

Chapter 6

Wireless and Mobile Networks

Wireless and Mobile Networks: context

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

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



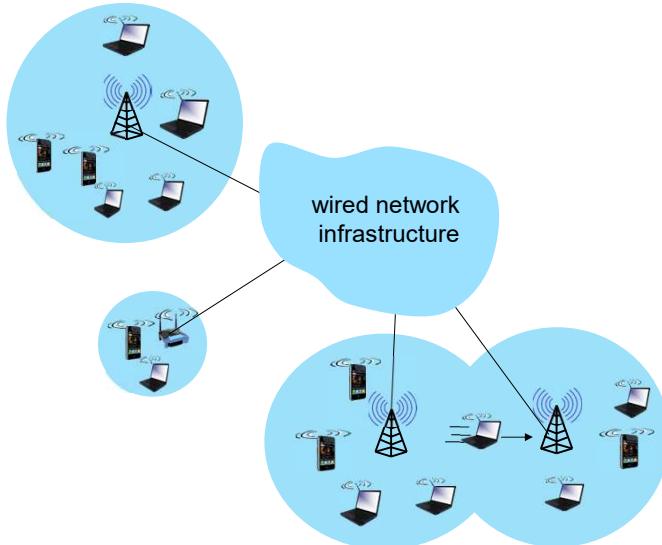
Wireless and Mobile Networks: 7-4

Wireless and Mobile Networks: context

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

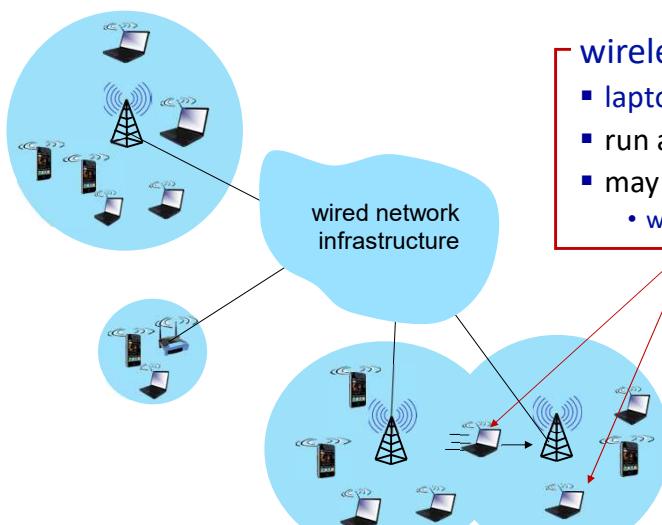
Wireless and Mobile Networks: 7-5

Elements of a wireless network



Wireless and Mobile Networks: 7- 8

Elements of a wireless network



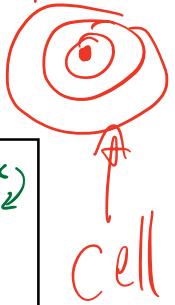
wireless hosts

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

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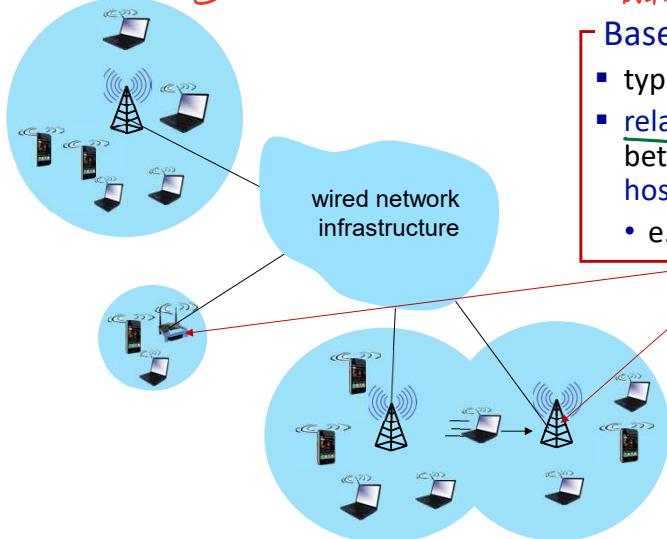


Omnidirectional Antenna → ເຄືອດັກທີ່ໄດ້ສະແດງສະບັບທີ່ມີ



Elements of a wireless network

Coverage Area



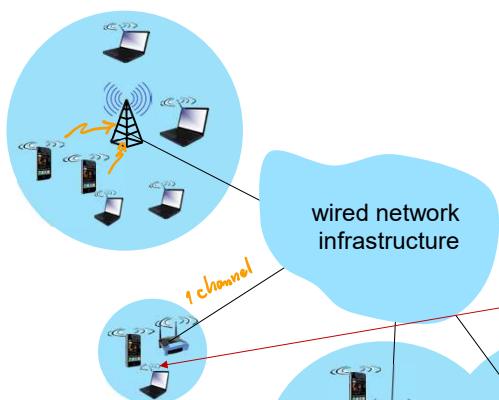
Wireless LAN → Access Point
Cellular Network → Base Station

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



TDMA
CDMA
FDMA

ALOHA
CSMA
CSMA/CD → LAN
CSMA/CA → wifi

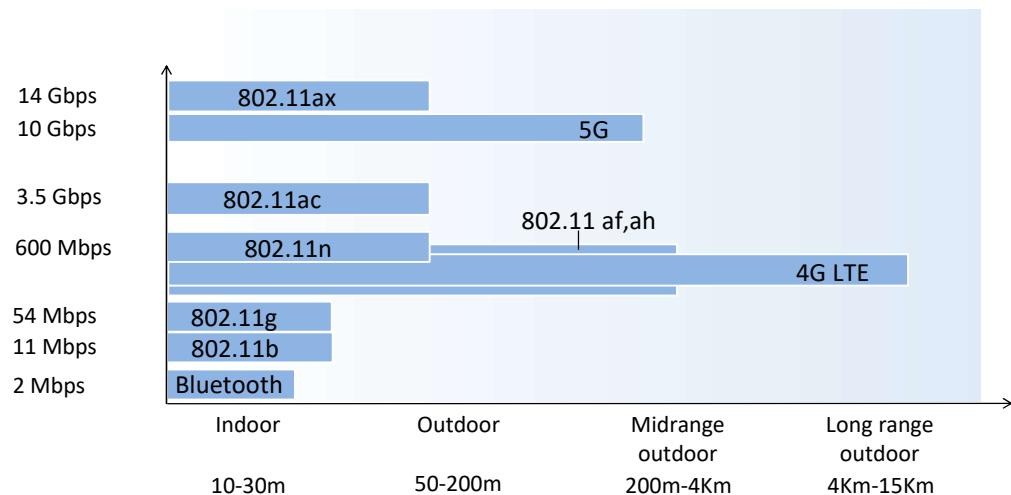
Wireless Link

- 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

ອຳນວຍໃຫຍ່/ຖາວອນ
ແລະ ອຸປະກອນ

Wireless and Mobile Networks: 7- 11

Characteristics of selected wireless links



Wireless and Mobile Networks: 7- 12

Evolution of mobile phone communications



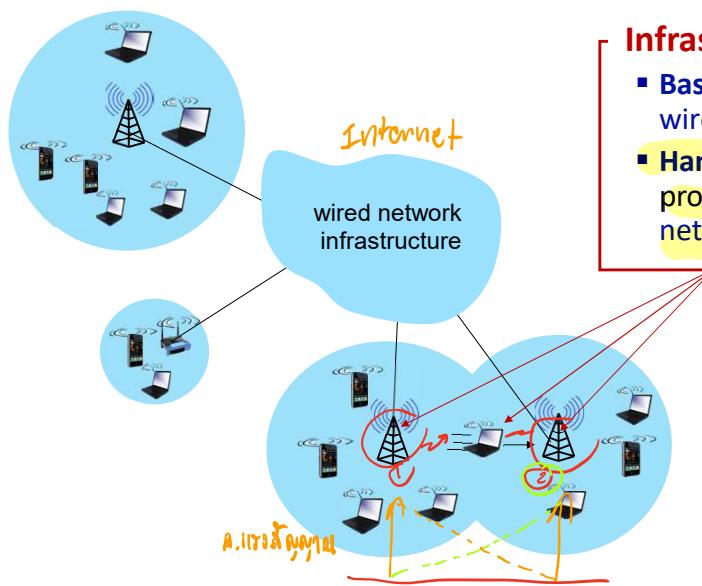
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Elements of a wireless network

Wireless Network Architecture

- Infrastructure Mode → Base station → *wired internet*
- Ad Hoc Mode → *2nd Base Station* → *2nd. wired internet*

Elements of a wireless network

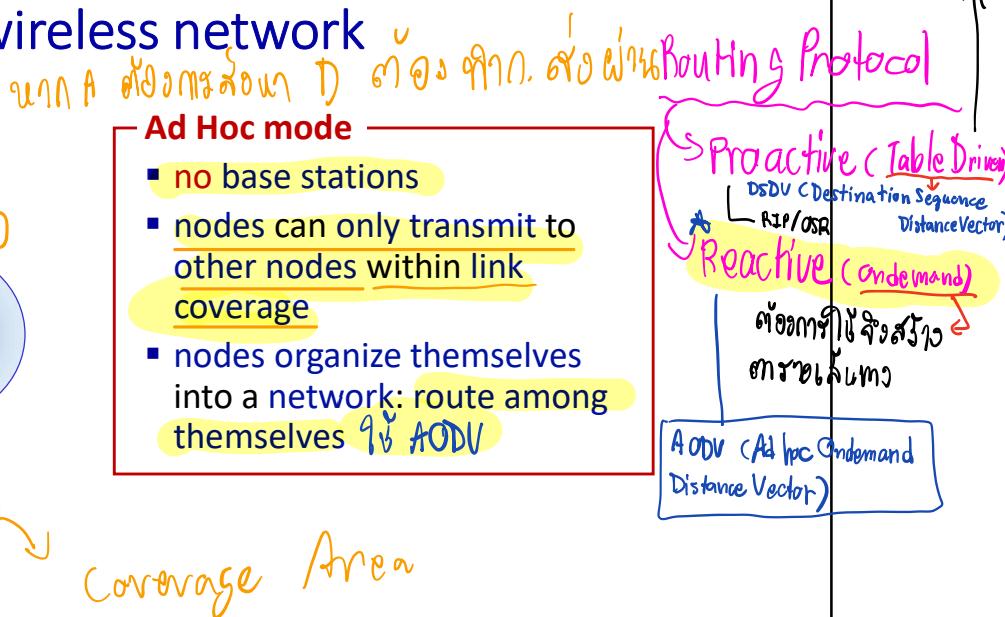
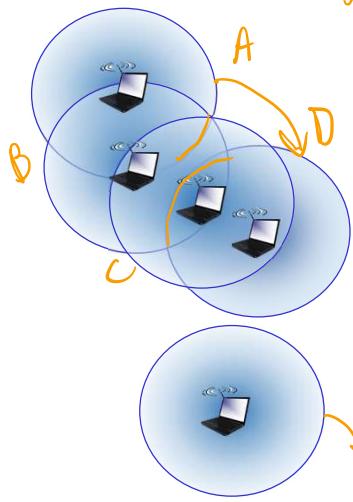


Infrastructure Mode

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

ຫົວໜ້າຂະໜາດ Ad Hoc
ສິນເຊີງຕະຫຼາດ ດີບວິທີ

Elements of a wireless network



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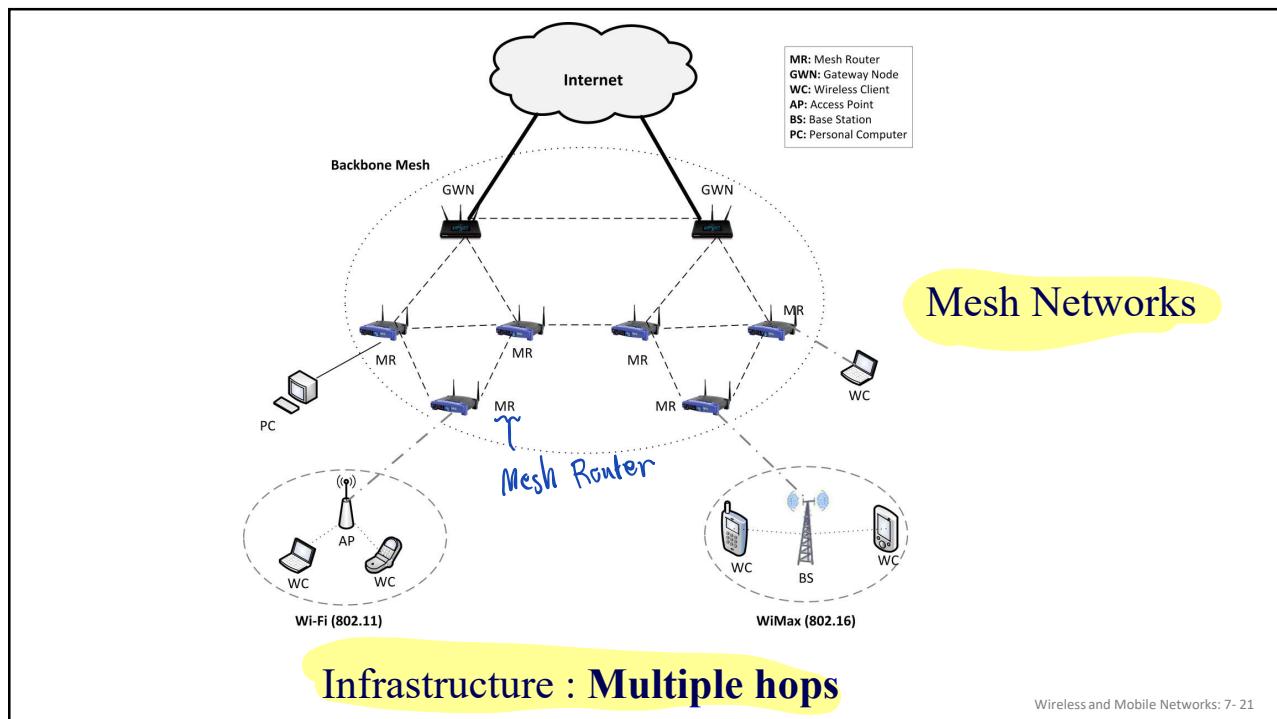
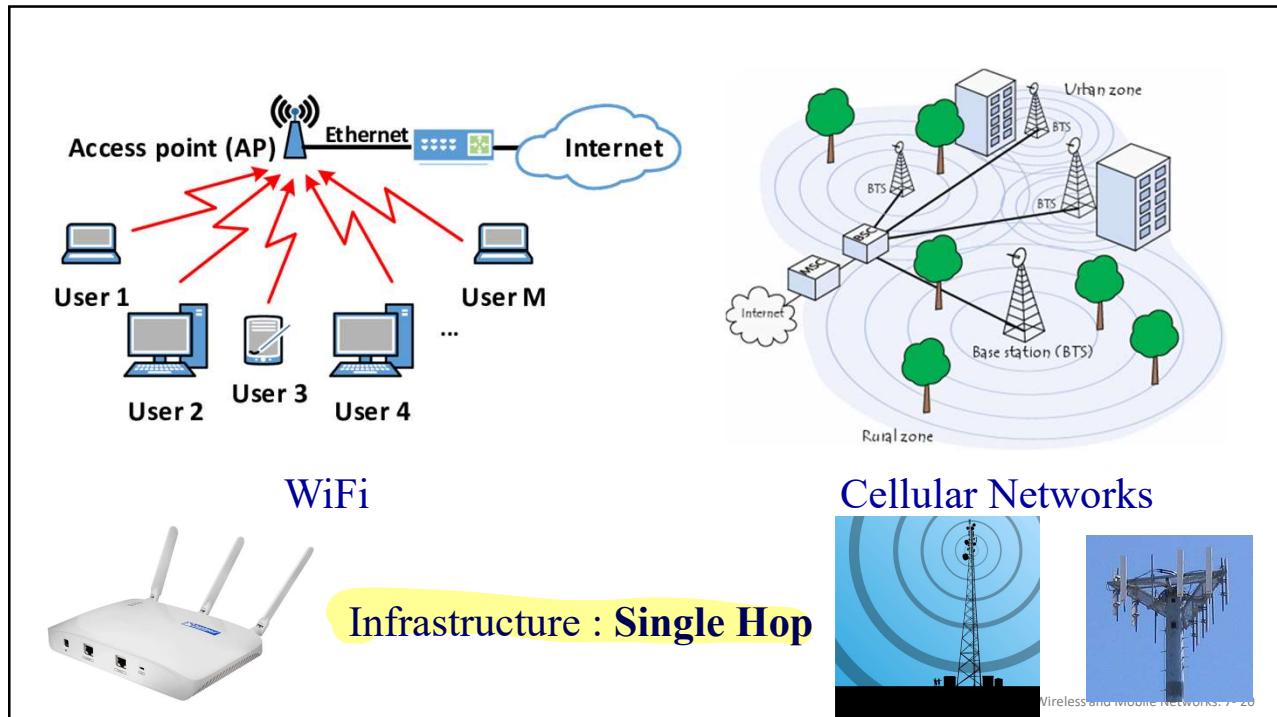
Wireless network taxonomy

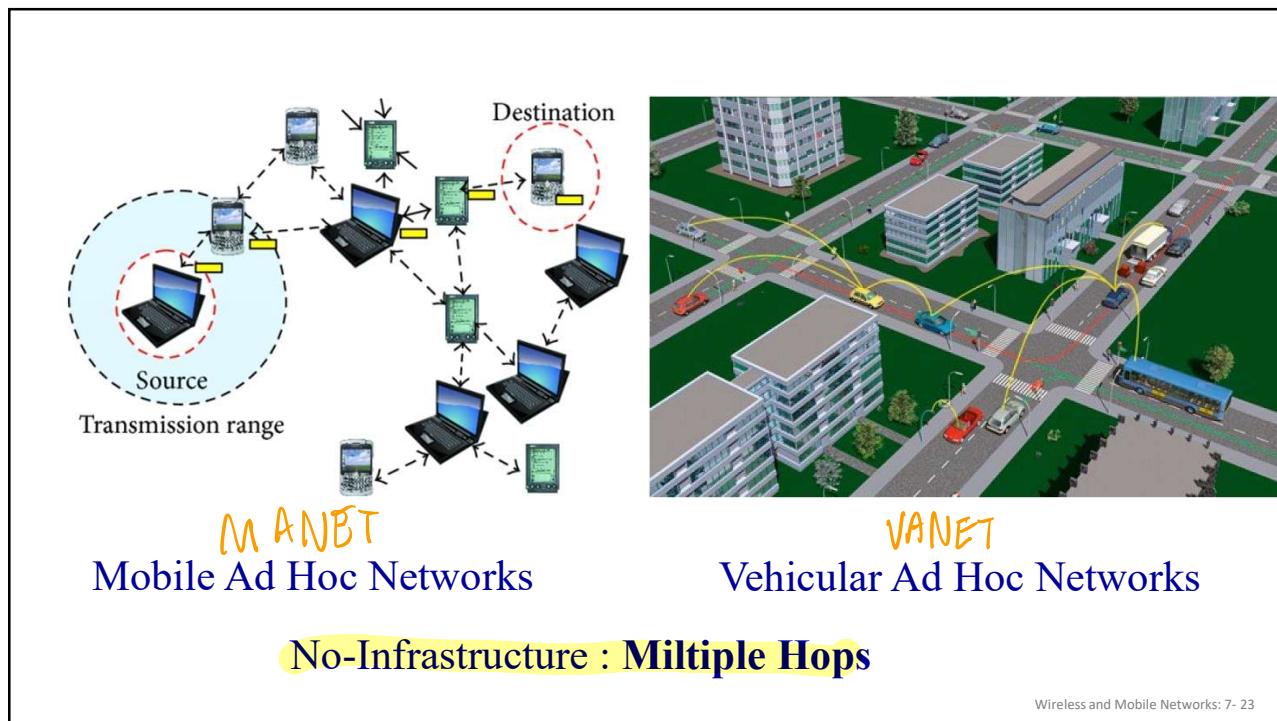
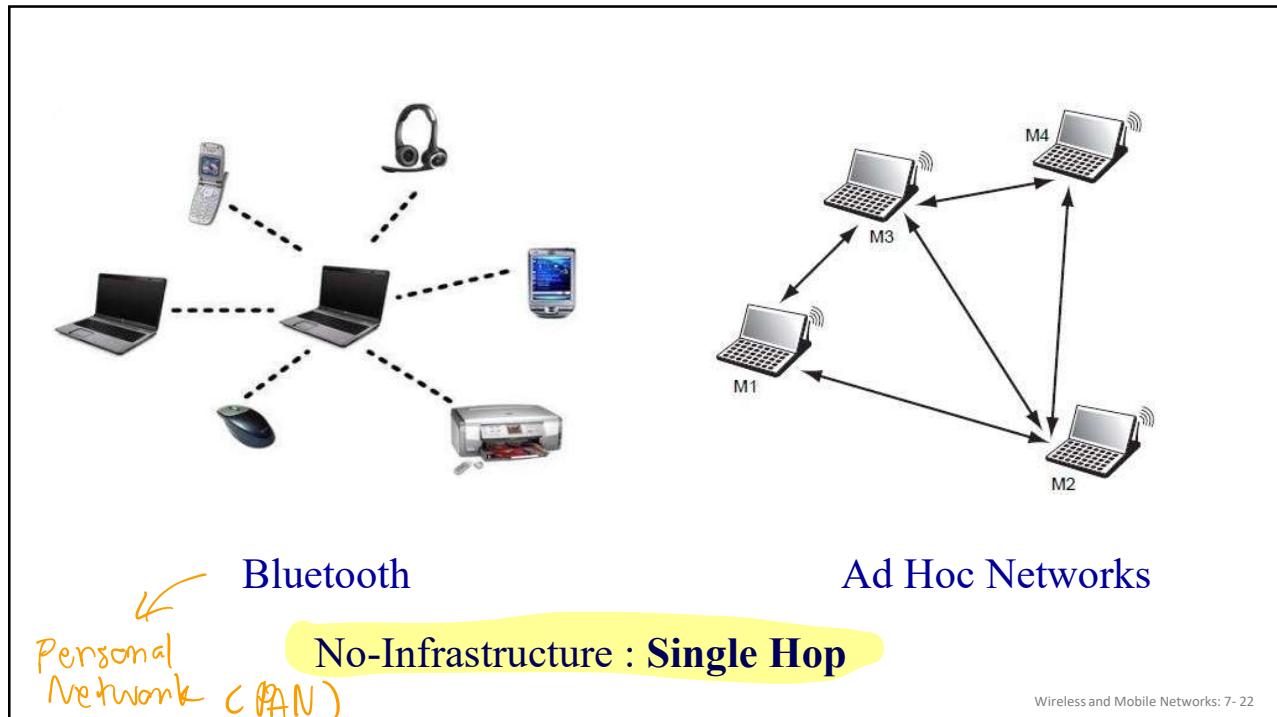
	Single Hop	Multiple Hops
Infrastructure (e.g., APs) no infrastructure	<p>host connects to base station (WiFi, Cellular) which connects to larger Internet</p> <p>no base station, no connection to larger Internet (Bluetooth, ad hoc nets)</p>	<p>host may have to relay through several wireless nodes to connect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

Mobile Ad Hoc Networks

Vehicular Ad Hoc Networks

Wireless and Mobile Networks: 7- 19





Wireless links and Network Characteristics

Wireless link characteristics (1)

important differences from wired link

- **decreased signal strength**
↳ ດີເລີກໃຫຍ່ງອາໄສລົງທະບຽນ (ດີເລີກໂຄນລົງທະບຽນ)
- **interference from other sources** ຊົ່ວໂມດີເຕີມງວດ
- **multipath propagation:** ເມນ.ກະຕາຍສ່ວນຈະນູອາຫຼາກ
ກຳຜູ້ປະປະຍາກວິຊ້ສັນຕະລຸກພາບ ຈາກນິຕາຍ ໂດຍໜຶກງາງ



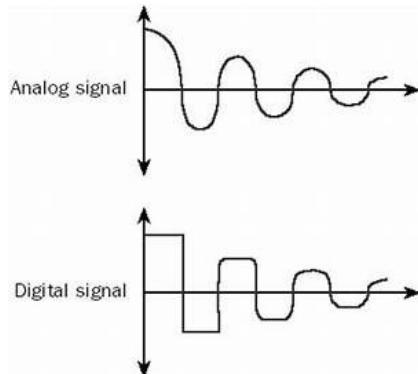
.... make communication across (even a point to point) wireless link much more "difficult"

Wireless link characteristics (1)

important differences from wired link

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

ରେଟାର୍ମାନ୍‌ଡିଫେଲ୍ସନ୍
ପାଥ୍ ଲୋସ୍



Wireless and Mobile Networks: 7- 28

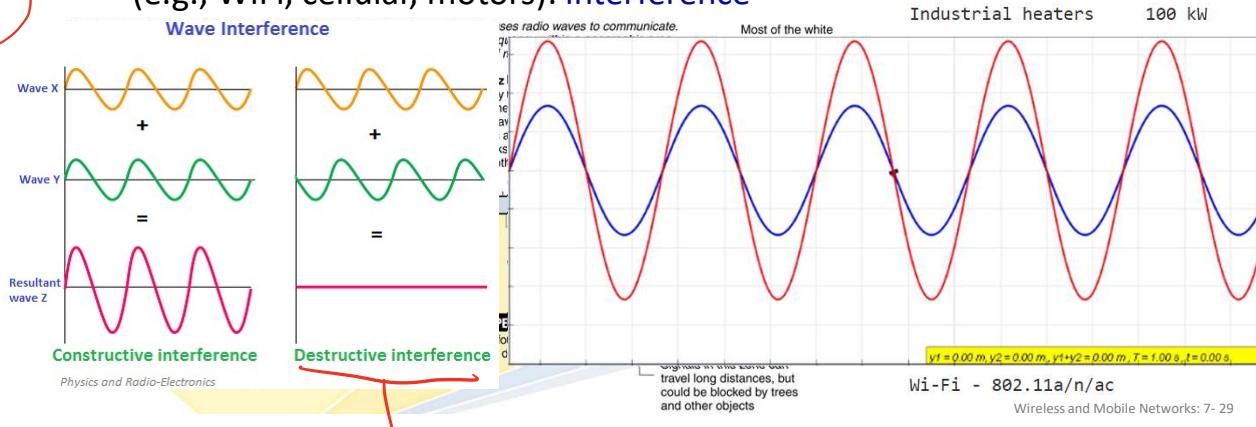
Industrial
Scientific
Medical
ISM band → Unlicensed
2.4 GHz
(କାନ୍ତିମାନକାରୀ)

Industrial, Scientific and Medical

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



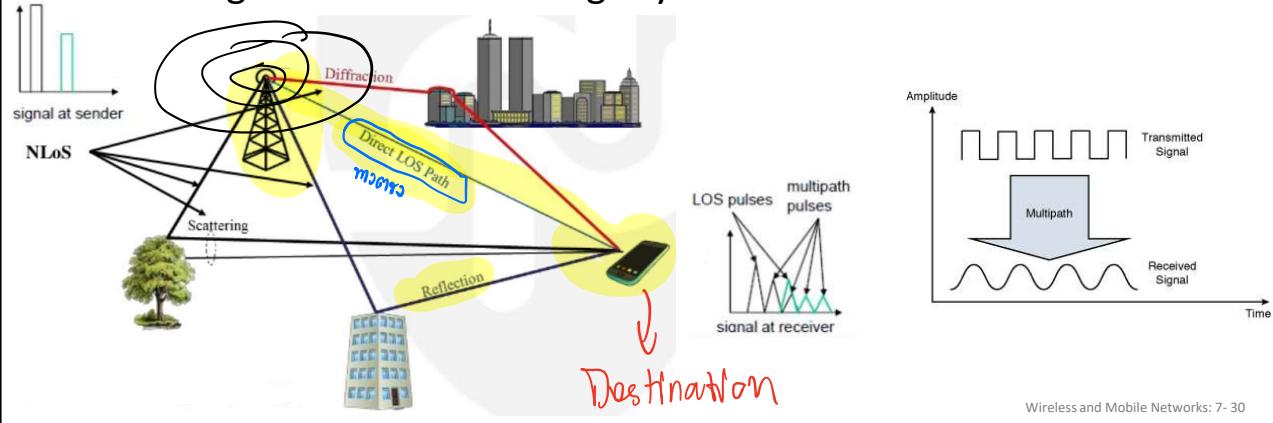
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Wireless link characteristics (1)

សំណុំរាយការងារកំណត់នៃការប្រើប្រាស់បណ្តុះបណ្តាល

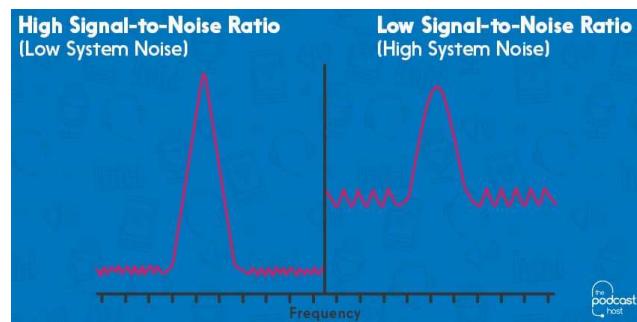
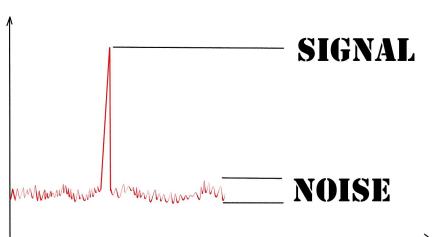
important differences from wired link

- **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”)

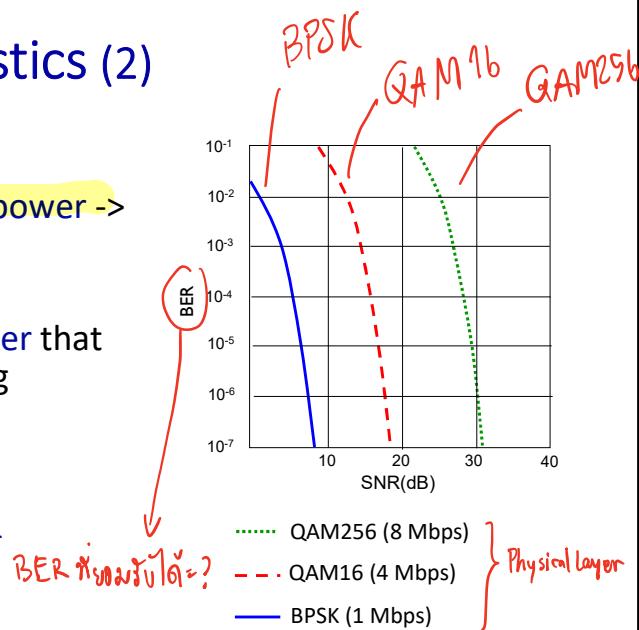


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Wireless link characteristics (2)

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)

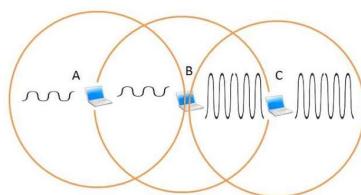


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Wireless link characteristics (3)

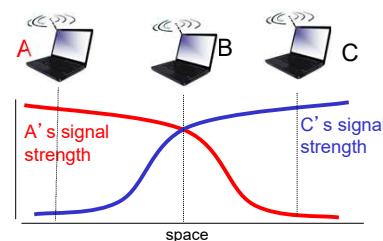
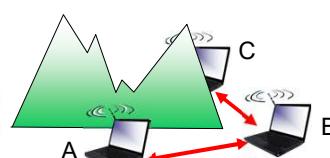
CSMA/CD → LAN, Ethernet

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

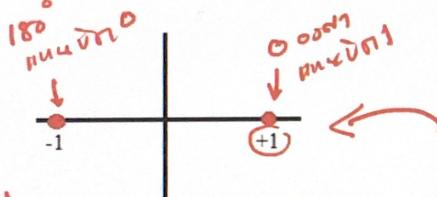


Signal attenuation:

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

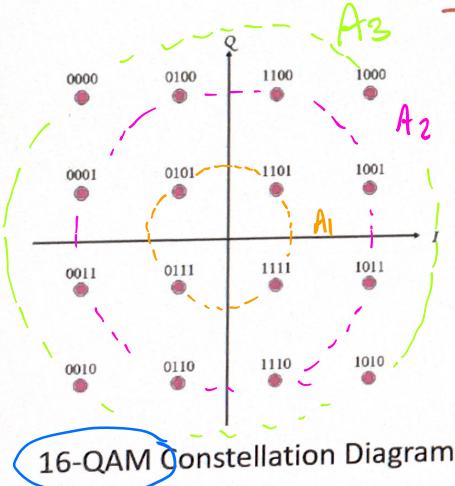
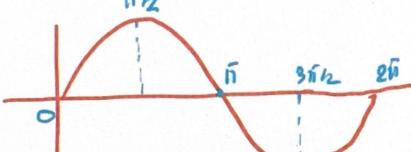
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Phase Shift Keying (PSK) → Modulation

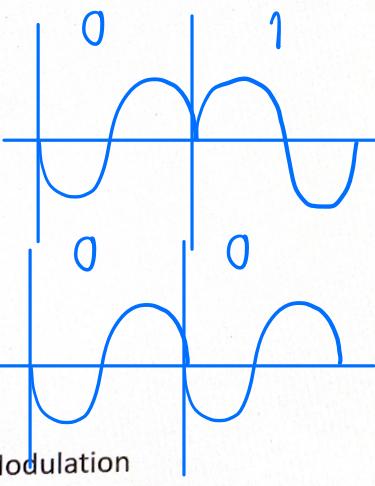


Binary
BPSK Constellation Diagram

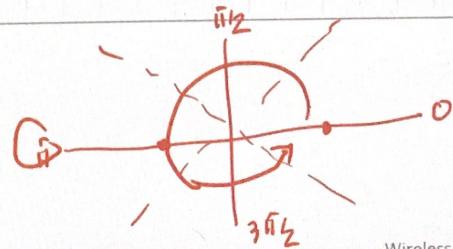
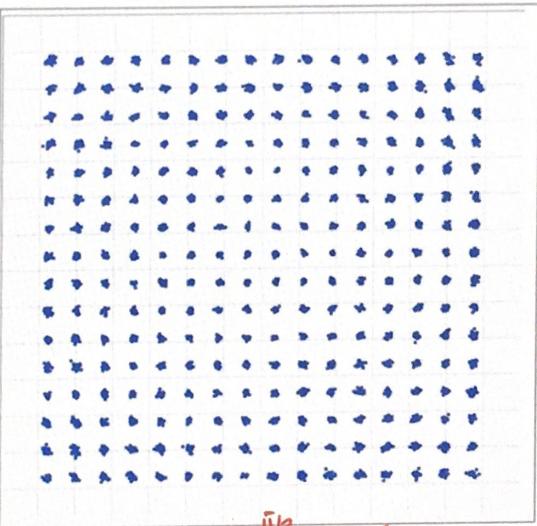
සුංජාල ප්‍රියවරු
සැපු ප්‍රියවරු
1 ප්‍රියවරු 1 වෙළ
1/2 π π $3\pi/2$ 2π



Phase + Amplitude
QAM : Quadrature Amplitude Modulation



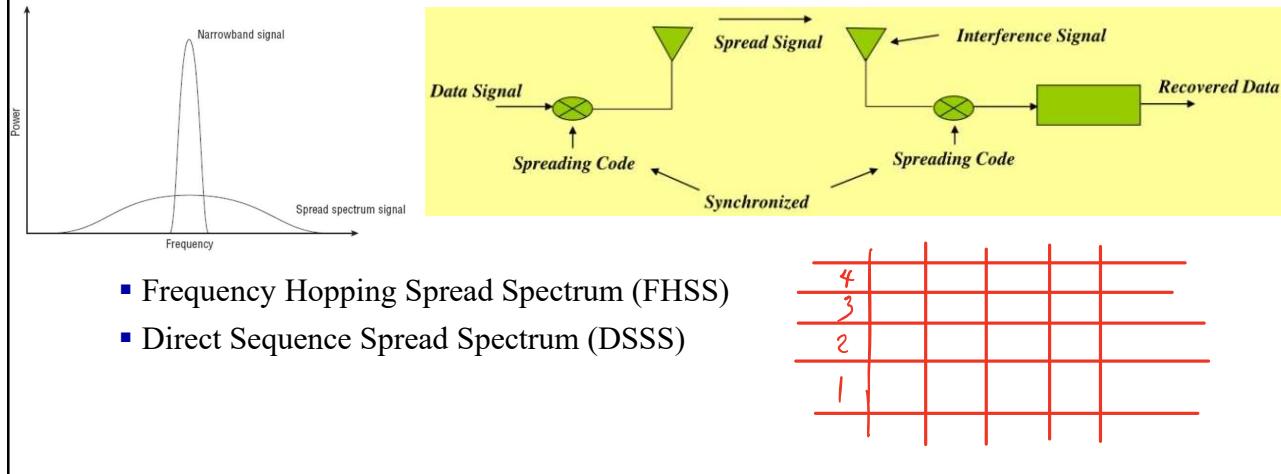
256-QAM Constellation



Wireless and Mobile Ne

Code Division Multiple Access (CDMA)

Basic Spread Spectrum Technique



Code Division Multiple Access (CDMA)

code ยังไง

- 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

$$W_{2n} = \begin{matrix} W_0 & W_n \\ W_n & \overline{W}_n \end{matrix}$$

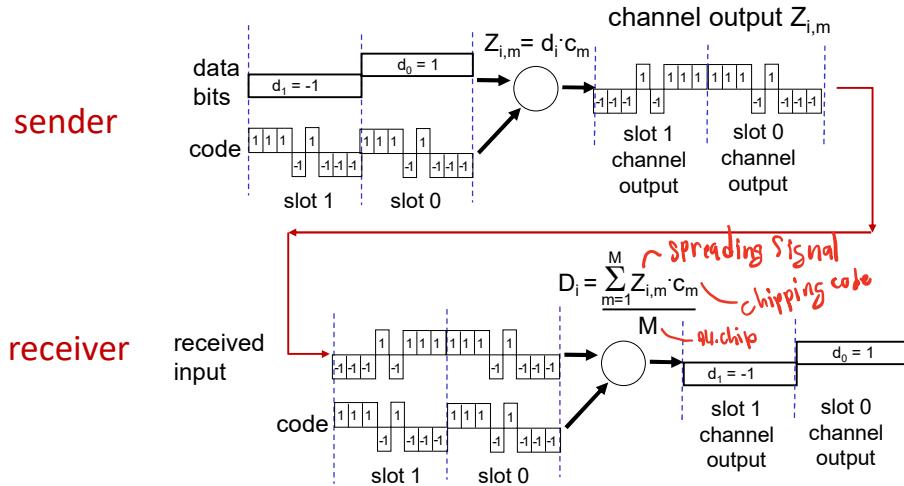
$$W_1 = \begin{matrix} 0 & 0 \\ 0 & 1 \end{matrix}$$

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

Wireless and Mobile Networks: 7- 37

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

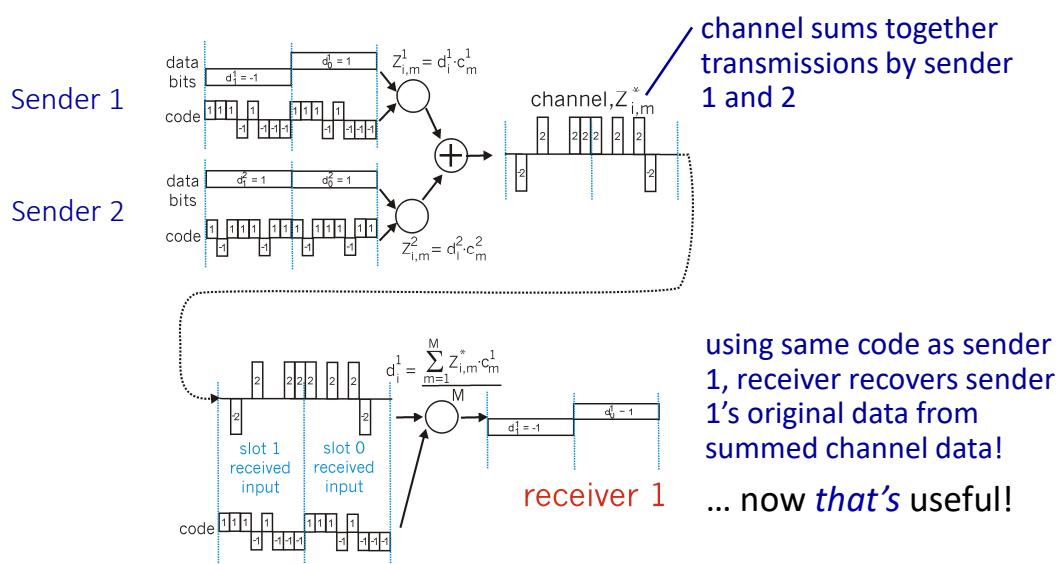
CDMA encode/decode



... but this isn't really useful yet!

Wireless and Mobile Networks: 7- 38

CDMA: two-sender interference



Wireless and Mobile Networks: 7- 38

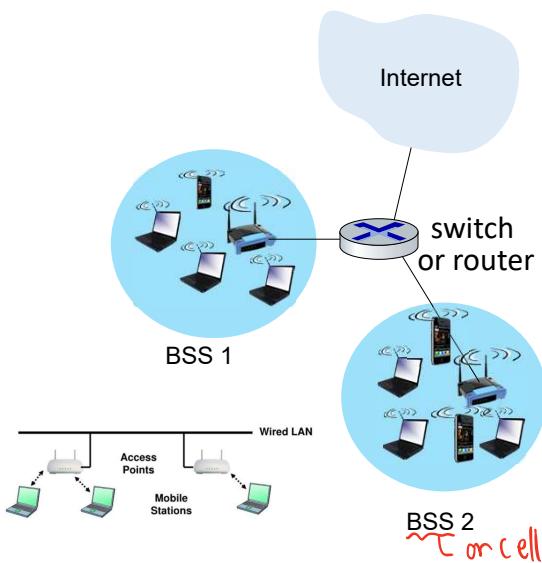
WiFi: 802.11 Wireless LANs

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	3.47Gbps	70m	5 Ghz
802.11ax (WiFi 6)	2020 (exp.)	14 Gbps	70m	2.4, 5 Ghz Dual Band
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

802.11 LAN architecture

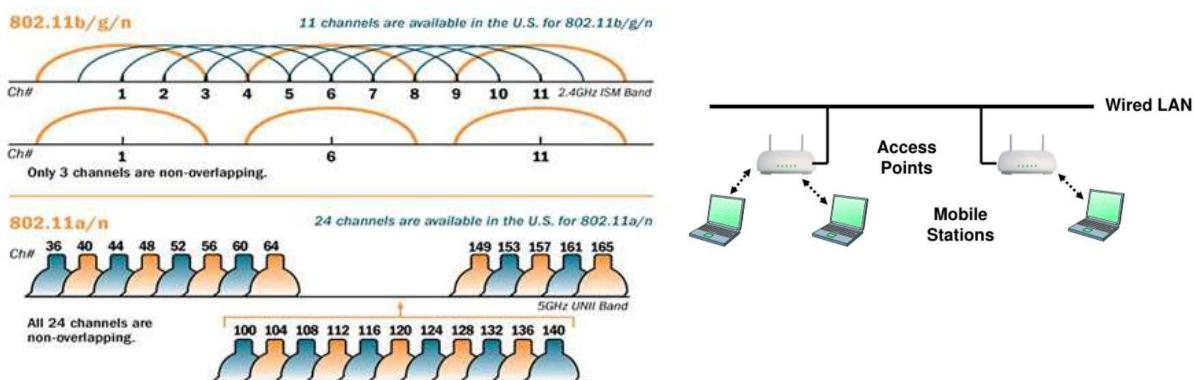


- **wireless host communicates with base station**
 - **base station = access point (AP)**
- **Basic Service Set (BSS) (aka “cell”) in infrastructure mode contains:**
 - wireless hosts
 - **access point (AP): base station**
- **ad hoc mode:** hosts only

Wireless and Mobile Networks: 7- 43

802.11: Channels, association

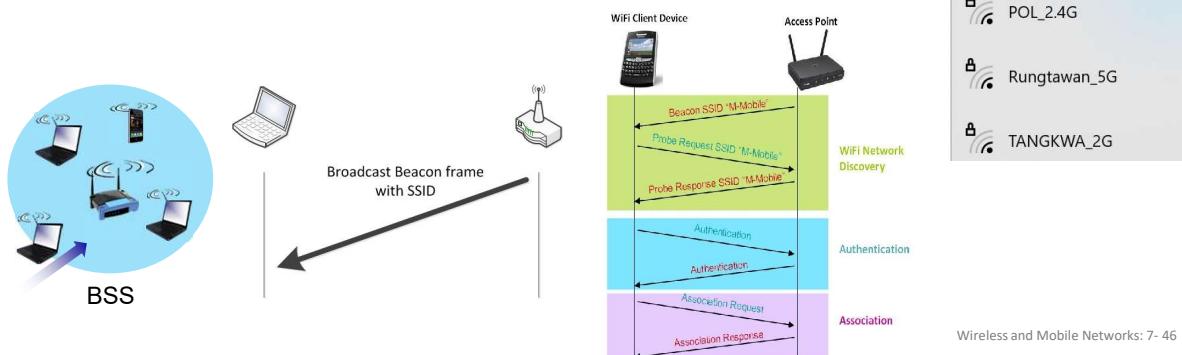
- spectrum divided into **channels** at different frequencies
 - AP admin chooses frequency for AP
 - interference possible: channel can be same as that chosen by neighboring AP!



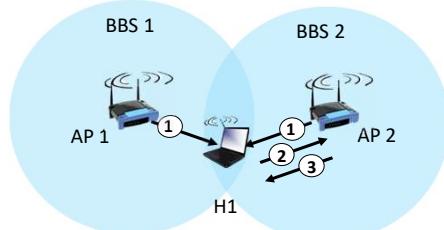
Wireless and Mobile Networks: 7- 45

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

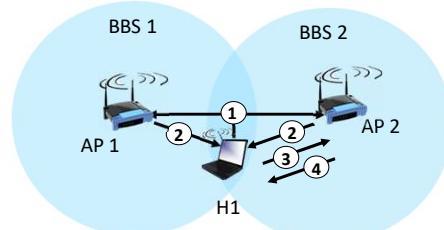


802.11: passive/active scanning



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



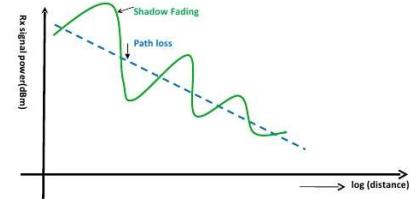
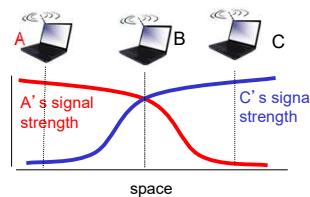
active scanning:

- (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

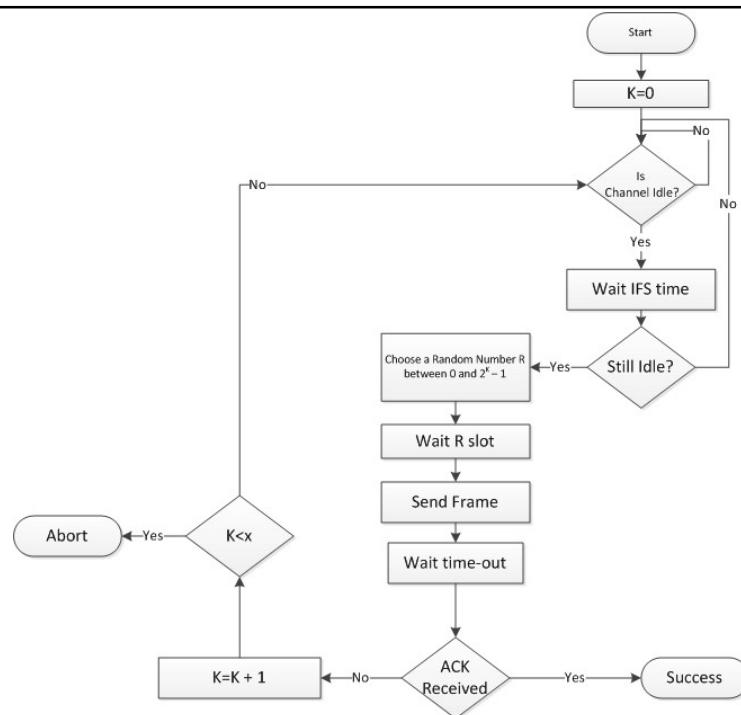
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IEEE 802.11: Multiple Access

- 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



Wireless and Mobile Networks: 7- 48



ess and Mobile Networks: 7- 49

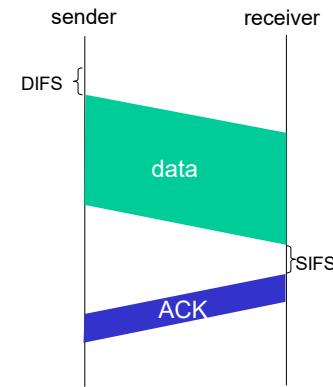
IEEE 802.11 MAC Protocol: CSMA/CA

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)



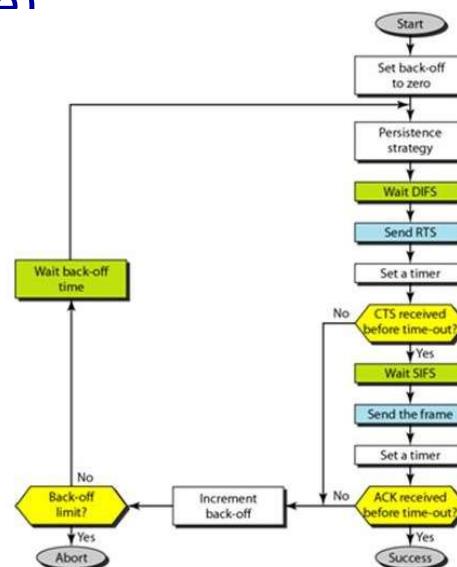
Distributed coordination function (DCF) is a mandatory technique used to prevent collisions in IEEE 802.11-based WLAN standard (Wi-Fi)

Wireless and Mobile Networks: 7- 50

Avoiding collisions (more)

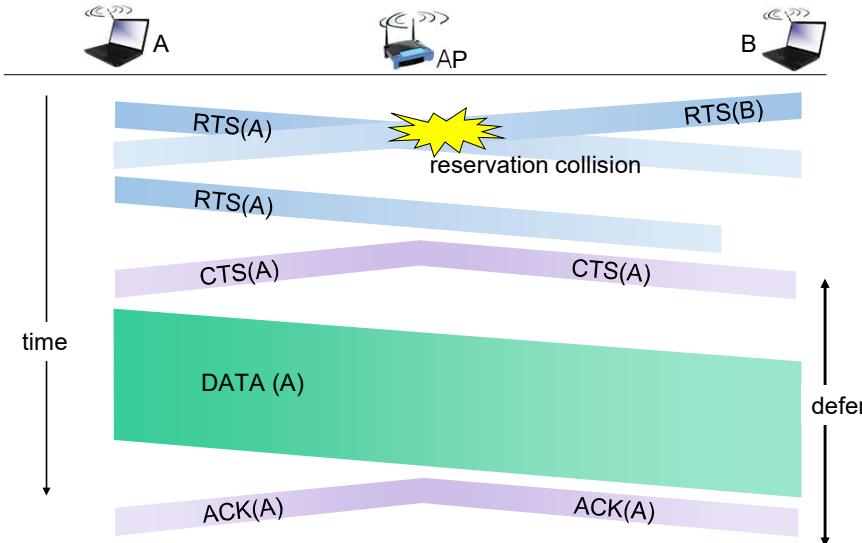
idea: sender “reserves” channel use for data frames using small reservation packets

- 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



Wireless and Mobile Networks: 7- 51

Collision Avoidance: RTS-CTS exchange



Wireless and Mobile Networks: 7- 52

802.11 frame: addressing

2	2	6	6	6	2	6	0 - 2312	4
frame control	duration	address 1	address 2	address 3	seq control	address 4	payload	CRC

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

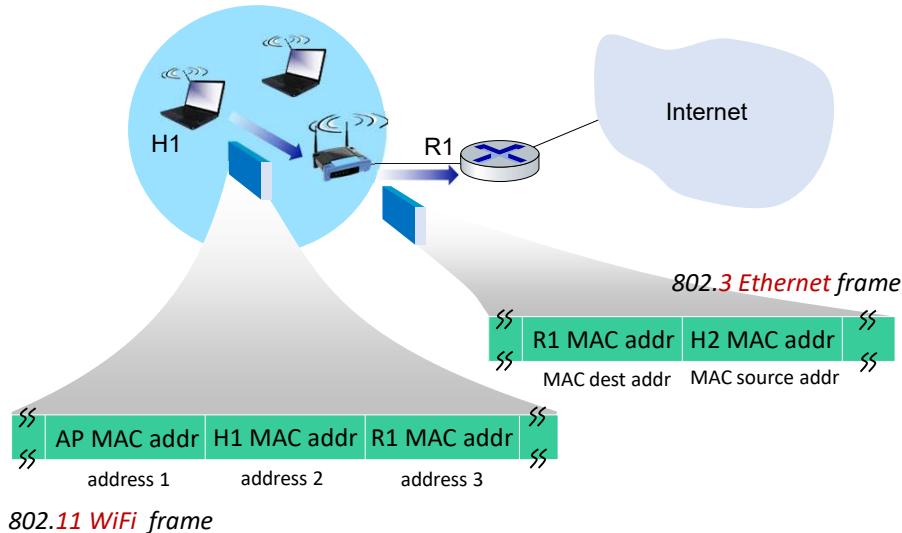
Address 2: MAC address of wireless host or AP transmitting this frame

Address 4: used only in ad hoc mode

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

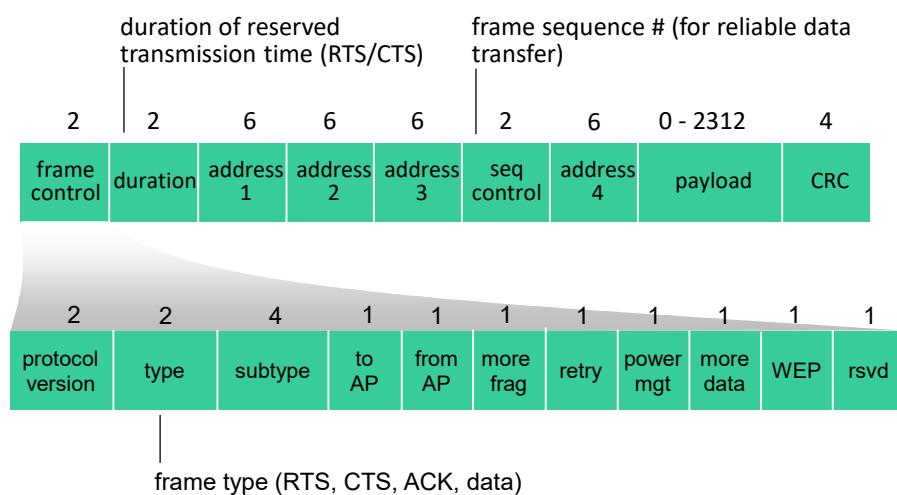
Wireless and Mobile Networks: 7- 53

802.11 frame: addressing



Wireless and Mobile Networks: 7- 54

802.11 frame: addressing



Wireless and Mobile Networks: 7- 55

802.11 frame: addressing

Protocol version	Type	Subtype	to AP	from AP	More frag	Retry	Power mgt	More data	WEP	rsvd
2	2	4	1	1	1	1	1	1	1	1

- **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

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

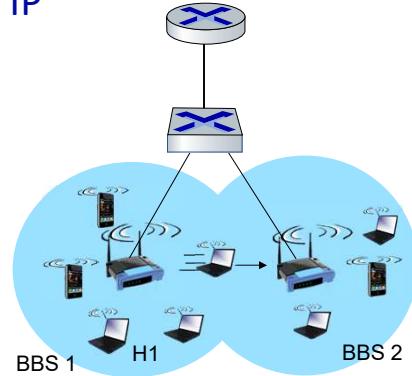
01	Control	0000-0010	Reserved
01	Control	0011	TACK
01	Control	0100	Beamforming Report Poll
01	Control	0101	VHT/HE NDP Announcement
01	Control	0110	Control Frame Extension
01	Control	0111	Control Wrapper
01	Control	1000	Block Ack Request (BAR)
01	Control	1001	Block Ack (BA)
01	Control	1010	PS-Poll
01	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

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

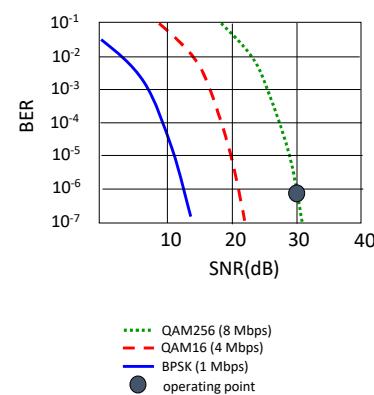


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802.11: advanced capabilities

Rate adaptation

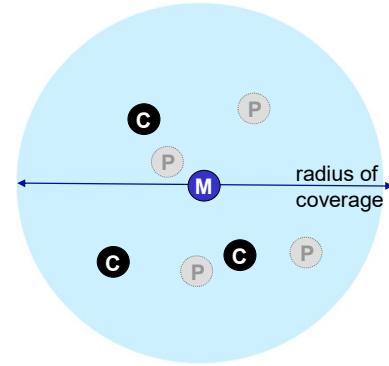
- base station, mobile **dynamically change transmission rate** (physical layer **modulation technique**) as mobile moves, SNR varies
 1. SNR decreases, BER increase as node moves away from base station
 2. When BER becomes **too high**, switch to **lower transmission rate** but with **lower BER**



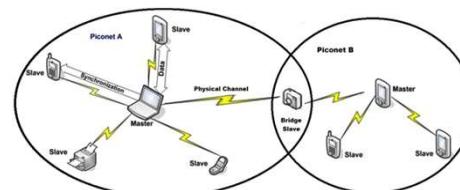
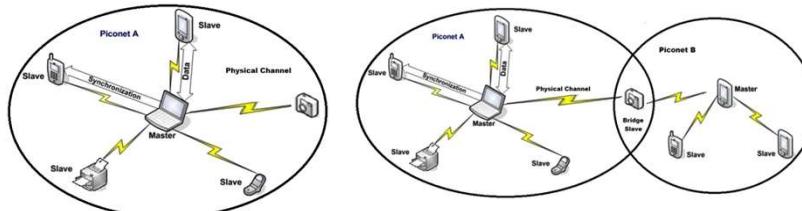
Wireless and Mobile Networks: 7- 59

Personal area networks: Bluetooth

- less than 10 m diameter
- replacement for cables (mouse, keyboard, headphones)
- ad hoc: no infrastructure
- 2.4-2.5 GHz ISM radio band, up to 3 Mbps
- master controller / clients devices:
 - master polls clients, grants requests for client transmissions

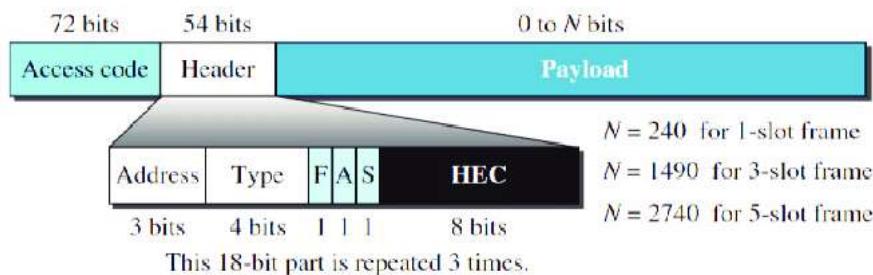


M master device
 C client device
 P parked device (inactive)



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Frame Format of Bluetooth



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