IEEE 802.11 MAC Sublayer
(Based on IEEE 802.11-1999)

Wireless Networking
Sunghyun Choi, Associate Professor
Multimedia & Wireless Networking Lab. (MWNL)
School of Electrical Engineering
Seoul National University

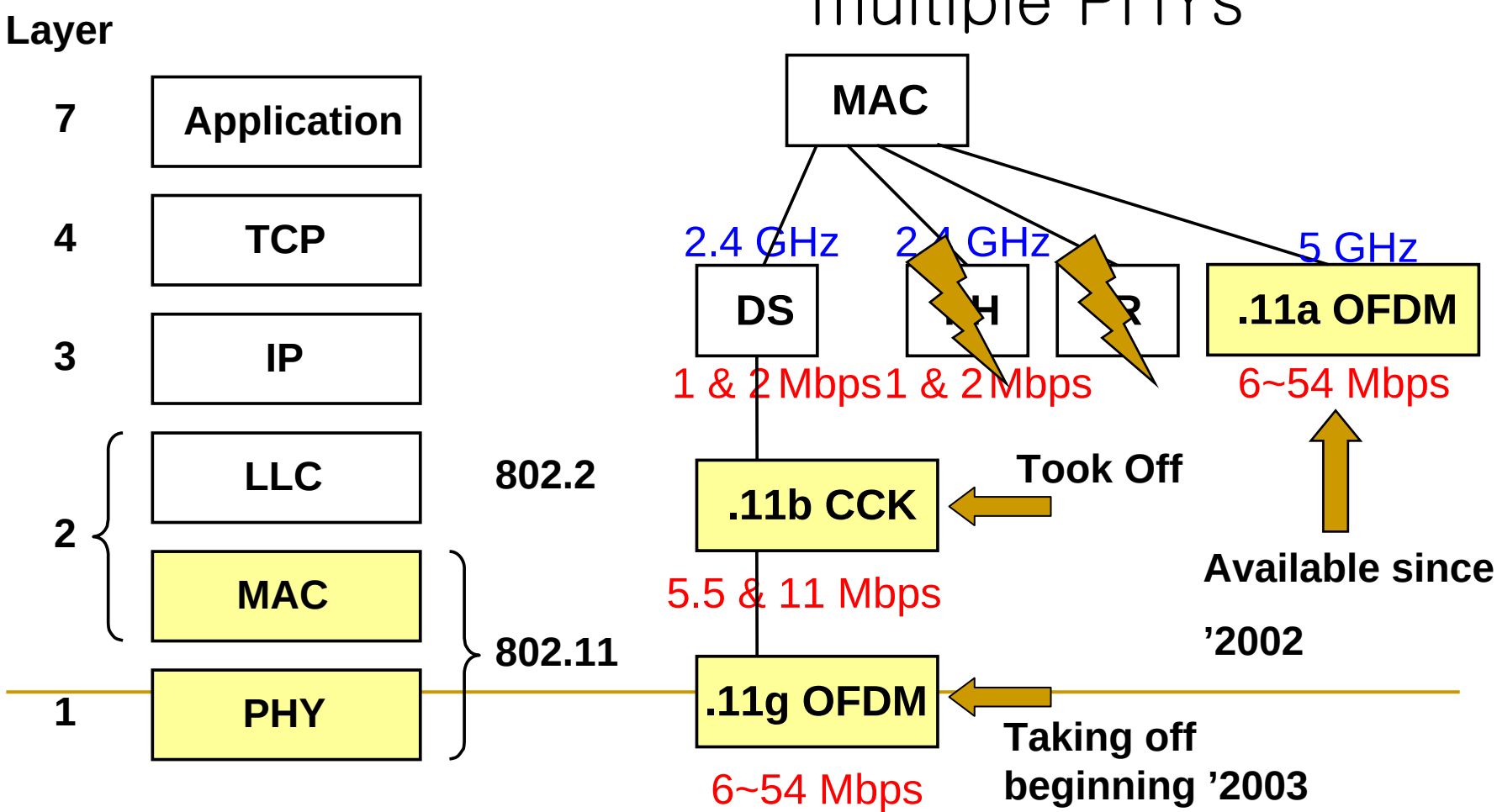
IEEE 802.11 WLAN Key Features

- Popular for enterprise, home, “hot-spot”
- Enables (indoor) wireless and mobile high-speed networking

- “Wireless Ethernet” with comparable speed
- Supports up to 54 Mbps within ~100 m range
- Runs at unlicensed bands at 2.4GHz and 5GHz
- Connectionless MAC and multiple PHYs

IEEE 802.11 Standard

- Layers 1 and 2
- One MAC and multiple PHYs



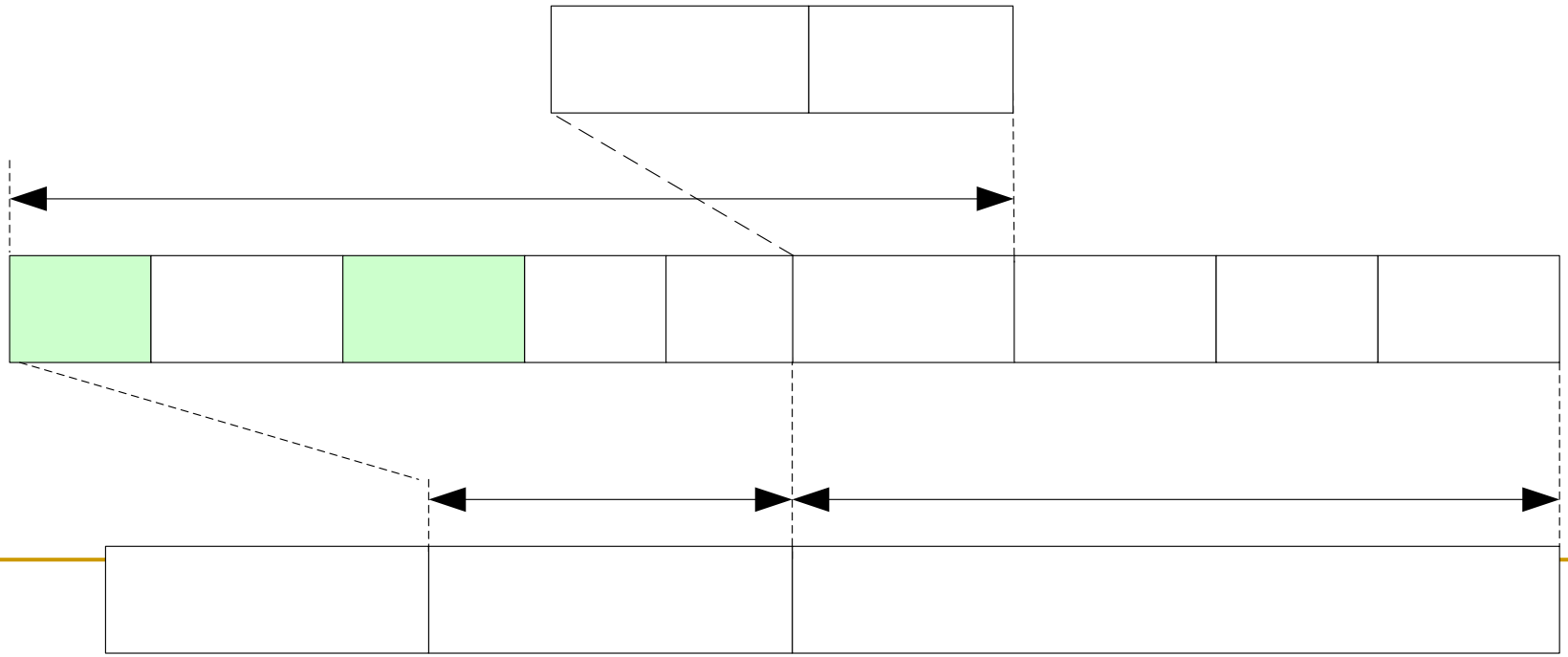
IEEE 802.11a PHY

- Operates in 5GHz bands
- Based on Orthogonal Frequency Division Multiplexing (OFDM)
- 20MHz channel

PHY Mode	Modulation	Conv. Code Rate	Data Rate (Mbps)
1	BPSK	1/2	6
2	BPSK	3/4	9
3	QPSK	1/2	12
4	QPSK	3/4	18
5	16-QAM	1/2	24
6	16-QAM	3/4	36
7	64-QAM	2/3	48
8	64-QAM	3/4	54

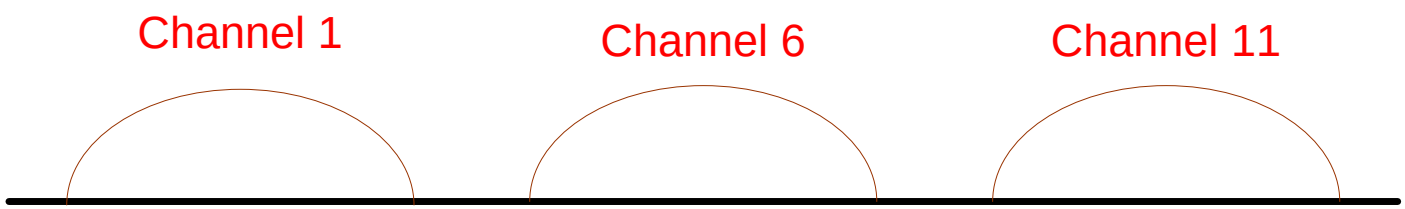
.11a PHY Protocol Data Unit (PPDU)

- RATE specifies the rate used for PSDU (=MPDU)
- LENGTH specifies the frame length



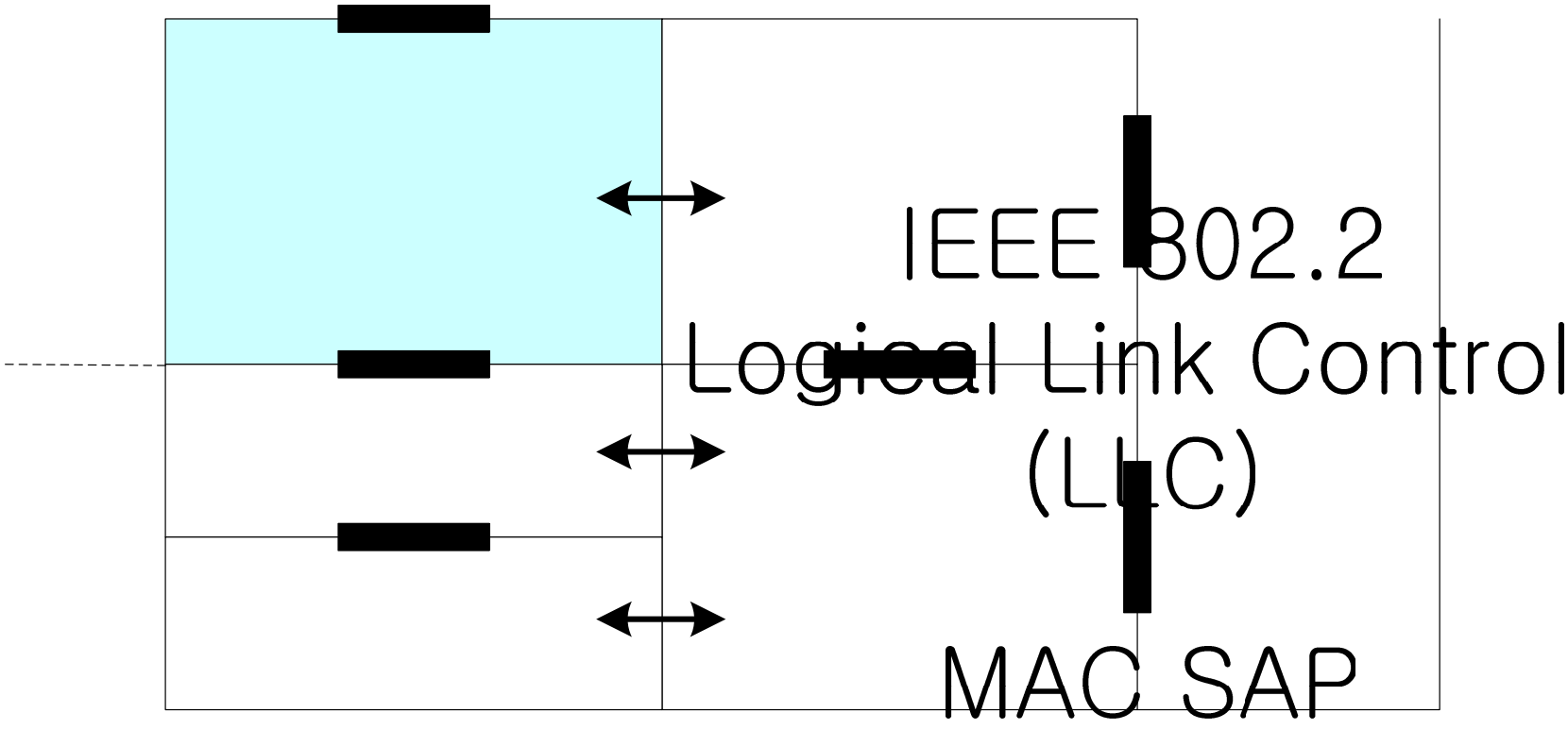
IEEE 802.11b PHY

- Runs in 2.4GHz ISM bands
  - 22MHz channel



- 4 different transmission rates:
  - Complementary Code Keying (CCK) for 5.5 & 11 Mbps
  - Direct-Sequence Spread Spectrum (DSSS) for 1 & 2 Mbps

802.11 Reference Model



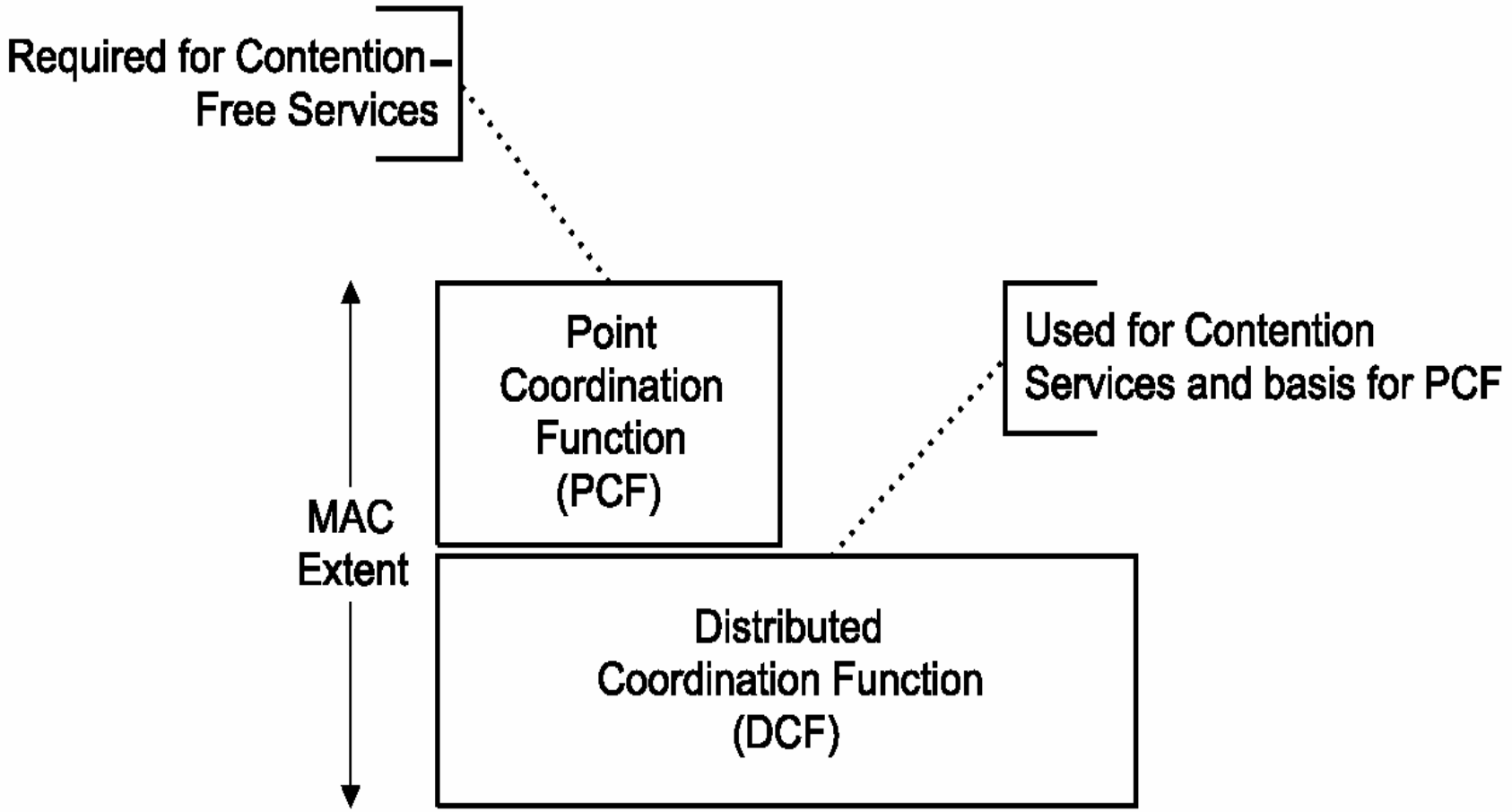
Two Modes

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

Two Coordination Functions

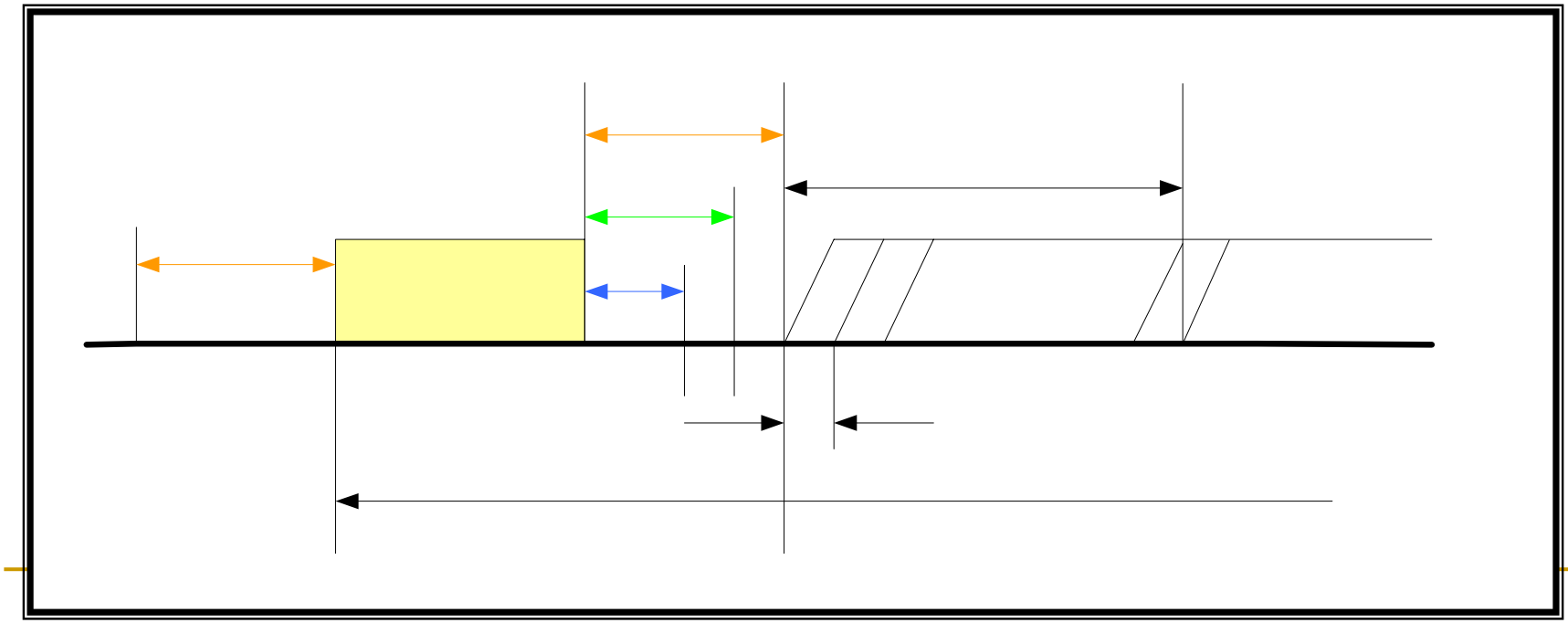
- *Mandatory* Distributed Coordination Function (DCF)
  - For distributed contention-based channel access
  - For both Infrastructure BSS and IBSS
- *Optional* Point Coordination Function (PCF)
  - For centralized contention-free channel access
  - For Infrastructure BSS only

MAC Architecture



Distributed Coordination Function (DCF)

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



Two Special Cases

- Immediate access
  - When no on-going backoff and over DIFS idle time, a frame can be transmitted immediately
- Post backoff
  - A backoff after a successful frame transmission even when no frame to transmit next
- Main differences in terms of statistical performance from p-persistent CSMA
  - Both differences no exist when the transmitters have always a frame to transmit

Interframe Spaces (IFSs) (1)

- To give priority to different frame transmissions
- Short IFS (SIFS)
  - Between a frame and an immediate response
    - ACK, CTS, ...
- PCF IFS (PIFS)
  - Before sending beacon under PCF; when no response after a polling frame
- DCF IFS (DIFS)
  - Before a backoff countdown

Interframe Spaces (IFSs) (2)

- Extended IFS (EIFS)
  - SIFS + ACK_Transmission_Time + DIFS
  - Used instead of DIFS after an erroneous frame reception
    - To protect the subsequent ACK transmission
- IFS values depends on the underlying PHY

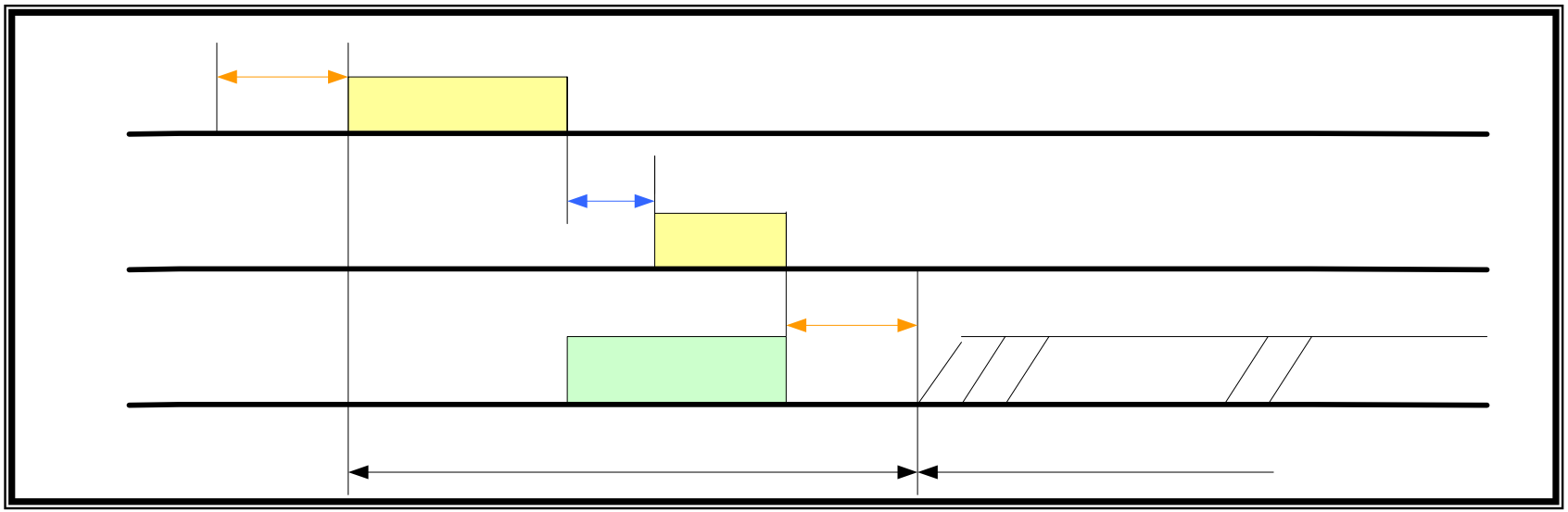
	SIFS	PIFS= SIFS+Slot	DIFS= SIFS+2*Slot
11a	16 usec	25 usec	34 usec
11b	10 usec	30 usec	50 usec

Carrier-Sense Mechanisms

- Physical carrier-sense
  - Provided by PHY, and depends on PHY
  - Clear Channel Assessment (CCA) by PHY
- Virtual carrier-sense
  - Provided by MAC via Network Allocation Vector (NAV) counter
  - Each frame carries Duration value in the header
  - Any correctly received frame updates NAV if the new NAV is larger
  - Assumes busy channel if non-zero NAV irrespective of CCA!

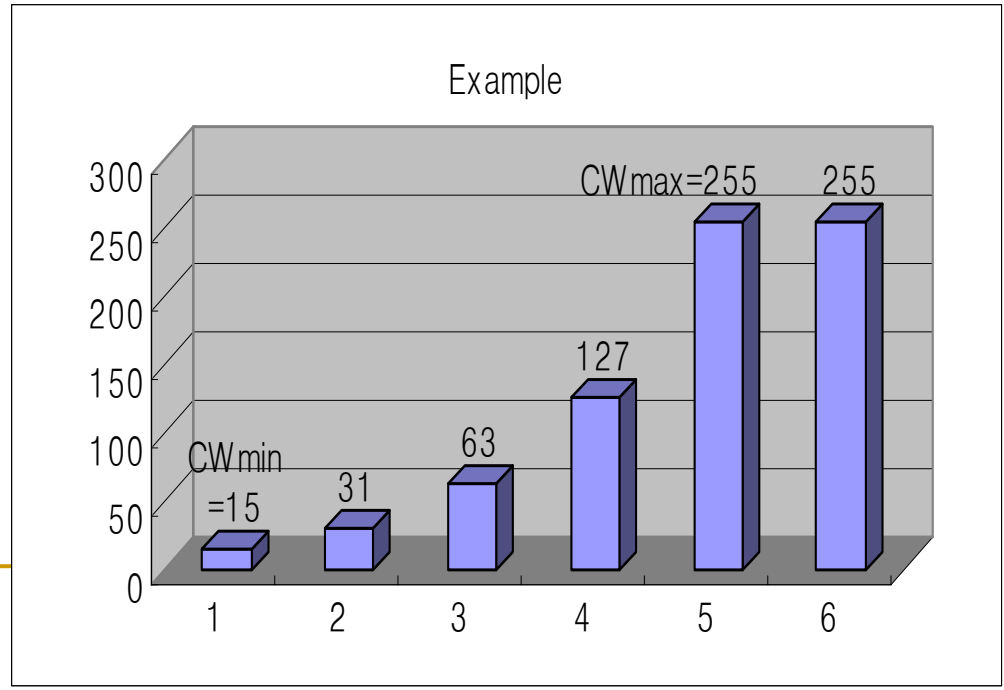
Stop-and-Wait ARQ

- Receiver of a directed frame returns an ACK
- If ACK not received, sender retransmits after another backoff

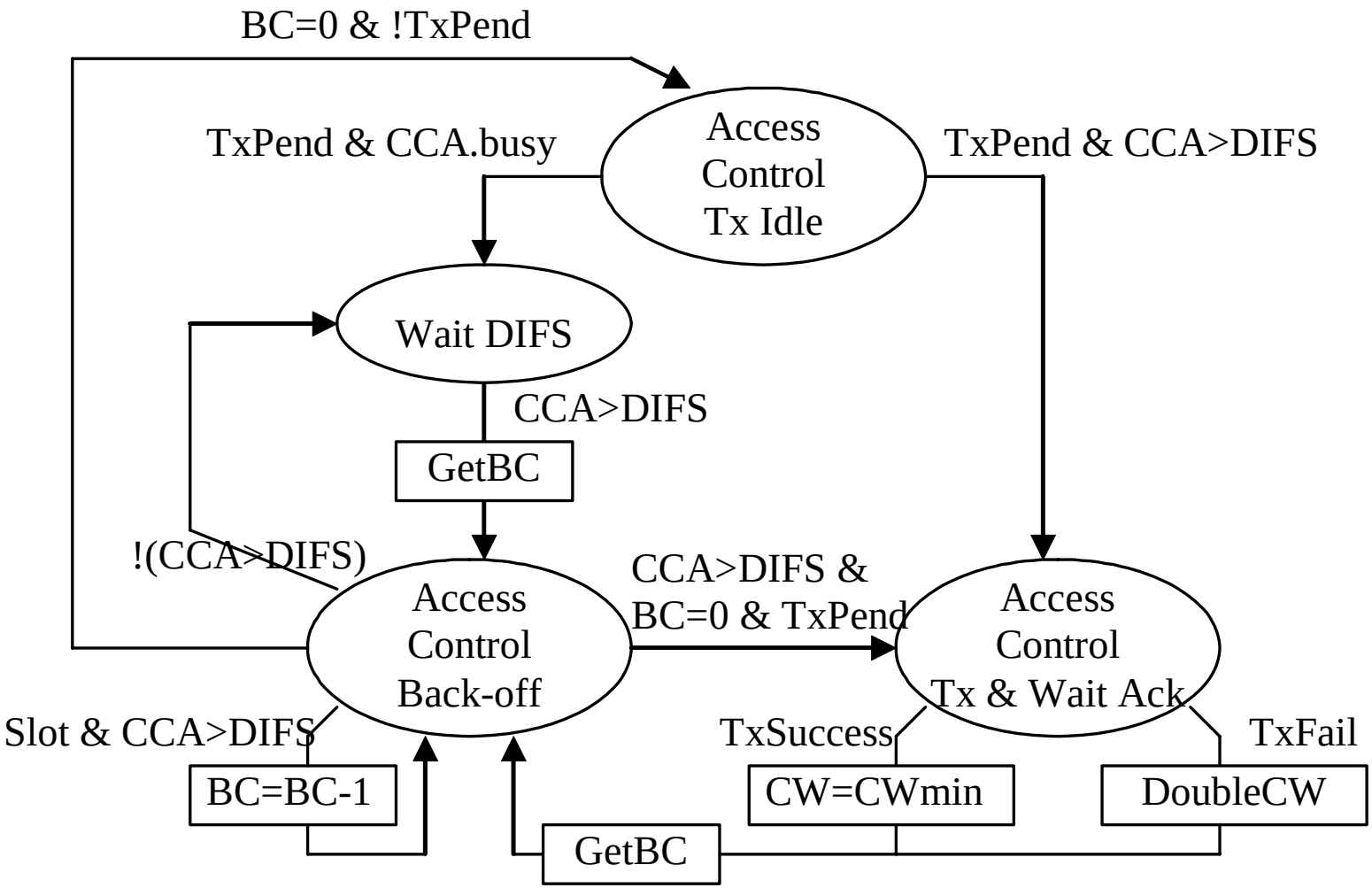


Exponential Backoff

- Backoff Counter is randomly selected from [0,CW], where CW is contention window
- For each unsuccessful frame transmission, CW doubles (from CWmin to CWmax)
- CW ← 2 (CW+1)−1
- Reduces the collision probability

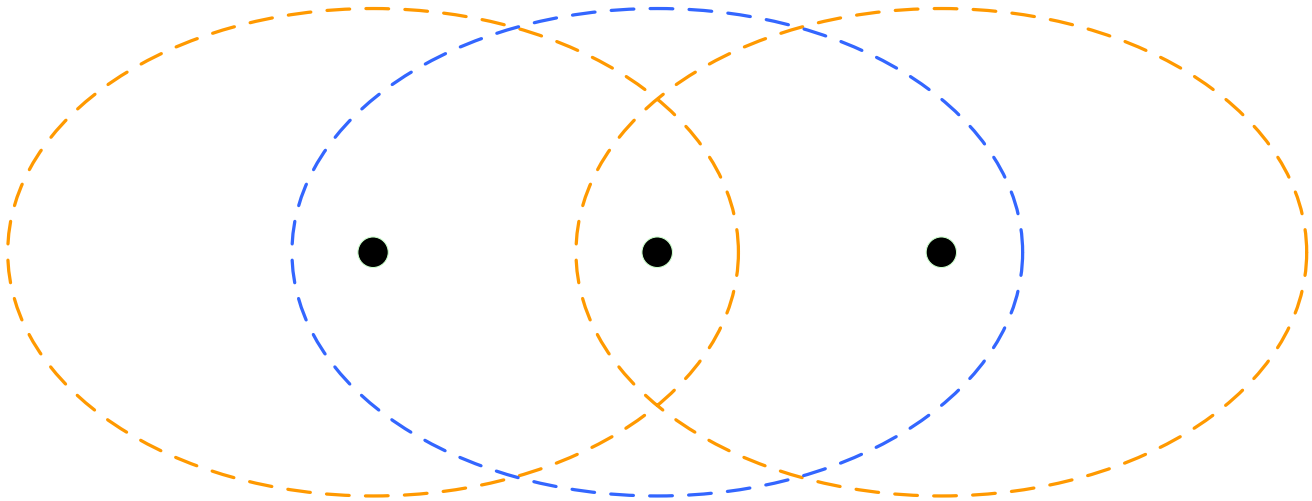


DCF State Diagram



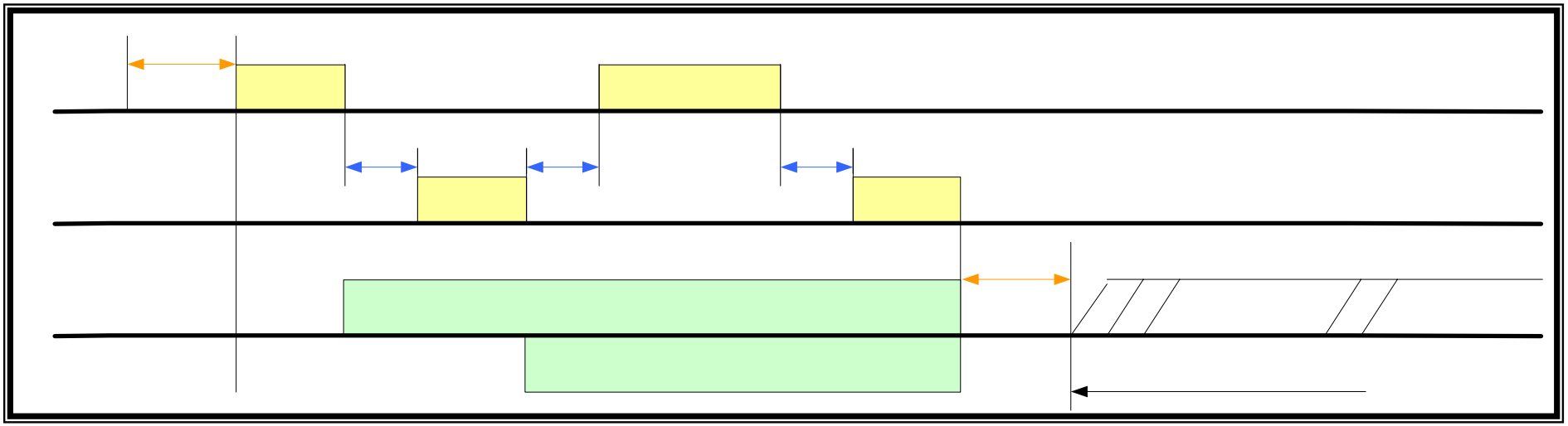
Hidden Terminal

- STA 1 and STA 2 can see STA 3, but they do not see each other
- May result in more collisions due to the failure of carrier-sensing!



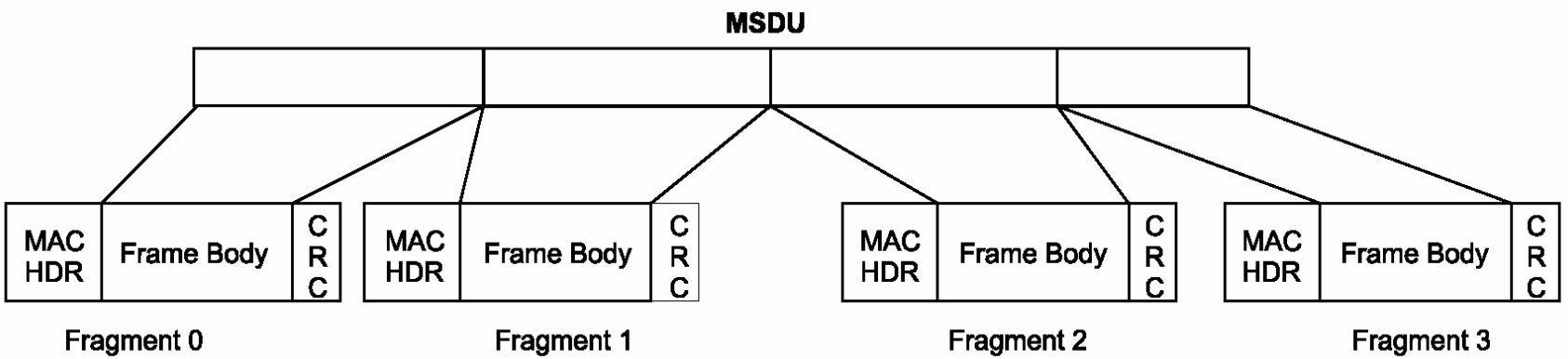
RTS/CTS Exchange

- A way to handle hidden terminals!
  - Request-To-Send / Clear-To-Send (RTS/CTS) to reserve medium
  - Works with virtual carrier-sense



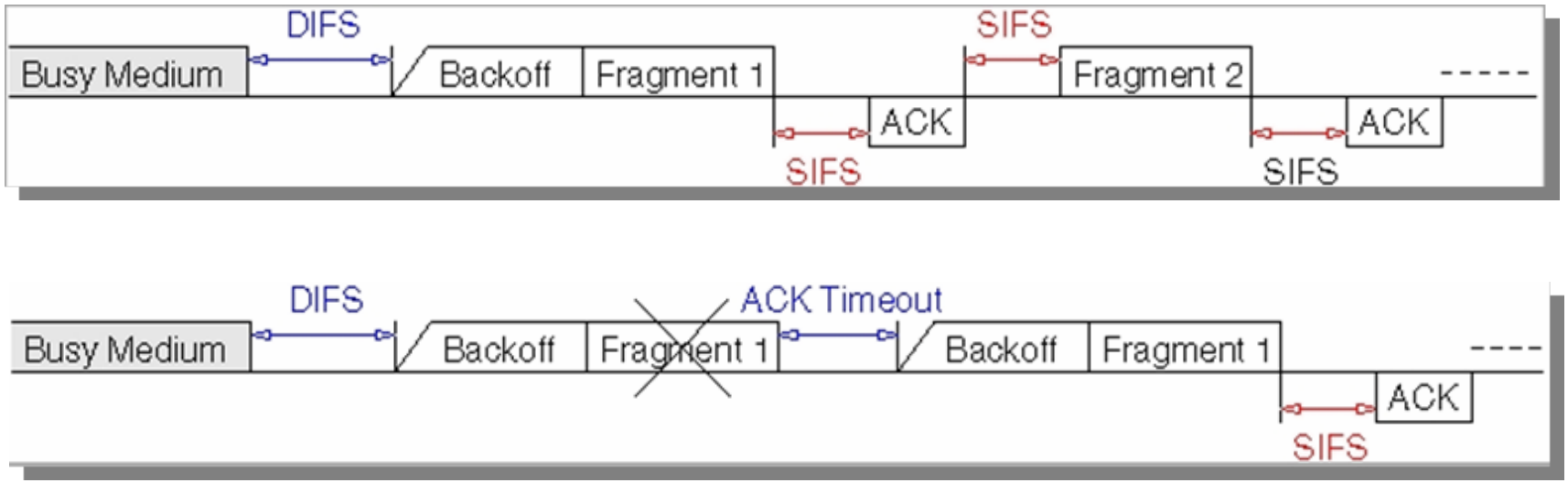
Fragmentation

- One MSDU can be fragmented into multiple MPDUs
  - All the fragments have virtually the same MAC header (except for the fragment number)
  - Theoretically up to 10 fragments from one MSDU



Fragmentation Burst

- Fragments are transmitted with SIFS intervals
- Backoff if a fragment transmission fails

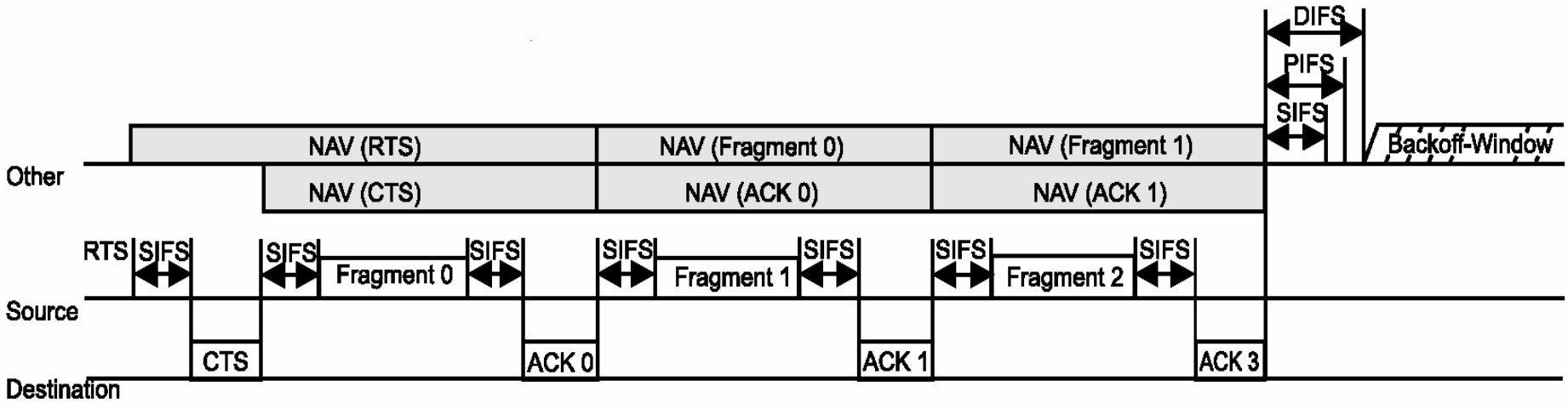


RTS & Fragment Thresholds

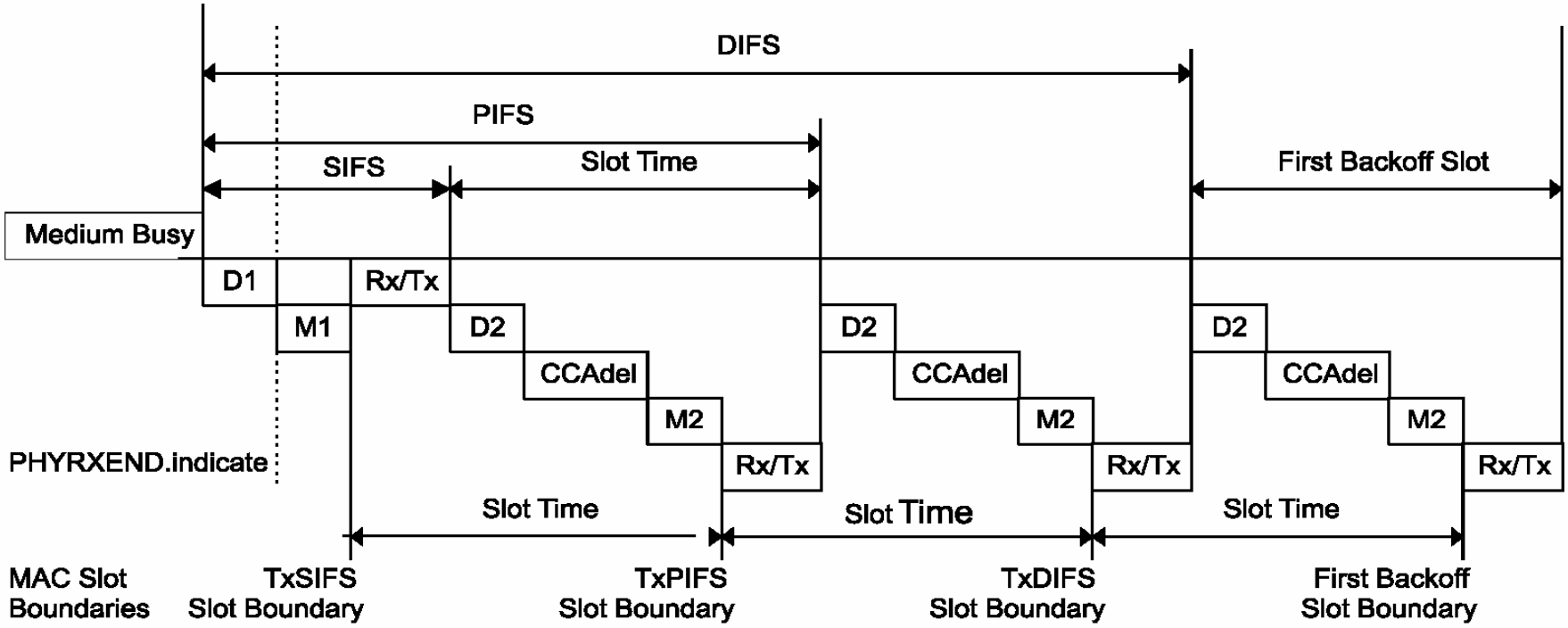
- RTS Threshold
  - Use RTS/CTS if MPDU_size >= threshold
  - Depending on the size of MPUD relative to RTS threshold, the max retransmission limit is determined differently!
    - LongRetryLimit (short) = 4 (7) by default
- Fragment Threshold
  - Use fragmentation if MPDU_size > threshold
- Default values of both are large enough such that none of them is used!
  - The max MSDU size = 2304 bytes in 802.11

RTS & Fragmentation in Combi

- Each frame protects up to the end of the subsequent frame exchange!



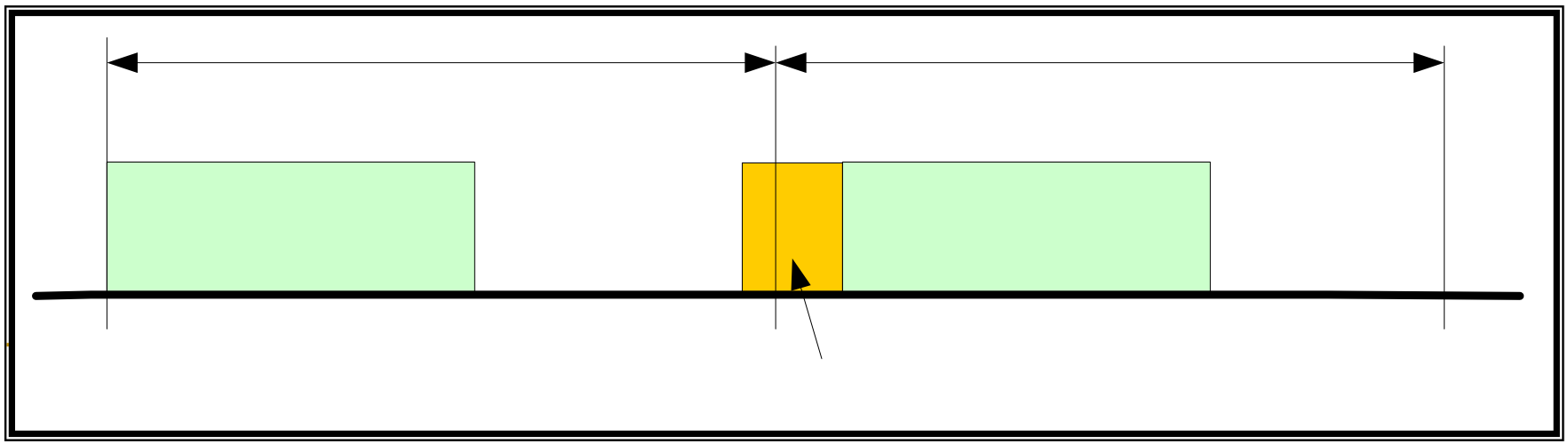
DCF Timing Relationship



D1 = aRxRFDelay + aRxPLCPDelay (referenced from the end of the last symbol of a frame on the medium)
D2 = D1 + Air Propagation Time
Rx/Tx = aRXTXTurnaroundTime (begins with a PHYTXSTART.request)
M1 = M2 = aMACPrcDelay
CCAdel = aCCA Time - D1

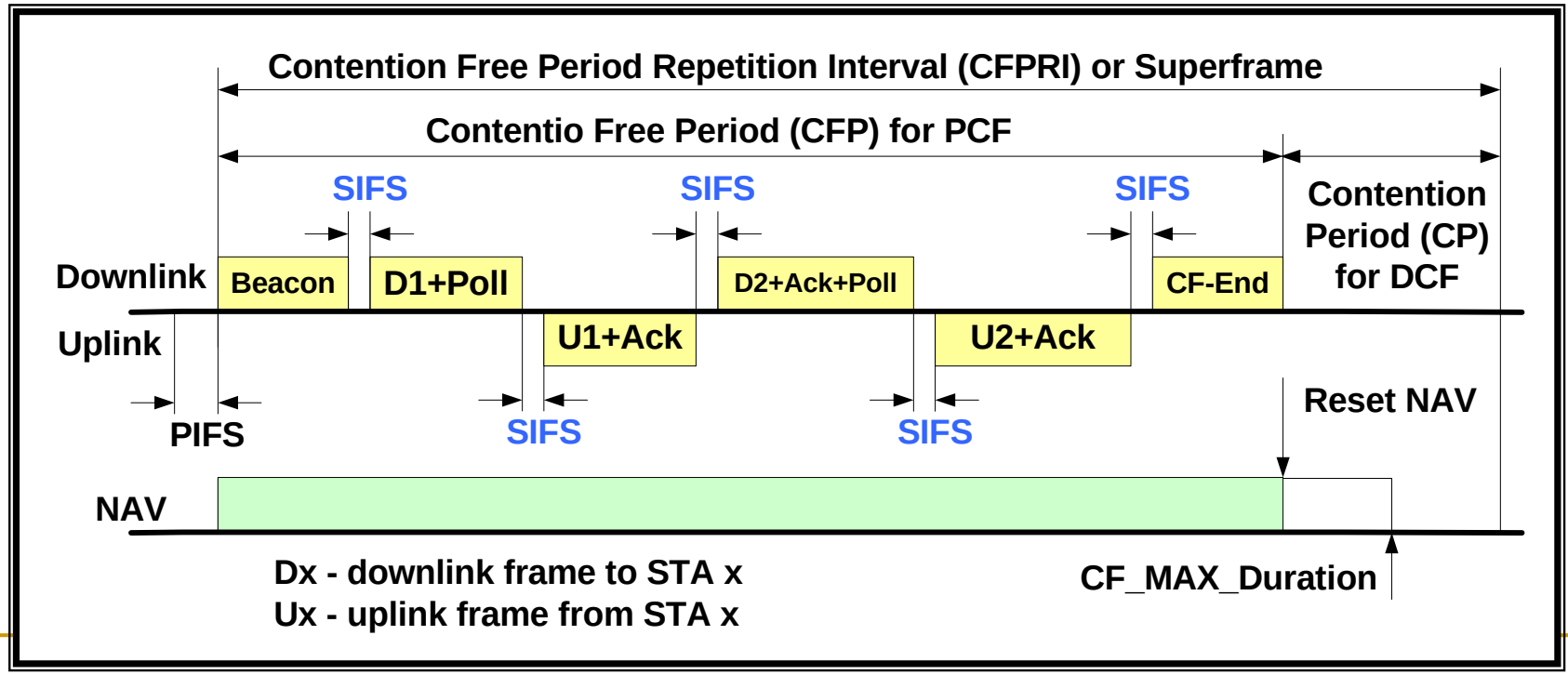
Point Coordination Function (PCF)

- Poll-and-response MAC for nearly Isochronous service
- In infrastructure BSS only – Point Coordinator (PC) resides in AP
- Alternating Contention-Free Period (CFP) and Contention Period (CP)

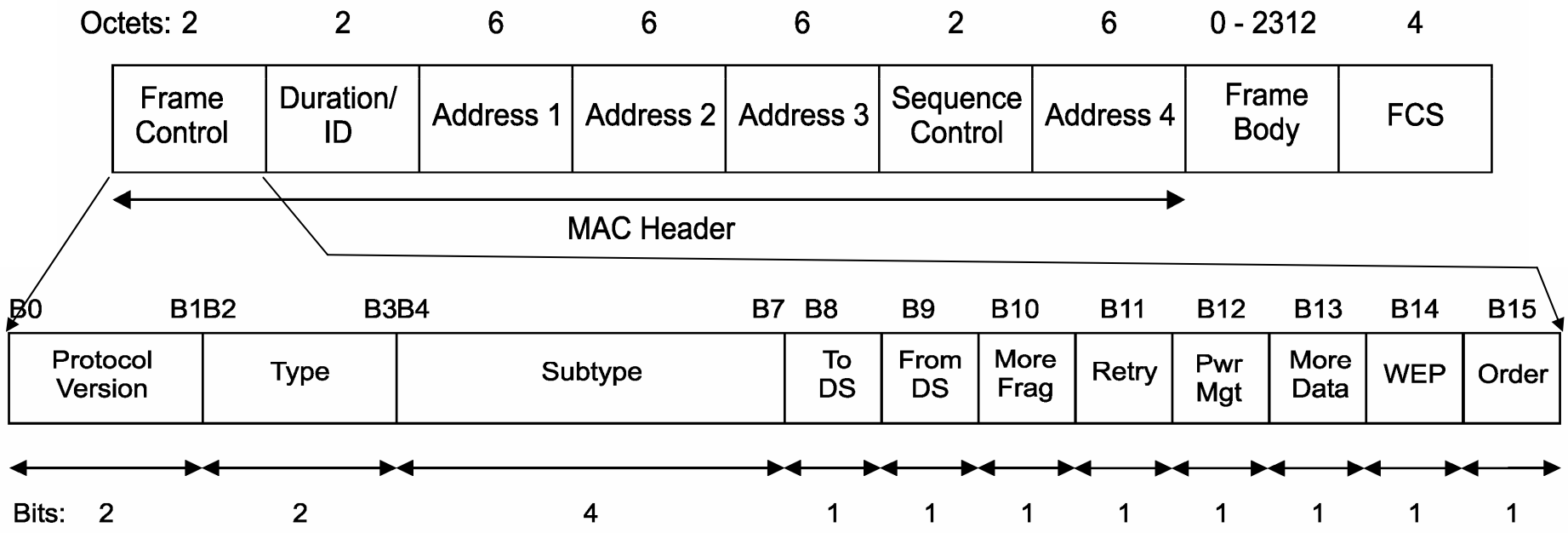


Contention Free Operation

- Two consecutive frames are separated by SIFS
- CFP lengths depend on traffic amount
  - Maximum length announced by AP; used for NAV set



MAC Frame Format



- Address 4 exists only for Wireless Distribution System (WDS)
- Usually 28-octet overhead (24 for header + 4 for FCS)

Address Field Contents

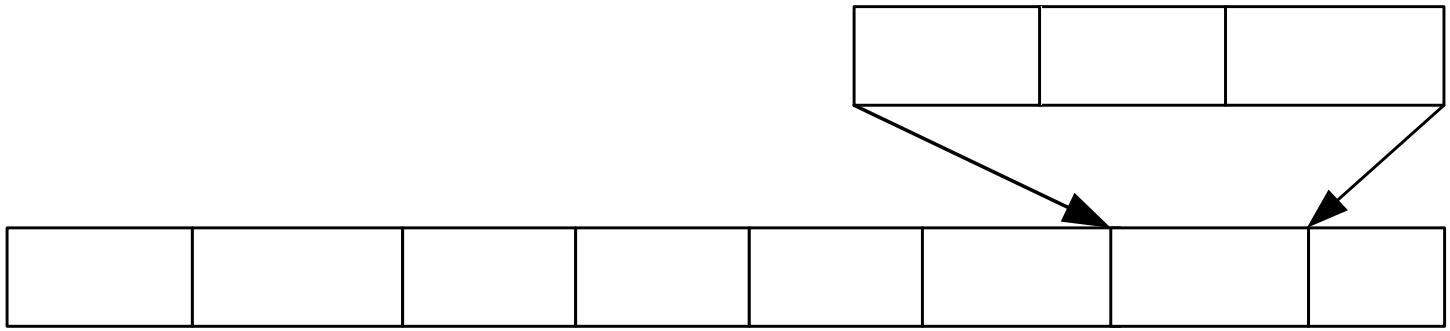
To DS	From DS	Addr 1	Addr 2	Addr 3	Addr 4	Dir.
0	0	DA	SA	BSSID	N/A	DiL
0	1	DA	BSSID	SA	N/A	DL
1	0	BSSID	SA	DA	N/A	UL
1	1	RA	TA	DA	SA	WDS

- Addr 1 specifies the receiving station
- Addr 2 specifies the transmitting station
  - Used for ACK transmission

Frame Types

- Data frames
  - Data, CF-Poll, CF-ACK, ...
  - Follows the general format
- Management frames
  - Probe Req/Resp, Authentication Req/Resp, Association Req/Resp, ...
  - Follows the general format (w/o Address 4)
- Control frames
  - ACK, RTS, CTS, PS-Poll, ...
  - Frame-dependent formats

802.11 Frame for IP Datagram



802.2 LLC

Theoretical Throughput Analysis

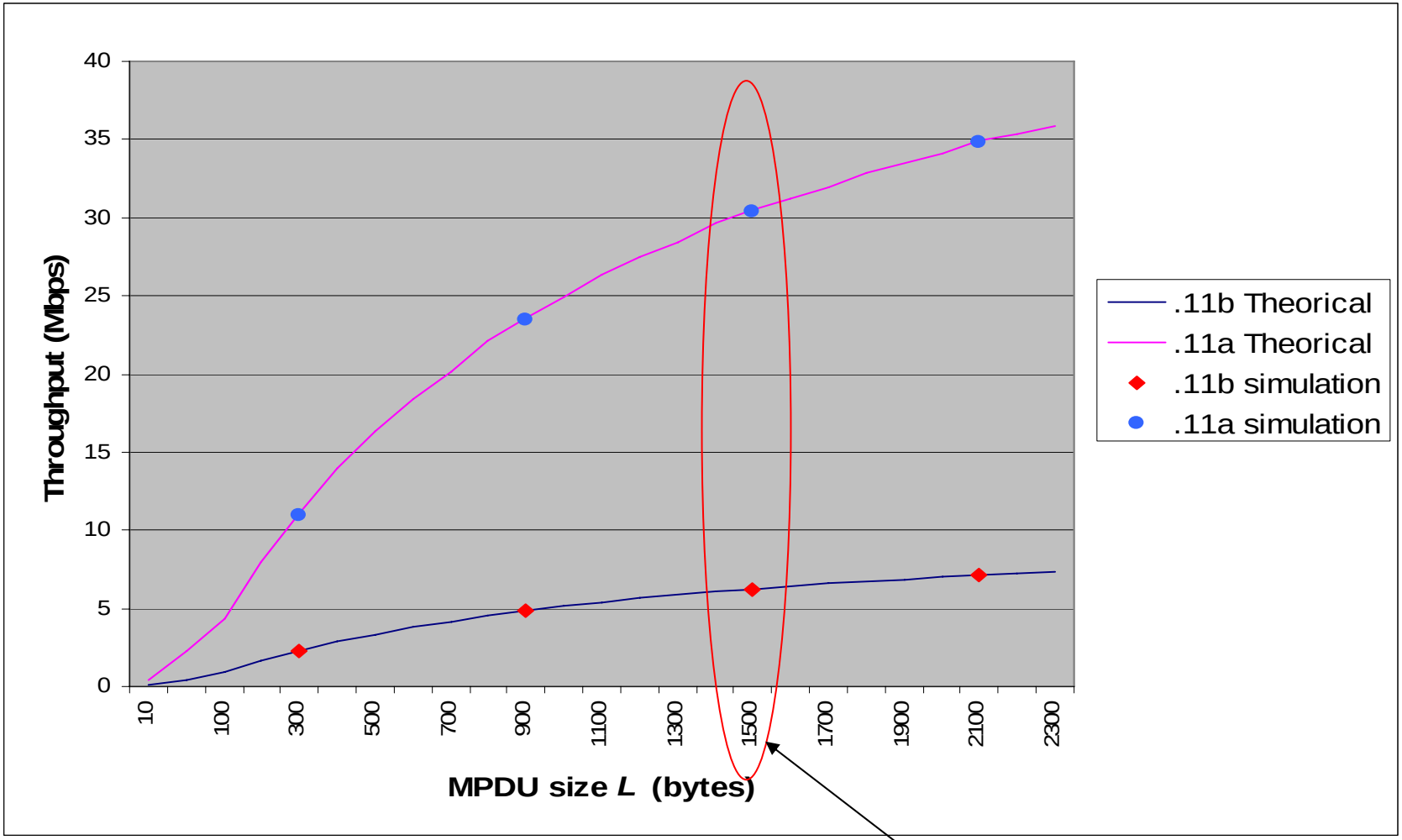
- Assumptions:
  - One sender and one receiver
  - Infinite amount of traffic from sender
  - No channel error
  - Fixed frame size
- Maximum theoretical throughput measured at MAC SAP

Theoretical Throughput Analysis

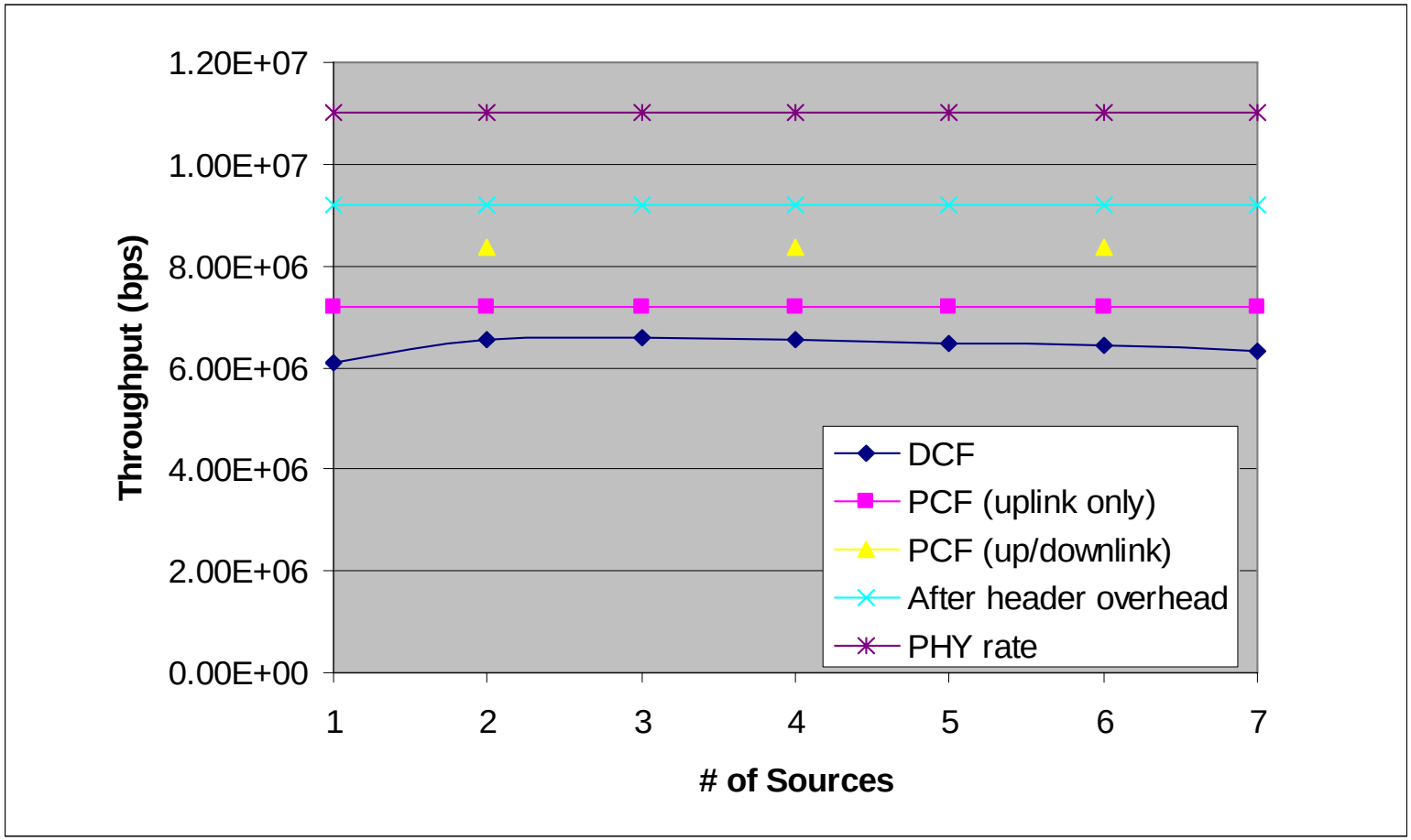
- Transmission cycle
  - DIFS
  - Backoff
  - Data transmission
  - SIFS
  - ACK
- Throughput

  = Data Size / (DIFS+Backoff+Data_Tx_Time+SIFS+ACK)

Max. Theoretical Throughput



DCF vs. PCF – Throughput Perspective



Source: S. Choi, "PCF vs DCF: trends and limitations," IEEE 802.11-01/054, January 2001.