

WLAN (802.11)

Renato Lo Cigno

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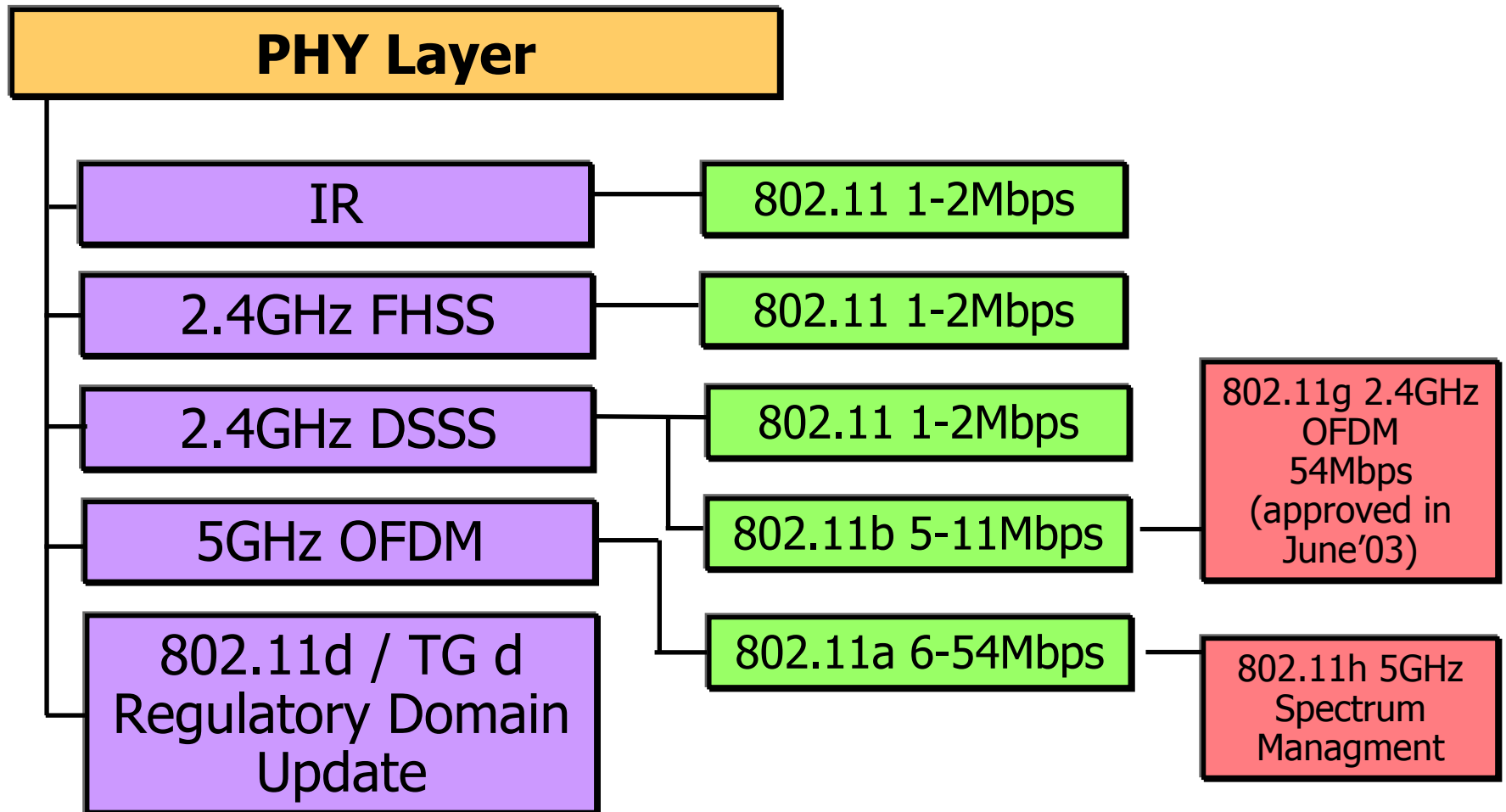


IEEE 802.11

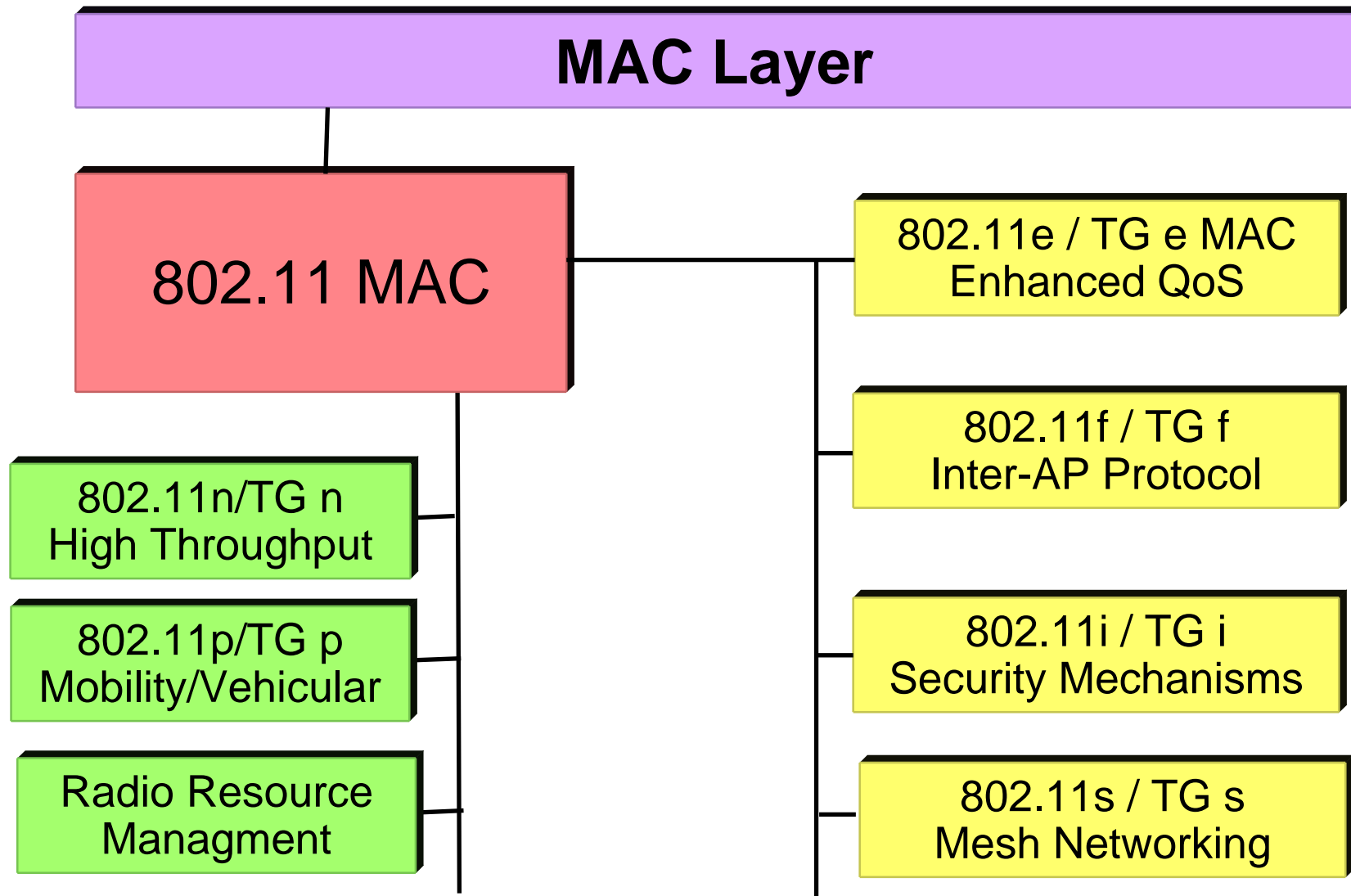
- Wireless LAN standard specifying a wireless interface between a client and a base station (or access point), as well as between wireless clients
- Defines the PHY and MAC layer (LLC layer defined in 802.2)
 - Physical Media: radio or diffused infrared
- Standardization process begun in 1990 and is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



IEEE 802.11 PHY Layer Activities



IEEE 802.11 MAC Layer Activities



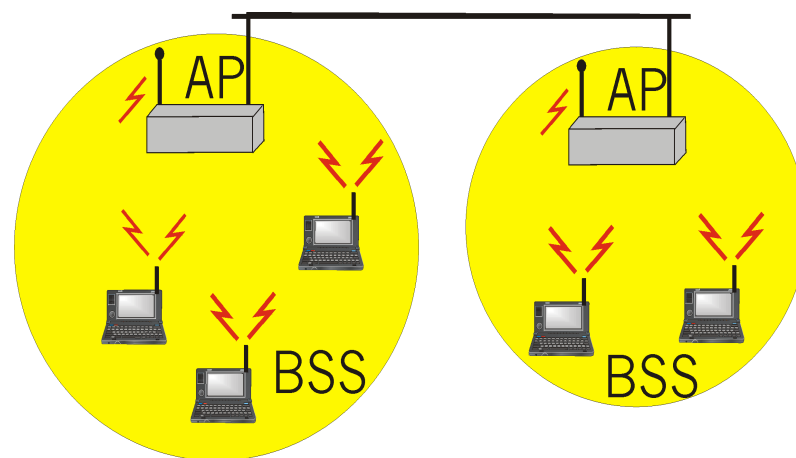
802.11 Architecture

- 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)



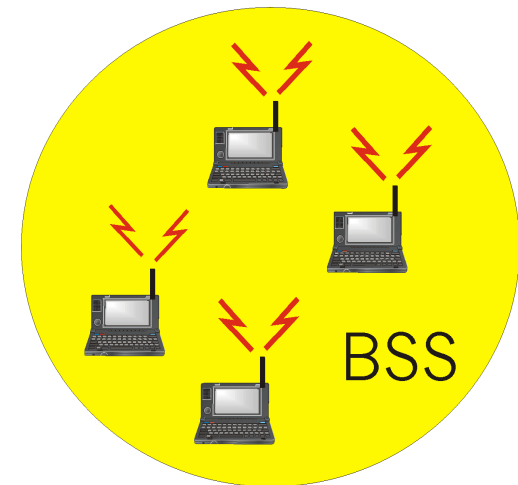
WLAN with Infrastructure

- 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



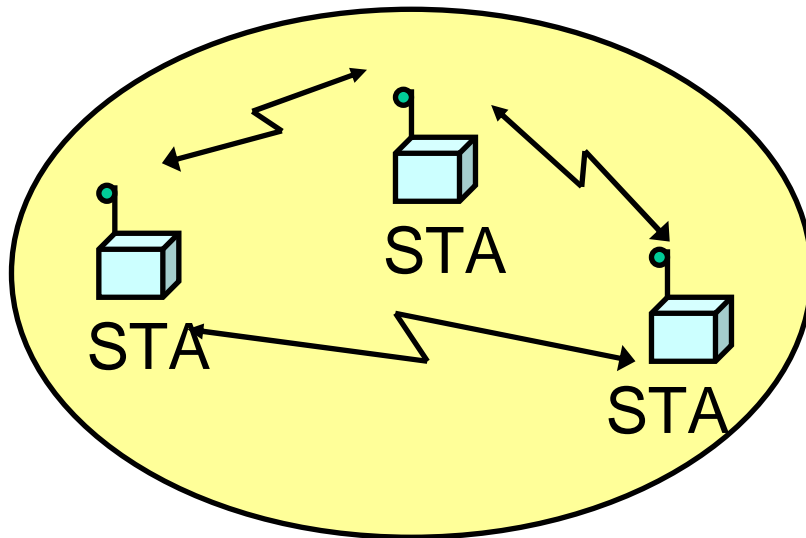
Extended Service Set (ESS)

- 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

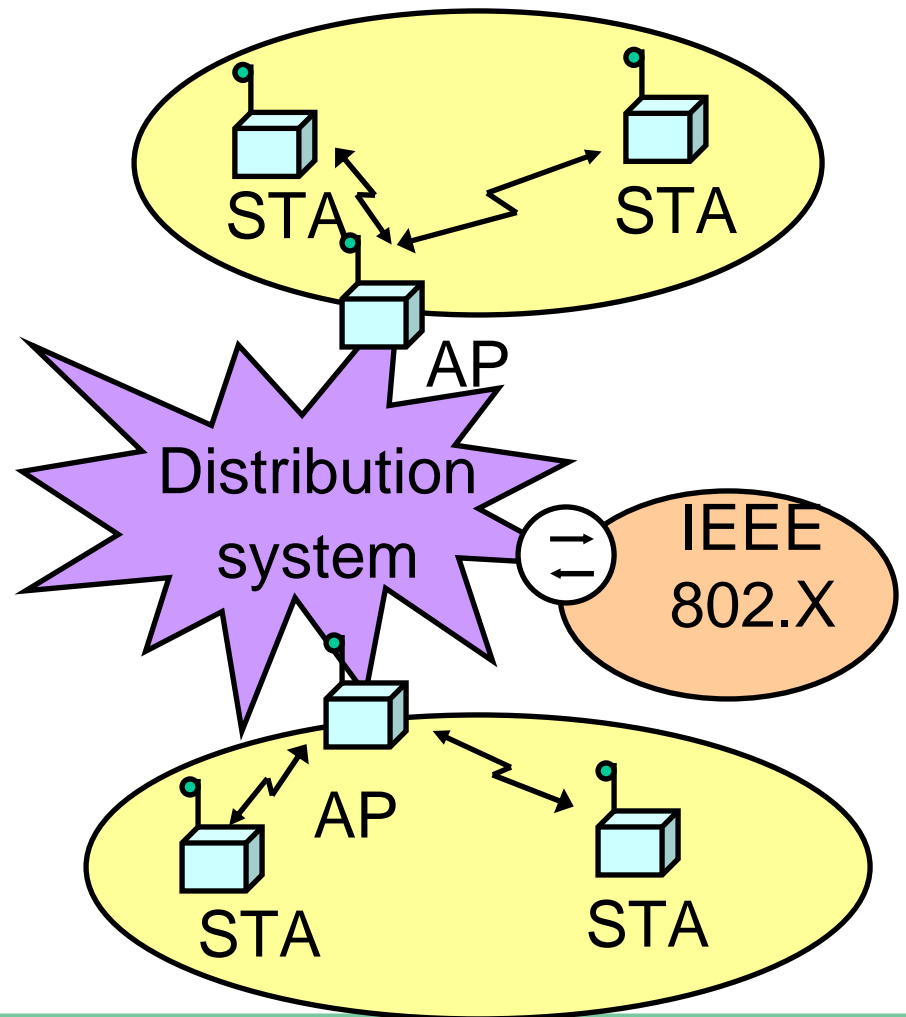


Possible Scenarios (1)

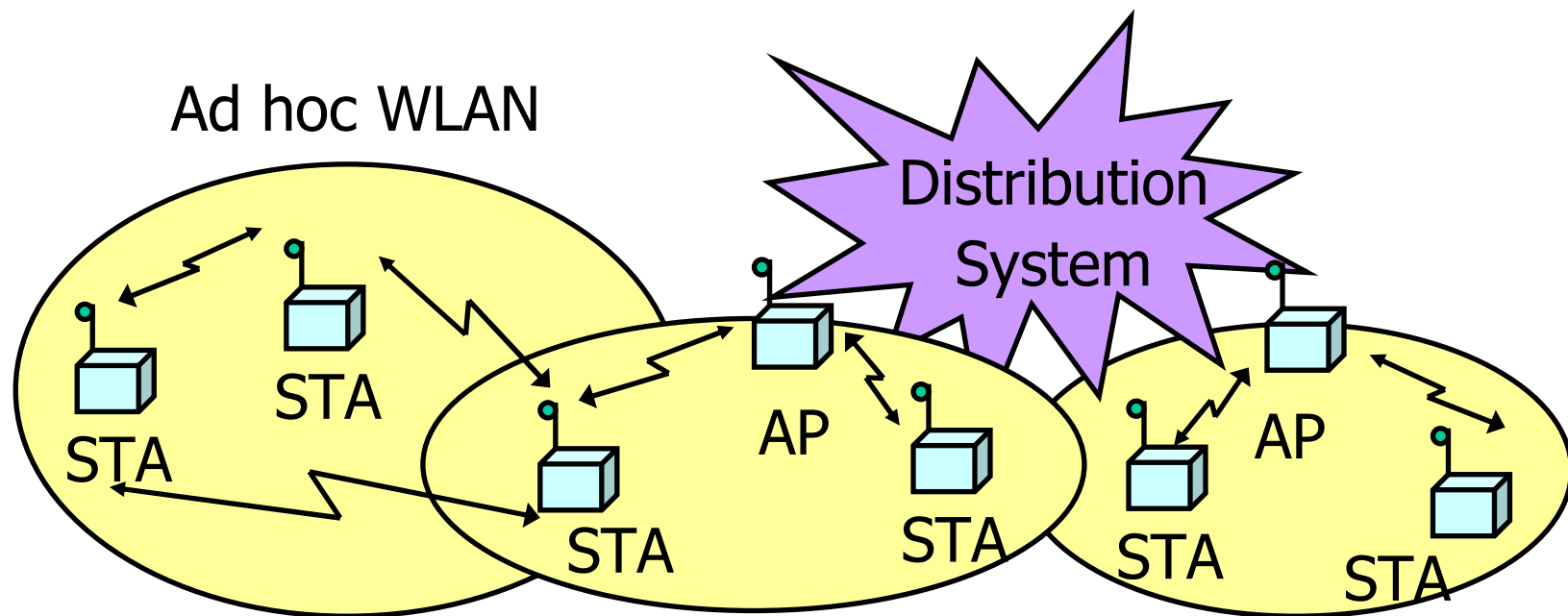
Ad hoc networking
Independent BSS (IBSS)



Network with infrastructure



Possible Scenarios (2)



WLANs with infrastructure



Joining a BSS



- BSS with AP: Both authentication and association are necessary for joining a BSS
- Independent BSS: Neither authentication nor 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
- Employs 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 reassembly
- 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: **20 μ s**
- Stations are **synchronized** with the AP in the infrastructure mode and among each other in the ad hoc mode \Rightarrow the system is **synchronous**
- Synchronization 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: 10 μ s



Point Coordination IFS (PIFS)

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



Distributed IFS (DIFS)

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



Extended IFS (EIFS)

- Used by a 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
- Reduce the priority of the first retransmission
- Set to: DIFS + 1 time slot



DCF Access Scheme



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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 **DIFS** sec.

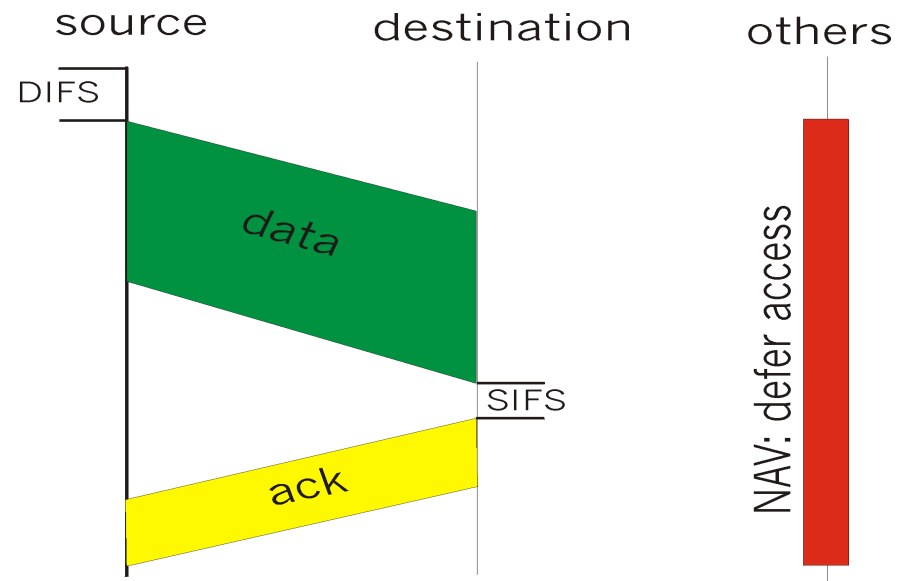
then transmit entire frame (no collision detection)

-if sense channel busy
then random access over a contention window CW_{min} (CA)

802.11 CSMA receiver:

if received OK

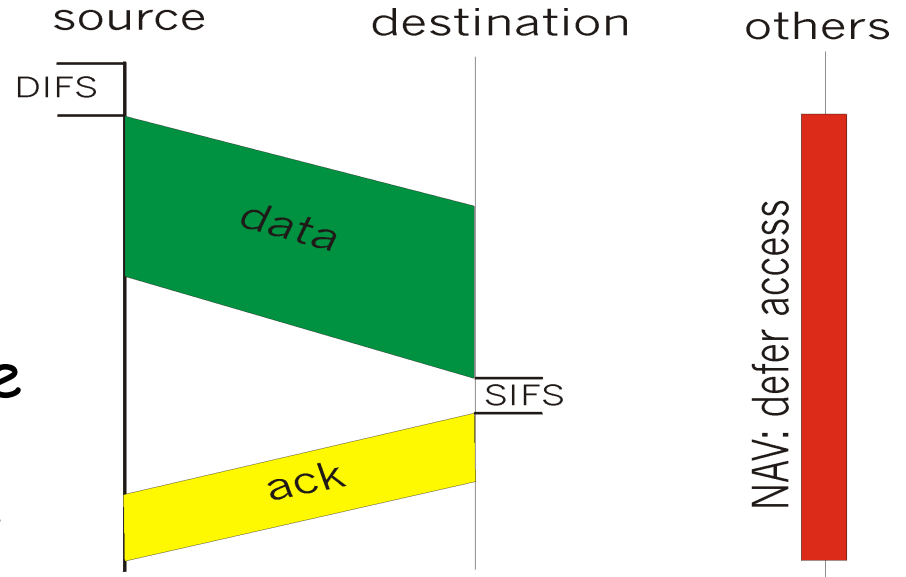
return ACK after **SIFS**



IEEE 802.11 MAC Protocol Overview

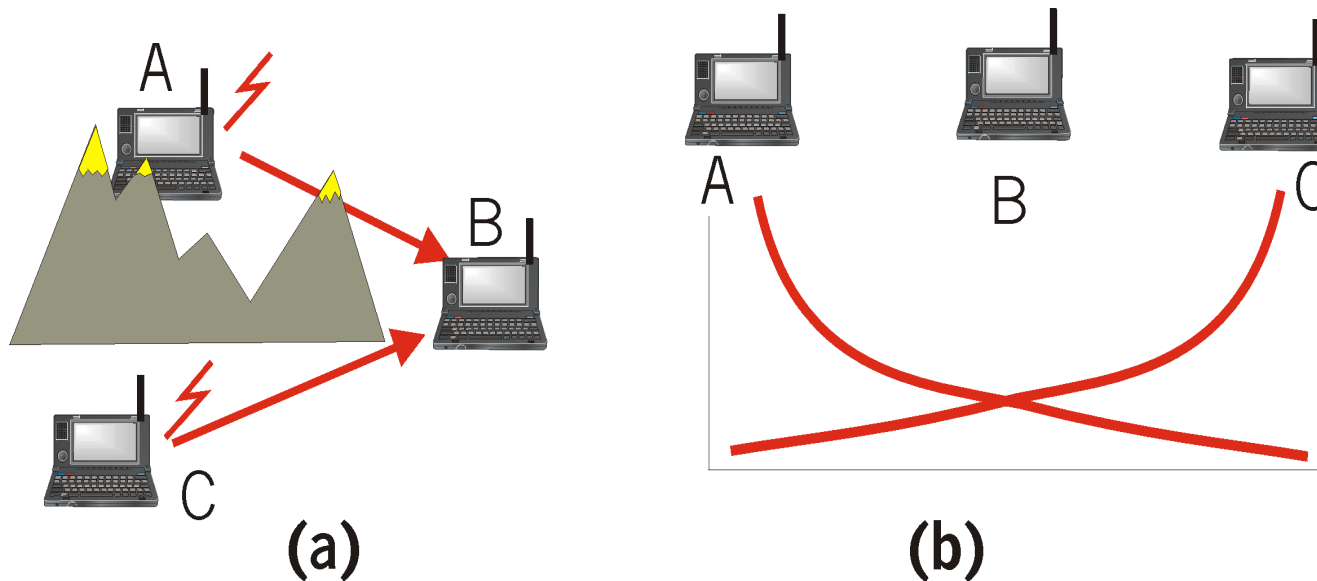
802.11 CSMA Protocol: others

- 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



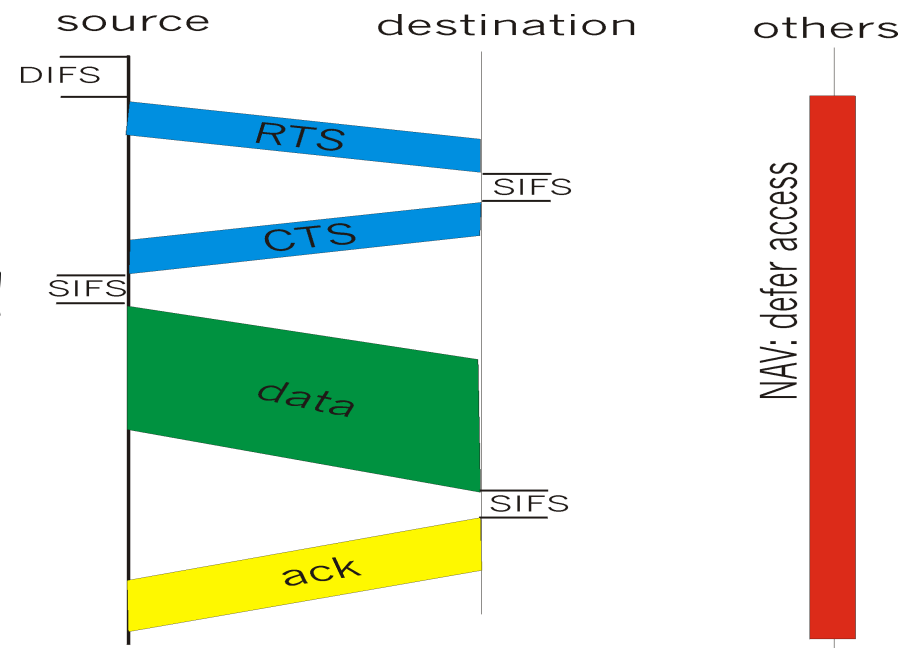
Hidden Terminal Effect

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



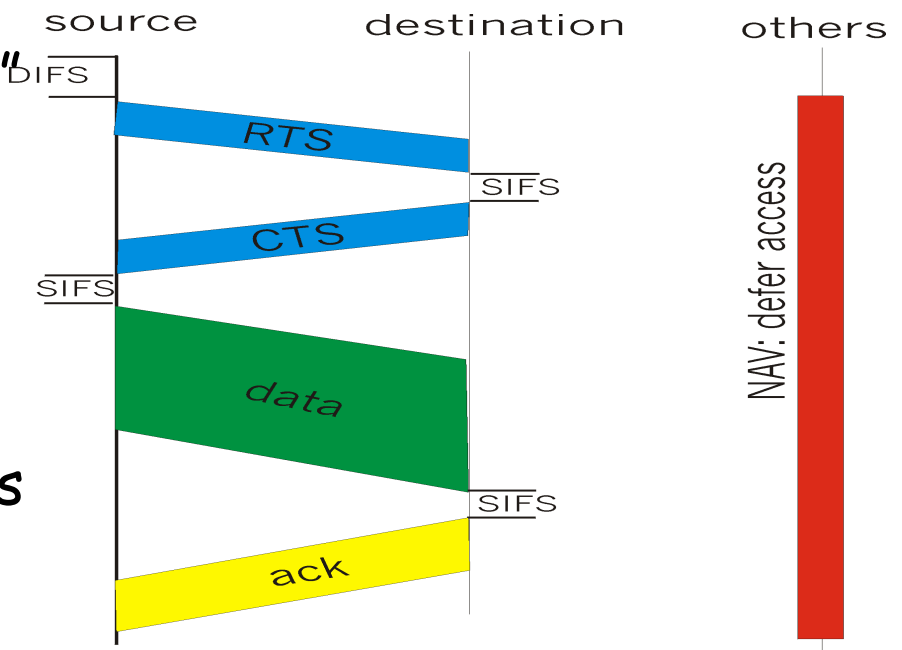
IEEE 802.11 MAC Protocol Overview: Handshaking

- 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



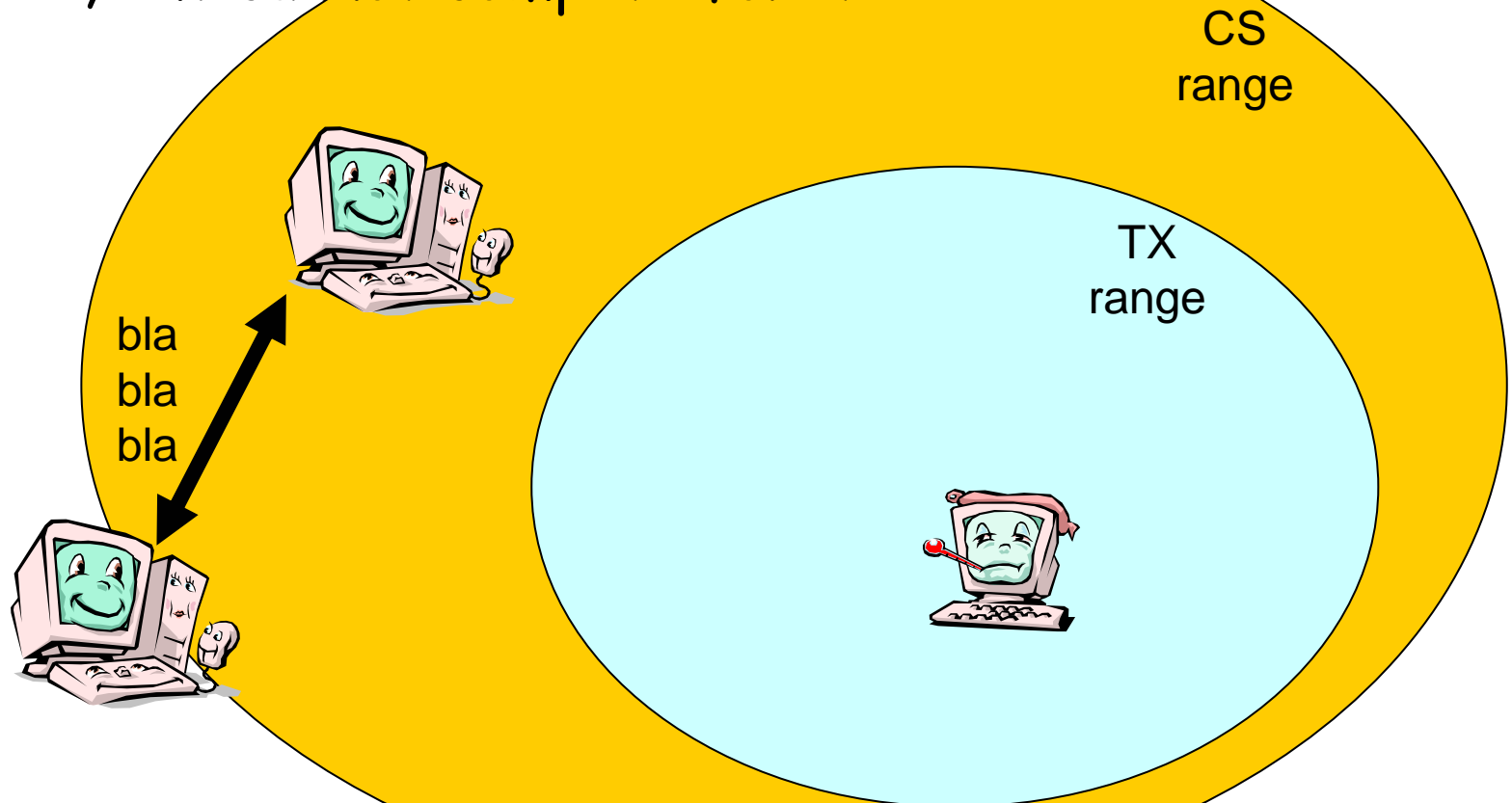
The DCF Access Scheme

- **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



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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

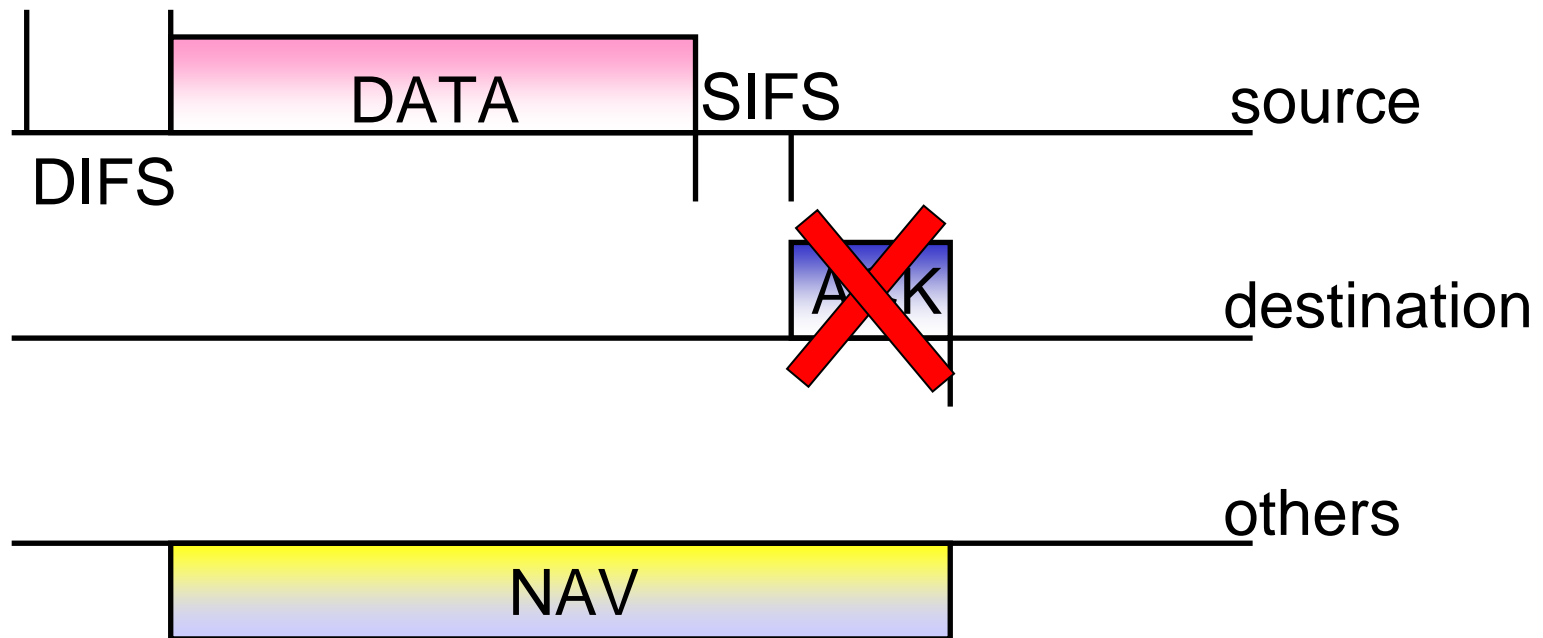


Using DIFS and SIFS

- **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



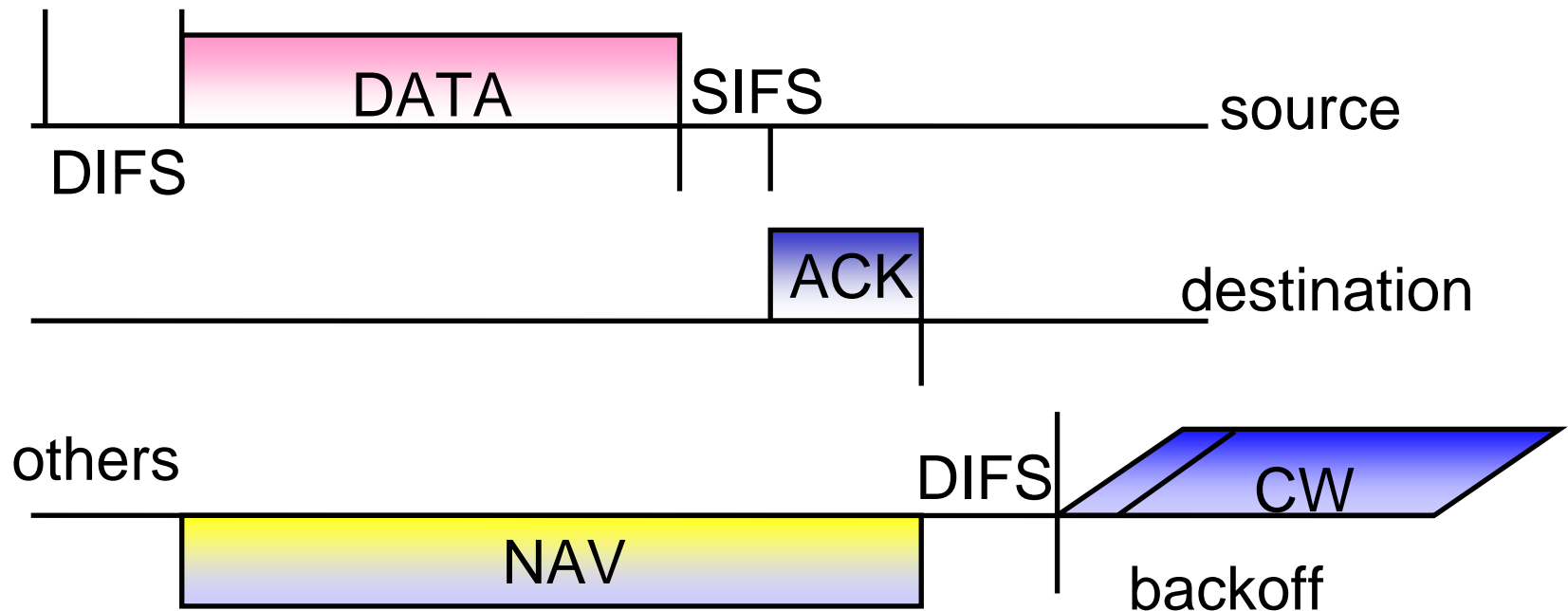
Collision Avoidance (CA)

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



CW=Contention Window



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

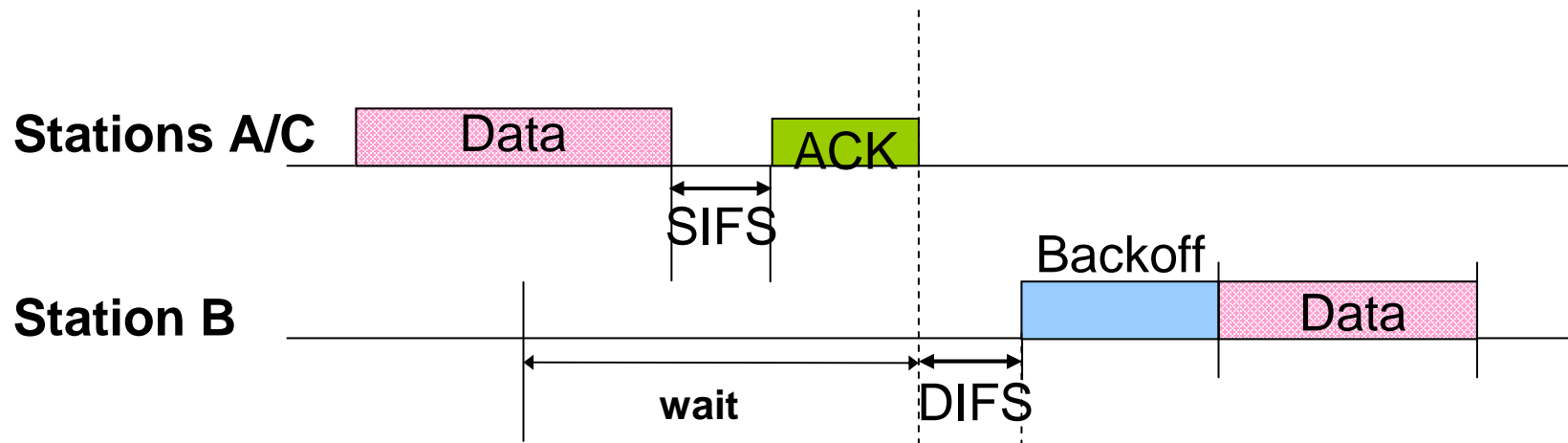


Accessing the Channel

- 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



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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

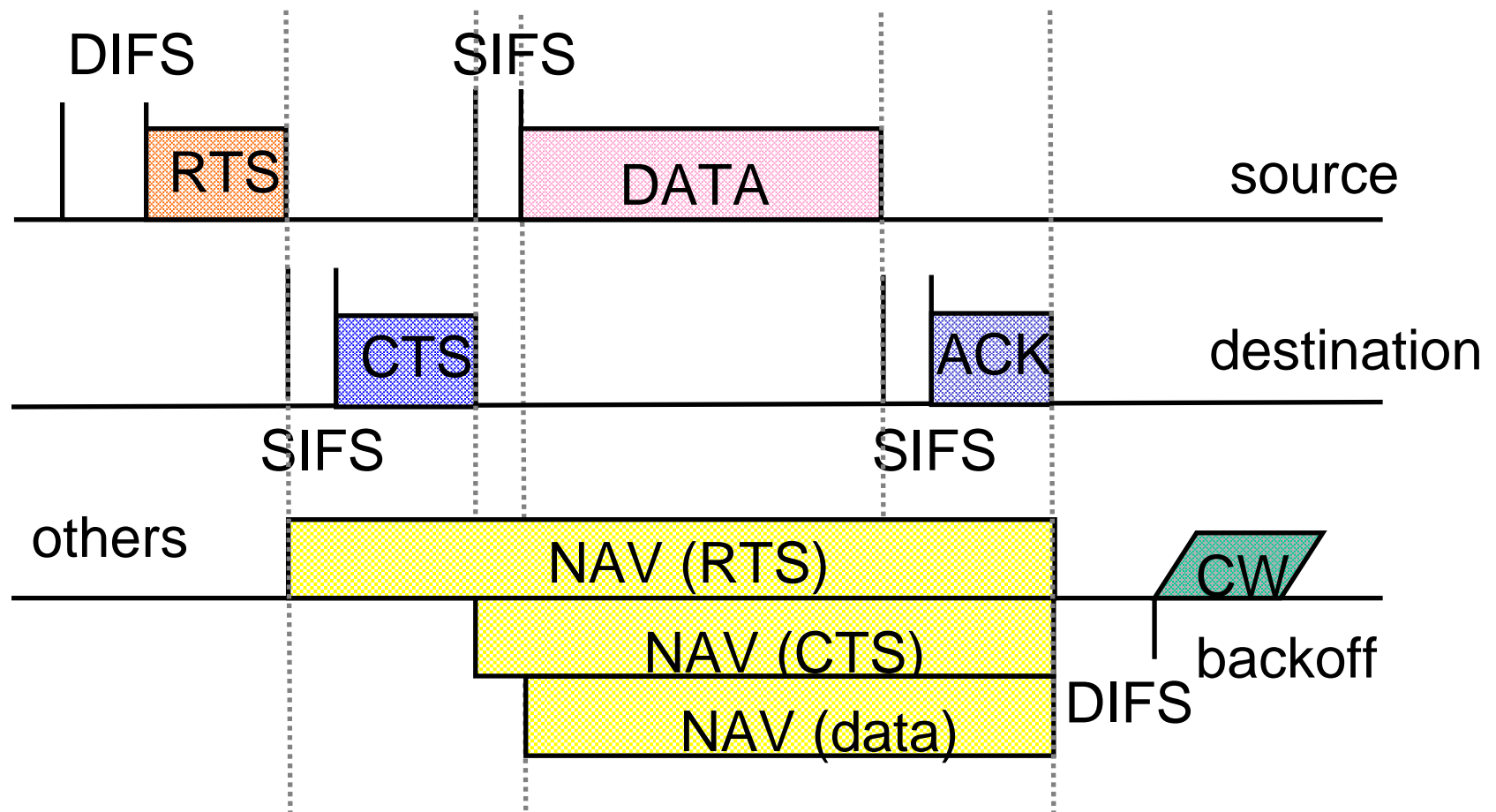


DCF with Handshaking

- **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



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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)

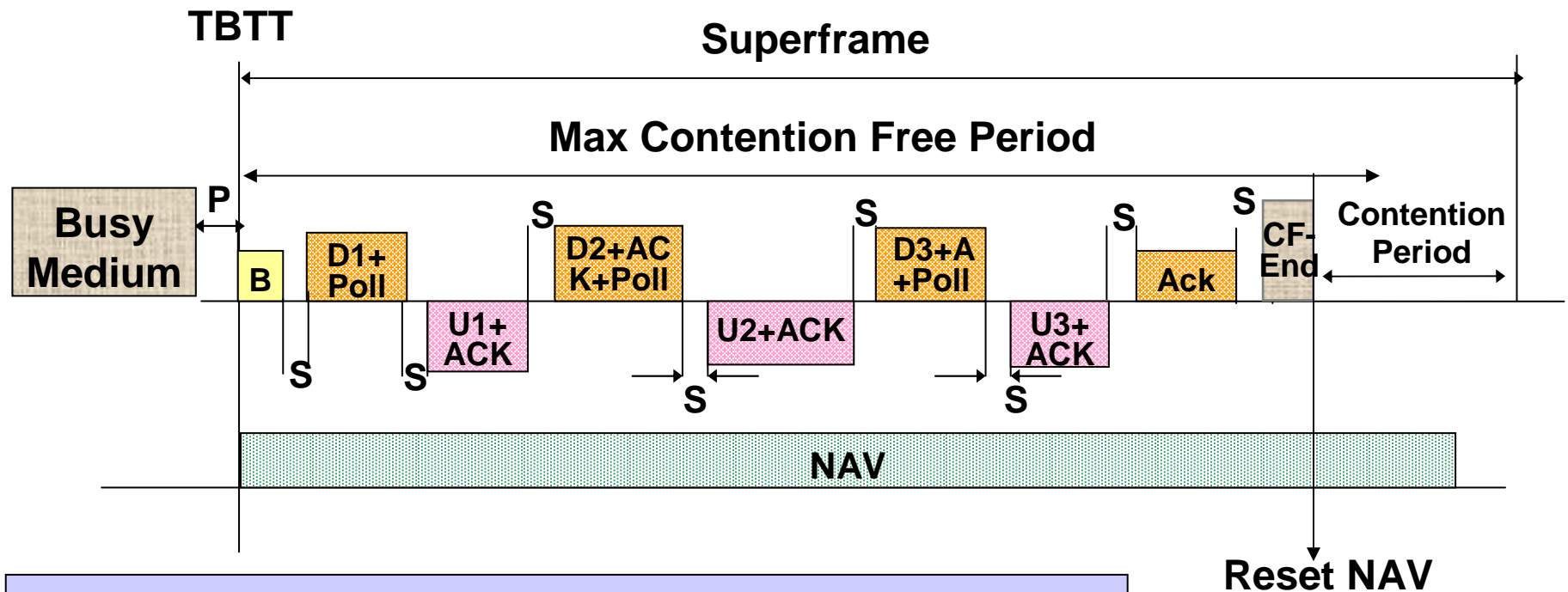


PCF

- 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



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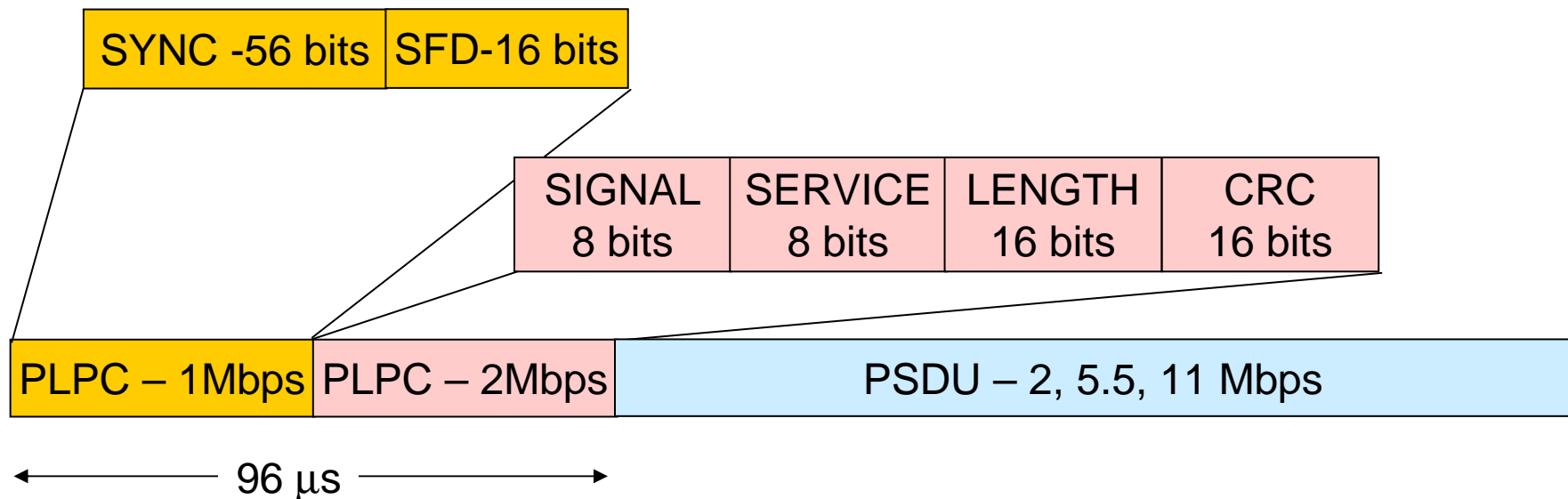
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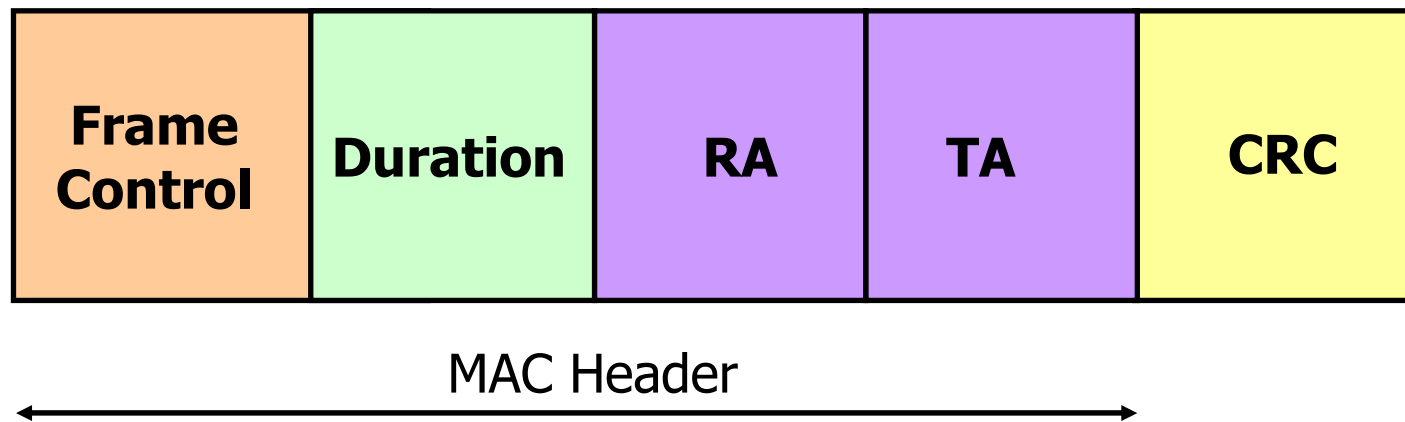
Generic DSSS packet

SFD – Start Frame Delimiter

PLPC – Physical Layer Convergence Protocol



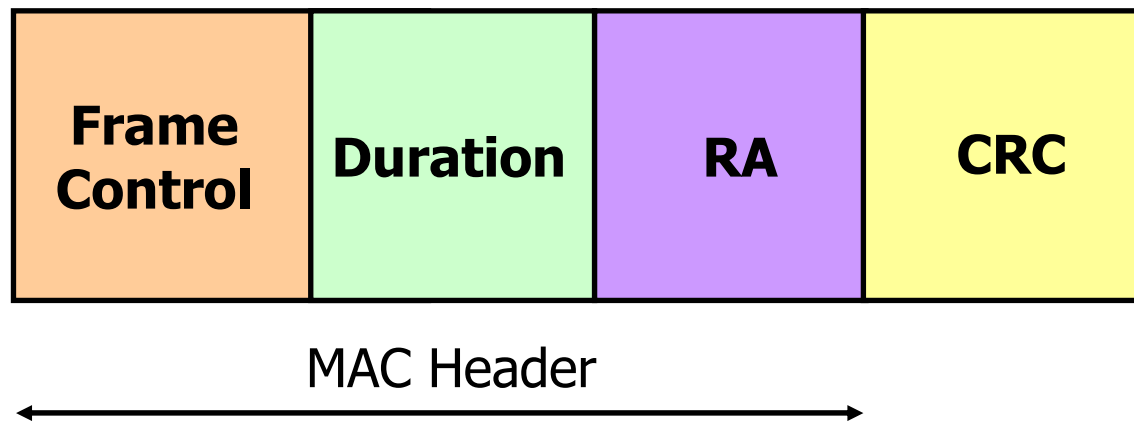
Example: RTS Frame



- **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



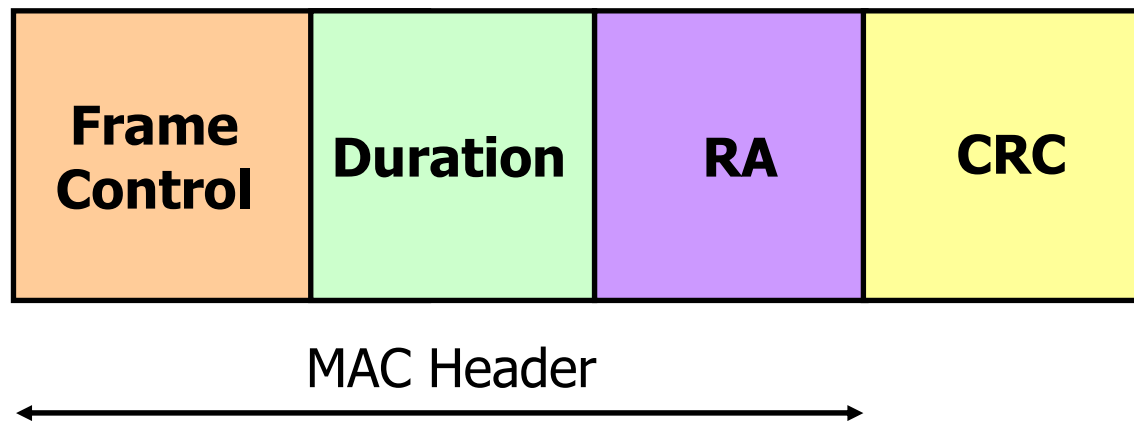
Example: CTS Frame



- **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=20 μ s, $PHY_{HDR} + MAC_{HDR} = 20$ slots
- $ACK = PHY_{HDR} + 14$ bytes, transmitted @ 1 Mbps
 - If slot=20 μ s, $ACK = 12$ 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 5.725-5.825 GHz	2.4-2.4835 GHz
Number of non-overlapping channels	3 Indoor/Outdoor	4 Indoor 4 Indoor/Outdoor	4 Indoor 4 Indoor/Outdoor
Data rate per channel	1,2,5.5,11 Mbps	6,9,12,18,24,36,48, 54 Mbps	1,2,5.5,11 // 6,9,12,18,24,36,48, 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 $\frac{1}{2}$, $\frac{2}{3}$ or $\frac{3}{4}$



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

