Introduction to Wireless Network

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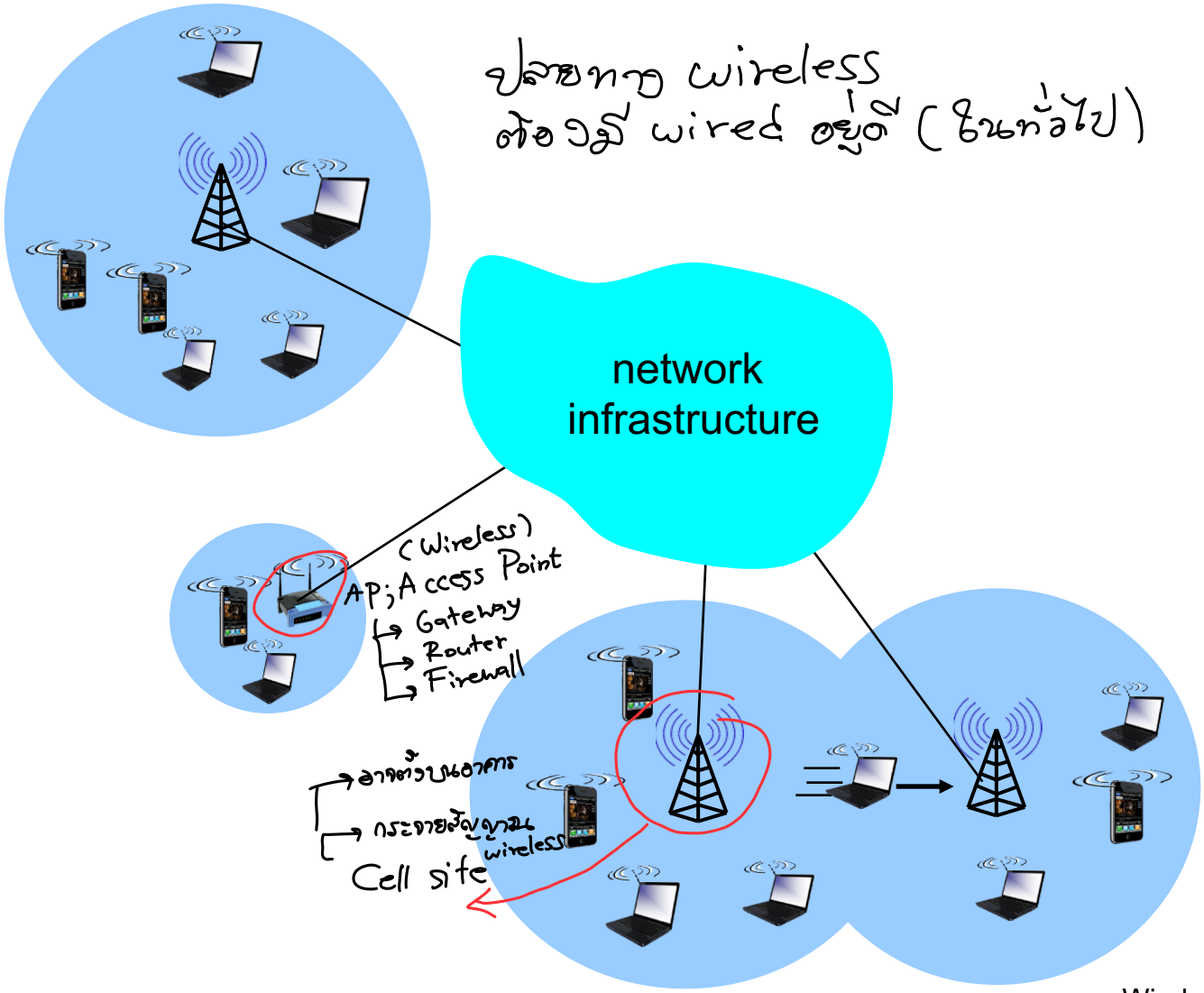
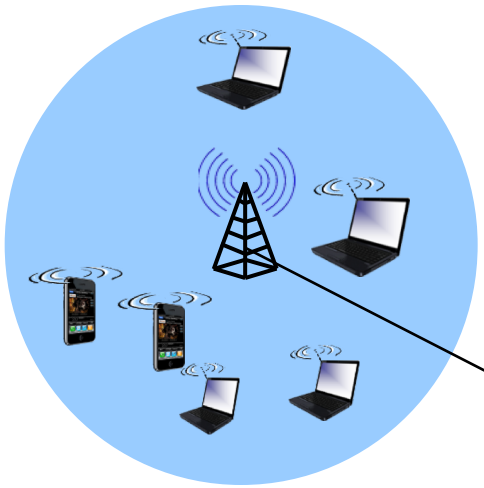
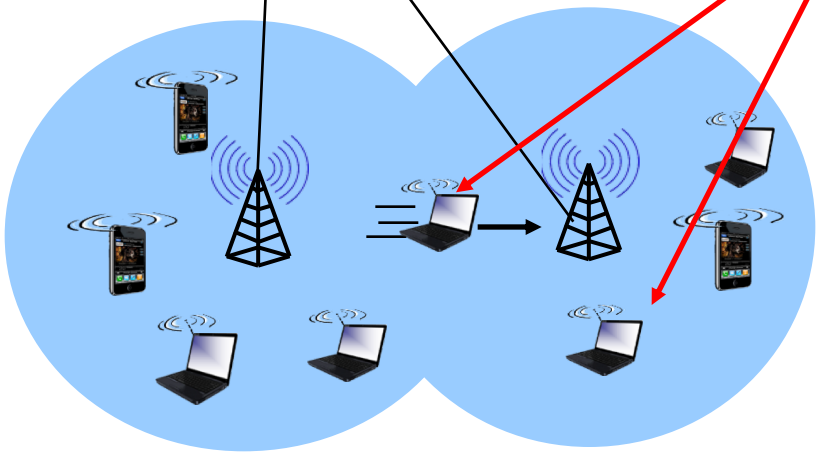
1. Elements of a wireless network



Elements of a wireless network



network infrastructure



wireless hosts

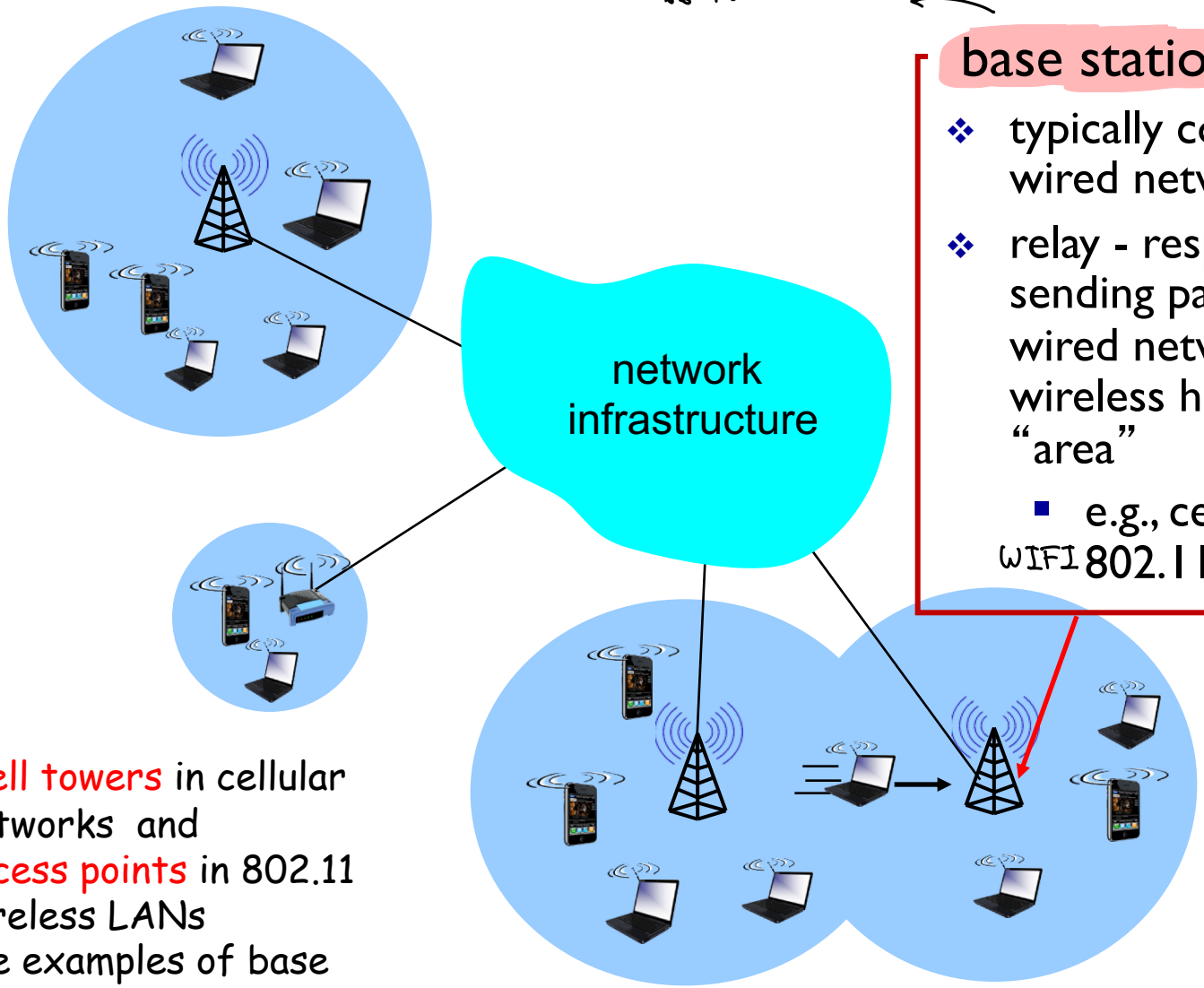
- laptop, smartphone, IoT
- run applications, software
- may be stationary (non-mobile) or mobile
  - wireless does *not* always mean mobility (ไม่มีรายเนียๆ → อาจเคลื่อนที่ไม่ได้)

Elements of a wireless network

เสาในการกระจายสัญญาณ

base station

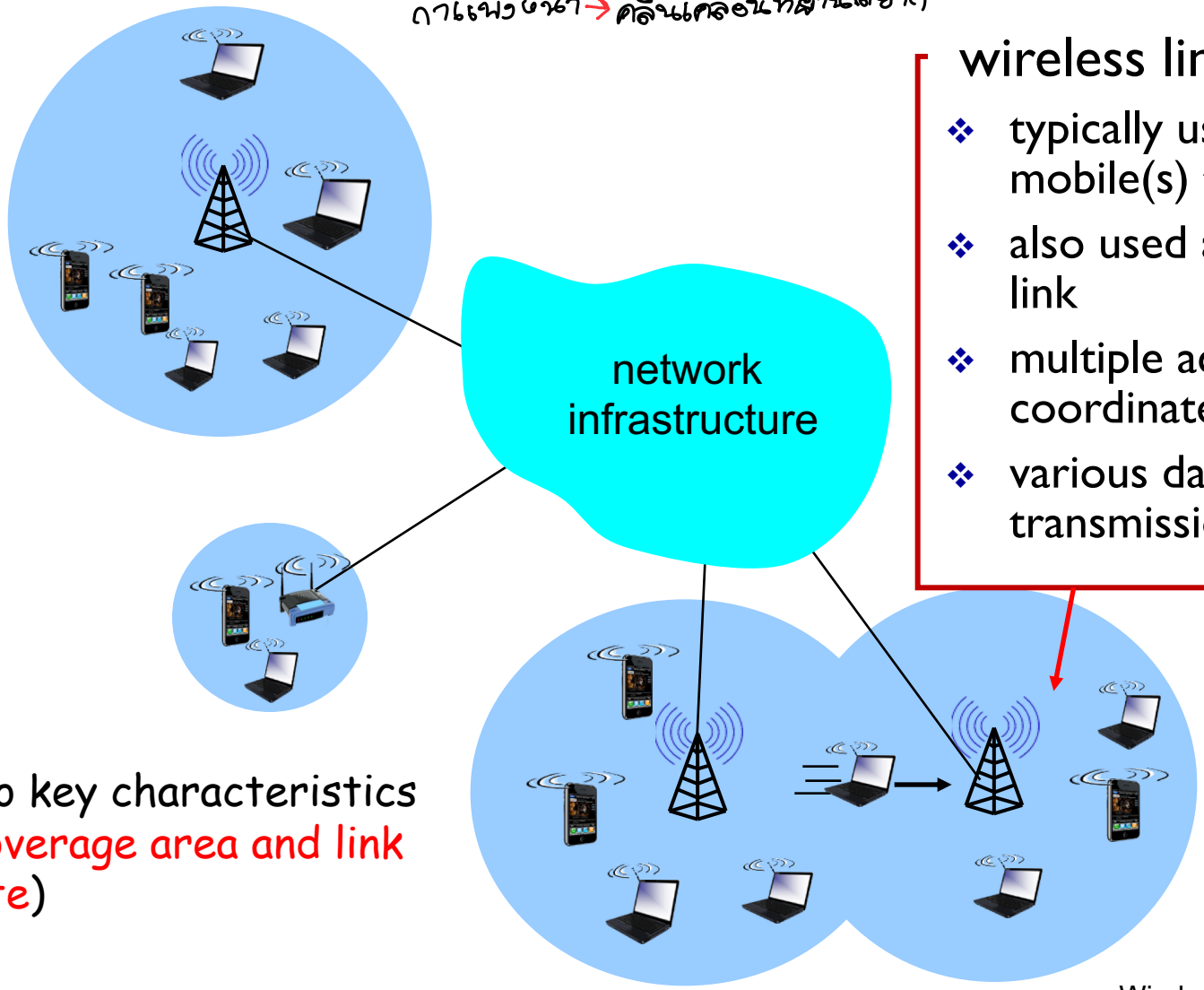
- typically connected to wired network
- relay - responsible for sending packets between wired network and wireless host(s) in its "area"
  - e.g., cell towers, WIFI 802.11 access points



Cell towers in cellular networks and access points in 802.11 wireless LANs are examples of base stations.

Elements of a wireless network

ถ้าแผงหนา → คลื่นเคลื่อนที่ผ่านได้ยาก

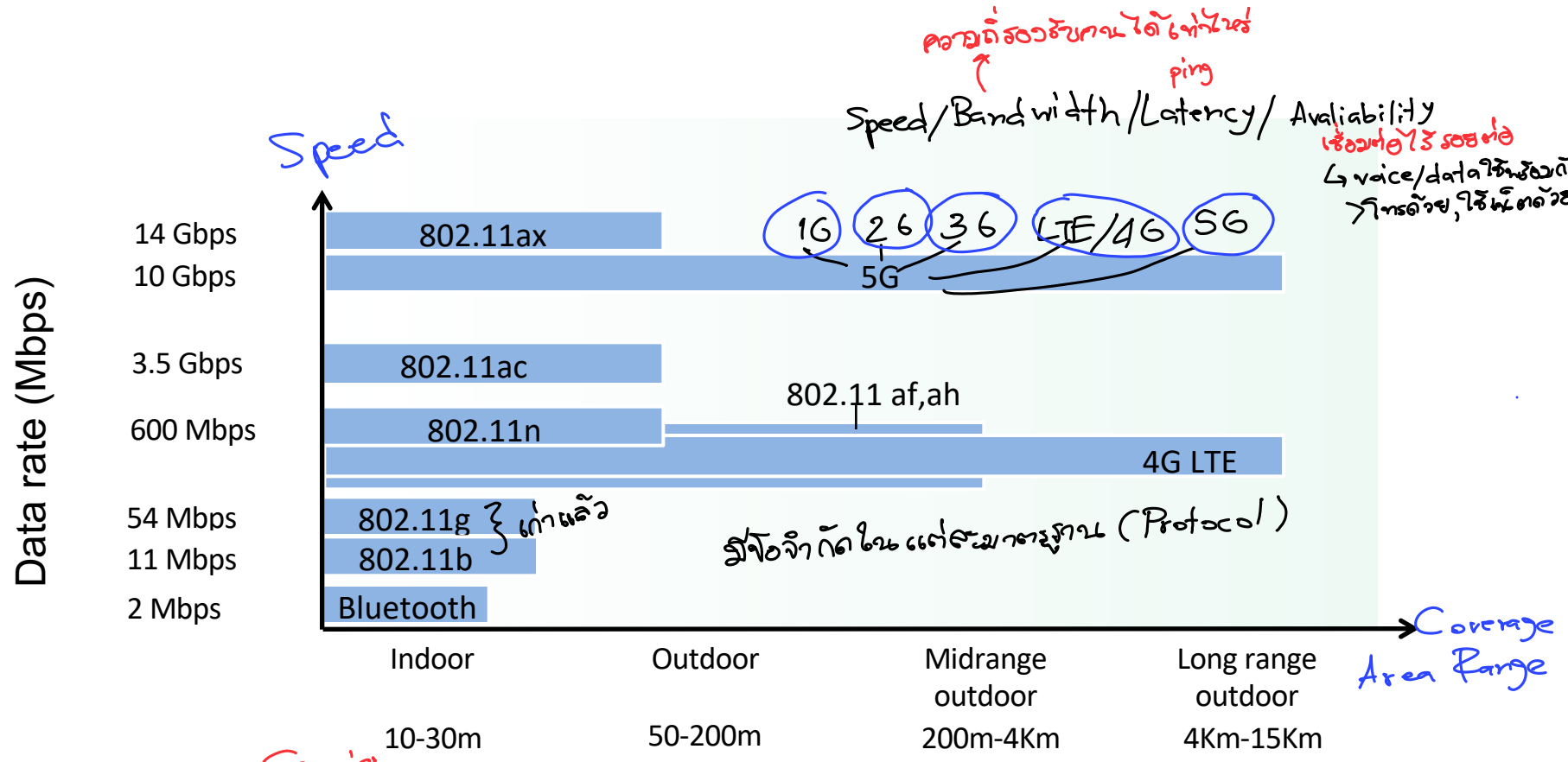


wireless link

- typically used to connect mobile(s) to base station
- also used as backbone link
- multiple access protocol coordinates link access
- various data rates, transmission distance

two key characteristics (coverage area and link rate)

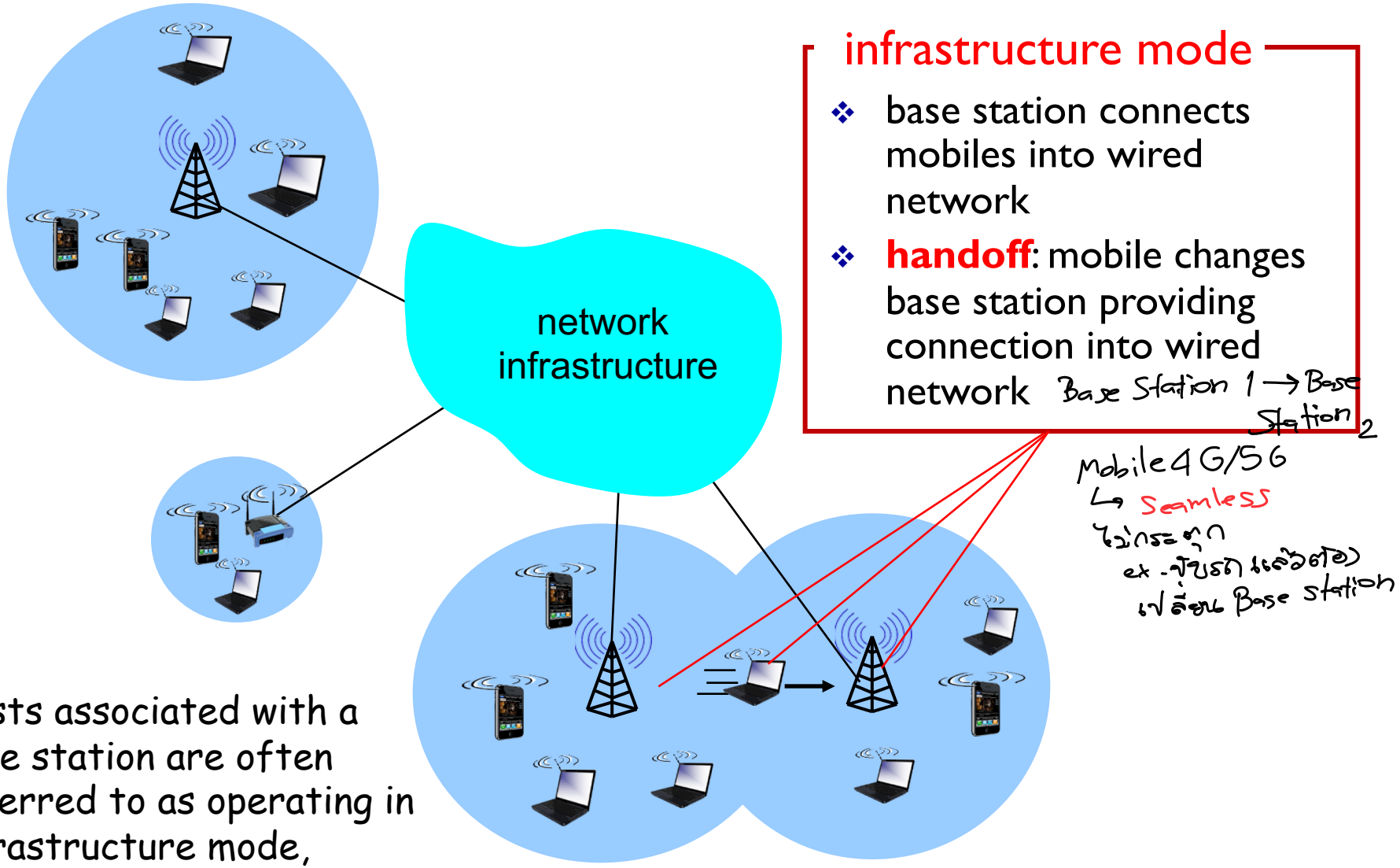
Characteristics of selected wireless links



ฝากข้อมูลไปกับ Hz(รูว)ในอากาศ(Invisible)

คลื่นวิทยุ???

Elements of a wireless network



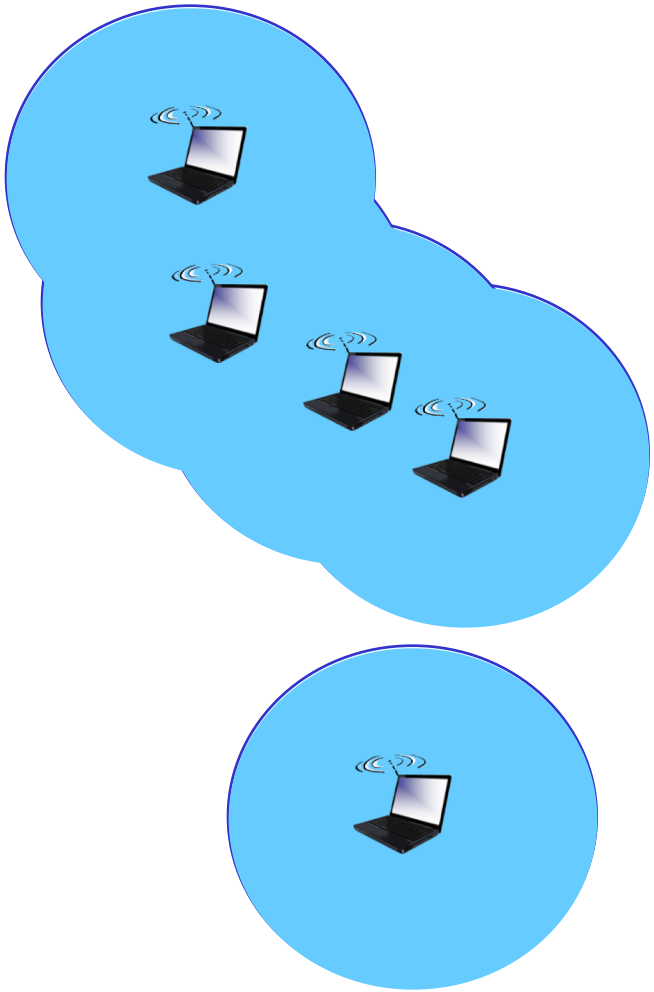
infrastructure mode

- base station connects mobiles into wired network
- **handoff**: mobile changes base station providing connection into wired network Base Station 1 → Base Station 2

Mobile 4G/5G
↳ Seamless
ไม่กระตุก
ex. ขับรถแล้วต่อ
เปลี่ยน Base station

Hosts associated with a base station are often referred to as operating in infrastructure mode,

Elements of a wireless network



กระจาย Wi-Fi ต่อ

ad hoc mode

Quickshare (Samsung)

Airdrop (Apple)

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

In ad hoc networks, wireless hosts have no such infrastructure with which to connect.

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 network*
no infrastructure	no base station, no connection to larger Internet (Bluetooth, ad hoc nets) เครื่องมือต่อ Device	no base station, no connection to larger Internet. May have to relay to reach other a given wireless node MANET, VANET

Note

mobile ad hoc networks (MANETs).

vehicular ad hoc network (VANET) รถเชื่อมต่อรถ

2. Wireless Link Characteristics (1)

important differences from wired link ….

- *decreased signal strength:* radio signal attenuates as it propagates through matter (path loss)
- *interference from other sources:* standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well
- *multipath propagation:* radio signal reflects off objects ground, arriving ad destination at slightly different times

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

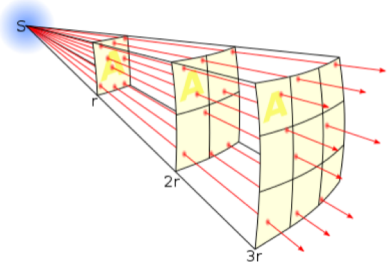
Wireless link characteristics: fading (attenuation)

Hz คือปัญหาอัตนการส่งsignalไกล

Wireless radio signal attenuates (loses power) as it propagates (free space "path loss")

Free space path loss ~ $(fd)^2$

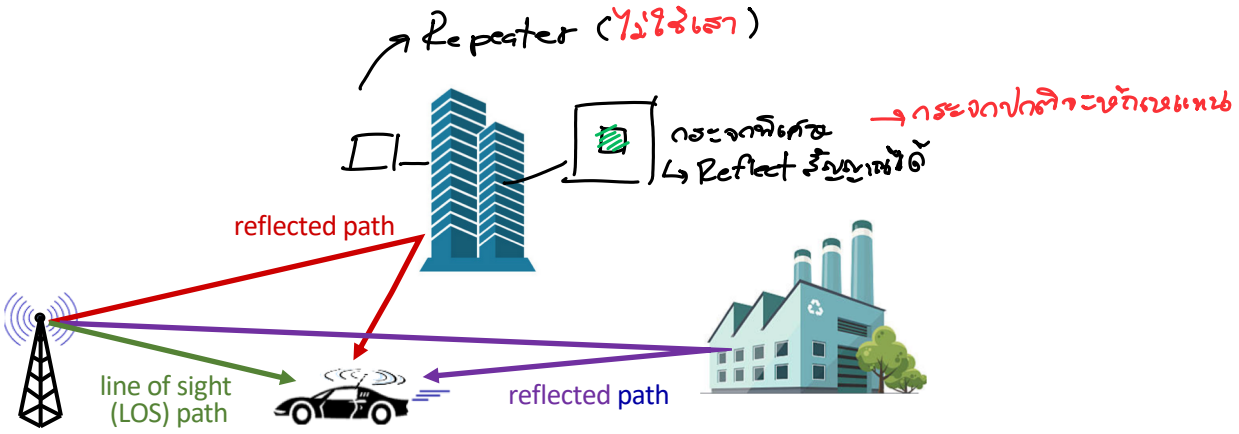
f: frequency
d: distance



higher frequency or longer distance → larger free space path loss

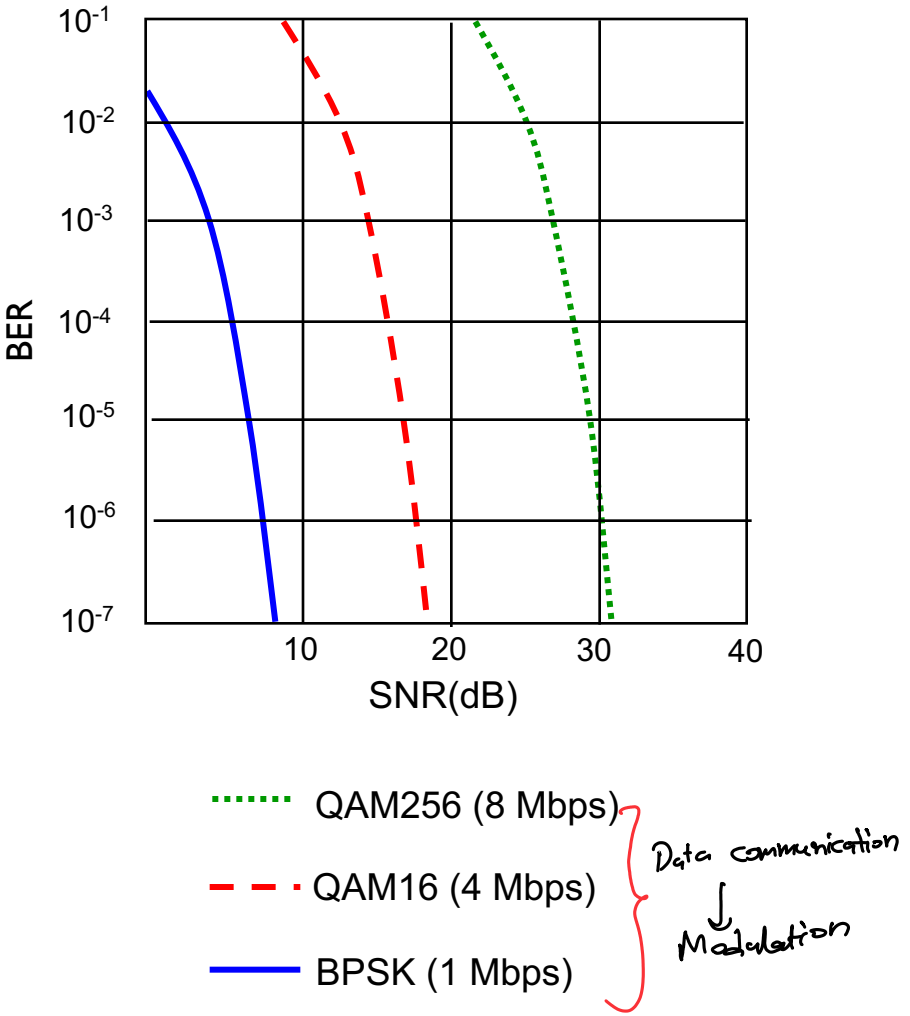
Wireless link characteristics: multipath

multipath propagation: radio signal reflects off objects ground, built environment, 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")
- *SNR versus BER tradeoffs*
  - *given physical layer:* increase power -> increase SNR->decrease BER (Bit Error Rate)
  - *given SNR:* choose physical layer that meets BER requirement, giving highest thruput
    - SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)



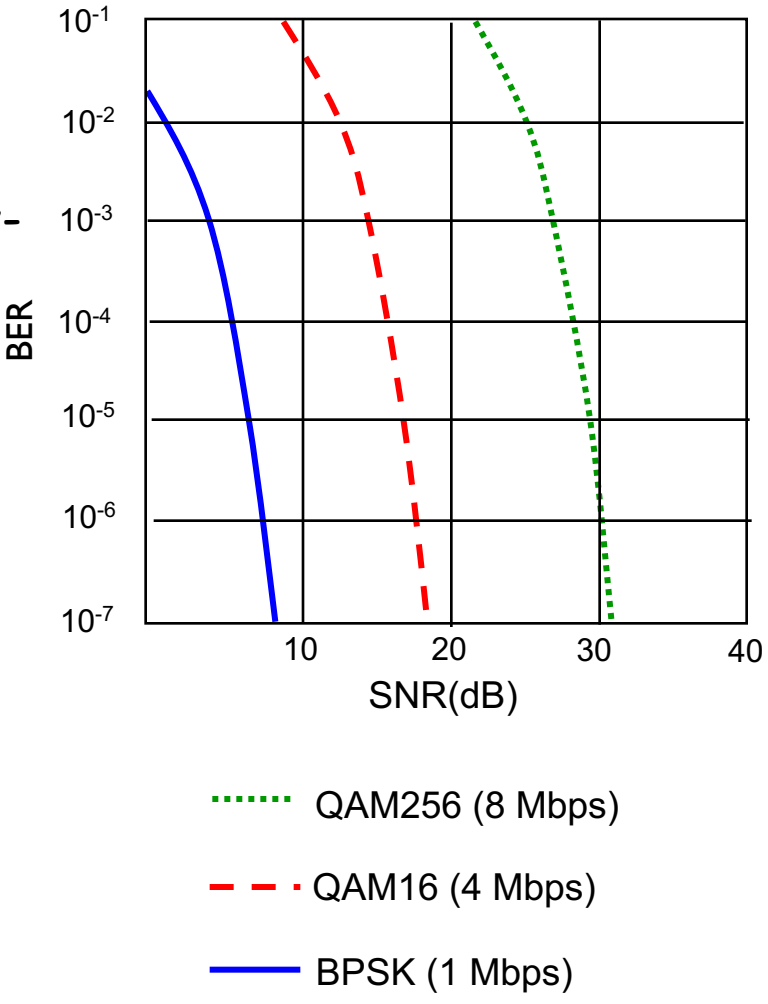
Wireless Link Characteristics (2)

There are also disadvantages associated with increasing the transmission power: More energy must be expended by the sender (an important concern for battery-powered mobile users

- เพิ่มกำลังส่ง สัญญาณ (แต่ไม่เพิ่ม BER)

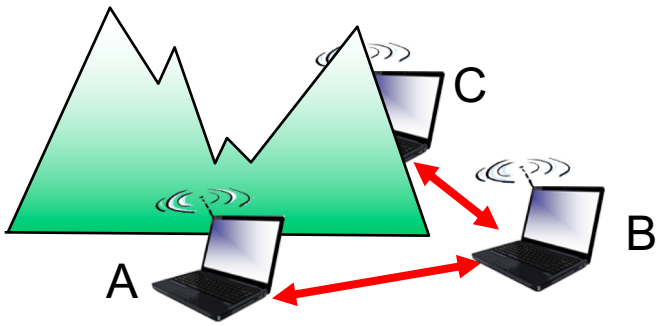
For a given SNR, a modulation technique with a higher bit transmission rate (whether in error or not) will have a higher BER.

Dynamic selection of the physical-layer modulation technique can be used to adapt the modulation technique to channel conditions.



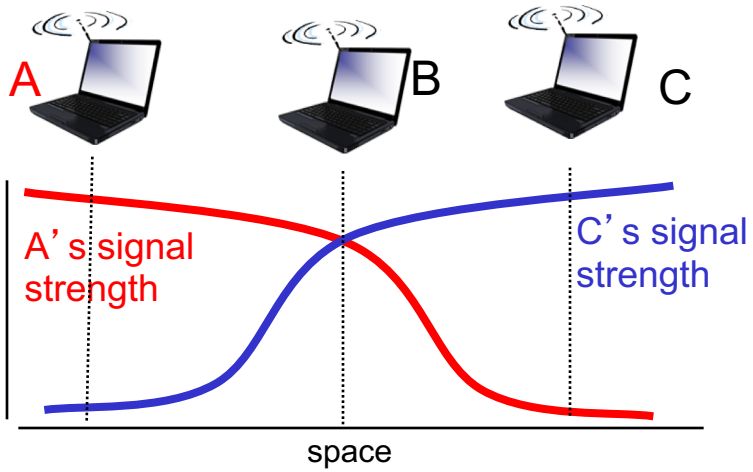
Wireless network characteristics : hidden terminal

Multiple wireless senders and 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

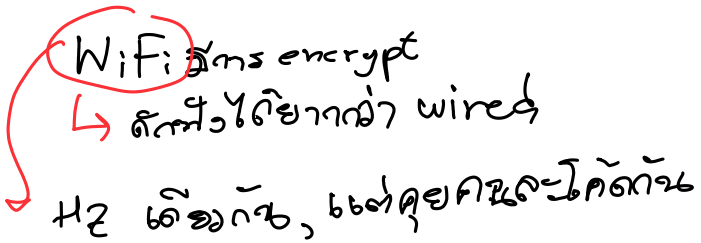


Signal attenuation also cause "hidden terminal"

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

2.1 Code Division Multiple Access (CDMA)

- Recall from last chapter that when hosts communicate over a shared medium, a protocol is needed so that the signals sent by multiple senders do not interfere at the receivers. In last chapter we described three classes of medium access protocols:
  - channel partitioning,
  - random access, and
  - taking turns.



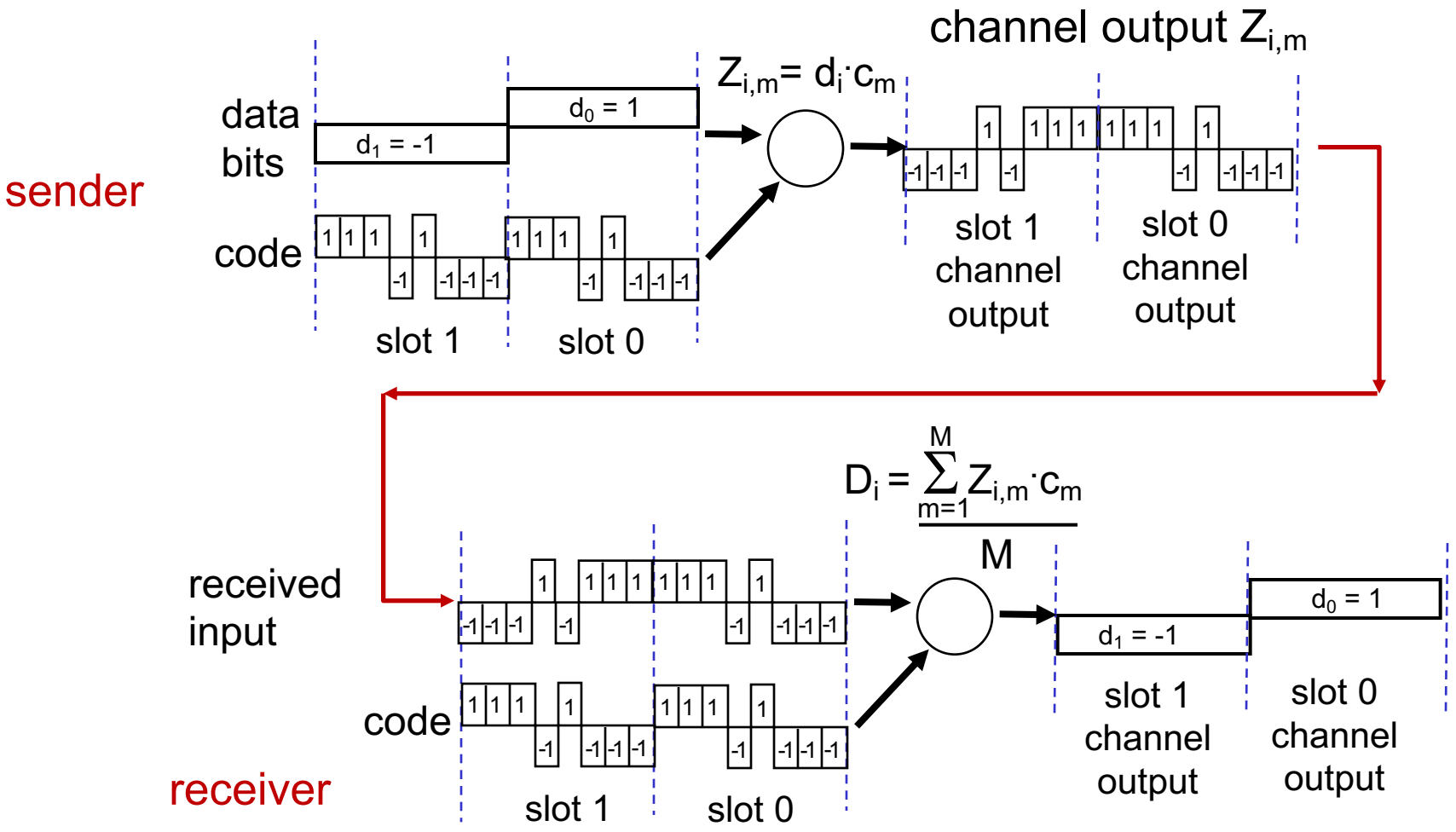
- Code division multiple access (CDMA) belongs to the family of channel partitioning protocols.

- It is prevalent in wireless LAN and cellular technologies. Because CDMA is so important in the wireless world, we'll take a quick look at CDMA now, before getting into specific wireless access technologies in the subsequent sections.

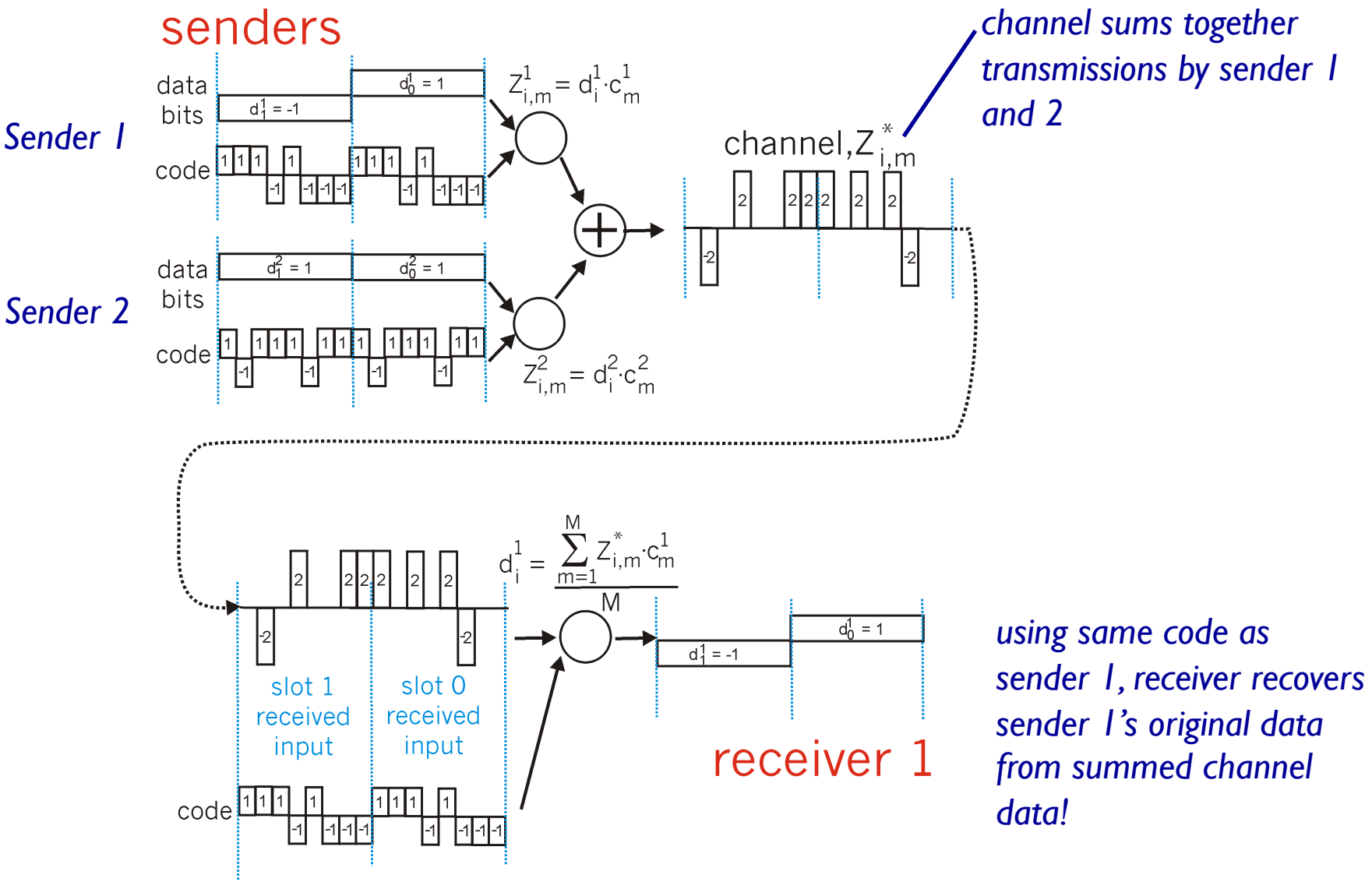
2.1 Code Division Multiple Access (CDMA)

- 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")
- *encoded signal* = (original data) X (chipping sequence)
- *decoding:* inner-product of encoded signal and chipping sequence

CDMA encode/decode



CDMA: two-sender interference



3. 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

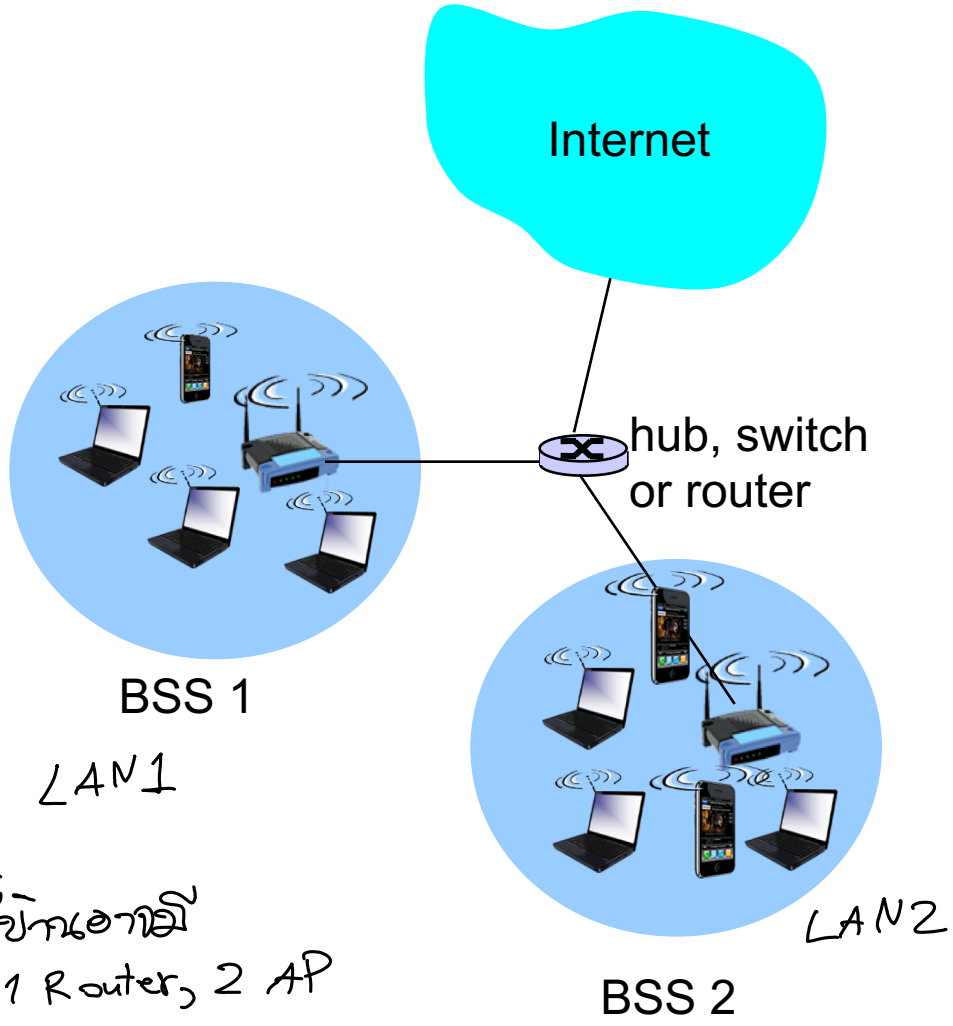
- all use CSMA/CA for multiple access, and have base-station and ad-hoc network versions

Modern Wi-Fi Standards

Protocol	802.11n	802.11ac	802.11ax	802.11be
Wi-Fi generation name	Wi-Fi 4	Wi-Fi 5	Wi-Fi 6 / Wi-Fi 6E	Wi-Fi 7
Introduced	2007	2013	2019 / 2021	Early 2024
Bands	2.4 & 5GHz	5 GHz	2.4 & 5 & 6 GHz	2.4, 5 & 6 GHz
Channels	20 & 40 MHz	20, 40, 80 & 80+80 MHz	20, 40, 80, 80+80 & 160 MHz	20, 40, 80, 80+80, 160 & 320 MHz
Communication	OFDM	OFDM	OFDMA	OFDMA
Highest Modulation	64-QAM	256-QAM	1024-QAM	4096-QAM
Maximum Data Rates	600 Mbps	6.9 Gbps (optimal) 433 Mbps to 1.7 Gbps (typical)	9.6 Gbps (optimal) 1.2 to 4.8 Gbps (typical)	36 Gbps (theoretical optimal)
Spatial Streams	1 – 4	1 – 8	1 – 8	1 – 8
Tx Beamforming	Yes	Yes	Yes	Yes
MU-MIMO	No	DL only	Yes	Yes
Significance	Introduction of MIMO	Introduction of MU-MIMO	Introduction of OFDMA	Introduction of Multi-Link Operation (MLO)

MIMO → Multi input, multi output → ส่งหลายเส้น แล้วค่อยมาชน

3.1 802.11 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

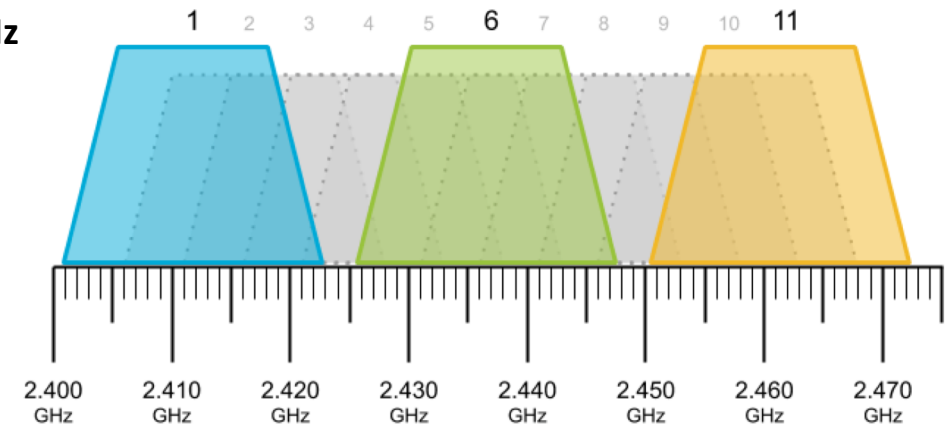
- spectrum divided into channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
- host: must *associate* with an AP
  - scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC address
  - selects AP to associate with
  - may perform authentication
  - will typically run DHCP to get IP address in AP's subnet

Dynamic Host Configuration Protocol
กำหนดค่าอัตโนมัติ → 192.168.1.X
↳ ไม่มีปัญหา IP ซ้ำ Subnet 255.255.255.0

802.11: Channels

- 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!

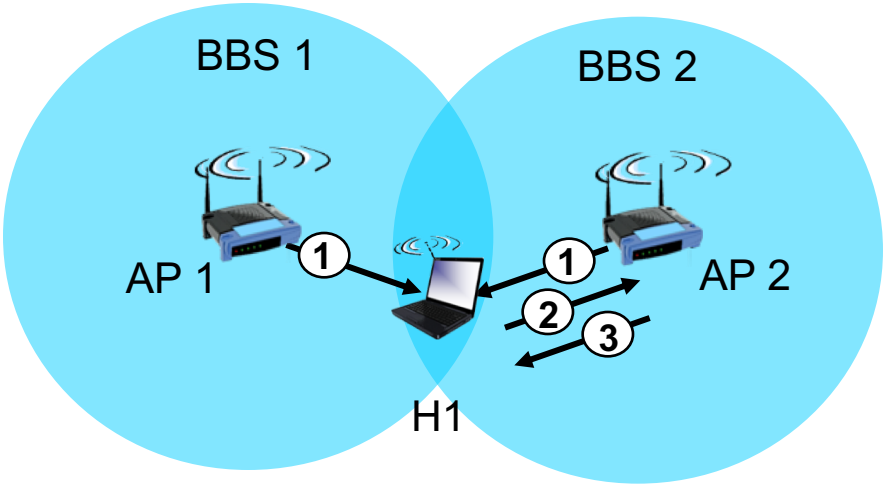
Example: 2.4 GHz

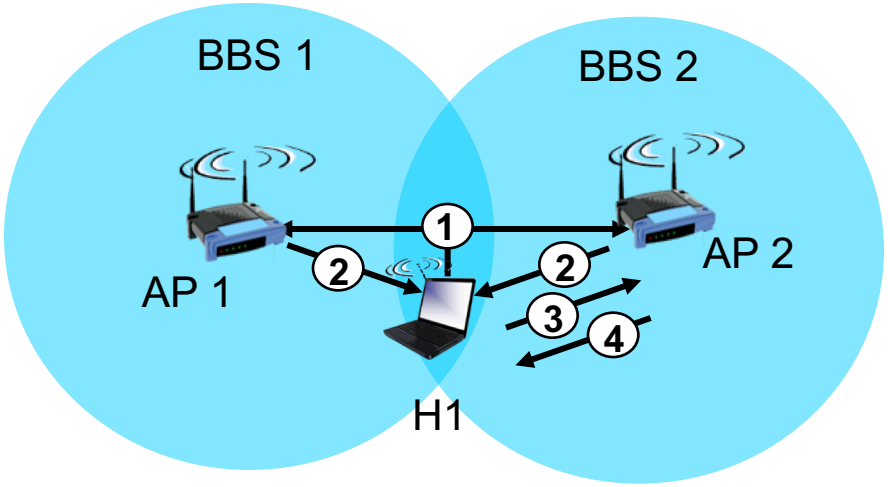


802.11: Association

- 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
  - 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

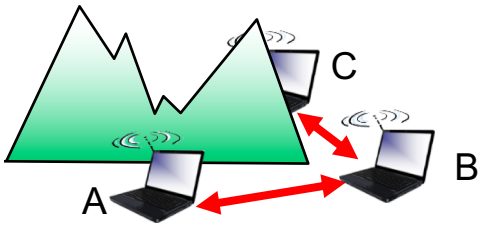
(2) Probe Response frames sent from APs

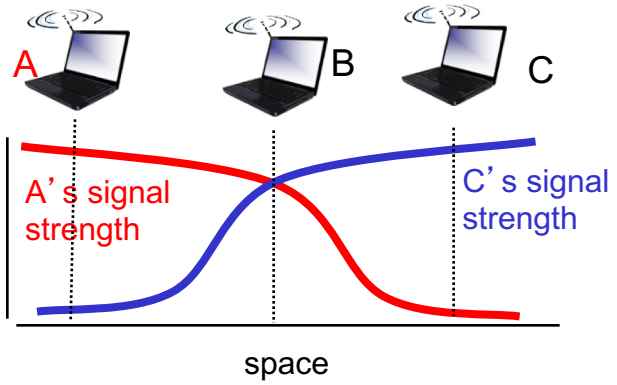
(3) Association Request frame sent: H1 to selected AP

(4) Association Response frame sent from selected AP to H1

IEEE 802.11: multiple access

- avoid collisions: 2^+ nodes transmitting at same time
- 802.11: CSMA - sense before transmitting
  - don't collide with ongoing transmission by another node
- 802.11: *no* collision detection!
  - difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
  - can't sense all collisions in any case: hidden terminal, fading
  - goal: *avoid collisions:* CSMA/C(ollision)A(voidance)





3.2 IEEE 802.11 MAC Protocol: CSMA/CA

Note
Distributed Inter-frame Space (DIFS);

802.11 sender

1 if sense channel idle for **DIFS** then

transmit entire frame (no CD)

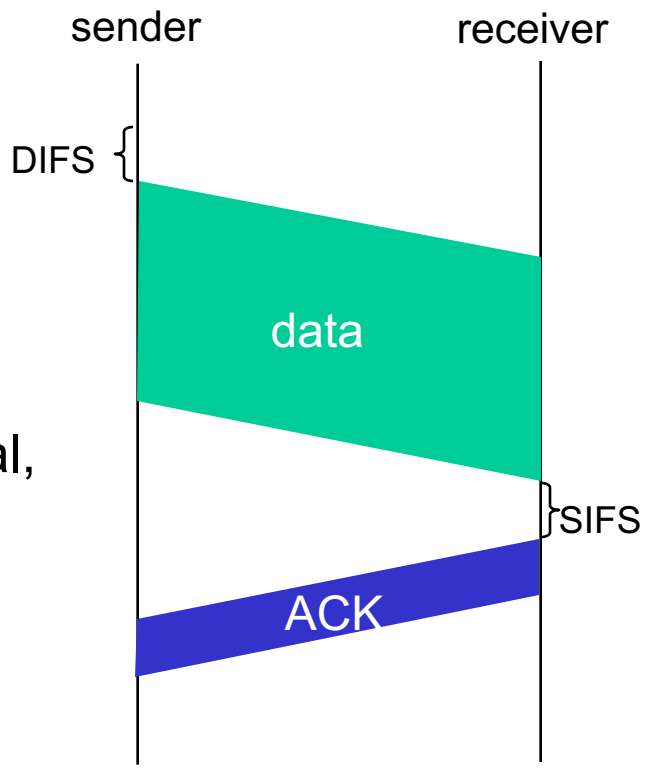
2 if sense channel busy then

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)

Short Inter-frame Spacing (SIFS)

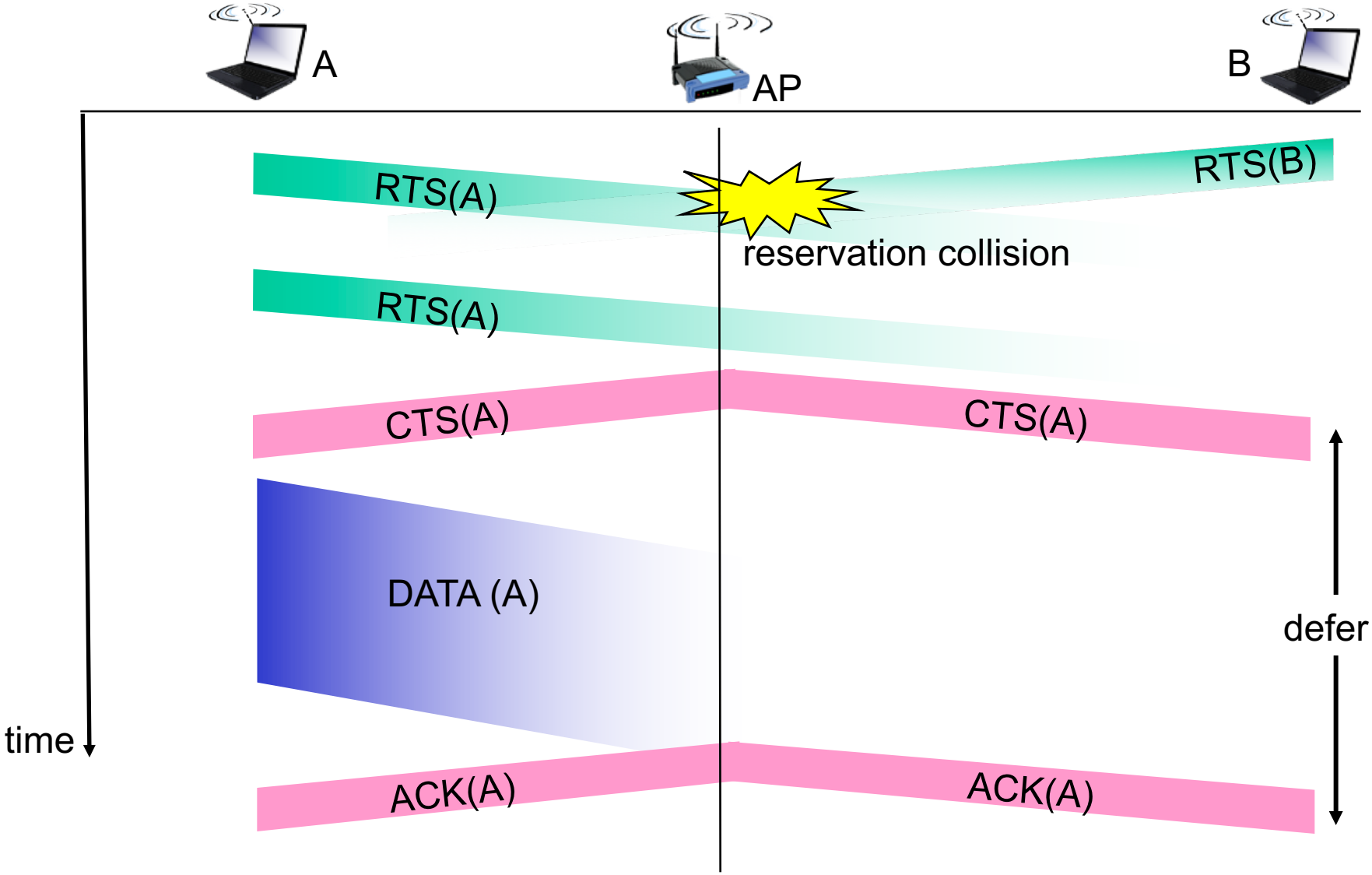
Avoiding collisions (more)

idea: allow sender to "reserve" channel rather than random access of data frames: avoid collisions of long data frames

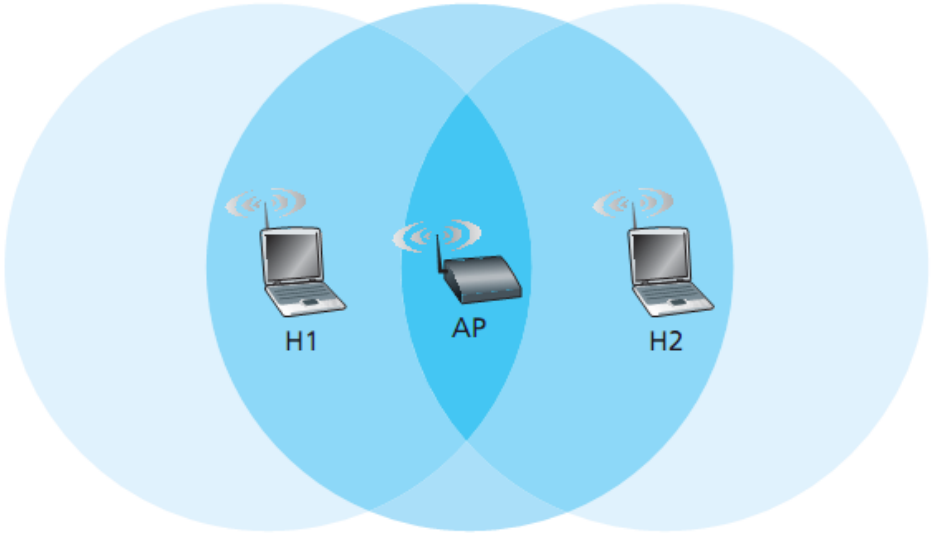
- sender first transmits *small* request-to-send (RTS) packets to BS using CSMA
  - RTSs may still collide with each other (but they're short)
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS exchange



Dealing with Hidden Terminals: RTS and CTS

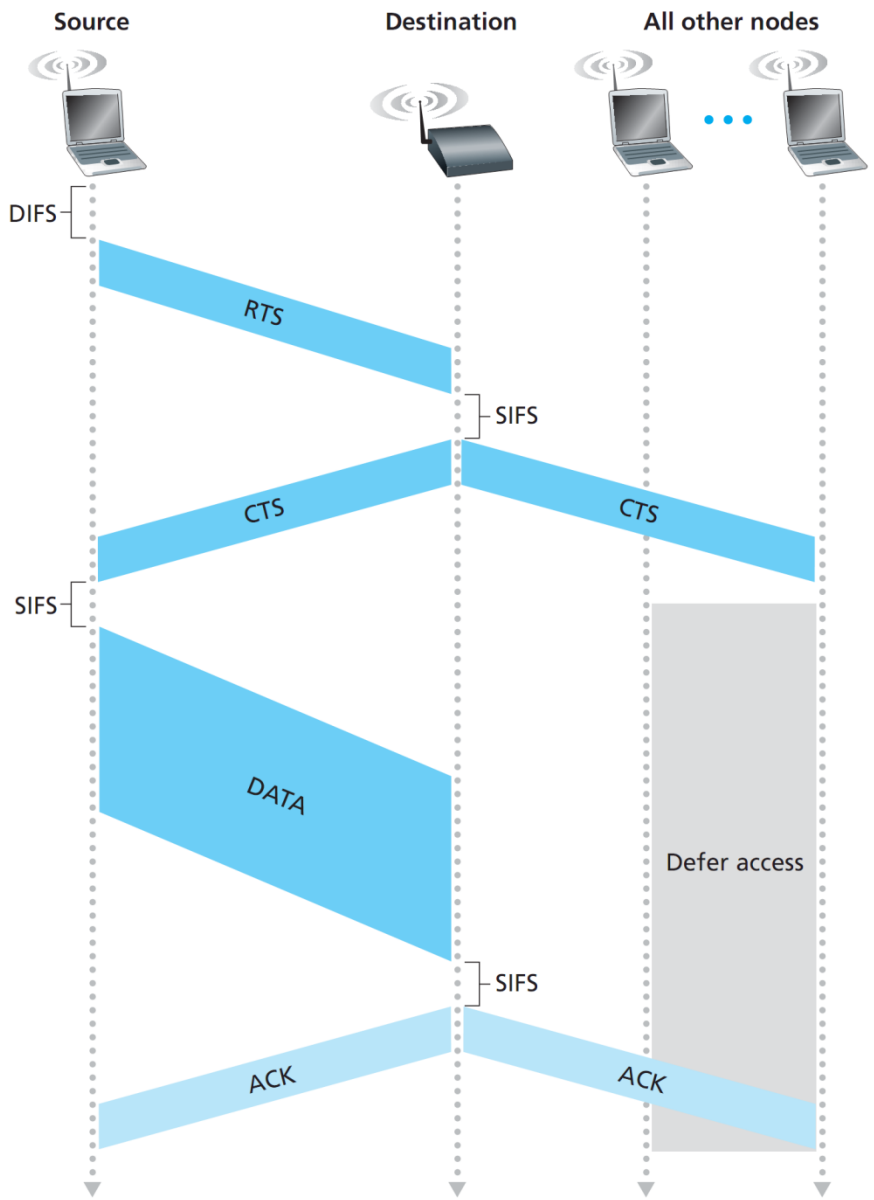


each of the wireless stations is hidden from the other, although neither is hidden from the AP

Figure 6.11 ♦ Hidden terminal example: H1 is hidden from H2, and vice versa

Suppose Station H1 is transmitting a frame and halfway through H1's transmission, Station H2 wants to send a frame to the AP. H2, not hearing the transmission from H1, will first wait a DIFS interval and then transmit the frame, resulting in a collision. The channel will therefore be wasted during the entire period of H1's transmission as well as during H2's transmission

Collision Avoidance: RTS-CTS exchange



RTS frame

indicating the total time required to transmit the DATA frame and the acknowledgment (ACK) frame.

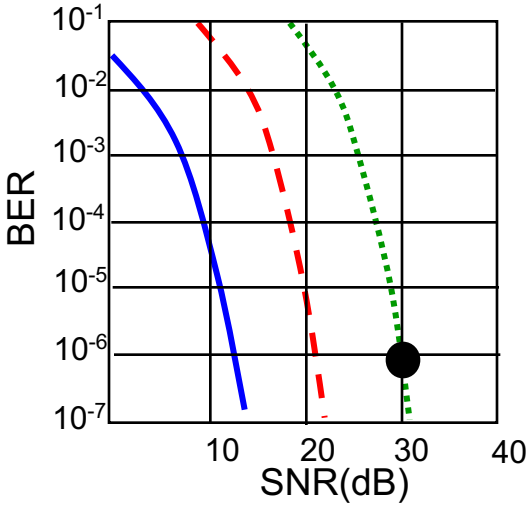
CTS frame

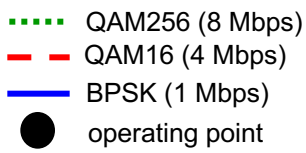
serves two purposes: It gives the sender explicit permission to send and also instructs the other stations not to send for the reserved duration.

3.3 802.11: 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

802.11: advanced capabilities

Power is a precious resource in mobile devices

power management

- node-to-AP: "I am going to sleep until next beacon frame"
  - AP knows not to transmit frames to this node
  - node wakes up before next beacon frame

  Ex: inter-beacon time of 100 msec, a wakeup time of 250 microseconds
- beacon frame: contains list of mobiles with AP-to-mobile frames waiting to be sent
  - node will stay awake if AP-to-mobile frames to be sent; otherwise sleep again until next beacon frame

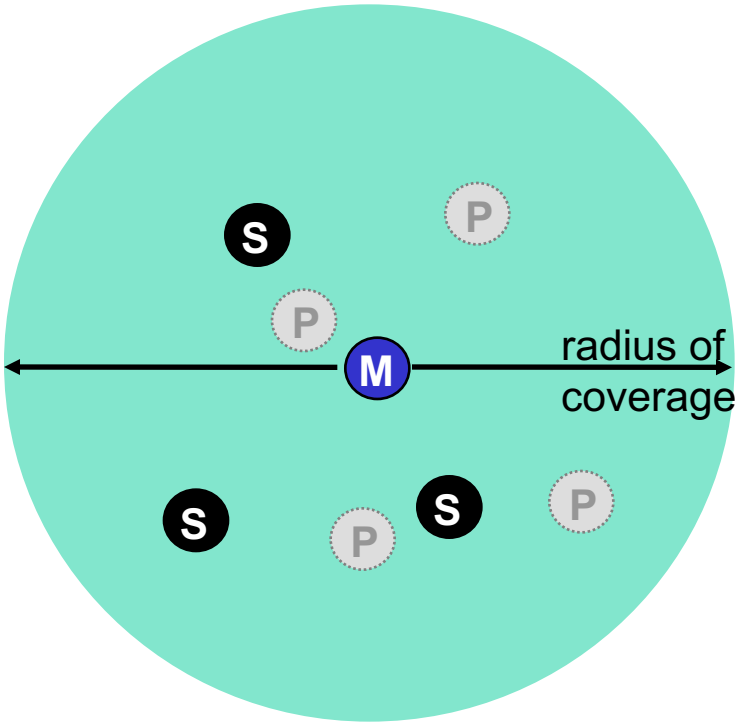
- The AP knows that it should not send any frames to that node, and will buffer any frames destined for the sleeping host for later transmission

- The beacon frames sent out by the AP contain a list of nodes whose frames have been buffered at the AP. If there are no buffered frames for the node, it can go back to sleep.

  Otherwise, the node can explicitly request that the buffered frames be sent by sending a polling message to the AP.

3.4 802.15: personal area network (PAN)

- less than 10 m diameter
- replacement for cables (mouse, keyboard, headphones)
- ad hoc: no infrastructure
- master/slaves:
  - slaves request permission to send (to master)
  - master grants requests
- 802.15: evolved from Bluetooth specification
  - 2.4-2.5 GHz radio band
  - up to 721 kbps



M Master device

S Slave device

P Parked device (inactive)

3.4 802.15: personal area network (PAN)

- Two other IEEE 802 protocols—Bluetooth and Zigbee (defined in the IEEE 802.15.1 and IEEE 802.15.4 standards [IEEE 802.15 2012])

อายอน WiFi ขายดี

PAN

- **Bluetooth**
- An IEEE 802.15.1 network operates over a short range, at low power, and at low cost. It is essentially a low-power, short-range, low-rate "cable replacement" technology for interconnecting notebooks, peripheral devices, cellular phones, and smart phones

- operate in the 2.4 GHz unlicensed radio band.

3.4 802.15: personal area network (PAN)

3.4 802.15: personal area network (PAN)

- **Bluetooth**
- 802.15.1 networks are ad hoc networks: No network infrastructure

- One of these devices is designated as the master, with the remaining devices acting as slaves. The master node truly rules the piconet—its clock determines time in the piconet, it can transmit in each odd-numbered slot, and a slave can transmit only after the master has communicated with it in the previous slot and even then the slave can only transmit to the master.

- In addition to the slave devices, there can also be up to 255 parked devices in the network

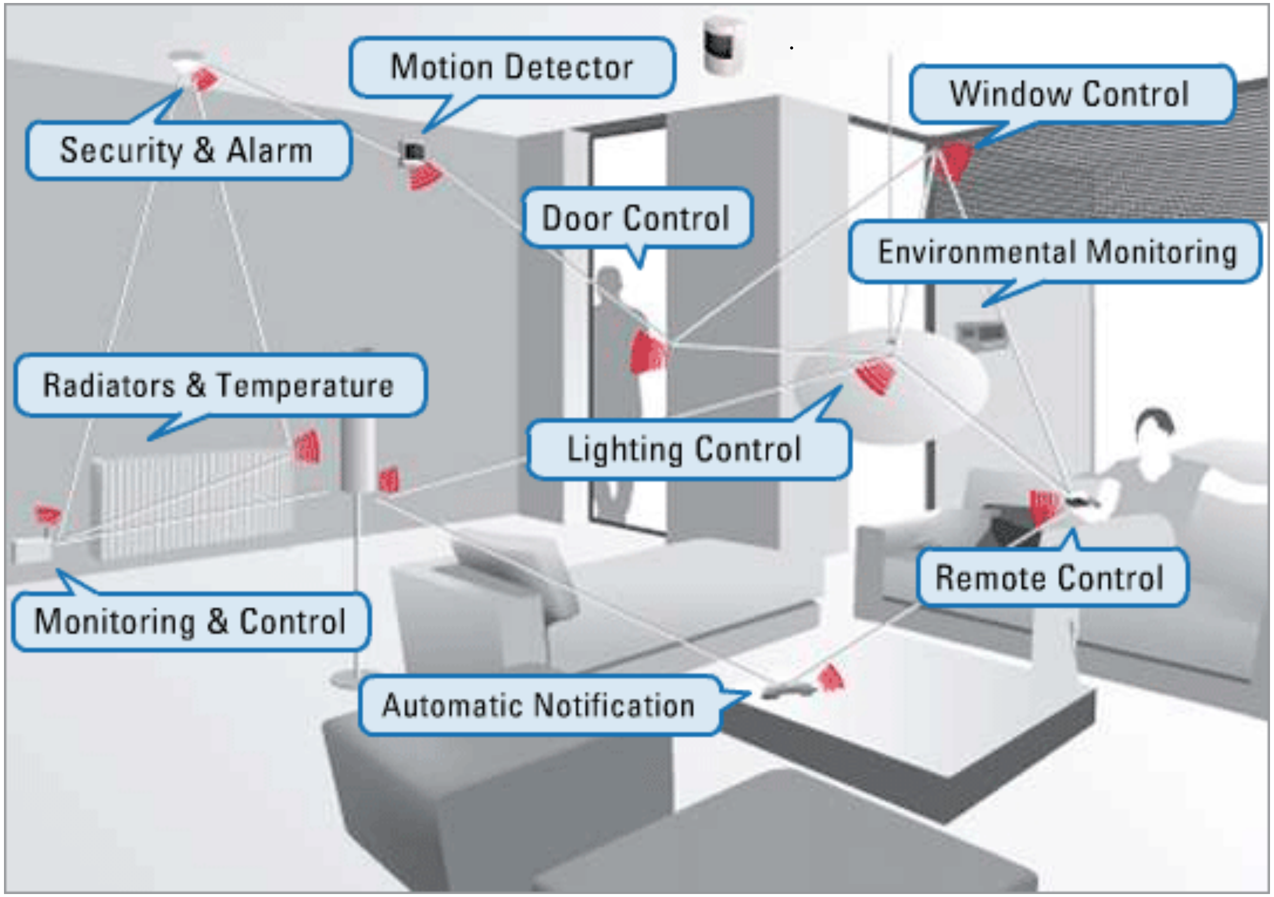
- These devices cannot communicate until their status has been changed from parked to active by the master node.

3.4 802.15: personal area network (PAN)

- **Zigbee**
- Zigbee is targeted at lower-powered, lower-data-rate, lower-duty-cycle applications than Bluetooth.
- While we may tend to think that "bigger and faster is better," not all network applications need high bandwidth and the consequent higher costs (both economic and power costs).
- For example, home temperature and light sensors, security devices, and wall-mounted switches are all very simple, low-power, low-duty-cycle, low-cost devices.
- Zigbee is thus well-suited for these devices. Zigbee defines channel rates of 20, 40, 100, and 250 Kbps, depending on the channel frequency.

3.4 802.15: personal area network (PAN)

ทำ network/LAN ของตัวเองจะสะดวกกว่า ↗ หลาย device ก็สั่ง control ด้วยหลาย App



Device ส่วนใหญ่ใช้ connect WiFi