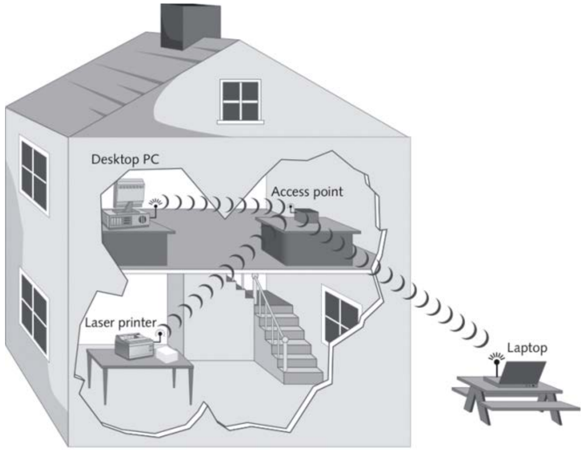
IEEE 802.11 Wireless LANs
Part I: Basics



Raj Jain
Professor of Computer Science and Engineering
Washington University in Saint Louis
Saint Louis, MO 63130
Jain@cse.wustl.edu

Audio/Video recordings of this class lecture are available at:
http://www.cse.wustl.edu/~jain/cse574-24/

Student Questions

1. IEEE 802.11 Features
2. IEEE 802.11 Physical Layers
3. IEEE 802.11 MAC
4. IEEE 802.11 Architecture
5. Frame Format
6. Power Management

Note: This is 1st of 2 lectures on Wi-Fi. The 2nd lecture covers recent developments such as high-throughput Wi-Fi, white spaces, etc.

Student Questions

IEEE 802.11 vs. Wi-Fi

- IEEE 802.11 is a standard
- Wi-Fi = “Wireless Fidelity” is a trademark
- Fidelity = Compatibility between wireless equipment from different manufacturers
- Wi-Fi Alliance is a non-profit organization that does the compatibility testing (WiFi.org)
- 802.11 has many options, and two pieces of equipment based on 802.11 can be incompatible.
- All equipment with the “Wi-Fi” logo has selected options such that they will interoperate.

Student Questions

- Do commercial Wi-Fi products support multiple 802.11 protocols like 802.11a/b/g or only one of them?

All of them up to the version claimed. 802.11a device will support 11b, 11g, and 11a.

IEEE Standards Numbering System

- IEEE 802.* and IEEE 802.1* standards (e.g., IEEE 802.1Q-2011) apply to all IEEE 802 technologies:
  - IEEE 802.3 Ethernet
  - IEEE 802.11 Wi-Fi
  - IEEE 802.16 WiMAX

802 Overview and Architecture					
802.2 Logical Link Control					
802.1 Bridging					
802.1 Management					
802.10 Security					
802.3 Ethernet	…	802.11 Wi-Fi	…	802.17 Resilient Packet Ring (RPR)	…

Student Questions

- Are the token ring / token bus working groups still active?

No IEEE 802.5 working group on token ring and IEEE 802.4 working group on Token Bus were disbanded over 20 years ago.

- Could you please explain the token ring and token bus? Are they still being used today? And will they be covered by the exam?

Token Ring and Token Bus were Ethernet competitors that are no longer in use.

- You mentioned that 802.10 is security. Will this be covered in this course?

No. Security is several courses by itself.

IEEE Standards Numbering (Cont)

- IEEE 802.11* (e.g., 802.11i) standards apply to all Wi-Fi devices but may not apply to ZigBee devices which are based on 802.15,
- Standards with all uppercase letters are base standards, e.g., IEEE 802.1AB-2009
- Standards with the lowercase are additions/extensions/revisions.
  It is merged with the base standard in its next revision.
  e.g., IEEE 802.1w-2001 was merged with IEEE 802.1D-2004
- Standards used to be numbered sequentially, e.g., IEEE 802.1a, …, 802.1z, 802.1aa, 802.1ab, …
- Recently, they started showing base standards in the additions, e.g., IEEE 802.1Qau-2010

Student Questions

- So if we have a standard 802.1ad and it is getting merged into an existing standard 802.1B, will it become 802.1C? Or will it become 802.1B-2020, or 802.1Ba...this process isn't super clear to me.

802.1ad cannot be merged with 802.1B. It will be merged with 802.1 and the new version of 802.1 will be called 802.1-2020. 802.1Qau-2010 was merged in 802.1Q-2011.

- What is the difference between 802.1a (lowercase) and 802.1AB (uppercase)?

These are just examples of IEEE standards. 802.1a, if there ever was one, was merged with 802.1 and no longer exists.

IEEE 802.11 Features

- Original IEEE 802.11-1997 was at 1 and 2 Mbps.
  Newer versions at 11 Mbps, 54 Mbps, 108 Mbps, 200 Mbps,…
- All versions use the "License-exempt" spectrum
- Need ways to share spectrum among multiple users and multiple LANs ⇒ *Spread Spectrum* (CDMA)
- Three Phys:
  - Direct Sequence (**DS**) spread spectrum using ISM band
  - Frequency Hopping (**FH**) spread spectrum using ISM band
  - Diffused Infrared (850-900 nm) bands
- Supports multiple priorities
- Supports time-critical and data traffic
- Power management allows a node to doze off

Student Questions

- What does it mean for a node to doze off?

A dozing node shuts off most of its power-hungry electronics and keeps only a small part of the system alive looking for any alerts/messages.

- What do the "supports multiple priorities" mean, or are there any examples in the application?

Yes, audio has a higher priority than video. Data has a higher priority than audio.

ISM Bands

- Industrial, Scientific, and Medical bands. License exempt

From	To	Bandwidth	Availability
6.765 MHz	6.795 MHz	30 kHz	
13.553 MHz	13.567 MHz	14 kHz	Worldwide
26.957 MHz	27.283 MHz	326 kHz	Worldwide
40.660 MHz	40.700 MHz	40 kHz	Worldwide
433.050 MHz	434.790 MHz	1.74 MHz	Europe, Africa, Middle east, Former Soviet Union
902.000 MHz	928.000 MHz	26 MHz	America, Greenland
2.400 GHz	**2.500 GHz**	**100 MHz**	**Worldwide**
5.725 GHz	**5.875 GHz**	**150 MHz**	**Worldwide**
24.000 GHz	24.250 GHz	250 MHz	Worldwide
61.000 GHz	61.500 GHz	500 MHz	
122.000 GHz	123.000 GHz	1 GHz	
244 GHz	246 GHz	2 GHz	

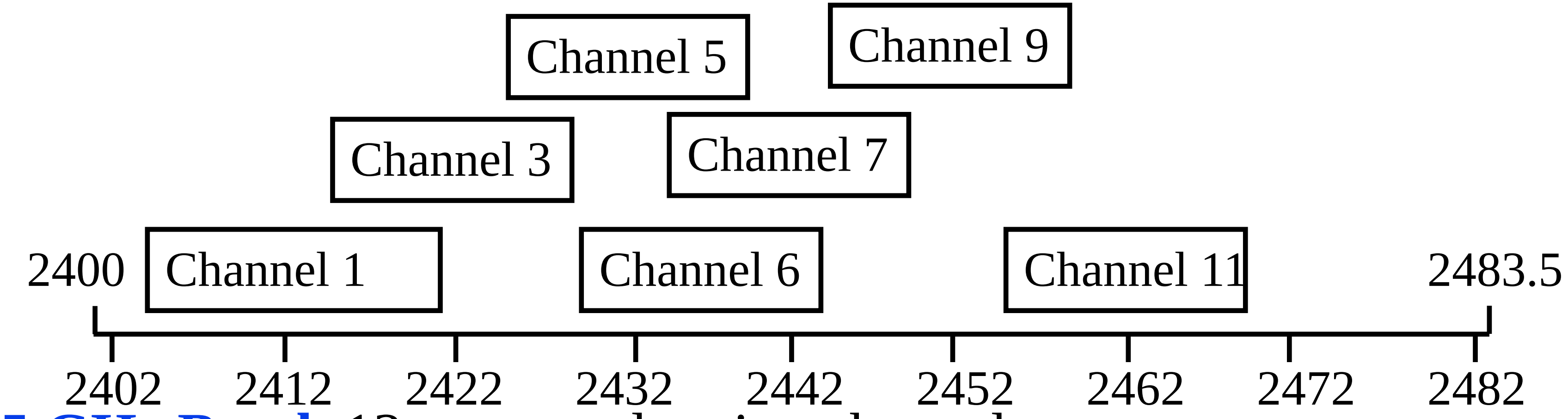
Ref: http://en.wikipedia.org/wiki/ISM_band

Student Questions

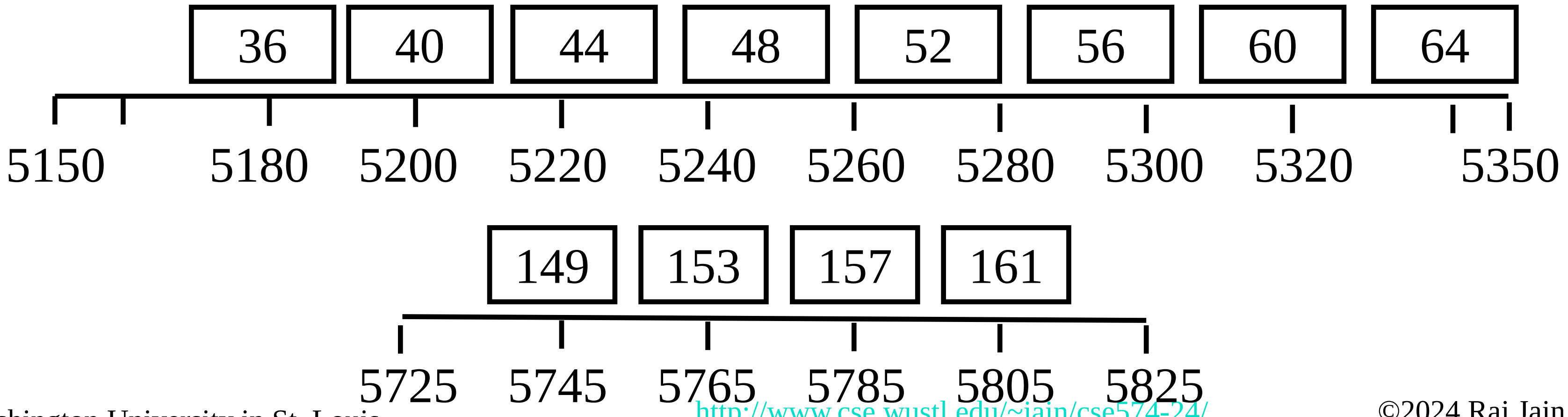
North American Channels

2.4 GHz Band: 14 5-MHz Channels. Only 12 in the USA.

20 MHz $\Rightarrow$ Only three non-overlapping channels



5 GHz Band: 12 non-overlapping channels



Student Questions

- So channels are 5 MHz? Or 20MHz?

FCC numbers channels in 5MHz width.
IEEE 802.11abg use 4 consecutive channels for each LANs. Higher versions use even more.

- Given the overlap in the 2.4 GHz band, how could you ever have more than three channels without interference? If true, why not just have channels 1, 6, and 11?

Other non-overlapping combinations, e.g., 3, 7, and 11, may be used if the initial part of channel 1 is noisy.

- Since the 5 GHz band only has 150 MHz bandwidth, how can 12 channels, 20MHz wide each channel, be non-overlapping?

Twelve channels are shown.

IEEE 802.11 Physical Layers

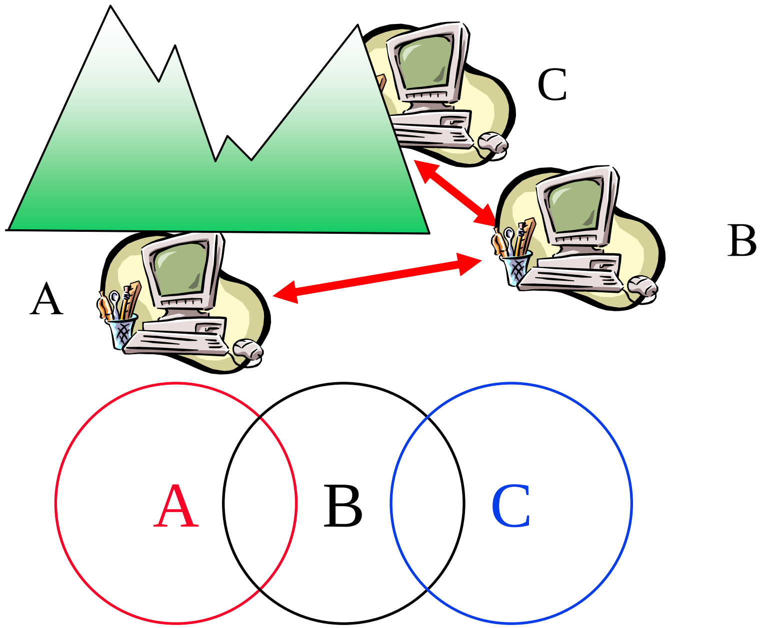
- Issued in several stages
- First version in 1997: IEEE 802.11
  - Includes MAC layer and three physical layer specifications
  - Two in the 2.4-GHz band and one infrared
  - All operating at 1 and 2 Mbps
  - No longer used
- Two additional amendments in 1999:
  - IEEE 802.11a-1999: 5-GHz band, 54 Mbps/20 MHz, **OFDM**
  - IEEE 802.11b-1999: 2.4 GHz band, 11 Mbps/22 MHz
- Fourth amendment:
  - IEEE 802.11g-2003: 2.4 GHz band, 54 Mbps/20 MHz, **OFDM**

Student Questions

- Are these data rates important to remember?

Yes.

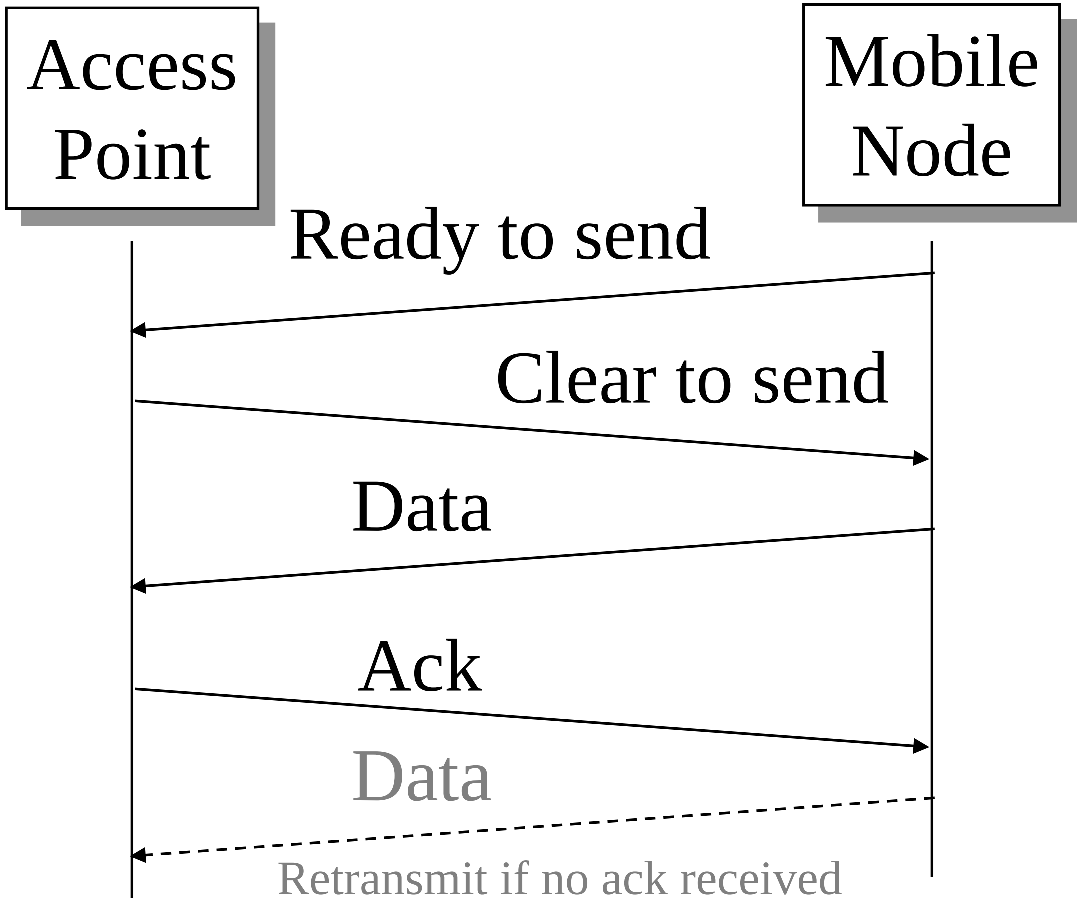
Hidden Node Problem



- A can hear B, B can hear C, but C cannot hear A.
- C may start transmitting while A is also transmitting
  ⇒ A and C can't detect collisions.
- CSMA/CD is not possible
  ⇒ Only the receiver can help avoid collisions

Student Questions

4-Way Handshake



Student Questions

- Is the ACK in this process in the transport layer? If so, how does it work with other protocols like TCP, or does it never happen?

The entire set is in Layer 2. This is how Wi-Fi is different from Ethernet.

- In a 4-way handshake, how does the access point pick a particular mobile node for data transmission? Assuming that the options of data-frames to transmit are identical.

The access point does not pick. The nodes count up to a random number and start when that count expires.

- Does the time duration in RTS include retransmission time?

No. Retransmission requires a whole new 4-way handshake.

- Will data remain in the buffer until winning the next access?

Yes. But it will be discarded after a timeout to avoid higher layers (TCP) retransmissions.

IEEE 802.11 MAC

- Carrier Sense Multiple Access with Collision Avoidance (**CSMA/CA**)
- Listen before you talk. If the medium is busy, the transmitter backs off for a random period.
- Avoids collision by sending a short message:
  Ready to send (**RTS**)
  RTS contains the destination address and <u>duration</u> of the message. It tells everyone to back off for the duration.
- Destination sends: Clear to send (**CTS**)
  Other stations set their network allocation vector (**NAV**) and wait for that duration
- Can not detect collision ⇒ Each packet is acked.
- MAC-level retransmission if not acked.

Student Questions

- What do you mean by MAC-level retransmission? Which step is it from the diagram in the previous slide?

MAC retransmits if no ack is received. Only after a certain number of retries, layer 3 (IP) is informed of the failure. Then Layer 4 (TCP) may retransmit again a few times (if required). It may do so only for data. For Video, TCP may not retransmit.

- Why is the retransmission done at the MAC level? What if the retransmission collides with no ack?

The handshake does not complete. The nodes try again.

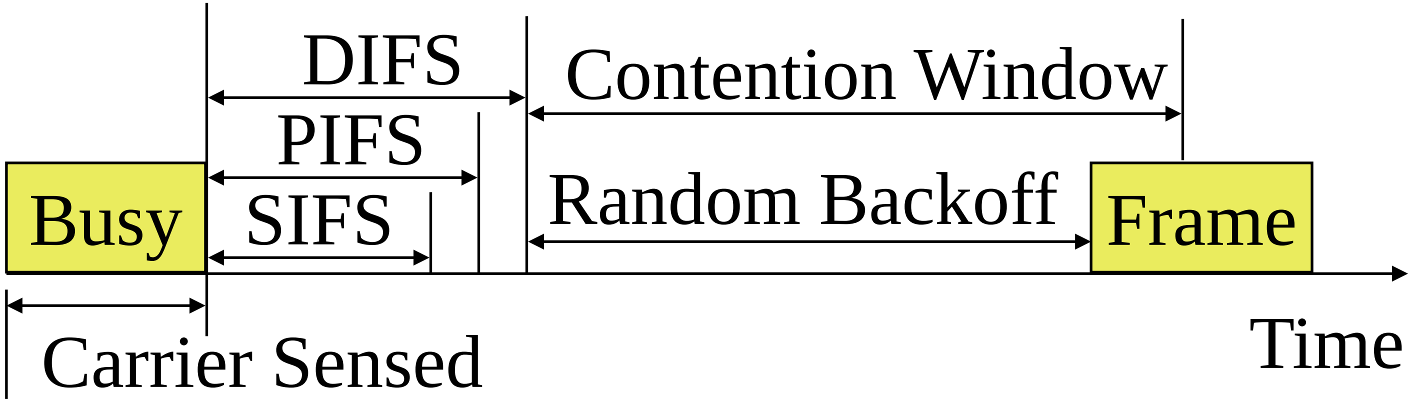
- ❖ NAV is set to the duration of the msg in the RTS, correct?

Yes.

- ❖ RTS is in plaintext?

Yes.

IEEE 802.11 Priorities



- Initial interframe space (**IFS**)
- Highest priority frames, e.g., Acks, use short IFS (**SIFS**)
- Medium priority time-critical frames use "Point Coordination Function IFS" (**PIFS**)
- Asynchronous data frames use "Distributed coordination function IFS" (**DIFS**)

Student Questions

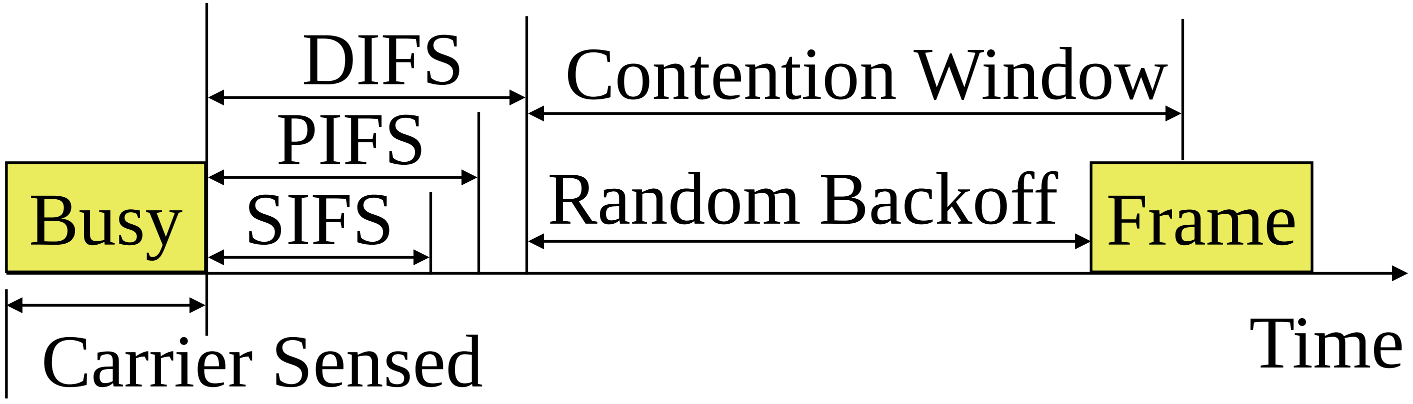
- Can you explain the concept of Random Backoff?
  See slides 5-15 thru 5-20
- Example of low priority frames that would use DIFS?
  Almost all frames use DIFS. Video may use PIFS. Control frames use SIFS.
- What is the contention window? Is it a period when you could have potential transmissions from other devices?
  Yes, a fixed amount of time is reserved during which anyone can try sending RTS if the medium is idle and no spacing rules will be violated.
- Is the message priority decided by the 802.11 standards?

By the application.

- What does the random backoff time represent in the diagram? Is it used in the event of a collision?

Even without a collision, everyone has to draw a random number and wait.

IEEE 802.11 Priorities



- Initial interframe space (**IFS**)
- Highest priority frames, e.g., Acks, use short IFS (**SIFS**)
- Medium priority time-critical frames use "Point Coordination Function IFS" (**PIFS**)
- Asynchronous data frames use "Distributed coordination function IFS" (**DIFS**)

Student Questions

- The entire process is not clear. I assume we wait for the duration of DIFS at first, then for the duration of a random backoff, and then send the data. But, if we hear anything in PIFS, what do we do?

These are intervals for which various traffic must wait before sending the medium. If the medium is busy, they draw a random number and come back to sense after that wait is over.

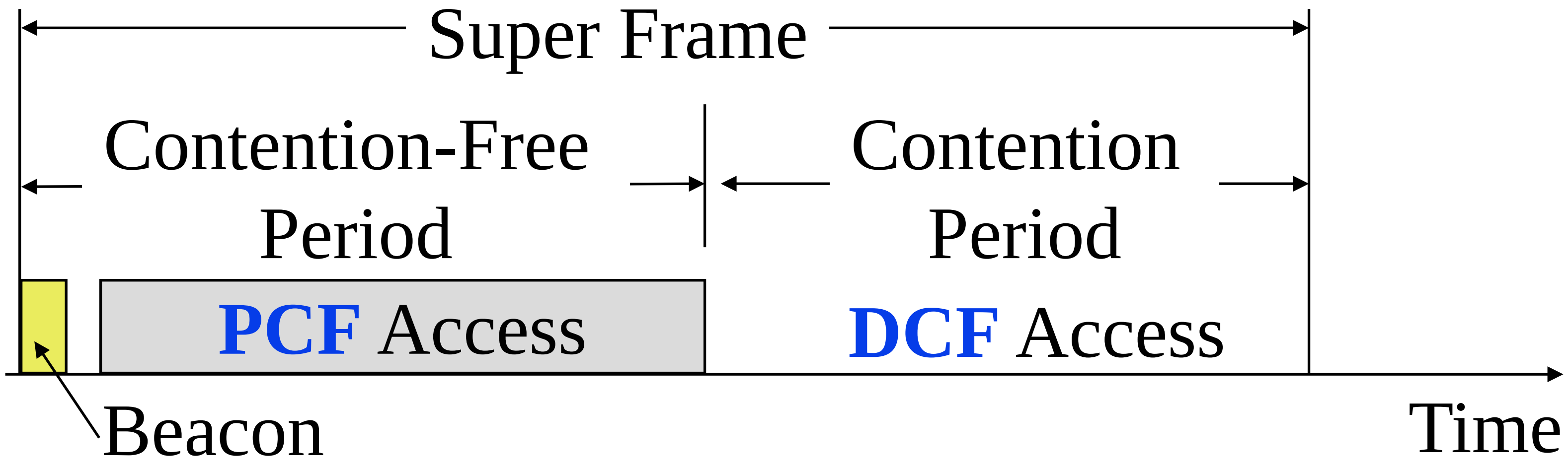
- Why does the contention window cover half of the frame size?

The frame can continue if started within the contention window.

- PIFS uses PCF , and DIFS uses DCF? What about SIFS?

PIFS is for PCF, DIFS is for DCF, and SIFS is for non-data traffic (RTS, CTS, Acks)

Time Critical Services



- Timer critical services use **Point Coordination Function**
- The point coordinator reserves time for stations to transmit
- Coordinator sends a beacon frame to all stations.
  Then uses a polling frame to allow stations to request contention-free access
- Contention Free Period (CFP) varies with the load.

Student Questions

- What types of traffic would be in the PCF frame vs the DCF frame (streaming video, large file downloads, web browsing)?
  Yes, video may use PCF. Most other frames use DCF.
- Can you give another example of PCF vs DCF. I am still unsure how those two work in time critical service.
  Audio and Video are both examples of traffic that is periodic and time critical so they may reserve access in advance and use PCF.
- What does a point coordination function look like?
  Periodic access like video.
- How does the coordinator select a station to transmit during polling?
  A polling frame is a set of empty time slots during which stations compete via random access to request PCF access.
- Is the beacon part of the contention-free period? Or does it come before it?
  Beacon and polling frames are transmitted contention-free. PCF access duration varies and is specified in each beacon. Total super frame duration is also specified in the beacon. CFP and CP are not specified but can be calculated if needed. Any transmission that overflows the super frame is allowed to complete.

IEEE 802.11 DCF Backoff

- MAC works with a single FIFO Queue
- Three variables:
  - Contention Window (CW)
  - Backoff count (BO)
  - Network Allocation Vector (NAV)
- If a frame (RTS, CTS, Data, Ack) is heard, NAV is set to the duration in that frame. Stations sense the media after NAV expires.
- If the medium is idle for DIFS, and backoff (BO) is not already active, the station draws a random BO in [0, CW] and sets the backoff timer.
- If the medium becomes busy during backoff, the timer is stopped, and a new NAV is set. After NAV, back off continues.

Student Questions

- When we set a new NAV, do I have to draw a new BO too?
  NAV is set for each new transmission.
  Backoff count is incremented after each unsuccessful attempt.
  A new random interval is drawn using increased range on each backoff.
- What is the significance of the FIFO queue? Does this refer to the data stream or how the stations are served?

The data packets at a station are served in FIFO order.

- So, AP sends a beacon. All stations with time-critical data reply. The AP selects one of them and tells it to send the data. Is this correct?

No. Time-critical data make a reservation beforehand. So they have a reserved slot.

IEEE 802.11 DCF Backoff (Cont)

- Initially and after each successful transmission:

$$CW = CW_{min}$$

- After each unsuccessful attempt

$$CW = \min\{2CW + 1, CW_{max}\}$$

Example: CWmin=3, CWmax=127

3, 7, 15, 31, 63, 127, 127, 127, …

Student Questions

- What is the unit of the numbers in the example? Is it in timeslots? mSec?

Slots

Typical Parameter Values

- For DS PHY: Slot time = 20 us, SIFS = 10 us, CWmin = 31, CWmax = 1023
- For FH PHY: Slot time = 50 us, SIFS = 28 us, CWmin = 15, CWmax = 1023
- 11a: Slot time = 9 us, SIFS= 16 us, CWmin= 15, CWmax=1023
- 11b: Slot time = 20 us, SIFS = 10 us, CWmin= 31, CWmax=1023
- 11g: Slot time = 20 us or 9 us, SIFS = 10 us, CWmin= 15 or 31, CWmax=1023
- PIFS = SIFS + 1 slot time
- DIFS = SIFS + 2 slot times

Student Questions

- What is frequency hopping PHY?

PHY = Physical layer. For frequency hopping, please review the module 3 video.

Virtual Carrier Sense

- Every frame has a "Duration ID," which indicates how long the medium will be busy.
  - RTS has duration of RTS + SIF + CTS + SIF + Frame + SIF + Ack
  - CTS has duration of CTS + SIF + Frame + SIF + Ack
  - Frame has a duration of Frame + SIF + ACK
  - ACK has a duration of ACK
- All stations keep a "**Network Allocation Vector (NAV)**" timer to record the duration of each frame they hear.
- Stations do not need to sense the channel until NAV becomes zero.

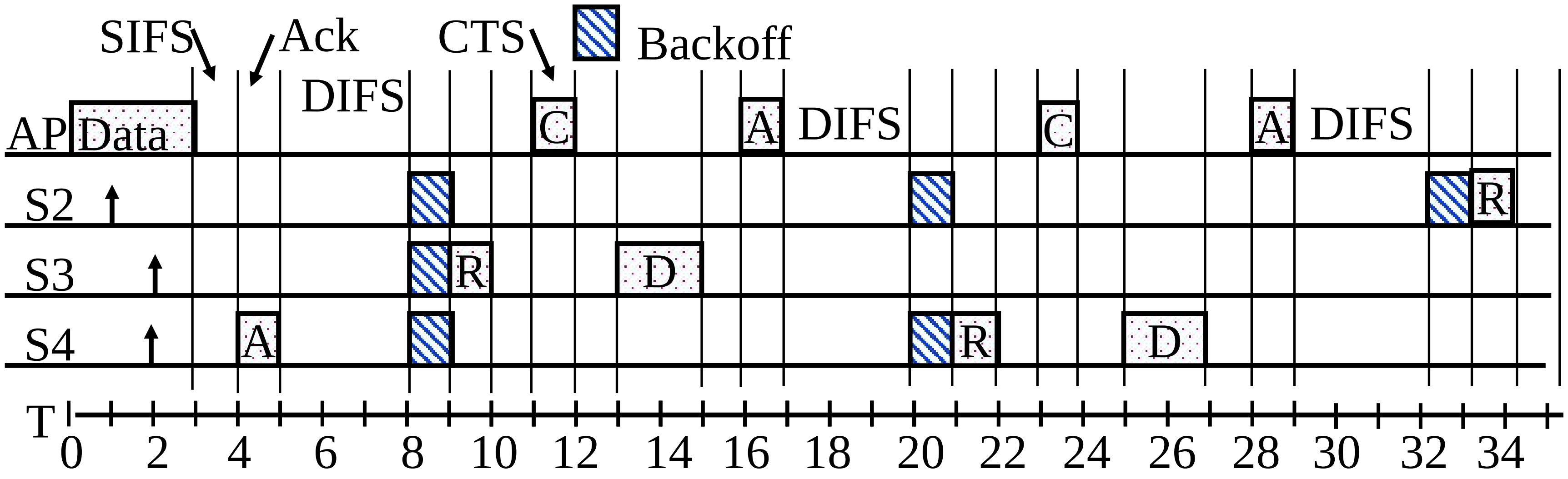
Student Questions

- Why is DIFS after ACK not included in NAV?

DIFS is always there beforehand and constant.

DCF Example

- Example: Slot Time = 1, CWmin = 3, DIFS=3, PIFS=2, SIFS=1
- T=1 Station 2 wants to transmit, but the media is busy
- T=2 Stations 3 and 4 want to transmit, but the media is busy
- T=3 Station 1 finishes transmission.
- T=4 Station 1 receives ack for its transmission (SIFS=1)
  Stations 2, 3, and 4 set their NAV to 1.
- T=5 Medium becomes free
- T=8 DIFS expires. Stations 2, 3, and 4 draw backoff count between 0 and 3.
  The counts are 3, 1, 2



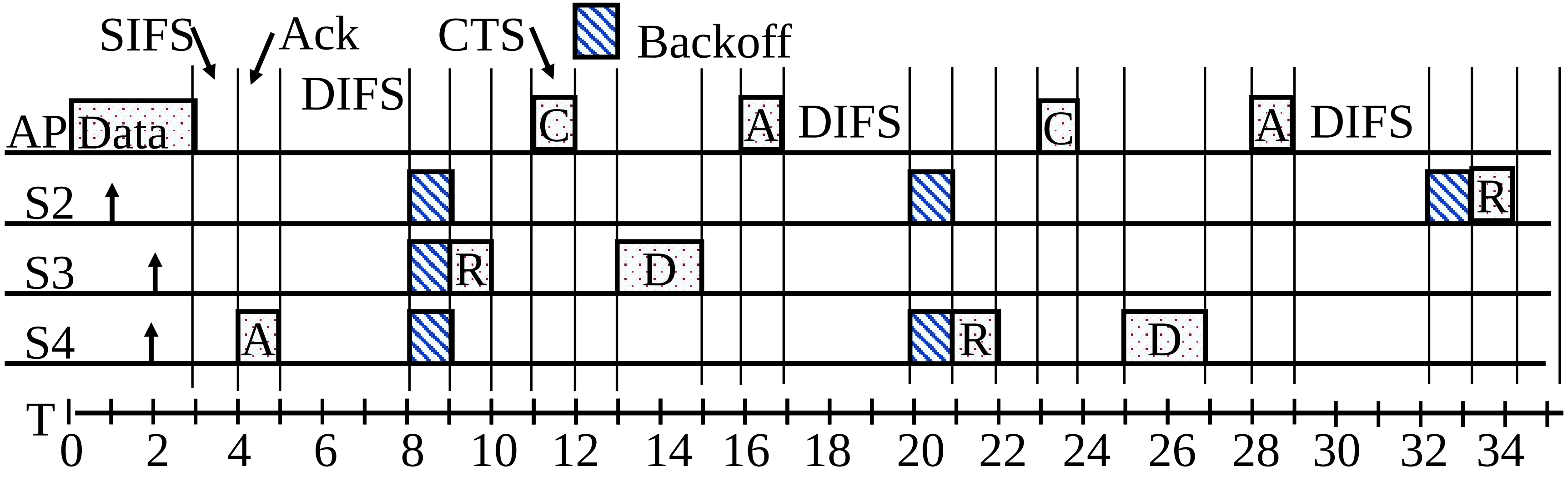
Student Questions

- How do CWmin, and CWmax affect the timing diagram?
  The congestion window affects the time after which they will retry. Larger windows allow for a larger number of stations to be supported.
- What happens if there is a conflict in the drawn backoff counts? (i.e., if the stations had drawn 1, 2, 2 instead of 3, 1, 2)
  Whoever draws the lowest number goes first.
- Since AP is already sending data to S4, S4 must have known that the medium is busy. I wonder why S4 would still try to transmit at time 2.

The vertical arrows indicate the instants at which a data frame comes to the MAC at that station.

DCF Example (Cont)

- T=9 Station 3 starts transmitting. Announces a duration of 8 (RTS + SIFS + CTS + SIFS + DATA + SIFS + ACK). Stations 2 and 4 pause the back-off counter at 2 and 1, respectively, and wait till T=17
- T=15 Station 3 finishes data transmission
- T=16 Station 3 receives Ack.
- T=17 Medium becomes free
- T=20 DIFS expires. Stations 2 and 4 notice that there was no transmission for DIFS. Stations 2 and 4 start their back-off counter from 2 and 1, respectively.
- T=21 Station 4 starts transmitting RTS



Student Questions

- What is the backoff count? Is that different from backoff duration?

Count goes up sequentially, 1, 2, 3, …
Duration is randomly drawn each time.

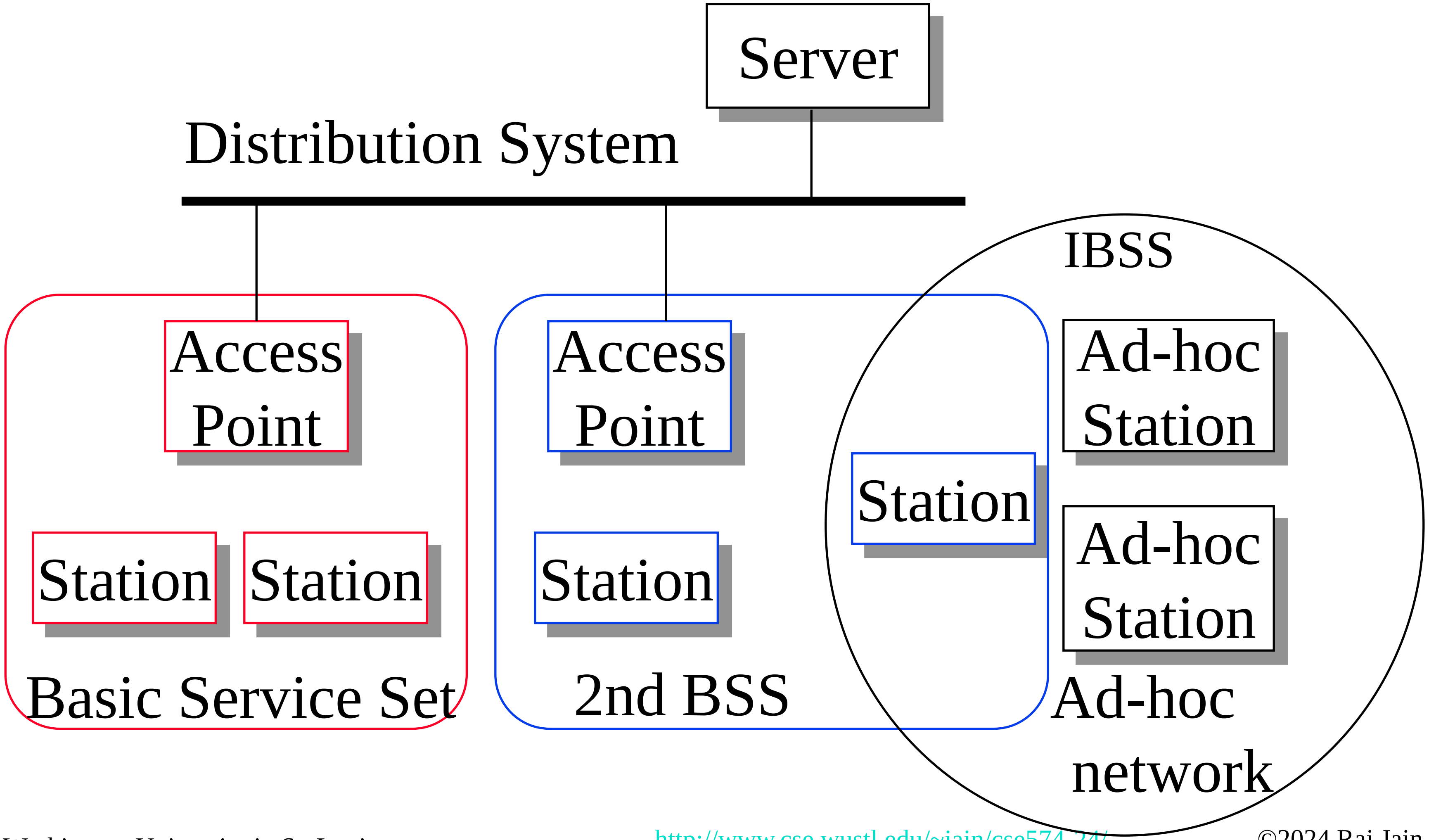
- If two SSs draw the same BO, how is the conflict resolved? Isn't this a collision?

Both will sense the medium after their NAV expires but RTS will collide, and CTS will not be received.

- How is CWmin used?

The first backoff is between 0 and CWmin. It is doubled on retry. The last backoff is CWmax. E.g., CWmin=15, CWmax=1023.
15, 31, 63, 127, 255, 511, 1023.

IEEE 802.11 Architecture



Student Questions

- ❑ Do we see if an Access point is present or not to distinguish a BSS from an IBSS?

No. IBSS can be there even if there is an AP.

IEEE 802.11 Architecture (Cont)

- **Basic Service Area (BSA)** = Cell
- Each BSA may have several access points (APs)
- **Basic Service Set (BSS)**
  = Set of stations associated with one AP
- **Distribution System (DS)** - the wired backbone
- **Extended Service Area (ESA)** = Multiple BSAs interconnected via a distribution system
- **Extended Service Set (ESS)**
  = Set of stations in an ESA
- **Independent Basic Service Set (IBSS)**: Set of computers in **ad-hoc mode**. It may not be connected to a wired backbone.
- Ad-hoc networks coexist and interoperate with infrastructure-based networks

Student Questions

Frame Format

Frame Control	Duration/ ID	Adr 1	Adr 2	Adr 3	Seq Control	Adr 4	Info	CRC
16b	16b	48b	48b	48b	16b	48b		32b

Prot. Ver.	Type	Sub type	To DS	From DS	More Frag.	Retry	Power mgt	More Data	WEP	Order
2b	2b	4b	1b	1b	1b	1b	1b	1b	1b	1b

- Type: Control, management, or data
- Sub-Type: Association, disassociation, re-association, probe, authentication, de-authentication, CTS, RTS, Ack, …
- Retry/retransmission
- Going to Power Save mode
- More buffered data at AP for a station in power save mode
- Wireless Equivalent Privacy (Security) info in this frame
- Strict ordering

Student Questions

MAC Frame Fields

- **Duration/Connection ID**:
  - If used as duration field, indicates time (in us) channel will be allocated for successfully transmitting MAC frame. Includes time until the end of Ack
  - In some control frames, contains association or connection identifier
- **Sequence Control**:
  - 4-bit fragment number subfield
    - For fragmentation and reassembly
  - 12-bit sequence number
  - Number frames between given transmitter and receiver

Student Questions

- Why is Seq Control between Address 3 and 4, does it because Address 4 might be empty?

See the next slide.

- My understanding is that we identify a packet with the sequence number and its fragments with a 4-bit fragment field. Is this correct? What if we don't use fragmentation or how to identify the last fragment?

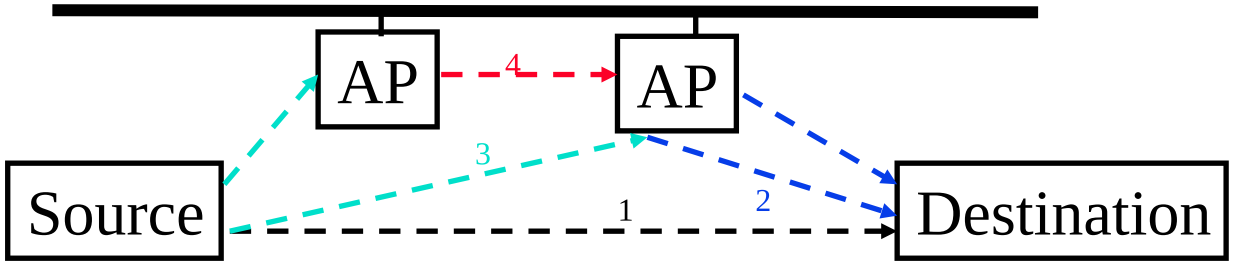
See the "More Fragment" field in the Frame control.

- So, if we want to send a packet from source to destination through the first and the second AP, the addresses that will be used are: 3 4 2. Is this correct?

See the next slide.

802.11 Frame Address Fields

- All stations filter on "Address 1"



	To Distribution System	From Distribution System	Address 1	Address 2	Address 3	Address 4
1	0	0	Destination Address	Source Address	BSS ID	-
2	0	1	Destination Address	BSS ID	Source Address	-
3	1	0	BSS ID	Source Address	Destination Address	-
4	1	1	Receiver Address	Transmitter Address	Destination Address	Source Address

Student Questions

- So does every device in this network have the same BSS ID, since they all belong to the same network?
  Yes.
- Can you go over the table again?
- When Address-4 is empty, does the frame not have 48 bits? Address-4 or Address-4 will be some specific number, like all 0.

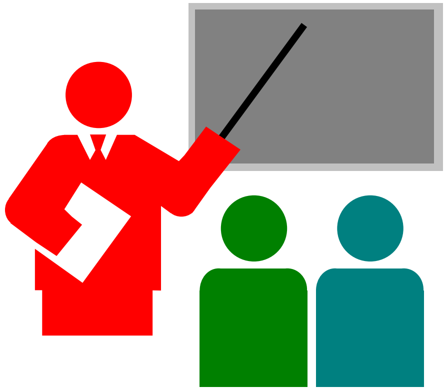
If the 4th address is not there, there is no Address-4 field. The header becomes shorter.

802.11 Power Management

- Station tells the base station its mode: Power saving (PS) or active
- Mode changed by power mgmt bit in the frame control header.
- All packets destined to stations in PS mode are buffered
- AP broadcasts a list of stations with buffered packets in its beacon frames: Traffic Indication Map (TIM)
- Subscriber Station (SS) sends a PS-Poll message to AP, which sends one frame. More bit in the header $\Rightarrow$ more frames.
- With 802.11e unscheduled Automatic Power Save Delivery (APSD): SS transmits a data or null frame with power saving bit set to 0. AP transmits all buffered frames for SS.
- With Scheduled APSD mode: AP will transmit at a pre-negotiated schedule. No need for polling.
- Hybrid APSD mode: PS-poll for some. Scheduled for other categories

Student Questions

Summary



1. 802.11 uses Frequency hopping, Direct Sequence CDMA, OFDM
2. 802.11 PHYs: 802.11, 802.11a, 802.11b, 802.11g
3. Allows both: Ad-Hoc vs. Infrastructure-based
4. 802.11 supports single FIFO Q. Uses SIFS, PIFS, DIFS

Student Questions

- How much do we need to know details like the exact makeup of Wi-Fi frames and header field values?

At least as much as on the slides (on the exam day) with or without a cheat sheet.

Homework 5

- Two 802.11 stations get frames to transmit at time t=0. The 3rd station (AP) has just finished transmitting data for a long packet at t=0 to Station 1. The transmission parameters are: Slot time=1, SIFS=1, DIFS=3, CWmin=5, CWmax=7. Assume that the pseudo-random number generated are 1, 3. The data size for both stations is three slots. Draw a transmission diagram. At what time the two packets will get acknowledged assuming no new arrivals?

Student Questions

Reading List

- IEEE 802.11 Tutorial, https://ptolemy.berkeley.edu/projects/ofdm/ergen/docs/ieee.pdf
- A Technical Tutorial on the IEEE 802.11 Protocol, http://www.sss-mag.com/pdf/802_11tut.pdf

Student Questions

Wikipedia Links

- http://en.wikipedia.org/wiki/Wireless_LAN
- http://en.wikipedia.org/wiki/IEEE_802.11
- http://en.wikipedia.org/wiki/Channel_access_method
- http://en.wikipedia.org/wiki/Direct-sequence_spread_spectrum
- http://en.wikipedia.org/wiki/Wi-Fi
- http://en.wikipedia.org/wiki/Distributed_Coordination_Function
- http://en.wikipedia.org/wiki/Carrier_sense_multiple_access
- http://en.wikipedia.org/wiki/Multiple_Access_with_Collision_Avoidance_for_Wireless
- http://en.wikipedia.org/wiki/Beacon_frame
- http://en.wikipedia.org/wiki/IEEE_802.11
- http://en.wikipedia.org/wiki/IEEE_802.11_(legacy_mode)
- http://en.wikipedia.org/wiki/IEEE_802.11_RTS/CTS
- http://en.wikipedia.org/wiki/List_of_WLAN_channels
- http://en.wikipedia.org/wiki/Point_Coordination_Function
- http://en.wikipedia.org/wiki/Service_set_(802.11_network)
- http://en.wikipedia.org/wiki/Wi-Fi_Alliance

Student Questions

Acronyms

- Ack Acknowledgement
- AP Access Point
- APSD Automatic Power Save Delivery
- BO Backoff
- BSA Basic Service Area
- BSS Basic Service Set
- BSSID Basic Service Set Identifier
- CA Collision Avoidance
- CD Collision Detection
- CDMA Code Division Multiple Access
- CFP Contention Free Period
- CRC Cyclic Redundancy Check
- CSMA Carrier Sense Multiple Access
- CTS Clear to Send
- CW Congestion Window
- CWmax Maximum Congestion Window

Student Questions

Acronyms (Cont)

- CWmin Minimum Congestion Window
- DA Destination Address
- DCF Distributed Coordination Function
- DIFS DCF Inter-frame Spacing
- DS Direct Sequence
- ESA Extended Service Area
- ESS Extended Service Set
- FH Frequency Hopping
- FIFO First In First Out
- GHz Giga Hertz
- IBSS Independent Basic Service Set
- ID Identifier
- IEEE Institution of Electrical and Electronics Engineers
- IFS Inter-frame spacing
- ISM Instrumentation, Scientific and Medical
- LAN Local Area Network

Student Questions

Acronyms (Cont)

MAC	Media Access Control
MHz	Mega Hertz
MIMO	Multiple Input Multiple Output
NAV	Network Allocation Vector
OFDM	Orthogonal Frequency Division Multiplexing
PCF	Point Coordination Function
PHY	Physical Layer
PIFS	PCF inter-frame spacing
PS	Power saving
RA	Receiver Address
RPR	Resilient Packet Ring
RTS	Ready to Send
SA	Source Address
SIFS	Short Inter-frame Spacing

Student Questions

Acronyms (Cont)

- SS Subscriber Station
- TA Transmitter's Address
- TIM Traffic Indication Map
- WEP Wired Equivalent Privacy
- Wi-Fi Wireless Fidelity
- WLAN Wireless Local Area Network

Student Questions

Scan This to Download These Slides

Raj Jain

http://rajjain.com

http://www.cse.wustl.edu/~jain/cse574-24/j_05lan.htm

Student Questions

Related Modules

CSE567M: Computer Systems Analysis (Spring 2013),
https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e_10TiDw

Recent Advances in Networking (Spring 2013),
https://www.youtube.com/playlist?list=PLjGG94etKypLHyBN8mOgwJLHD2FFIMGq5

CSE571S: Network Security (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u

Video Podcasts of Prof. Raj Jain's Lectures,
https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw

Student Questions