

# IEEE 802.11 Wireless LANs

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# References

- 802.11 Wireless Networks: The Definitive Guide, M. Gast, O'Reilly, 2002\*
- ANSI/IEEE Std 802.11, 1999 Edition
- ANSI/IEEE Std 802.11b-1999
- ANSI/IEEE Std 802.11a-1999

\*Most drawings used in the lectures are from this book



## IEEE 802 Standards & OSI Model



- Observe 802.11 MAC is common to all 802.11 Physical Layer (PHY) standards
- 802.11 PHY is split into Physical Layer Convergence Procedure (PLCP) and Physical Medium Dependent (PMD) sublayers



# **Related Standards**

### Bluetooth

- Originally intended for interconnecting computing and communication devices
- HIPERLAN
  - European standard for Wireless LANs
- IEEE 802.16 Broadband Wireless
  - Addresses needs of fixed and mobile broadband wireless access replacing fibers, cables, etc.



## 802.11 Standards and Spectrum

Key Standards	Max Rate	Spectrum (U.S.)	Year
802.11	2 Mbps	2.4 GHz	1997
802.11a	54 Mbps	5 GHz	1999
802.11b	11 Mbps	2.4 GHz	1999
802.11g	54 Mbps	2.4 GHz	2003

- 2.4 2.5 GHz for all above except 802.11a (referred to as C-Band Industrial, Scientific, and Medical (ISM))
  - Microwave ovens and some cordless phones operate in the same band
- 802.11a uses Unlicensed National Information Infrastructure bands
  - □ 5.15 5.25 GHz
  - □ 5.25 5.35 GHz
  - □ 5.725 5.825 GHz



# **Basic Service Sets (BSSs)**



- Independent BSSs are also referred to as Ad Hoc BSSs
- Observe that the AP in an Infrastructure BSS is the centralized coordinator and could be a bottleneck



# **Extended Service Set (ESS)**



Inter Access Point protocol (IAPP) is not yet fully standardized



# **Network Services**

- Distribution
- Integration
- Association
- Reassociation
- Disassociation
- Authentication
- Deauthentication
- Privacy
- MAC Service Data Unit (MSDU) delivery



# **Seamless Transition**

- Seamless transition between two BSSs within an ESS
- Between ESSs, transitions are not supported





# 802.11b: HR/DSSS\* PHY

- Use Complementary Code Keying (CCK) instead of Differential Quadrature Phase Shift Keying (DQPSK) used at lower rates
  - Provides good performance in presence of interference and multipath fading
- 4-bit (for 5.5 Mbps) or 8-bit (for 11 Mbps) symbols form MAC layer arrive at 1.375 million symbols per second
- Each symbol is encoded using CCK code word

   {e<sup>j(φ1+φ2+φ3+φ4)</sup>, e<sup>j(φ1+φ3+φ4)</sup>, e<sup>j(φ1+φ2+φ4)</sup>, -e<sup>j(φ1+φ4)</sup>, e<sup>j(φ1+φ2+φ3)</sup>,
   e<sup>j(φ1+φ3)</sup>, -e<sup>j(φ1+φ2)</sup>, e<sup>jφ1</sup>
   }
  - $\square$   $\phi$ 1,  $\phi$ 2,  $\phi$ 3, and  $\phi$ 4 are decided by symbol bits

\*High Rate Direct-Sequence Spread Spectrum



# 802.11b: HR/DSSS PHY - 2

- Uses same channels as by the low rate DS
- In US, channels 1-11 (with center frequencies at 2.412 2.462 GHz and 5 MHz distance) are available
- For 11 Mbps, Channels 1, 6, and 11 give maximum number of channels with minimum interference





# 802.11b: HR/DSSS PHY - 3





Optional Short PLCP format is offered for better efficiency



- Fundamental Orthogonal Frequency Division Multiplexing (OFDM) work was done in 1960s, and a patent was issued in 1970
- Basic idea is to use number of subchannels in parallel for higher throughput
- Issues with 802.11a
  - Denser Access Point deployment needed due to higher path loss
  - Higher power need



- OFDM is similar to Frequency Division Multiplexing except it does not need guard bands
  - But need guard times to minimize inter-symbol and inter-carrier interference
- Relies on "orthogonality" in frequency domain





 In U.S., there are 12 channels, each 20 MHz wide

Regulatory domain	Band (GHz)	Operating channel numbers	Channel center frequencies (MHz)
United States	U-NII lower band (5.15–5.25)	36 40 44 48	5180 5200 5220 5240
United States	U-NII middle band (5.25–5.35)	52 56 60 64	5260 5280 5300 5320
United States	U-NII upper band (5.725–5.825)	149 153 157 161	5745 5765 5785 5805



Spectrum layout



- Each channel is divided into 52 subcarriers: 48 are used for data
- PLCP Protocol Data Unit (PPDU) format



- PHY uses rate of 250K symbols per second
- Each symbol uses all 48 subcarriers
- Convolution code is used by all subcarriers



#### Modulation and Coding

Data rate (Mbits/s)	Modulation	Coding rate (R)	Coded bits per subcarrier (N <sub>BPSC</sub> )	Coded bits per OFDM symbol (N <sub>CBPS</sub> )	Data bits per OFDM symbol (N <sub>DBPS</sub> )
6	BPSK	1/2	1	48	24
9	BPSK	3/4	1	48	36
12	QPSK	1/2	2	96	48
18	QPSK	3/4	2	96	72
24	16-QAM	1/2	4	192	96
36	16-QAM	3/4	4	192	144
48	64-QAM	2/3	6	288	192
54	64-QAM	3/4	6	288	216

# **MAC: Access Modes**

- MAC Access Modes:
  - Distributed Coordination Function (DCF)
    - Based on Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)
  - Point Coordination Function (PCF)
    - Restricted to Infrastructure BSSs
    - Not widely implemented
    - Access Point polls stations for medium access





# Main Ideas of MAC: CSMA/CA

- Interframe Spacing (IFS)
  - Short IFS: For atomic exchanges
  - PCF IFS: For prioritized PCF access
  - DCF IFS: For Normal DCF access
  - Extended IFS: For access after error
- Medium Access



# Main Ideas of MAC: CSMA/CA - 2

- If medium is idle for DIFS interval after a correctly received frame and backoff time has expired, transmission can begin immediately
- If previous frame contained errors, medium must be free for EIFS
- If medium is busy, access is deferred until medium is idle for DIFS and exponential backoff
- Backoff counter is decremented by one if a time slot is determined to be idle
- Unicast data must be acknowledged as part of an atomic exchange



## **Interframe Spacing**

- Interframe Spacing values are physical layer dependent
- SIFS and Slot\_Time are explicitly specified, and the others are derived
  - $\Box PIFS = SIFS + Slot_Time$
  - $\Box DIFS = SIFS + 2 \cdot Slot_Time$
  - EIFS = SIFS + DIFS + (Ack\_Time @ 1 Mbps)
- For 802.11a and 802.11b
  - SIFS is 16  $\mu$ s and 10  $\mu$ s, respectively
  - $\hfill\square$  Slot\_Time is 9  $\mu s$  and 20  $\mu s,$  respectively



## **Contention Window**

- Backoff is performed for R slots: R is randomly chosen integer in the interval [0, CW]
- CWmin  $\leq$  CW  $\leq$  CWmax
  - $\Box$  CW<sub>min</sub> = 31 slots and CW<sub>max</sub> = 1023 slots (for 802.11b)
  - □ Up to  $CW_{max}$ ,  $CW = (CW_{min} + 1) \cdot 2^n 1$ , where n = 0, 1, 2, ... is (re)transmission number

Initial attempt	Previous frame	31 slots
1st retransmission	Previous frame	63 slots
2nd retransmission	Previous frame	127 slots
3rd retransmission	Previous frame	255 slots
4th retransmission	Previous frame	511 slots
5th retransmission	Previous frame	Contention window=1,023 slots
6th retransmission	Previous frame	Contention window=1,023 slots

# **Error Recovery**

- Each frame is associated with a retry counter based on frame size as compared to RTS/CTS threshold
  - Short retry counter
  - Long retry counter
- Fragments are given a maximum lifetime by MAC before discarding them



## **WLAN Problems**

#### Hidden Terminal and Exposed Terminal problems





# **RTS/CTS Clearing**

- RTS/CTS Clearing
- Used for frames larger than RTS/CTS threshold
- Tradeoff between overhead and retransmission costs



## **Virtual Carrier Sensing**

 Virtual Carrier Sensing using Network Allocation Vector (NAV)



## **Fragmentation Burst**

 Fragmentation and RTS/CTS thresholds are typically set to the same value





# **Framing Details: Format**

### Generic 802.11 MAC

Frame	bytes 2	2	6	6	6	2		6	1 1	0-	-2,312	4
	Frame	Duration/ /	Address 1	Address 2	Address	B Sei	<b>P</b> *	Addres	ss 4	Fram Body	e sis	FCS
			<u>, , , , l</u>	11111	1111			11	1.1	1	2	
Frame	bits	2	2	4		1 1-	-1-	-1-	-1-	_1_	_1	_1
		Protocol	Type=data	Sub type	To	DS From DS	More Frag	Retry	Pwr Mgmt	More Data	WEP	Order
Control Field		0 1	2 3	4 5 6	5 7	8 9	10	11	12	13	14	15

#### Sequence Control Field

2	2	6	6	6	2	6	0-2,312	4
Frame Control	Duration/	Address 1	Address 2	Address 3	Seq- cti	Address 4	Frame Body	FCS
		0 Fra	1 2 3 gment number	4 5 6	7 8	9 10 1 Sequence number	1 12 13	14 15
				<u> </u>		<u> </u>	1 1	

# Framing Details: Frame Types

- Type and Subtype Identifiers
  - Management Frames
  - Control Frames
  - Data Frames

Subtype value	Subtype name
Management frames (type=00) <sup>a</sup>	
0000	Association request
0001	Association response
0010	Reassociation request
0011	Reassociation response
0100	Probe request
0101	Probe response
1000	Beacon
1001	Announcement traffic indication message (ATIM)
1010	Disassociation
1011	Authentication
1100	Deauthentication
Control frames (type=01) <sup>b</sup>	
1010	Power Save (PS)-Poll
1011	RTS
1100	CTS
1101	Acknowledgment (ACK)
1110	Contention-Free (CF)-End
1111	CF-End+CF-Ack
Data frames (type=10) <sup>c</sup>	and the set of the second s
0000	Data
0001	Data+CF-Ack
0010	Data+CF-Poll
0101	CF-Ack (no data transmitted)
0110	CF-Poll (no data transmitted)
0111	Data+CF-Ack+CF-Poll
(Frame type 11 is reserved)	



## **Broadcast/Multicast**

 No Acknowledgements for Broadcast or Multicast frames





## **NAV for Fragmentation**

- Fragmentation threshold provides tradeoff between overhead and retransmission costs
- Chaining of NAV to maintain control of the medium



# NAV for RTS/CTS and Power Save (PS)-Poll

RTS/CTS Lockout

- Immediate PS-Poll Response
- Deferred PS-Poll
  Response



SIES

## **Data Frames and Addresses**

#### Generic Data Frames



- Addressing and DS Bits
  - BSSID is MAC address of AP WLAN interface

Function	ToDS	FromDS	Address 1 (receiver)	Address 2 (transmitter)	Address 3	Address 4
IBSS	0	0	DA	SA	BSSID	not used
To AP (infra.)	1	0	BSSID	SA	DA	not used
From AP (infra.)	0	1	DA	BSSID	SA	not used
WDS (bridge)	1	1	RA	TA	DA	SA



## **Illustrations of use of Addresses**

- Frames to Distribution
  System
- Frames from
  Distribution System
- Wireless Distribution
  System





## **RTS/CTS Control Frames**

#### RTS Frame

					0				4	
ntrol	Duration	Receiver Address		Tra	nsmitter	Address			FCS	
2	2	4		-1-	-1-	-1-	-1-	_1_	_1_	1
Protocol	Type = control	4   5   6   7 Sub type = RTS	To DS	From DS	More Frag	Retry	Pwr Mgmt	More Data	WEP	Orde
	2 1 1 Protocol	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	2  2  4  1  1  1  1    1  2  3  4  5  6  7  8  9  10  11    Protocol  Type = control  Sub type = RTS  To DS  From DS  More Frag  Retry    0  1  0  1  0  1  0  0  0	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$				

#### CTS Frame





## Ack and PS-Poll Control Frames

#### Acknowledgement Frame

	hvte	\$ 2	2	MAC hea	der –	6				4			
	U) le	Frame Control	Duration		Rec	eiver Ado	dress		1	FCS			
oits	12	2		4		1		-1-	-1-	-1-	_1_	_1_	1
	Protocol	Type = control	Sub ty	pe = ACH	<	To DS	From DS	More Frag	Retry	Pwr Mgmt	More Data	WEP	Order
			A REAL PROPERTY OF THE PARTY OF		-	1	0		0	-	0	0	

Power-Save Poll (PS-Poll) Frame



## **Management Frames**

#### Generic Management Frames





## **Fixed-Length Management Fields**

- Beacon Interval Field
  - In 1024 μs Time Units (TUs)
  - Typically 100 TUs or about 0.1 Seconds



- Capability Information
  - Used in Beacon, Probe request and Probe Response Frames





## Fixed-Length Management Fields - 2

#### Listen Interval

 Number of Beacon Intervals a station waits before listening to Beacon frames

0	1	2	3	4	5	6	7	8	9 '	10	11 '	12	13	14	15
							Listen i	nterval							

#### Timestamp

- Allows synchronization
- Number of microseconds timekeeper has been active



## **Management Information Elements**



## Main Management Frames

#### Beacon Frame

	-			- MAC h	eader					
ytes	2	2	6	anter a la	6	6	2	Variabl	le	4
	Frame Control	Duration	DA		SA	BSSID	Seq- cti	Frame Body	~~~~	FCS
oytes		8	2	-2	Variable	7	2	8	4	Variable
		Timestamp	Beacon	Capability Info	SS ID	FH ParameterSet	DS Parameter Set	CF Parameter Set	IBSS Parameter Set	TIM
	L		- Mandatory	, —				— Optional ——		

#### Probe Request Frame

	-			MAC header			Fra	ame body ———	10200
bytes	2	2	6	6	6	2	Variable	Variable	4
	Frame Control	Duration	DA	SA	BSSID	Seq- cti	SS ID	Supported Rates	FCS

#### Probe Response Frame



## Main Management Frames - 2

#### Authentication Frames

		1	MA	Cheader —	and the second second			- Frame bo	dy		1
bytes	2	2	6	6	6	2	2	2	2	Variable	4
	Frame Control	Duration	DA	SA	BSSID	Seq. ctl.	Authentication Algorithm Number	Authentication Transaction Seq. No.	Status Code	Challenge Text	FCS

#### Association Request



#### (Re)Association Response

			M	AC header —				— Fra	me body -		7
bytes	2	2	6	6	6	2	2	2	2	Variable	4
	Frame Control	Duration	DA	SA	BSSID	Seq- cti	Capability Info	Status Code	Association ID	Supported Rates	FCS

## Management Operations: Scanning





## Management Operations: Authentication and Association

#### Shared key Authentication Exchange

Makes use of WEP



#### Association Procedure





## Management Operations: Buffered Frame Retrieval

Unicast Buffered Frames



Broadcast and Multicast Buffered Frames





# **PCF: Mechanism**

- AP polls stations on its list, and maintains control of the medium
  - Announces CFPMaxDuration in Beacon
  - Transmissions are separated by PIFS
  - Each CF-Poll is a license for one frame

 Basic PCF exchanges and timing







# **PCF Frames**

Data, Ack, and Poll can be combined in one frame

- Data and Poll must be for the same station
- Usage of Data + CF-Ack +
  CF-Poll



SIFS

CF-Poll Usage

# PCF Frames - 2

CF-Ack + CF-Poll Usage

- CF End
- CF Parameter Set



Count/Period in DTIM intervals, Duration in TUs

bytes	1	1	1	1	2	2
	Element ID	Length	CFP	CFP	(EP MaxDuration	(EP DurRemaining
	4	6	Count	Period		err banenannig



# **QoS: Shortcomings of PCF**

- PCF falls short of guaranteeing desired QoS due to
  - Beacon frame delays beyond Target Beacon Transition Time (TBTT)
  - Unpredictable demand from the polled station
- 802.11e proposes an enhanced MAC protocol



# Enhanced DCF of 802.11e

- Introduces Traffic Categories (TCs)
- Following attributes are functions of TC
  - AIFS (arbitration IFS)
  - $\Box$  CW<sub>min</sub> and CW<sub>max</sub>
  - PF (Persistence Factor)
  - TXOP (Transmission Opportunity) Start Time & Duration



<u>TOC</u> – <u>802.11</u> – QoS (802.11e)

# Intra-station Virtual Backoff (802.11e)

 Intra-Station backoff to differentiate QoS across TCs





# Hybrid Coordination Function of 802.11e

- Hybrid Coordination (HC) can initiate polling during contention period using PIFS
- HC can learn desired TXOPs by mobile stations
- HC uses own scheduling algorithms



# **Security Goals**

### Security solution should provide

- Confidentiality
- Authentication
- Integrity
- Maintain processing required to "reasonable" levels



## **Security: States of Mobile Stations**

- Authentication and Association States
  - Allowed frames depend on the state



#### Class 1 Frames

Control	Management	Data
Request to Send (RTS)	Probe Request	Any frame with ToDS and FromDS false (0)
Clear to Send (CTS)	Probe Response	and the for and here interested at
Acknowledgment (ACK)	Beacon	
CF-End	Authentication	
CF-End+CF-Ack	Deauthentication	
	Announcement Traffic Indication Message (ATIM)	

#### Class 2 Frames

Control	Management	Data	
None	Association Request/Response	None	
	Reassociation Request/Response		
	Disassociation		
	Class 3 Frar	nes	

Control	Management	Data
PS-Poll	Deauthentication	Any frames, including those with either the ToDS or FromDS bits set



# Wired Equivalent Privacy (WEP)

- Based on Symmetric Secret Key
- A Keystream is created using the Secret Key
- Generic Stream Cipher Operation



# **WEP Encipherment**

- WEP uses 40 bit RC4 secret key and 24 bit Initialization Vector (IV)
- Crucial aspect is how to create Keystream using Pseudorandom Number Generator



- WEP Frame Extensions
- Frame body and ICV are encrypted

<b></b>	IV head	ler —				
Frame header	Initialization vector	Pad	Key ID	Frame body	Integrity check value	FCS



# **WEP Decipherment**

WEP Decipherment using Symmetric Secret Key





## **WEP based Authentication**

#### WEP based authentication using Secret Key





# **WEP Flaws**

- Secret key distribution
- Cipher Stream creation needs to be based true random generator
- ICV collision allows attacker to decipher
- A weak class of keys and known first byte of payload



# 802.1x Authentication

- 802.1x provides strong authentication
- Based on IETF's Extensible Authentication Protocol (EAP)



# 802.1x Architecture

- 802.1x Architecture
  - Typical EAP Exchange

 EAP can also be used for Dynamic exchange



# Flaws of 802.1x

#### Session Hijacking



- Man-in-the-middle attacks
- Denial of service attacks ...



# **Take Away Points**

- Hidden and exposed terminals
- MAC based on a CSMA/CA strategy
  - Medium access scheme
  - RTS/CTS
  - NAV
- Differences with Ethernet
- Access prioritization with different IFSs
  - RTS/CTS/Data/Ack atomic exchange
- Don't need to remember
  - Frame formats
  - Physical layer details (modulation, etc.)
  - 802.11e details
  - Parameter values (will be provided if required for a problem)
  - See Wi-Fi Study Guide on the class syllabus page for more information

