Chapter 7

Wireless and Mobile Networks

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Wireless and Mobile Networks: context

- more wireless (mobile) phone subscribers than fixed (wired) phone subscribers.
- more mobile-broadband-connected devices than fixed-broadband-connected devices devices.
  - 4G/5G cellular networks now embracing Internet protocol stack, including SDN

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Wireless and Mobile Networks: context

- Advantages of Cell Phones
  - Anywhere
  - Anytime
  - Untethered access to global telephone network via portable lightweight device
- More recently, laptops, smartphones, tablets are wirelessly connected to Internet via cellular or WiFi network.
- Increasingly, devices such as gaming consoles, thermostats, home security systems, home appliances, watches, eye glasses, cars traffic control systems and more are being wirelessly connected to Internet




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Wireless and Mobile Networks: context

- two important (but different) challenges
  - wireless: communication over wireless link
  - mobility: handling the mobile user who changes point of attachment to network

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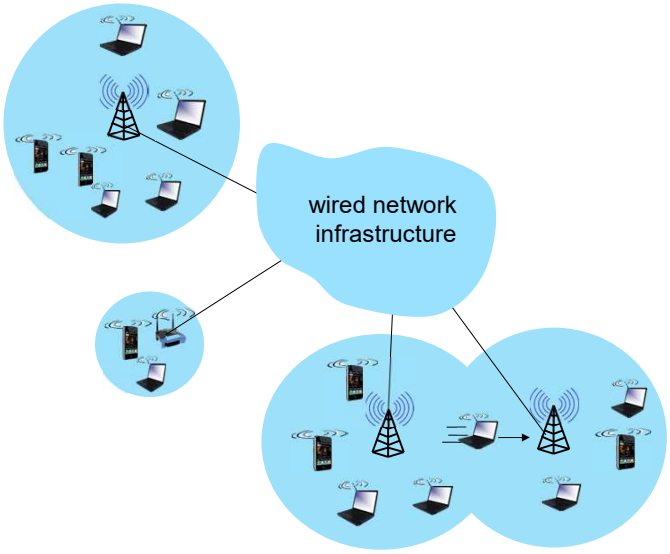
Elements of a wireless network



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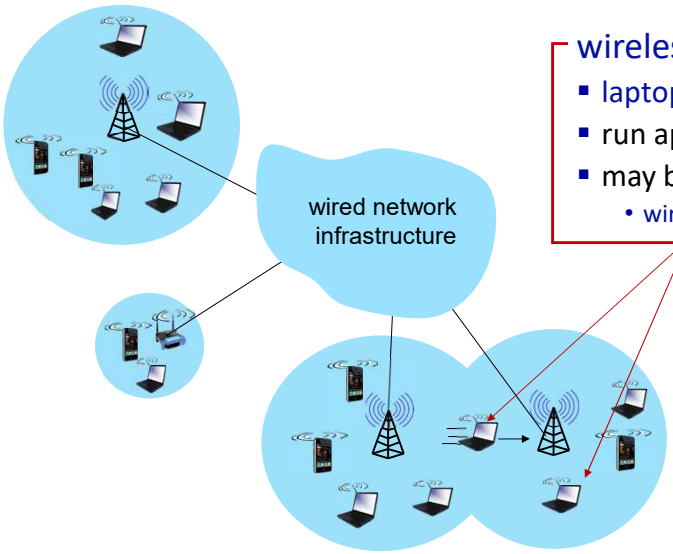
Elements of a wireless network



wireless hosts

- laptop, smartphone, IoT
- run applications
- may be stationary (non-mobile) or mobile
  - wireless does *not* always mean mobility!

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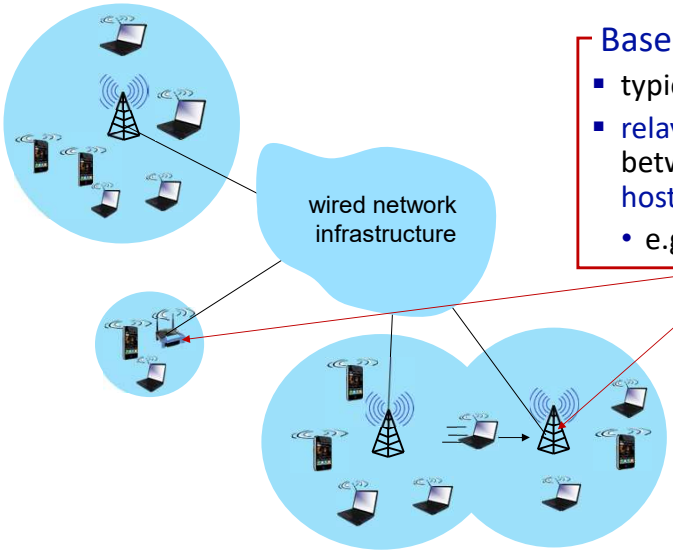
Elements of a wireless network



Base Station

- typically connected to wired network
- relay - responsible for sending packets between wired network and wireless host(s) in its "area"
  - e.g., cell towers, 802.11 access points

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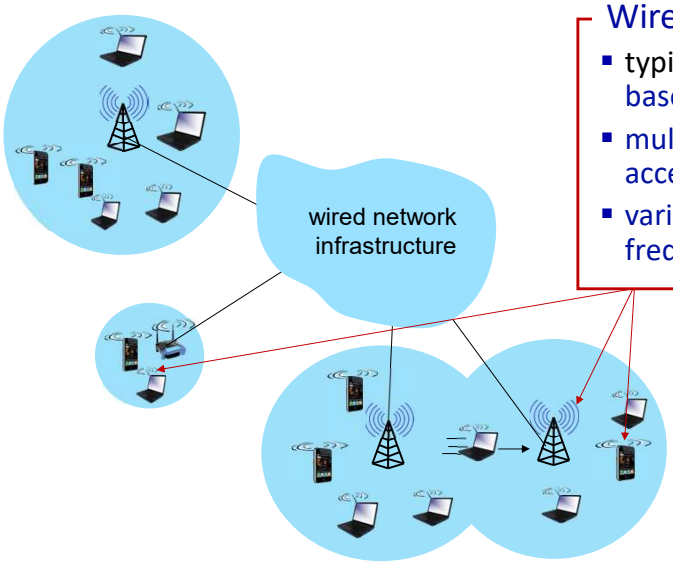
Elements of a wireless network



Wireless Link

- typically used to connect mobile(s) to base station, also used as backbone link
- multiple access protocol coordinates link access
- various transmission rates and distances, frequency bands

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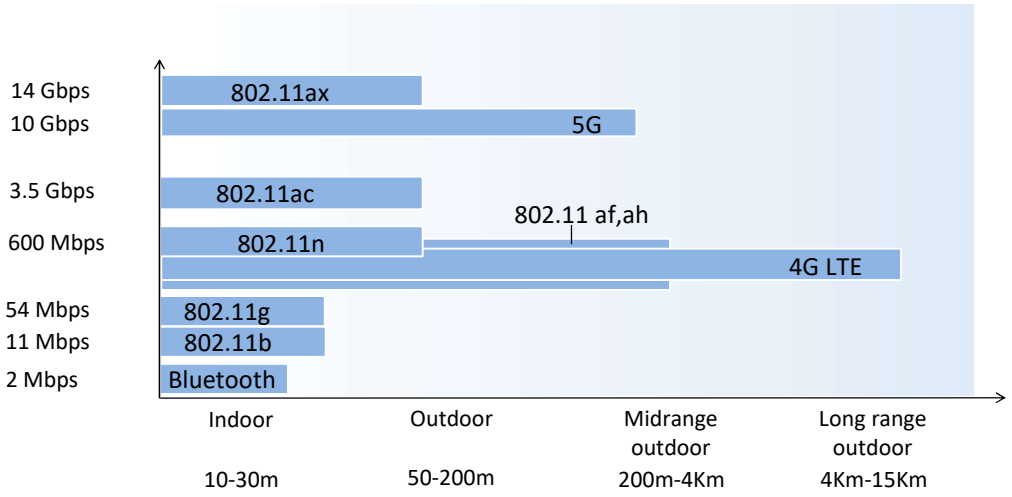
Characteristics of selected wireless links



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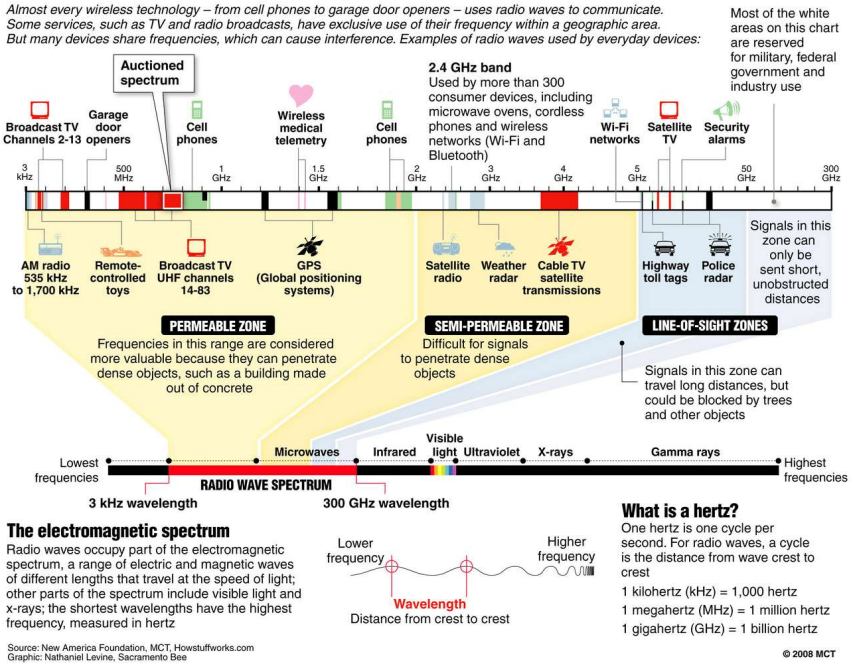

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	1G	2G	3G	4G	5G
Period	1980 – 1990	1990 – 2000	2000 – 2010	2010 – (2020)	(2020 - 2030)
Bandwidth	150/900MHz	900MHz	100MHz	100MHz	1000x BW pr unit area
Frequency	Analog signal (30 KHz)	1.8GHz (digital)	1.6 – 2.0 GHz	2 – 8 GHz	3 – 300 GHz
Data rate	2kbps	64kbps	144kbps – 2Mbps	100Mbps – 1Gbps	1Gbps <
Characteristic	First wireless communication	Digital	Digital broadband, increased speed	High speed, all IP	
Technology	Analog cellular	Digital cellular (GSM)	CDMA, UMTS, EDGE	LTE, WiFi	WWWW

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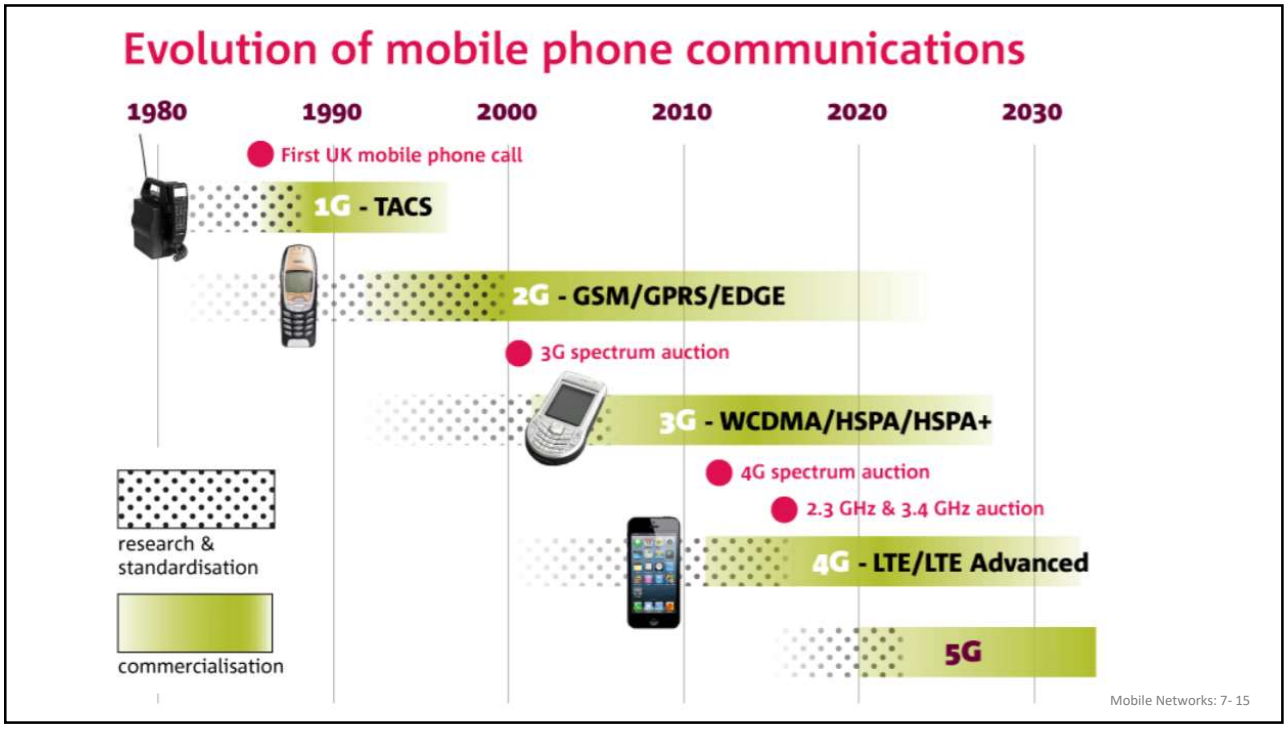

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Elements of a wireless network

Wireless Network Architecture

- Infrastructure Mode
- Ad Hoc Mode

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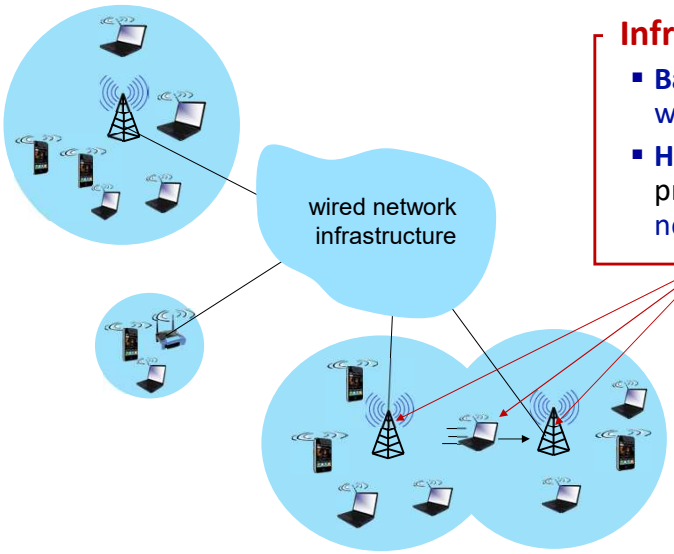
Elements of a wireless network



Infrastructure Mode

- **Base Station** connects mobiles into wired network
- **Handoff**: mobile changes base station providing connection into wired network

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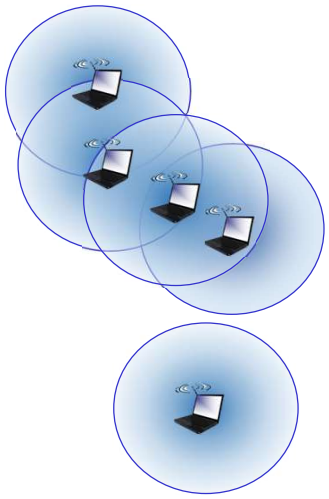
Elements of a wireless network



Ad Hoc mode

- no base stations
- nodes can only transmit to other nodes within link coverage
- nodes organize themselves into a network: route among themselves

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Wireless network taxonomy

	Single Hop	Multiple Hops
Infrastructure (e.g., APs)	host connects to base station (WiFi, Cellular) which connects to larger Internet	host may have to relay through several wireless nodes to connect to larger Internet: ***mesh net***
no infrastructure	**no base station**, no connection to larger Internet (Bluetooth, ad hoc nets)	no base station, no connection to larger Internet. May have to relay to reach other a given wireless node MANET, VANET

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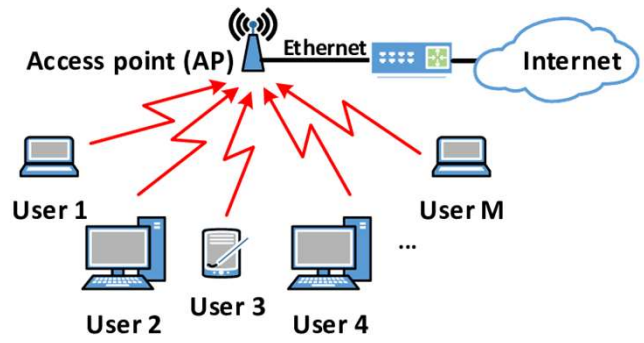

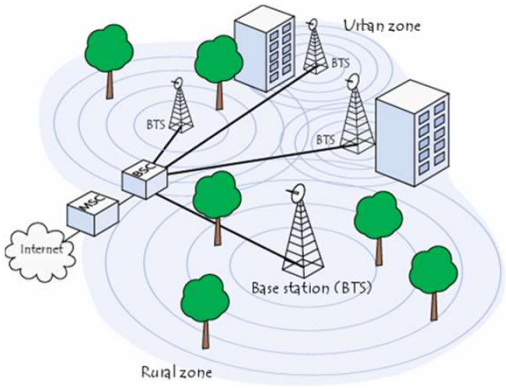

WiFi

Cellular Networks

Infrastructure : **Single Hop**

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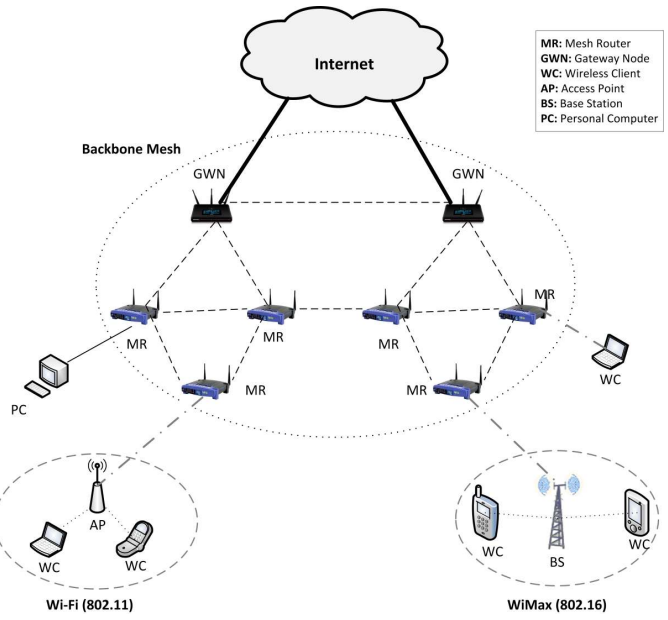

Mesh Networks

Infrastructure : **Multiple hops**

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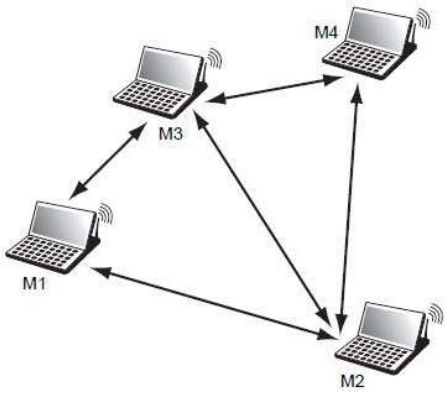

Bluetooth

Ad Hoc Networks

No-Infrastructure : **Single Hop**

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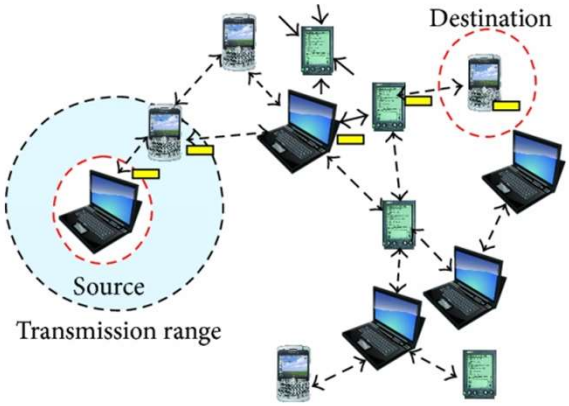

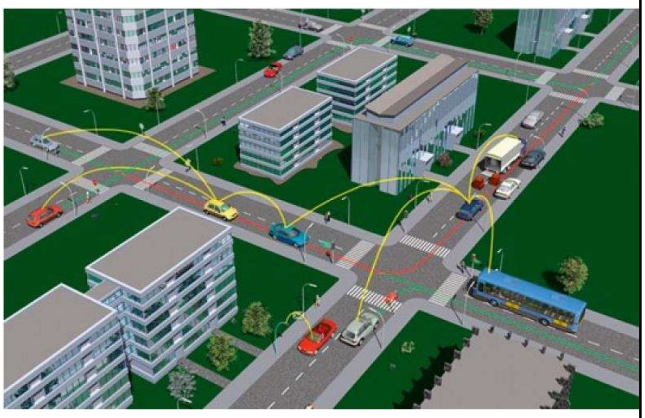

Mobile Ad Hoc Networks

Vehicular Ad Hoc Networks

No-Infrastructure : **Miltiple Hops**

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Wireless links and Network Characteristics

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Wireless link characteristics (1)

important differences from wired link ….

- decreased signal strength
- interference from other sources
- multipath propagation:

…. make communication across (even a point to point) wireless link much more "difficult"

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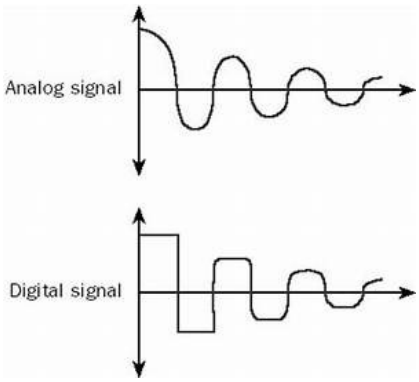
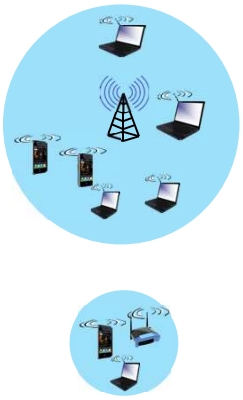
Wireless link characteristics (1)

important differences from wired link ….

- decreased signal strength*:* radio signal attenuates as it propagates through matter (path loss)





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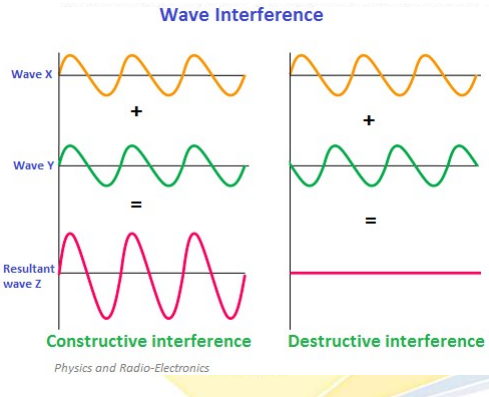
Wireless link characteristics (1)

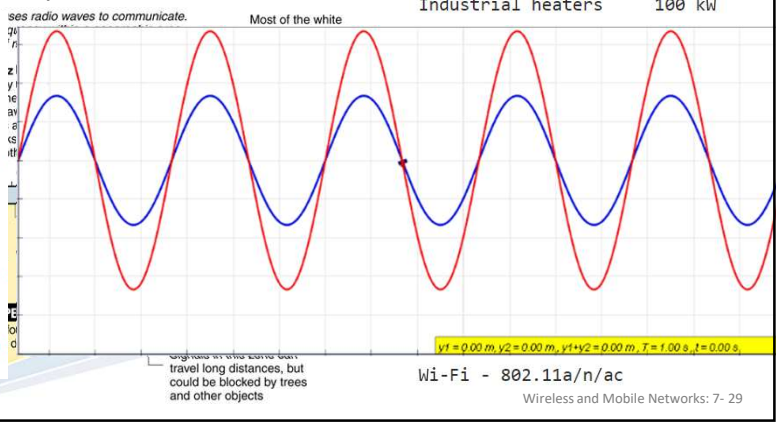
important differences from wired link ….

- interference from other sources: wireless network frequencies (e.g., 2.4 GHz) shared by many devices (e.g., WiFi, cellular, motors): interference

Industrial, Scientific and Medical

ISM Bands	Power Limit (Watts)
902 - 928 MHz	
Cordless phones	1 W
Microwave ovens	750 W
Industrial heaters	100 kW





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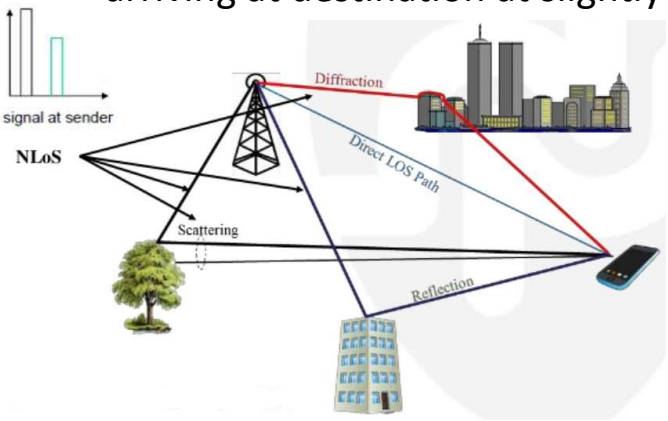
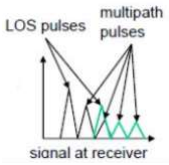
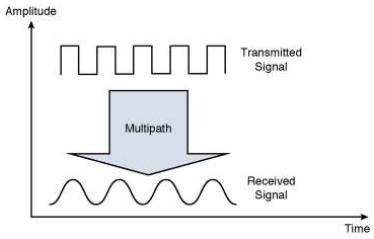
Wireless link characteristics (1)

important differences from wired link ….

- multipath propagation: radio signal reflects off objects ground, arriving at destination at slightly different times

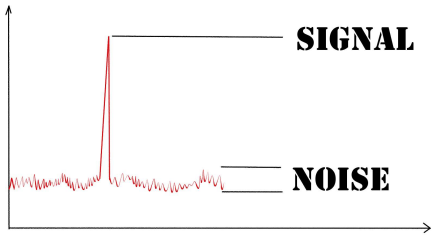


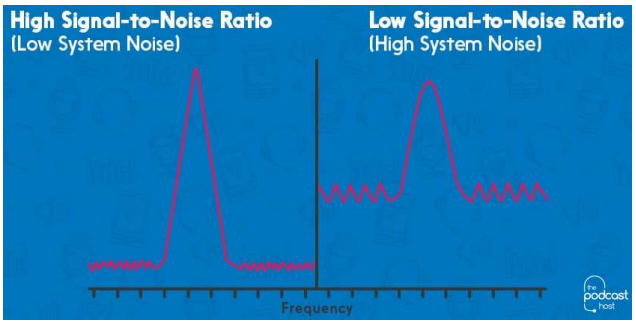




Wireless link characteristics (2)

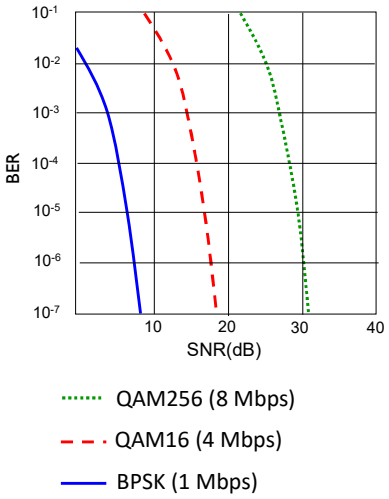
- SNR: Signal-to-Noise Ratio
  - larger SNR – easier to extract signal from noise (a "good thing")





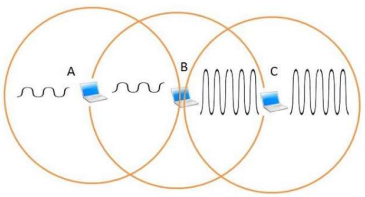
Wireless link characteristics (2)

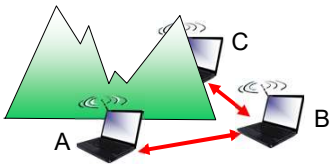
- SNR versus BER tradeoffs
  - *given physical layer:* increase power -> increase SNR->decrease BER
  - *given SNR:* choose physical layer that meets BER requirement, giving highest throughput
    - SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)

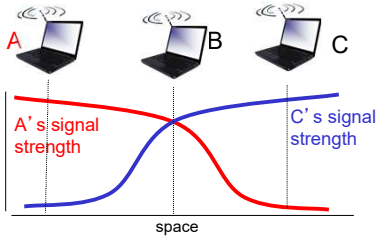


Wireless link characteristics (3)

Multiple wireless senders, receivers create additional problems (beyond multiple access):







Hidden terminal problem

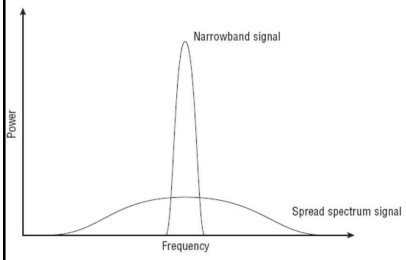
- B, A hear each other
- B, C hear each other
- A, C can not hear each other means A, C unaware of their interference at B

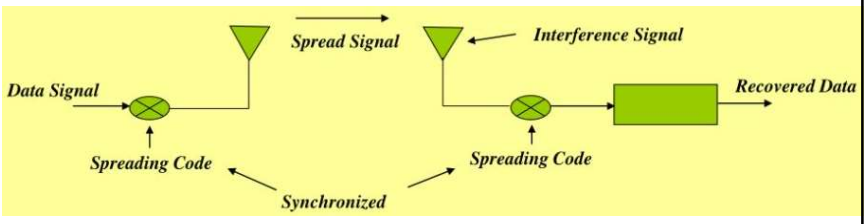
Signal attenuation:

- B, A hear each other
- B, C hear each other
- A, C can not hear each other interfering at B

Code Division Multiple Access (CDMA)

Basic Spread Spectrum Technique





- Frequency Hopping Spread Spectrum (FHSS)
- Direct Sequence Spread Spectrum (DSSS)

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Code Division Multiple Access (CDMA)

- unique "code" assigned to each user; i.e., code set partitioning
  - all users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data
  - allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")

Walsh code

$$W_{2n} = \begin{matrix} W_n & W_n \\ W_n & \overline{W}_n \end{matrix}$$

$$W_1 = \quad W_2 = \begin{matrix} 0 & 0 \\ 0 & 1 \end{matrix} \quad W_4 = \begin{matrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{matrix}$$

- encoding: inner product: (original data) X (chipping sequence)
- decoding: summed inner-product: (encoded data) X (chipping sequence)

Wireless and Mobile Networks: 7- 37

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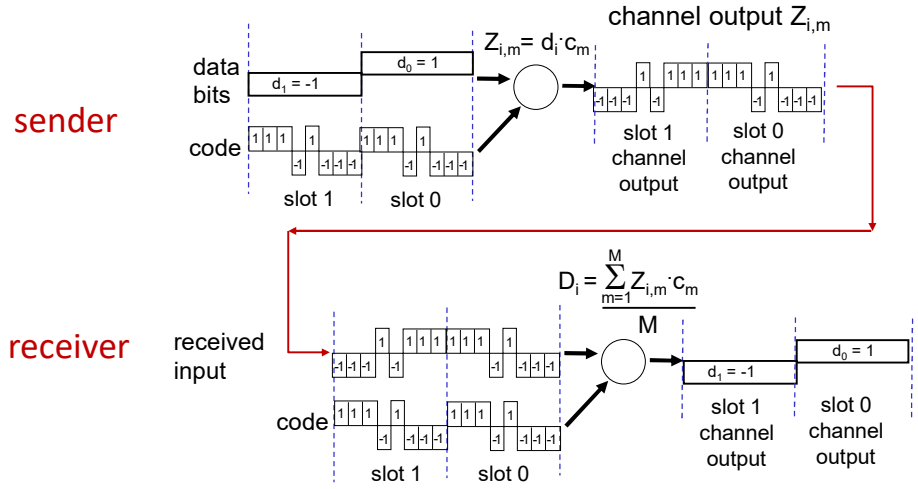
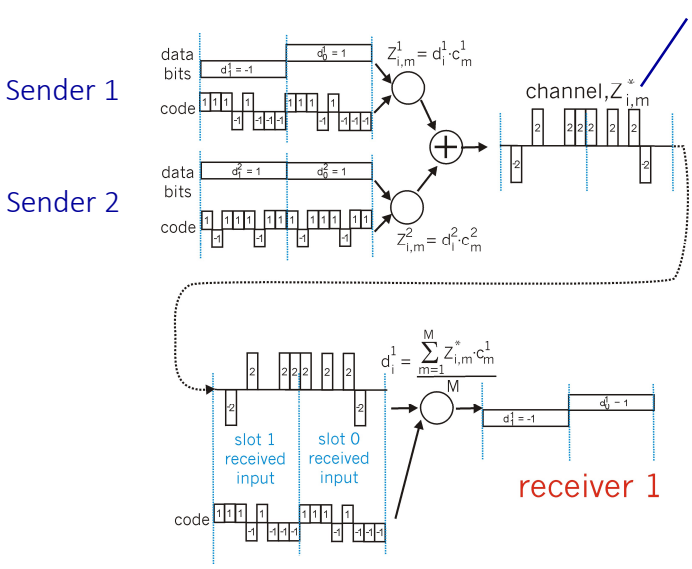
CDMA encode/decode



… but this isn't really useful yet!

CDMA: two-sender interference



channel sums together transmissions by sender 1 and 2

using same code as sender 1, receiver recovers sender 1's original data from summed channel data!

… now *that's* useful!

WiFi: 802.11 Wireless LANs

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IEEE 802.11 Wireless LAN

IEEE 802.11 standard	Year	Max data rate	Range	Frequency
802.11b	1999	11 Mbps	30 m	2.4 Ghz
802.11g	2003	54 Mbps	30m	2.4 Ghz
802.11n (WiFi 4)	2009	600	70m	2.4, 5 Ghz
802.11ac (WiFi 5)	2013	3.47Gpbs	70m	5 Ghz
802.11ax (WiFi 6)	2020 (exp.)	14 Gbps	70m	2.4, 5 Ghz
802.11af	2014	35 – 560 Mbps	1 Km	unused TV bands (54-790 MHz)
802.11ah	2017	347Mbps	1 Km	900 Mhz

- all use CSMA/CA for multiple access, and have base-station and ad-hoc network versions

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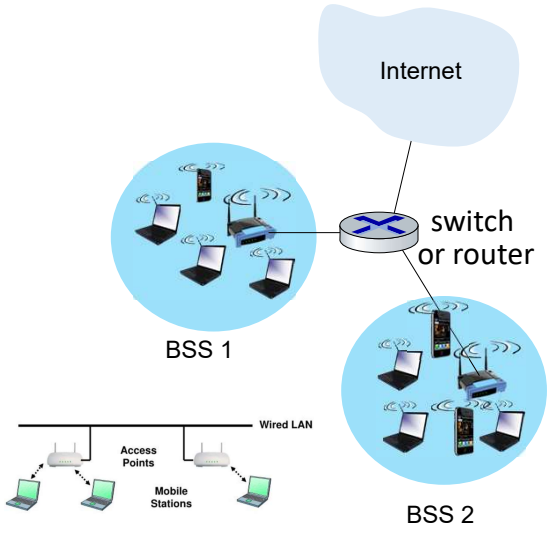
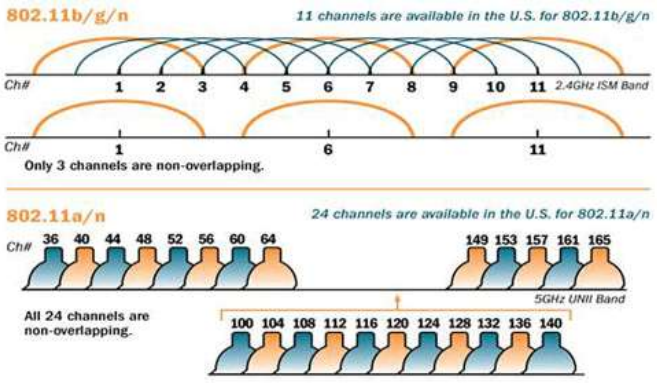
802.11 LAN architecture

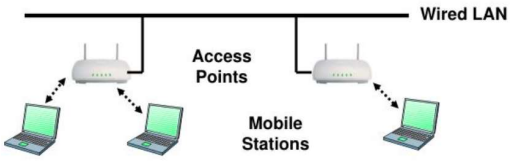


- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

802.11: Channels, association

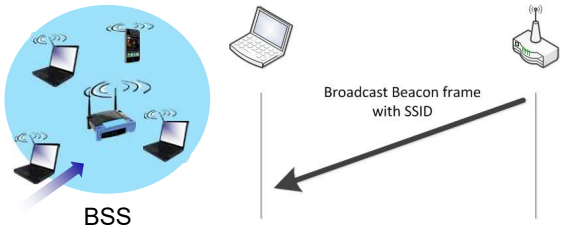
- spectrum divided into channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!

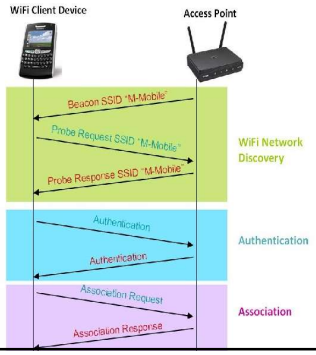




802.11: Channels, association

- arriving host: must associate with an AP
  - scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC address
  - selects AP to associate with
  - then may perform authentication [Chapter 8]
  - then typically run DHCP to get IP address in AP's subnet





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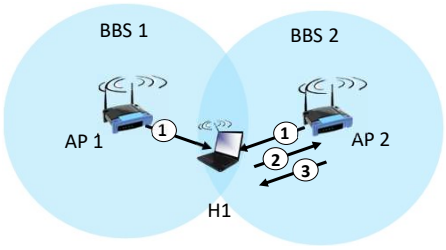
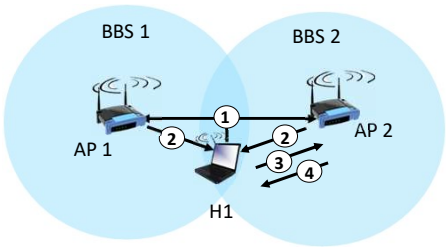
802.11: passive/active scanning





passive scanning:
- (1) beacon frames sent from APs
- (2) association Request frame sent: H1 to selected AP
- (3) association Response frame sent from selected AP to H1

active scanning:
- (1) Probe Request frame broadcast from H1
- (2) Probe Response frames sent from APs
- (3) Association Request frame sent: H1 to selected AP
- (4) Association Response frame sent from selected AP to H1

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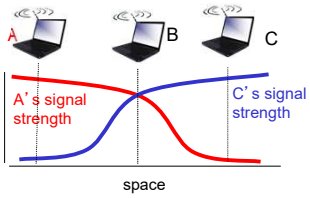
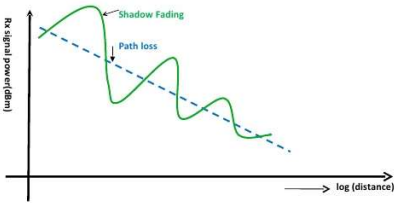
IEEE 802.11: Multiple Access

- avoid collisions: 2+ nodes transmitting at same time
- 802.11: Carrier Sense Multiple Access (CSMA) - sense before transmitting
  - don't collide with detected ongoing transmission by another node
- 802.11: *no* collision detection!
  - difficult to sense collisions: high transmitting signal, weak received signal due to fading
  - can't sense all collisions in any case: hidden terminal, fading
  - Goal: *avoid collisions:* CSMA/CollisionAvoidance





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IEEE 802.11 MAC Protocol: CSMA/CA

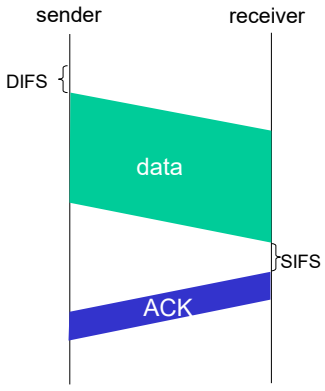
802.11 sender

1 if sense channel idle for **DIFS** then
transmit entire frame (no CD)

2 if sense channel busy then
start random backoff time
timer counts down while channel idle
transmit when timer expires
if no ACK, increase random backoff interval, repeat 2

802.11 receiver

if frame received OK
return ACK after **SIFS** (ACK needed due to hidden terminal problem)



Distributed coordination function (DCF) is a mandatory technique used to prevent collisions in IEEE 802.11-based WLAN standard (Wi-Fi)

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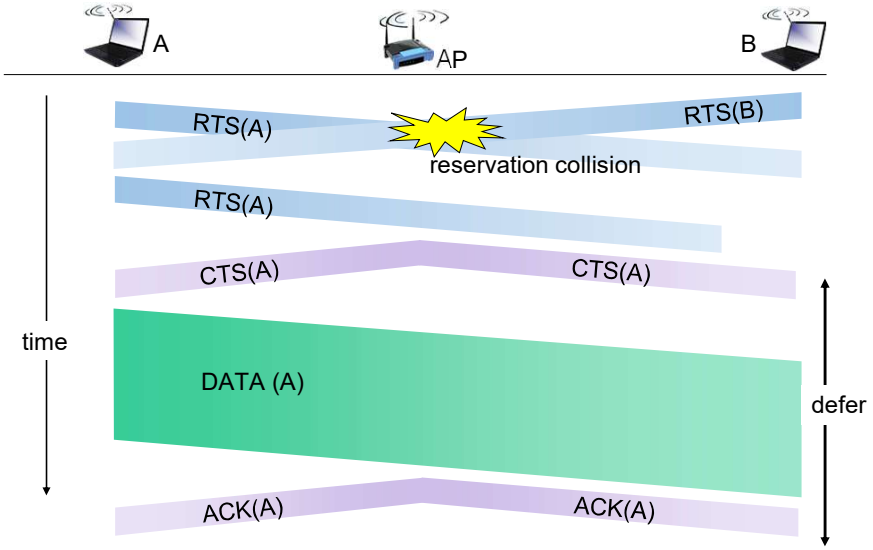
Avoiding collisions (more)

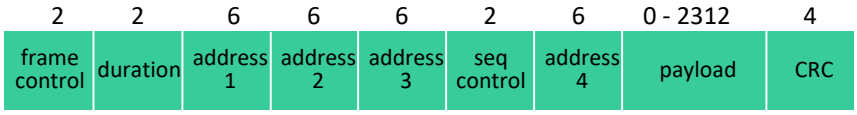
idea: sender "reserves" channel use for data frames using small reservation packets

- sender first transmits *small* request-to-send (RTS) packet to BS using CSMA
  - RTSs may still collide with each other (but they're short)
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

Collision Avoidance: RTS-CTS exchange



802.11 frame: addressing



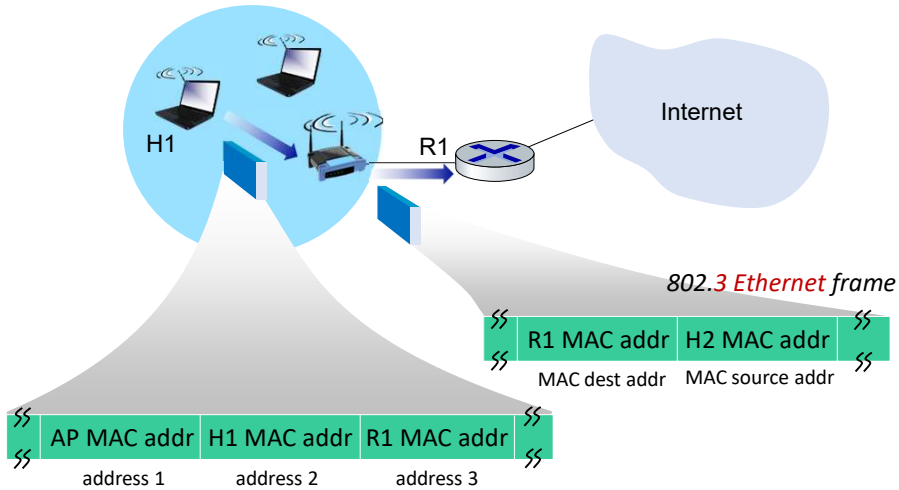
Address 1: MAC address of wireless host or AP to **receive** this frame

Address 2: MAC address of wireless host or AP **transmitting** this frame

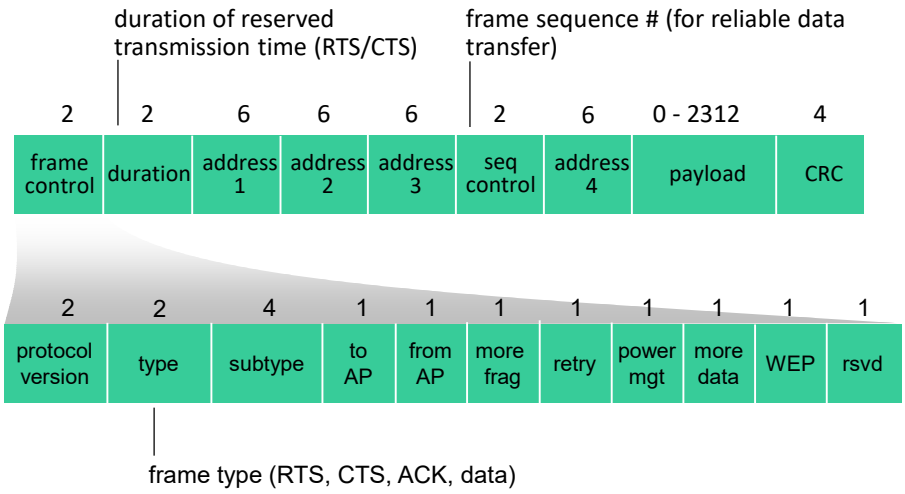
Address 3: MAC address of **router interface** to which AP is attached

Address 4: used only in ad hoc mode

802.11 frame: addressing



802.11 frame: addressing



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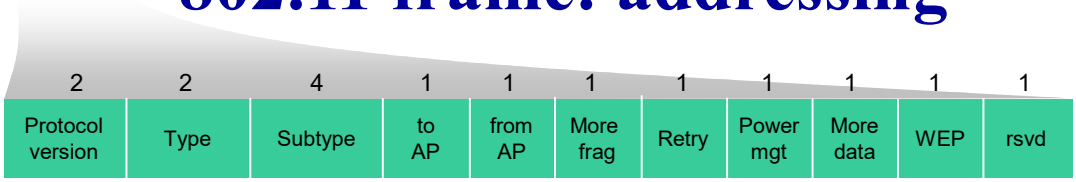
802.11 frame: addressing



- Type : Control Frame, Management Frame, or Data Frame
- Subtype : Association, disassociation, re-association, probe, beacon, authentication, de-authentication, CTS, RTS, ACK,…
- Retry : Retransmission

  Set to 1 if the Data or Management frame is part retransmission of earlier frame.
- Power mgt : going to Power Save Mode.
- More data : more buffered data at AP for station in power save mode
- WEP : Wireless Equivalent Privacy (Security) info in this frame
- Rsvd : reserved

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802.11 frame: addressing

Various 802.11 Frame Types and Subtypes

Type Value B3..B2	Type Description	Subtype Value B7 .. B4	Subtype Description
00	Management	0000	Association Request
00	Management	0001	Association Response
00	Management	0010	Reassociation Request
00	Management	0011	Reassociation Response
00	Management	0100	Probe Request
00	Management	0101	Probe Response
00	Management	0110	Timing Advertisement
00	Management	0111	Reserved
00	Management	1000	Beacon
00	Management	1001	ATIM
00	Management	1010	Disassociation
00	Management	1011	Authentication
00	Management	1100	Deauthentication
00	Management	1101	Action
00	Management	1110	Action No Ack (NACK)
00	Management	1111	Reserved

01	Control	0000-0010	Reserved
01	Control	0011	TACK
01	Control	0100	Beamforming Report Poll
01	Control	0101	VHT/HE NDP Announcement
01	Control	0110	Control Frame Extension
01	Control	0111	Control Wrapper
01	Control	1000	Block Ack Request (BAR)
01	Control	1001	Block Ack (BA)
01	Control	1010	PS-Poll
01	Control	1011	RTS
01	Control	1100	CTS
01	Control	1101	ACK
01	Control	1110	CF-End
01	Control	1111	CF-End + CF-ACK

10	Data	0000	Data
10	Data	0001	Reserved
10	Data	0010	Reserved
10	Data	0011	Reserved
10	Data	0100	Null (no data)
10	Data	0101	Reserved
10	Data	0110	Reserved
10	Data	0111	Reserved
10	Data	1000	QoS Data
10	Data	1001	QoS Data + CF-ACK
10	Data	1010	QoS Data + CF-Poll
10	Data	1011	QoS Data + CF-ACK + CF-Poll
10	Data	1100	QoS Null (no data)
10	Data	1101	Reserved
10	Data	1110	QoS CF-Poll (no data)
10	Data	1111	QoS CF-ACK + CF-Poll (no data)

11	Extension	0000	DMG Beacon
11	Extension	0001	S1G Beacon
11	Extension	0010-1111	Reserved

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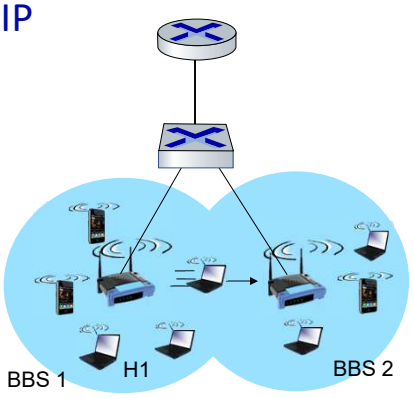
802.11: mobility within same subnet

- H1 remains in same IP subnet: IP address can remain same
- switch: which AP is associated with H1?
  - self-learning (Ch. 6): switch will see frame from H1 and "remember" which switch port can be used to reach H1



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802.11: advanced capabilities

Rate adaptation

- base station, mobile dynamically change transmission rate (physical layer modulation technique) as mobile moves, SNR varies

  1. SNR decreases, BER increase as node moves away from base station

  2. When BER becomes too high, switch to lower transmission rate but with lower BER