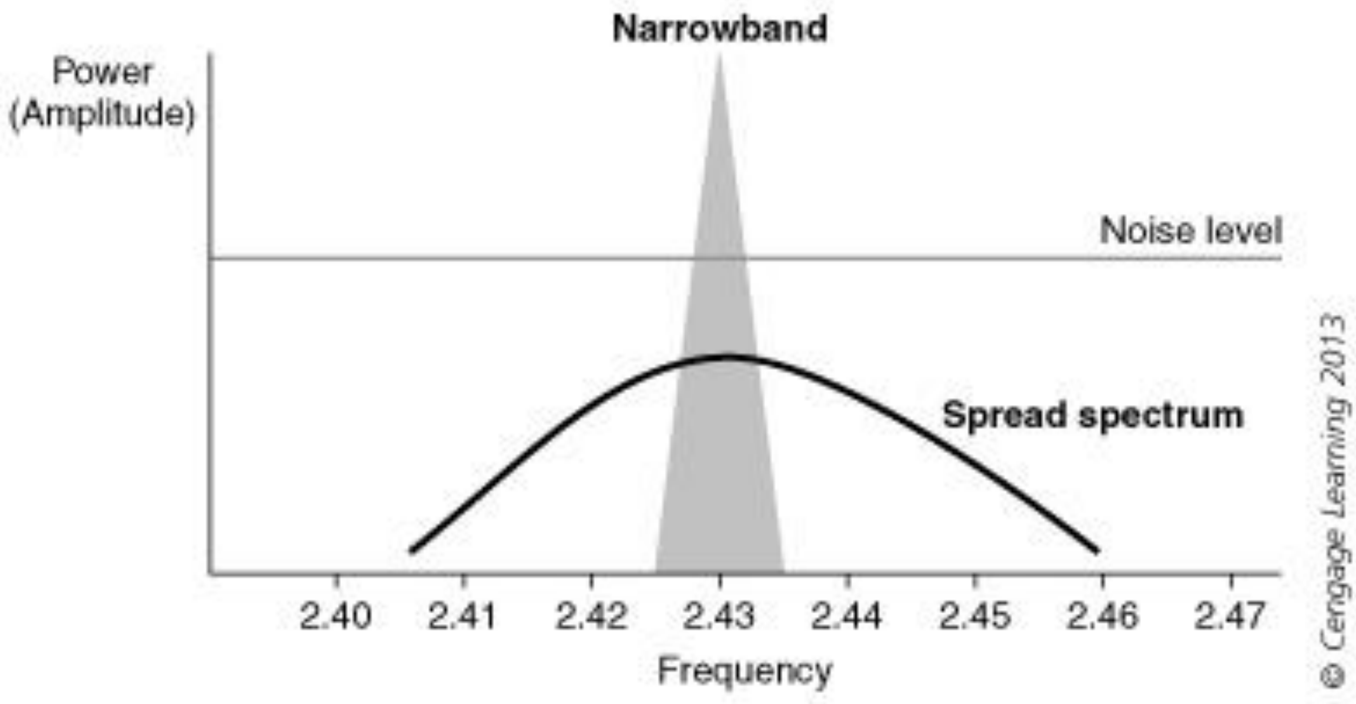
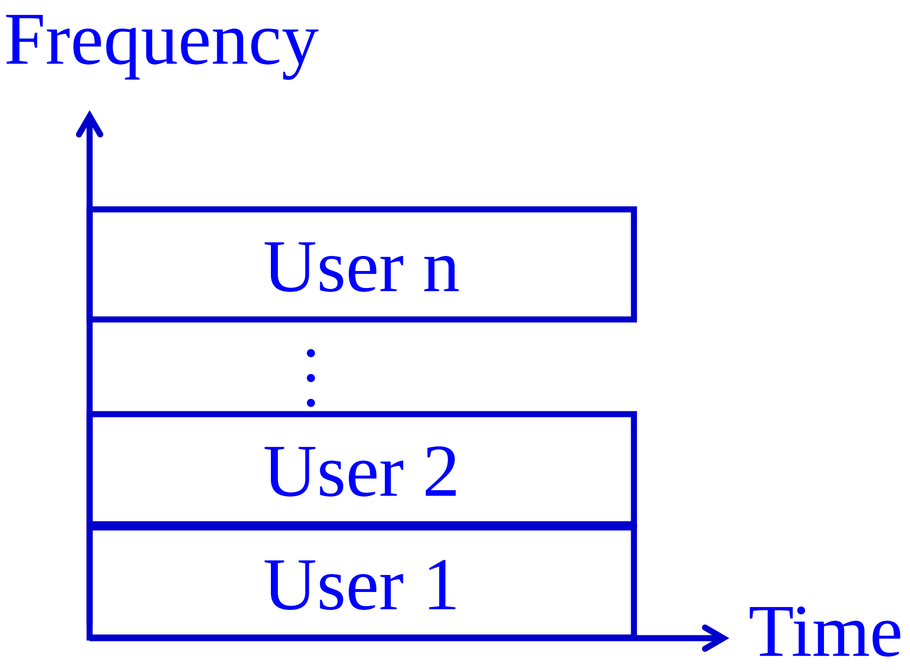
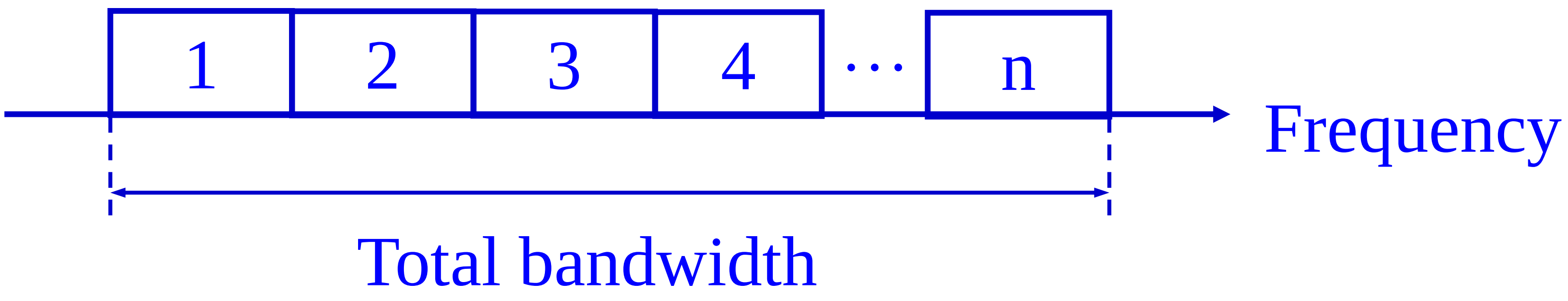



Figure 5-2 Narrowband vs. spread spectrum transmission

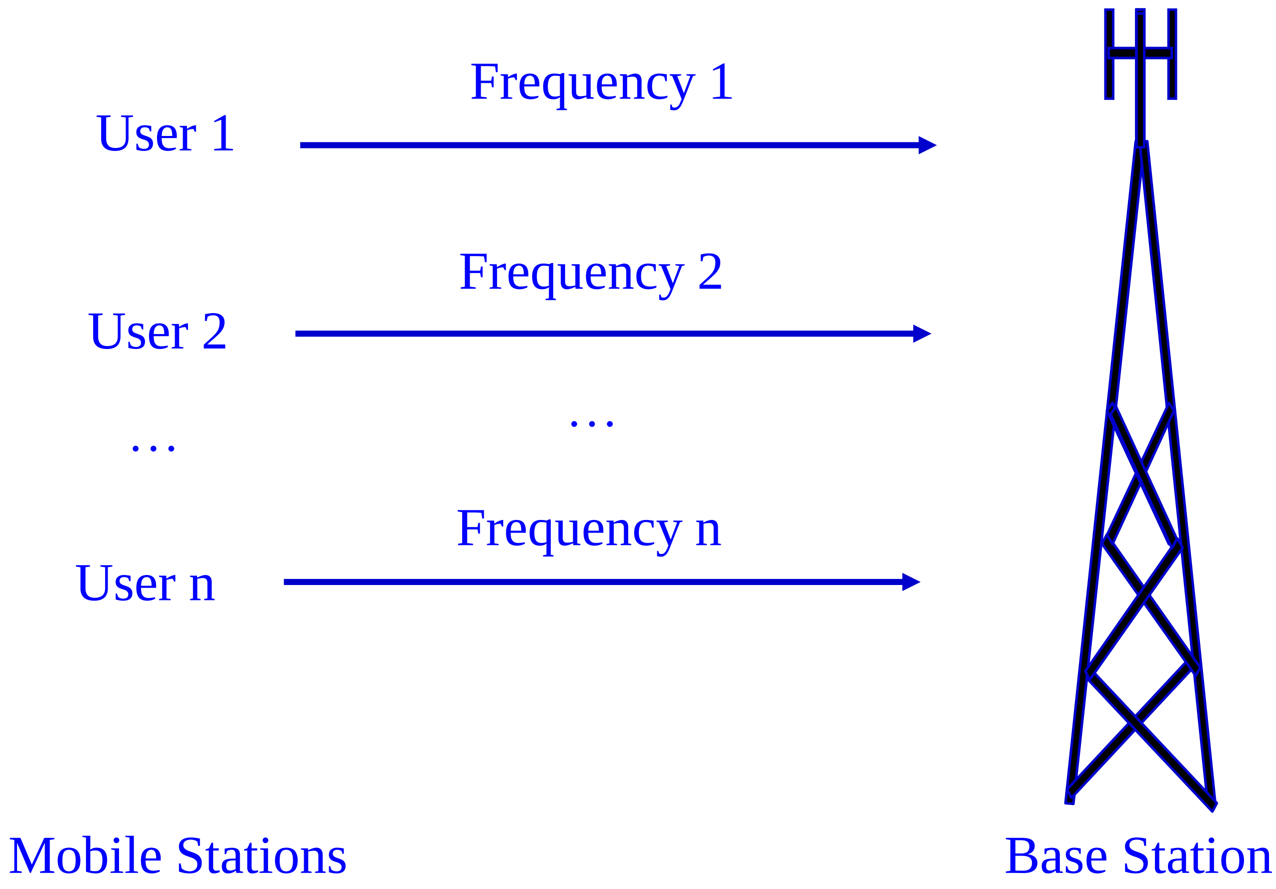
# FDMA (Frequency Division Multiple Access)



# FDMA Bandwidth Structure



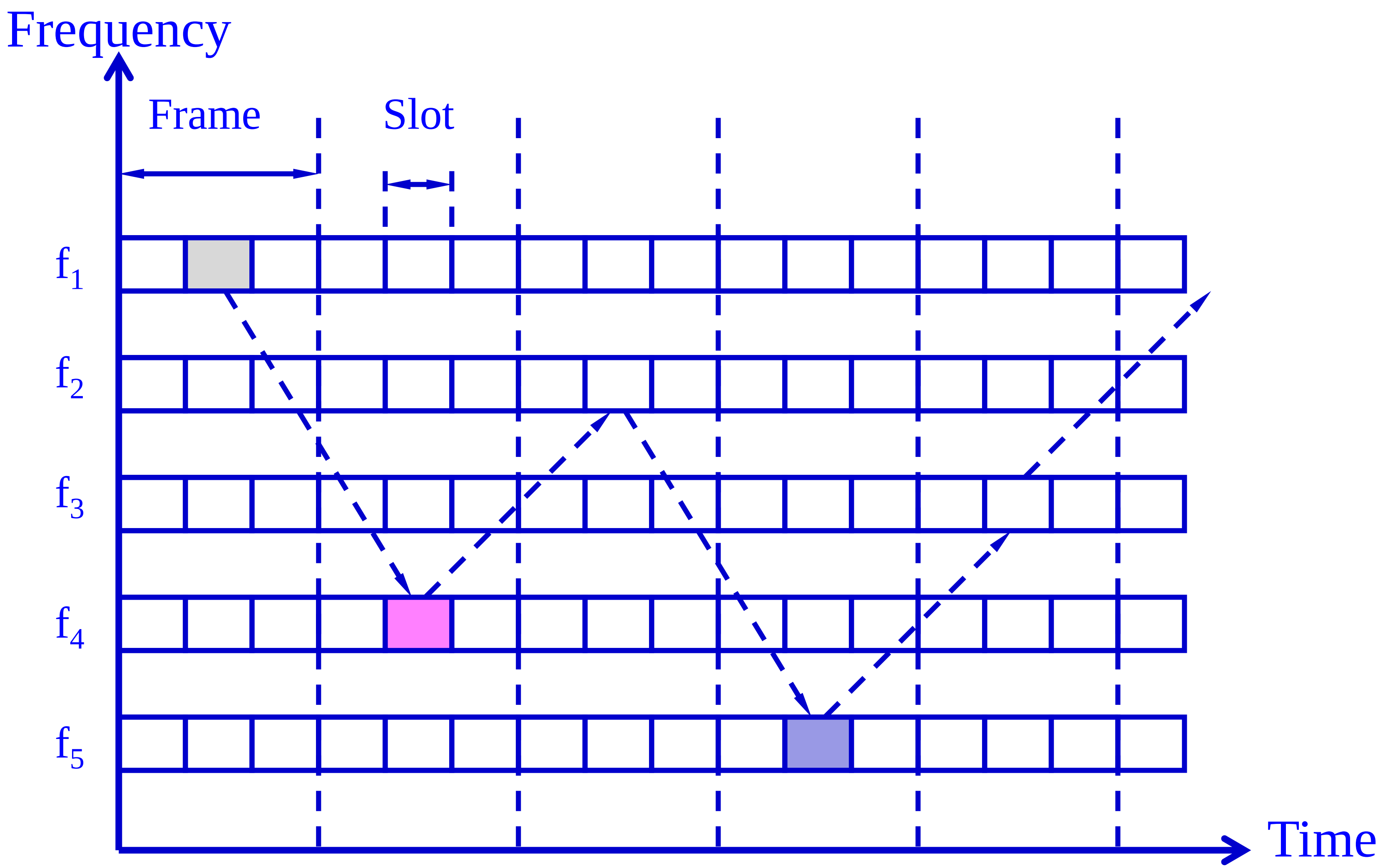
# FDMA Channel Allocation



# Frequency Hopping Spread Spectrum (FHSS)

- Uses range of frequencies (called the bandwidth)
  - Change during transmission
- **Dwell time**: amount of time that a transmission occurs on a specific frequency
- **Hop time**: time it takes to change a frequency
- **Hopping code:** Sequence of changing frequencies
  - If interference encountered on particular frequency then that part of signal will be retransmitted on next frequency of hopping code
- Due to speed limitations FHSS not widely implemented in today's WLAN systems

# Frequency Hopping



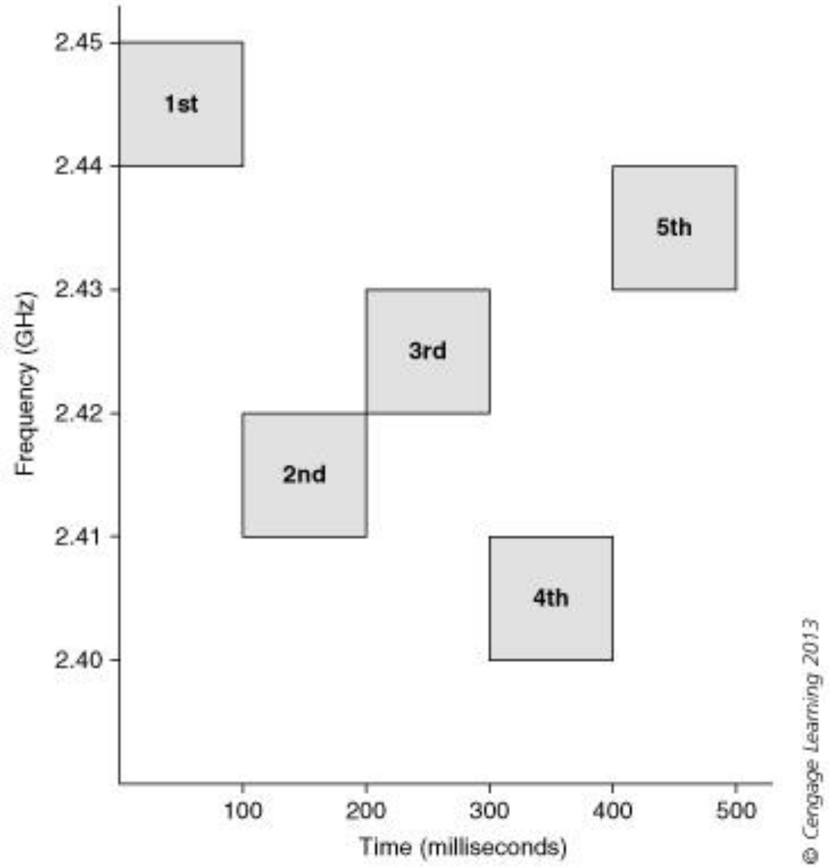



Figure 5-3 FHSS transmission

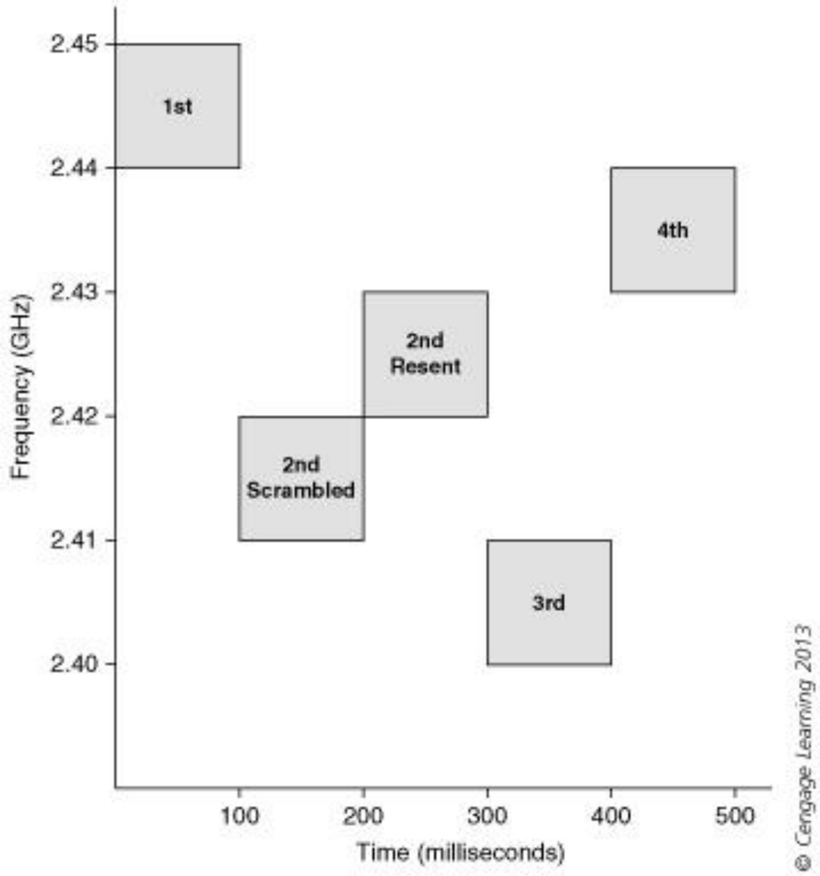
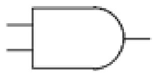
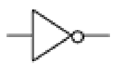
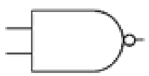
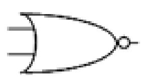



Figure 5-4 FHSS error correction

# Direct Sequence Spread Spectrum (DSSS)

- Uses expanded redundant code to transmit data bits
- **Chipping code:** Bit pattern substituted for original transmission bits
  - Advantages of using DSSS with a chipping code:
    - Error correction
    - Less interference on other systems
    - Shared frequency bandwidth
      - **Co-location:** Each device assigned unique chipping code
    - Security

# Direct Sequence Spread Spectrum (DSSS)

| Gate | Symbol | Operator |
|---|---|---|
| and |  | $A \cdot B$ |
| or |  | $A + B$ |
| not |  | $\bar{A}$ |
| nand |  | $\overline{A \cdot B}$ |
| nor |  | $\overline{A + B}$ |
| xor |  | $A \oplus B$ |

*Exclusive-OR gate*


| A | B | Output |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

# Direct Sequence Spread Spectrum (DSSS)

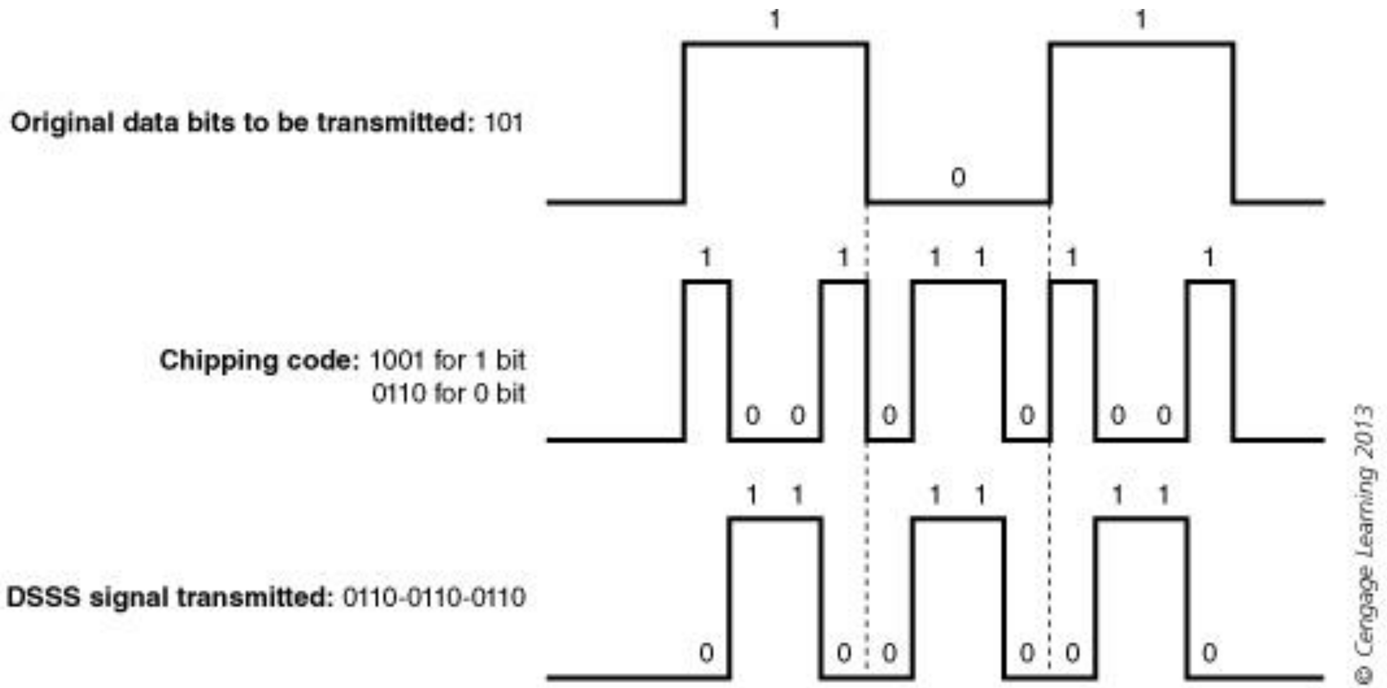



Figure 5-5 DSSS

# Orthogonal Frequency Division Multiplexing (OFDM)

OFDM is a special case of Frequency Division Multiplex (FDM). As an analogy, a FDM channel is like water flow out of a faucet, in contrast the OFDM signal is like a shower. In a faucet all water comes in one big stream and cannot be sub-divided. OFDM shower is made up of a lot of little streams.


**Fig. 1 – (a) A Regular-FDM single carrier – A whole bunch of water coming all in one stream. (b) Orthogonal-FDM – Same amount of water coming from a lot of small streams.**

Think about what the advantage might be of one over the other? One obvious one is that if I put my thumb over the faucet hole, I can stop the water flow but I cannot do the same for the shower. So although both do the same thing, they respond differently to interference.

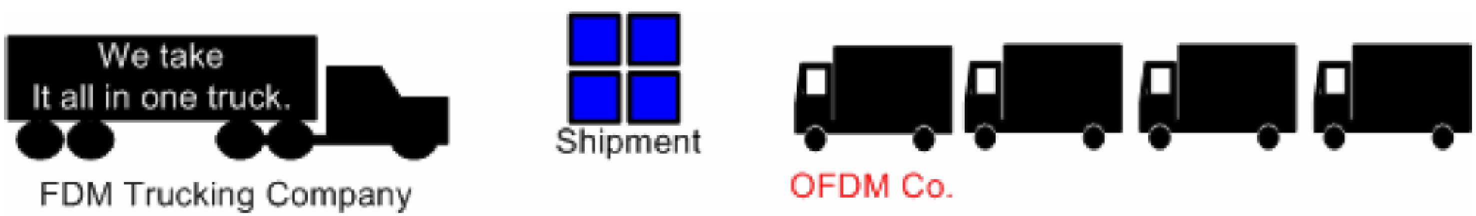



**Fig. 2 – All cargo on one truck vs. splitting the shipment into more than one.**

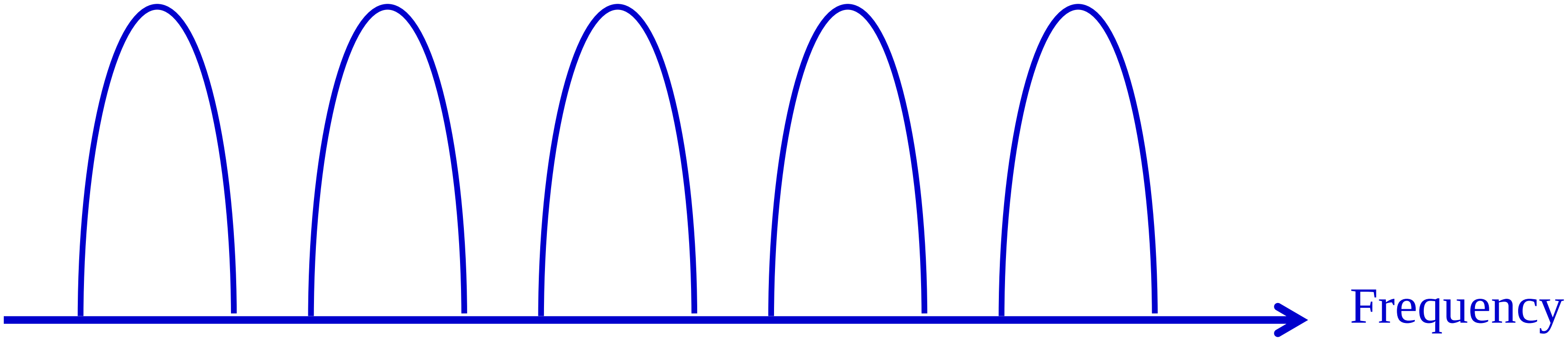
Another way to see this intuitively is to use the analogy of making a shipment via a truck. We have two options, one hire a big truck or a bunch of smaller ones. Both methods carry the exact same amount of data. But in case of an accident, only 1/4 of data on the OFDM trucking will suffer.

# Orthogonal Frequency Division Multiplexing (OFDM)

- **OFDM:** Send multiple signals at same time
  - Split high-speed digital signal into several slower signals running in parallel
- OFDM *increases* throughput by sending data more *slowly*
- Avoids problems caused by multipath distortion
- With multipath distortion, receiving device must wait until all reflections received before transmitting
  - Puts ceiling limit on overall speed of WLAN
- **Intersymbol interference (ISI)**: Signal interference as a result of multipath transmission

https://www.youtube.com/watch?v=tPQ_ahjCujY
https://www.youtube.com/watch?v=kqkYUzYiLF4

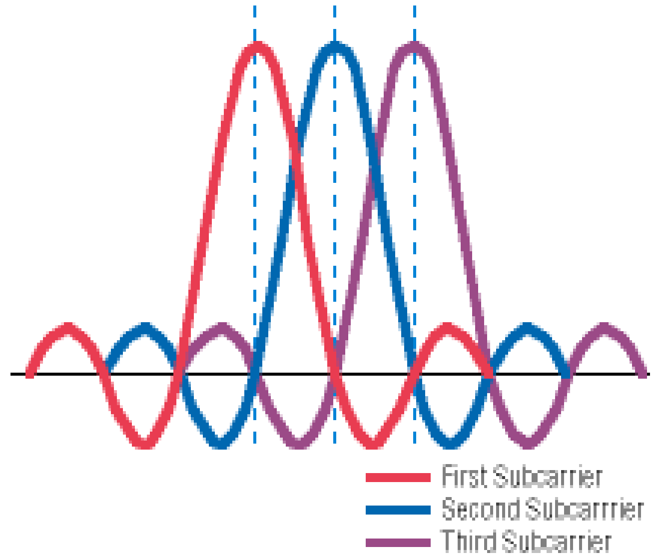
# FDMA-OFDM

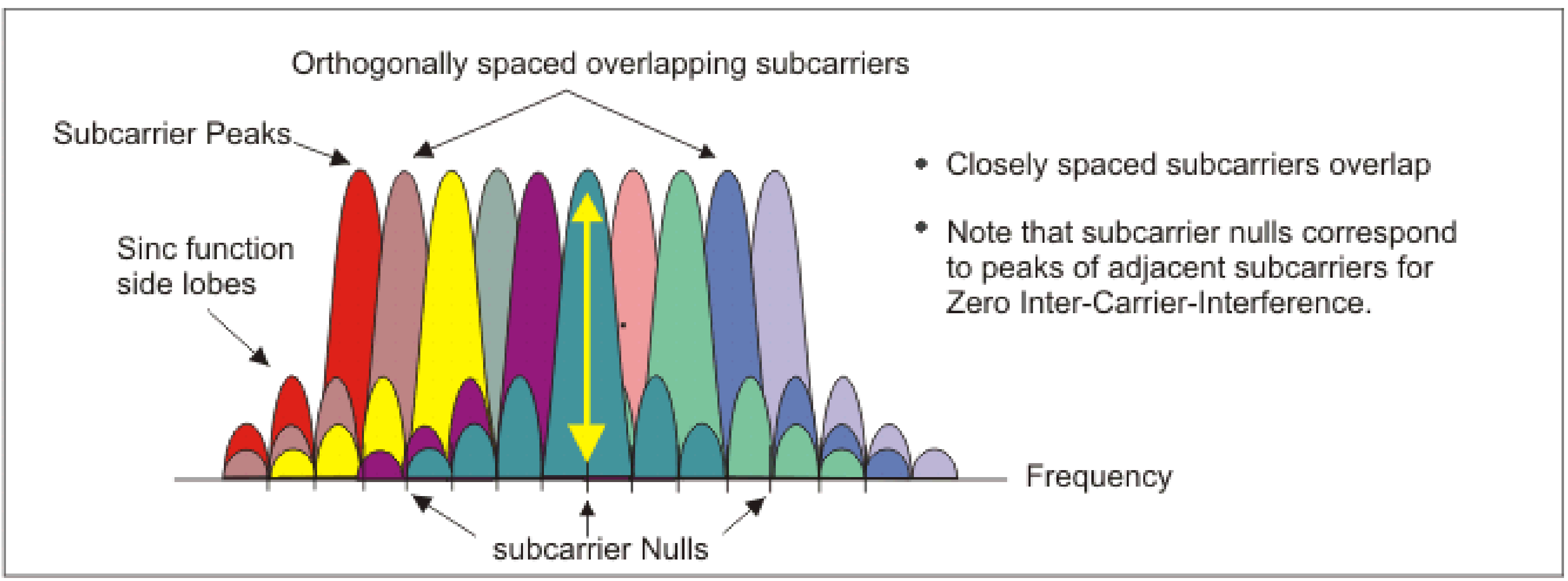



Conventional multicarrier modulation used in FDMA


Orthogonal multicarrier modulation used in OFDM

# OFDM (Orthogonal Frequency Division Multiplexing)




OFDM Signal Frequency Spectra

# OFDM

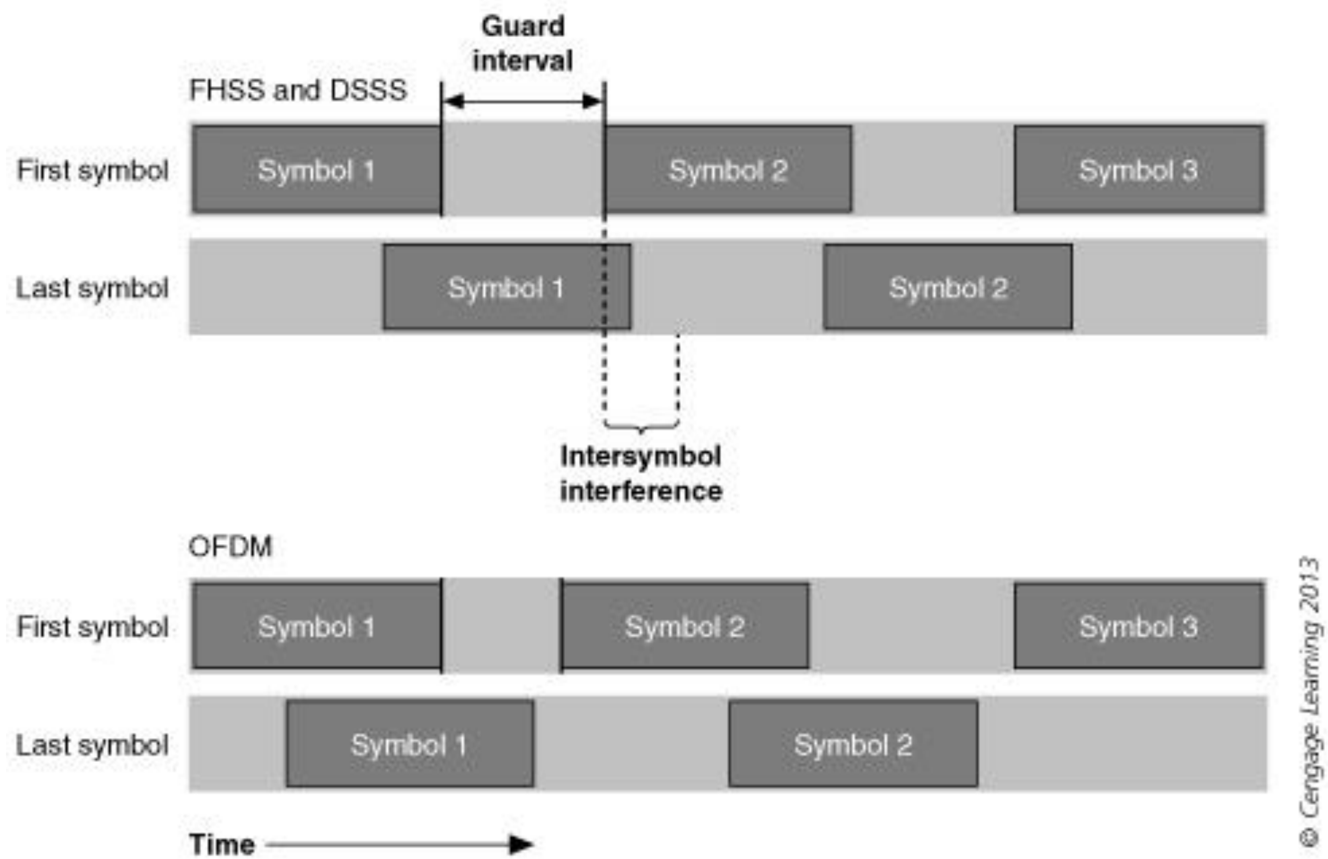



Figure 5-6 OFDM

# Comparison of Modulation Technologies

- Narrowband transmission require more power and are more vulnerable to interference
- FHSS transmissions less prone to interference from outside signals than DSSS
- WLAN systems that use FHSS have potential for higher number of co-location units than DSSS
- DSSS has potential for greater transmission speeds over FHSS
- **Throughput** much greater for OFDM and has become the preferred modulation technique for faster WLANs

# IEEE 802.11 Physical Layer Standards

- IEEE wireless standards follow OSI model, with some modifications
- Data Link layer divided into two sublayers:
  - **Logical Link Control (LLC) sublayer:** Provides common interface, reliability, and flow control
  - **Media Access Control (MAC) sublayer:** Appends physical addresses to frames

# Data Link Sublayers

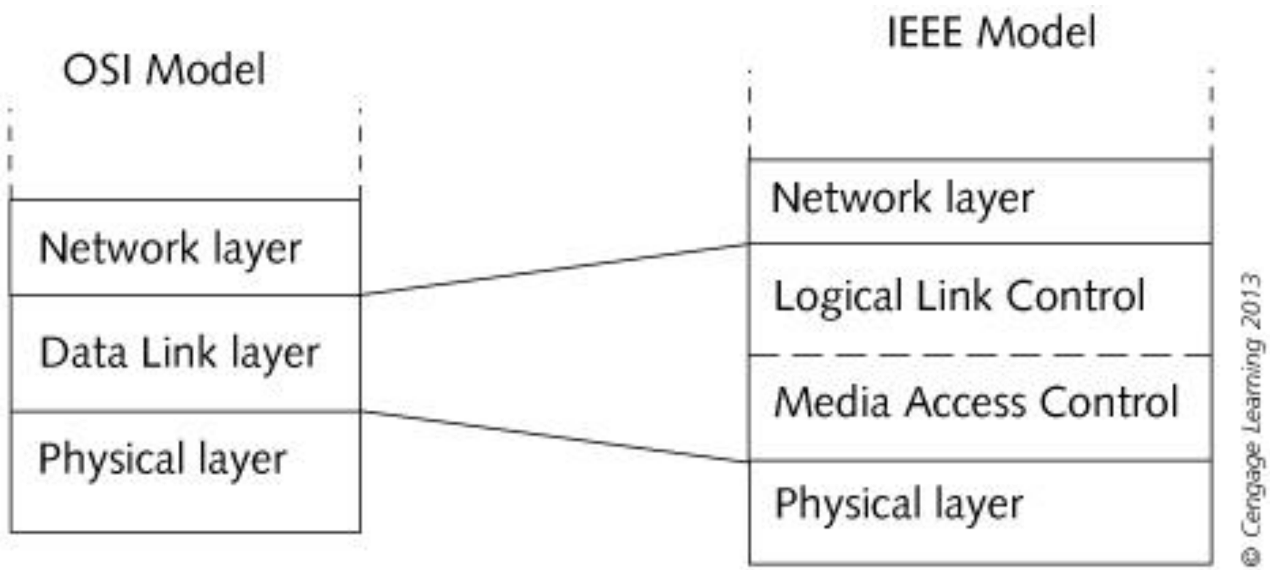



Figure 5-7 Data Link sublayers

# IEEE 802.11 Physical Layer Standards

- Physical layer divided into two sublayers:
  - **Physical Medium Dependent (PMD) sublayer:** Makes up standards for characteristics of wireless medium (such as DSSS or FHSS) and defines method for transmitting and receiving data
  - **Physical Layer Convergence Procedure (PLCP) sublayer:** Performs two basic functions
    - Reformats data received from MAC layer into frame that PMD sublayer can transmit
    - "Listens" to determine when data can be sent

# IEEE 802.11 Physical Layer Standards

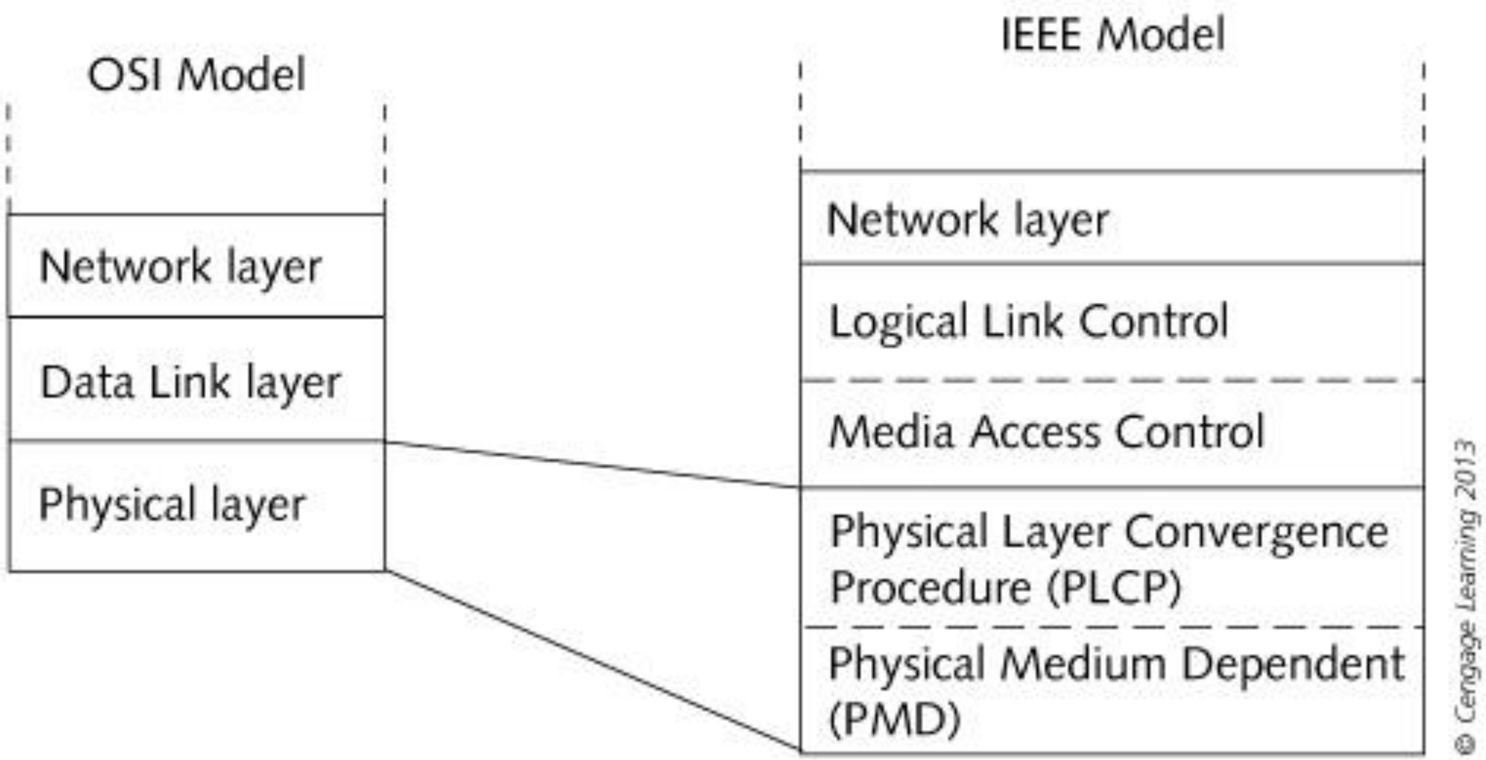



Figure 5-8 PHY sublayers

# PLCP sublayer functions

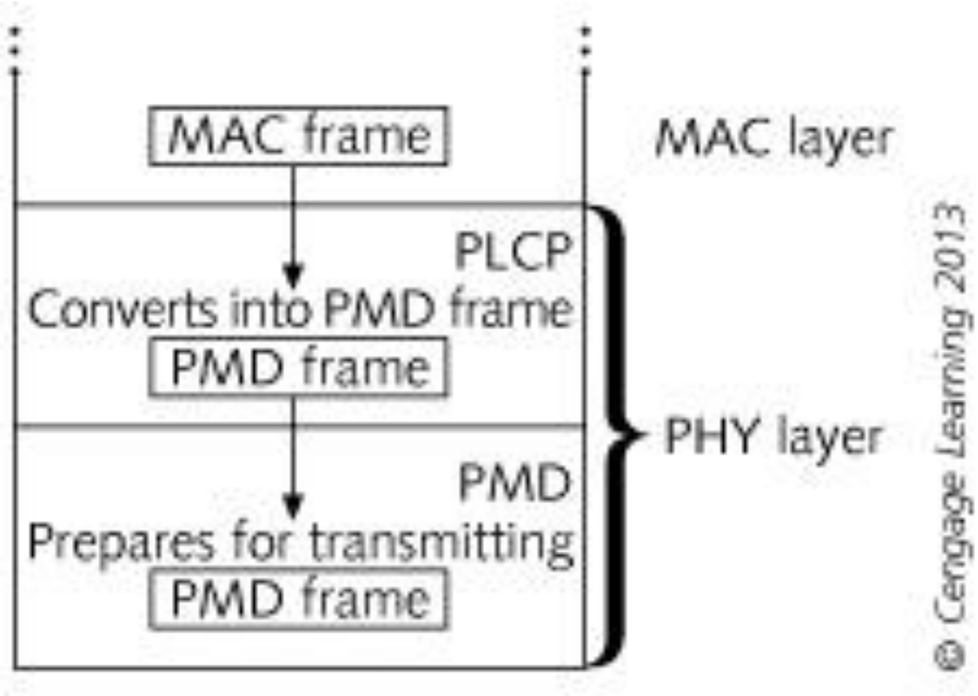



Figure 5-9 PLCP sublayer functions

# IEEE 802.11b Physical Layer Standards

- **Physical Layer Convergence Procedure Standards:** Based on DSSS
  - PLCP must reformat data received from MAC layer into a frame that the PMD sublayer can transmit

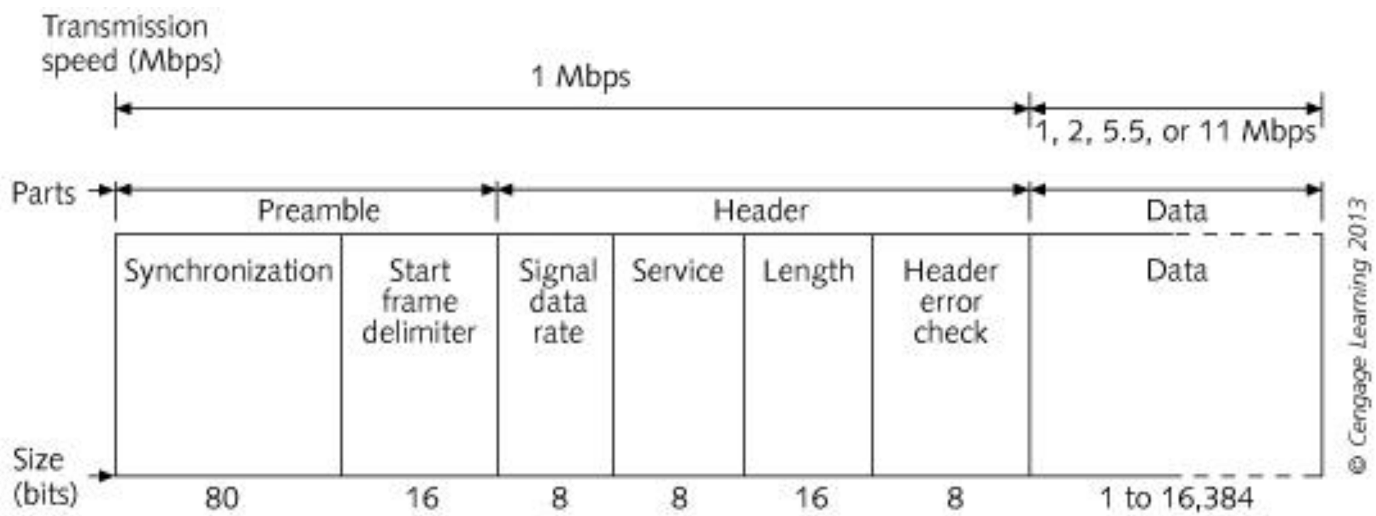



Figure 5-10 802.11b PLCP frame

# IEEE 802.11b Physical Layer Standards

- PLCP frame made up of three parts:
  - **Preamble:** prepares receiving device for rest of frame
  - **Header:** Provides information about frame
  - **Data:** Info being transmitted
    - Synchronization field
    - Start frame delimiter field
    - Signal data rate field
    - Service field
    - Length field
    - Header error check field
    - Data field

# IEEE 802.11b Physical Layer Standards

- **Physical Medium Dependent Standards:** PMD translates binary 1's and 0's of frame into radio signals for transmission
  - Can transmit at 11, 5.5, 2, or 1 Mbps
  - 802.11b uses ISM band
    - 14 frequencies can be used
  - Two types of modulation can be used
    - **Differential binary phase shift keying (DBPSK):** For transmissions at 1 Mbps
    - **Differential quadrature phase shift keying (DQPSK):** For transmissions at 2, 5.5, and 11 Mbps

# IEEE 802.11b Physical Layer Standards

- 802.11b standard outlines the type of DSSS coding to be used
  - DSSS uses the expanded redundant code (also called **Barker code**) to transmit each data bit
  - Barker code is used when transmitting at 1 or 2 Mbps
  - **Complementary code keying (CCK)** is used to transmit at rates above 2 Mbps

# IEEE 802.11b Physical layer standards

| Transmission Speed (Mbps) | Modulation | DSSS Coding Technique |
|---|---|---|
| 1 | Differential binary phase shift keying (DBPSK) | Barker code |
| 2 | Differential quadrature phase shift keying (DQPSK) | Barker code |
| 5.5 | Differential quadrature phase shift keying (DQPSK) | Complementary code keying (CCK) |
| 11 | Differential quadrature phase shift keying (DQPSK) | Complementary code keying (CCK) |



Table 5-3 IEEE 802.11b Physical layer standards

# IEEE 802.11a Physical Layer Standards

- 802.11a standards are significantly different from 802.11b standards
- Differences have to do with:
  - Increasing speed from 11 Mbps to 54 Mbps
  - The PLCP frame contents
  - Modulation techniques

# Higher Speed Enhancements

- IEEE 802.11a achieves increase in speed and flexibility over 802.11b primarily through OFDM
  - Use higher frequency
  - Accesses more transmission channels
  - More efficient error-correction scheme

# Higher Speed Enhancements

- Unlicensed National Information Infrastructure (UNII) band: intended for short-range, high-speed wireless digital communications devices
  - Total bandwidth using U-NII is almost four times that available for 802.11b networks using ISM band
- Disadvantage:
  - Not all countries permit transmissions in all of the UNII bands
  - Maximum power output can vary between countries
- Transmit power control: an IEEE 802.11a technology to reduce interference

| UNII Band | Frequency (GHz) | Maximum Power Output (mW) |
|---|---|---|
| UNII-1 (Low Band) | 5.15–5.25 | 50 |
| UNII-2 (Middle Band) | 5.25–5.35 | 250 |
| UNII-2 (Extended) | 5.47–5.725 | 250 |
| UNII-3 (High Band) | 5.725–5.825 | 1000 |



Table 5-4 UNII characteristics

# Higher Speed Enhancements

- **Error correction**
  - 802.11a has fewer errors than 802.11b
  - Transmissions sent over parallel subchannels
  - Interference tends to only affect one subchannel

- **Forward Error Correction (FEC):** Transmits secondary copy along with primary information
  - 4 of 52 channels used for FEC
  - Secondary copy used to recover lost data
    - Reduces need for retransmission

# Higher Speed Enhancements

- PLCP for 802.11a based on OFDM
- Three basic frame components: Preamble, header, and data

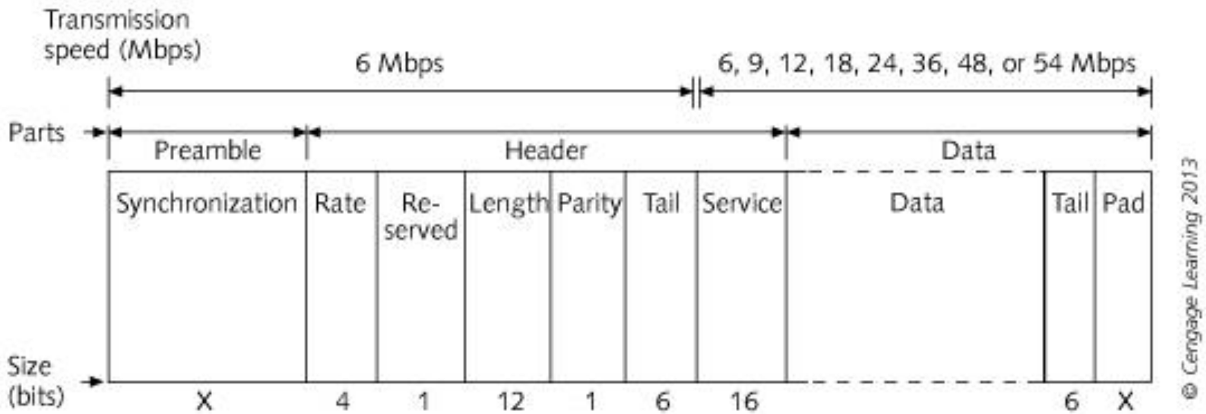



Figure 5-12 802.11a PLCP frame

# Modulation Techniques

- Modulation techniques used to encode 802.11a data vary depending upon speed
- Speeds higher than 54 Mbps may be achieved using **2X mode (turbo mode)**

| Transmission Speed (Mbps) | Modulation |
|---|---|
| 6 | Phase shift keying (PSK) |
| 12 | Quadrature phase shift keying (QPSK) |
| 24 | 16-level quadrature amplitude modulation (16-QAM) |
| 54 | 64-level quadrature amplitude modulation (16-QAM) |



Table 5-6 802.11a characteristics

# Phase shift keying (PSK)

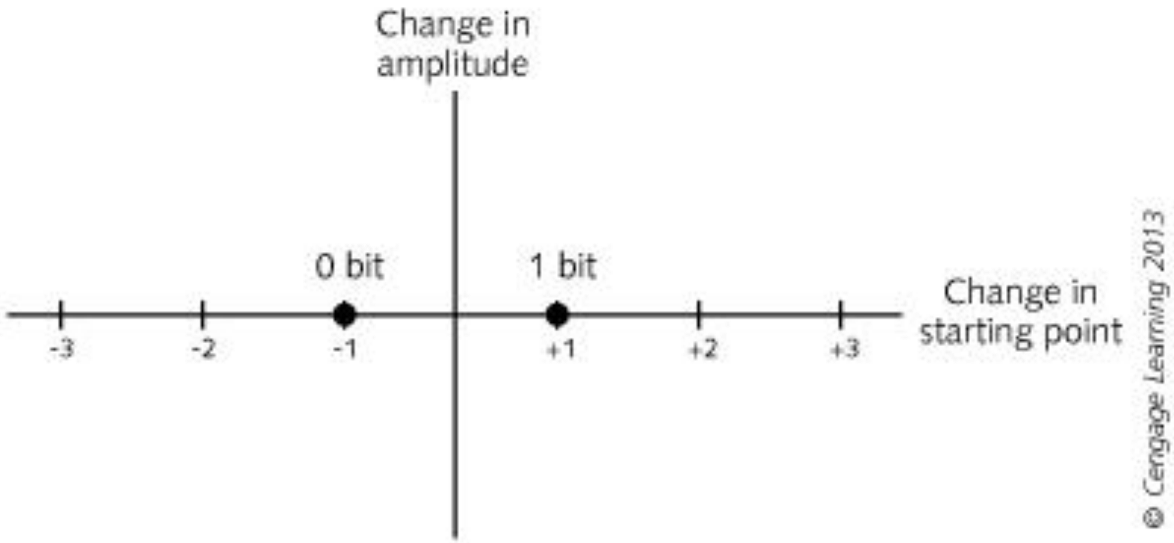



Figure 5-13 Phase shift keying (PSK)

# Quadrature phase shift keying (QPSK)

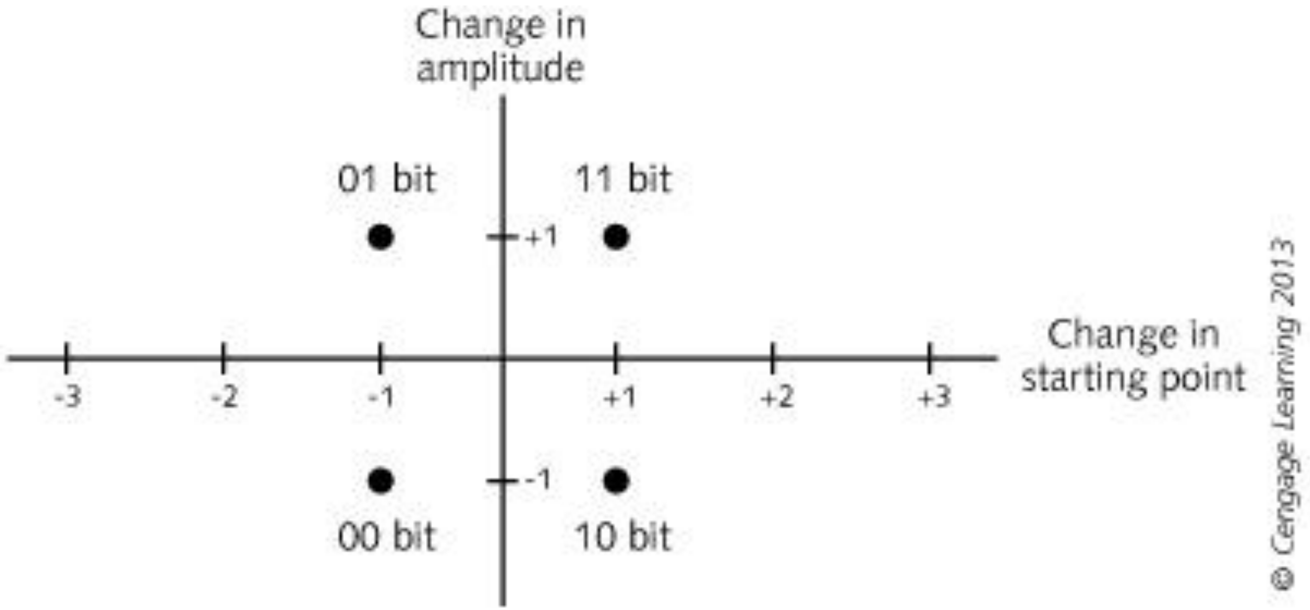



Figure 5-14  Quadrature phase shift keying (QPSK)

# 16-level quadrature amplitude modulation (16-QAM)

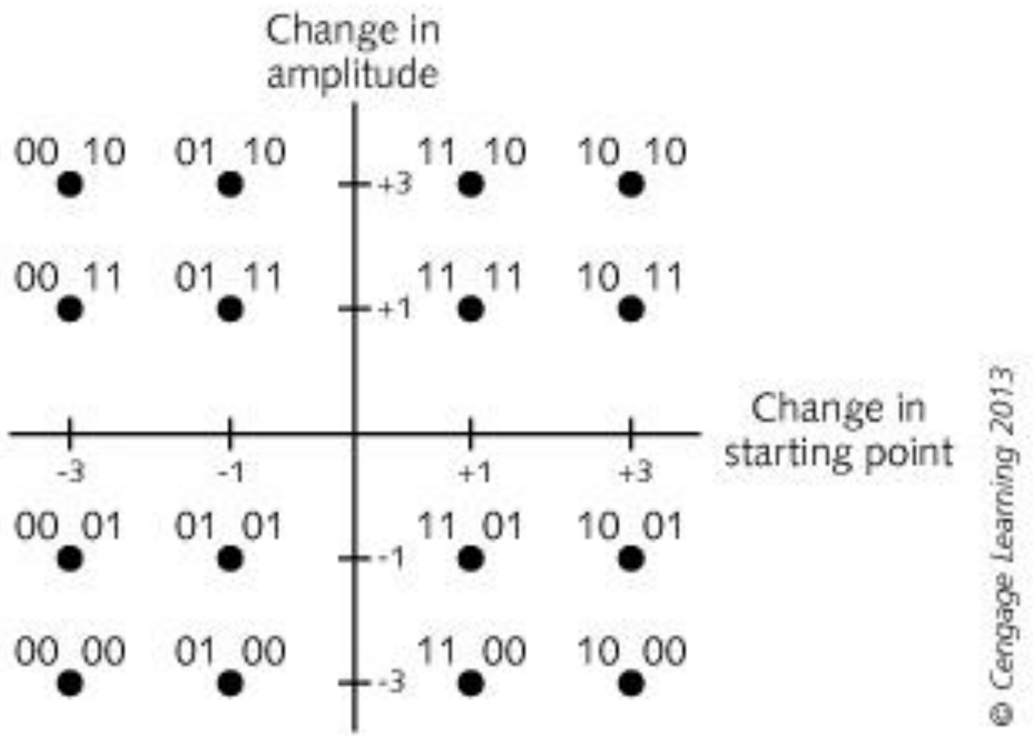



Figure 5-15 16-level quadrature amplitude modulation (16-QAM)

# 64-level quadrature amplitude modulation (64-QAM)

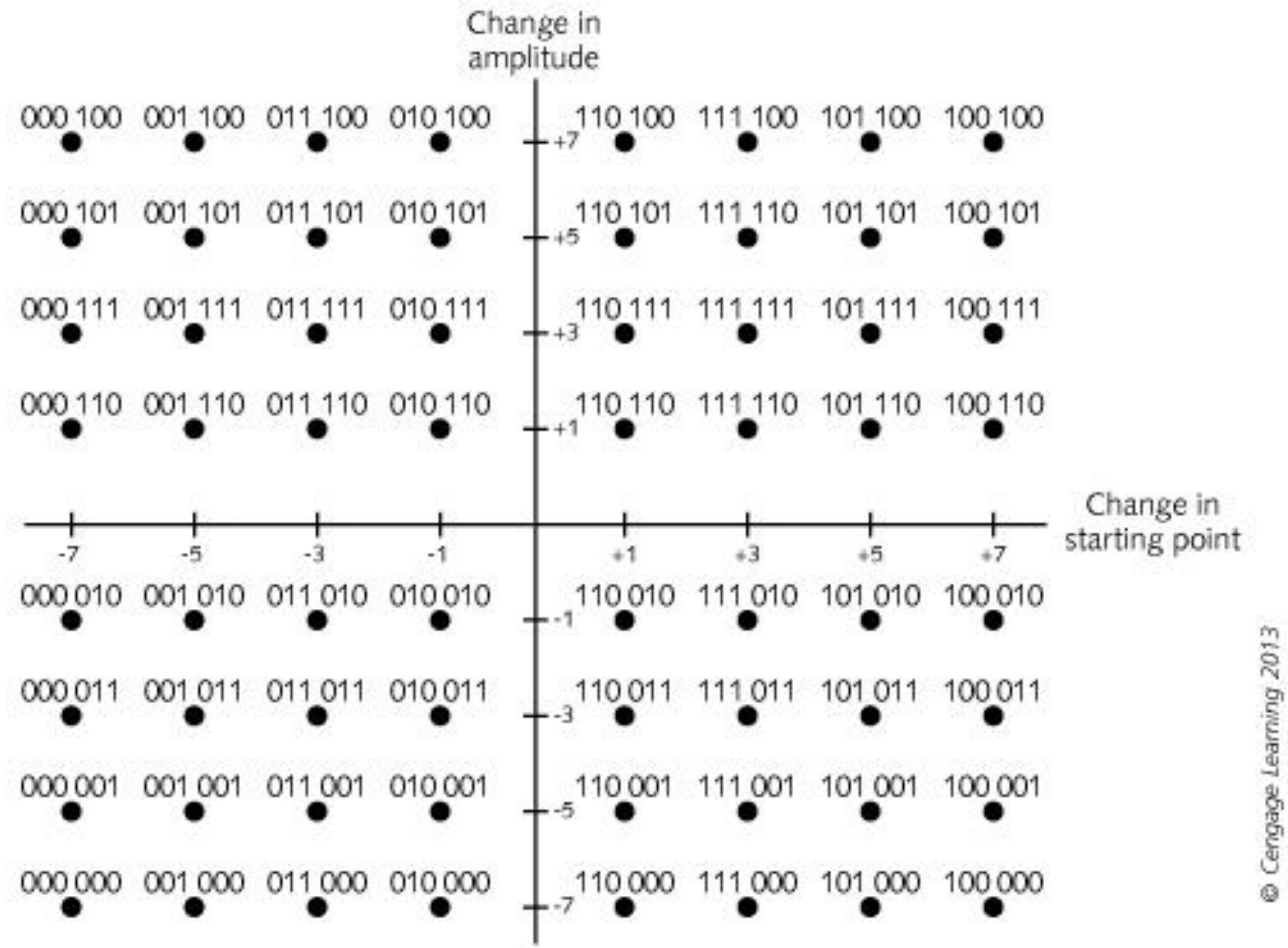



Figure 5-16 64-level quadrature amplitude modulation (64-QAM)

# Channel Allocation

- With 802.11b, the available frequency spectrum is divided into 11 useable channels
  - Only three of which are nonoverlapping channels available for simultaneous operation

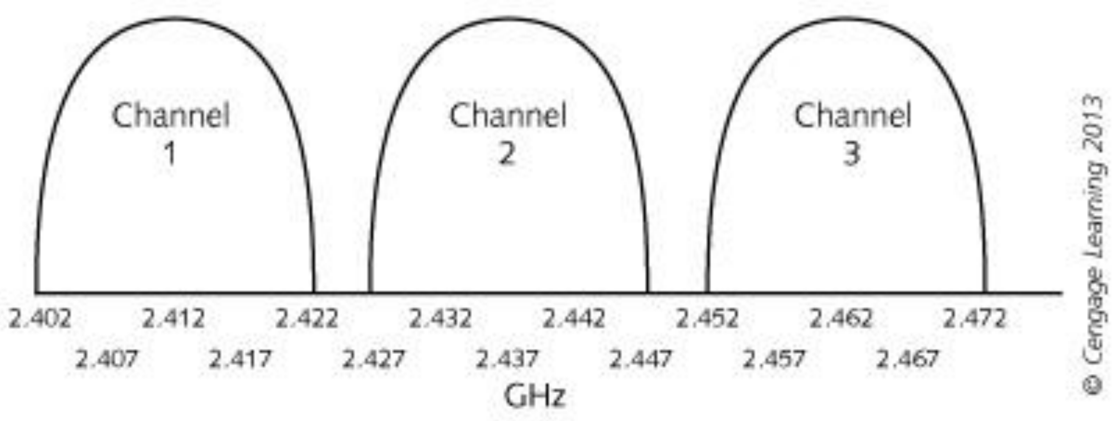



Figure 5-17 802.11b channels

# Channel Allocation

- Within each 802.11a frequency channel, there is a 20 MHz wide channel that supports 52 carrier signals

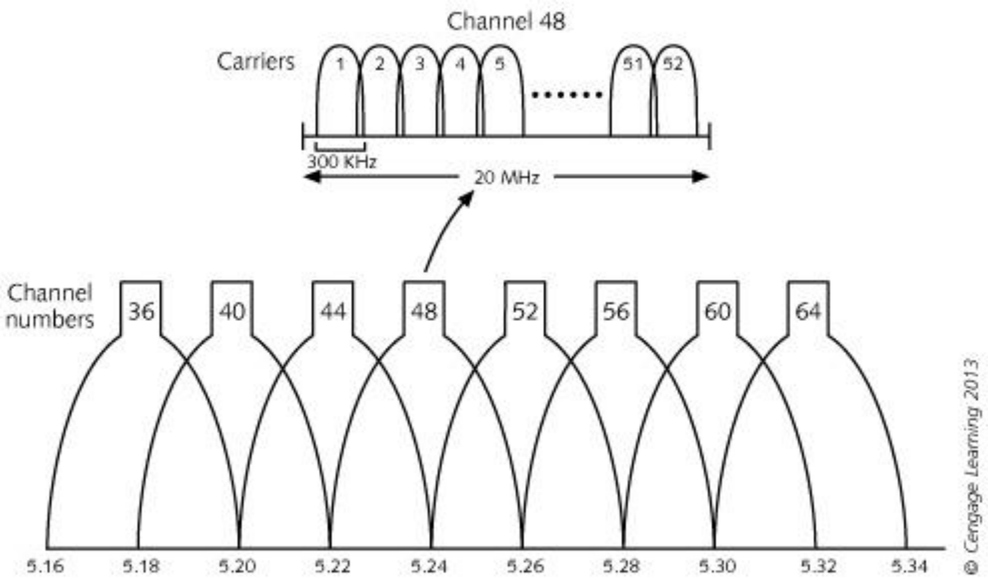



Figure 5-18 802.11a channels

# IEEE 802.11g Physical Layer Standards

- 802.11g combines best features of 802.11a and 802.11b
- Operates entirely in 2.4 GHz ISM frequency
- Two mandatory modes and one optional mode
  - CCK mode used at 11 and 5.5 Mbps (mandatory)
  - OFDM used at 54 Mbps (mandatory)
  - **PBCC-22 (Packet Binary Convolution Coding):** Optional mode
    - Can transmit between 6 and 54 Mbps

# IEEE 802.11g Physical layer standards

| Transmission Speed (Mbps) | Modulation | DSSS Coding Technique |
|---|---|---|
| 1 | Differential binary phase shift keying (DBPSK) | Barker code |
| 2 | Differential quadrature phase shift keying (DQPSK) | Barker code |
| 5.5 | Differential quadrature phase shift keying (DQPSK) | Complementary code keying (CCK) |
| 6 (mandatory speed) | OFDM | n/a |
| 11 | Differential quadrature phase shift keying (DQPSK) | Complementary code keying (CCK) |
| 12 (mandatory speed) | OFDM | n/a |
| 18 (optional speed) | OFDM | n/a |
| 22 (optional speed) | PBCC-22 | n/a |
| 24 (mandatory speed) | OFDM | n/a |
| 36 (optional speed) | OFDM | n/a |
| 48 (optional speed) | OFDM | n/a |
| 54 (optional speed) | OFDM | n/a |



Table 5-8  IEEE 802.11g Physical layer standards

# IEEE 802.11g Physical Layer Standards

- Characteristics of 802.11g standard:
  - Greater throughput than 802.11b networks
  - Covers broader area than 802.11a networks
  - Backward compatible
  - Only three nonoverlapping channels
  - If 802.11b and 802.11g devices transmitting in same environment, 802.11g devices drop to 11 Mbps speeds

# IEEE 802.11n Physical Layer Standards

- Enhancements to the IEEE 802.11n standard:
  - 40-MHz channels
  - Variable guard interval
- Results can be categorized in the modulation and coding schemes tables

# 40-MHz Channels

- Bandwidth of the channel determines the speed of the transmission and measures efficiency
  - Efficiency is known as spectral efficiency and is measured in the number of bits per Hertz (Hz)

- 802.11n WLANs can use 20 MHz or 40 MHz
  - 40-MHz channels are actually two adjacent 20-MHz channels that are bonded together
  - Two channels are known as the **primary channel** and the **secondary channel**

# 40-MHz Channels

- Channel bonding increases likelihood of interference with other WLANs
- Two safeguards to protect against interference:
  - WLANs using 40-MHz channels are required to listen for other wireless devices
    - Can move to another channel or switch to 20-MHz operation if another AP starts operating
    - Known as Dynamic Frequency Selection (DFS)
  - AP alternates between using 20-MHz and 40-MHz channels
    - Known as Phased Coexistence Operation (PCO)

# Variable Guard Interval

- Guard interval (GI): a delay built-in to the receiver to allow for late-arriving symbols
  - IEEE 802.11 a/b/n WLANs use 800 nanoseconds as the GI
- Variable guard interval: an 802.11n technology that uses a reduced guard interval of 400 nanoseconds
  - Can increase the rate of transmission

# Modulating and Coding Scheme (MCS)

- For IEEE 802.11n there are a wide number of options for transmitting
  - In total, there are 77 possible combinations of these factors:
    - Modulation
    - Convolutional coding rate (type of error-correcting)
    - Guard interval
    - Channel width
    - Spatial streams
- Modulation and Coding Scheme outlines the different combinations and assigns an index number to each scheme

# Summary

- RF signals that are transmitted on only one frequency are called narrowband transmissions
- Three modulation schemes are used in IEEE 802.11 wireless LANs: frequency hopping spread spectrum (FHSS), direct sequence spread spectrum (DSSS), and orthogonal frequency division multiplexing (OFDM)
- Spread spectrum is a technique that takes a narrow, weaker signal and spreads it over a broader portion of the radio frequency band
- Spread spectrum transmission uses two different methods to spread the signal over a wider area: FHSS and DSSS

# Summary

- OFDM splits a single high-speed digital signal into several slower signals running in parallel
- IEEE has divided the OSI model Data Link layer into two sublayers: the LLC and MAC sublayers
- The Physical layer is subdivided into the PMD sublayer and the PLCP sublayer
- The Physical Layer Convergence Procedure Standards (PLCP) for 802.11b are based on DSSS

# Summary

- IEEE 802.11a networks operate at speeds up to 54 Mbps with an optional 108 Mbps
- The 802.11g standard specifies that it operates entirely in the 2.4 GHz ISM frequency and not the U-NII band used by 802.11a
- Enhancements to the IEEE 802.11n standard include using 40 MHz wide channels and variable guard interval
- Modulation and Coding Scheme outlines different combinations and assigns an index number to each scheme