# WLAN (802.11)

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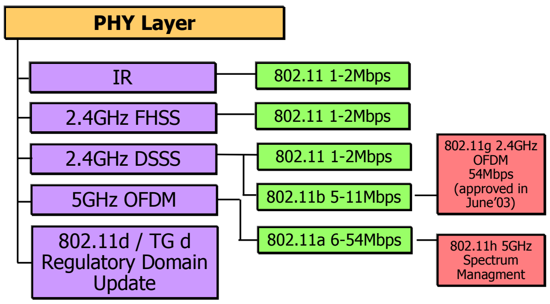
## IEEE 802.11

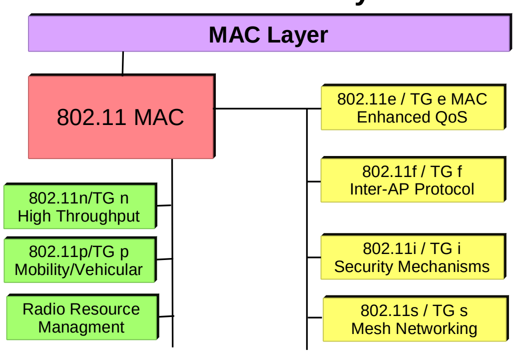
- Wireless LAN standard specifying a wireless interface between a client and a base station (or access point), as well as between wireless clients
- Defines the PHY and MAC layer (LLC layer defined in 802.2)
  - Physical Media: radio or diffused infrared
- Standardization process begun in 1990 and is still going on (1st release '97, 2nd release '99, then '03, '05, ...)

## IEEE 802.11 PHY Layer Activities






## IEEE 802.11 MAC Layer Activities



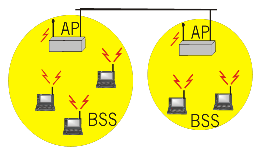



## 802.11 Architecture

- BSS (Basic Service Set): set of nodes using the same coordination function to access the channel
- BSA (Basic Service Area): spatial area covered by a BSS (WLAN cell)
- BSS configuration mode
  - ad hoc mode
  - with infrastructure: the BSS is connected to a fixed infrastructure through a centralized controller, the so-called Access Point (AP)

## WLAN with Infrastructure

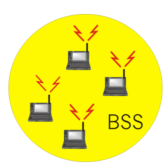
- BSS contains:
  - wireless hosts
  - access point (AP): base station
- BSS's interconnected by distribution system (DS)






## Ad Hoc WLANs

- Ad hoc network: IEEE 802.11 stations can dynamically form a network *without* AP and communicate directly with each other
- Applications:
  - "laptop" meeting in conference room, car
  - interconnection of "personal" devices
  - battlefield
- IETF MANET (Mobile Ad hoc Networks) working group

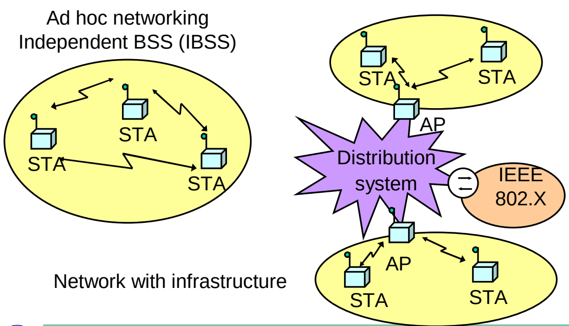





## Extended Service Set (ESS)

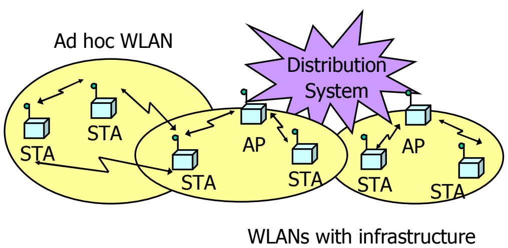
- Several BSSs interconnected with each other at the MAC layer
- The backbone interconnecting the BSS APs (Distribution System) can be a:
  - LAN (802.3 Ethernet/802.4 token bus/802.5 token ring)
  - wired MAN
  - IEEE 802.11 WLAN, possibly meshed (routing problems!)
- An ESS can give access to the fixed Internet network through a gateway node
  - If fixed network is a IEEE 802.X, the gateway works as a bridge thus performing the frame format conversion

## Possible Scenarios (1)






## Possible Scenarios (2)






## Joining a BSS

**Scanning** → **Authentication** → **Association**

- BSS with AP: Both authentication and association are necessary for joining a BSS
- Independent BSS: Neither authentication neither association procedures are required for joining an IBSS

## Joining BSS with AP: Scanning

A station willing to join a BSS must get in contact with the AP. This can happen through:

1. **Passive scanning**
   - The station scans the channels for a Beacon frame (with sync. info) that is periodically sent by the AP
2. **Active scanning (the station tries to find an AP)**
   - The station sends a ProbeRequest frame
   - All AP's within reach reply with a ProbeResponse frame



## Joining BSS with AP: Authentication

Once an AP is found/selected, a station goes through authentication

- **Open system authentication** (default, 2-step process)
  - Station sends authentication frame with its identity
  - AP sends frame as an ack / nack
- **Shared key authentication**
  - Stations receive shared secret key through secure channel independent of 802.11
  - Stations authenticate through secret key (requires encryption via WEP)



## Joining BSS with AP: Association

Once a station is authenticated, it starts the association process, i.e., information exchange about the AP/station capabilities and roaming

- **STA → AP:** AssociateRequest frame
- **AP → STA:** AssociationResponse frame
- New AP informs old AP via DS

- Only after the association is completed, a station can transmit and receive data frames

# IEEE 802.11 / 802.11b

## Physical Layer

Three different access techniques:

- Infrared (IR)
- Frequency hopping spread spectrum (FHSS)
- Direct sequence spread spectrum (DSSS)



## Infrared

- Works in the regular IR LED range, i.e. 850-950 nm
- Used indoor only
- Employes diffusive transmissions, nodes can receive both scattered and line-of-sight signals
- 2 Mbps obtained through 4-pulse position modulation (4-PPM), i.e., 2 information bits encoded with 4 bits
- Max output power: 2W
- Not really used – IrDA is more common and cheaper

## Spread Spectrum

- **Idea:** spread signal over wider frequency band than required
- **Frequency Hopping :** transmit over random sequence of frequencies
- **Direct Sequence**

  random sequence (known to both sender and receiver), called **chipping code**



## FHSS

- Not really used anymore
- Frequency band: ISM @ 2.4 GHz
- In the U.S., the FCC has specified 79 ISM frequency channels with width equal to 1 MHz. Central frequency is @ 2.402 GHz
- 3 channels each corresponding to 1Mbps with GFSK modulation
- 20 ms dwell time $\Rightarrow$ 50 hop/s



## DSSS (1)

- Radiated power is limited
  - Typical values: 85 mW
  - Maximum EIRP: 100mW EU, 1W USA
- Frequency band: ISM bands @ 2.4 GHz
- Band divided into 11 (USA) / 13(EU) overlapping channels
- 3 non overlapping channels, each 11MHz wide and with spacing 25MHz

## IEEE 802.11 (Radio) Evolution

| | 802.11 | 802.11b (Wi-Fi) |
|---|---|---|
| Standard approval | July 1997 | Sep. 1999 |
| Bandwidth | 83.5 MHz | 83.5 MHz |
| Frequency of operation | 2.4-2.4835 GHz | 2.4-2.4835 GHz |
| Number of non-overlapping channels | 3 Indoor/Outdoor | 3 Indoor/Outdoor |
| Data rate per channel | 1,2 Mbps | 1,2,5.5,11 Mbps |
| Physical layer | FHSS, DSSS | DSSS |



## IEEE 802.11 MAC Protocol

Performs the following functions:

- Resource allocation
- Data segmentation and reassemby
- MAC Protocol Data Unit (MPDU) address
- MPDU (frame) format
- Error control



## MAC Frames

Three frame types are defined

1. **Control**: positive ACK, handshaking for accessing the channel (RTS, CTS)
2. **Data Transfer**: information to be transmitted over the channel
3. **Management**: connection establishment/release, synchronization, authentication. Exchanged as data frames but are not reported to the higher layer

## Data Transfer

- Asynchronous data transfer for delay-tolerant traffic (like file transfer)
  - **DCF** (Distributed Coordination Function)
- Synchronous data transfer for real-time traffic (like audio and video)
  - **PCF** (Point Coordination Function): based on the polling of the stations and controlled by the AP (PC)
  - Its implementation is optional (not really implemented)



## Time Slot

- Time is divided into intervals, called **slots**
- A slot is the system unit time and its duration depends on the implementation of the physical layer
  - 802.11b: **20μs**
- Stations are **synchronized** with the AP in the infrastructure mode and among each other in the ad hoc mode ⇒ the system is **synchronous**
- Synchornization maintained through Beacon frames



## IFS

- Interframe space (IFS)
  - time interval between frame transmissions
  - used to establish priority in accessing the channel
- 4 types of IFS:
  - Short IFS (SIFS)
  - Point coordination IFS (PIFS) >SIFS
  - Distributed IFS (DIFS) >PIFS
  - Extended IFS (EIFS) > DIFS
- Duration depends on physical level implementation

## Short IFS (SIFS)

- **To separate transmissions belonging to the same dialogue**
- Associated to the highest priority
- Its duration depends on:
  - Propagation time over the channel
  - Time to convey the information from the PHY to the MAC layer
  - Radio switch time from TX to RX mode
- 802.11b: 10μs



## Point Coordination IFS (PIFS)

- Used to give priority access to Point Coordinator (PC)
- Only a PC can access the channel between SIFS and DIFS
- PIFS=SIFS + 1 time slot



## Distributed IFS (DIFS)

- Used by stations waiting for a free channel to contend
- Set to: PIFS + 1 time slot

## Extended IFS (EIFS)

- Used by every station when the PHY layer notifies the MAC layer that a transmission has not been correctly received
- Avoids that stations with bad channels disrupt other stations' performance
- Forces fairness in the access is one station does not receive an ACK (e.g. hidden terminal)
- Reduce the priority of the first retransmission (indeed make it equal to all others)
- Set to: DIFS + 1 ACK slot



## DCF Access Scheme



## Basic Characteristics

- Its implementation is mandatory
- DCF is based on the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) scheme:
  - stations that have data to transmit contend for accessing the channel
  - a station has to repeat the contention procedure every time it has a new data frame to transmit

# IEEE 802.11 MAC Protocol Overview: CSMA/CA

802.11 CSMA: sender

- if sense channel idle for **DISF** sec.

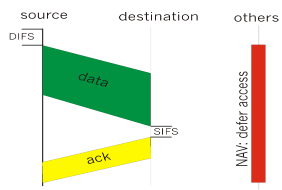
  then transmit entire frame (no collision detection)

- if sense channel busy then random access over a contention window CWmin (CA)

802.11 CSMA receiver:

if received OK

return ACK after **SIFS**

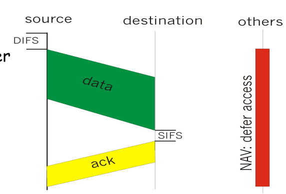





# IEEE 802.11 MAC Protocol Overview

802.11 CSMA Protocol: others

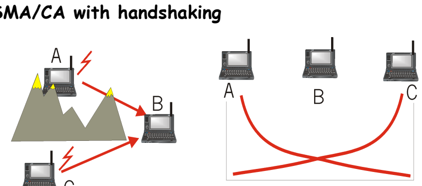
- **NAV**: Network Allocation Vector
  - 802.11 frame has transmission time field
  - others (hearing data) defer access for NAV time units
  - NAV is contained in the header of frames
  - Allows reducing energy consumption
  - Helps reducing hidden terminals problems






# Hidden Terminal Effect

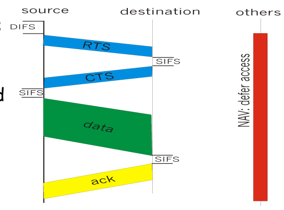
- hidden terminals: A, C cannot hear each other
  - obstacles, signal attenuation
  - collisions at B
- goal: avoid collisions at B
- ***CSMA/CA with handshaking***




(a) (b)

## IEEE 802.11 MAC Protocol Overview: Handshaking

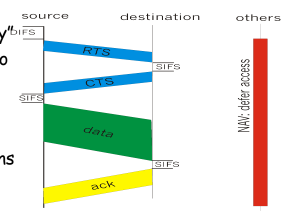
- CSMA/CA: explicit channel reservation
  - sender: send short RTS: request to send
  - receiver: reply with short CTS: clear to send
- CTS reserves channel for sender, notifying (possibly hidden) stations
- avoid hidden station collisions






## IEEE 802.11 MAC Protocol Overview: Handshaking

- RTS and CTS are short:
  - collisions of shorter duration, hence less "costly"
  - the final result is similar to collision detection
- DCF allows:
  - CSMA/CA
  - CSMA/CA with reservations



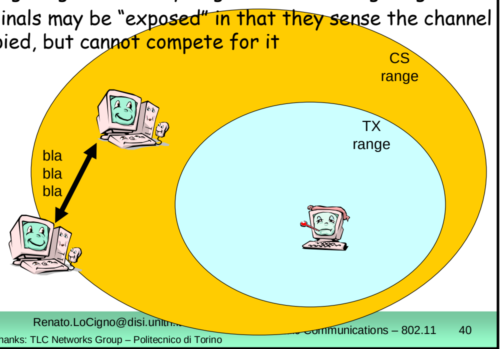



## The DCF Access Scheme

- **Basic**
  - the simplest scheme
  - used when the data frames to be transmitted have a fairly short duration
- **With handshaking**
  - Uses additional control frames for channel access
  - Designed to solve the problems of hidden terminals
  - Provides higher reliability in data transmission

## The exposed terminal problem

- Sensing range is normally larger than receiving range
- Terminals may be "exposed" in that they sense the channel occupied, but cannot compete for it






## DCF
## The Basic Access Mode



## Carrier Sensing

- Used to determine whether the channel is busy or idle
- Performed at the physical layer (physical carrier sensing) and at the MAC layer (virtual carrier sensing)
  - **Physical carrier sensing**: detection of nearby energy sources
  - **Virtual carrier sensing**: the frame header indicates the remaining duration of the current Channel Access Phase (till ACK is received)

## Network Allocation Vector (NAV)

- Used by the stations nearby the transmitter to store the duration of the frame that is occupying the channel
- The channel will become idle when the NAV expires
- Upon the NAV expiration, stations that have data to transmit listen to the channel again



## Using DIFS and SIFS

- **Transmitter:**
  - senses the channel
  - if the channel is idle, it waits a time equal to DIFS
  - if the channel remains idle for DIFS, it transmits its MPDU



## Using DIFS and SIFS

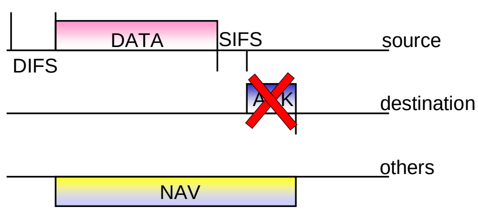
- **Receiver:**
  - computes the checksum thus verifying whether the transmission is correct
  - if so, it sends an ACK after a time equal to SIFS
  - it should always transmit an ACK with a rate less than or equal to the one used by the transmitter and no larger than 2Mbit/s

## Using DIFS and SIFS

- **Neighbors:**
  - set their NAV to the value indicated in the transmitted MPDU
  - NAV set to: the MPDU tx time + 1 SIFS + ACK time



## MPDU Transmission






## Frame Retransmissions

- A frame transmission may fail because of collision or errors on the radio channel
- A failed transmission is re-attempted till a max no. of retransmissions is reached
- ARQ scheme: Stop&Wait

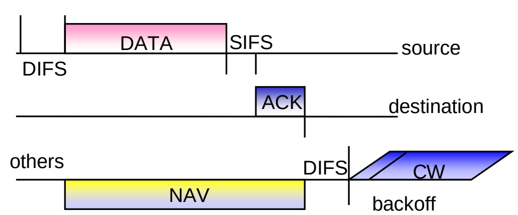
# Collision Avoidance (CA)

**Backoff procedure**

- If a station senses the channel busy, it waits for the channel becoming idle
- As soon as the channel is idle for DIFS, the station
  - computes the backoff time interval
  - sets the backoff counter to this value
- The station will be able to transmit when its backoff counter reaches 0



# MPDU Transmission






# Backoff Value

- Integer value corresponding to a number of time slots
- The number of slots is a r.v. uniformly distributed in [0,CW-1]
- CW is the Contention Window and at each transmission attempt is updated as:
  - For i=1, $CW_1=CW_{min}$
  - For i>1, $CW_i=2CW_{i-1}$ with i>1 being the no. of consecutive attempts for transmitting the MPDU
  - For any i, $CW_i \leq CW_{max}$

## Backoff Decrease

- While the channel is busy, the backoff counter is frozen
- While the channel is idle, and available for transmissions the station decreases the backoff value until
  - the channel becomes busy or
  - the backoff counter reaches 0

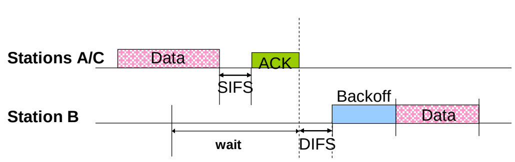


## Accessing the Channel

- If more than one station decrease their counter to 0 at the same time → collision
- Colliding stations have to recompute a new backoff value



## Basic DCF: An Example



## Data Fragmentation (1)

- A MSDU is fragmented into more than one frame (MPDU) when its size is larger than a certain **fragmentation threshold**
  - In the case of failure, less bandwidth is wasted
- All MPDUs have same size except for the last MPDU that may be smaller than the fragmentation threshold
- PHY header is inserted in every fragment → convenient if the fragmentation threshold is not too little



## Data Fragmentation (2)

- MPDUs originated from the same MSDU are transmitted at distance of SIFS + ACK + SIFS
- The transmitter releases the channel when
  - the transmission of all MPDUs belonging to a MSDU is completed
  - the ACK associated to an MPDU is lost



## Data Fragmentation (3)

- Backoff counter is increased for each fragment retransmission belonging to the same frame
- The receiver reassembles the MPDUs into the original MSDU that is then passed to the higher layers
- Broadcast and multicast data units are never fragmented

## Recontending for the Channel

- A station recontends for the channel when
  - it has completed the transmission of an MPDU but still has data to transmit
  - a MPDU transmission fails and the MPDU must be retransmitted
- **Before recontending the channel after a successful transmission, a station must perform a backoff procedure with CWmin**



## DCF
## Access with handshaking



## Access with Handshake

- Used to reserve the channel
- Why?
  - Hidden stations
  - Colliding stations keep transmitting their MPDU; the larger the MPDU involved in the collision, the more bandwidth is wasted
  - Need to avoid collisions, especially when frame is large
  - Particularly useful when a large no. of STAs contend for the channel

## RTS/CTS

- Handshaking procedure uses the Request to send (RTS) and Clear to send (CTS) control frames
- RTS / CTS should be always transmitted @1Mbps (they are only headers)
- Access with handshaking is used for frames larger than an RTS_Threshold

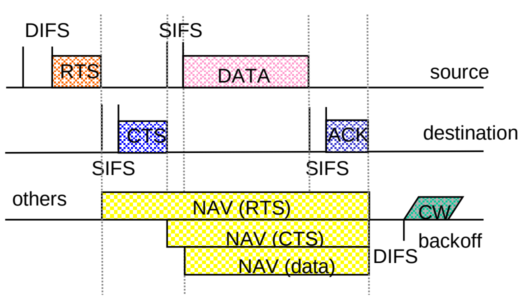


## DCF with Handshaking

- Transmitter:
  - send a RTS (20 bytes long) to the destination
- Neighbors:
  - read the duration field in RTS and set their NAV
- Receiver:
  - acknowledge the RTS reception after SIFS by sending a CTS (14 bytes long)
- Neighbors:
  - read the duration field in CTS and update their NAV
- Transmitter:
  - start transmitting upon CTS reception



## MPDU Transmission & NAV



## PCF
## Centralized access scheme



## Basic Characteristics

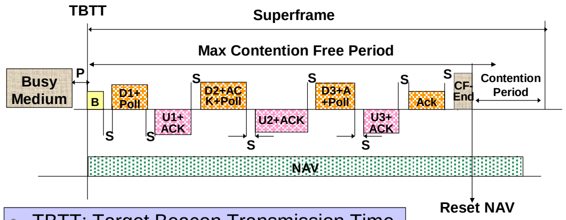
- Used for services with QoS requirements, it provides a contention-free access to the channel
- Needs a Point Coordination (PC) that polls the stations → it can be implemented in networks with infrastructure only (AP=PC)
- Stations enabled to operate under the PCF mode are said to be CF-aware (CF=Contention Free)



## PCF

- Stations declare their participation in the CF phase in the Association Request
- PC builds the polling list based on the received requests
- Polling list is static
- Implementation of the polling list and tables are left to the system operator

## Superframe and PCF Protocol




- TBTT: Target Beacon Transmission Time
- D1, D2: frames sent by PC
- U1, U2, U3: frames sent by polled station
- B: beacon frame (sent by AP)
- CFP repetition interval

**D=CF-Downlink**
**U=CF-UPlink**
**S=SIFS**
**P=PIFS**

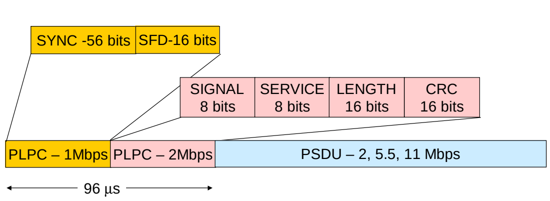


## Examples of frame format

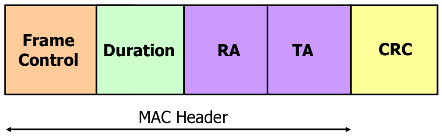


## Generic DSSS packet

SFD – Start Frame Delimiter
PLPC – Physical Layer Convergence Protocol



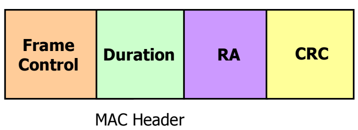
## Example: RTS Frame




- **Duration** (in µs): Time required to transmit next (data) frame + CTS + ACK + 3 SIFs
- **RA**: Address of the intended immediate recipient
- **TA**: Address of the station transmitting this frame



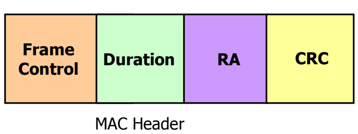
## Example: CTS Frame




- **Duration** (in µs): Duration value of previous RTS frame – 1 CTS time – 1 SIFS
- **RA**: The TA field in the RTS frame



## Example: ACK Frame




- **Duration**: set to 0 if More Fragments bit was 0, otherwise equal to the duration of previous frame – 1 ACK – 1 SIFS
- **RA**: copied from the Address 2 field of previous frame

## Some Numerical Values…

- $PHY_{HDR}$: 16 bytes, transmitted @ 1 Mbps
- $MAC_{HDR}$: 34 bytes, transmitted @ 1 Mbps
  - If slot=20μs, $PHY_{HDR}$+ $MAC_{HDR}$=20 slots
- ACK=$PHY_{HDR}$+14 bytes , transmitted @ 1 Mbps
  - If slot=20μs, ACK=12 slots



## Detailed MAC Format (bytes)

| Frame Control | Duration ID | Address1 (source) | Address2 (destination) | Address3 (rx node) |
|---|---|---|---|---|
| 2 | 2 | 6 | 6 | 6 |

| Sequence Control | Address4 (tx node) | Data | FCS |
|---|---|---|---|
| 2 | 6 | 0 - 2,312 | 4 |



## MAC Format fields

| Field | Bits | Notes/Description |
|---|---|---|
| Frame Control | 15 - 14 | Protocol version. Currently 0 |
| | 13 - 12 | Type |
| | 11 - 8 | Subtype |
| | 7 | To DS. 1 = to the distribution system. |
| | 6 | From DS. 1 = exit from the Distribution System. |
| | 5 | More Frag. 1 = more fragment frames to follow (last or unfragmented frame = 0) |
| | 4 | Retry. 1 = this is a re-transmission. |
| | 3 | Power Mgt. 1 = station in power save mode, 1 = active mode. |
| | 2 | More Data. 1 = additional frames buffered for the destination address (address x). |
| | 1 | WEP. 1 = data processed with WEP algorithm. 0 = no WEP. |
| | 0 | Order. 1 = frames must be strictly ordered. |

## MAC Format fields

| Field | Bits | Notes/Description |
|---|---|---|
| Duration ID | 15 - 0 | For data frames = duration of frame. For Control Frames the associated identity of the transmitting station. |
| Address 1 | 47 - 0 | Source address (6 bytes). |
| Address 2 | 47 - 0 | Destination address (6 bytes). |
| Address 3 | 47 - 0 | Receiving station address (destination wireless station) |
| Sequence Control | 15 - 0 | |
| Address 4 | 47 - 0 | Transmitting wireless station. |
| Frame Body | | 0 - 2312 octets (bytes). |
| FCS | 31 - 0 | Frame Check Sequence (32 bit CRC). defined in P802.11. |



## IEEE 802.11 (Radio) Evolution

| | 802.11b (Wi-Fi) | 802.11a | 802.11g |
|---|---|---|---|
| **Standard approval** | Sep. 1999 | Sep. 1999 | Sep. 1999 |
| **Bandwidth** | 83.5 MHz | 300 MHz | 83.5 MHz |
| **Frequency of operation** | 2.4-2.4835 GHz | 5.15-5.35 GHz<br>5.725-5.825 GHz | 2.4-2.4835 GHz |
| **Number of non-overlapping channels** | 3 Indoor/Outdoor | 4 Indoor<br>4 Indoor/Outdoor | 4 Indoor<br>4 Indoor/Outdoor |
| **Data rate per channel** | 1,2,5.5,11 Mbps | 6,9,12,18,24,36,48<br>54 Mbps | 1,2,5.5,11 //<br>6,9,12,18,24,36,48,<br>54 Mbps |
| **Physical layer** | DSSS | OFDM | DSSS // OFDM |



## 802.11g PHY

- Full backward compatibility with 802.11b
- Supports the 802.11b specified data rates of 1, 2, 5.5 and 11 Mbps
- Adds further data rates of 6, 9, 12, 18, 24, 36, 48 and 54 Mbps using OFDM
- Only Tx and Rx of OFDM @ 6, 12 and 24 Mbps is mandatory
- OFDM uses 52 sub-carriers are modulated using BPSK, QPSK, 16-QAM or 64-QAM
- Forward Error Correction (convolutional coding) is used with a coding rate of ½, 2/3 or ¾

## 802.11g PHY

- Improved data rate is paid for with a smaller transmission range
- Improved data rates apply only to the payload: useless with small packets (60-80% of Internet packets are < than 100 bytes!)
- The overall performance is heavily influenced by the "worst channel syndrome"
- 802.11 MAC shares the channel based on access rounds not time