

Wireless Networks

Wireless infrastructure, ad hoc, and
mesh networks

RF propagation: Fading

- Time variation in signal strength caused by changes in transmission medium (or path)
- Causes:
 - Free space path loss
 - Multi-path propagation
 - Mobility

Free space path loss

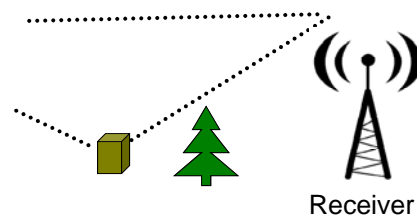
$$P_r \approx \frac{P_t \times \lambda^2}{(4\pi d)^2} = \frac{P_t \times c^2}{(4\pi f d)^2}$$

- Note: P_r is a decreasing function of d, f
- For 802.11b, typical $P_t = 20$ dBm (100 mW), $P_r = -80$ dBm (0.00000001 mW)

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Multi-path propagation

- RF signal reaches receiver from multiple propagation routes
– reflection, scattering, etc.
- Multiple signals with amplitude and phase shifting



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Single input, single output systems



$$C = B \times \log_2 \left(1 + \frac{S}{N} \right)$$

- Independent paths between antennas -- boost SNR through diversity

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Multiple input, multiple output systems

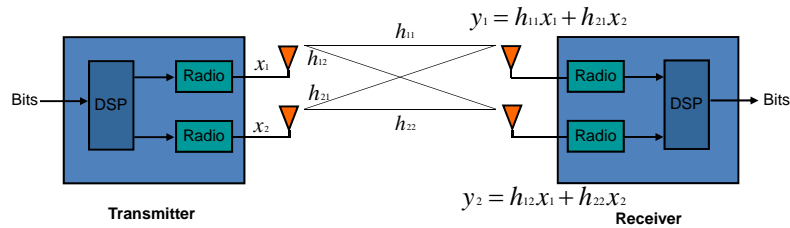


- Use multipath to our advantage!
- Capacity increase linear with no. of antennas!

– For an $X \times Y$ MIMO: $C = \min(X, Y) \times B \times \log_2 \left(1 + \frac{S}{N} \right)$

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MIMO systems



- Channel gain \mathbf{H} represents both the amplitude attenuation and phase shift
- Training fields in MIMO packet headers to estimate \mathbf{H}

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Carrier Sense Multiple Access

- Listen to medium; wait until it is free before talking
- Ethernet uses CSMA with collision detection
- CD not feasible in wireless
 - Transmit signal much stronger than received
 - Collision happens at receiver, not transmitter!

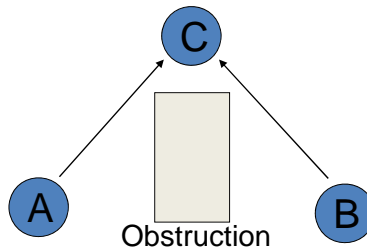
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CSMA/CA

- Use CSMA with Collision Avoidance
- RTS/CTS to vacate spectrum around receiver
 - T sends RTS to R; R responds with CTS
 - Neighbors of R defer tx. for duration of this transaction
- RTS/CTS can also resolve (some) hidden terminals

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Hidden terminal problem



- Simultaneous tx. by nodes that cannot hear each other (nodes A & B) : collision at C
- RTS/CTS to reserve channel – virtual CS
 - Small control frames reduce the probability of collisions
 - What if B is outside tx. range (but within interference range) of C?

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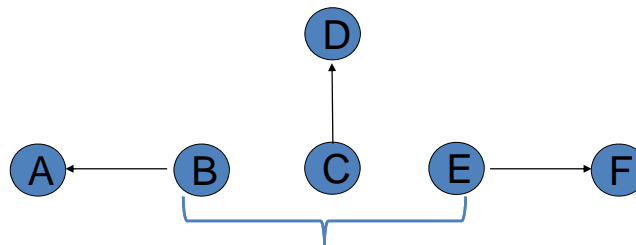
Exposed terminal problem



- Node in CS range of transmitter, but out of interference range of receiver
 - Prevents C from transmitting to D when B transmits to A
- In principle, RTS/CTS can solve exposed terminal
 - C transmits when it hears B's RTS but not A's CTS
 - Problematic with 802.11 protocol that uses ACKs

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Flow-in-the-middle problem

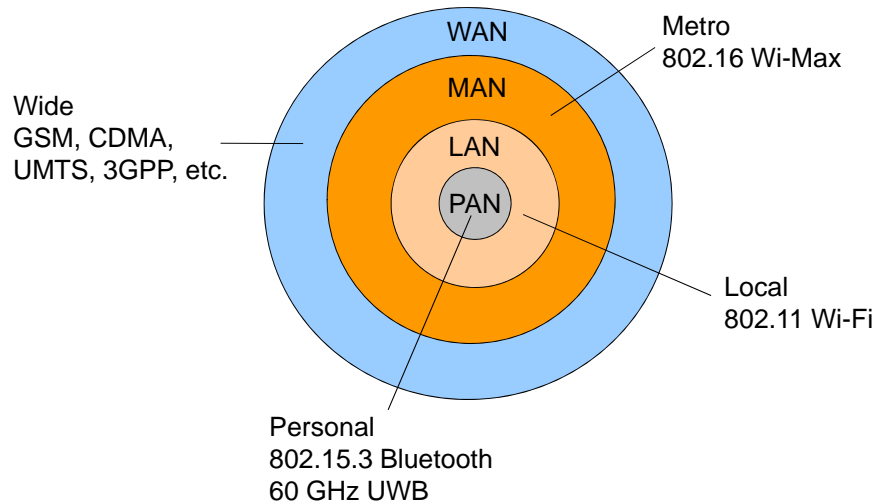


C within CS range of B and E.
B and E outside mutual CS range

- Node C starves, while B and E are at 100 % utilization
- Explicit feedback needed to limit B and E

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Part of wireless landscape...



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History of IEEE 802.11

- **1989:** FCC authorizes Industrial, Scientific, and Medical (ISM) band
 - 902–928 MHz, 2.4–2.5 GHz, 5.725–5.875 GHz
- **1990:** IEEE 802.11 working group started
- **1997:** 802.11 standard approved
- **1998:** FCC authorizes Unlicensed National Information Infrastructure (U-NII) band
 - 5.15–5.25 GHz (U-NII-1), 5.25–5.35 GHz (U-NII-2), 5.725–5.825 GHz (U-NII-3)
- **1999:** 802.11 a, b ratified

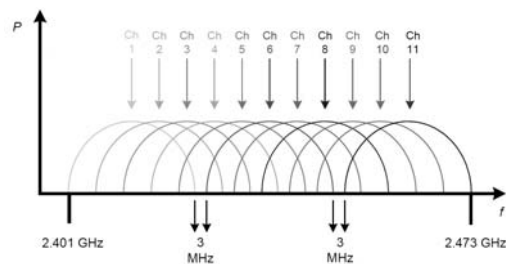
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History of IEEE 802.11 (contd.)

- **1999:** Wi-Fi Alliance (initially WECA) certification established
- **2003:** 802.11 g ratified
- **2003:** FCC allocates 5.47-5.725 GHz (U-NII-2-Extended)
- **2009:** 802.11 n ratified

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2.4 GHz ISM band



- 11 channels, (22 MHz each for 802.11b, 20 MHz for 802.11g)
 - 3 non-overlapping channels

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5 GHz U-NII band

- Non-overlapping channels (20 MHz each for 802.11a)
 - 4 each in U-NII-1, U-NII-2, and U-NII-3
 - 11 in U-NII-2 Extended
- Variable power limits: 50 mW for U-NII-1, 250 mW for U-NII-2, 1 W for U-NII-3
- 5 GHz spectrum has less contention, but smaller range

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White spaces

- Freed-up TV spectrum from analog to digital transition
 - Analog (6 MHz channels, 2-69)
 - VHF: 54-72 MHz, 76-88 MHz, 174-216 MHz
 - UHF: 470-806 MHz
 - 2009 digital TV transition frees up channels 52-69
- Broadband and mobile services – ‘Wi-Fi on steroids’
 - Rural area (e.g., WRAN IEEE 802.22) and mobile
- Spectrum to be shared with ‘primary’ users
 - Sep. 2010: FCC rules that devices can coordinate access via online database

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802.11 variants

- 802.11
 - 2 Mb/s and 1 Mb/s link rate
 - 900 MHz and 2.4 GHz ISM bands
- 802.11b
 - 11 Mb/s, 5.5 Mb/s, 2 Mb/s, and 1 Mb/s
 - 2.4 GHz ISM band
- 802.11a
 - Up to 54 Mb/s link rate
 - 5 GHz U-NII band
- 802.11g
 - Up to 54 Mb/s link rate (backwards compatible with 802.11b)
 - 2.4 GHz ISM band

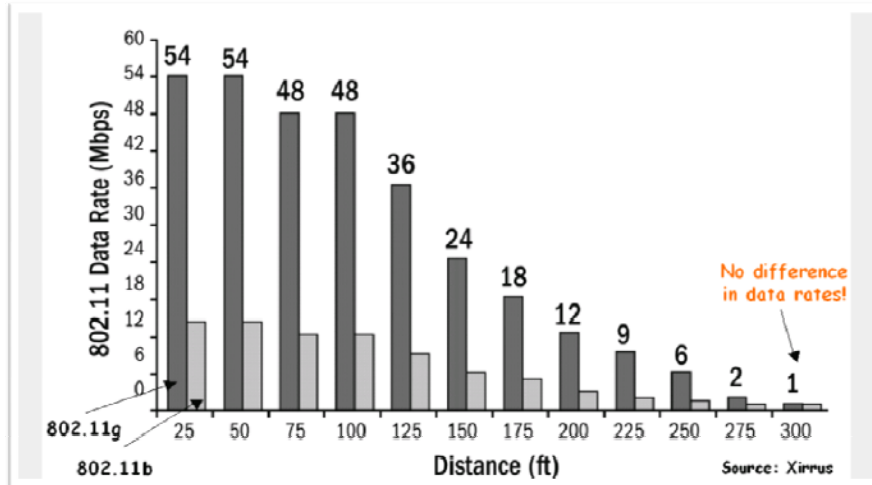
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802.11n

- Backwards compatible with 802.11 a/b/g
- Max. link rate up to 600 Mb/s
 - Up to 4 spatial streams
 - Channel bonding (20 & 40 MHz channels)
 - PHY/MAC layer optimizations

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Data rate vs. range



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802.11 Standards

- 802.11, 802.16, 802.20, 802.22

Network								
Data Link	LLC Sublayer	802.1 Overview, Architecture, Management, Internetworking	802.2 Logical Link Control					
	MAC Sublayer		CSMA /CD	Wireless Local Area Networks	Wireless Personal Area Networks	Broadband Wireless Access	Mobile Broadband Wireless Access	Wireless Regional Area Networks
Physical			802.3	802.11	802.15	802.16	802.20	802.22

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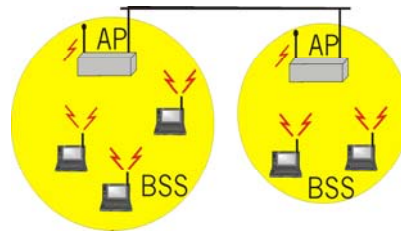
802.11 Standard and Amendments

Ratified Amendments		Amendments under Development	
a	54 Mbit/s 5 GHz PHY (9/1999)	j	Japanese 5 GHz Standard
b	11 Mbit/s 2.4 GHz PHY (9/1999)	k	Radio Resource Measurement
d	Compliance in multiple regulatory domains (6/2001)	m	Standard Maintenance
g	54 Mbit/s 2.4 GHz PHY (6/2003)	n	High Throughput
h	Transmit Power Control, Dynamic Channel Selection (12/2003)	r	Fast Roaming
i	Security Enhancements (6/2004)	s	Extended Service Set
e	Quality of Service (9/2005)	u	Interworking with External Networks
		v	Wireless Network Management
		w	Protected Management Frames

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IEEE 802.11 Wireless LAN

- IEEE 802.11 standard:
 - PHY and MAC protocol
 - Radio spectrum: 900 MHz, 2.4 GHz, 5 GHz
- Basic Service Set (BSS) :
 - Mobile stations
 - Access Point (AP)
- BSSs combine to form Distributed System (DS)



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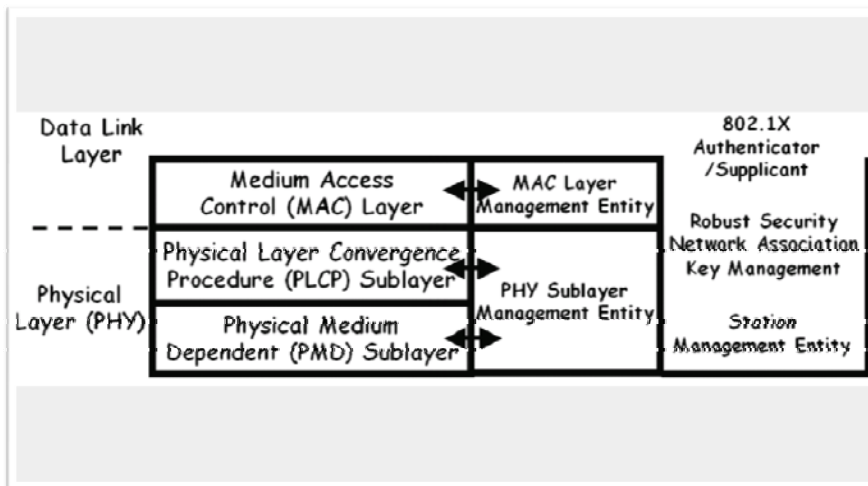
Ad hoc networks

- **Ad hoc network:** 802.11 stations form a network without AP: Independent BSS
- Applications:
 - “laptop” meeting in conference room, car
 - interconnecting ‘personal’ devices
 - battlefield
- IETF MANET (Mobile Ad hoc Networks) working group



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IEEE 802.11 Reference Model



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Physical layer

- Divided into 2 sub-layers
 - Physical Medium Dependent (PMD) sub-layer
 - Responsible for various characteristics of wireless medium
 - Defines modulation and coding for tx. and recv. data
 - Physical Layer Convergence Protocol (PLCP) sub-layer
 - Maps the MAC Protocol Data Units (MPDUs) into PLCP Service Data Units (PSDUs) required for PMD
 - Performs carrier sensing for MAC

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MAC layer

- Interface with functions used by higher layer protocols
 - Fragmentation, error recovery, mobility management, power, etc.
 - Functions that allow MAC to hide unique characteristics of physical layer from higher layers
- Two coordination functions for medium access:
 - (optional) Point Coordination Function (PCF)
 - Contention-free access through a point coordinator
 - (mandatory) Distributed Coordination Function (DCF)
 - Contention-based access based on CSMA/CA
 - Can operate in IBSS mode

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Interframe space (IFS)

- DCF enforces tx. priority through various IFS
 - Short IFS (SIFS)
 - Highest priority tx. e.g., transmitting CTS, ACK
 - 10 μ s for 802.11b, 16 μ s for 802.11a/g
 - DCF IFS (DIFS)
 - Min. medium idle duration before commencing tx.
 - 50 μ s for 802.11b, 34 μ s for 802.11a/g

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DCF operation

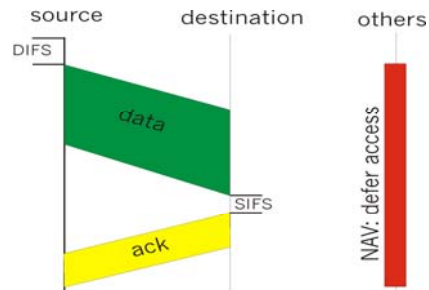
- 802.11 sender
 - 1. If channel idle for DIFS interval, transmit frame
 - 2. If channel busy, then start a random backoff timer
 - Count down timer when channel idle
 - Tx. when timer expires
 - If no ACK within SIFS, double random backoff interval, repeat step 2.
- 802.11 receiver
 - If frame received OK, send ACK after SIFS interval

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DCF operation (contd.)

Sender

- if sense channel idle for **DIFS** then transmit entire frame (no collision detection)

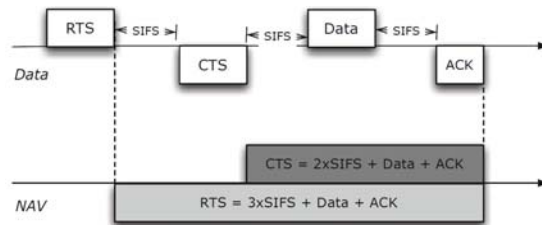


Receiver:

- if received OK then return ACK after SIFS

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Virtual carrier sensing in DCF : NAV

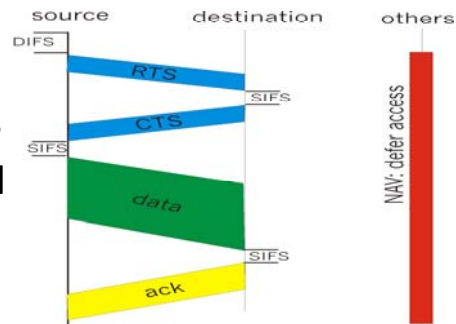


- RTS, CTS, and Data have 'Duration' field
- Neighbors set their Network Allocation Vector (NAV)
 - Defer channel access for duration of NAV

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Collision Avoidance: RTS-CTS exchange

- CSMA/CA: explicit channel reservation
 - sender sends RTS
 - receiver replies with CTS
- CTS reserves channel for sender, notifying (possibly hidden) stations



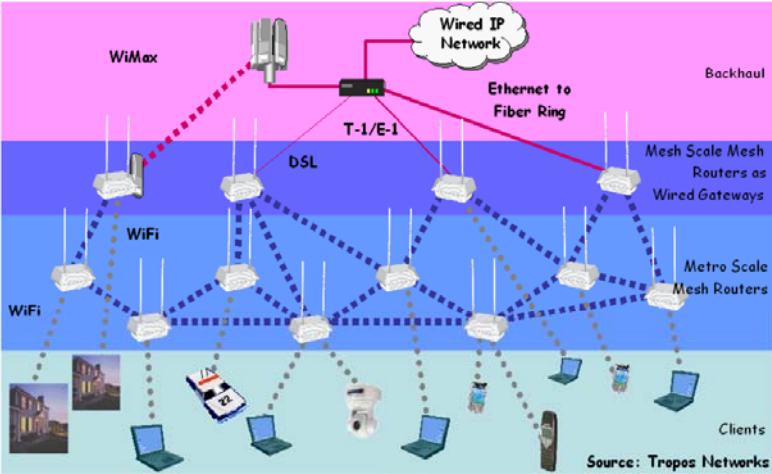
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IEEE 802.11 roaming

- Supports mobility with walking speeds up to 10 Km/h
- Handoff procedure:
 - Client decides to roam
 - Signal strength, missed beacons, etc.
 - Determine new AP
 - Preemptive discovery vs. roam-time discovery
 - Initiate association request
- Complete layer-2 roaming before beginning layer-3 roaming (if required)

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Mesh Networks



Cisco mesh network at KAUST



Why Mesh Networks?

- Convenient network access
 - Connection can be made from any available close-by AP
 - No extra equipment required
- Multiple connection paths
 - Improve connection reliability
 - QoS and better data routing
- Scalable network deployment
 - Can start with few AP and increase upon device availability
 - Large-scale network can be created easily.
 - Large number of clients can be served easily

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Mesh Routing

- Some routers act as gateways to Internet, therefore not completely ad-hoc
- Routing can be done by both clients and AP

Vendor	Product	Radios per Router	Radios for Client Access	Radios for Backbone (Backhaul)	Ethernet Ports
BelAir	BelAir 200	1, 2 or 4	One 802.11b/g	Up to 3 proprietary 5 GHz	8
Cisco	Aironet 1500	2	One 802.11b/g	One 802.11a	0
Firetide	HotPort 3203	1	One 802.11a/b/g	Same radio as client	2
Nortel	AP 7220	2	One 802.11b	One 802.11a	1
Strix	OWS 3600	2 to 6	Up to three 802.11b/g	Up to three 802.11a	1
Tropos	5210 Mesh	1 to 2	One 802.11b/g	Same radio as client	1

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