Lecture 5: IEEE 802.11

Hung-Yu Wei
National Taiwan University

IEEE 802.11

Outline: 802.11

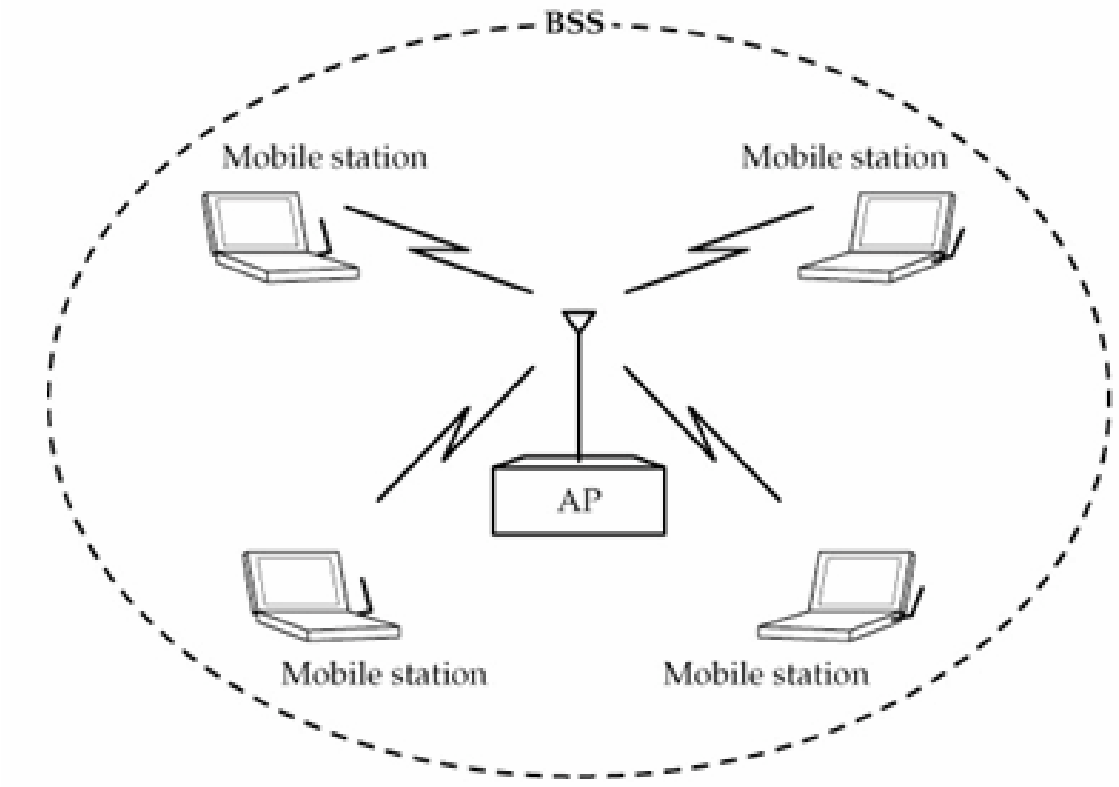
- 802.11 network terminologies
- PHY
- MAC
- Management functions
  - Registration
  - Handoff
  - Power management
  - Security

802.11 Network Terminologies

- BSS
- BSA
- ESS
- IBSS

BSS

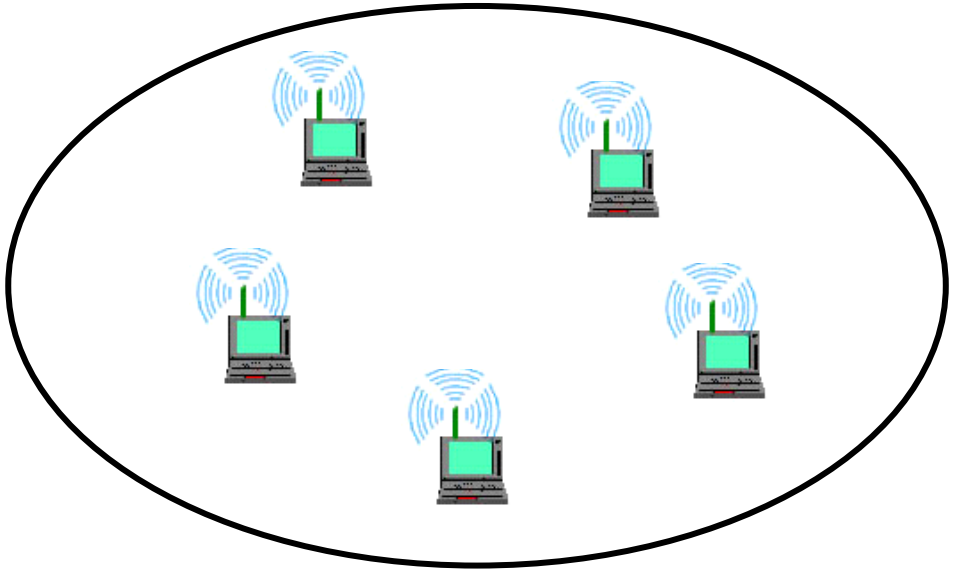
- basic service set (BSS): A set of stations controlled by a single coordination function
  - [concept] A cell with 1 AP and some MSs



BSA (basic service area): cell

IBSS

- **Independent basic service set (IBSS): stand-alone BSS**
  - [concept] Ad hoc network

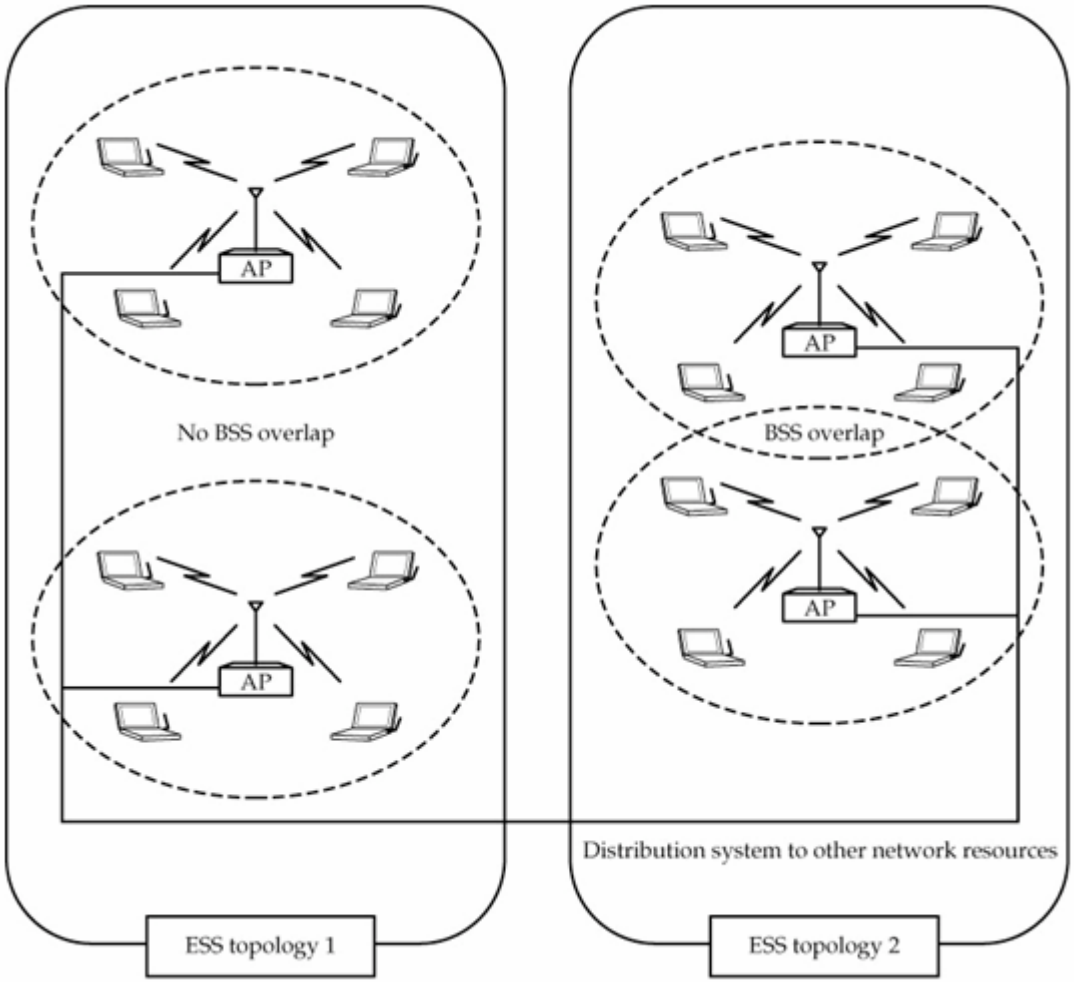


ESS

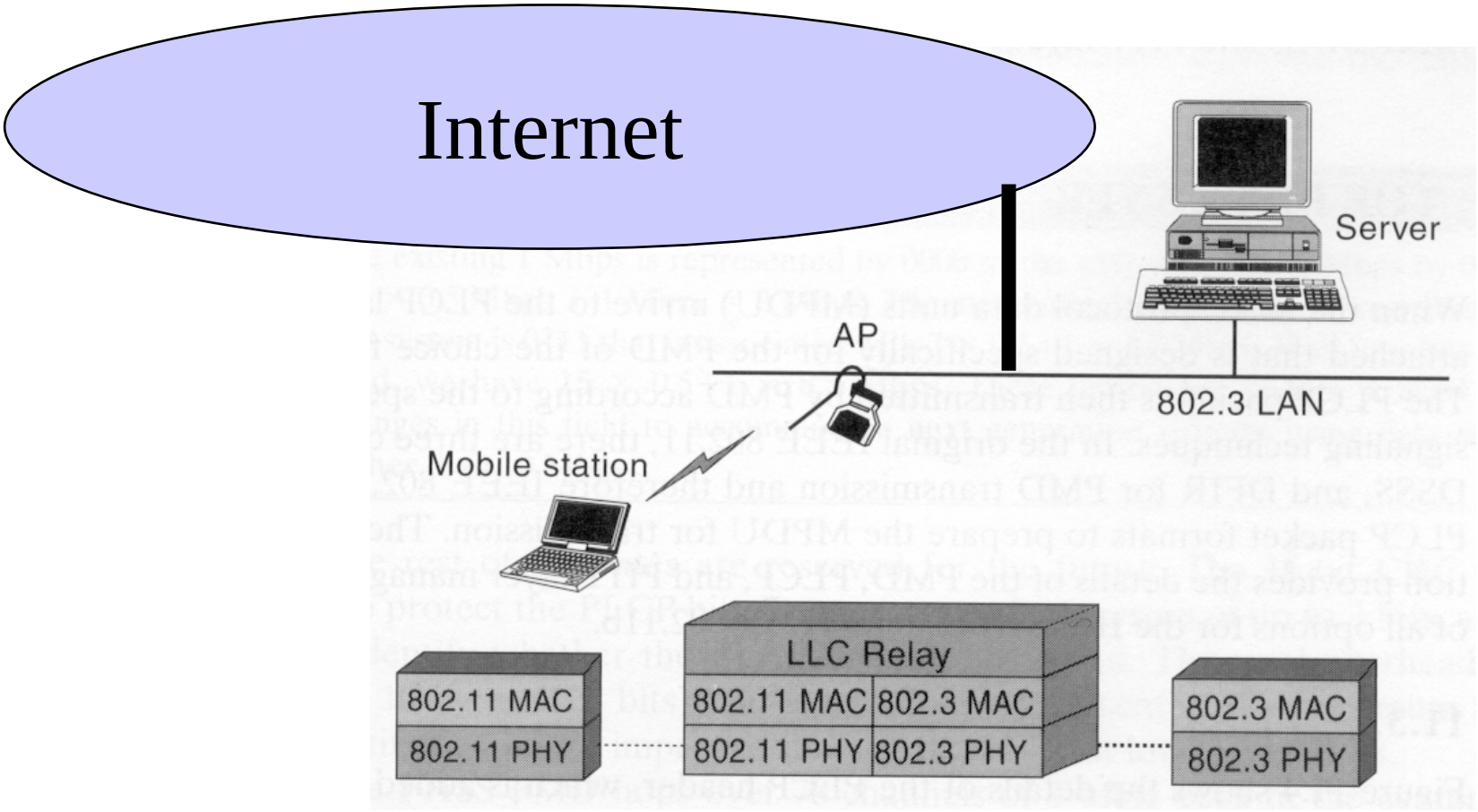
- Extended service set (ESS): A set of one or more interconnected basic service sets (BSSs) and integrated local area networks (LANs)
  - [concept] Cellular system with multiple cells and multiple BSs
- Identifier
  - ESSID: network name
  - BSSID: MAC address of AP
  - Several BSSID with 1 ESSID

ESS

- Two topologies
  - No overlap
  - With overlap



Layered Protocol Architecture

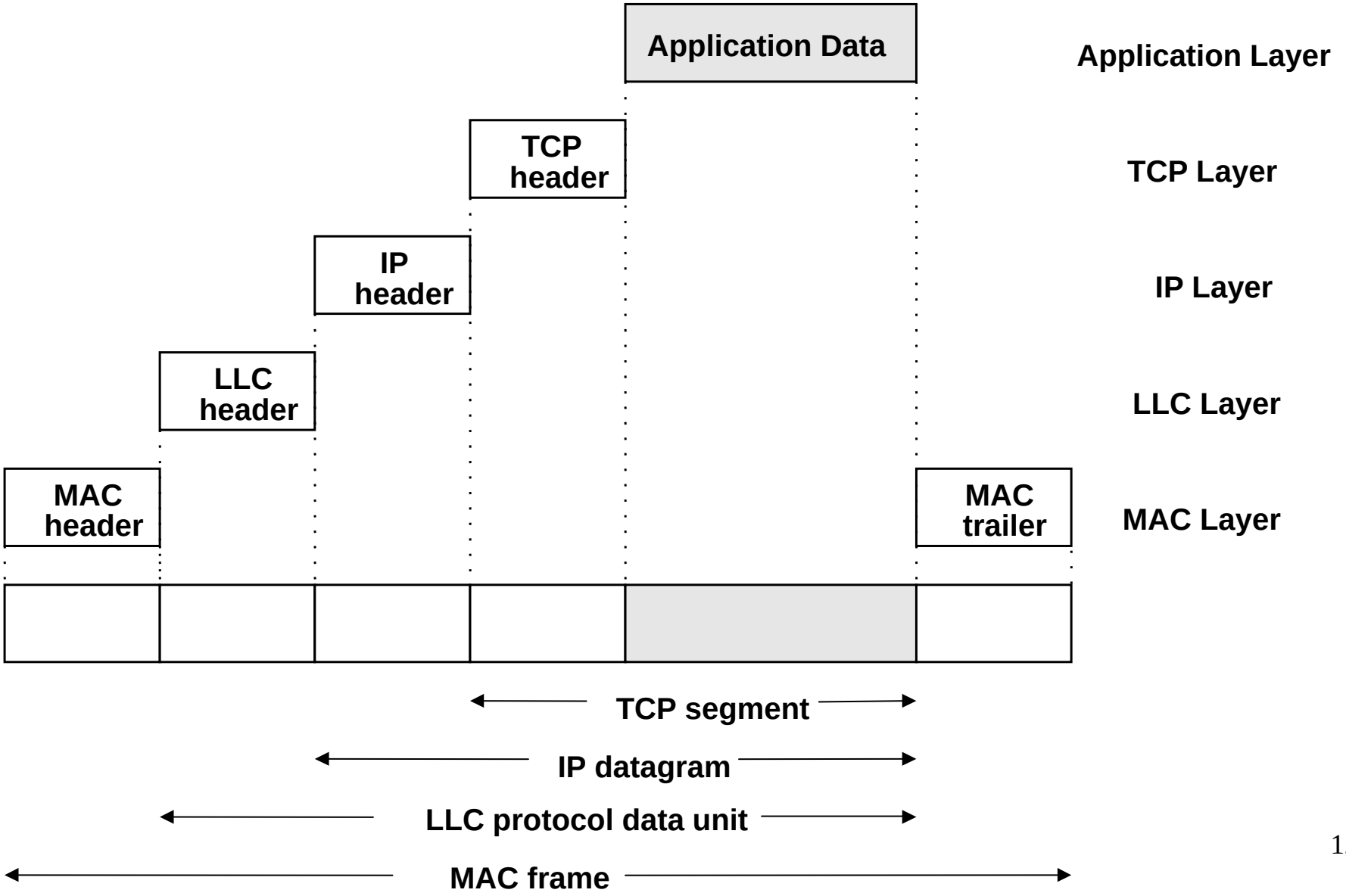


High Level Requirements

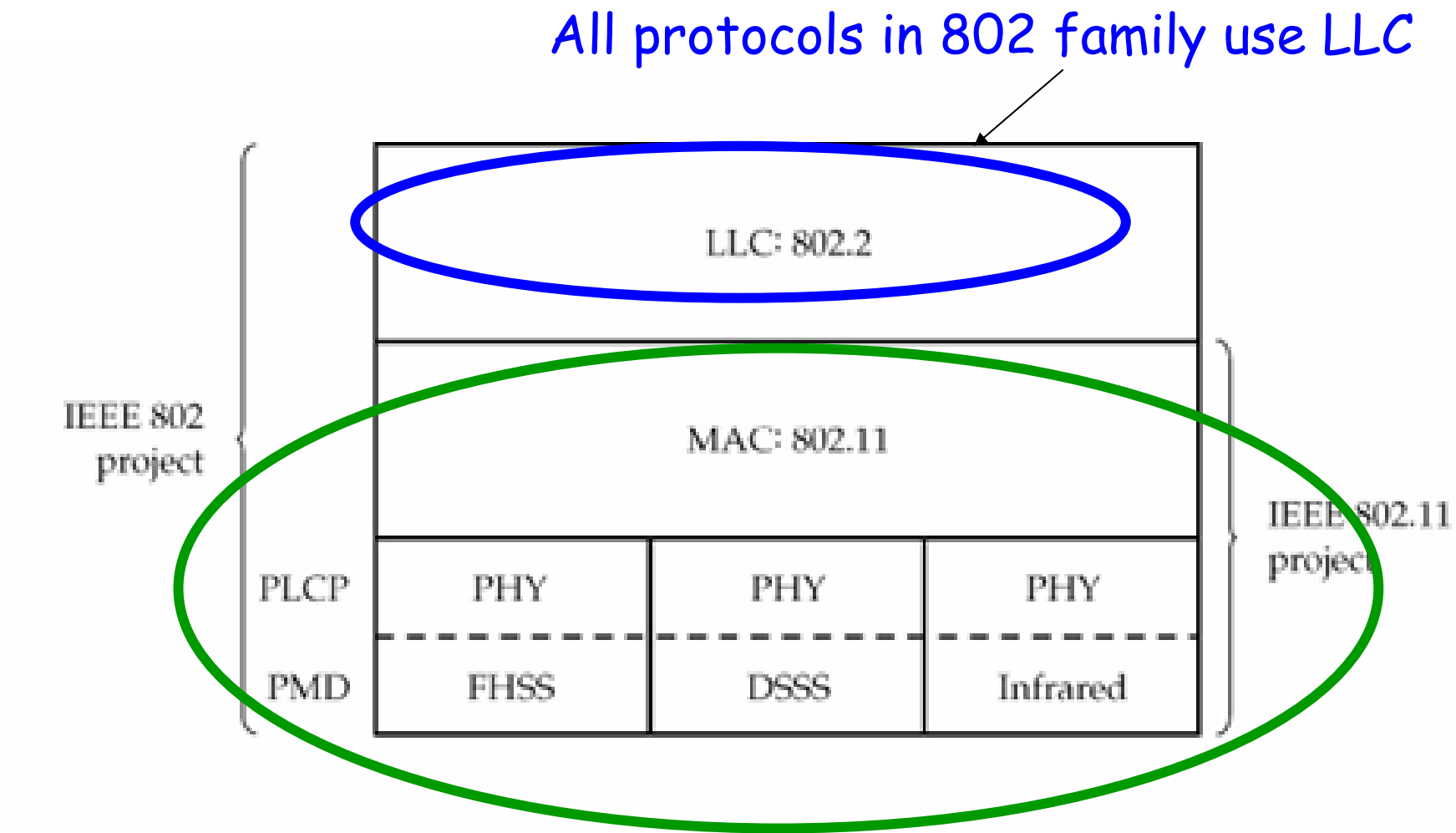
- Single MAC to support multiple PHY layers
  - DSSS, FHSS, IR
    - 802.11-1999, 802.11b
  - OFDM (2.4GHz, 5GHz)
    - 802.11a, 802.11g
- Mechanism to allow multiple overlapping networks
- Provision to handle inference from other users of the ISM band
- Support for co-existence (relatively new) of other radios in the ISM band such as 802.15 (BlueTooth)
- Mechanisms for hidden terminals
- Options to support bounded delay services
- Provisions for privacy and access control

IEEE 802.11 Protocol Stack

Layered Protocol



802.11 Protocol Stack Overview



802.11 Protocol Stack Overview

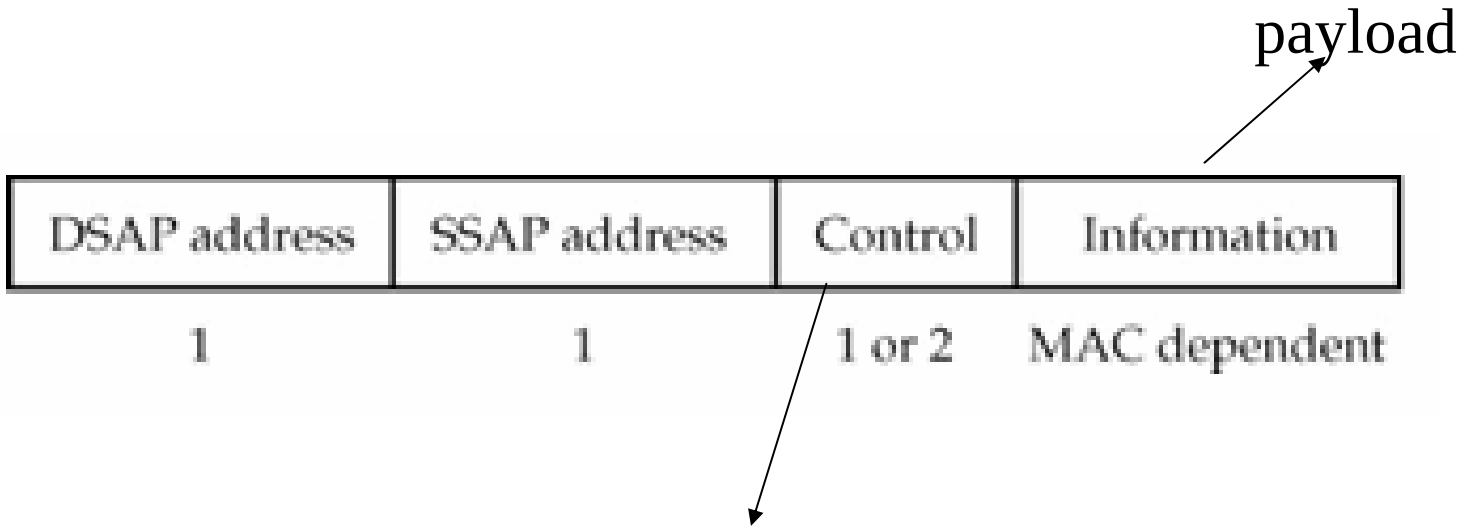
- Data Link Layer (L2)
  - Logical Link Control (LLC)
    - Shared LLC protocol within 802 protocol family
  - 802.11 MAC
    - Common 802.11 MAC for contention resolution
- Physical Layer (L1)
  - PMD (physical medium dependence) sublayer
    - Different PHY technologies
      - DSSS, FHSS, IR
  - PLCP (physical layer convergence procedure) sublayer
    - Insulate MAC from different PMDs

Logical Link Control (LLC)

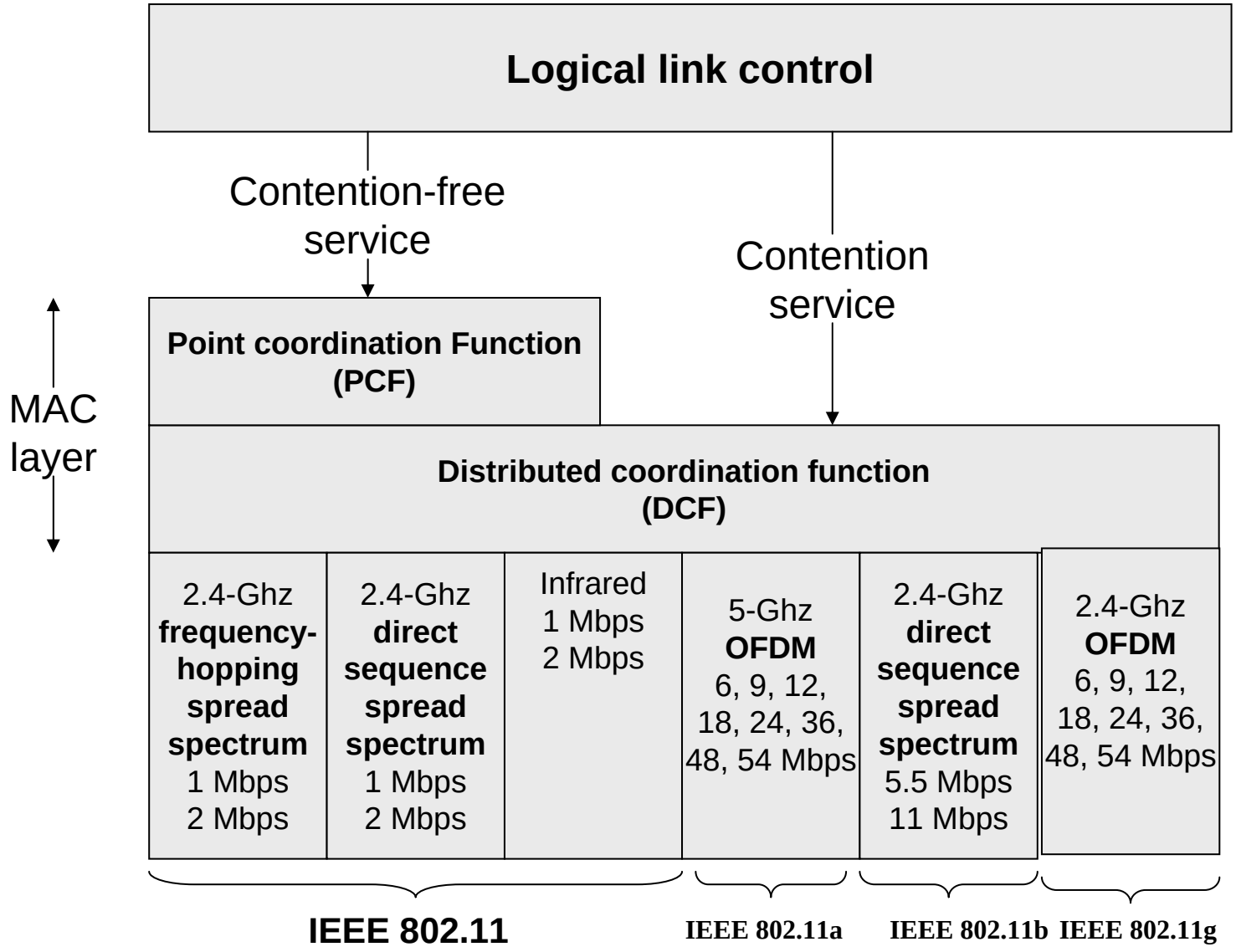
- In 802 family of protocols, the LLC layer is the same
  - Insulate higher layers from various lower-layer standards
    - L3 uses the same way to request L2 service
  - LLC could ensure a reliable L2 data stream between source and destination
  - Flow control

LLC frame structure

- DSAP (destination service access point)
  - SAP at destination node
- SSAP (source service access point)
  - SAP at source node



802.11: L2/L1 Protocol Stack

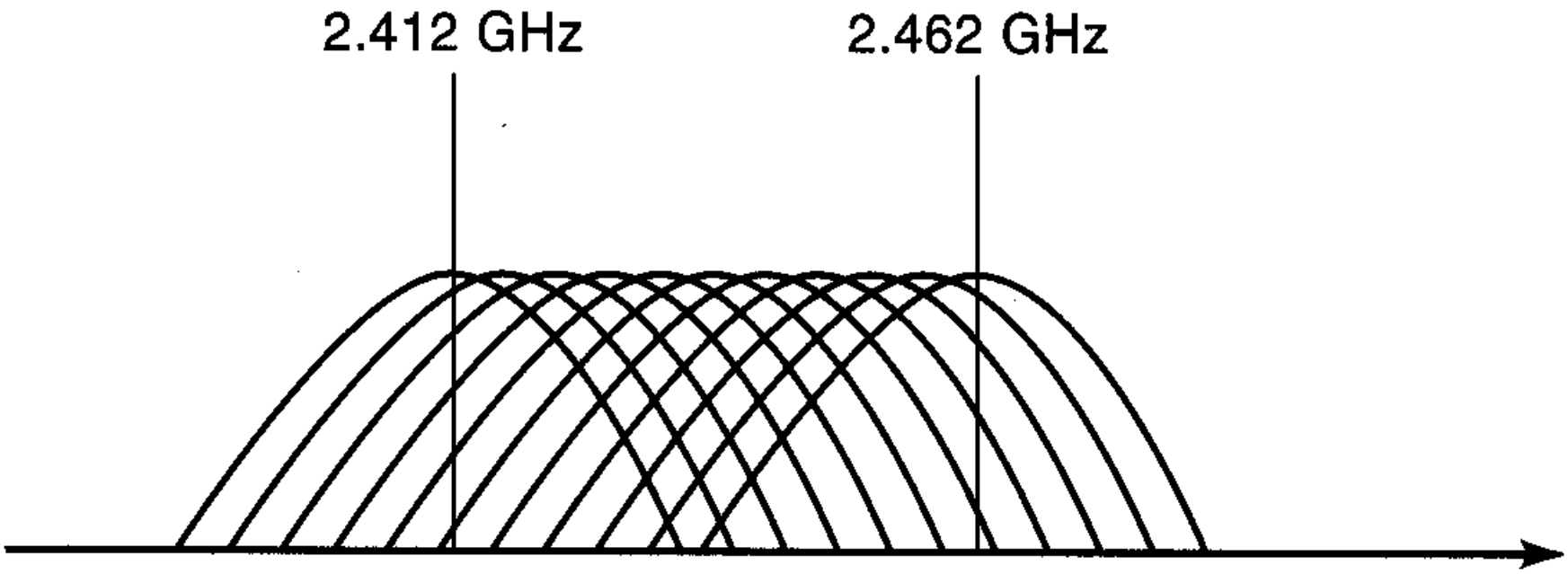


802.11 PHY

The "PHY" Layer

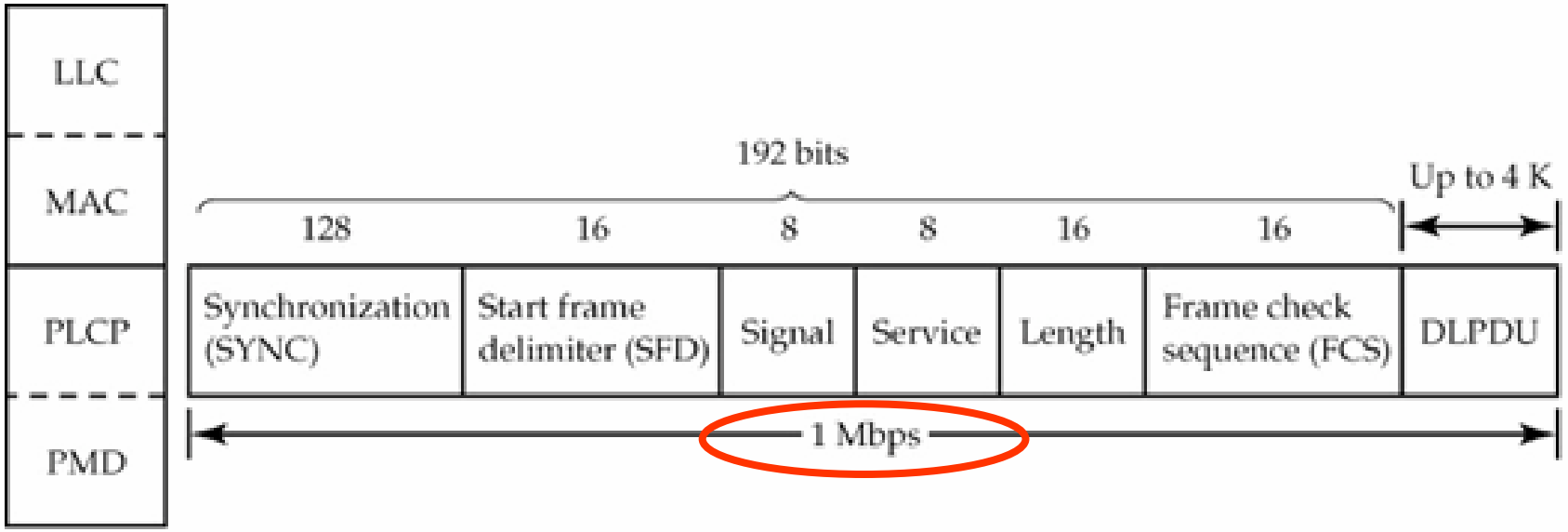
- Multiple physical layers
  - First offering:
    - 2.4 GHz 802.11 Frequency Hopping Spread Spectrum (FHSS) for 1-2 Mbps
    - 2.4 GHz 802.11 Direct Sequence Spread Spectrum (DSSS) for 1, 2, **5.5 and 11 Mbps widely used**
  - Emerging High Speed WLAN – exciting future:
    - 5 GHz 802.11 uses Orthogonal Frequency Division Multiplexing (OFDM) → 802.11a
    - 2.4 GHz uses OFDM → 802.11g
- Not widely used:
  - 802.11 Diffused Infrared (DFIR)
- Note, same MAC layer but all 802.11, 802.11a and 802.11b all are incompatible at the physical layer!
  - Multi-mode backward compatibility in the integrated wireless NICs

Overlapping Frequency channels for the 2.4GHz DSSS



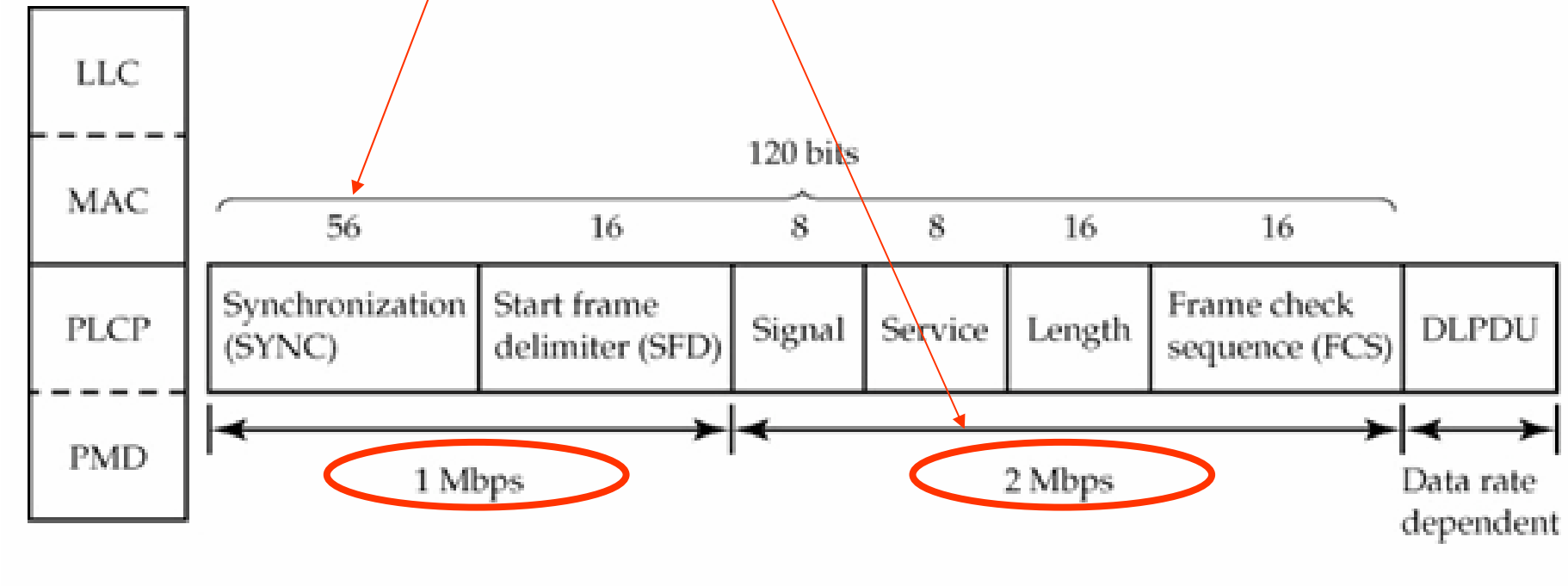
DSSS PLCP PDU (long preamble)

- Sync: fixed pattern for synchronization
  - Alternating 1 and 0
- SFD: define the beginning of PLCP
  - 1111001110100000
- Signal: data rate
- Service: reserved
- Length: in microseconds
- FCS: CRC code



DSSS PLCP PDU (short preamble)

- Short preamble PLCP
  - Reduce preamble transmission time
    - Shorter (56 bits) SYNC
    - 2 Mbps for the 4 other fields



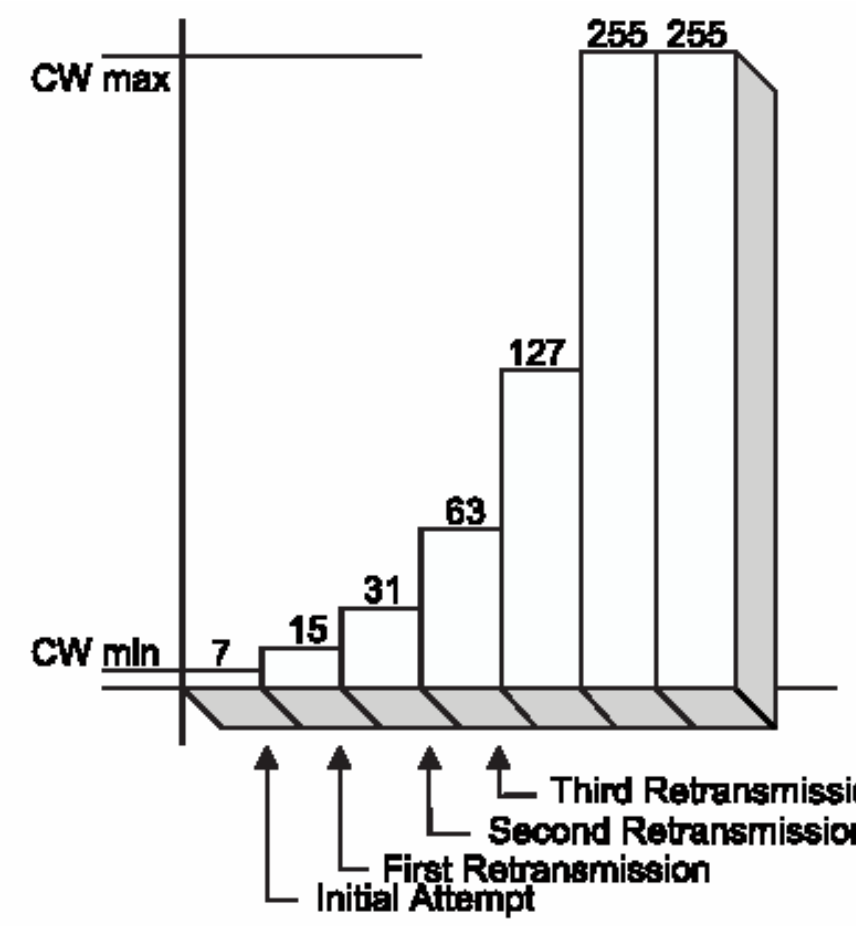
802.11 MAC: contention resolution

802.11: Random Backoff

- Backoff Time = random() * Slot_Time
  - Slot_Time is a PHY layer parameter
    - (e.g. 20 μs in 802.11-1999 DSSS PHY)
  - random() is a random integer number drawn uniformly from [0,CW]
    - CW is the contention window size
    - CWmin$\leq$CW $\leq$CWmax
  - CWmin and CWmax are PHY-dependent parameters
    - E.g. 802.11-1999 DSSS PHY
      - CWmin=31; CWmax=1023

802.11: Contention Window

- Increment of CW
  - In 802.11, $CW=2^n-1$
  - Initialization, CW=CWmin
  - CW increase with every retry
  - CW increases up to CWmax
- (truncated) binary exponential backoff

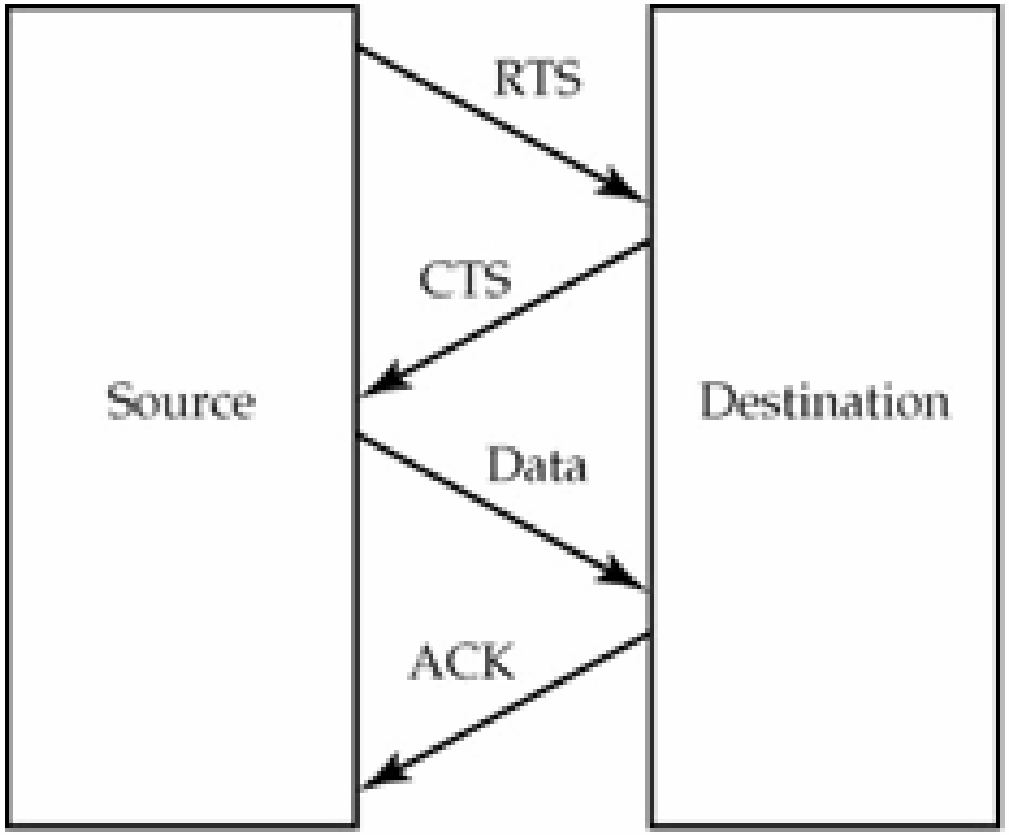


Example: CWmin=7, CWmax=255

MAC Layer Functionality

- MAC Sublayer
  - Format of messages (data and control)
  - Access control/mechanisms
    - contention mode
      - For access to the channel by multiple contending devices
    - contention-free schemes
      - RTS/CTS, DATA and PCF for time bounded access
- MAC layer management sublayer
  - Roaming support in the ESS, power management and security
- After transmission of a packet all mobiles wait for one of three devices IFS (inter-frame spacings) according to the level of priority of their packet
  - DCF-IFS (DIFS) used for contention, lowest priority, longest delay
  - Short-IFS (SIFS) used for high priority such as ACKs, CTS, etc. has the lowest duration time
  - PCF-IFS (PCF) has second priority rate with duration between DIFS and SIFS

RTS/CTS/data/ACK



RTS and CTS frames

RTS

2	2	6	6	4
Frame control	Duration RTS	Receiver address	Transmitter address	CRC

CTS

2	2	6	4
Frame control	Duration CTS	Receiver address	CRC

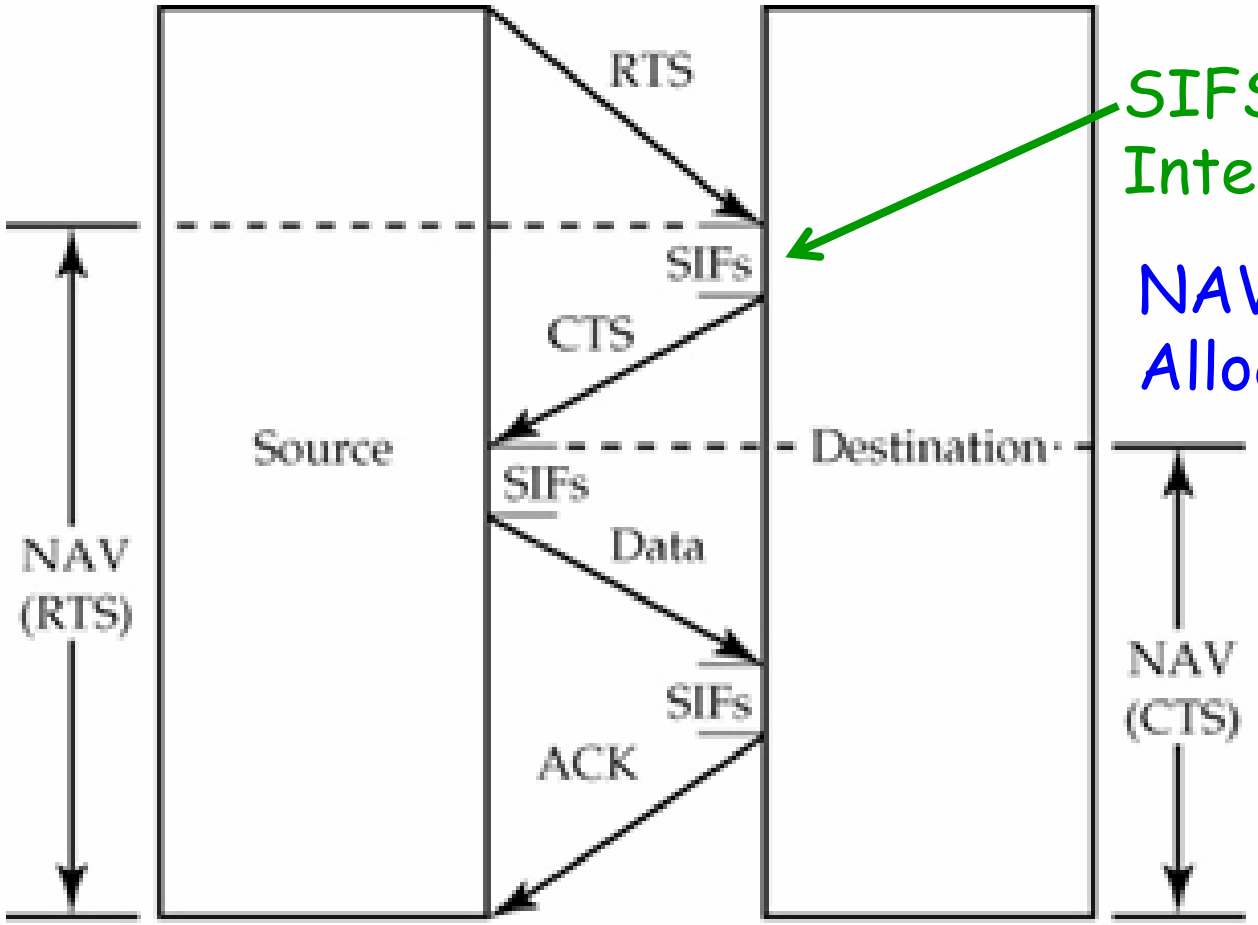
The duration RTS calculation (in ms) is determined by adding the times to transmit:

1. The information frame itself.
2. 1 CTS frame.
3. 1 ACK frame.
4. 3 SIFS frames.

The duration CTS calculation (in ms) is determined by taking the duration frame transmission time and subtracting:

1. 1 CTS frame.
2. 1 SIFS frame.

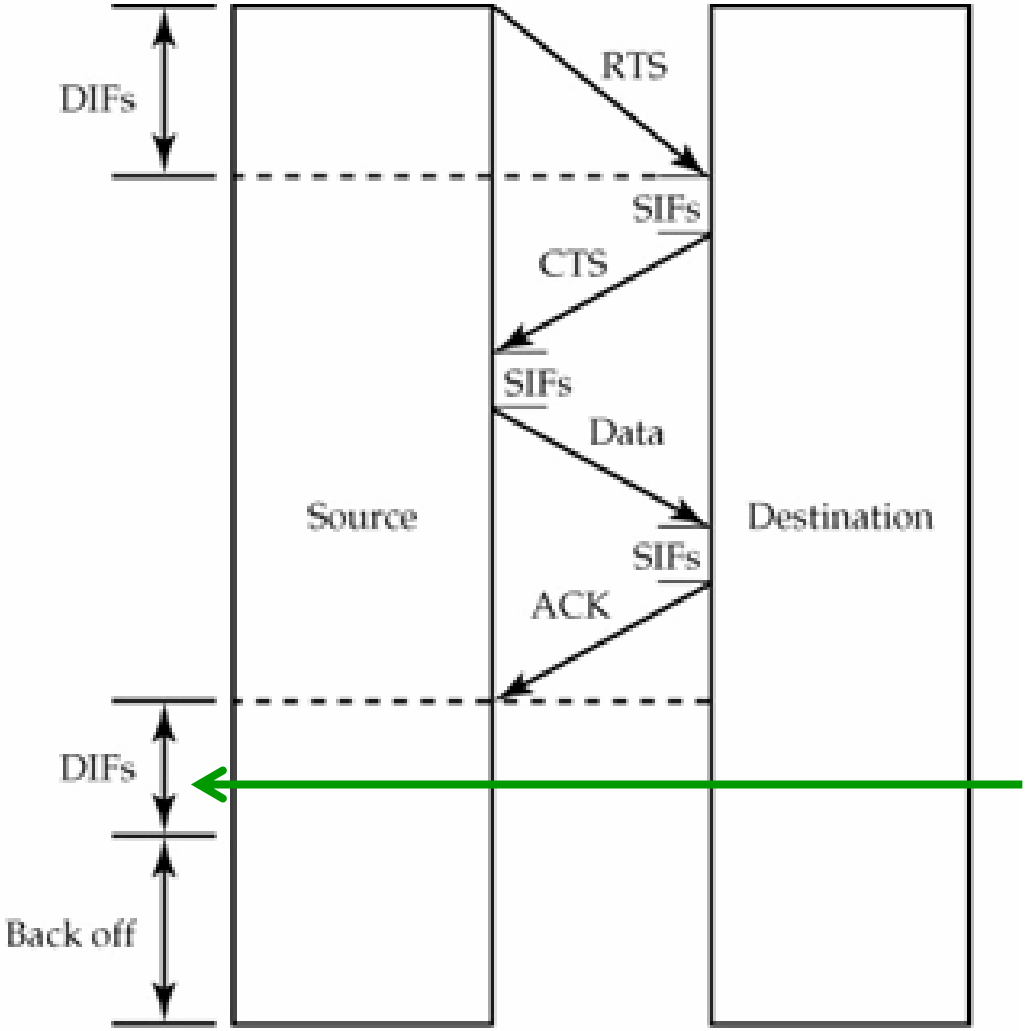
RTS/CTS/data/ACK, SIFS, and NAV



SIFS (Short Interframe Space)

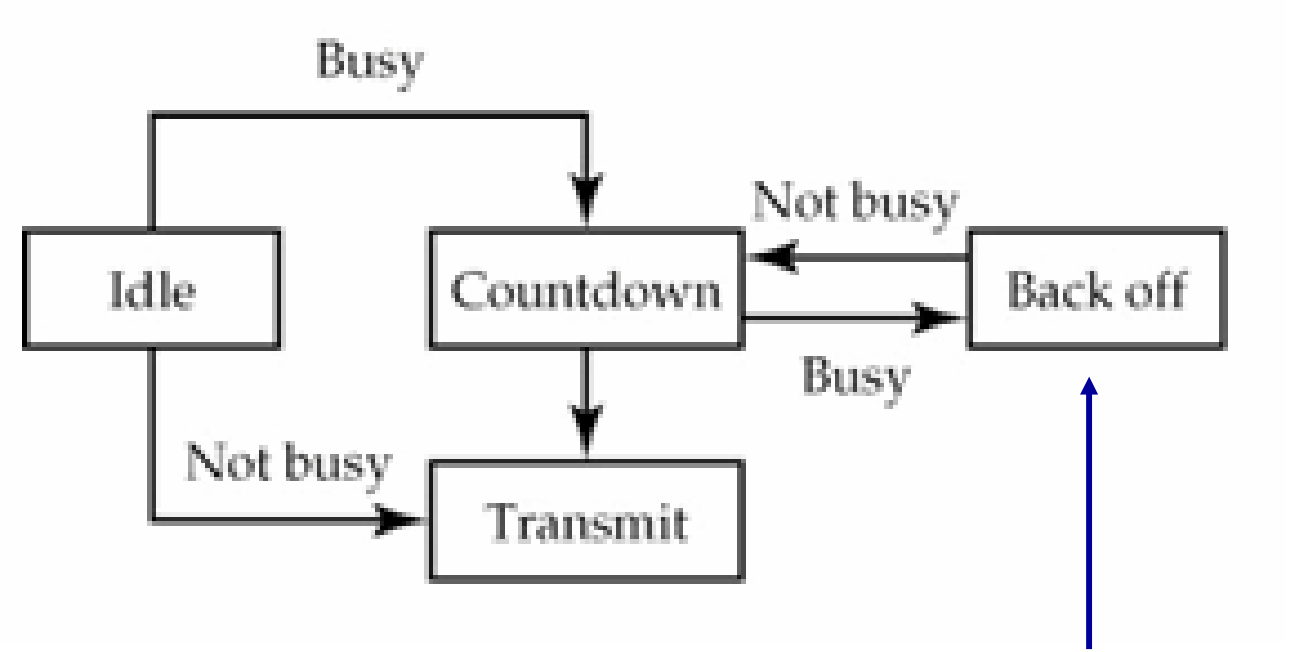
NAV: Network Allocation Vector

RTS/CTS/data/ACK and DIFS



DIFS (Distributed Interframe Space)

CSMA/CA Backoff

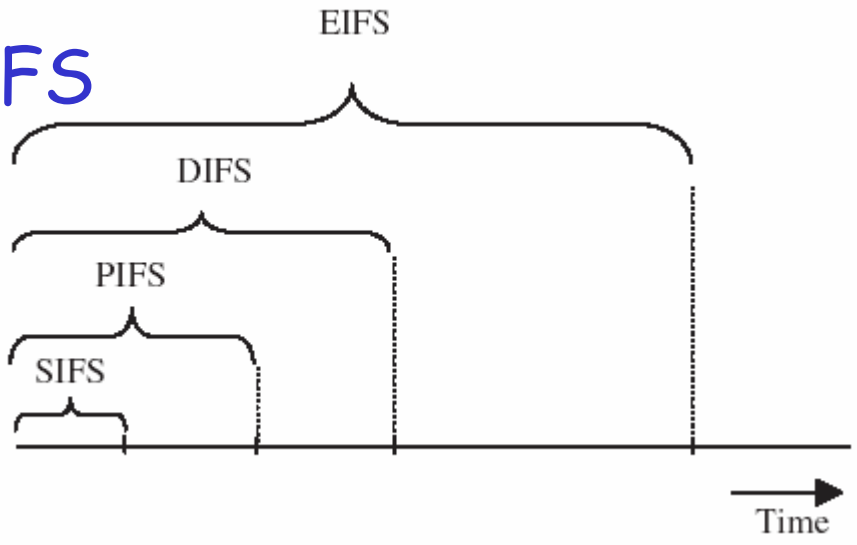


Backoff = random_time(x)

$0 \leq$ random_time(x) $\leq$ collision window

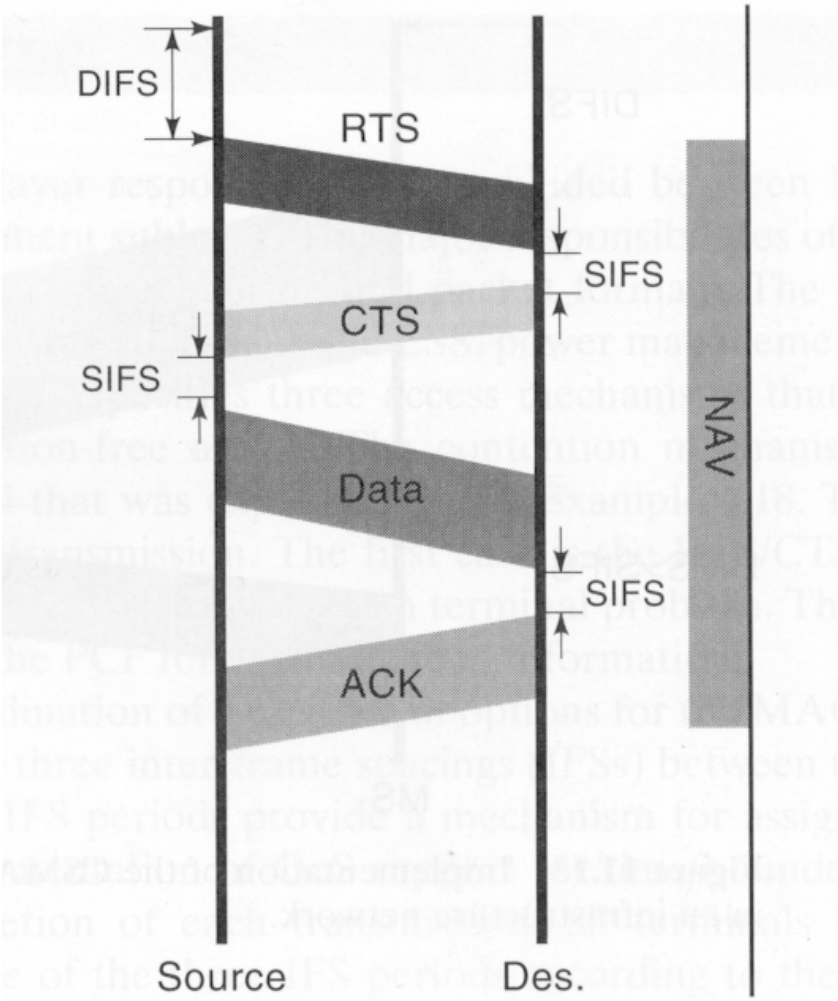
Prioritize IFSs

- interframe spacing (IFS)
  - SIFS: short IFS
  - PIFS: point (coordinated function) IFS
    - PCF IFS
  - DIFS: distributed (coordinated function) IFS
    - DCF IFS
  - EIFS: extended IFS
- SIFS < PIFS< DIFS < EIFS

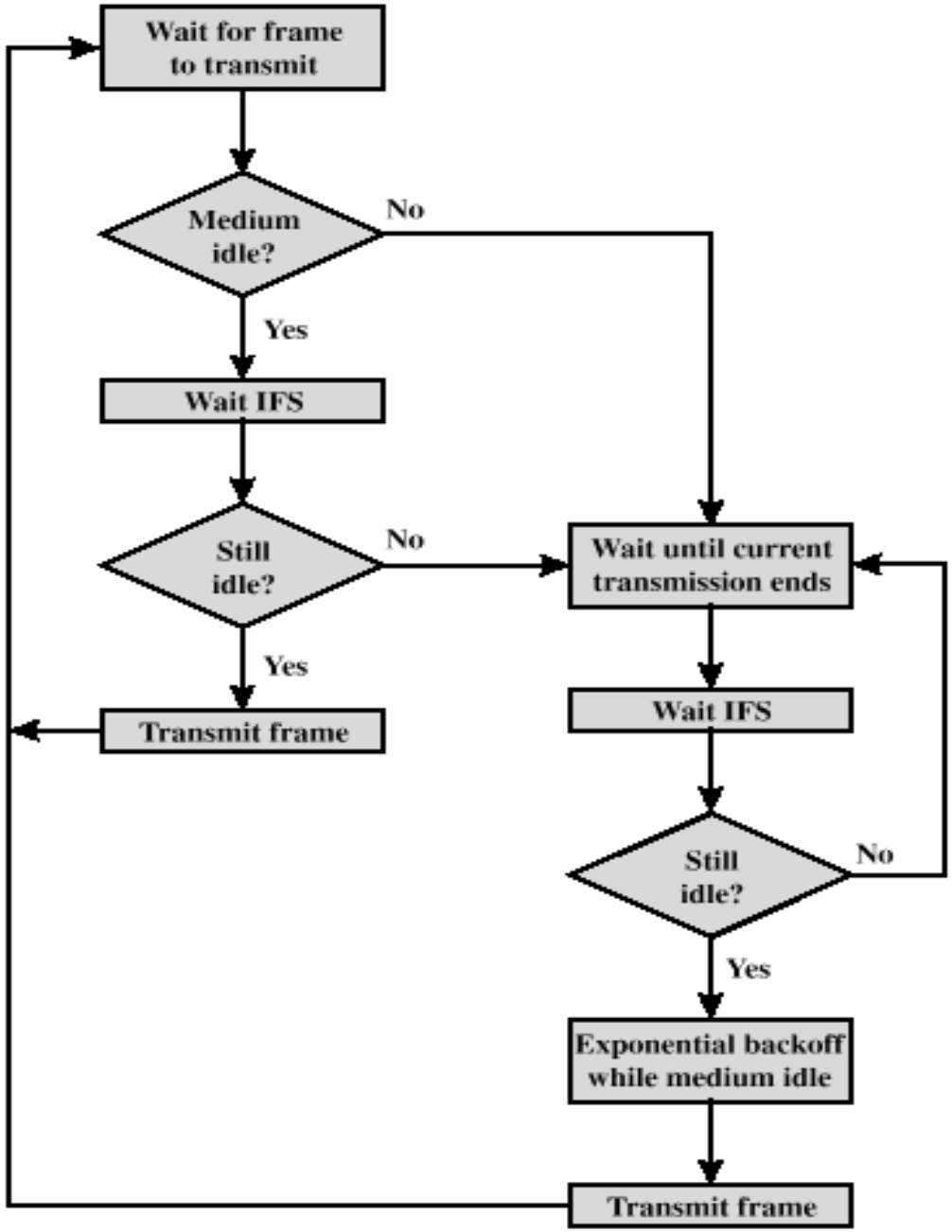


RTS (20 Bytes) /CTS (16 Bytes) Mechanism

- Toggling the NAV
  - Hear an RTS
    - Switch NAV on
    - CTS
    - DATA
- Hear the ACK
  - Switch NAV off
- This provides contention free transmission

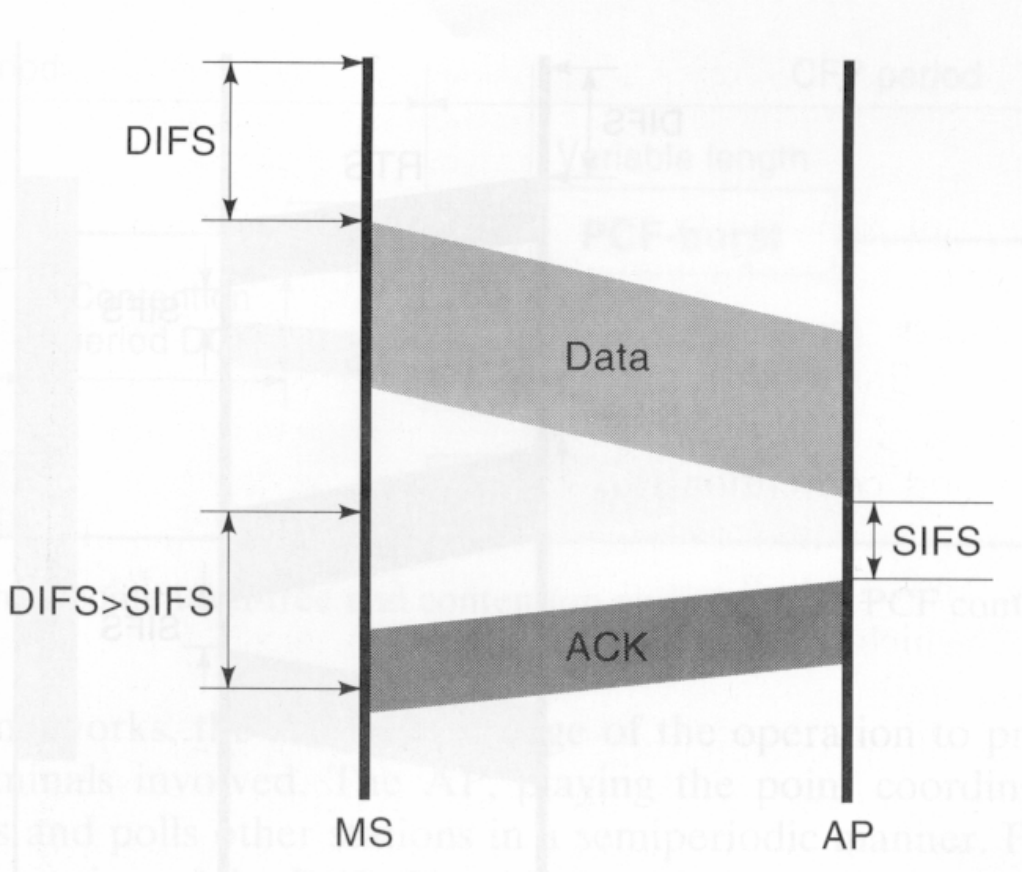


MAC State Diagram



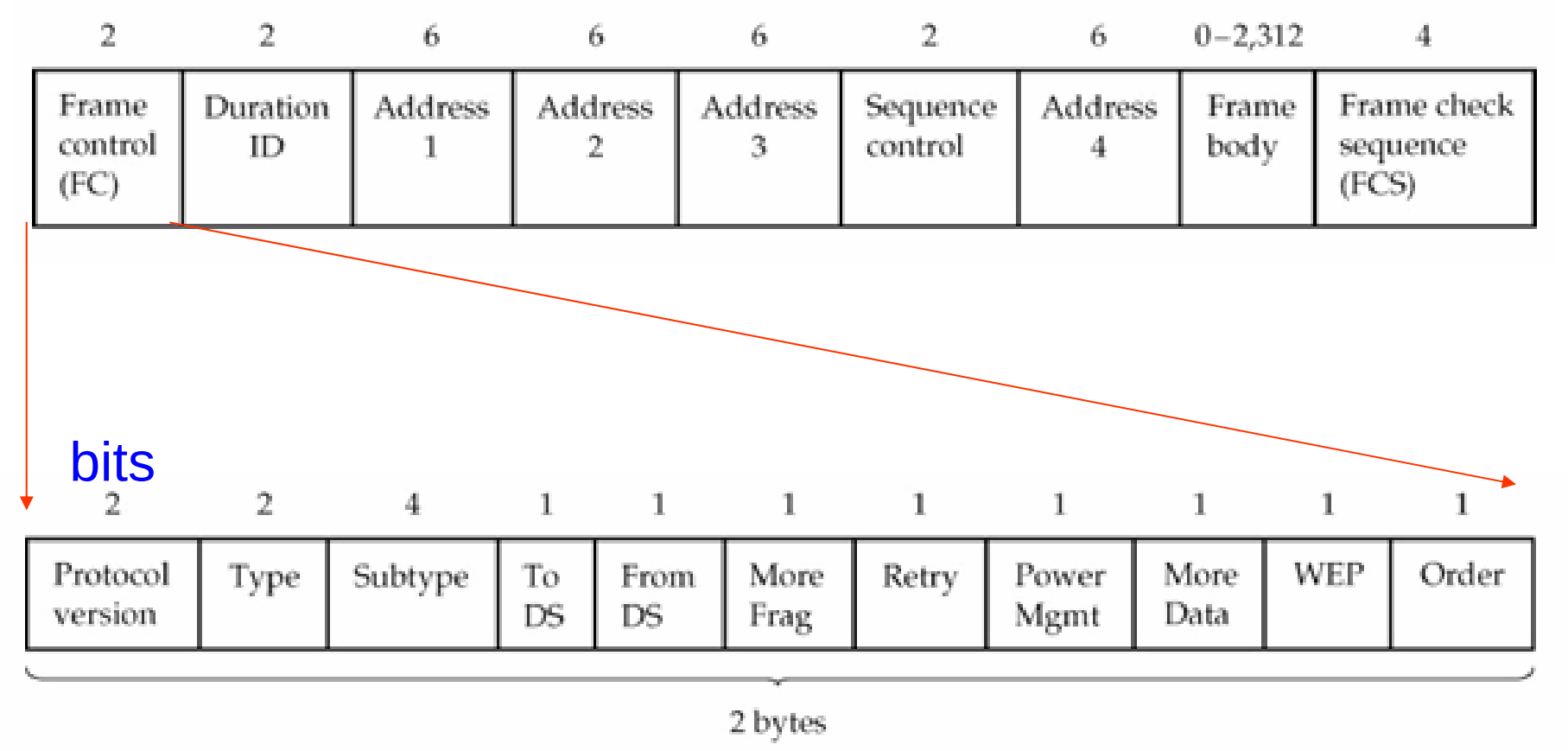
CSMA/CA with ACK in an Infrastructure Network

- RTS/CTS could be turned off
  - Only CSMA/CA



802.11 MAC frame structure

MAC Frame structure



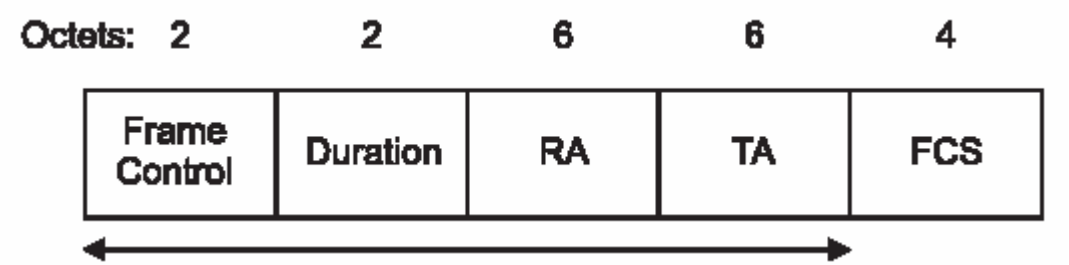
Type/Subtype

- Management Type (00)
  - Assoc. request/response
  - Reassoc. request/response
  - Probe-request/response
  - Beacon
  - Announcement traffic indication (used for sleep mode operations)
  - Authentication/Deauthentication
- Control Type (01)
  - Power save poll
  - RTS/CTS
  - Ack
  - CF end and CF end with ACK
- Data Type (10)
  - Data/ Data with CF ACK
  - Data Poll with CF/ Data Poll with CF and ACK
  - CF poll/ CF poll CK

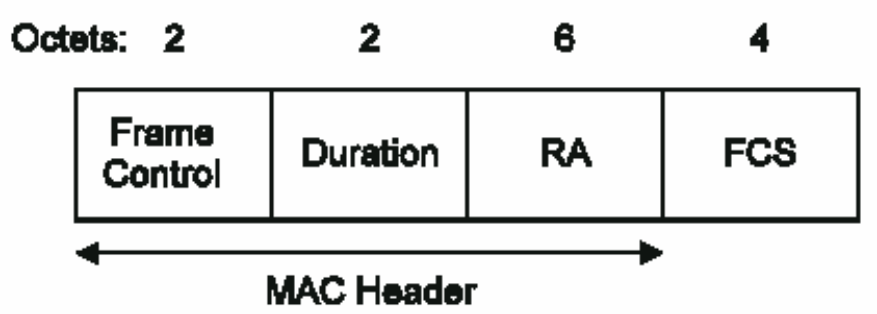
Example: Type/Subtype in frame control field (within MAC header)

Type (2 bits)	Type Description	Subtype (4 bits)	Message Description
00	Management	0000	Association request
00	Management	0001	Association response
01	Control	1011	RTS
01	Control	1100	CTS
01	Control	1101	ACK
10	Data	0000	Data

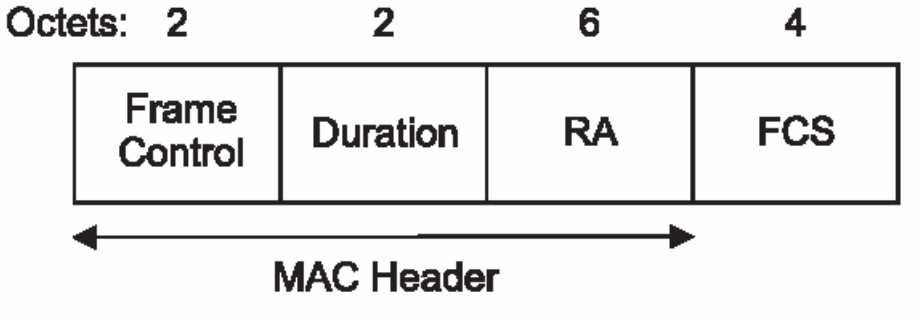
Control message format



RTS(20 bytes)



CTS(16 bytes)

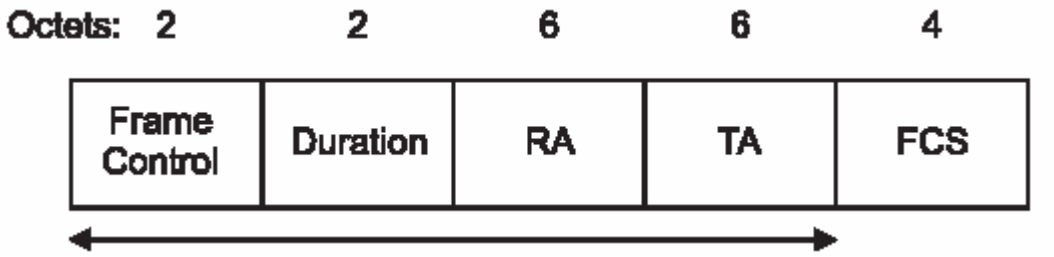


ACK(14 bytes)

RTS

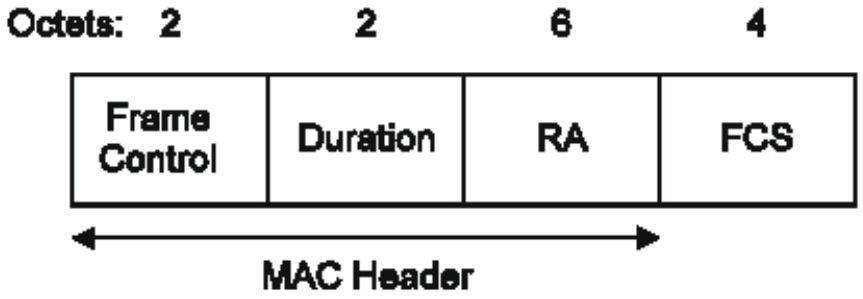
- FCS frame check sequence = 32-bit CRC
- RA: receiver address
  - Data/RTS receiver
- TA: transmitter address
  - Data/RTS transmitter
- Duration
  - Microseconds
    - Round up to the higher integer
  - T=data_tim+CTS_time+ACK_time+SIFS *3

Do you know why?



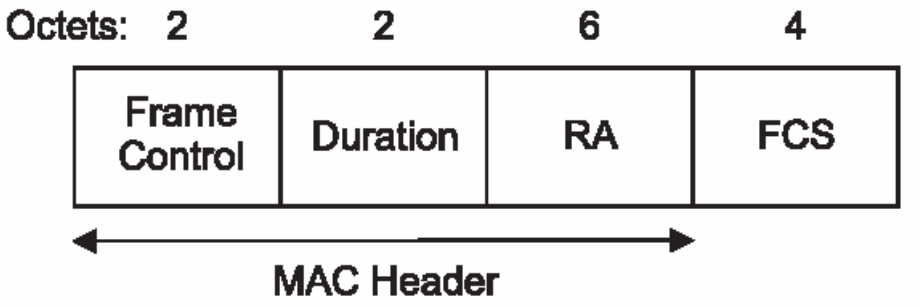
CTS

- FCS frame check sequence = 32-bit CRC
- RA: receiver address
  - CTS receiver (i.e. data transmitter)
  - Copy from TA in RTS message
- Duration
  - Microseconds
    - Round up to the higher integer
  - T=data_tim+ACK_time+SIFS *2
    = (Duration in RTS) – SIFS – CTS_time



ACK

- RA: receiver address
  - ACK receiver (i.e. data transmitter)
- Duration
  - Microseconds
    - Round up to the higher integer
  - T=ACK_time+SIFS

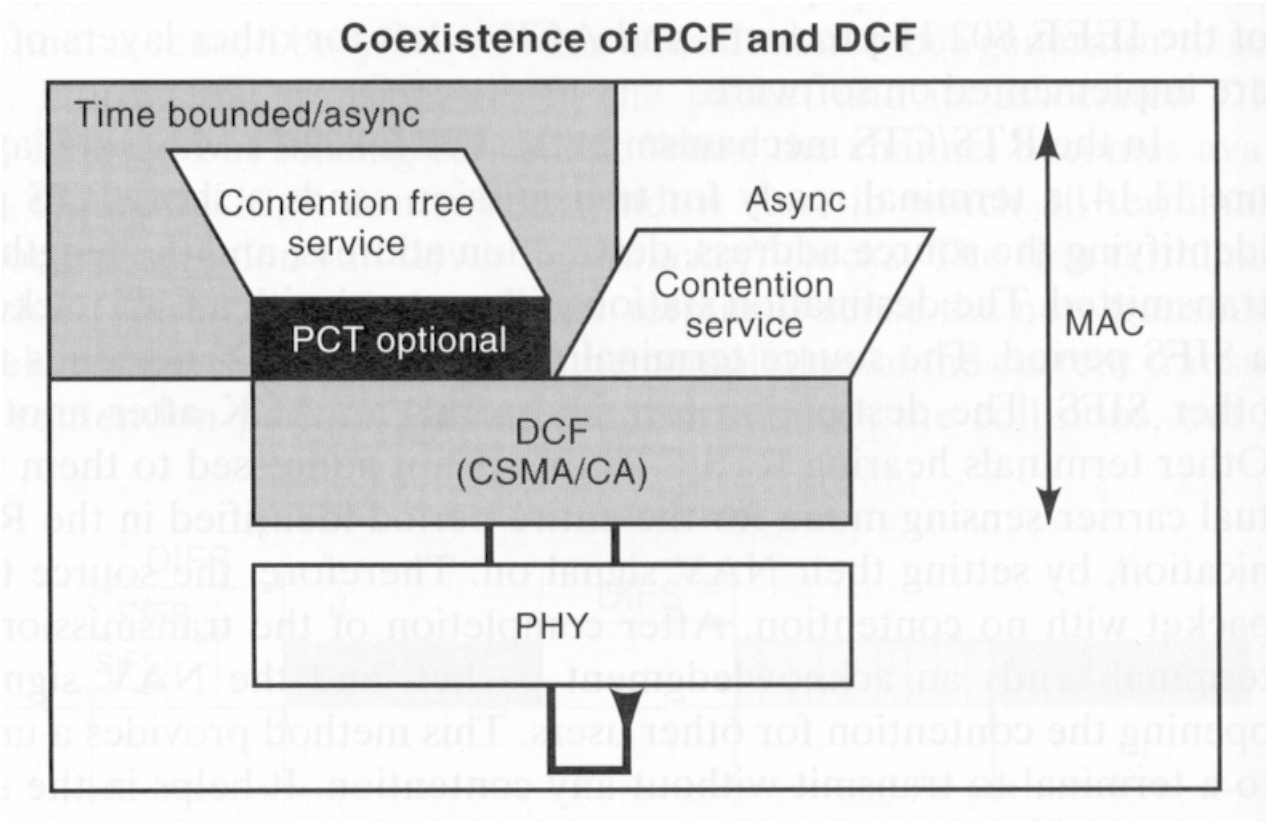


802.11 Coordinated Functions: DCF and PCF

802.11: Coordinated Functions

- 2 types of coordinated functions
  - DCF: distributed coordinated function
  - PCF: point Coordination Function
    - Built upon DCF
    - Optional
      - Not always implemented in products
    - Centralized coordination
      - More like cellular BS

PCF on top of DCF



PCF (Point Coordination Function) Mode

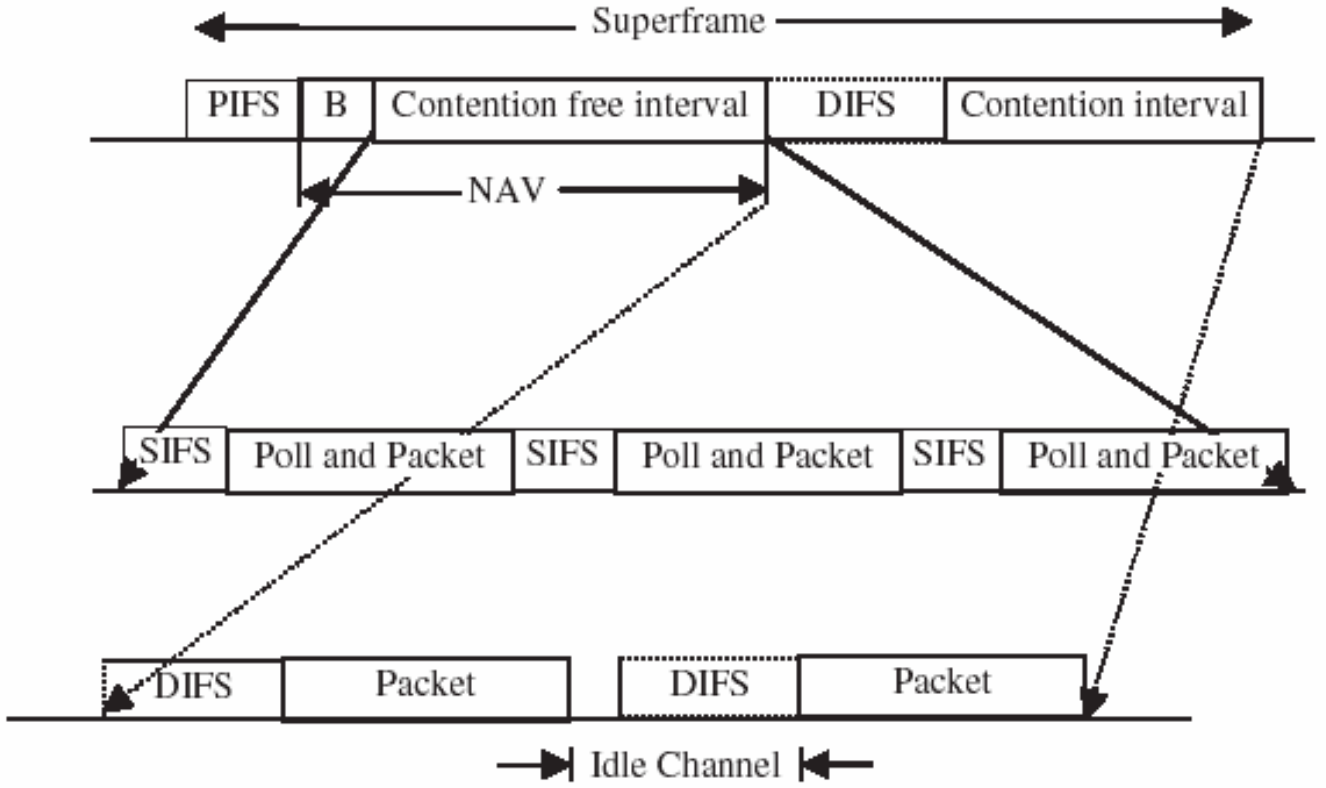
- Built of top of DCF
  - Supports contention-free, time bounded and asynchronous transmission operations
  - Optional MAC function/feature – not widely available in products
  - Mostly available as part of infrastructure mode with an AP, which can be set up as a central coordinator (like BS in cellular)
- Operation in PCF mode
  - AP polls devices periodically
  - Sets up contention-free period (CFP)
  - Coordinates time bounded data to be transmitted in each CFP
  - During that period when a device is transmitting data PCF sets all the NAV signals **ON** at all other stations
  - Length of PCF period is variable and only occupies a potion of the CFP
  - The remainder of the CFP is used for contention and DCF packets
  - If DCF has not completed before the start of the next CFP period, the starting time of the CFP is deferred but NAV is turned **ON**

PCF: pollable stations

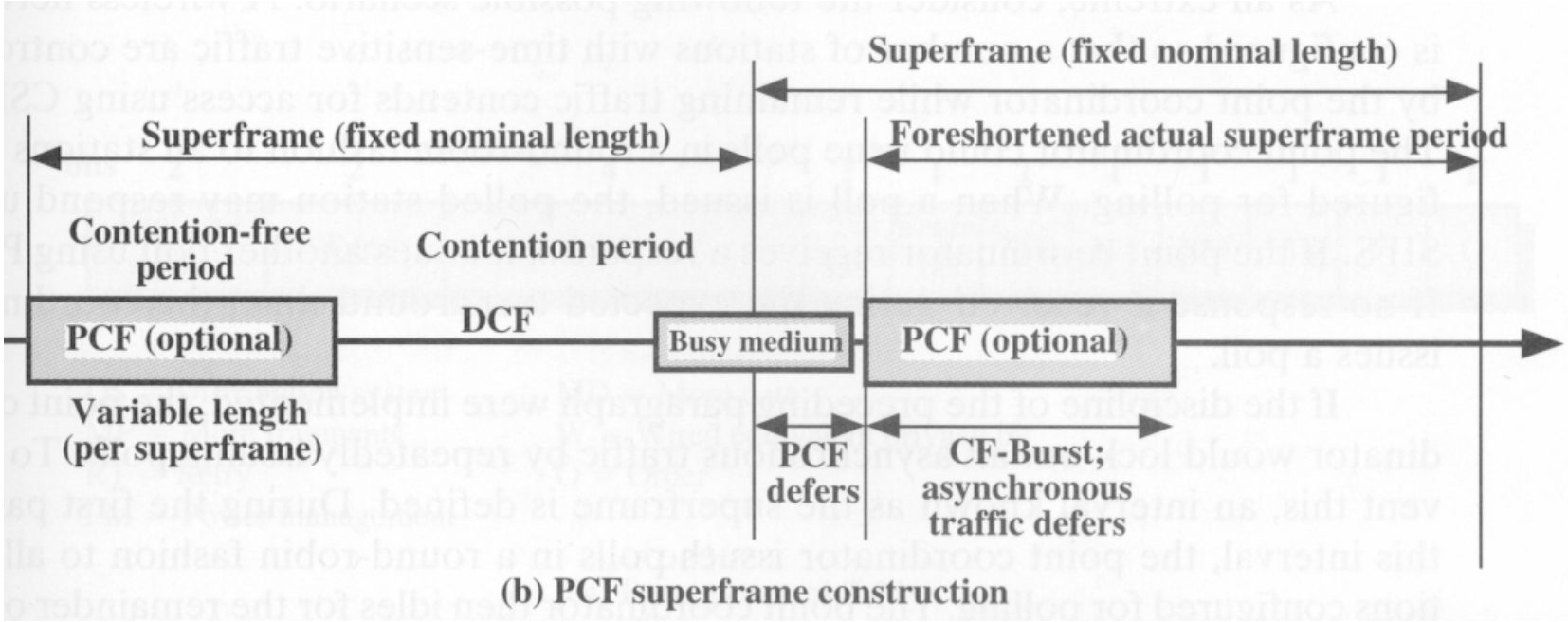
- Pollable station
  - Able to respond to CF-Poll in PCF mode
    - A node in PCF mode that has MSDU (MAC SDU) to transmit in contention-free period
  - Set More Data field = 1 to notify the point coordinator
- Piggyback control messages are allowed
  - CF-ACK and CF-Poll could be piggybacked after data transmission. For example,
    - Data+CF-Poll
    - Data+CF-ACK
    - Data+CF-ACK+CF-Poll

PCF time frames

- Two periods
  - Contention free interval
  - Contention interval

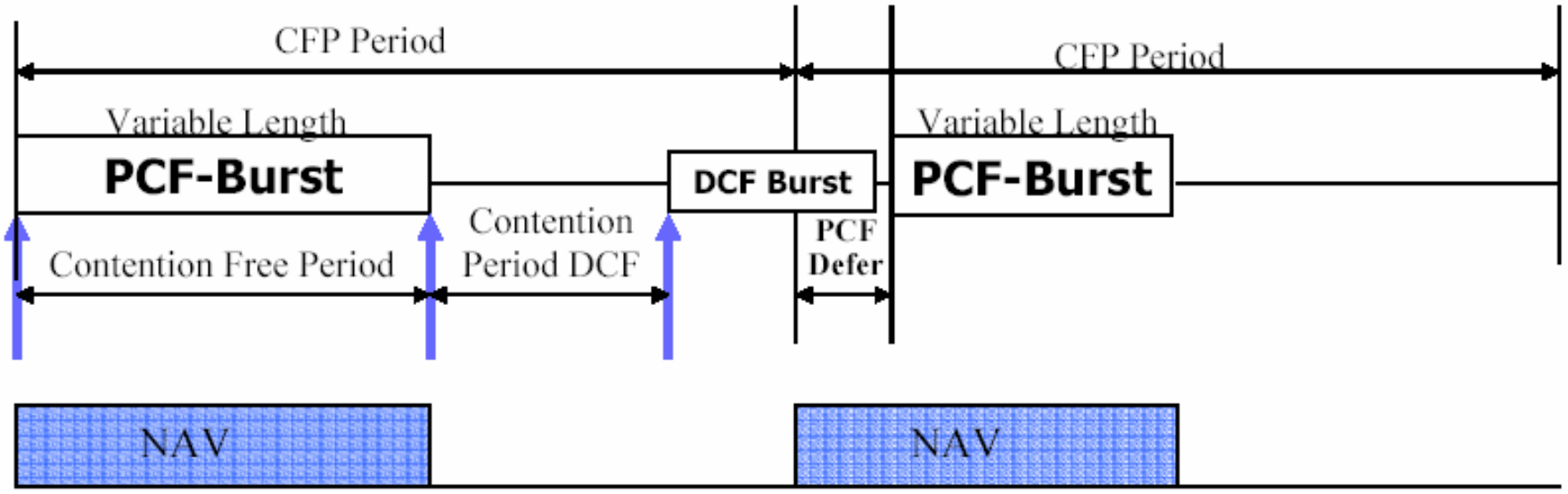


MAC Timing: PCF Operation



(b) PCF superframe construction

Alternation of Contention-Free and contention periods under PCF control from the AP



802.11: other functions

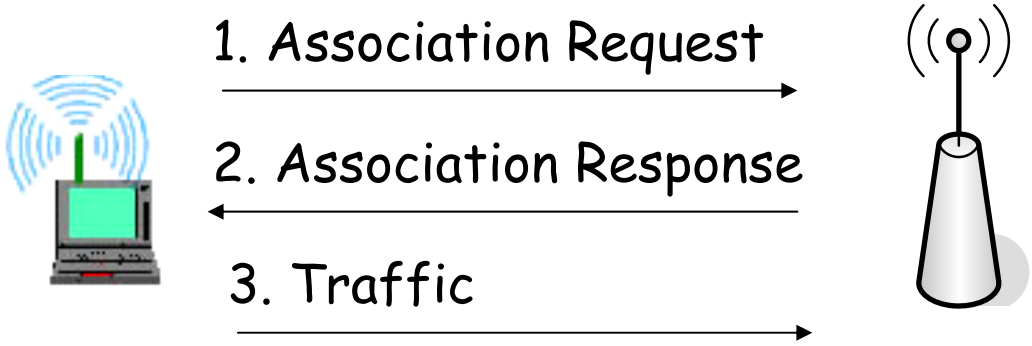
MAC Management Sublayer Functions

- Registration
- Handoff
- Power Management
- Security

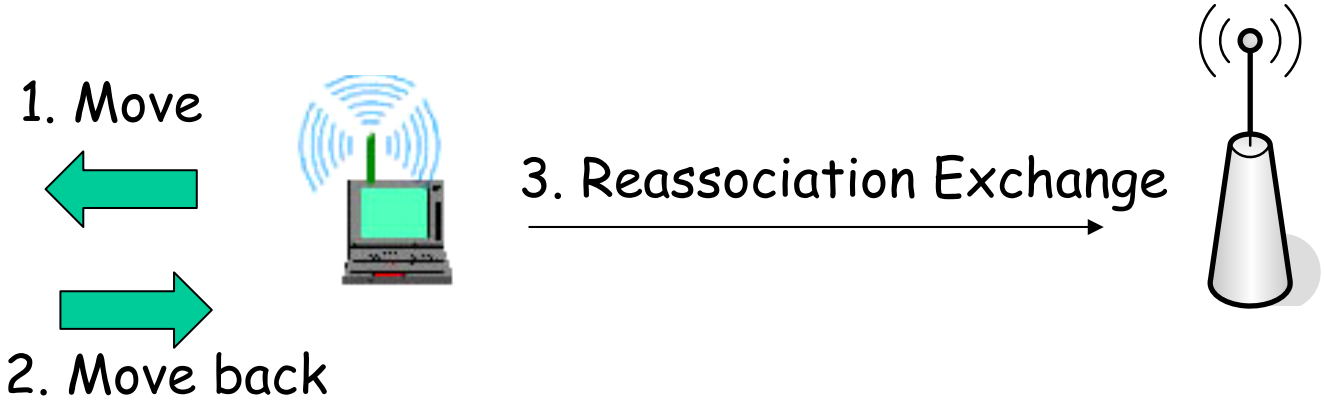
Registration

- Beacons sent periodically (every 100ms) by AP to establish time sync. (TSF) and maintain connectivity or associations
  - contains BSS-ID used to identify the AP and network, traffic indication map (for sleep mode), power management, roaming
  - RSS measurements are based on the beacon message
- AP and mobile devices form "associations", mobile device "registers" with AP.
- Mobiles send "requests" and APs "responses"
- Only after registering can mobiles send/receive DATA

Association Procedure



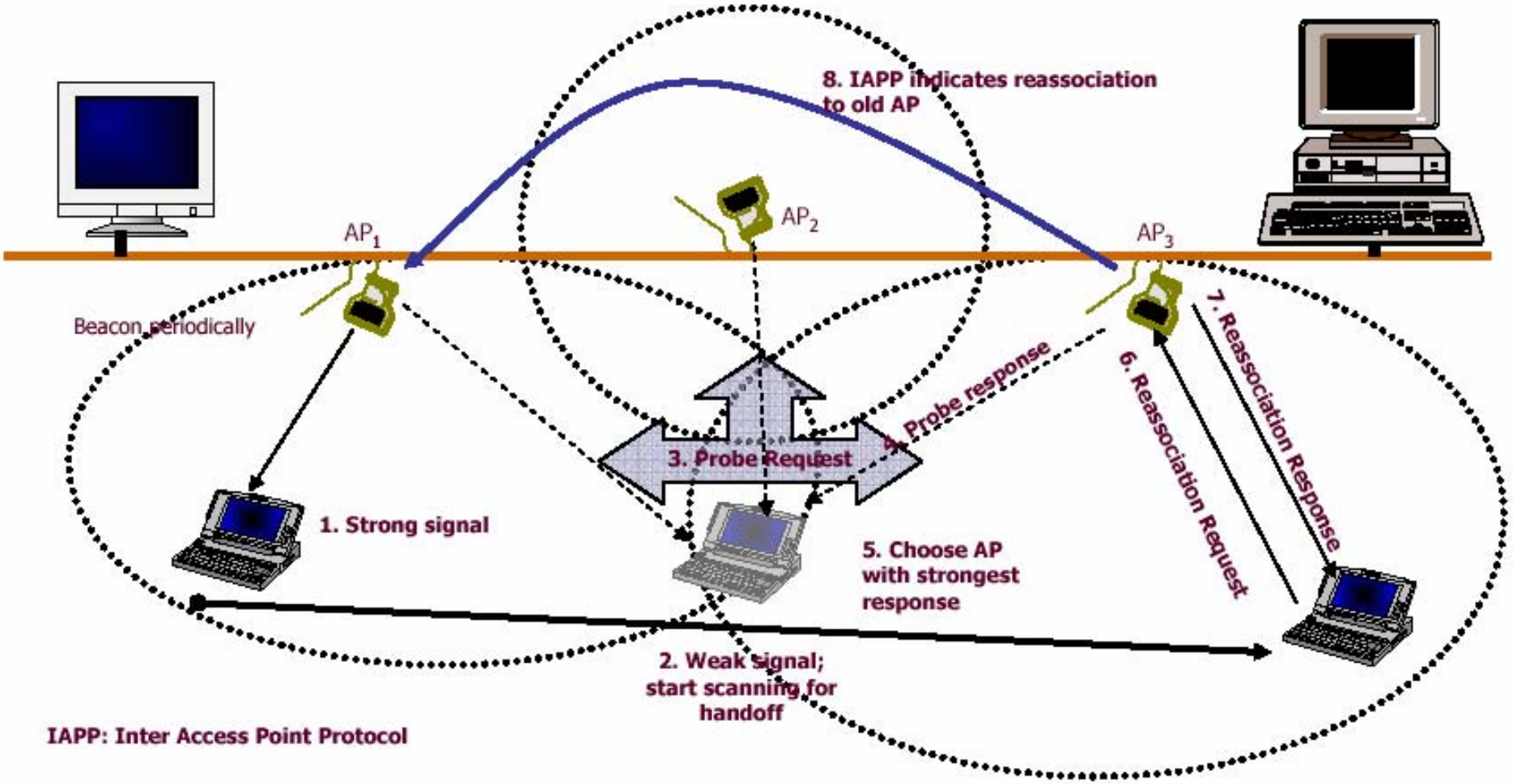
Re-association with old AP



Roaming between APs

- IAPP (Inter Access-Point Protocol)
  - 802.11f
- Layer-2 handoff in 802.11 networks
  - Topic of research
    - Reduce L2 handoff latency
    - Integrate with L3 handoff to improve overall handoff performance
  - Issues
    - Security: authentication
    - Scanning channels (multiple possible channels)

Layer-2 Handoff



Power Management Overview

- Why power management?
  - Most of the time mobile devices receive data in burst and then are idle for the rest of the time.
  - Can exploit that by going into a power saving idle mode – "powering off". However, need to maintain on-going sessions
- Basic idea
  - Mobile sleeps, AP buffers downlink data, and sends the data when the mobile device is awakened
  - Using the Timing Sync Function all mobiles are synchronized and they will wake up at the same time to listen to the beacon.
    - Check the beacon to see if the mobile needs to wake up
- Compare to cellular network power control
  - In comparison to the continuous power control in cellular networks this power conservation is geared towards burst data

Power Management in 802.11

- MS has 2 modes
  - Active mode (AM)
  - power-save (PS) mode
- MS enters power-save (PS) mode
  - Notify AP with "Power Management bit" in Frame Control field
  - PS mode MSs listen for beacons periodically
- MS enters active mode
  - The MS sends a power-save poll (PS-Poll) frame to the AP and goes active

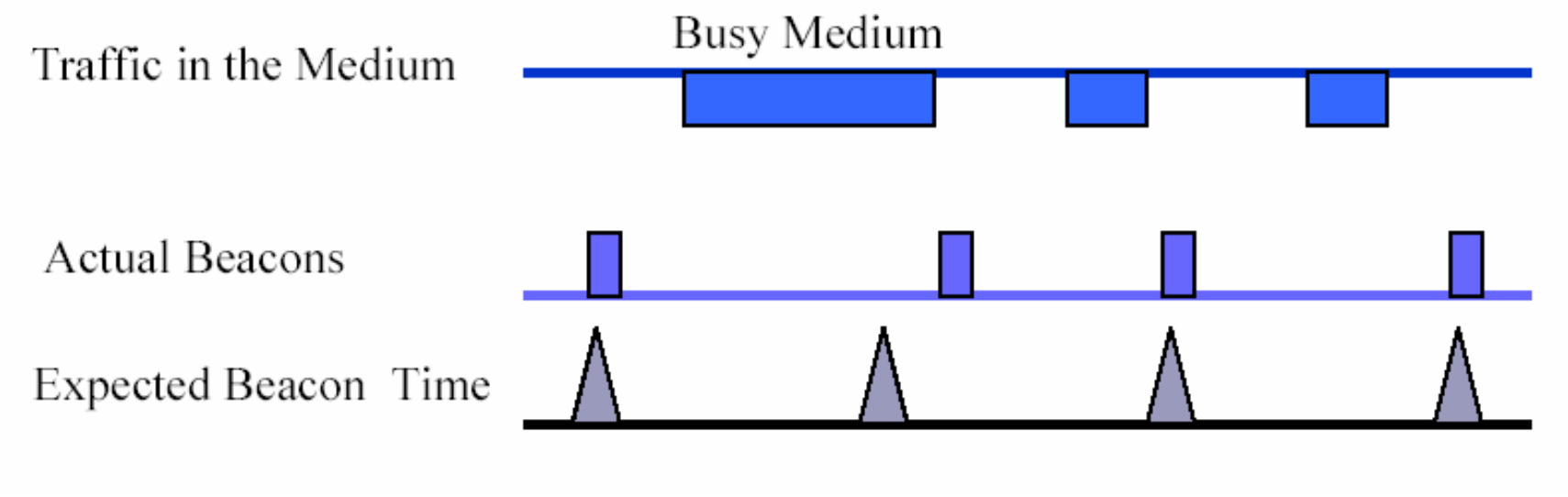
Power Management in 802.11

- AP operations (when MS is in PS mode)
  - Does not arbitrarily sends MSDU to MS in PS mode
  - Buffer MSDUs at AP until MS "wake up"
  - MSs with buffered MPDUS at AP are identified with traffic indication map (TIM).
    - TIM is included in periodic beacons
    - MS learns that it has data buffered by checking the beacon/TIM
- AP operations when MS goes into active mode
  - The AP then sends the buffered data to the mobile in active mode

Concept: Paging and Sleep mode

- Sleep mode (dormant mode)
  - Save power
- Wake up mechanism
  - Paging
- Combine with location management mechanism (in cellular networks not in 802.11)
  - Paging area V.S. location area
  - Frequency of location area update
  - Savings
    - Power consumption
    - Signaling overhead
- Paging + IP → IP Paging

Listening to the beacon for power management



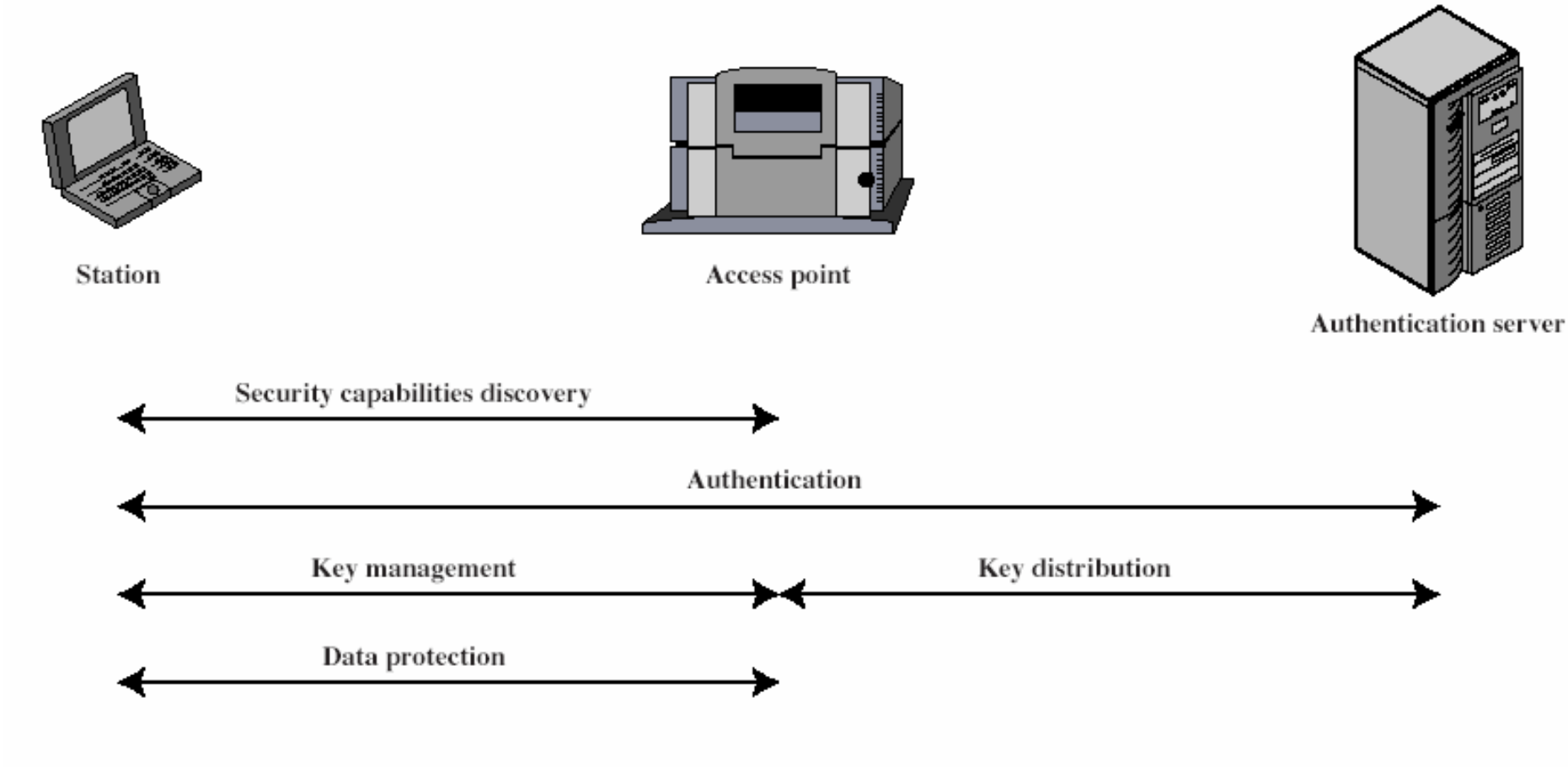
Security: Two schemes supported

- Open system authentication is default
  - AP and mobile use a shared key that they exchange as a request/response
  - Sends the "key" using a 40-bit secret code that is shared by the AP and mobile
- Wired Equivalent Privacy (WEP)
  - Pseudo random generator is used along with a 40-bit secret key to create a key sequence that is simply XOR-ed with the message
  - Susceptible to attacks

802.11i: Security Enhancement

- WEP security is weak
- 802.11i standard for better security
  - Authentication
    - Authentication protocol
      - EAP (Extensible Authentication Protocol)
    - Authentication Server
      - RADIUS (Remote Authentication Dial-In Service) server
  - Data privacy (encryption)
    - 128-bit AES keys
    - 104-bit RC4 keys
      - WEP uses 40-bit RC4
- Wi-Fi Protected Access (WPA)

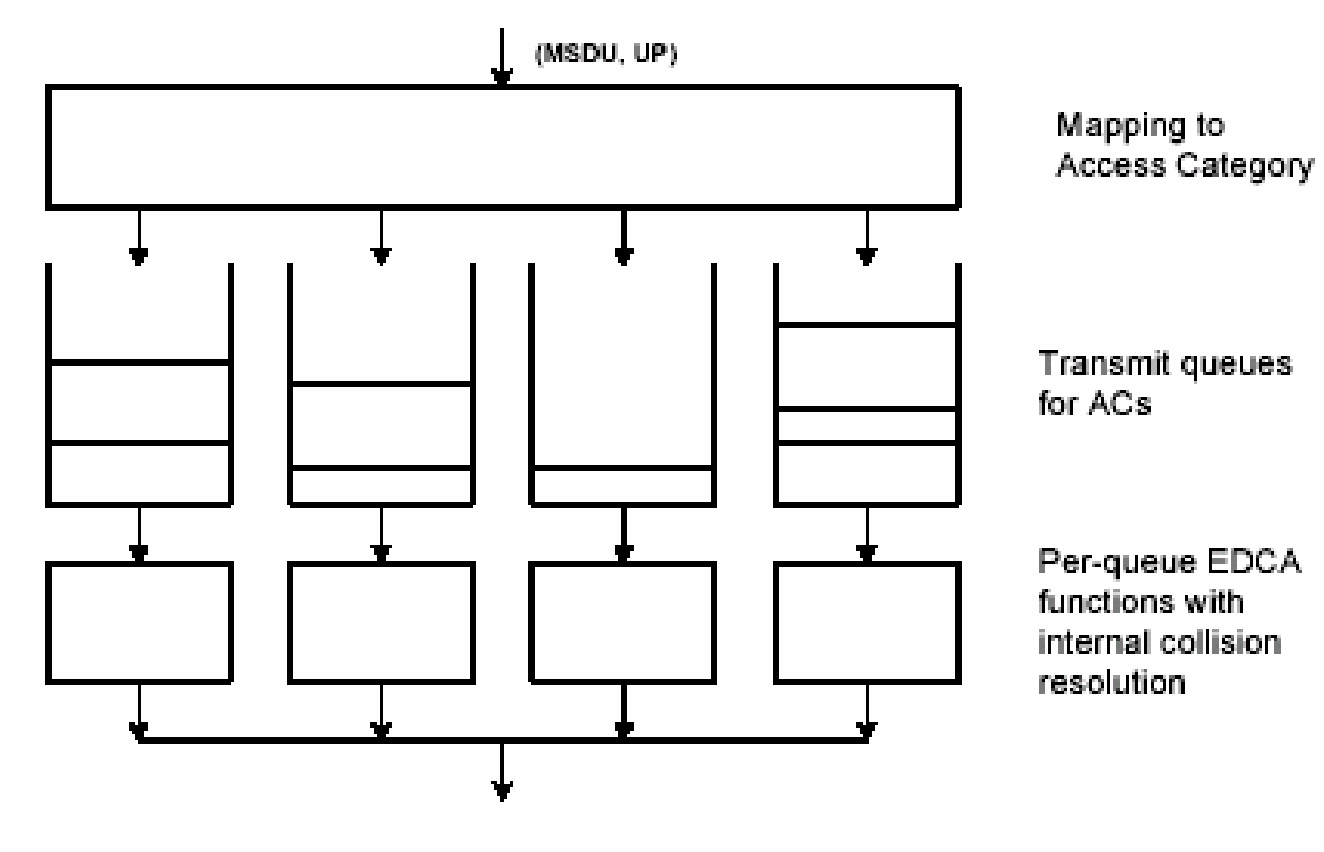
802.11i service flow



QoS Enhancement for 802.11

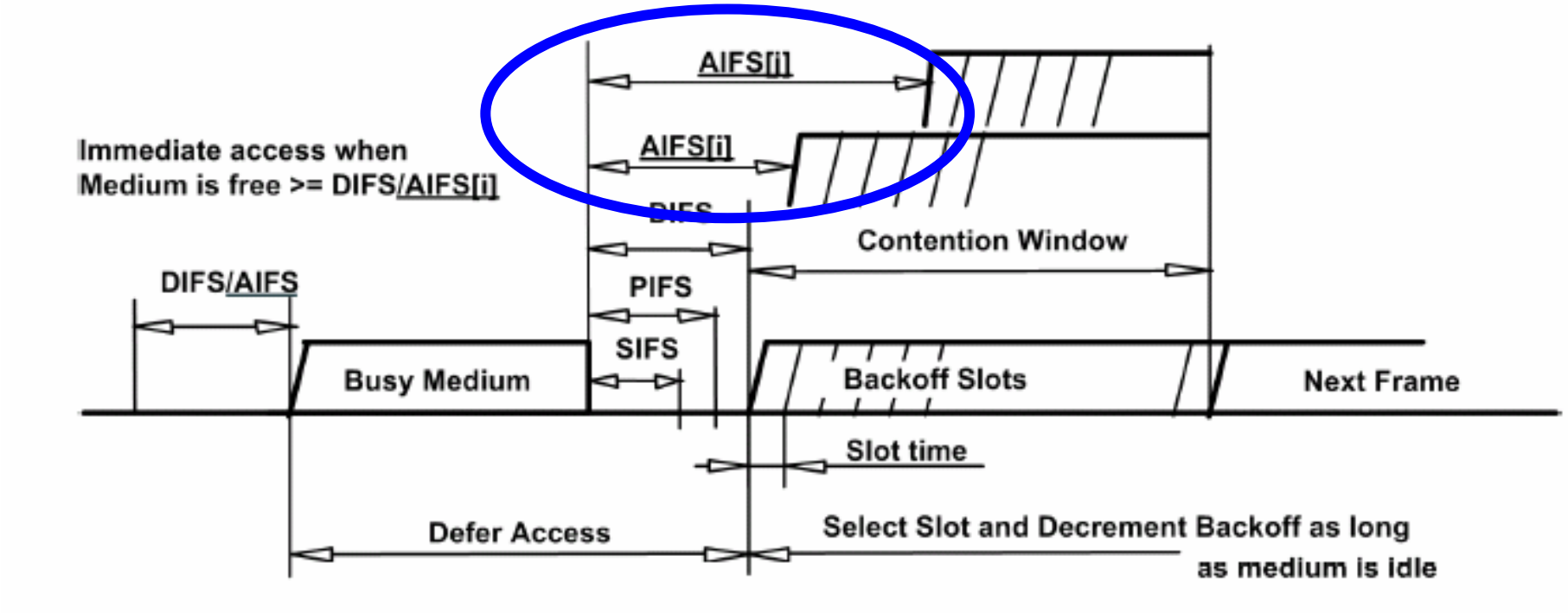
- IEEE 802.11e
  - Enhanced DCF (EDCF), to provide service differentiation
    - Traffic Classes (TC)
      - Give priorities to different TCs
      - Multiple prioritized queues
    - Assign different CWmin values to different traffic classes
    - Assign an Arbitration IFS (AIFS) instead of DIFS, to different traffic classes, resulting in smaller AIFS values for high priority classes
    - Transmit Opportunity (TXOP)
      - "time" window to send as many packets as possible
      - Avoid low-rate nodes use excessive amount of resources
    - Wi-Fi Multimedia (WMM) certified products
  - Hybrid coordination function (HCF) to replace PCF.

Access Categories



IFS

Different AIFS for different traffic classes



Some other interesting 802.11 standards

- IEEE 802.11i - Enhanced security
- IEEE 802.11n - Higher throughput
  - High-rate PHY
    - MIMO
- IEEE 802.11s - ESS Mesh Networking
  - L2 WLAN mesh