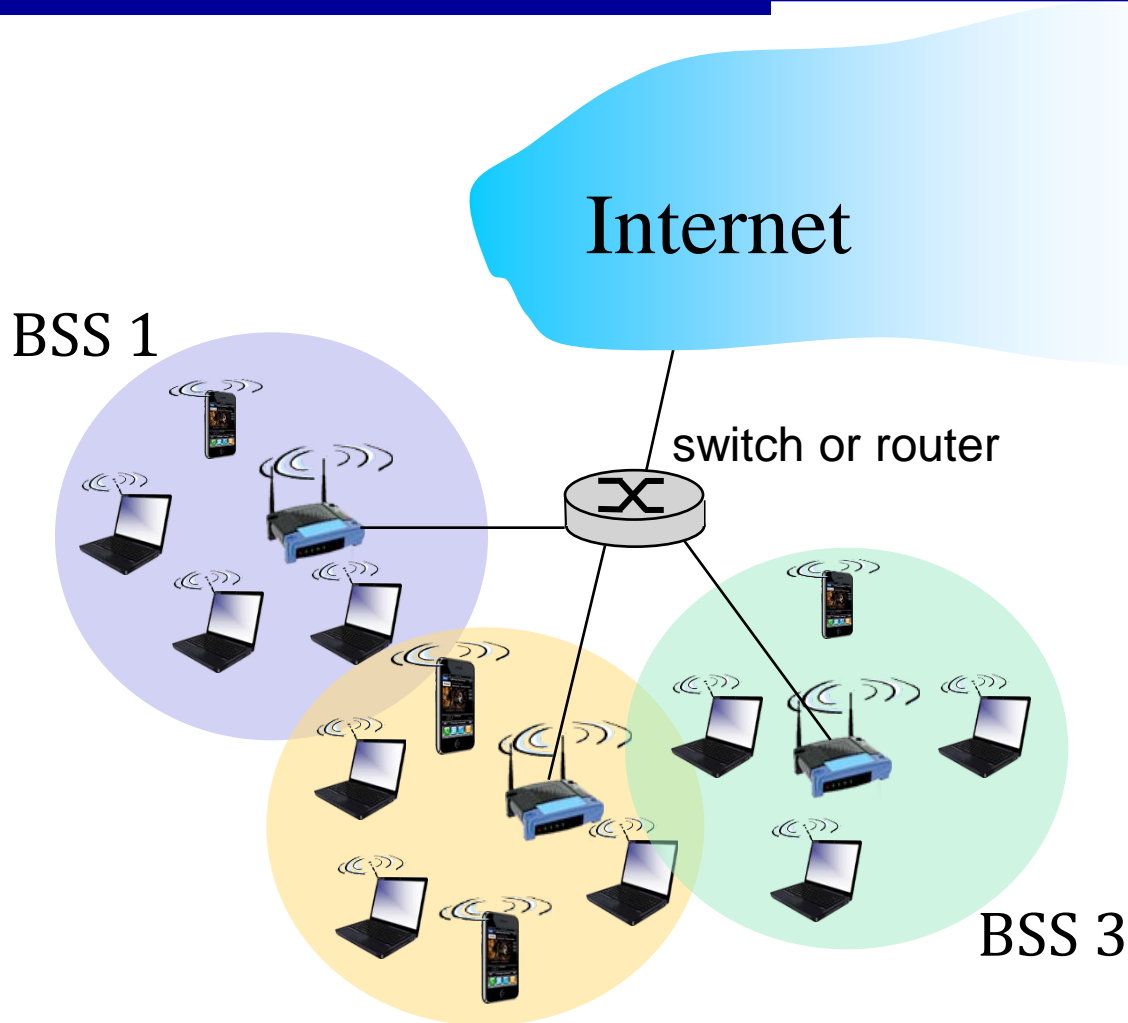


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# Wireless LAN (IEEE 802.11 WiFi)

# Typical 802.11 LAN Configuration

---



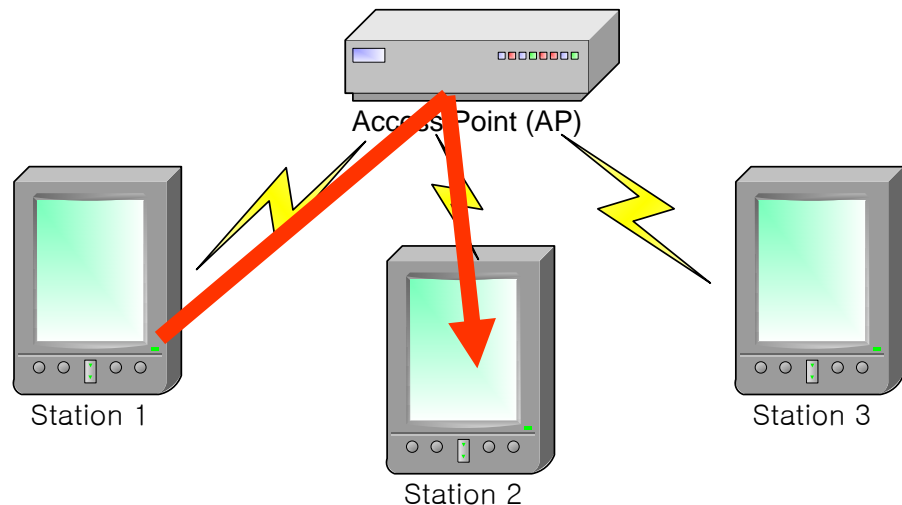
BSS: Basic Service Set

BSS 2

# Two Modes (1)

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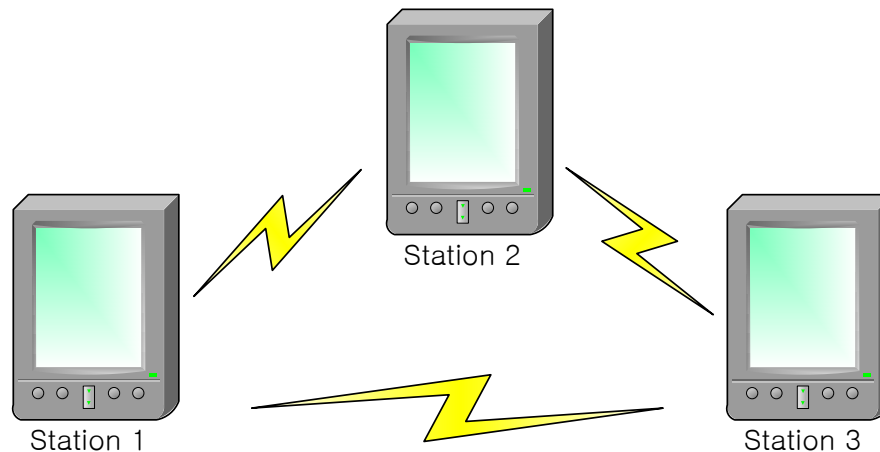
- Infrastructure mode
  - Infrastructure Basic Service Set → BSS
  - An access point (AP) and multiple stations (STAs)
  - Every transmission is with AP; no peer-to-peer communication



# Two Modes (2)

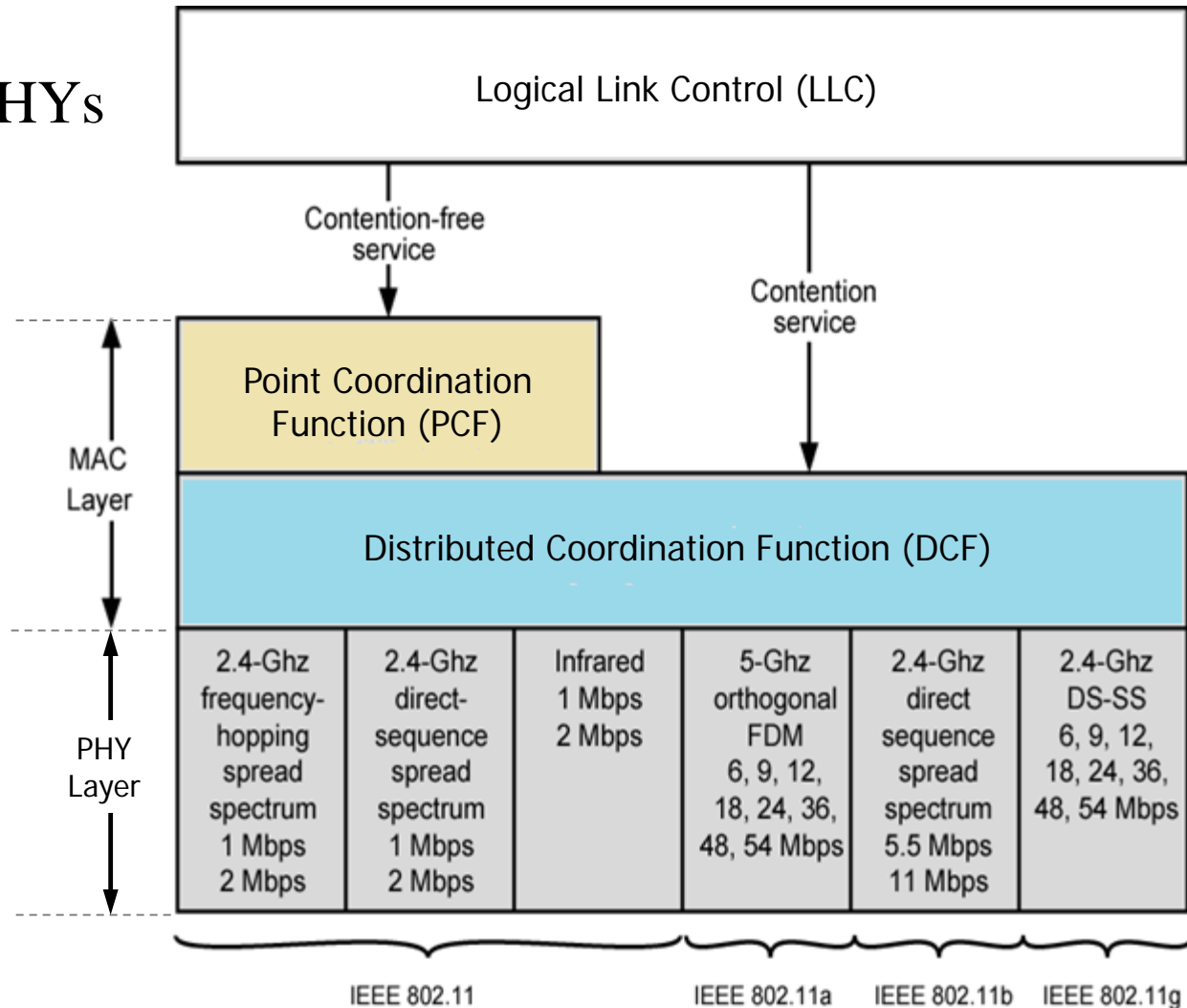
---

- Ad hoc mode
  - Independent Basic Service Set → IBSS
  - Multiple stations (STAs), and no AP
  - Peer-to-peer communication only



# IEEE 802.11 Protocol Architecture

- One MAC
- Multiple PHYs



# IEEE 802.11 PHY Enhancement

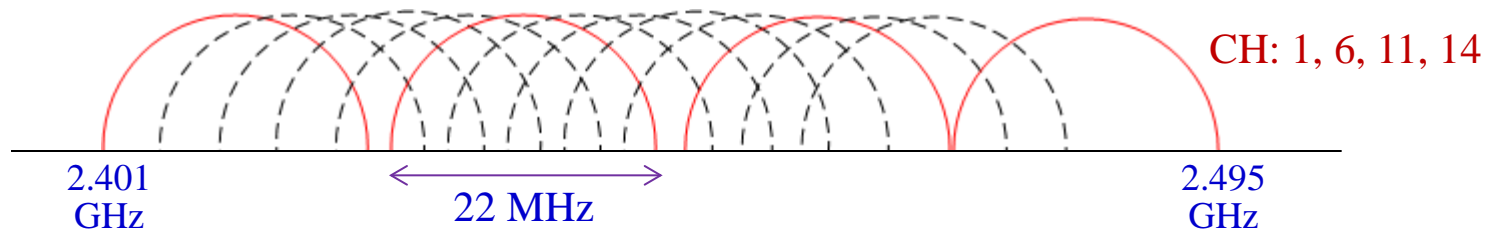
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standard	802.11a	802.11b	802.11g	802.11n	802.11ac (WiFi 5)	802.11ax (WiFi 6)	802.11ad
Year	1999	1999	2003	2009	2013	2019	2014
Maximum rate	54 Mbps	11 Mbps	54Mbps	600 Mbps	6.93 Gbps	9.6 Gbps	6.76 Gbps
Frequency Band	5 GHz	2.4 GHz	2.4 GHz	2.4/5 GHz	5 GHz	2.4/5/6 GHz	60 GHz
Channel Bandwidth	20 MHz	20 MHz	20 MHz	20, 40 MHz	20, 40, 80, 160 MHz	20,40, 80, 160 MHz	2160 MHz
Highest modulation order	64 QAM	11 CCK	64 QAM	64 QAM	256 QAM	1024 QMA	64 QMA
Spectrum usage	OFDM	DSSS	DSSS, OFDM	OFDM	OFDM	OFDM, OFDMA	SC, OFDMA
Antenna configuration	1x1 SISO	1x1 SISO	1x1 SISO	Up to 4x4 MIMO	Up to 8x8 MIMO, DL MU-MIMO (4U)	Up to 8x8 MIMO, UL/DL MU-MIMO (8U)	1x1 SISO

# 802.11: Channels, Association

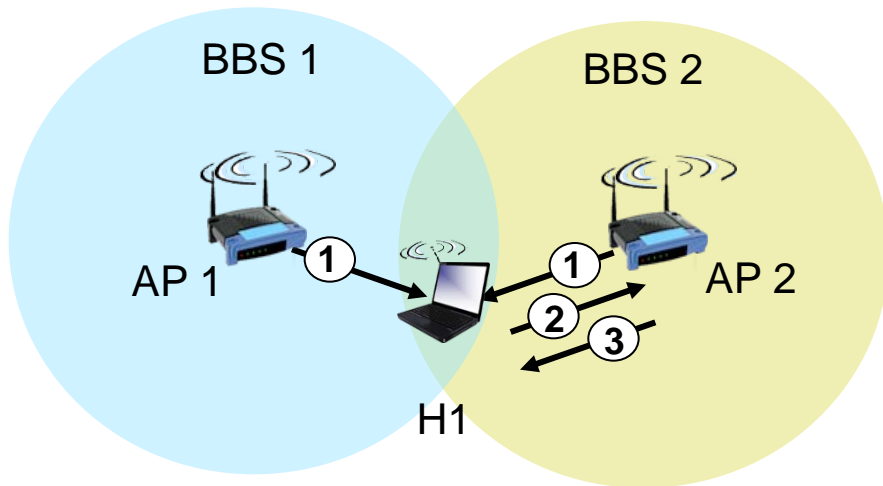
---

- [Example] IEEE 802.11b
  - 2.401 GHz - 2.495GHz (ISM band) spectrum divided into 14 channels (bandwidth: 20MHz) at different frequencies
  - AP admin chooses frequency for AP
  - Interference possible: channel can be same as that chosen by neighboring AP!



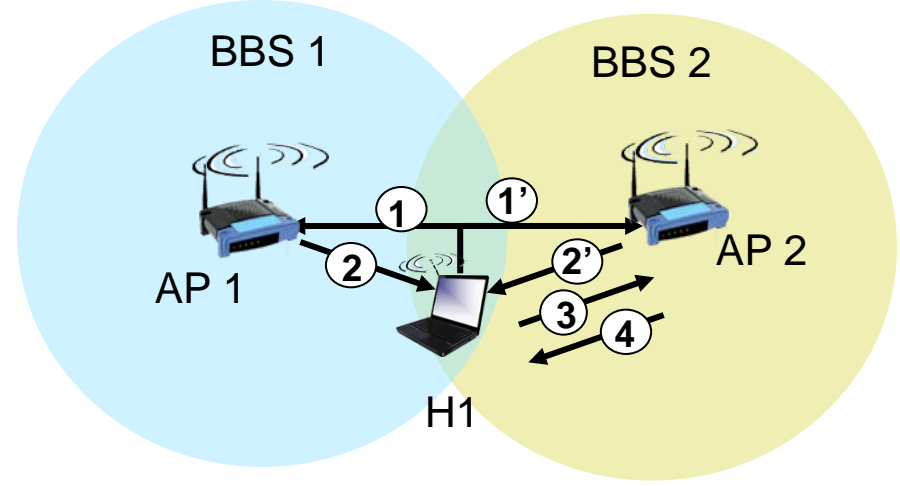
- Host: must be **associated** with an AP
  - scans channels, listening for **beacon frames** containing AP's name (SSID: service set ID) and MAC address
  - selects AP to associate with
  - may perform authentication
  - will typically run DHCP to get IP address in AP's subnet

# 802.11: passive/active scanning



## Passive scanning:

- ① Beacon frames sent from APs
- ② Association Request frame sent from H1 to selected AP
- ③ Association Response frame sent from selected AP to H1



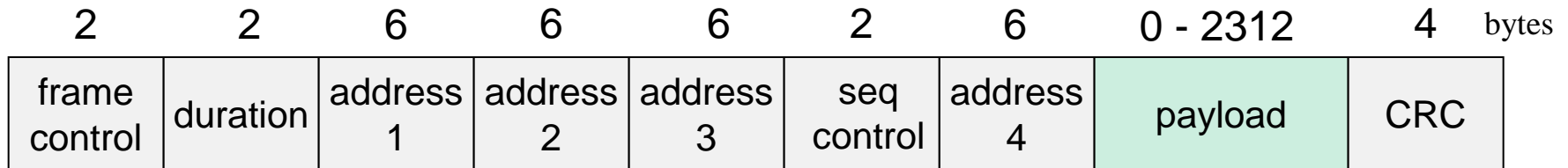
## Active scanning:

- ①①' Probe Request frame for each channel broadcast from H1
- ②②' Probe Response frames sent from APs
- ③ Association Request frame sent from H1 to selected AP
- ④ Association Response frame sent from selected AP to H1



# 802.11 MAC frame: addressing (1/2)

---



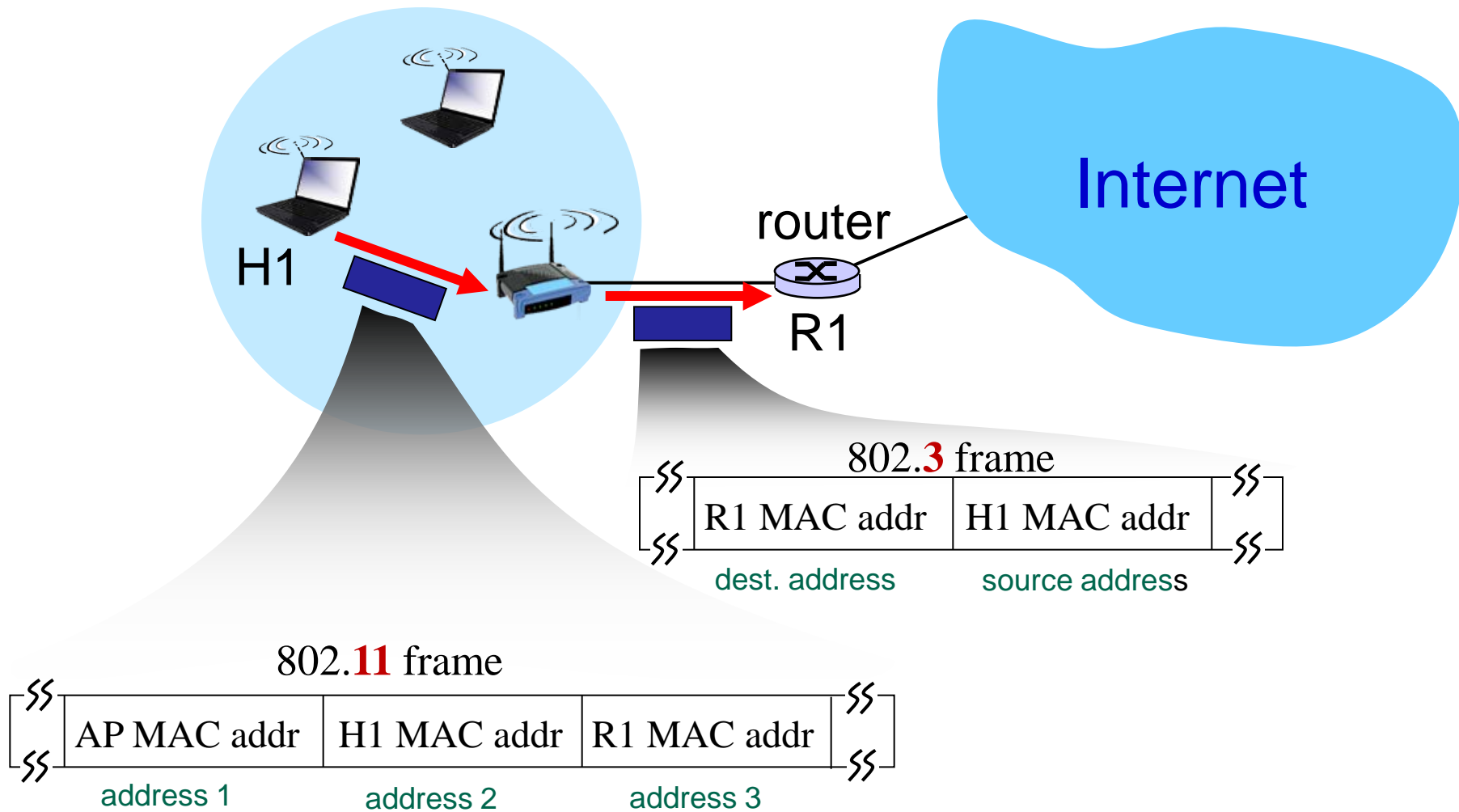
**Address 1:** MAC address of wireless host or AP to receive this frame

**Address 2:** MAC address of wireless host or AP transmitting this frame

**Address 3:** MAC address of router interface to which AP is attached

**Address 4:** used only in ad hoc mode

# 802.11 MAC frame: addressing (2/2)



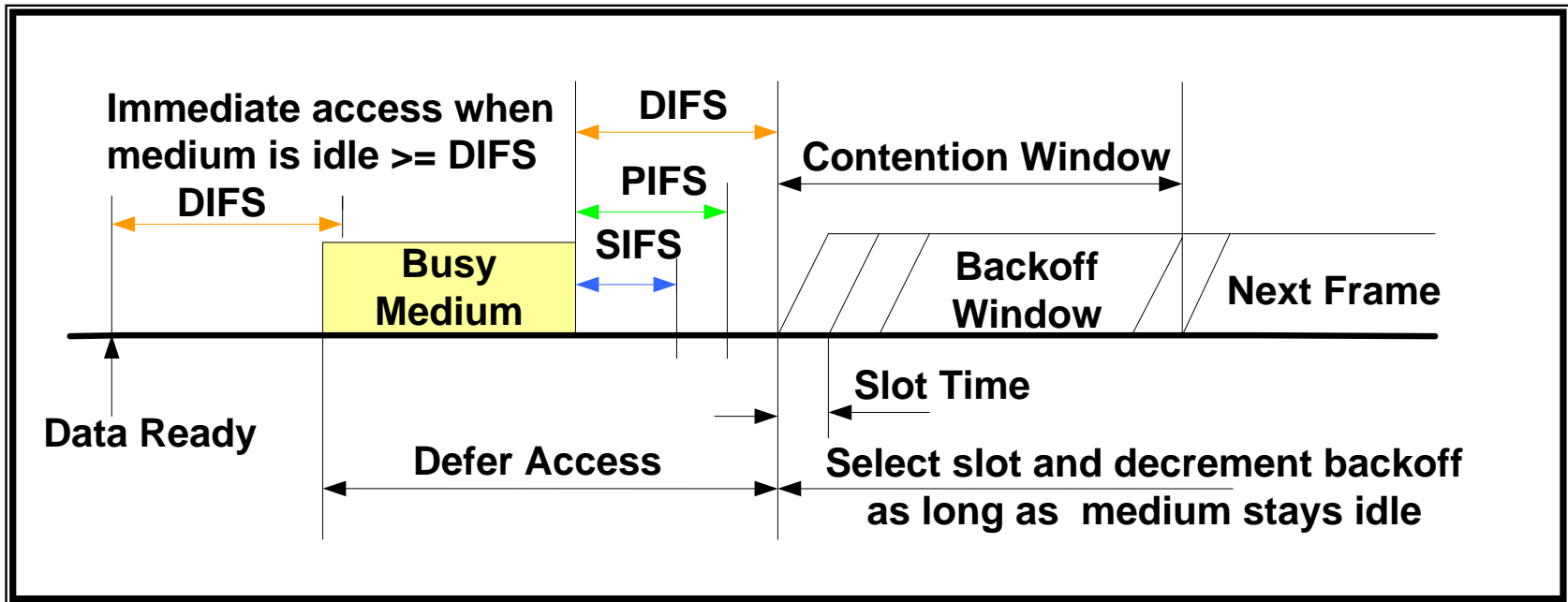
# Two Coordination Functions

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- Distributed Coordination Function (DCF)
  - For distributed contention-based channel access
  - CSMA/CA (Collision Avoidance)
  - Mandatory
- Point Coordination Function (PCF)
  - For centralized contention-free channel access
  - Optional

# Distributed Coordination Function

- Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)
  - similar to IEEE 802.3 Ethernet CSMA/CD



# DCF

---

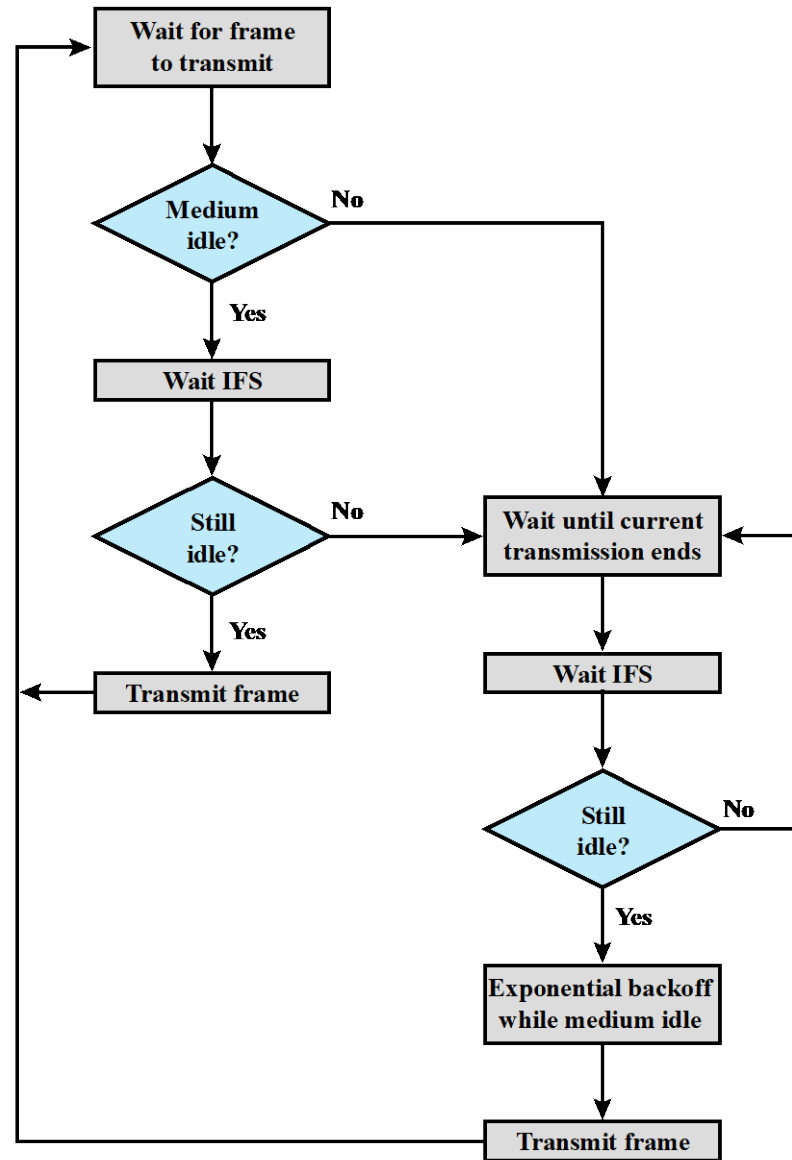
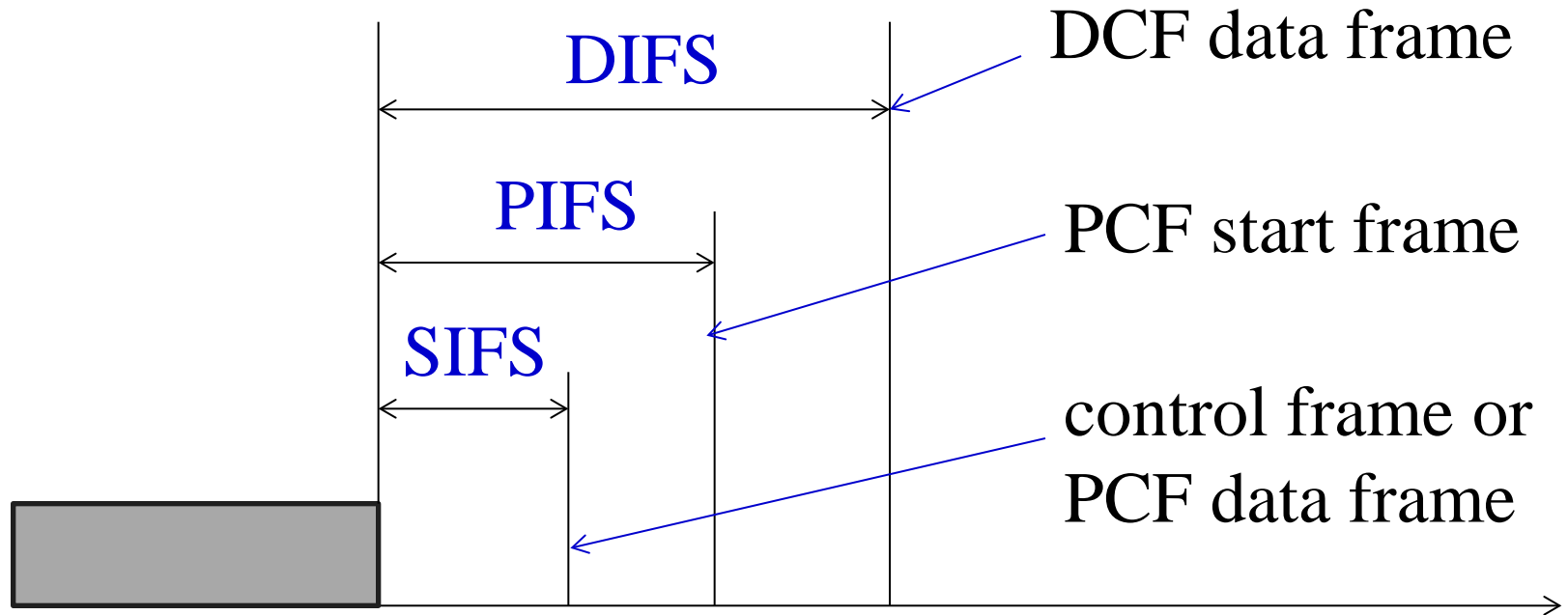


Figure 13.6 IEEE 802.11 Medium Access Control Logic

# IFS

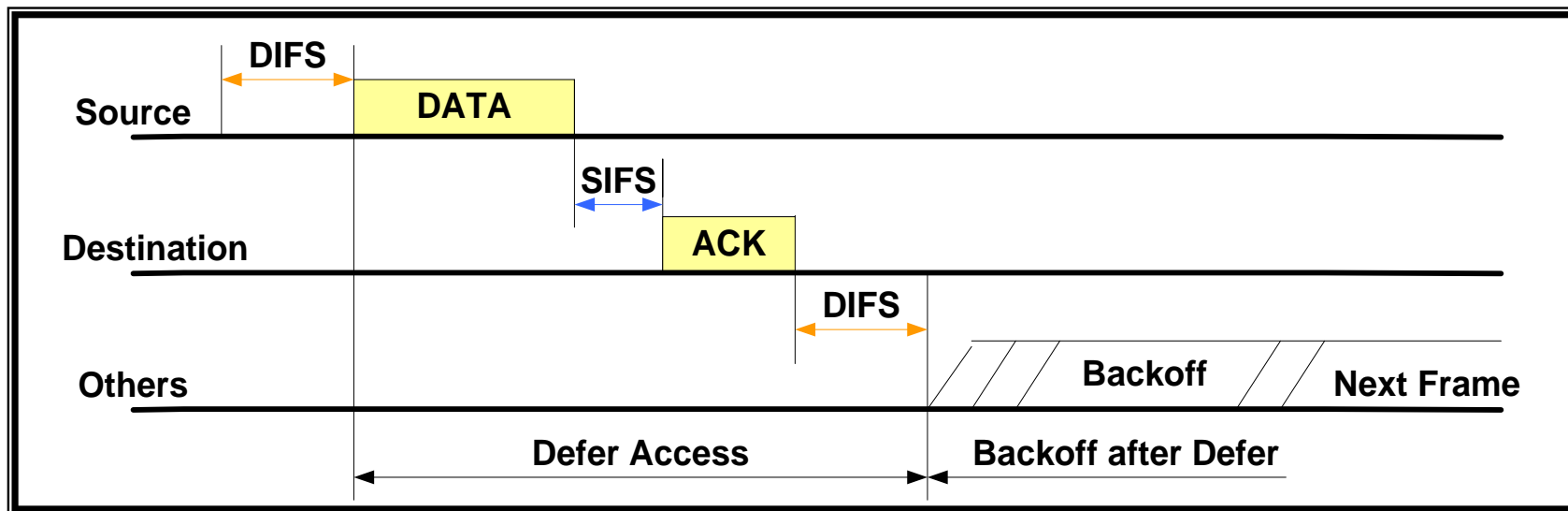
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The shorter IFS, the higher channel access priority

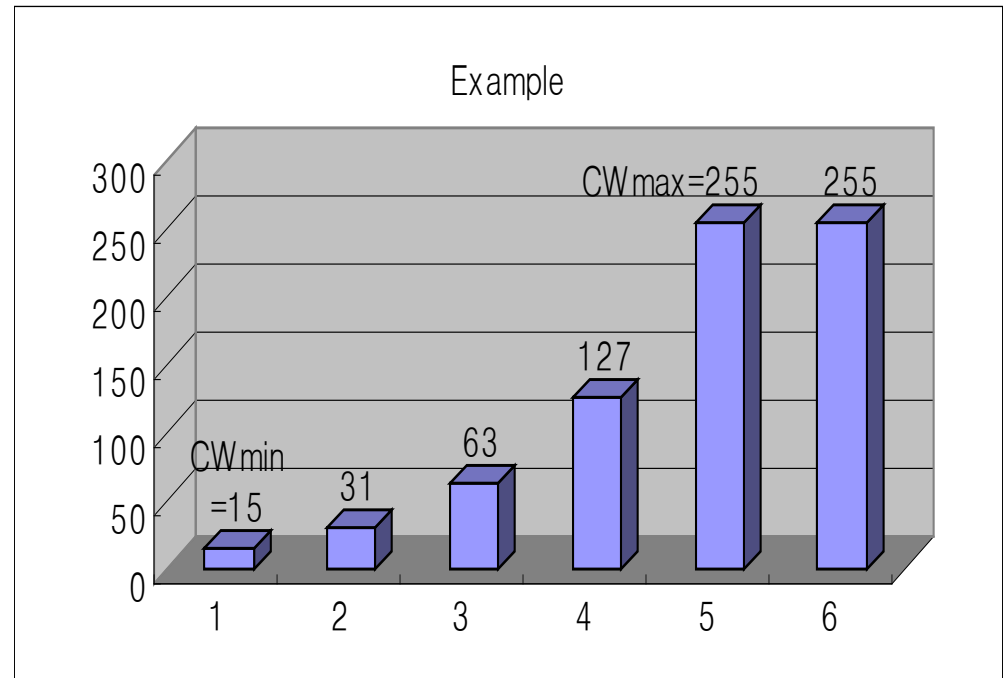
# Stop-and-Wait ARQ

- Receiver of a directed frame returns an ACK
- If ACK not received, sender retransmits after another backoff
- Basic data transfer involves exchange of two frames



# Exponential Backoff

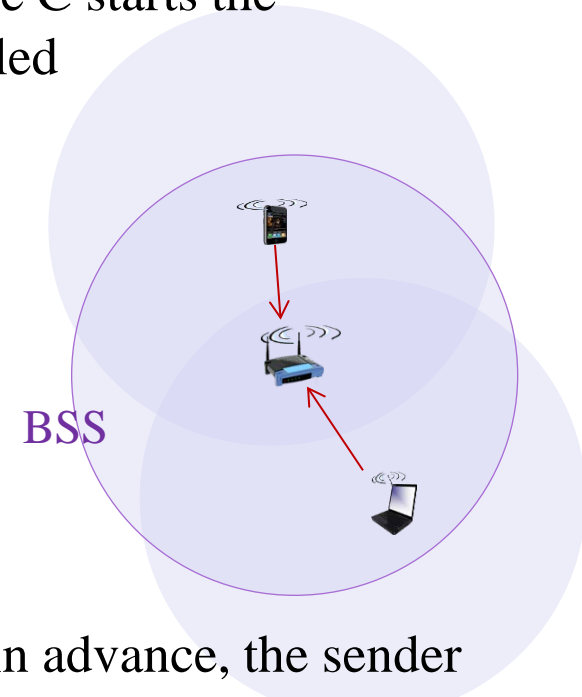
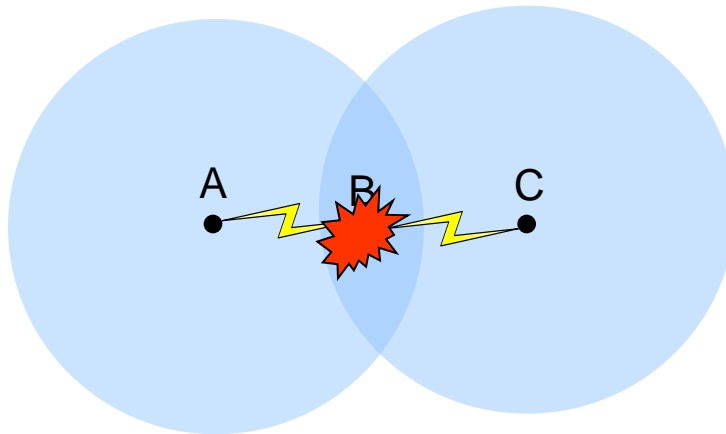
- Backoff Counter is randomly selected from  $[0, CW]$ , where  $CW$  is contention window
- For each unsuccessful frame transmission,  $CW$  doubles (from  $CW_{min}$  to  $CW_{max}$ )
- $CW \leftarrow 2 CW + 1$
- Reduces the collision probability





# Hidden Terminal Problem

- Basic data transfer involves exchange of two frames (data, ACK)
- Hidden terminal problem
  - Nodes A and C are **hidden** to each other
  - When node A is transmitting to node B, if node C starts the transmission, the transmission to node B is failed

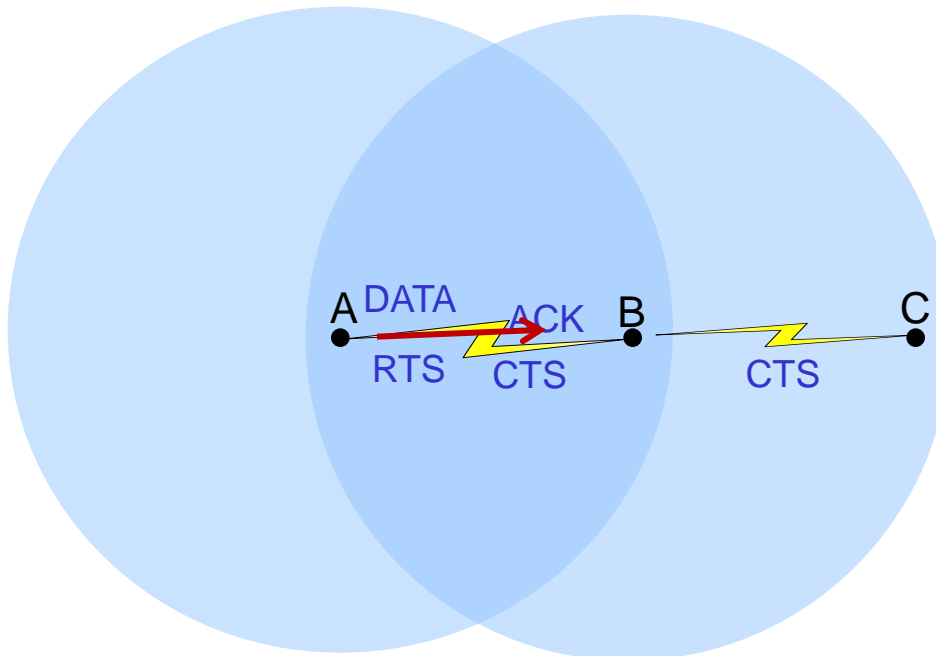


- Solution: By exchanging RTS and CTS frame in advance, the sender and receiver nodes inform their transmission to all stations within both the range of sender and the range of receiver

# Four frame exchange

---

- RTS → CTS → Data → ACK
  - RTS (request to send) alerts all stations within range of source that exchange is under way
  - CTS (clear to send) alerts all stations within range of destination
- RTS/CTS exchange is the required function of MAC but may be disabled

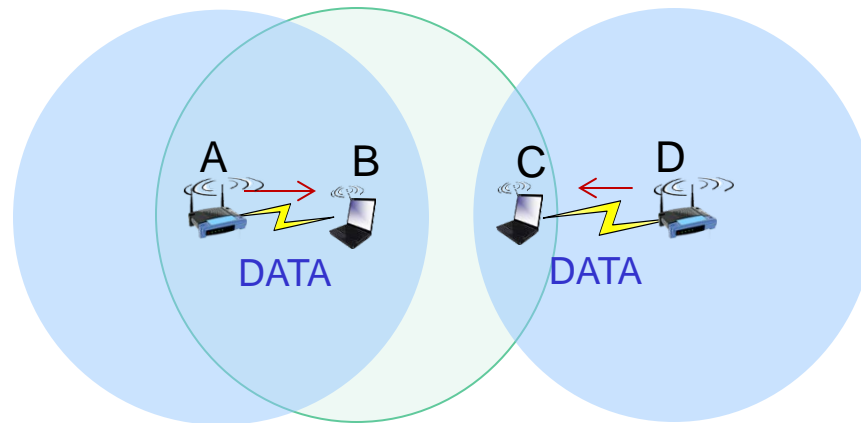


Data Transmission  
from node A (STA)  
to node B (AP)

# Exposed Terminal problem

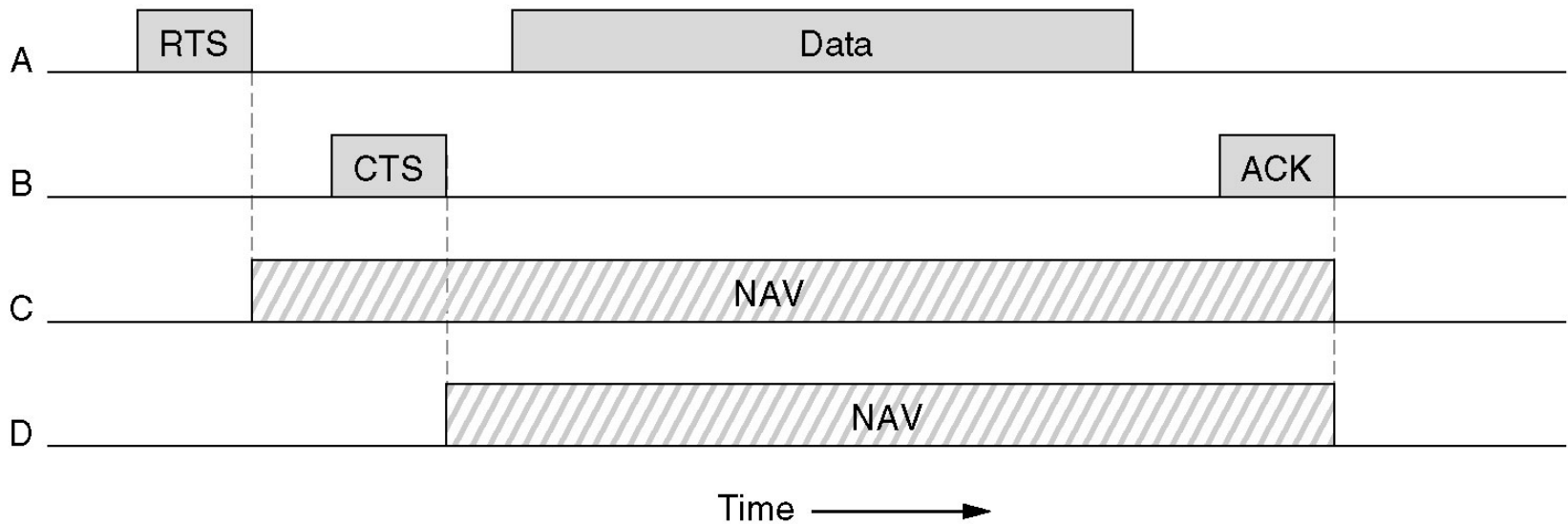
---

- RTS/CTS exchange for solving the hidden terminal problem incurs the exposed terminal problem
- Exposed Terminal Problem
  - Transmission from node D to node C does not disturb the transmission from node A to node B
  - However, the node C rejects the transmission request from node D, by not sending CTS



# Virtual Carrier Sensing (NAV)

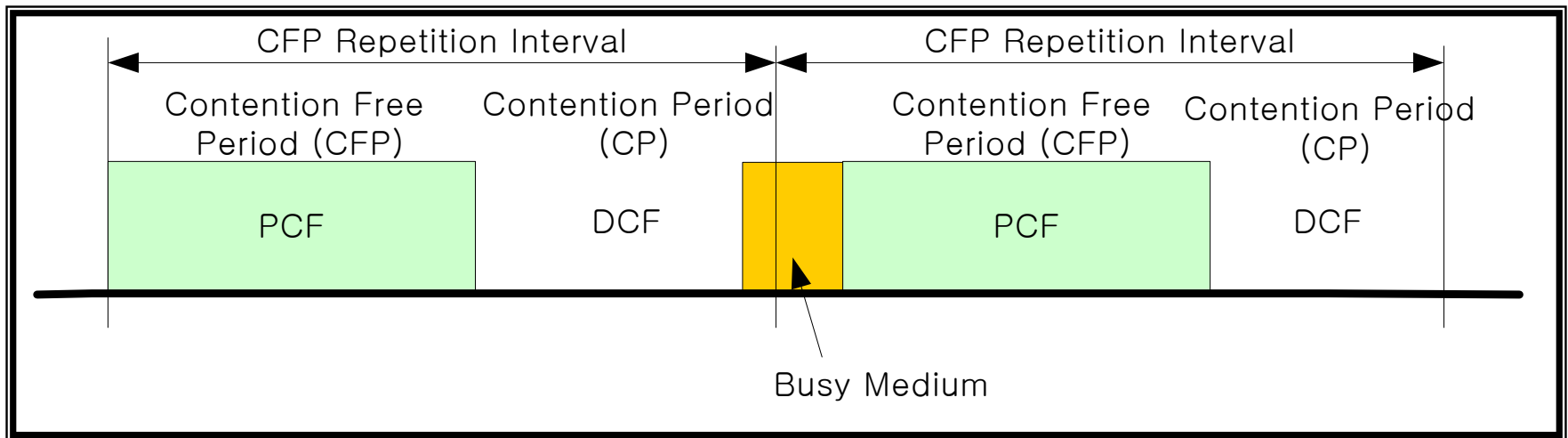
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NAV: network allocation vector,  
Duration value of MAC frame header

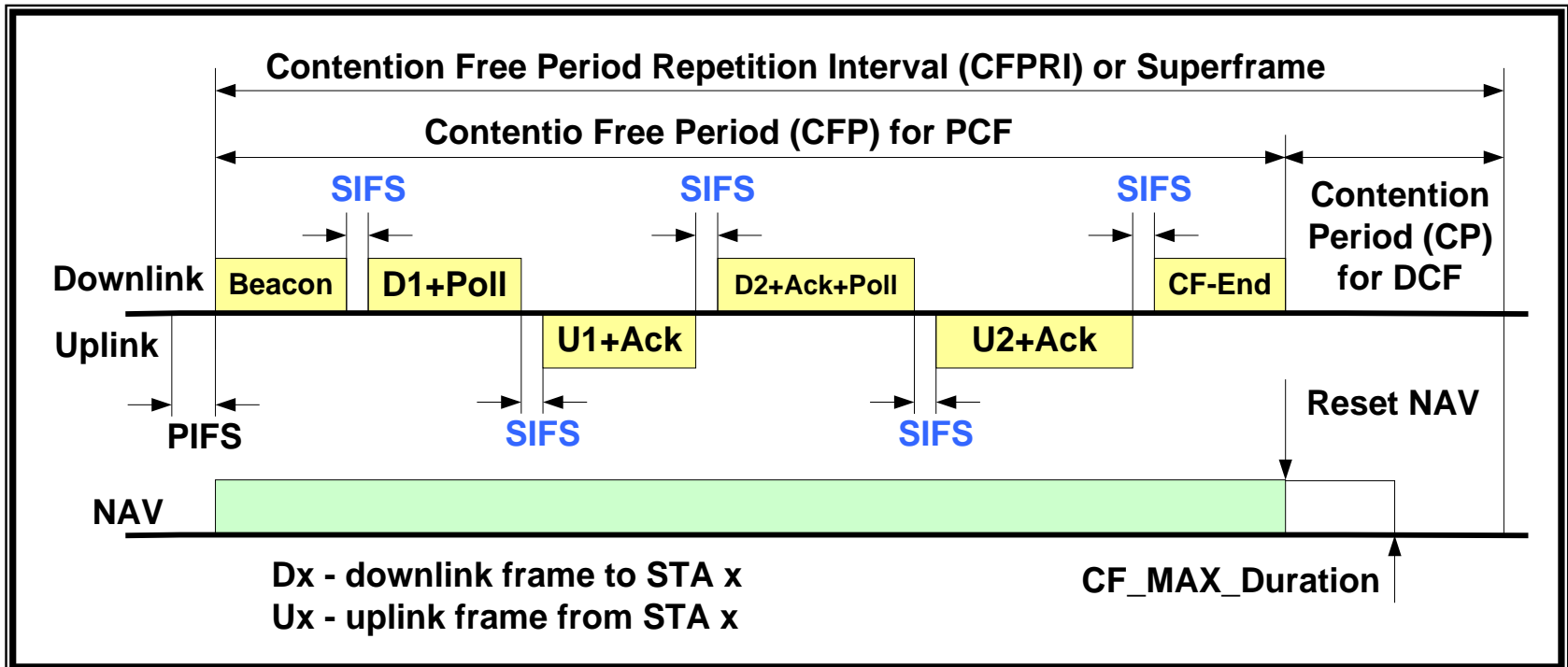
# Point Coordination Function (PCF)

- In infrastructure mode only
  - **Point Coordinator** (PC) resides in AP
- Alternating Contention-Free Period (CFP) and Contention Period (CP)



# Contention Free Operation

- Poll-and-response MAC for nearly isochronous service
- Two consecutive frames are separated by SIFS
- CFP lengths depend on traffic amount
  - Maximum length announced by AP; used for NAV set



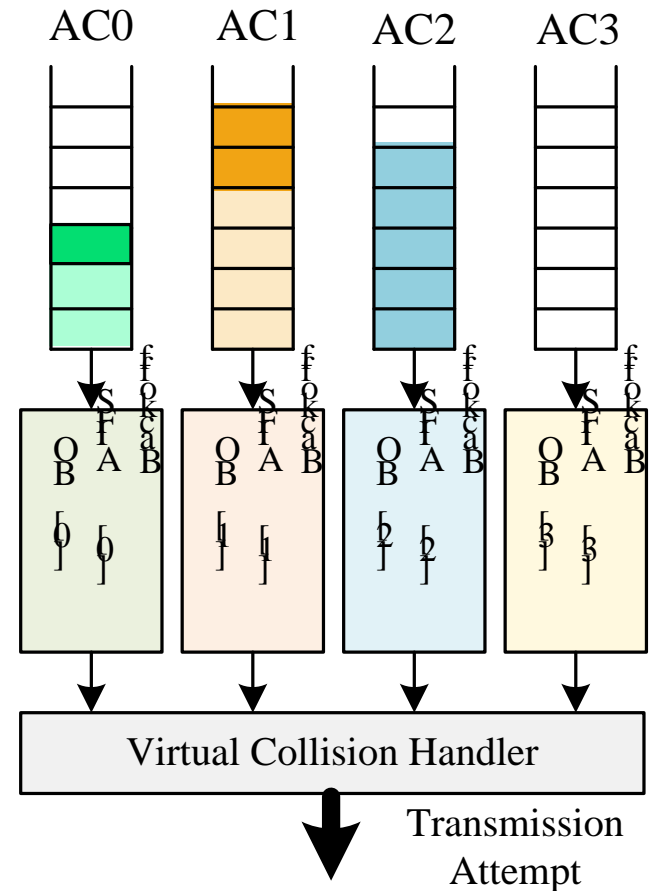
# IEEE 802.11e

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- MAC Enhancement for QoS Support
- Enhanced DCF (EDCF)
  - Transmission Opportunity (TXOP)
    - An interval of time when a QoS STA (QSTA) has the transmission right
      - Multiple frames (i.e., MSDUs) can be transmitted during a TXOP with certain rules
    - Two different TXOPs
      - EDCF TXOP – acquired by EDCF contention
      - Polled TXOP – polled by HC

# Enhanced DCF (1)

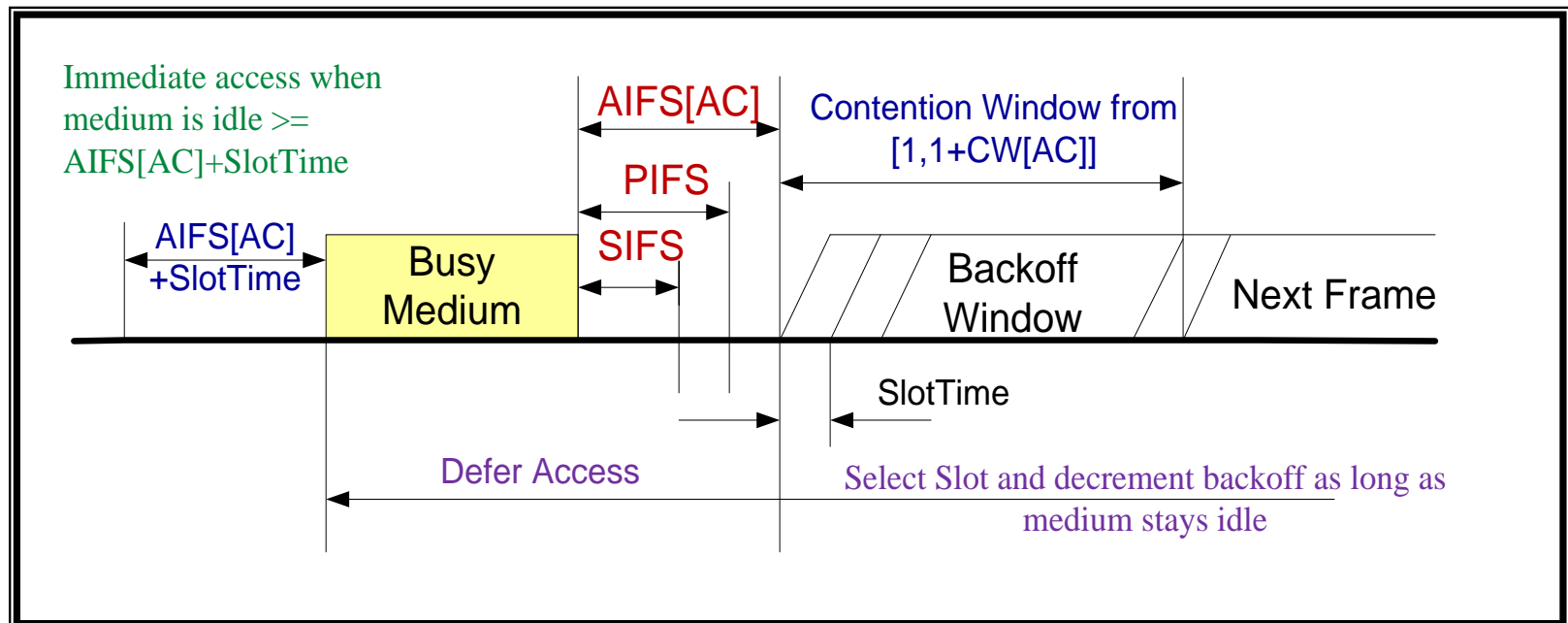
- Access Category (AC)
  - AC as a virtual DCF
  - 4 ACs implemented within a QSTA to support 8 user priorities
  - Multiple ACs contend independently
  - The winning AC transmits frames





# Enhanced DCF (2)

- Each AC contends with
    - AIFS[AC] (instead of DIFS)
    - CWmin[AC]/CWmax[AC] (instead of CWmin/CWmax)
- : Differentiated Channel Access



# Enhanced DCF (3)

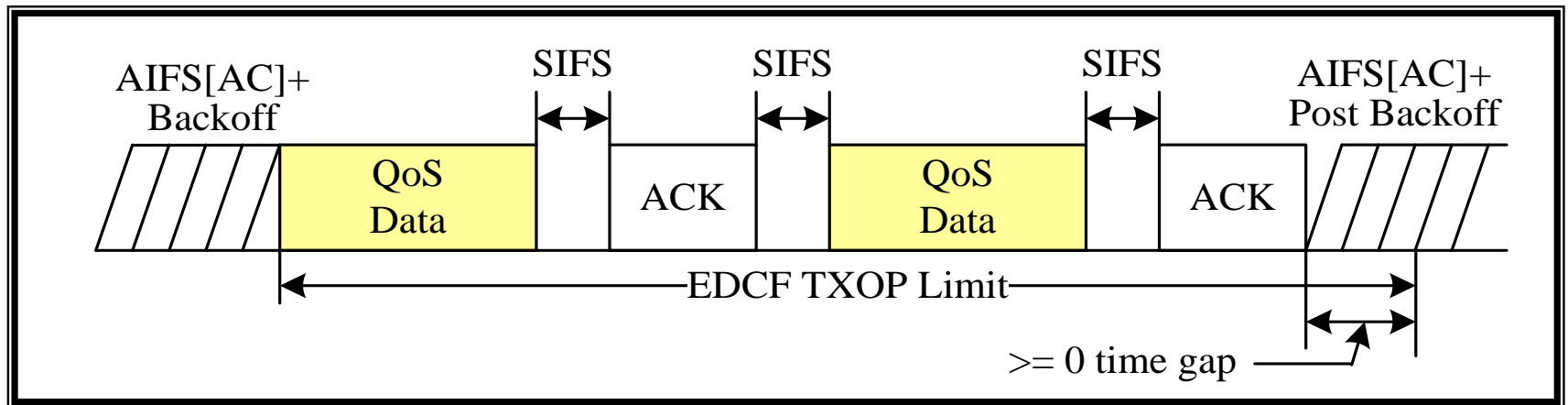
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- Priority to AC Mapping

Priority (Same as 802.1D Priority)	802.1D Designation	Access Category(AC)	Designation (Informative)
1	BK	0	Best Effort
2	-	0	Best Effort
0	BE	0	Best Effort
3	EE	1	Video Probe
4	CL	2	Video
5	VI	2	Video
6	VO	3	Voice
7	NC	3	Voice

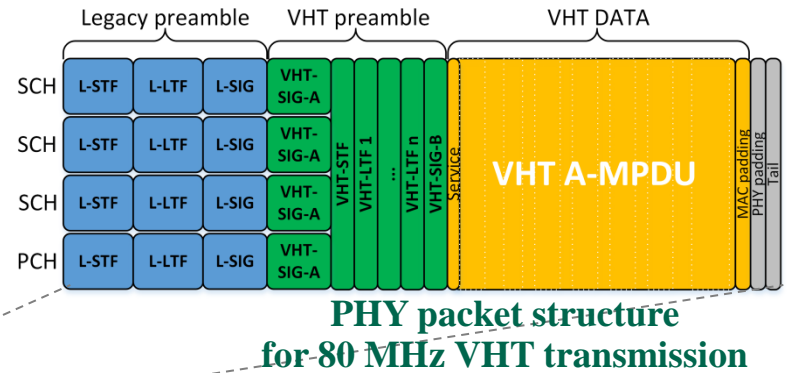
# EDCF Contention-Free Burst (CFB)

- Multiple MSDUs can be transmitted with the limit of EDCF TXOPLimit[AC]
- EDCF TXOPLimit[AC] is announced via beacons

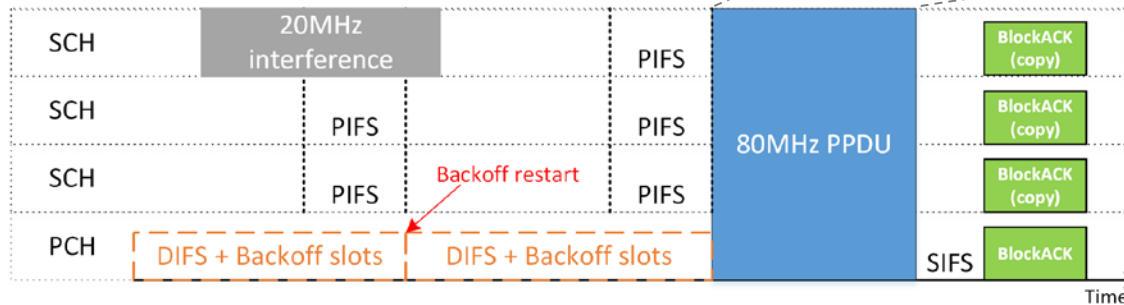


# IEEE 802.11ac

## Wide Channel Access



(a) Static channel access



(b) Dynamic channel access

