# 無線通訊協定

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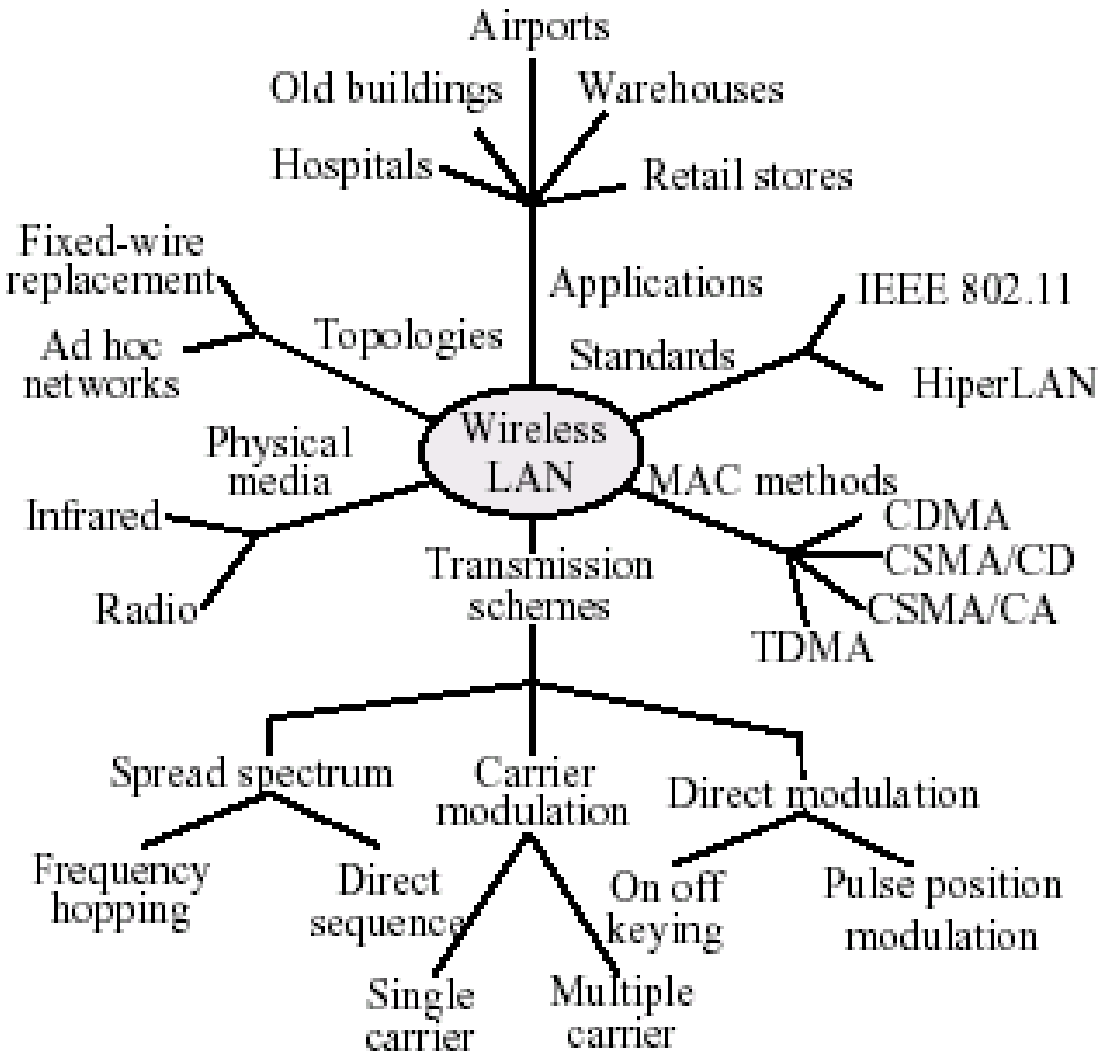
# Outline

1. 802.11 Architecture and Overview
2. Baseband Infrared (IR) Physical Layer Specification
3. Direct Sequence Spread Spectrum (DSSS) Physical Layer Specification
4. Orthogonal Frequency Division Multiplexing (OFDM) Physical Layer Specification
5. IEEE 802.11g Extended Rate PHY (ERP) Specification
6. Frequency Hopping Spread Spectrum PHY of the 802.11 Wireless LAN Standard
7. IEEE 802.11 Wireless LAN MAC Standard

# 1. 802.11 Architecture and Overview

# Technology Tree for Wireless LAN

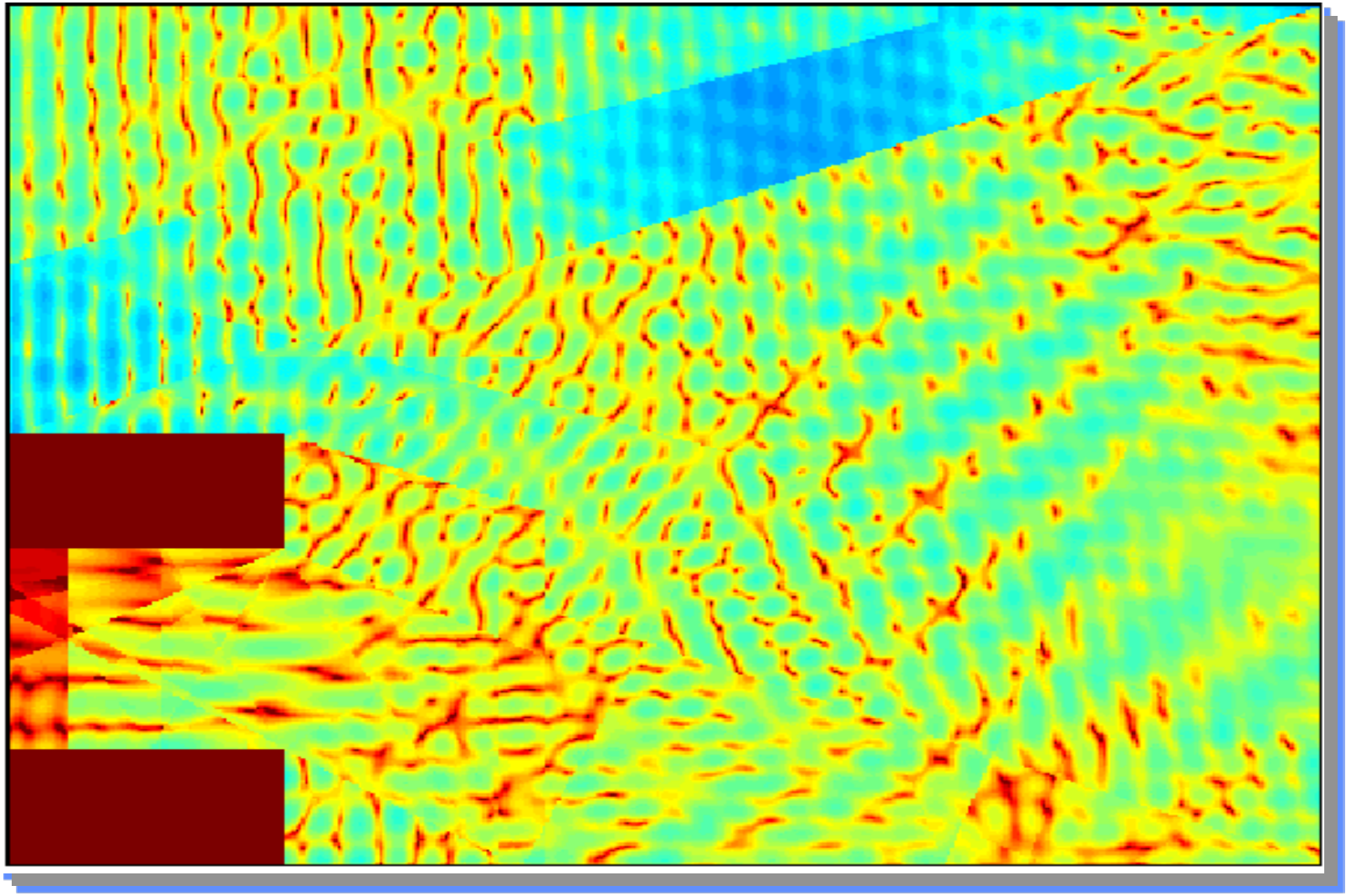



HomeRF
Bluetooth
Zigbee

# What is unique about wireless?

- **Difficult media**
  - **interference and noise**
  - **quality varies over space and time**
  - **shared with unwanted 802.11 devices**
  - **shared with non-802 devices (unlicensed spectrum:** microwave ovens, bluetooth, Zigbee, etc.,**)**
- **Full connectivity cannot be assumed**
  - Hidden node problem
- **Multiple international regulatory requirements**

# Medium Variations



# Uniqueness of Wireless (continued)

- **Mobility**
  - **variation in link reliability**
  - **battery usage: requires power management**
  - **want seamless connections**

**power control ???**

- **Security**
  - **no physical boundaries**
  - **overlapping LANs**

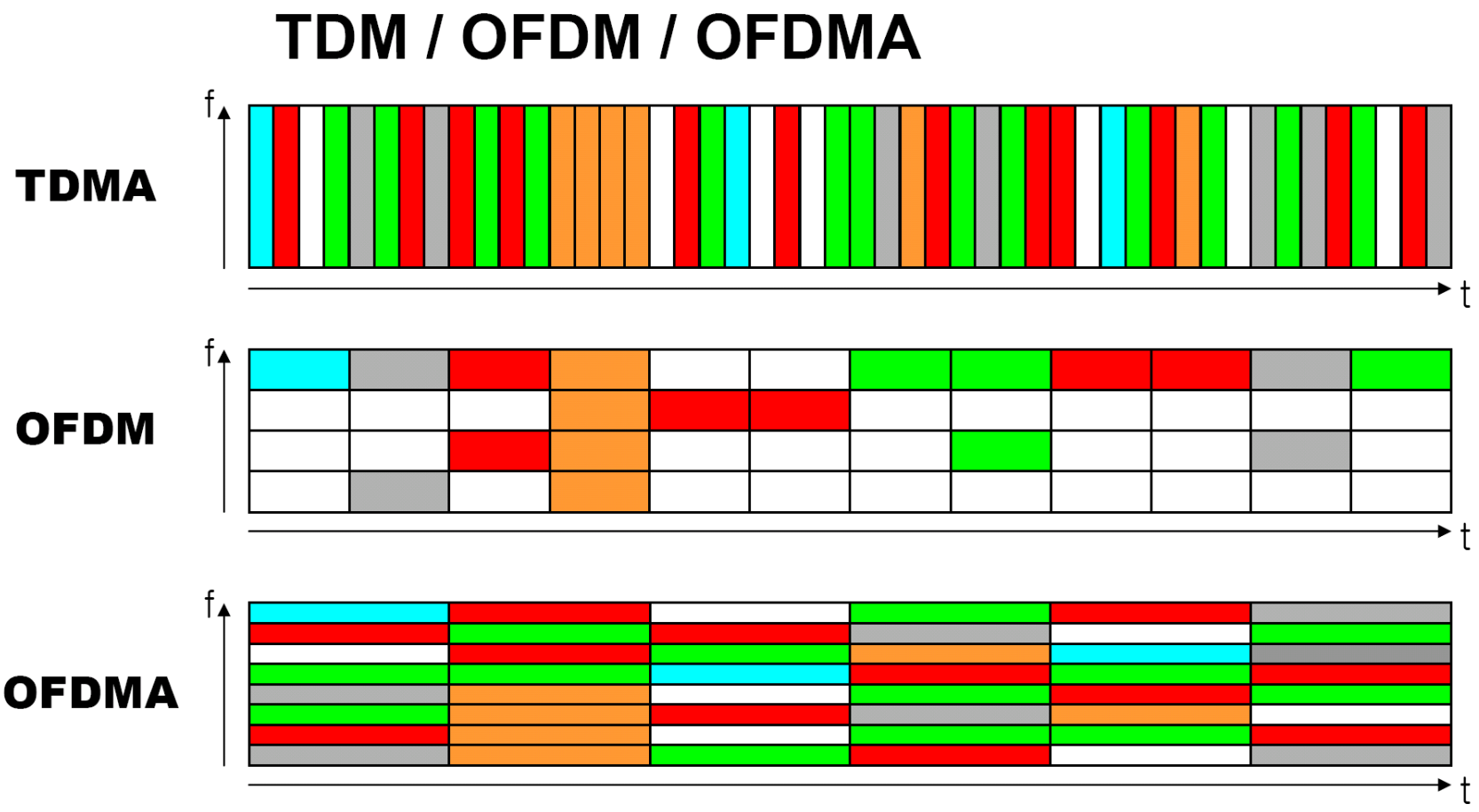
# Requirements

- **Single MAC to support multiple PHYs.**
  - **Support single and multiple channel PHYs.**
  - **Different PHYs have different medium sense characteristics.**
- **Should allow overlap of multiple networks in the same area and channel space.**
- **Need to be Robust for Interference?**
  - **ISM band (Industry, Science and Medicine)**
    - » **13.56 MHz, 27.55 MHz, 303 MHz, 315 MHz, 404 MHz, 433 MHz, 868 MHz (Europe), 915 MHz (North America), 2.45 GHz, 5.2 GHz (North America), 5.3 GHz, and 5.7 GHz (North America)**
    - » **Microwave, other non-802.11 interferers.**
    - » **Co-channel interference.**
- **Need mechanisms to deal with Hidden Nodes?**
- **Need provisions for Time Bounded Services (real-time service).**

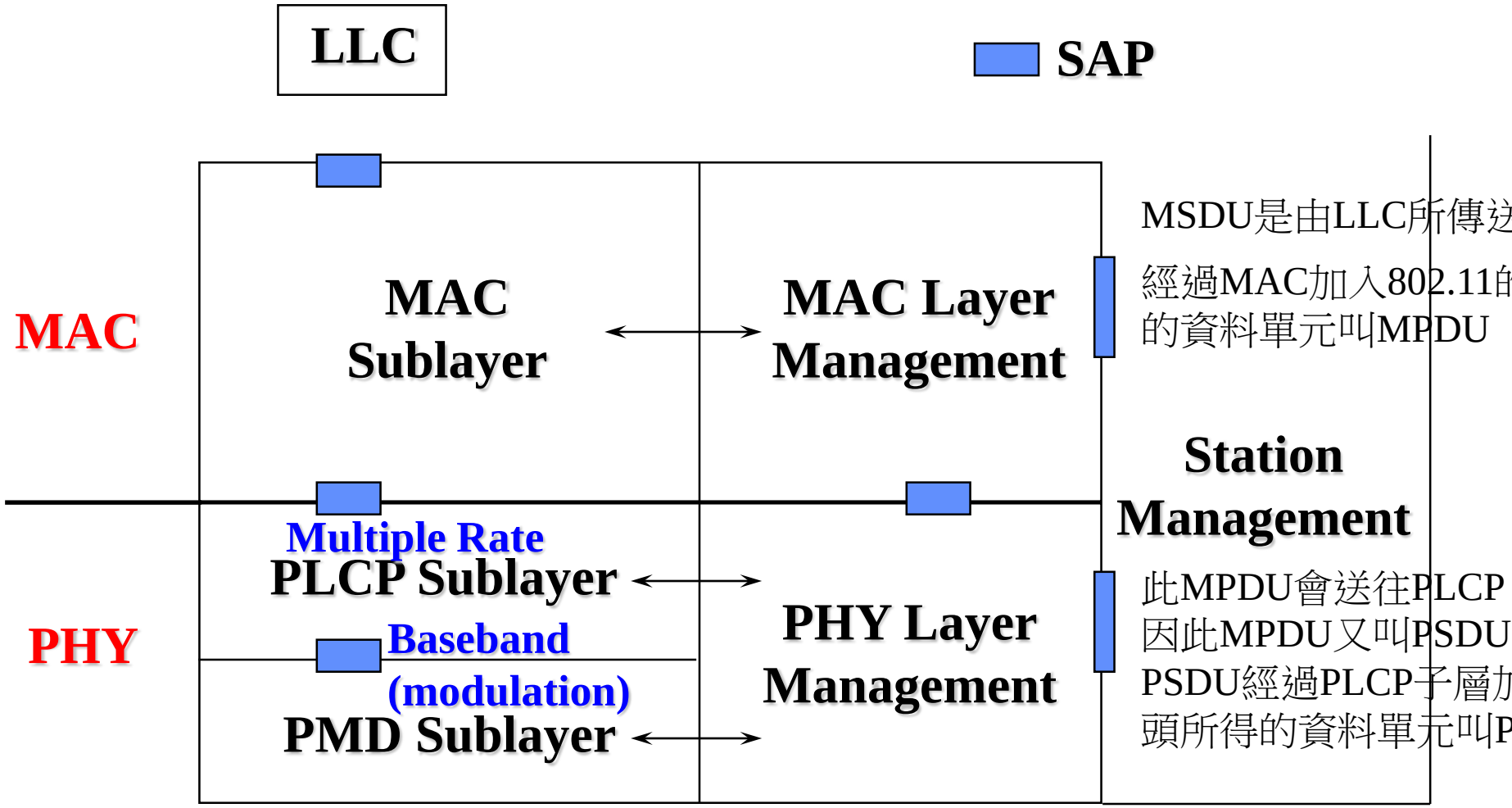
# Architecture Overview

- **One MAC supporting multiple PHYs**
  - **Frequency Hopping Spread Spectrum**
  - **Direct Sequence Spread Spectrum**
  - **Infrared**
  - **Orthogonal Frequency Division Multiplexing**
  - **Orthogonal Frequency Division Multiple Access (OFDMA)**
- **Two configurations**
  - **Independent (ad hoc)** **and** **Infrastructure**
  - Hybrid configuration has being studied (802.11s)
- **CSMA/CA (collision avoidance)** **with optional** **Point Coordination Function (PCF)**

# TDMA/OFDM/OFDMA



# 802.11 Protocol Entities



# 802.11 Protocol Architecture

- **MAC Entity**
  - basic access mechanism
  - fragmentation/defragmentation
  - encryption/decryption
- **MAC Layer Management Entity**
  - synchronization
  - power management
  - roaming
  - MAC Management Information Base (MIB)
- **Physical Layer Convergence Protocol (PLCP)**
  - PHY-specific, supports common PHY SAP
  - provides Clear Channel Assessment signal (carrier sense)

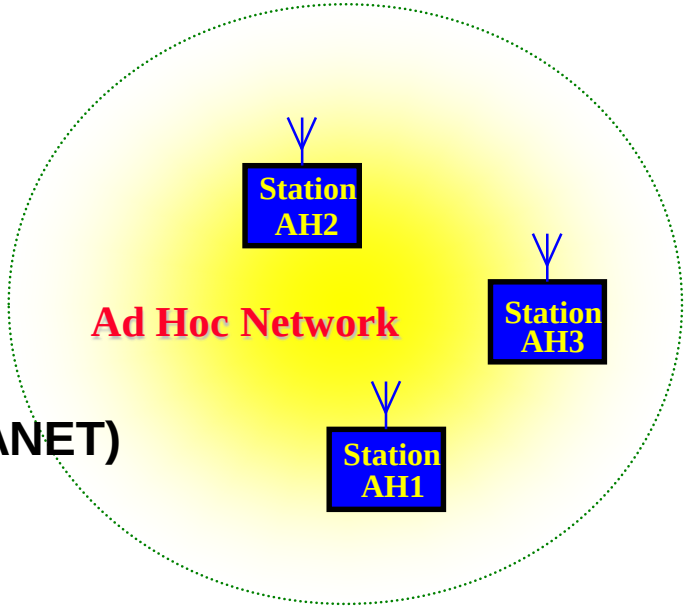
# 802.11 Protocol Architecture (cont.)

- **Physical Medium Dependent Sublayer (PMD)**
  - **modulation and encoding (baseband)**
- **PHY Layer Management**
  - **channel tuning (channel switching delay : 224us in 802.11b)**
  - **PHY MIB**
- **Station Management**
  - **interacts with both MAC Management and PHY Management**

# 802.11 Configurations - Independent

- **Independent**
  - **one Basic Service Set (BSS)**
  - **Ad Hoc network**
  - **direct communication**
  - **limited coverage area**

- **Research topics**
  - **Multi-Hop Routing (IETF MANET; VANET)**
  - **Multicasting**
  - **Multi-channel Access**
  - **Security**
  - **QoS ...**



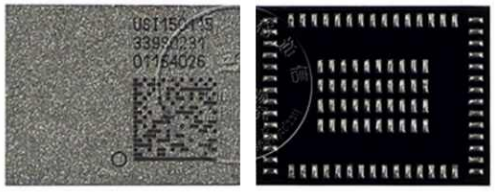

**Mobile Station : STA**

Vehicular Ad-Hoc Network (VANET)
Mobile Ad Hoc Network (MANET)

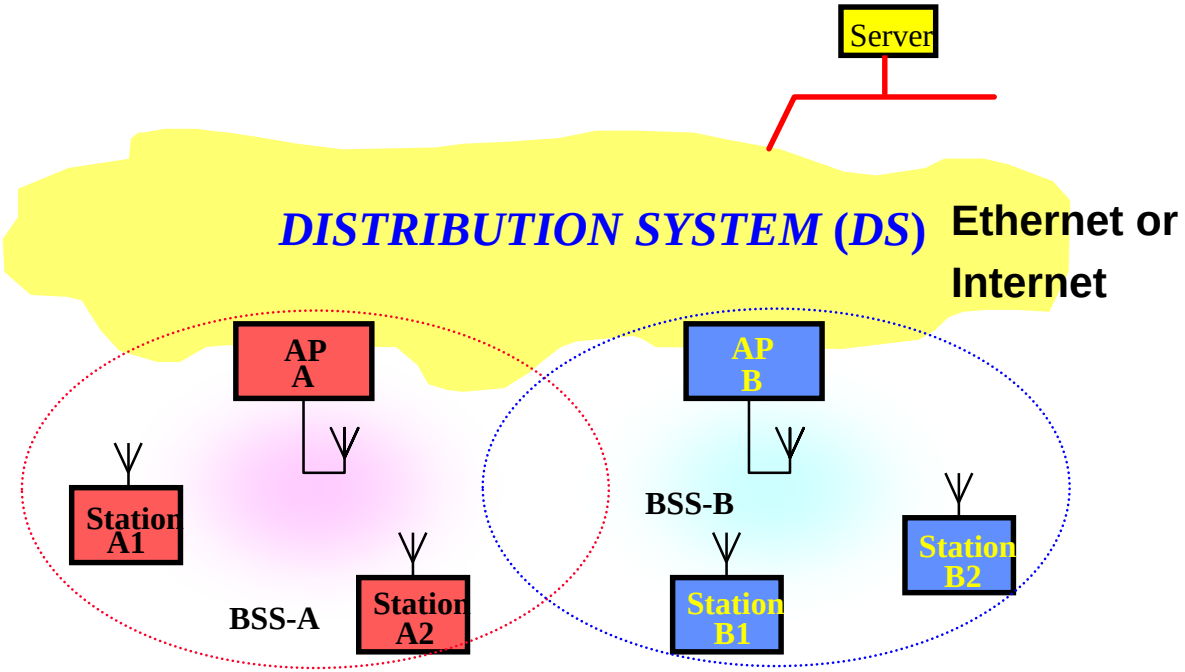
# Commercial Products : WLAN Cards

- One piece
- Two pieces

Pasadena Networks, LLC http://www.pasadena.net



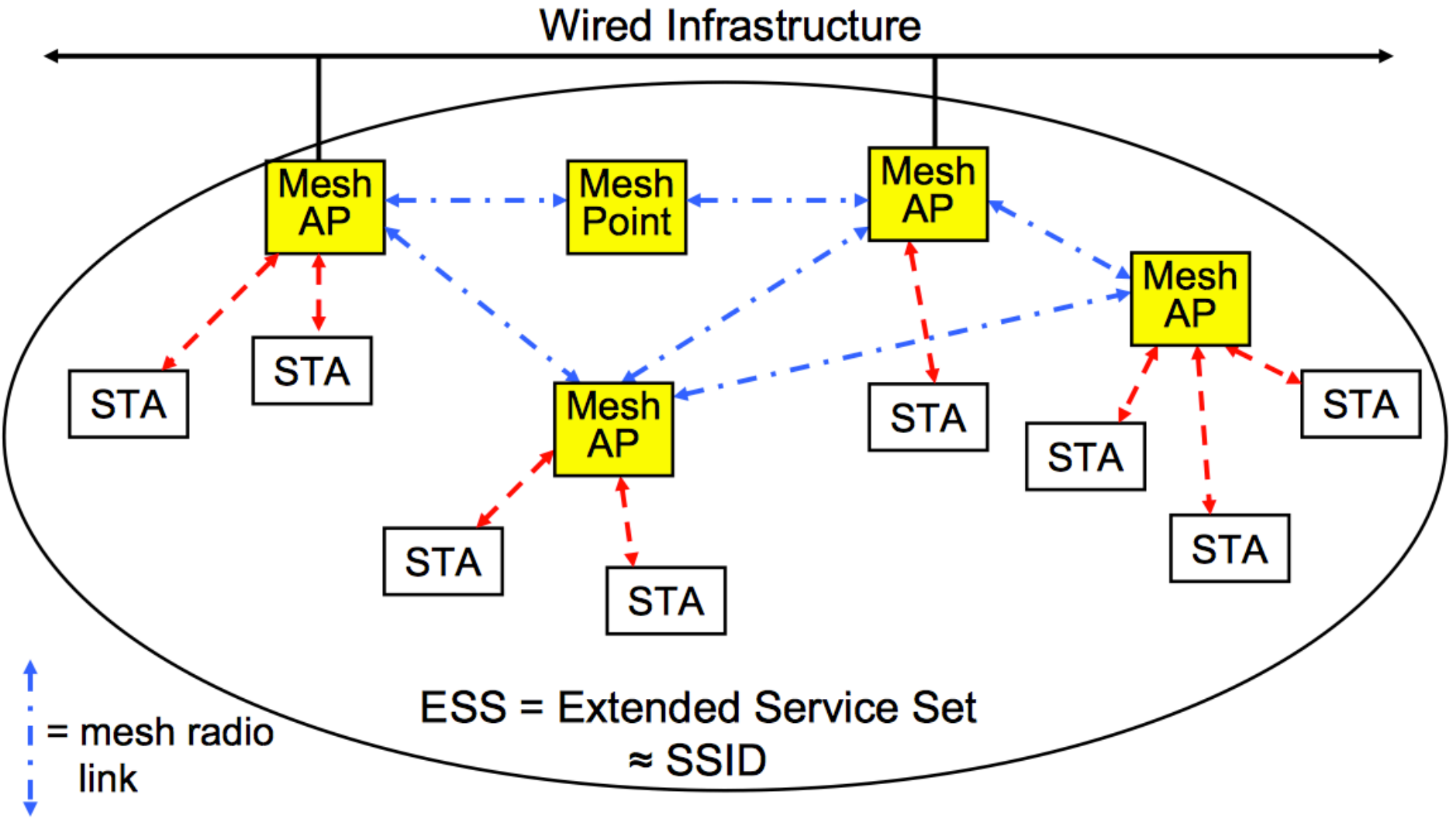
# 802.11 Configurations - Infrastructure



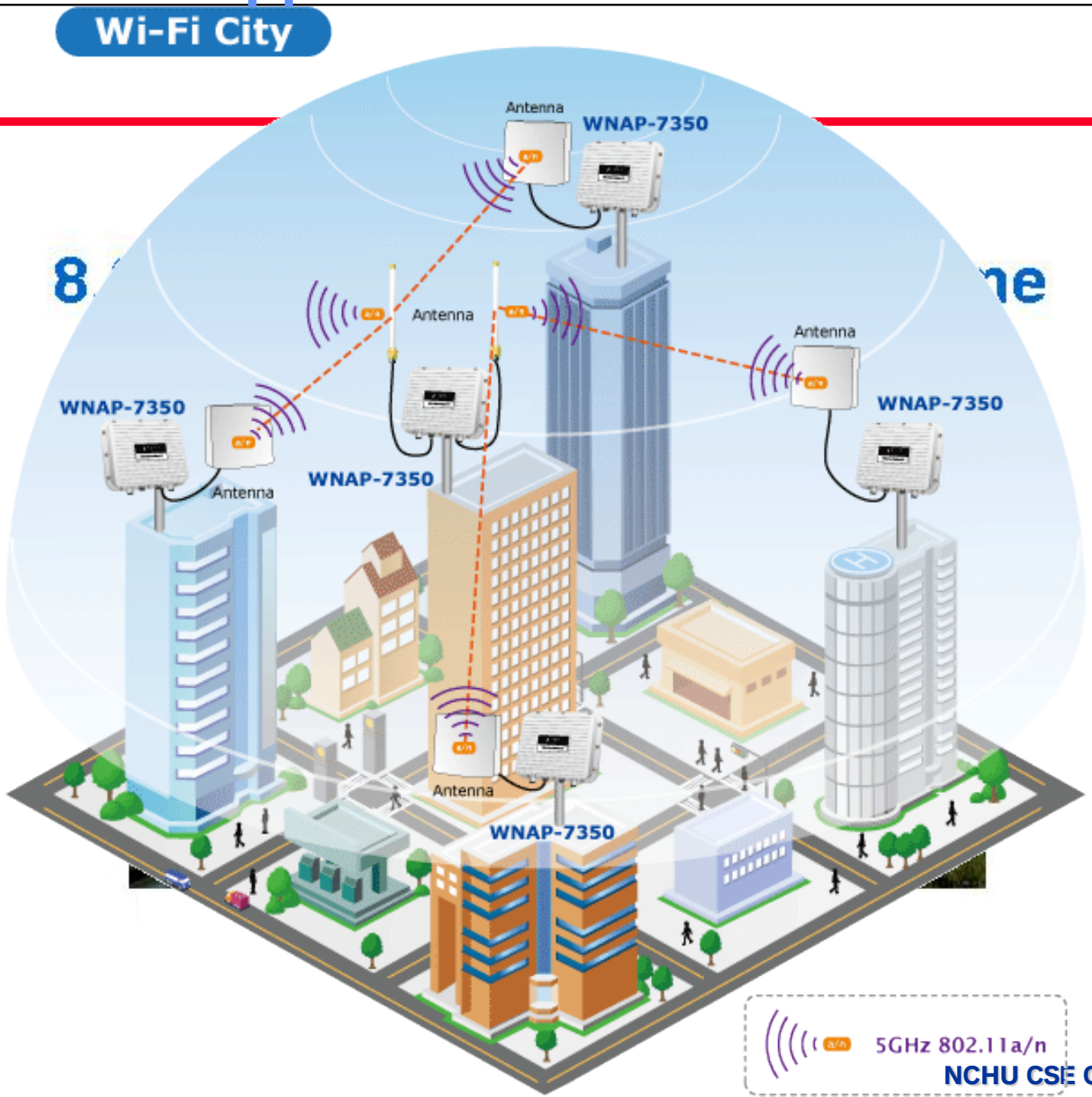

- **Infrastructure**
  - Access Points (AP) and stations (STA)
- Distribution System interconnects Multiple Cells via Access Points to form a single Network.
  - extends wireless coverage area
- **Wireless bridge** application

# Commercial Products : AP

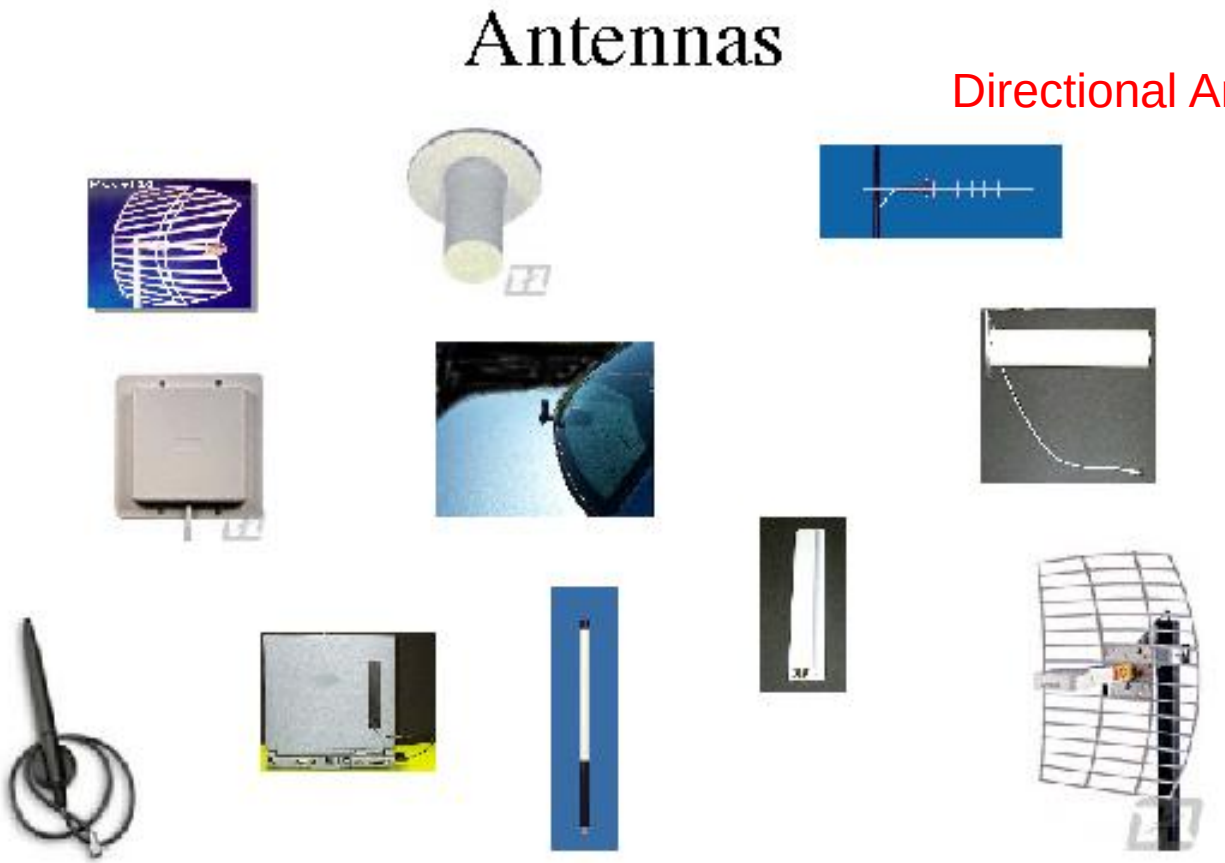
# Wireless Bridging



# Outdoor Application



# Outdoor Application - Antenna

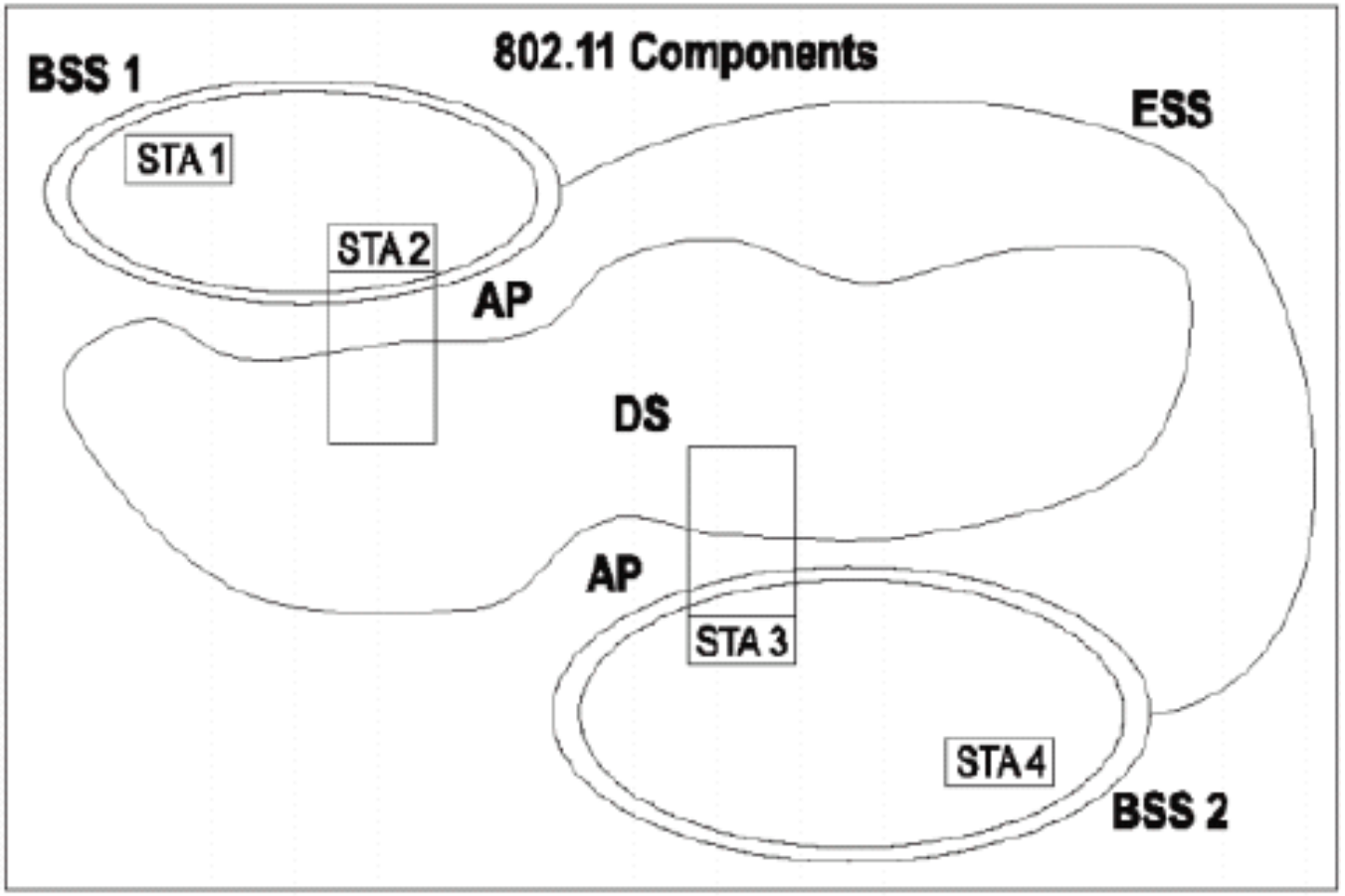


# Distribution System

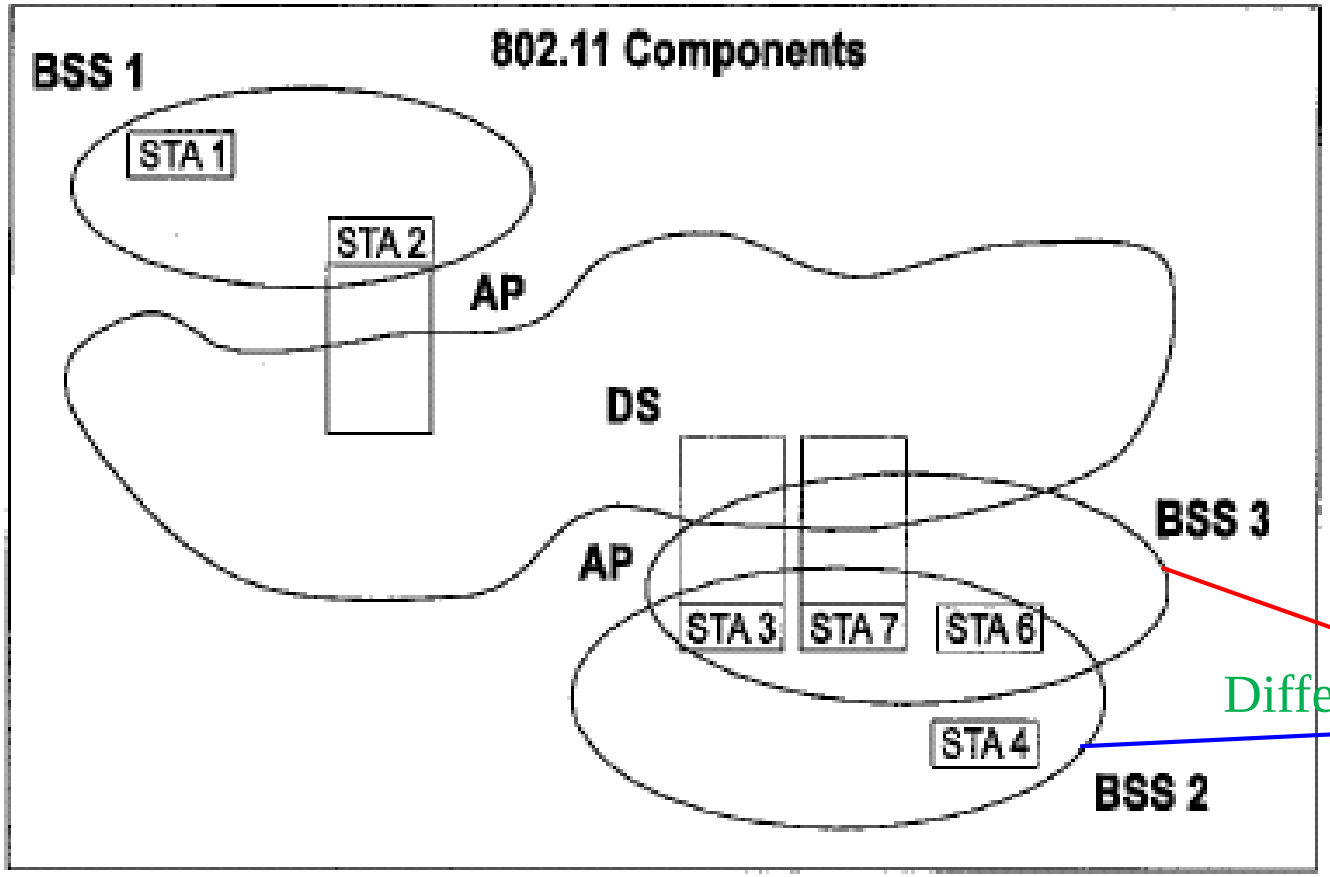
- **Used to interconnect wireless cells**
  - **multiple BSS connected together form an ESS (Extended Service Set)**
  - **Allows mobile stations to access fixed resources**

- **Not part of 802.11 standard**
  - **could be bridged IEEE LANs, wireless, other networks**
  - **Only Distribution System Services are defined**

# BSS vs ESS

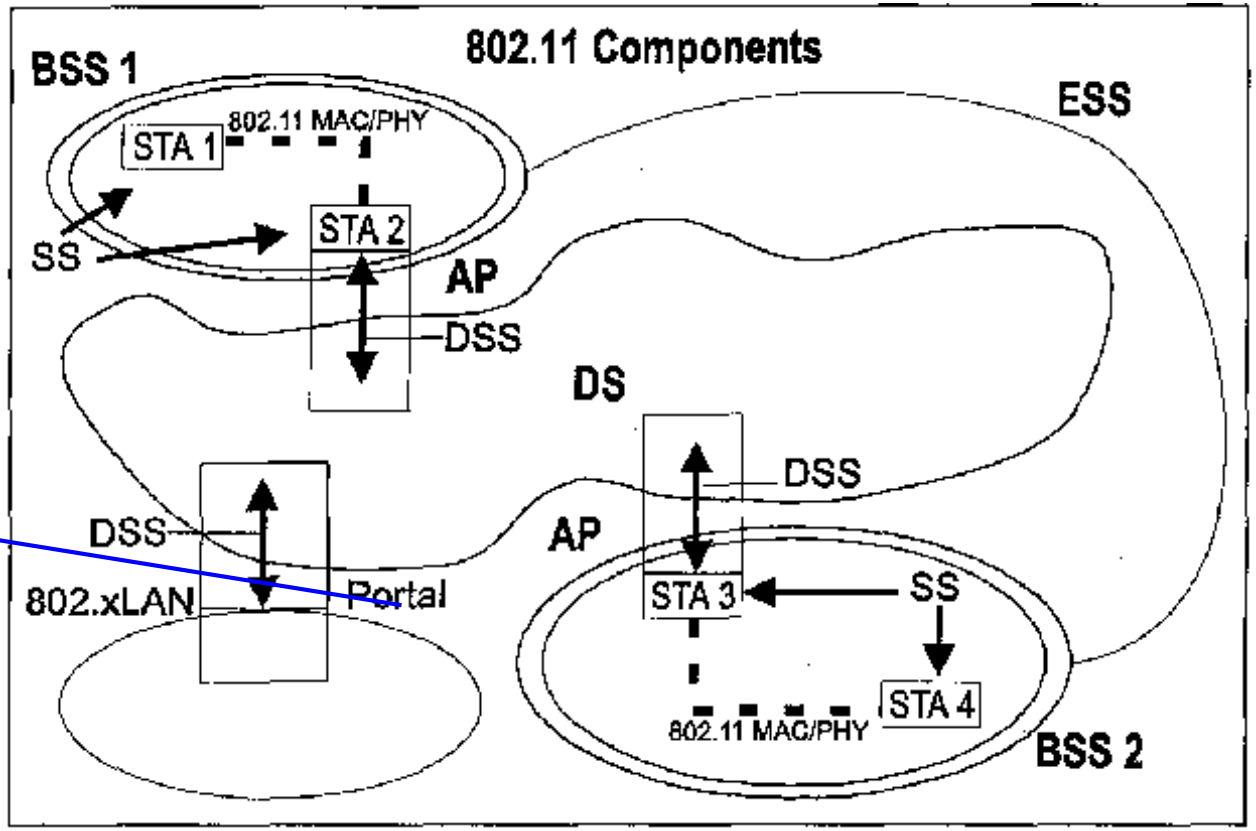


# Collocated Coverage Areas




DS : Distribution System

# Complete Architecture




Service Entry

**DSS : Distribution System Service**

# Access Points

- Stations select an AP and Associate with it
- Support roaming
  - IAPP (Inter Access Point Protocol) IEEE 802.11f (Layer 2)
  - Mobile IP (Layer 3; IETF)
- Provide other functions
  - time synchronization (beaconing)
  - power management support (if any)
  - point coordination function (PCF) (if any)
- Traffic typically (but not always) flows through AP
  - direct communication possible (Ad-Hoc)

# Access Points

- **In an Infrastructure BSS, all mobile stations communicate with the AP**
  - **quoted from "IEEE 802.11 Handbook", Bob O'Hara and Al Petrick**
  - **Disadvantage :**
    - » **bandwidth is consumed twice than directional communication between STAs**
    - » **more contentions and more collisions**
  - **Advantage :**
    - » **easily solve hidden terminal problem**
    - » **provide power saving function**
    - » **meet the AAA (authentication, authorized, accounting) architecture**
    - » **provide per flow bandwidth control, QoS guarantee (IEEE 802.11e)**

# 802.11 Defines the Airwaves IF

- **The airwaves interface between stations (including that between station and AP) is standardized**
  - **PHY and MAC**
- **No exposed MAC/PHY interface specified**
- **No exposed interface to Distribution System**
  - **only required DS services are defined**
- **Internals of Distribution System not defined**

# MAC Services

- **Asynchronous MSDU Data Delivery**
  - **provided to LLC (2304 octets maximum)**
- **Time Bounded Services**
  - **optional point coordination function (PCF)**
  - **Existing in commercial products ?**
    - » **Bandwidth is not enough for supporting real-time service**
    - » **Not necessary, CSMA/CA works well (likes Ethernet history)**
    - » **IEEE 802.11e enhances QoS**
- **Security Services**
  - **confidentiality, authentication, access control**
- **Management Services**
  - **scanning, joining, roaming, power management**

# MAC Functionality

- **Independent and Infrastructure configuration support**
  - **Each BSS has a unique 48 bit address**
  - **Each ESS has a variable length address**

- **CSMA with collision avoidance (CSMA/CA)**
  - **MAC level acknowledgment (positive acknowledgement)**
  - **allows for RTS/CTS exchanges**
    - » **hidden node protection** 41%
    - » **virtual carrier sense**
    - » **bandwidth saving**
  - **MSDU fragmentation**
  - **Point Coordination Function (option)**
    - » **AP polling**

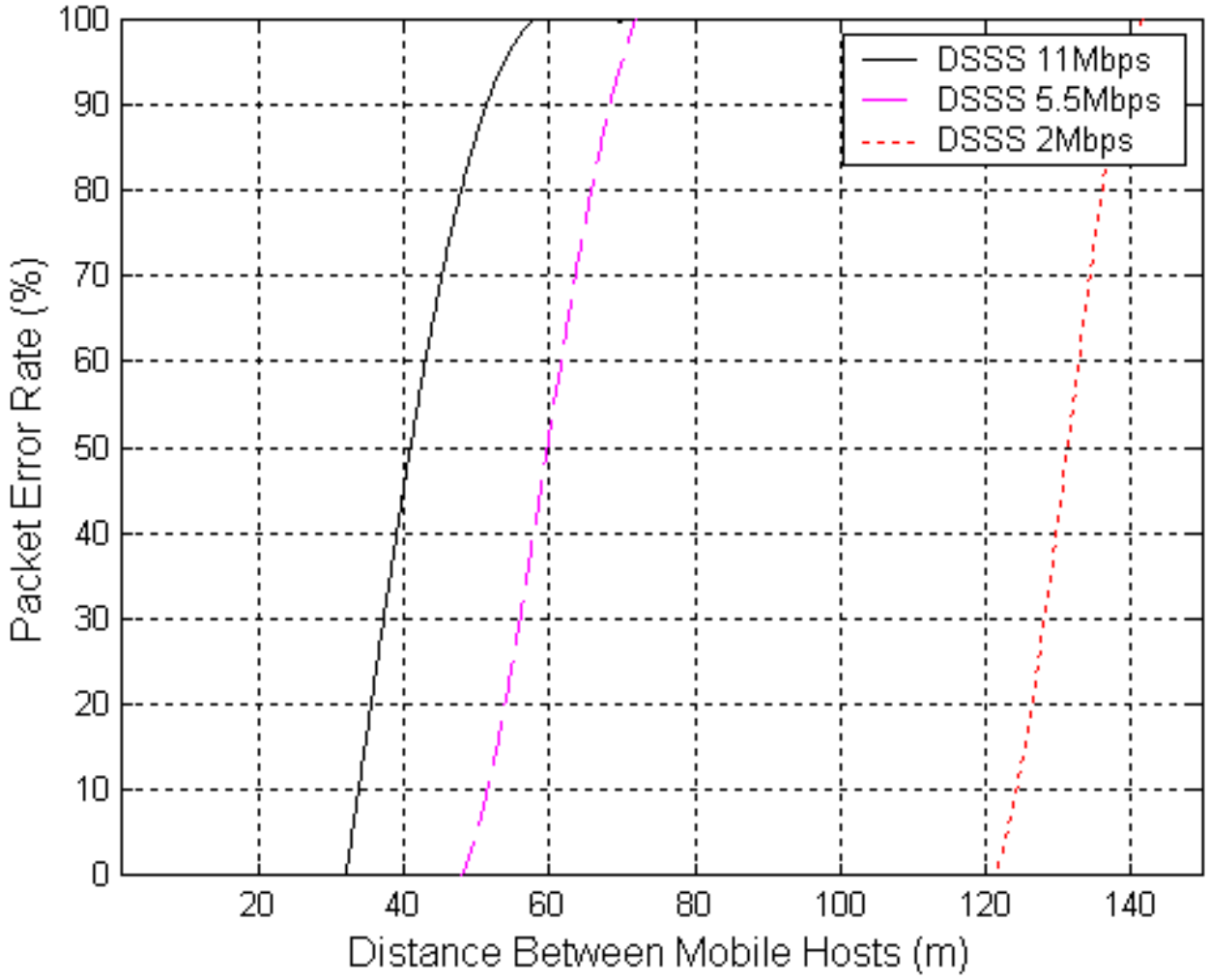
# MAC Functionality (continued)

- **Roaming support within an ESS**
  - station scans for APs, association handshakes
- **Power management support**
  - stations may power themselves down
  - AP buffering, distributed approach for IBSS
- **Authentication and privacy**
  - Optional support of Wired Equivalent Privacy (WEP)
  - Key exchange
  - Authentication handshakes defined
  - IEEE 802.1x spec. enhances authentication control (EAP)
  - IEEE 802.11i enhances security (IEEE 802.11i over IEEE 802.1x)

# PHY Layer Services

- **PHY_DATA transfers**
  - **multiple rates (1, 2, 5.5, 11Mbps)**
  - **extended rates (22, 33 or 6, 9, 12, 19, 24, 36, 48, 54Mbps)**
  - **The algorithm for performing rate switching is beyond the scope of the standard. (p6, 802.11b)**
    - » **Question : how to decide the proper data rate ?**
- **Clear Channel Assessment (CCA)**
  - **carrier sense**
  - **detect start frame delimiter**
- **PHY Management**
  - **channel tuning**

# Data Rate vs. Range

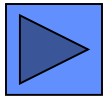


# Four PHYs

- **Frequency Hopping Spread Spectrum (FHSS)**
  - **2.4 GHz band, 1 and 2 Mbps transmission**
    - » **2GFSK, 4GFSK**
    - » **2.5 hops/sec over 79 1MHz channels (North America)**
- **Direct Sequence Spread Spectrum (DSSS)**
  - **2.4 GHz band, 1 and 2 Mbps transmission**
    - » **11 chip Barker sequence**
    - » **DBPSK, DQPSK (Differential Binary/Quadrature Phase Shift Keying)**
  - **2.4 GHz band, 5.5 and 11 Mbps transmission**
    - » **CCK (Complementary Code Keying), PBCC (Packet Binary Convolutional Code)**
    - » **CCK : DQPSK(5.5Mbps, 11Mbps)**
    - » **PBCC : BPSK(5.5Mbps), QPSK(11Mbps) (optional)**
    - » **Sep. 1999 (802.11b)**
  - **2.4 GHz band, 22 and 33 Mbps transmission**
    - » **PBCC-22, PBCC-33**

# Four PHYs

- **Baseband IR (Infrared)**
  - Diffuse infrared
  - 1 and 2 Mbps transmission, 16-PPM and 4-PPM
    - » PPM : Pulse Position Modulation
- **Orthogonal Frequency Division Multiplexing (OFDM)**
  - 2.4 GHz band (IEEE 802.11g DSSS-OFDM, OFDM)
  - 5 GHz band (IEEE 802.11a)
    - » Similar ETSI HIPERLAN/II PHY Spec.
  - 6, 9, 12, 18, 24, 36, 48 and 54 Mbps
    - » BPSK(6,9Mbps), QPSK(12,18Mbps), 16-QAM(24,36Mbps), 64-QAM(48,54Mbps)
    - » Convolutional Code with coding rates ½,2/3,¾.
    - » 20MHz/64 subcarriers per channel
      - 52 subcarriers occupy 16.6MHz
      - 12 additional subcarriers are used to normalized the average power of OFDM symbol
    - » Mandatory : 6, 12, 24 Mbps
    - » Extended (turbo mode 5-UP protocol): 72/108Mbps (proposed by Atheros Corp.)



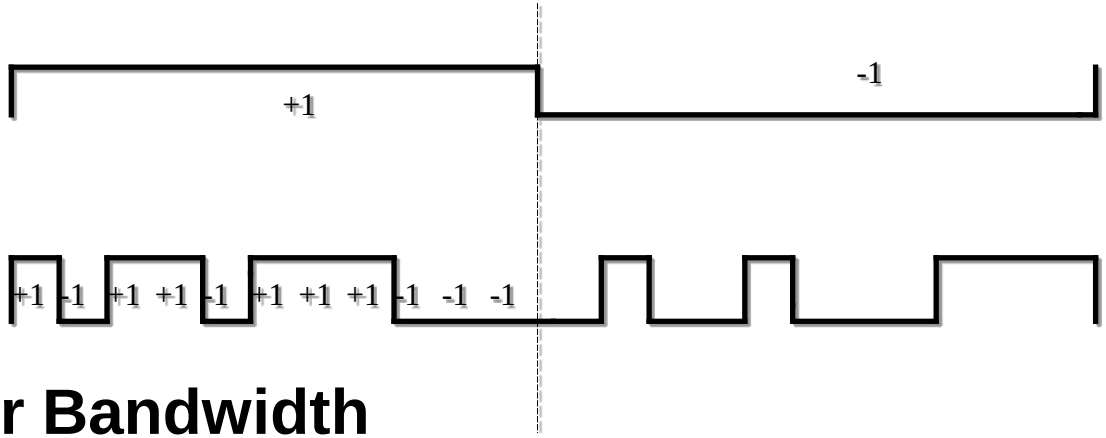
# Unlicensed Operation RF Bands

- **902MHz**
  - **26MHz BW (902-928MHz)**
  - **Crowded and Worldwide limited**
  - **IEEE 802.11 WLAN, IEEE 802.15.4 LR-WPAN, coreless phone, .etc.,**
- **2.4GHz**
  - **83.5MHz BW (2400-2483.5MHz)**
  - **Available worldwide**
  - **IEEE 802.11(b/g) WLAN, Bluetooth, IEEE 802.15.4 LR-WPAN and IEEE 802.15.6 WBAN, etc.,**
- **5.1GHz**
  - **300MHz (three 100MHz segments)**
  - **Unlicensed NII**
  - **802.11a WLAN**
    - » **OFDM / 6,12,18,24,36,48,54Mbps / BPSK,QPSK,16-QAM, 64-QAM**
  - **HiperLAN I and HiperLAN II**
    - » **23.5Mbps/GMSK and 6-54Mbps/BPSK,QPSK,16-QAM, 64-QAM**

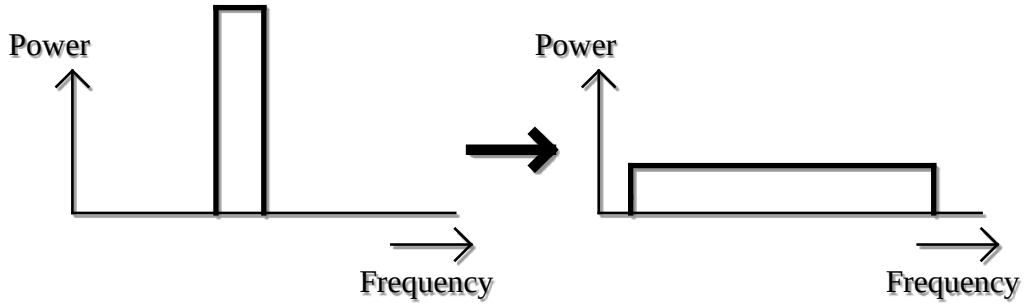
# 3. Direct Sequence Spread Spectrum (DSSS) Physical Layer Specification

# What is DSSS?

- **Signal symbol is spread with a sequence**

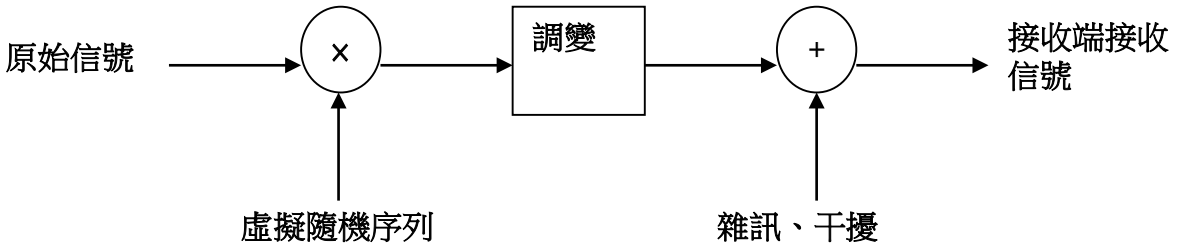


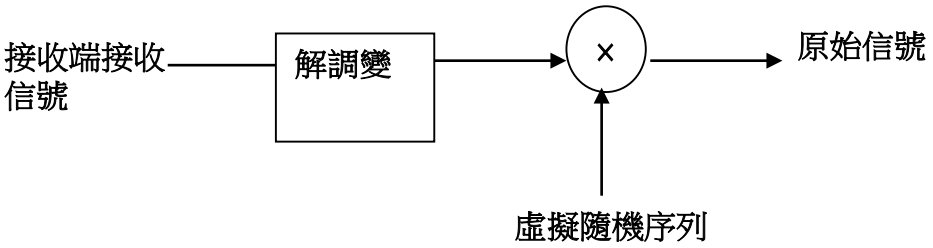

- **Wider Bandwidth**
- **Less power density**



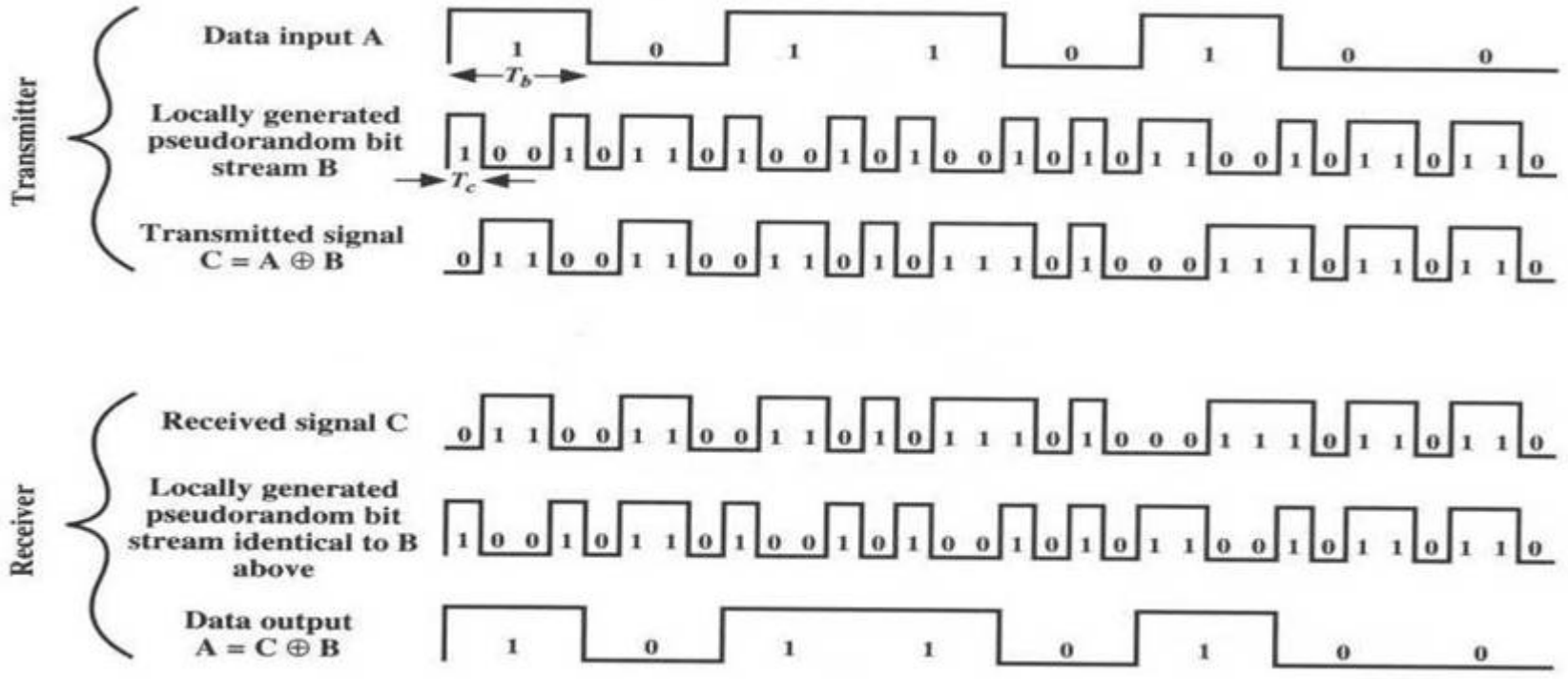
# 展頻技術-直接序列展頻

- 直接序列展頻技術（Direct Sequence Spread Spectrum：DSSS）是將原始信號乘上一虛擬隨機序列，再經過調變後送出去，當然在環境中會受到雜訊及干擾的影響，在接收端，會將接收到的信號經過解調變後，再乘上原本的虛擬隨機序列，最後就會將原始信號還原 。



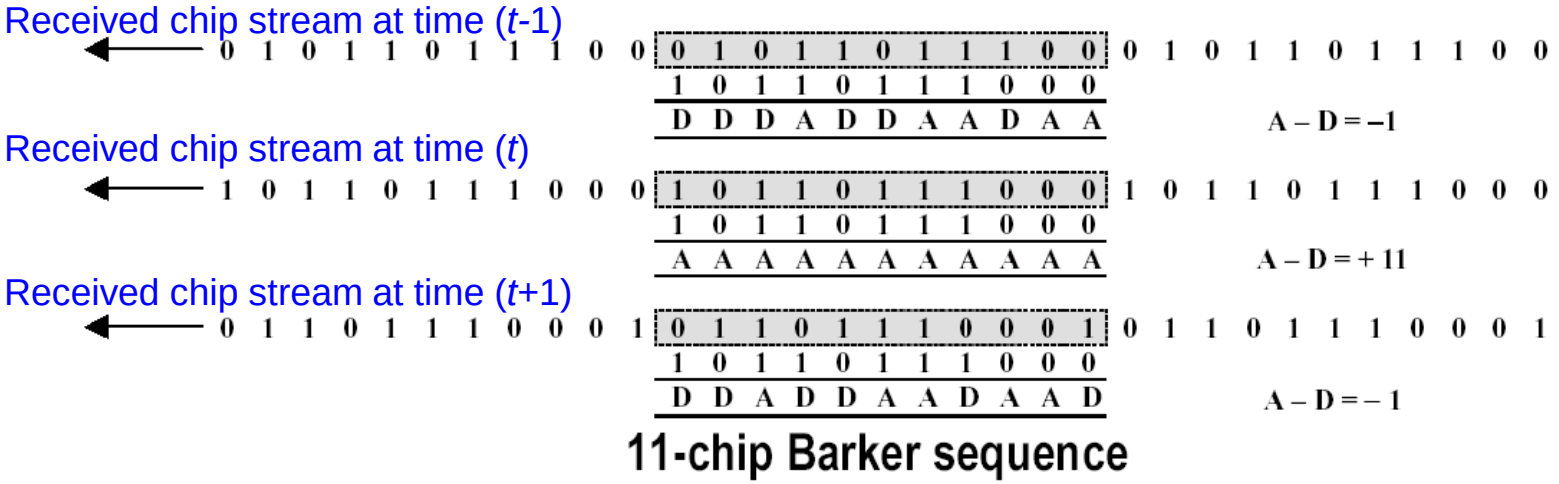



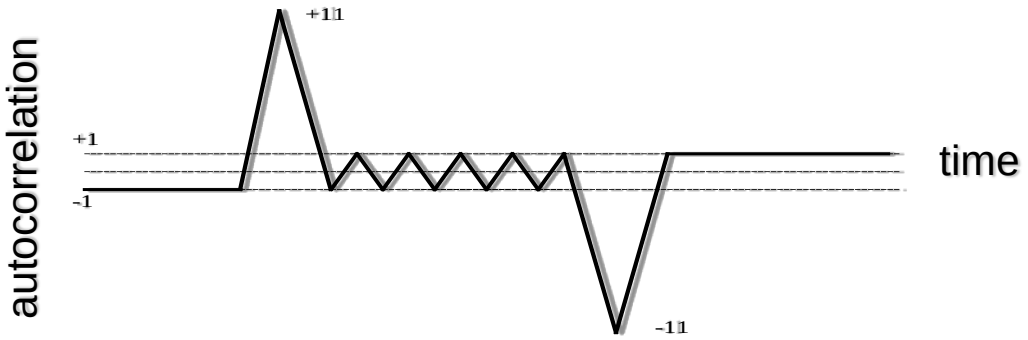
# DSSS


Transmitter
Data input A
1 0 1 1 0 1 0 0
$T_b$
Locally generated pseudorandom bit stream B
1 0 0 1 0 1 1 0 1 0 0 1 0 1 0 0 1 0 1 0 1 1 0 0 1 0 1 1 0 1 1 0
$T_c$
Transmitted signal C = A ⊕ B
0 1 1 0 0 1 1 0 0 1 1 0 1 0 1 1 1 0 1 0 0 0 1 1 1 0 1 1 0 1 1 0
Receiver
Received signal C
0 1 1 0 0 1 1 0 0 1 1 0 1 0 1 1 1 0 1 0 0 0 1 1 1 0 1 1 0 1 1 0
Locally generated pseudorandom bit stream identical to B above
1 0 0 1 0 1 1 0 1 0 0 1 0 1 0 0 1 0 1 0 1 1 0 0 1 0 1 1 0 1 1 0
Data output A = C ⊕ B
1 0 1 1 0 1 0 0

# 11 Chip BARKER Sequence

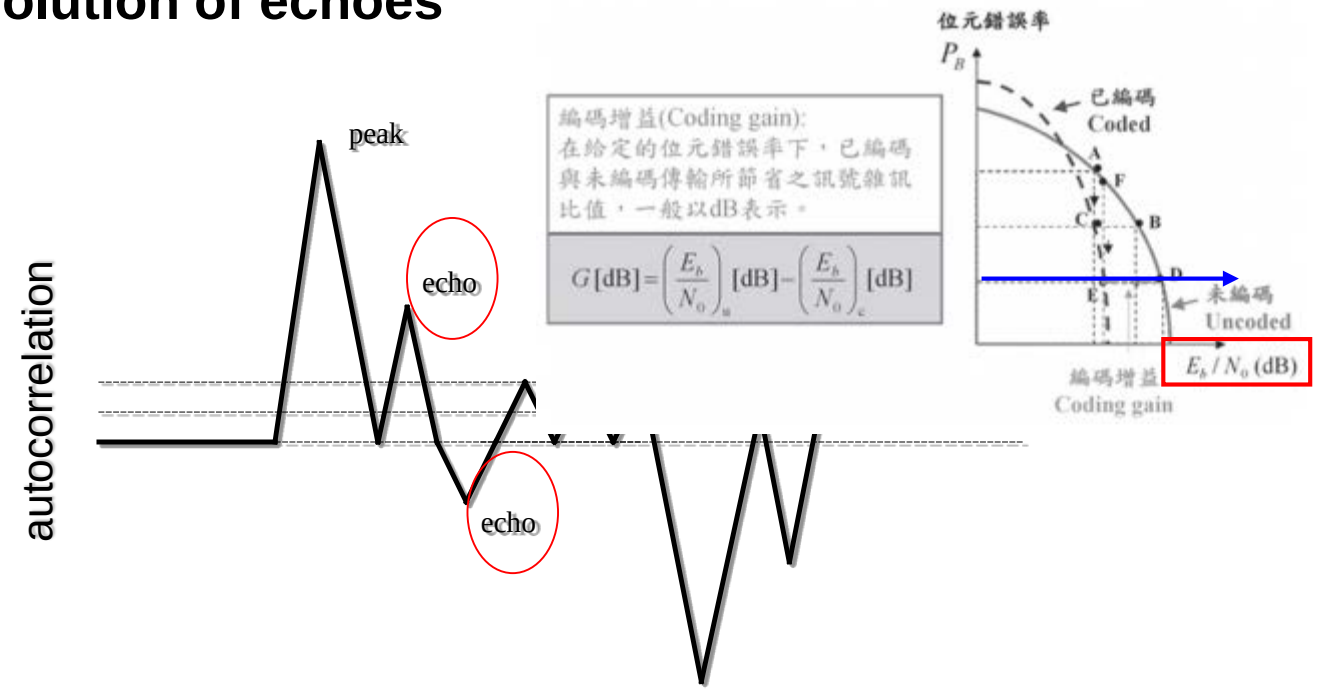
- **Good autocorrelation properties**
- **Minimal sequence allowed by FCC**
- **Coding gain 10.4 dB**



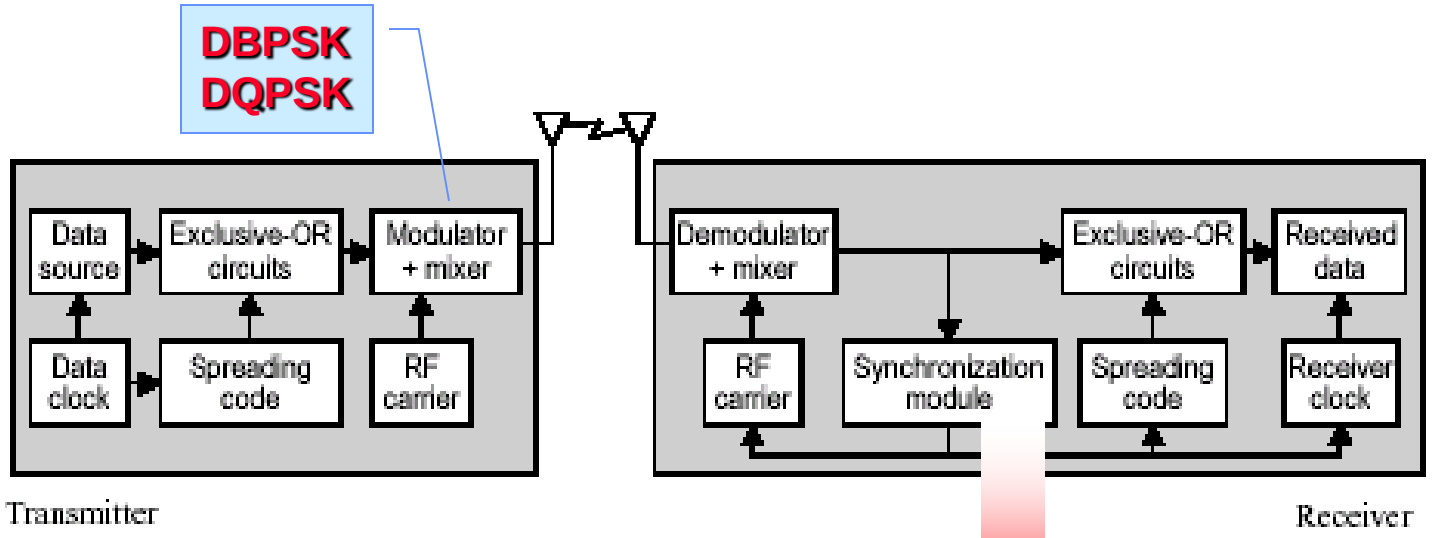



# DSSS Benefits

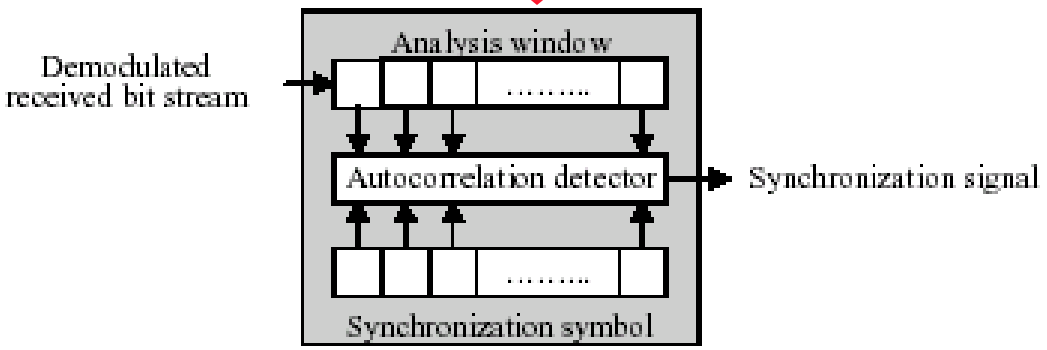
- **10 dB coding gain:**
  - **Robust against interferers and noise (10 dB suppression)**
- **Robust against time delay spread**
  - **Resolution of echoes**



# DSSS Hardware Block Diagram




**Transmitter and receiver schematic**




**Synchronization module schematic**

# IEEE 802.11 DSSS PHY characteristics

- 2.4 GHz ISM band (FCC 15.247)
- 1 and 2 Mb/s datarate
  - DBPSK and DQPSK modulation
  - Chipping rate 11 MHz with 11 chip Barker sequence
- 5.5 and 11Mbps (802.11b)
  - CCK (QPSK, DQPSK modulations – mandatory)
  - PBCC (BPSK, QPSK modulations – optional)
- 22 and 33Mbps (802.11g)
  - PBCC-22, PBCC-33 modulation (TI proposal – optional)
- Multiple channels in 2.4 to 2.4835 GHz band

# DSSS Channels

| CHNL_ID | Frequencies | FCC Channel Frequencies | ETSI Channel Frequencies | Japan Frequency (MKK) | Japan Frequency (New MKK) |
|---|---|---|---|---|---|
| 1 | 2412 MHz | X | X | - | X |
| 2 | 2417 MHz | X | X | - | X |
| 3 | 2422 MHz | X | X | - | X |
| 4 | 2427 MHz | X | X | - | X |
| 5 | 2432 MHz | X | X | - | X |
| 6 | 2437 MHz | X | X | - | X |
| 7 | 2442 MHz | X | X | - | X |
| 8 | 2447 MHz | X | X | - | X |
| 9 | 2452 MHz | X | X | - | X |
| 10 | 2457 MHz | X | X | - | X |
| 11 | 2462 MHz | X | X | - | X |
| 12 | 2467 MHz | - | X | - | X |
| 13 | 2472 MHz | - | X | - | X |
| 14 | 2484 MHz | - | - | X | X |

**Table 1, DSSS PHY Frequency Channel Plan**

- **FCC(US), IC(Canada) and ETSI(Europe) : 2.4GHz - 2.4835GHz**
- **Japan : 2.471GHz - 2.497GHz (MKK : channel 14; new MKK : channels 1-14)**
- **France : 2.4465GHz - 2.4835GHz (channels 10, 11, 12, 13)**
- **Spain : 2.445GHz - 2.475GHz (channels 10, 11)**
- **Adjacent cells using different channels : ≥ 30MHz (25MHz in 802.11b)**
- FCC pushes the unused unlicensed TV broadcasting band 3.65GHz-3.70GHz as WLAN band.

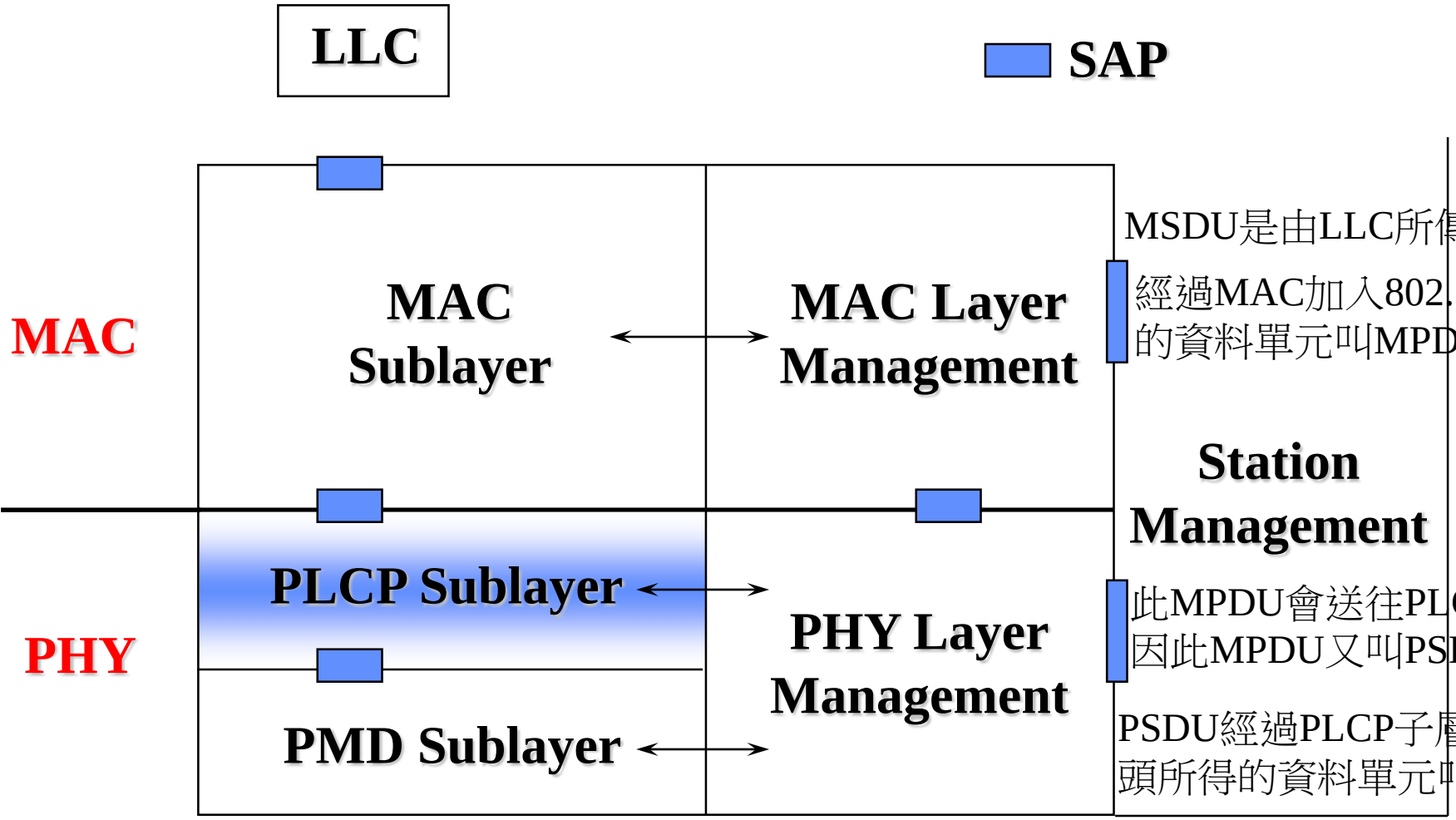
# IEEE 802.11 PHY Terminology in Spec.(s)

- 1 Mbps : Basic Rate (BR)
- 2 Mbps : Extended Rate (ER)
- 5.5/11 Mbps : High Rate (HR)
- 22~33/6~54 Mbps : Extended Rate PHY (ERP)
- 150 Mbps : Multi-Input Multi-Output (MIMO); 11n
- 500Mbps : IEEE 802.11ac

# PLCP Frame Formats in IEEE 802.11b

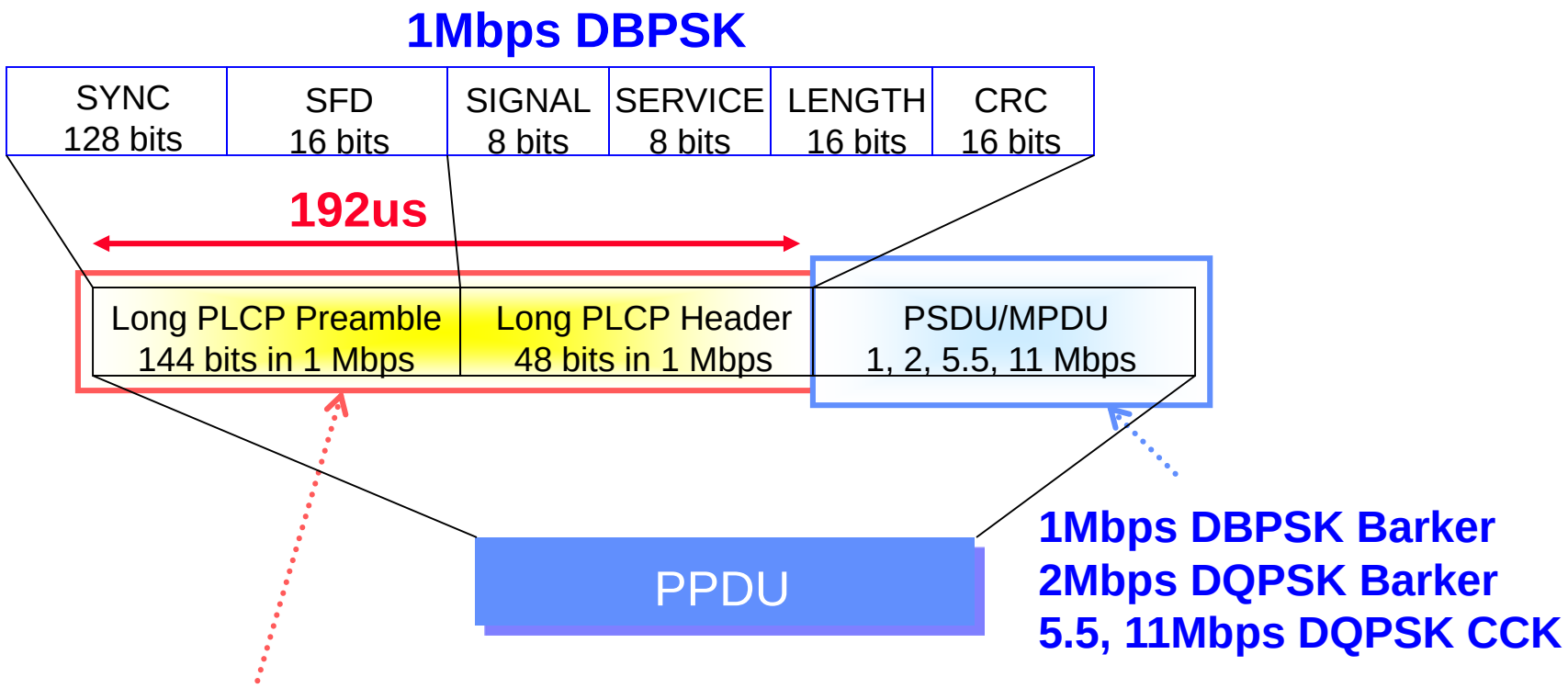
- **Two different preamble and header formats**
  - **Long PLCP PPDU format (Mandatory in 802.11b)**
    - » **144-bit preamble : 1Mbps DBPSK**
    - » **48-bit header : 1Mbps DBPSK**
    - » **Spend 192us**
    - » **PSDU : 1, 2, 5.5, 11Mbps**
    - » **Compatible with 1 and 2 Mbps**
  - **Short PLCP PPDU format (Optional in 802.11b)**
    - » **Minimize overhead, maximize data throughput**
    - » **72-bit preamble : 1Mbps DBPSK**
    - » **48-bit header : 2Mbps DQPSK**
    - » **Spend 96us**
    - » **PSDU : 2, 5.5, 11 Mbps**

# PLCP (PHY Convergence) Sublayer



# Long PLCP Frame Format

- **Mandatory in 802.11b**




**Preamble and Header always at 1Mb/s DBPSK Barker**

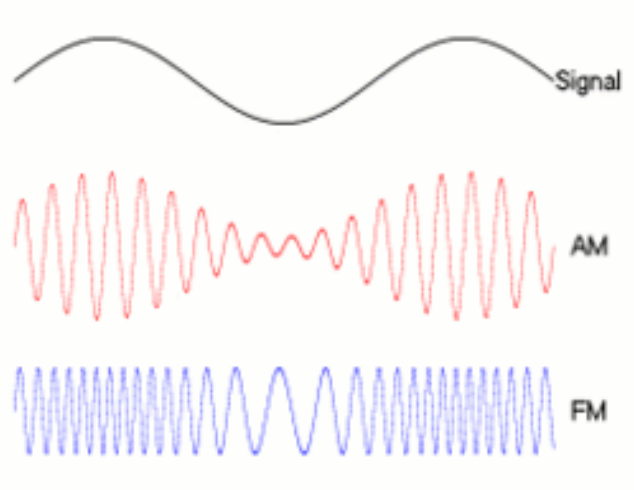
# Modulation

- **Modulation** is the process of varying one or more properties of a periodic waveform, called the *carrier signal*, with a modulating signal that typically contains information to be transmitted.
- Most radio systems in the 20th century used frequency modulation (FM) or amplitude modulation (AM) to make the carrier carry the radio broadcast.

# Modulation

- Modulation is a process of conveying message signal, for example, a digital bit stream or an analog audio signal, inside another signal that can be physically transmitted.

- Modulation of a sine waveform transforms a narrow frequency range baseband message signal into a moderate to high frequency range passband signal, one that can pass through a filter.



# Digital Modulation Methods

- Digital modulation methods can be considered as digital-to-analog conversion and the corresponding demodulation or detection as analog-to-digital conversion.

- The changes in the carrier signal are chosen from a finite number of M alternative symbols (the *modulation alphabet*).

# Example

- A telephone line is designed for transferring audible sounds, for example, tones, and not digital bits (zeros and ones).

- Computers may communicate over a telephone line by means of modems, which are representing the digital bits by tones, called symbols.

- If there are four alternative symbols (corresponding to a musical instrument that can generate four different tones, one at a time), the first symbol may represent the bit sequence 00, the second 01, the third 10 and the fourth 11.

# Example

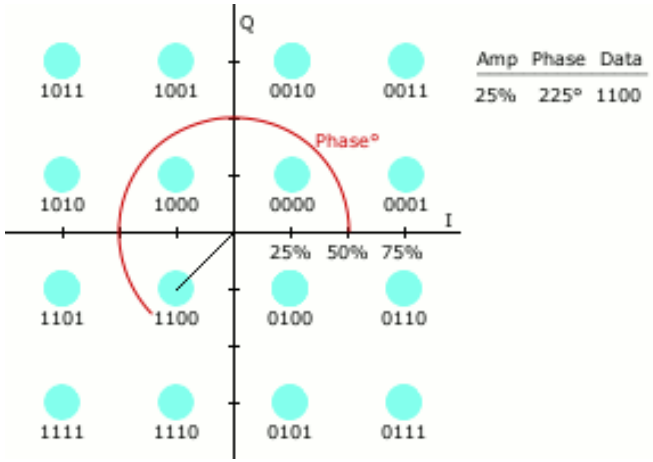
- If the modem plays a melody consisting of 1000 tones per second, the symbol rate is 1000 symbols/second, or baud.
- Since each tone (i.e., symbol) represents a message consisting of two digital bits in this example, the bit rate is twice the symbol rate, i.e. 2000 bits per second.
  - This is similar to the technique used by dial-up modems as opposed to DSLmodems.

# Fundamental Digital Modulation Methods

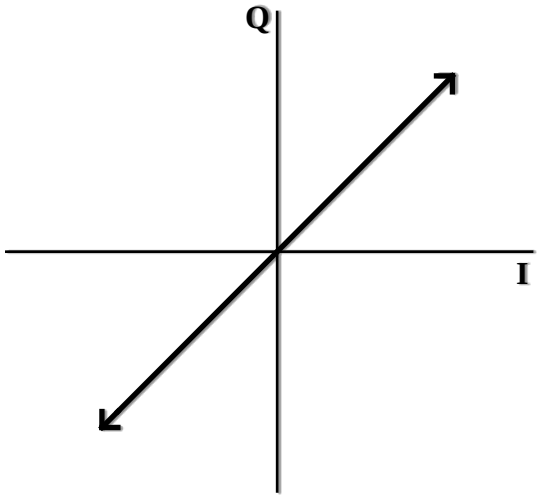
- The most fundamental digital modulation techniques are based on keying:
  - PSK (phase-shift keying): a finite number of phases are used.
  - FSK (frequency-shift keying): a finite number of frequencies are used.
  - ASK (amplitude-shift keying): a finite number of amplitudes are used.
  - QAM (quadrature amplitude modulation): a finite number of at least two phases and at least two amplitudes are used.

# QAM

- An in-phase signal (or **I**, with one example being a cosine waveform) and a quadrature phase signal (or **Q**, with an example being a sine wave) are amplitude modulated with a finite number of amplitudes and then summed.
- It can be seen as a two-channel system, each channel using ASK. The resulting signal is equivalent to a combination of PSK and ASK.



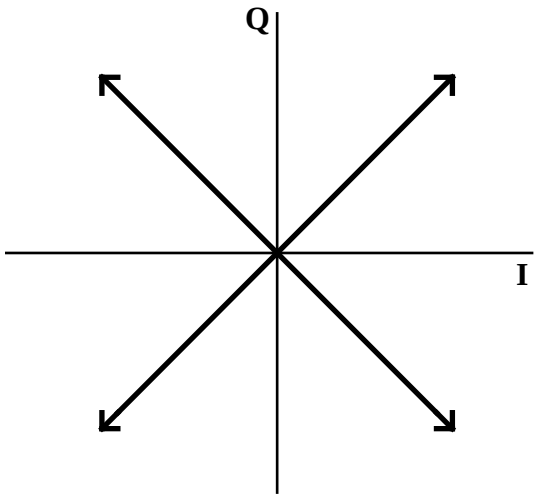
# DBPSK Modulation




| Bit Input | Phase Change (+jω) |
|---|---|
| 0 | 0 |
| 1 | π |

**Table 1, 1 Mb/s DBPSK Encoding Table.**

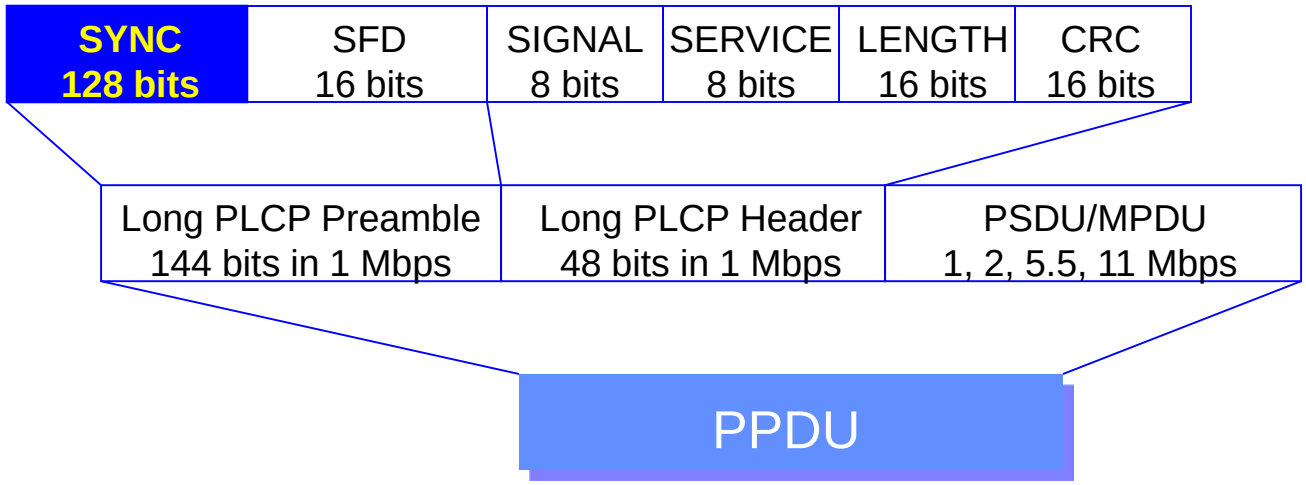
# DQPSK Modulation




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

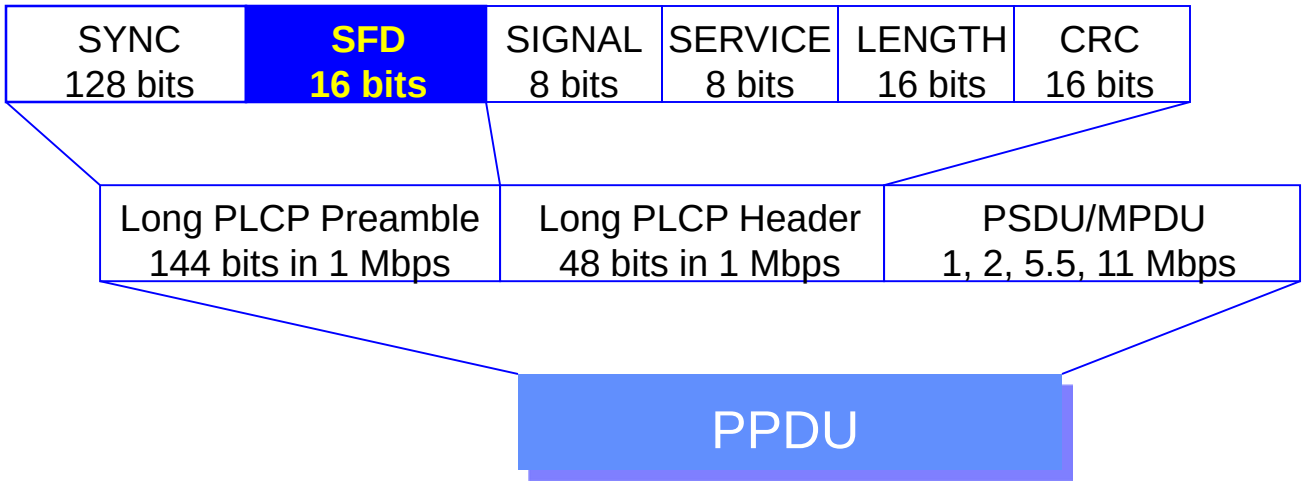
**Table 1, 2 Mb/s DQPSK Encoding Table**

# PLCP synchronization



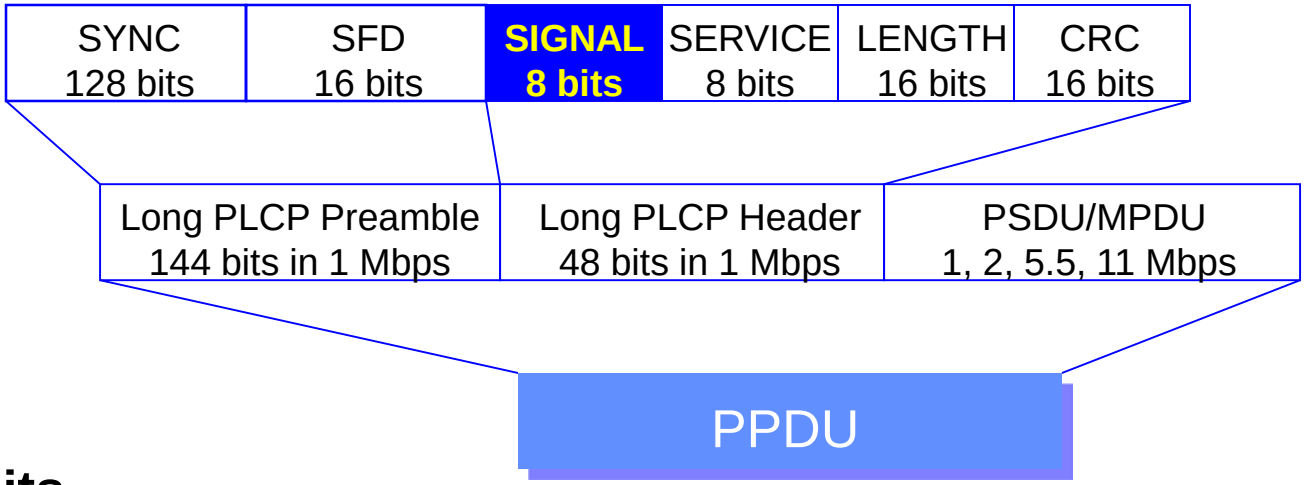

- **128 one bits (‘1’)**
- **scrambled by scrambler**
- **Used for receiver to clock on to the signal and to correlate to the PN (Pseudo Noise) code**

# Start Frame Delimiter



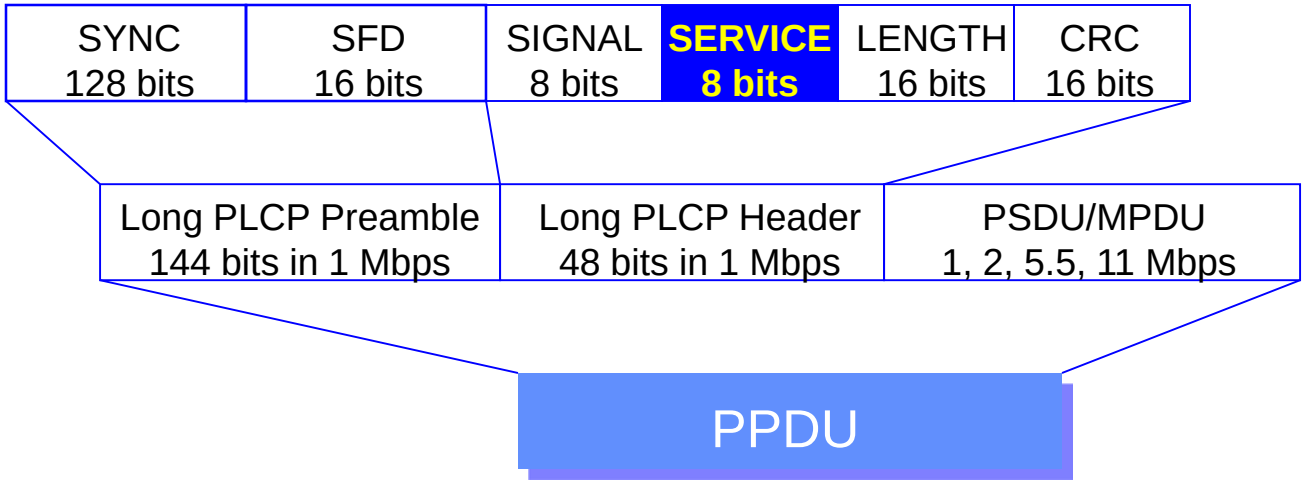

- **16 bit field (hF3A0)**
- **used for**
  - **bit synchronization**

# Signal Field



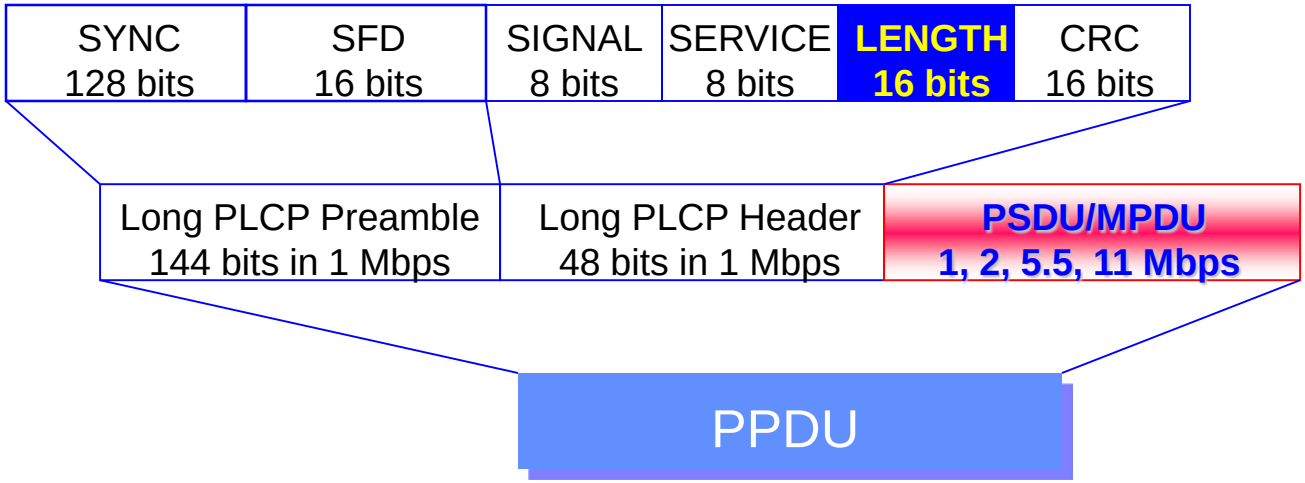

- **8 bits**
- **Rate indication**
  - **h0A 1Mb/s DBPSK**
  - **h14 2Mb/s DQPSK**
  - **h37 5.5Mb/s CCK or PBCC**
  - **h6E 11Mbps CCK or PBCC**
- **Other values reserved for future use (100 kb/s quantities)**

# Service Field



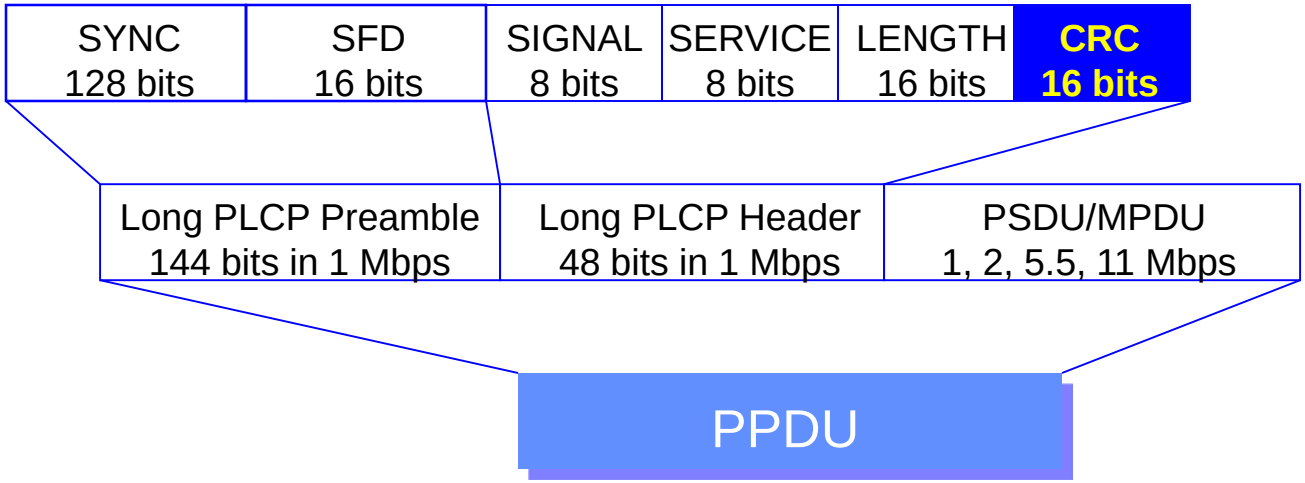

- **Reserved for future use**
  - **Bit 2 : locked clock bit**
    - » **Indicate transmit freq. (mixer) & symbol clocks (baseband) derived from same oscillator**
    - » **optional in 802.11b and mandatory in 802.11g**
  - **Bit 3 : modulation selection**
    - » **0 : CCK / 1 : PBCC**
  - **Bit 7 : length extension bit (in the case datarate > 8Mbps)**
- **h00 signifies 802.11 compliant**

# Length Field



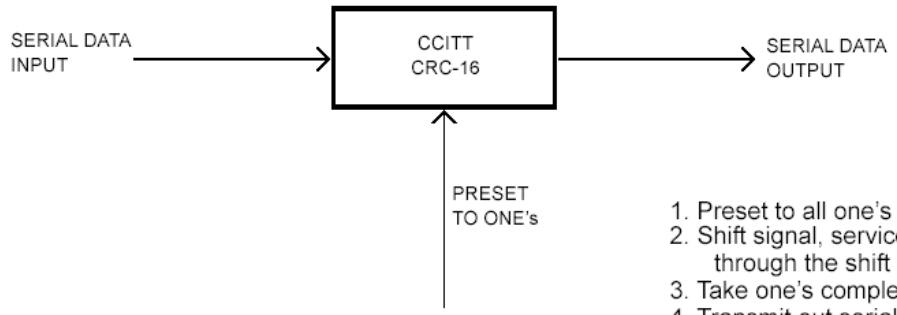

- **Indicates number of micosceonds to be transmitted in PSDU/MPDU**
  - **Decided by Length and datarate (in TXvector)**
- **Used for**
  - **End of frame detection**
  - **Perform Virtual Carrier Sense (for those with lower datarate)**
  - **MPDU CRC sync**

# CRC field

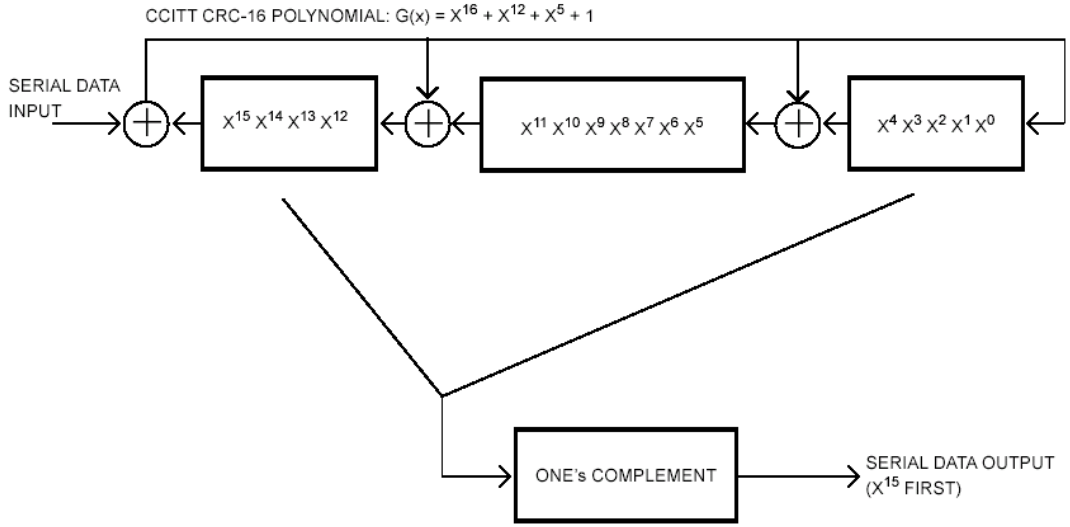



- **CCITT CRC-16**
- **Protects Signal, Service and Length Field**

# CRC Implementation




1. Preset to all one's
2. Shift signal, service length fields through the shift register
3. Take one's complement of the remainder
4. Transmit out serial $X^{15}$ first




| Data | CRC Registers msb lsb |
|---|---|
| | 1111111111111111 |
| 0 | 1110111111011111 |
| 1 | 1101111110111110 |
| 0 | 1010111101011101 |
| 1 | 0101111010111010 |
| 0 | 1011110101110100 |
| 0 | 0110101011001001 |
| 0 | 1101010110010010 |
| 0 | 1011101100000101 |
| 0 | 0110011000101011 |
| 0 | 1100110001010110 |
| 0 | 1000100010001101 |
| 0 | 0000000100111011 |
| 0 | 0000001001110110 |
| 0 | 0000010011101100 |
| 0 | 0000100111011000 |
| 0 | 0001001110110000 |
| 0 | 0010011101100000 |
| 0 | 0100111011000000 |
| 0 | 1001110110000000 |
| 0 | 0010101100100001 |
| 0 | 0101011001000010 |
| 0 | 1010110010000100 |
| 1 | 0101100100001000 |
| 1 | 1010001000110001 |
| 0 | 0101010001000011 |
| 0 | 1010100010000110 |
| 0 | 0100000100101101 |
| 0 | 1000001001011010 |
| 0 | 0001010010010101 |
| 0 | 0010100100101010 |
| 0 | 0101001001010100 |
| 0 | 1010010010101000 |