CS343: Data Communication

Wireless LAN

by
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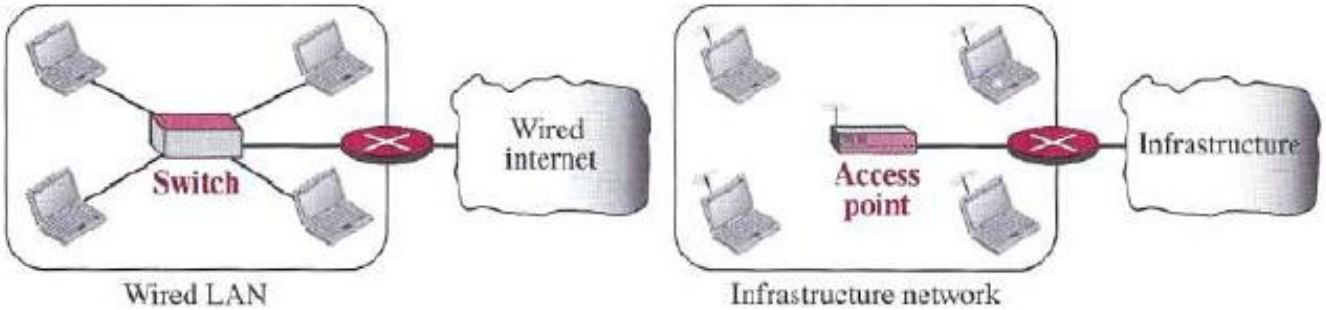
Wireless LAN



Control module (CM)
User module (UM)

- Wireless LAN satisfies requirements for
  - mobility,
  - relocation,
  - ad hoc networking,
  - coverage of locations difficult to wire.

- Influential Characteristics in WLAN
  - Attenuation
  - Error
  - Interference
  - Multipath Propagation

- Dr O'Sullivan and his colleagues are credited with inventing Wi-Fi in 1992-96

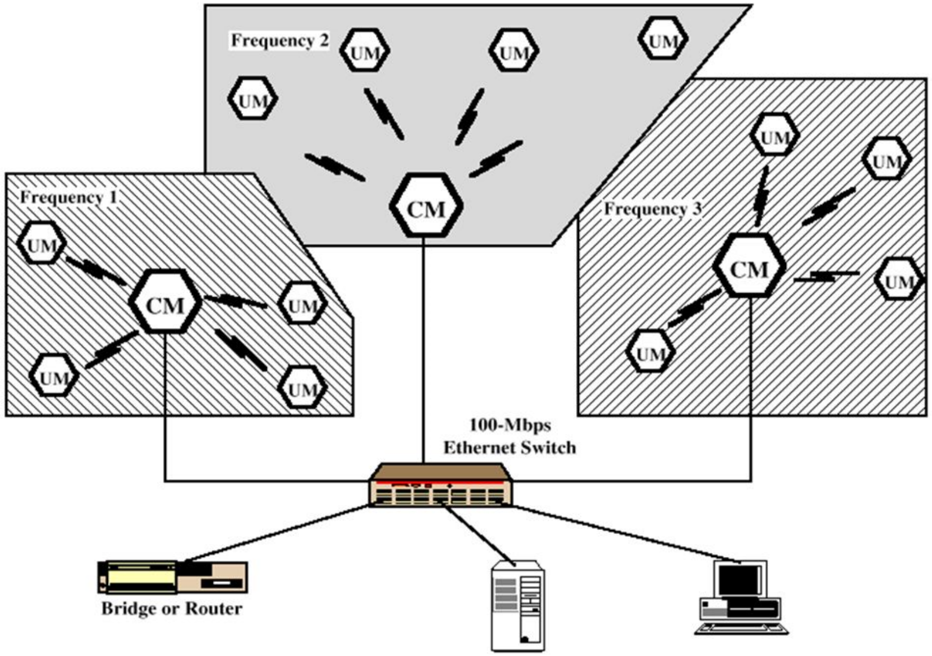
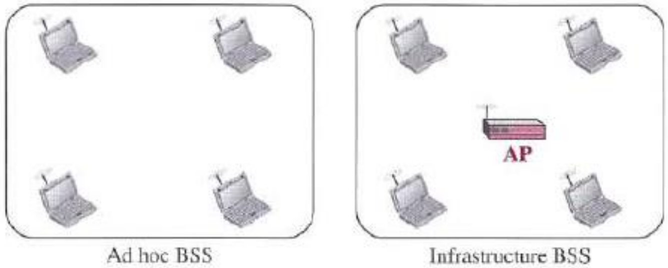


Figure 13.2 Example Multiple-Cell Wireless LAN Configuration

WLAN Configuration

- Configuration:
  - Ad hoc mode
  - Infrastructure mode



- Basic Architecture:
  - BSS (Basic Service Set)
  - ESS (Extended Service Set)

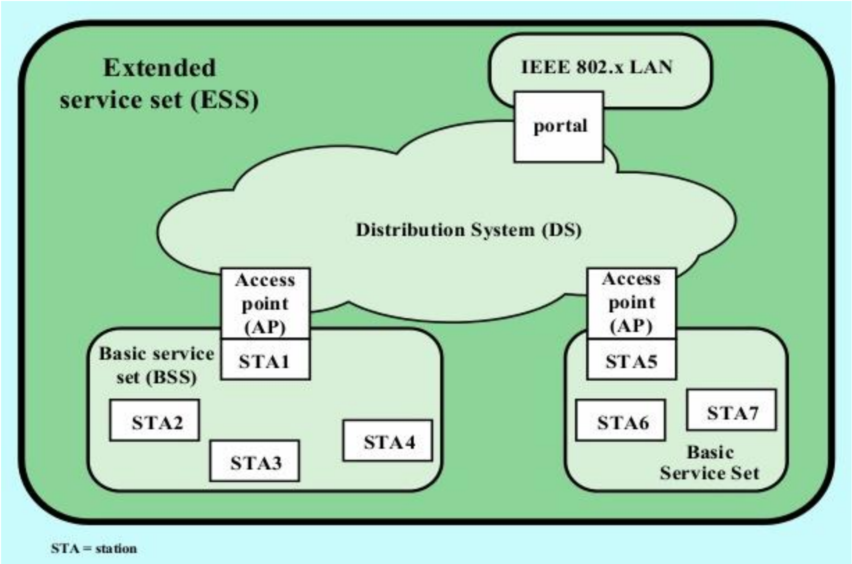


Figure 13.4 IEEE 802.11 Architecture

- Important requirements for WLANs:
  - Throughput
  - Number of nodes
  - Connection to backbone LAN
  - Service area
  - Battery power consumption
  - Robustness
  - Security
  - Collocated network operation
  - License-free operation
  - Handoff/roaming
  - Dynamic configuration

The distribution system (DS) is a wired backbone LAN but can be any communications network.

The portal logic is implemented in a device (e.g., bridge or router) that is part of the wired LAN and is attached to the DS.

IEEE 802.11 Services

- Institute of Electrical and Electronics Engineers (IEEE) defines standard for Wireless LANs (802.11)
- IEEE 802.11 defines a number of services that need to be provided by the WLAN

- Three of the services are used to control IEEE 802.11 LAN access and confidentiality.
- Six of the services are used to support delivery of MAC service data units (MSDUs) between stations.

- The MSDU is a block of data passed down from the MAC user to the MAC layer; typically this is a LLC PDU.

Service	Provider	Used to Support
Association	Distribution system	MSDU delivery
Disassociation	Distribution system	MSDU delivery
Re-association	Distribution system	MSDU delivery
Authentication	Station	LAN access and security
De-authentication	Station	LAN access and security
Integration	Distribution system	MSDU delivery
Distribution	Distribution system	MSDU delivery
MSDU delivery	Station	MSDU delivery
Privacy	Station	LAN access and security

IEEE 802.11 Medium Access Control

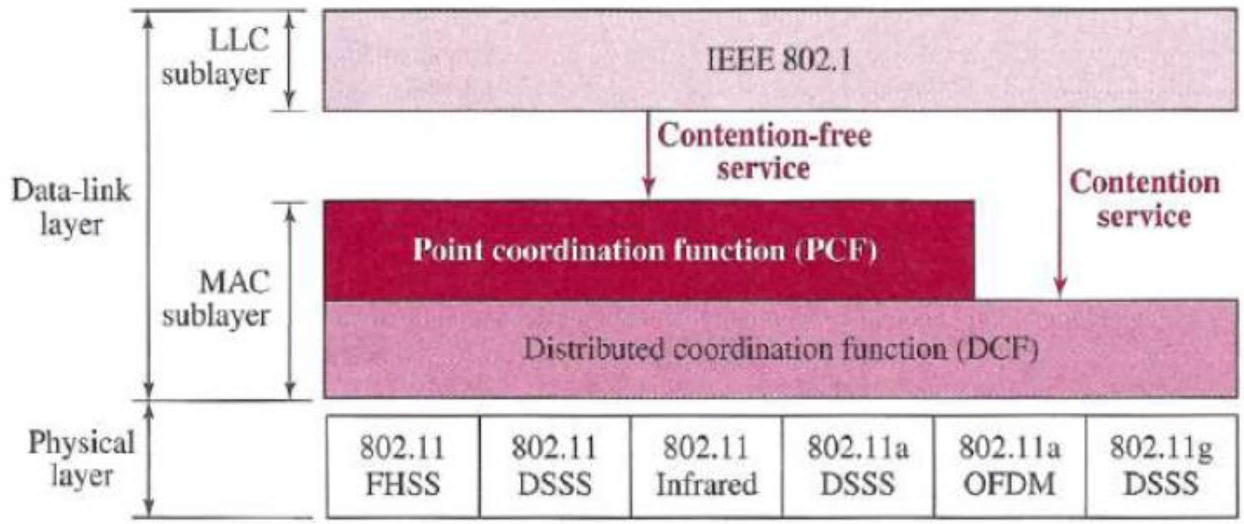
- The IEEE 802.11 MAC layer covers three functional areas
  - reliable data delivery,
  - access control,
  - security.

- Reliable Data Delivery:
  - This situation can be dealt with by reliability mechanisms at a higher layer, such as TCP.
  - However, wireless medium is subject to considerable unreliability.
  - It is therefore more efficient to deal with errors at the MAC level
  - Solution: ACK and re-transmission after timeout

- Security:
  - User authentication
  - Data Privacy
  - Solution: Wired Equivalent Privacy (WEP), Wi-Fi Protected Access (WPA)

Cont…

- Access Control:



- The Distributed Coordination Function (DCF) makes use of a simple CSMA/CA (carrier sense multiple access with collision avoidance) algo

CSMA/CA (Collision Avoidance)

- CSMA/CD is not useful in wireless networks
- This is because wireless transceivers can't send and receive on the same channel at the same time .
- So, CSMA/CA (collision avoidance) was invented

- Why does it so??
  - In wired networks (like Ethernet) the voltage is around 1 to 2.5v; sending and receiving are roughly same voltage
  - Let, sending a 2.5v signal, and someone else collides with a 2.5v signal;
  - So, receive signal would be around 5v.

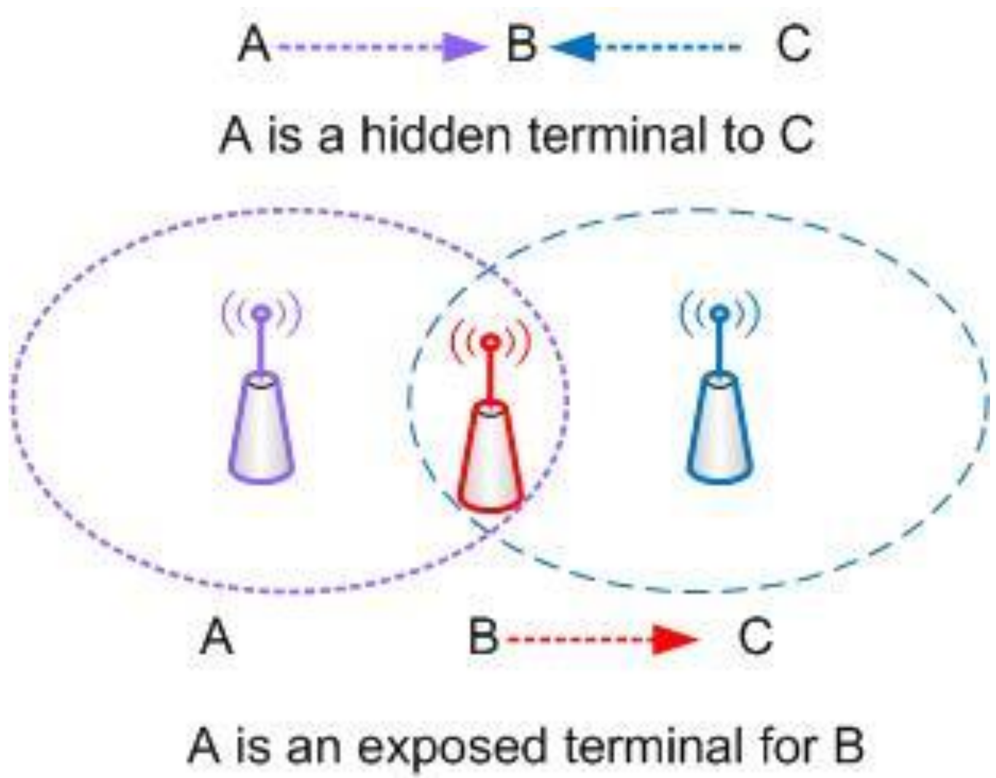
  - In wireless, send power (generally around 100mw) and receive sensitivity (commonly around 0.01 to 0.0001mw)
  - The sending would cover up any possible chance of receiving a foreign signal, and thus no chance of "Collision Detection“

Cont…

- Basic features in DCF:
  - Channel sensing
  - Retransmission
  - Backoff

- Important modifications / inclusions in DCF:
  - Inter-Frame Space (IFS): it is used instead of persistent methods
  - Contention window (CW) and Binary exponential backoff (BEB) : time is treated in slots; randomness is introduced
  - Acknowledgement (ACK) / Timeout : no collision detection; achieve reliability
  - Basic / RTS-CTS mode of transmission: to avoid hidden terminal problem
  - Use of Network Allocation Vector (NAV): to defer transmission instead of one slot or backoff slot; It is also called Virtual Carrier Sense function

HT/ET Problem



Inter-Frame Space

- Slot time: basic unit of MAC algorithm

  = Time required for station to sense end of frame, start transmitting, and beginning of frame to propagate to others

- SIFS (Short Inter-Frame Space)

  = duration of time allowed for a wireless interface to process the received RF signal and its associated frame, and to generate a response frame

  = By that time the transmitting station will be able to switch back to receive mode and be capable of decoding the incoming packet

- DIFS (DCF Inter-Frame Space)

  = SIFS + 2 *Slot time

- PIFS (PCF Inter-Frame Space)

  = SIFS + Slot time

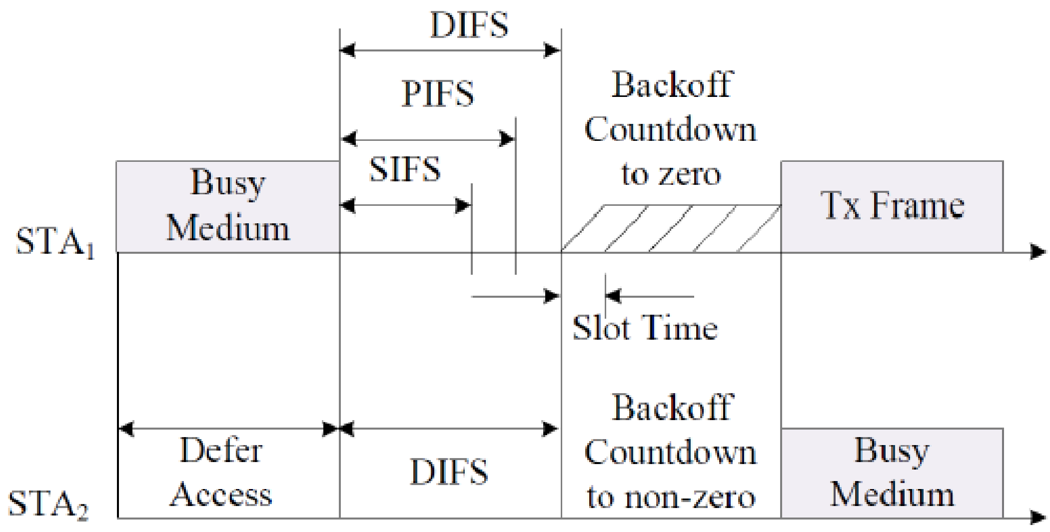
- AIFS (Arbitration Inter-Frame Space)

  = AIFSN[AC] * ST + SIFS

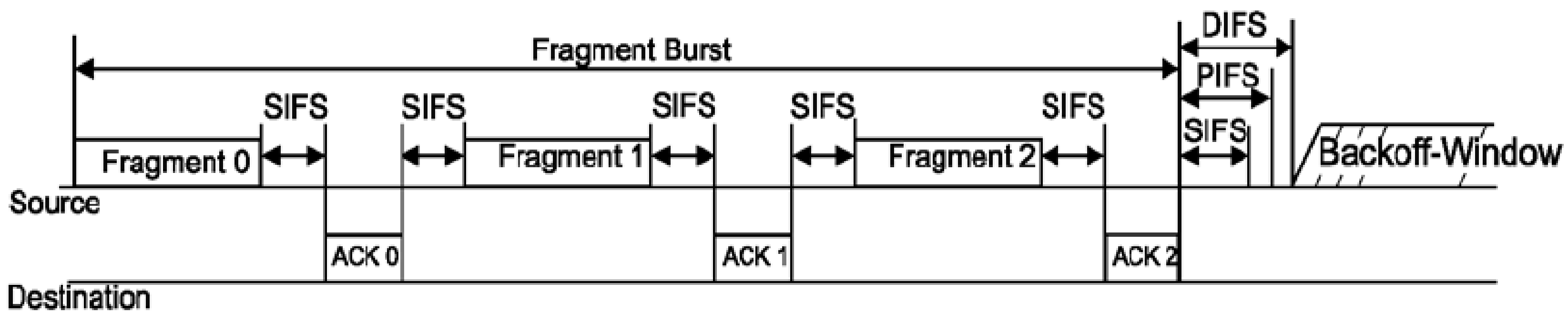
  AC={Background, Best Effort, Video, Voice)

Standard	Slot time (µs)	DIFS (µs)
IEEE 802.11-1997 (FHSS)	50	128
IEEE 802.11-1997 (DSSS)	20	50
IEEE 802.11b-1999 (2.4 GHz)	20	50
IEEE 802.11a (5 GHz)	9	34
IEEE 802.11g (2.4 // 5 GHz)	9 // 20	28 // 50
IEEE 802.11n-2007 (2.4 GHz)	9 or 20	28 or 50
IEEE 802.11n-2007 (5 GHz)	9	34
IEEE 802.11ac - 2012 (5 GHz)	9	34

DCF (with basic access mode)



Timing diagram of basic steps in DCF



Timing diagram for a fragmented frame in DCF

DCF Flowchart

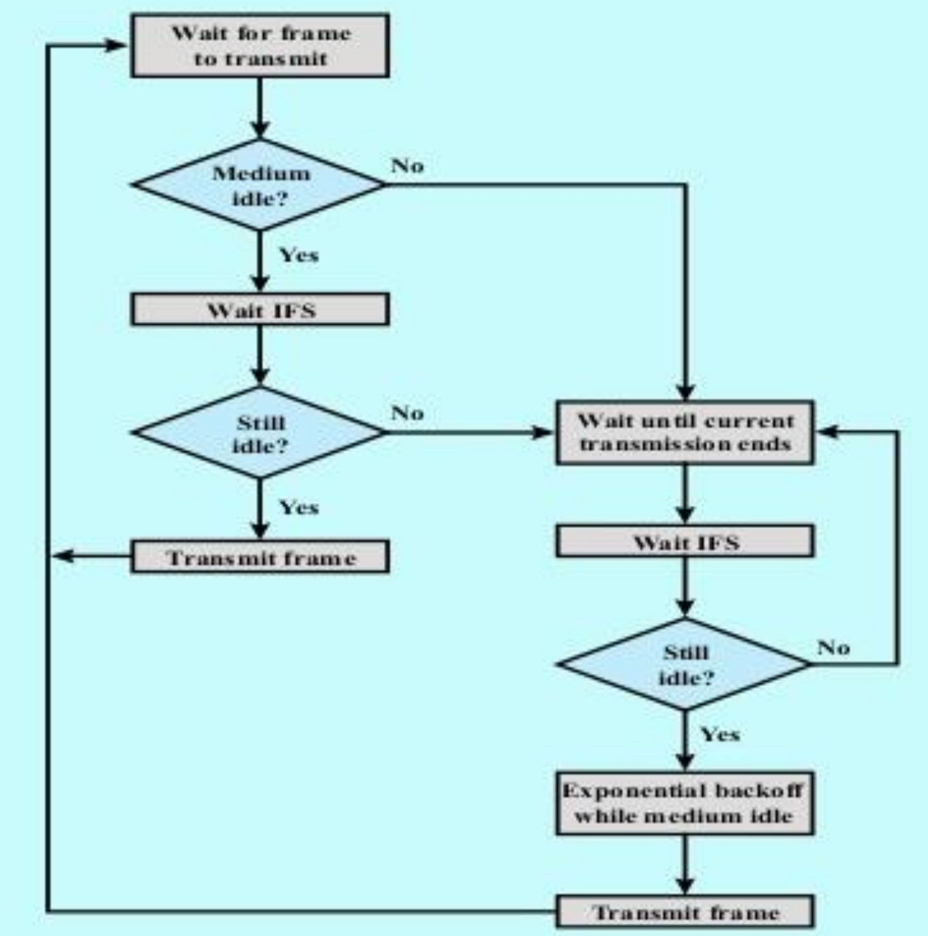
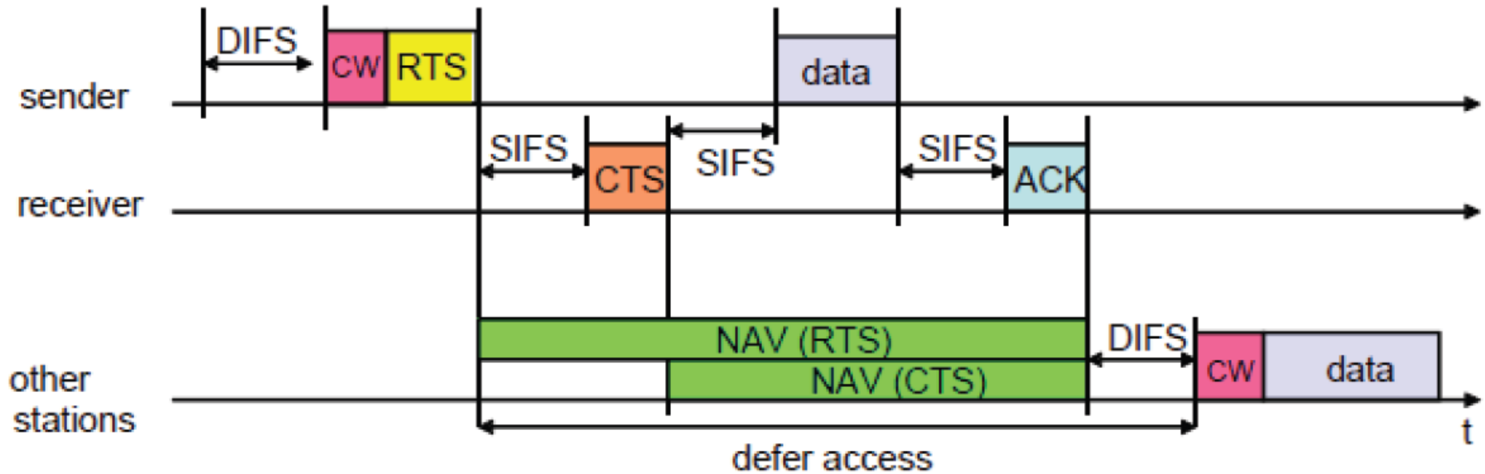
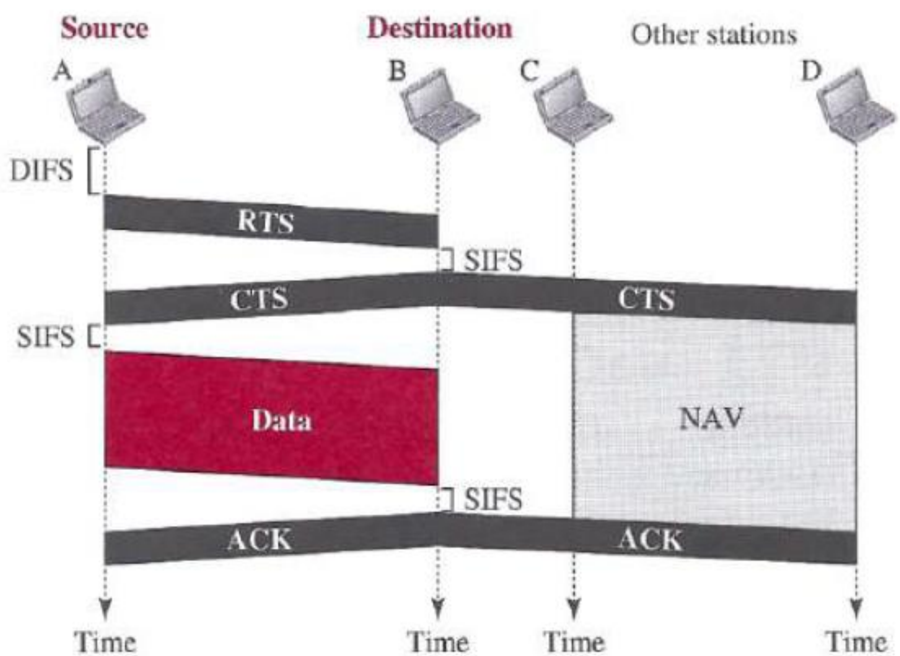


Figure 13.6 IEEE 802.11 Medium Access Control Logic

DCF (with RTS/CTS mode)

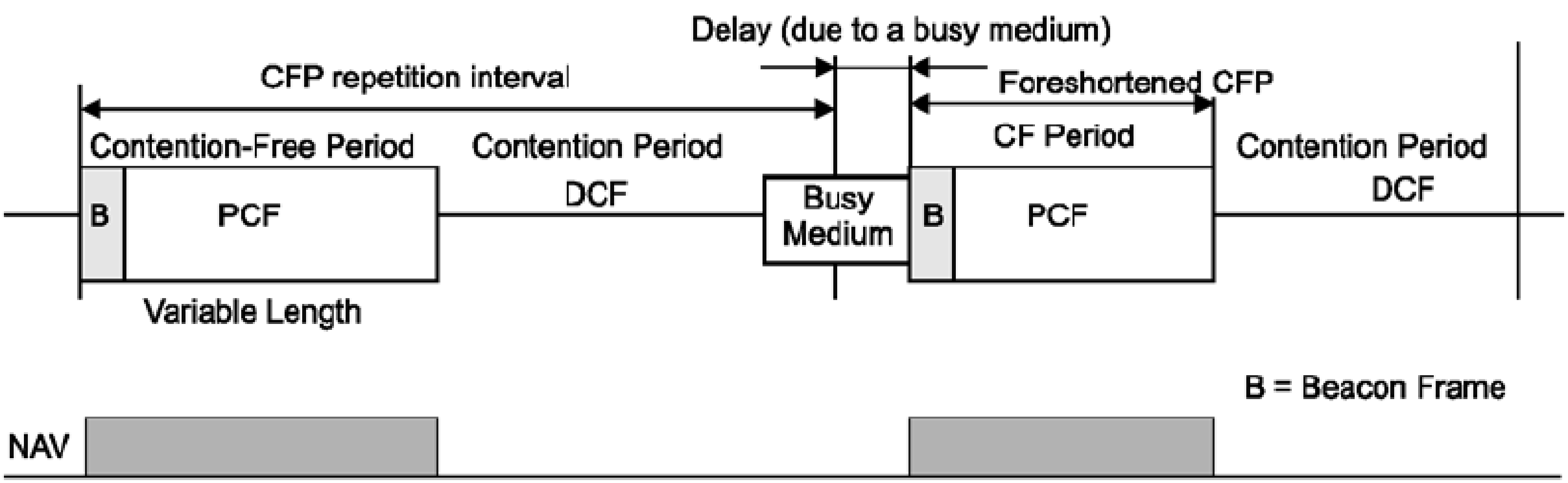




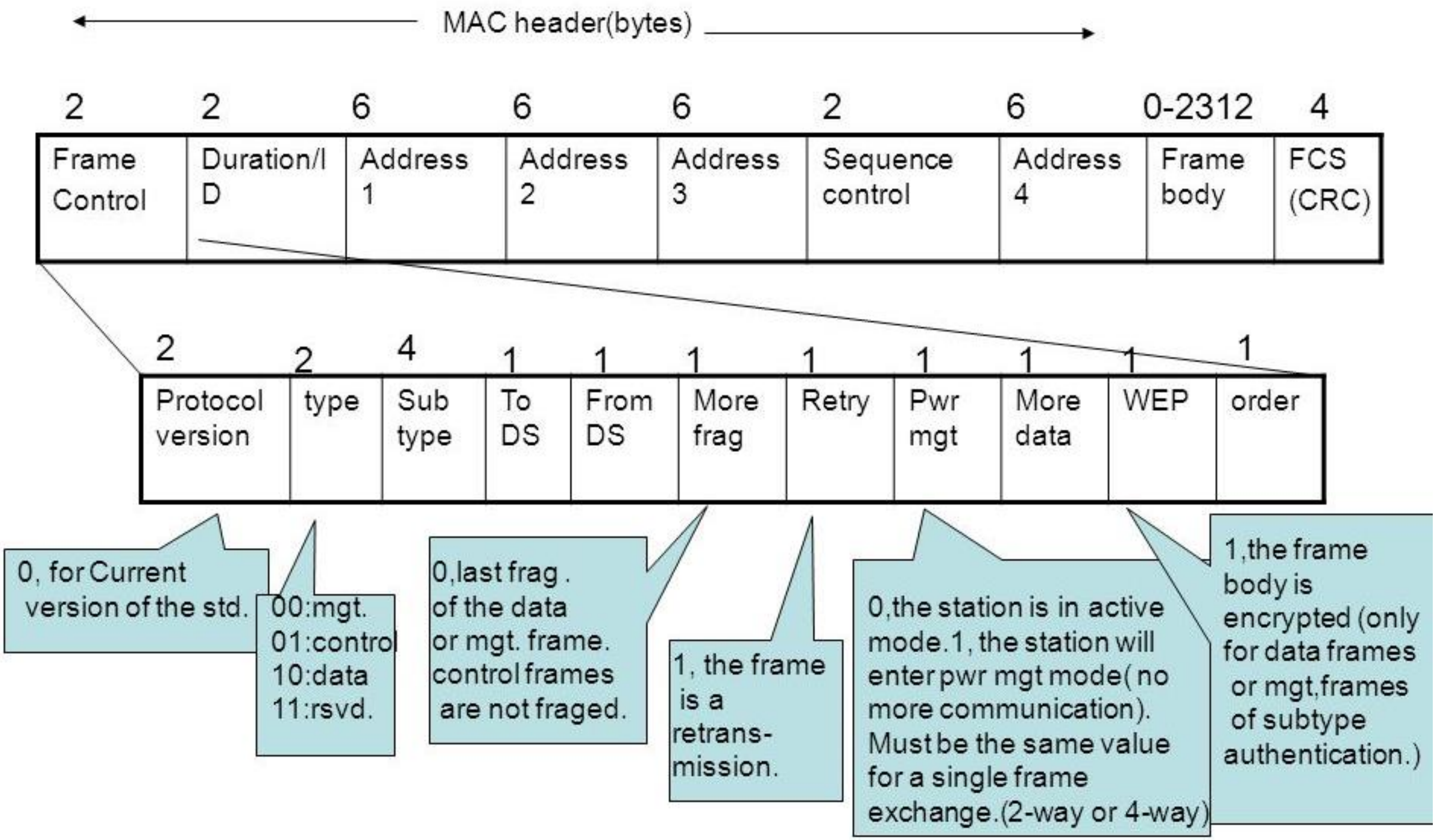
PCF (Point Coordination Function)

- PCF is an alternative access method implemented on top of the DCF.
- The operation consists of
  - polling by the centralized polling master (point coordinator).
  - makes use of PIFS when issuing polls.

- In general, point coordinators reside in access points (APs).
- Contention-free service is not provided for full-time. Periods of contention-free service arbitrated by the point coordinator alternate with the DCF-based service.
- When the PCF is used,
  - time on the medium is divided into the contention-free period (CFP) and the contention period.
  - Access to the medium in the former case is controlled by the PCF, while access to the medium in the latter case is controlled by the DCF



MAC Frame Format



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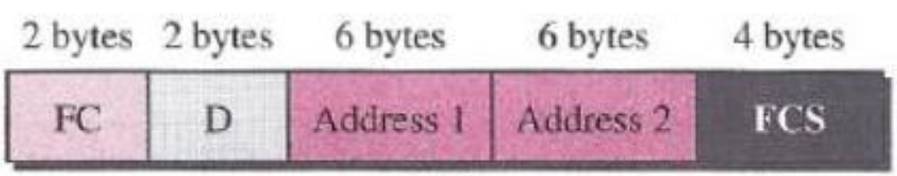
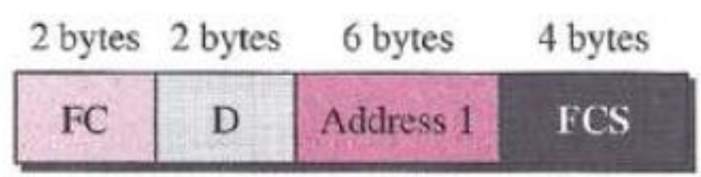
Subtype	*Meaning*
1011	Request to send (RTS)
1100	Clear to send (CTS)
1101	Acknowledgment (ACK)

To DS	*From DS*	*Address 1*	*Address 2*	*Address 3*	*Address 4*
0	0	Destination	Source	BSS ID	N/A
0	1	Destination	Sending AP	Source	N/A
1	0	Receiving AP	Source	Destination	N/A
1	1	Receiving AP	Sending AP	Destination	Source

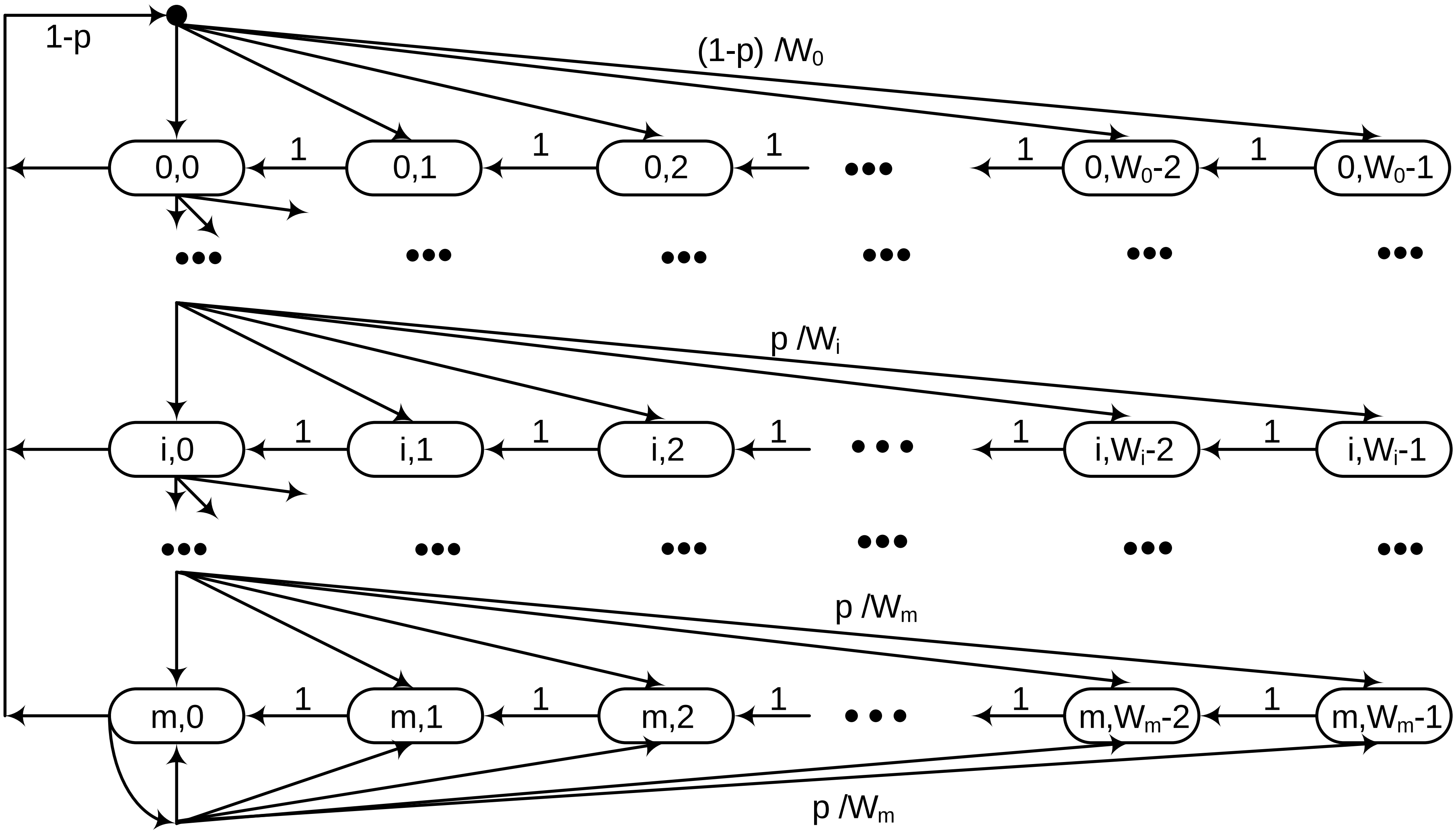


RTS



CTS or ACK

Performance of DCF



- p=conditional collision probability ; W=minimum contention window size ; m=maximum retransmission limit

Cont…

- According to Bianchi's analysis, Maximum Throughput = 82% (basic mode), = 84% (RTS/CTS mode)

G. Bianchi, "Performance analysis of the IEEE 802.11 distributed coordination function," IEEE Journal on Selected Areas in Communications, vol. 18, no. 3, pp. 535–547, March 2000.

TABLE IV

COMPARISON BETWEEN MAXIMUM THROUGHPUT AND THROGHPUT RESULTING FROM APPROXIMATE SOLUTION (28)—THE CASE $n = \infty$ IS OBTAINED FROM (31)

BASIC ACCESS		
n	Max Throughput	Max Throughput Approx.
5	0.832827 (τ=0.022869)	0.832662 (τ=0.021426)
10	0.828279 (τ=0.010848)	0.828272 (τ=0.010713)
20	0.826111 (τ=0.005294)	0.826105 (τ=0.005357)
50	0.824841 (τ=0.002089)	0.824814 (τ=0.002143)
∞	0.823957	
RTS/CTS ACCESS		
n	Max Throughput	Max Throughput Approx.
5	0.838511 (τ=0.090399)	0.838436 (τ=0.097940)
10	0.837281 (τ=0.043712)	0.837129 (τ=0.048970)
20	0.836686 (τ=0.021520)	0.836490 (τ=0.024485)
50	0.836335 (τ=0.008532)	0.836110 (τ=0.009794)
∞	0.835859	

Cont…

- Interested readers can go through the following articles for further details:

1) G. Bianchi, “Performance analysis of the IEEE 802.11 distributed coordination function,” IEEE Journal on Selected Areas in Communications, vol. 18, no. 3, pp. 535–547, March 2000.

2) F. Cali, M. Conti, and E. Gregori, “Dynamic tuning of the IEEE 802.11 protocol to achieve a theoretical throughput limit,” IEEE/ACM Transactions on Networking, vol. 8, no. 6, pp. 785–799, December 2000.

3) B.-J. Kwak, N.-O. Song, and L. E. Miller, “Performance analysis of exponential backoff,” IEEE/ACM Transactions on Networking, vol. 13, no. 2, pp. 343–355, April 2005.

4) Y. Xiao, “Performance analysis of priority schemes for IEEE 802.11 and IEEE 802.11e wireless LANs,” IEEE Transactions on Wireless Communications, vol. 4, no. 4, pp. 1506–1515, July 2005.

5) S. Misra and M. Khatua, "Semi-Distributed Backoff: Collision-Aware Migration from Random to Deterministic Backoff", IEEE Transactions on Mobile Computing, Vol. 14, No. 5, pp. 1071–1084, May 2015.

6) M. Khatua and S. Misra, "D2D: Delay-aware Distributed Dynamic Adaptation of Contention Window in Wireless Networks", IEEE Transactions on Mobile Computing, Vol. 15, No. 2, pp. 322–335, February 2016.

IEEE 802.11
Physical Layer

Pathway to Gigabit WiFi

- IEEE 802.11-1997: The WLAN standard was originally 1 Mbps and 2 Mbps, RF (2.4 GHz) and infrared (>300 GHz) standard (1997)
- IEEE 802.11b: Enhancements to 802.11 to support 5.5 Mbps and 11 Mbps (1999)
- IEEE 802.11a: To increase datarate upto 54 Mbps. Uses OFDM, and 5GHz channel
- IEEE 802.11e: Enhancements: QoS, including packet bursting (2005)
- IEEE 802.11g: 54 Mbps, 2.4 GHz standard (backwards compatible with b) (2003)

- IEEE 802.11-2007: A new release of the standard that includes amendments a, b, d, e, g, h, i, and j. (July 2007)
- IEEE 802.11n: Higher-throughput improvements using MIMO (multiple-input, multiple-output antennas); datarate upto 600 Mbps (September 2009)

- IEEE 802.11-2012: A new release of the standard that includes many amendments (March 2012)
- IEEE 802.11ac: Very High Throughput 1-3 Gbps (December 2013)
  - potential improvements over 802.11n: better modulation scheme (expected ~10% throughput increase), wider channels (estimate in future time 80 to 160 MHz), multiuser MIMO
- IEEE 802.11ad: Very High Throughput upto 7 Gbps; uses 60 GHz ISM band; Typical distances 1-10 m; uses beamforming (Dec’ 2013) — see WiGig / Microwave Wi-Fi

IEEE 802.11 Physical Layer Standards

Table 13.4 IEEE 802.11 Physical Layer Standards

Standard	802.11a	802.11b	802.11g	802.11n	802.11ac	802.11ad
Year introduced	1999	1999	2003	2000	2012	2014
Maximum data transfer speed	54 Mbps	11 Mbps	54 Mbps	65 to 600 Mbps	78 Mbps to 3.2 Gbps	6.76 Gbps
Frequency band	5 GHz	2.4 GHz	2.4 GHz	2.4 or 5 GHz	5 GHz	60 GHz
Channel bandwidth	20 MHz	20 MHz	20 MHz	20, 40 MHz	40, 80, 160 MHz	2160 MHz
Highest order modulation	64 QAM	11 CCK	64 QAM	64 QAM	256 QAM	64 QAM
Spectrum usage	DSSS	OFDM	DSSS, OFDM	OFDM	SC-OFDM	SC, OFDM
Antenna configuration	1×1 SISO	1×1 SISO	1×1 SISO	Up to 4×4 MIMO	Up to 8×8 MIMO, MU-MIMO	1×1 SISO

IEEE 802.11n

- The goal of this effort is to not just increase the bit rate of the transmitting antennas but to increase the effective throughput of the network.

- This standard operates in both the 2.4-GHz and the 5-GHz bands and can therefore be made upwardly compatible with either IEEE 802.11a or IEEE 802.11b/g.

- IEEE 802.11n embodies changes in three general areas:
  - use of MIMO,
  - enhancements in radio transmission,
  - MAC enhancements.

- Multiple-input multiple-output (MIMO)
  - antenna architecture is the most important one
  - the transmitter and receiver employ multiple antennas => (n x m) MIMO

  - The source data stream is divided into *n* sub-streams, one for each of the *n* transmitting antennas.
  - The individual sub-streams are the input to the transmitting antennas (multiple input).

  - At the receiving end, *m* antennas receive the transmissions from the *n* source antennas via a combination of line-of-sight transmission and multipath.
  - The outputs from the *m* receiving antennas (multiple output) are combined.
  - the result is a much better receive signal than SISO or Multiple Frequency Channel

Cont…

- Radio transmission
  - Uses channel bonding which combines two 20-MHz channels to create a 40-MHz channel to increase capacity.
  - In the IEEE 802.11a and 802.11g WiFi standards, channel widths were strictly defined as being 20 MHz in size.
  - The usable frequency band for most of the world on the 2.4 GHz band is only 72 MHz wide (2.401 GHz to 2.473 GHz).
    - Accordingly, there are only three independent 20 MHz channels
  - The 5 GHz band has up to 500 MHz width
    - providing up to 25 independent 20 MHz channels.
  - Channel bonding was first introduced with 802.11n to allow 40 MHz channels,
  - then extended further with 802.11ac to allow 80 MHz and 160 MHz channels.

Cont…

- MAC enhancements
  - The most significant change is to aggregate multiple MAC frames into a single block for transmission
  - includes 3 forms of aggregation
    - A-MSDU aggregation
      - combines multiple MSDUs (MAC Service Data Units) into a single MPDU
      - there is a single MAC header and single FCS for all of the MSDUs rather than for each of the MSDUs
    - A-MPDU aggregation
      - combines multiple MPDUs (MAC Protocol Data Units) in a single physical transmission
      - with A-MSDU, only a single physical-layer header is needed.
      - But, each MPDU includes the MAC header and FCS
    - A-MPDU of A-MSDU aggregation
      - the two above forms of aggregation can be combined

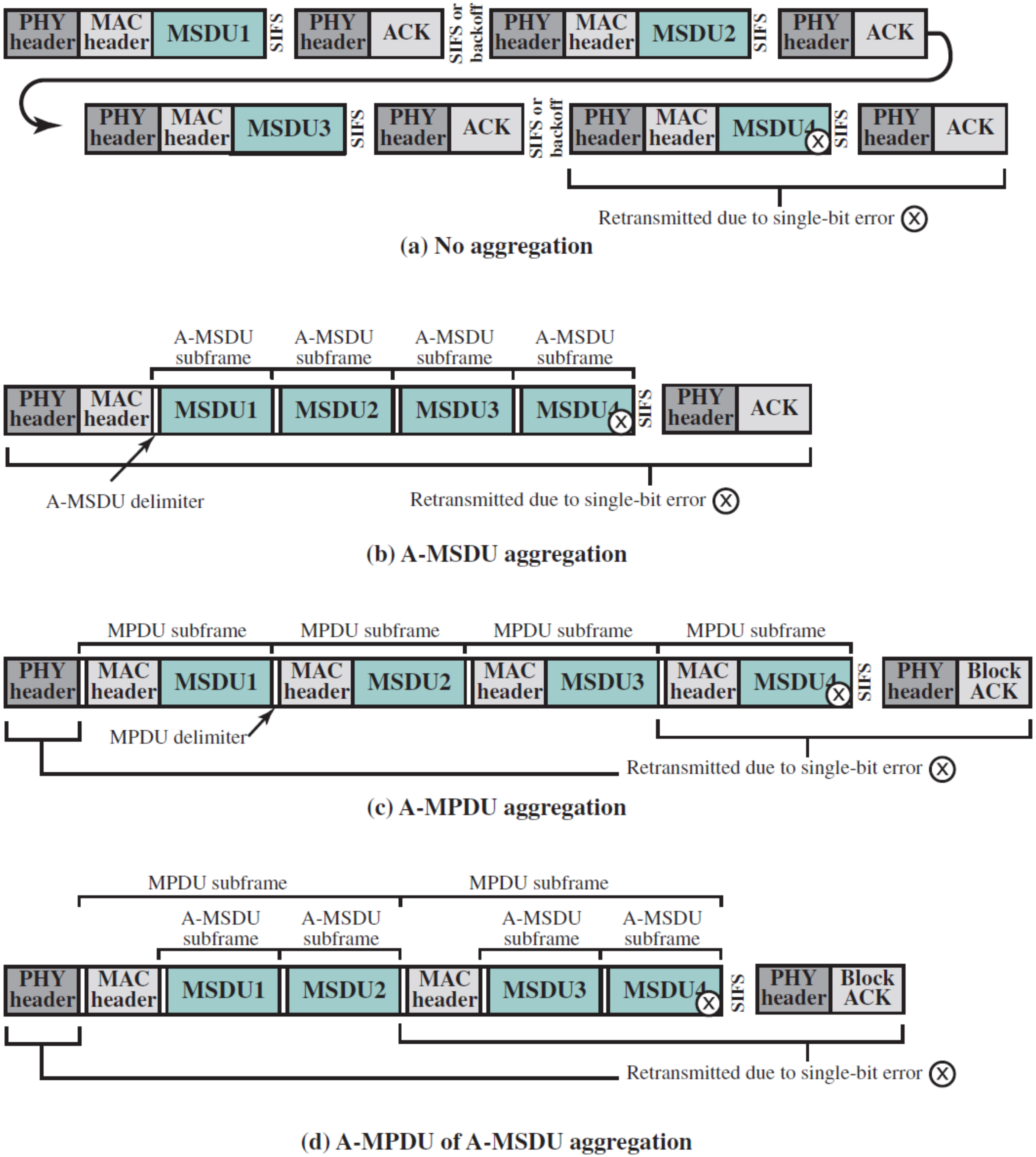


Figure 13.11 Forms of Aggregation

IEEE 802.11ac

- IEEE 802.11ac operates in the 5-GHz band, as does 802.11a & 802.11n.
- This is designed to provide Gigabit WiFi

- Enhancements in three areas
  - Bandwidth: The maximum bandwidth of 802.11n is 40 MHz; the maximum bandwidth of 802.11ac is 160 MHz.
  - Signal encoding: 802.11n uses 64 QAM with OFDM, and 802.11ac uses 256 QAM with OFDM. Thus, more bits are encoded per symbol.
  - MIMO: With 802.11n, there can be a maximum of 4 x 4 antennas. 802.11ac increases this to 8 x 8.

Thanks!

Figure and slide materials are taken from the following sources:

1. W. Stallings, (2017), Data and Computer Communications, 10th Ed.
2. B. A. Forouzan, (2012), Data Communication and Networking, 5th Ed.
3. Kurose and Ross, (2013), Computer Networking – A Top Down Approach, 6th Ed.