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Computer Networks

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Material with thanks to James F. Kurose, Mosharaf Chowdhury, and other colleagues.

Chapter 2. Direct Link Networks

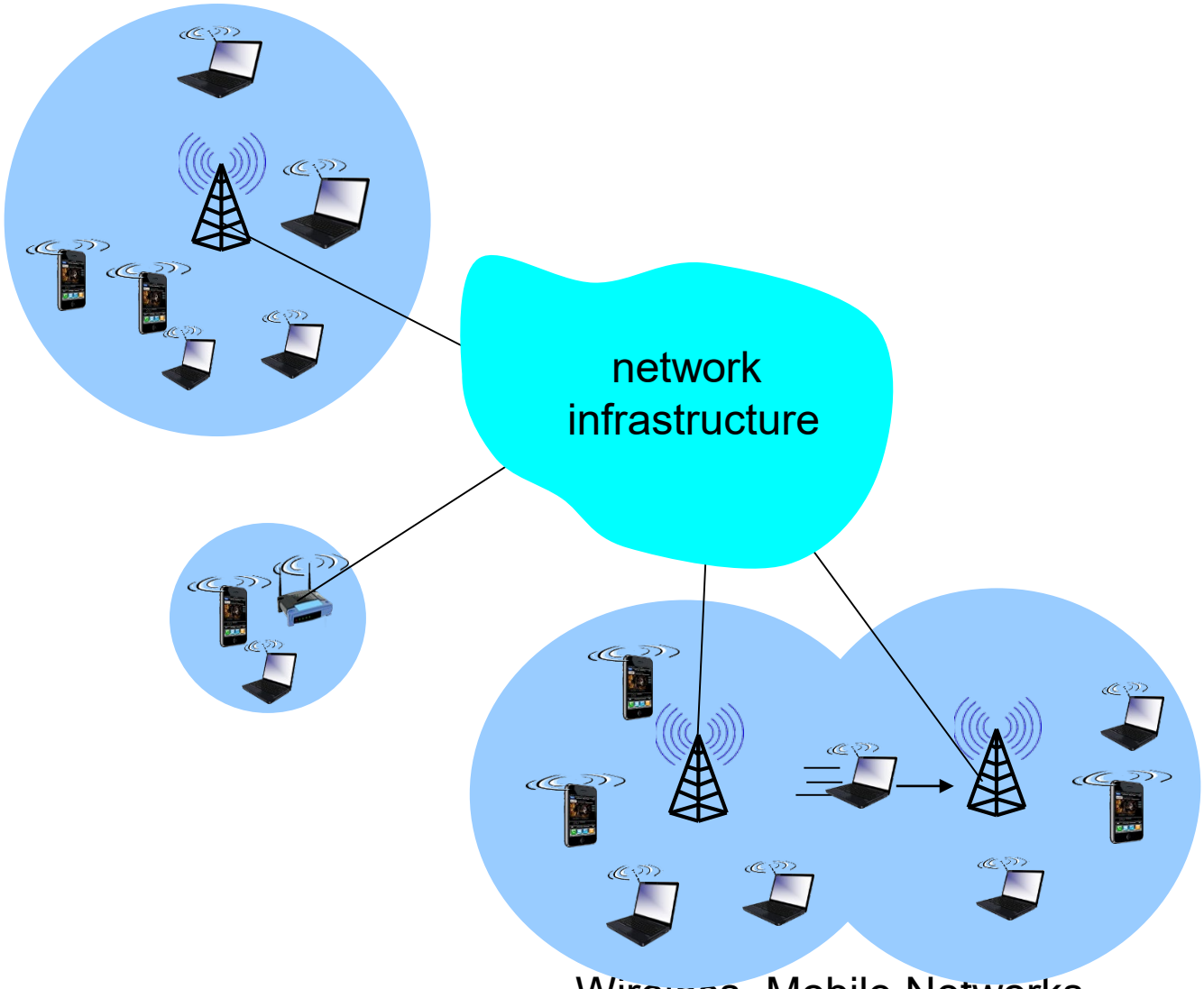
- Link Service and Framing
- Error Detection and Reliable Transmission
- HDLC, PPP, and SONET
- Token Ring
- Ethernet
- Bridges and Layer-2 switch
- Wireless Networks
- Network Performance

Wireless and Mobile Networks

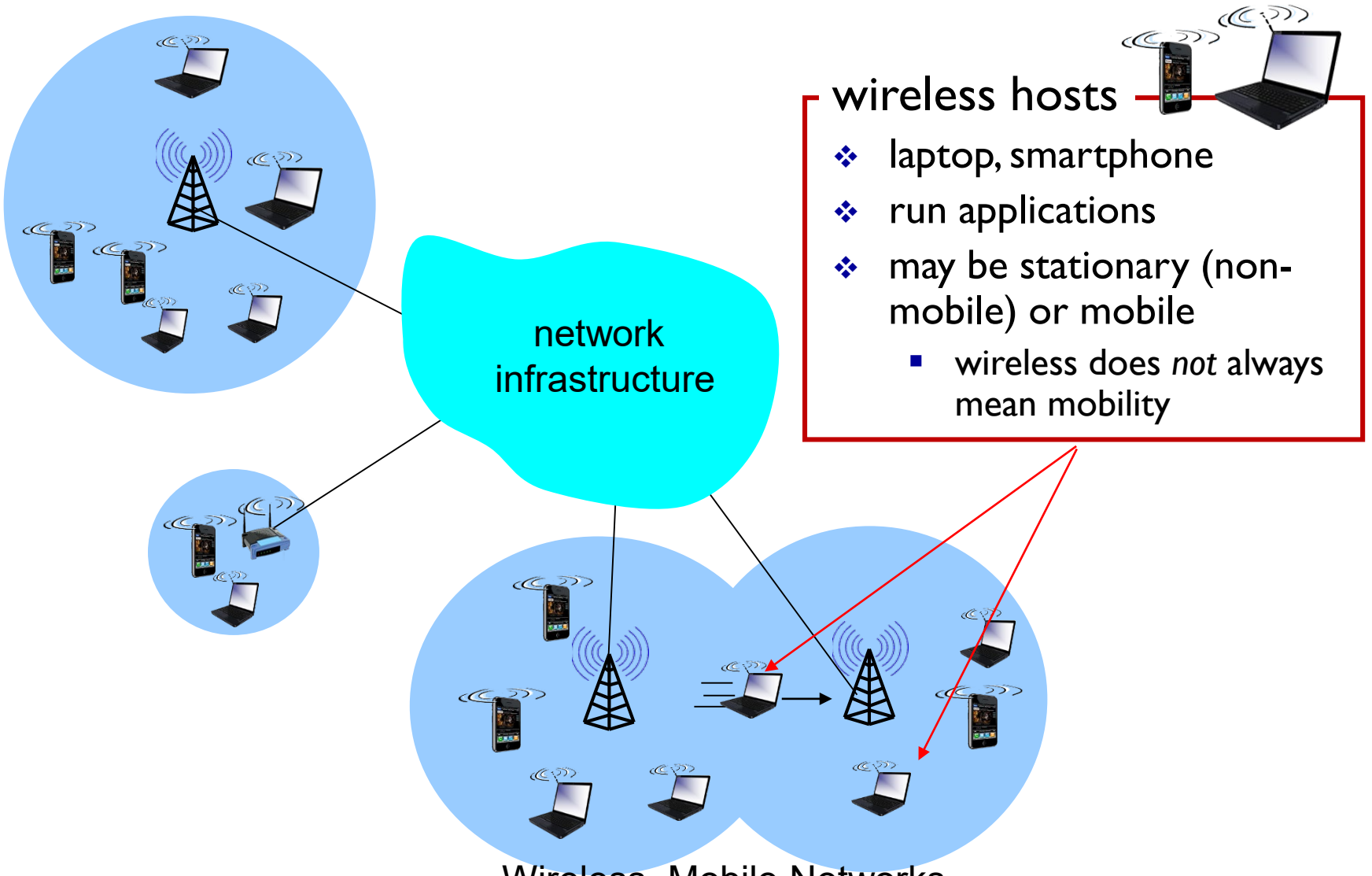
Wireless and Mobile Networks

- Extremely popular in the recent years
- Mobile users now exceeds wired phone users (>5:1)
- Two important challenges
  - **Wireless**: communication over wireless link
  - **Mobility**: handling the mobile user who changes point of attachment to network
    - Non-wireless networks may also have to deal with mobility issues
    - Handoff: Mobile changes base station providing connection into wired network

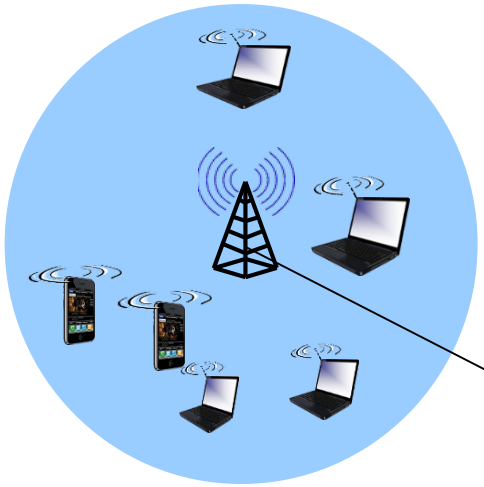
Elements of a wireless network



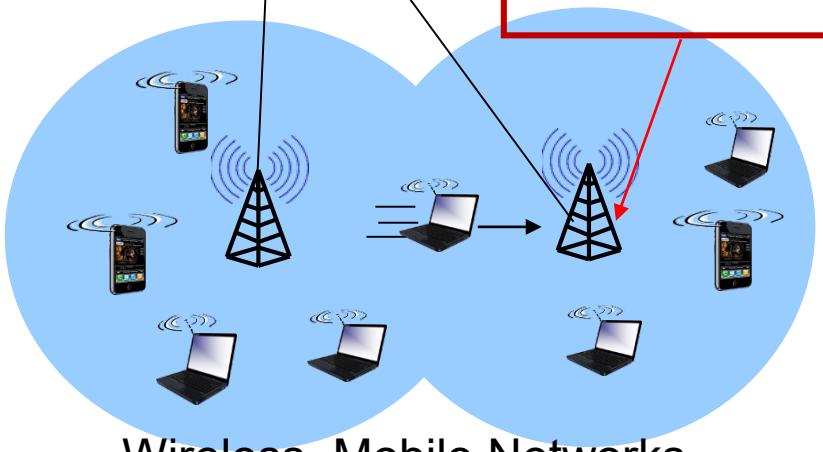
Elements of a wireless network



Elements of a wireless network



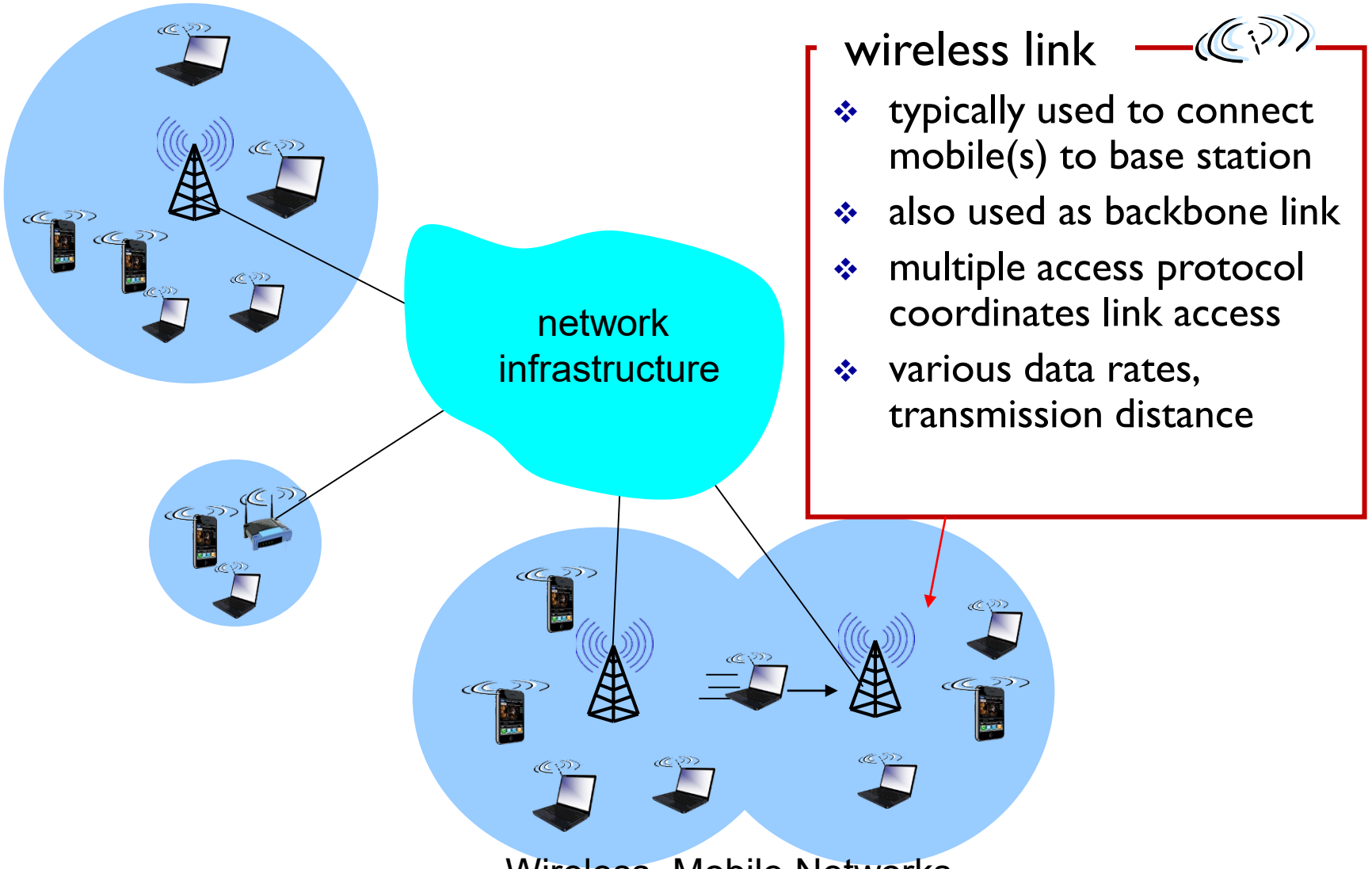
network infrastructure



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

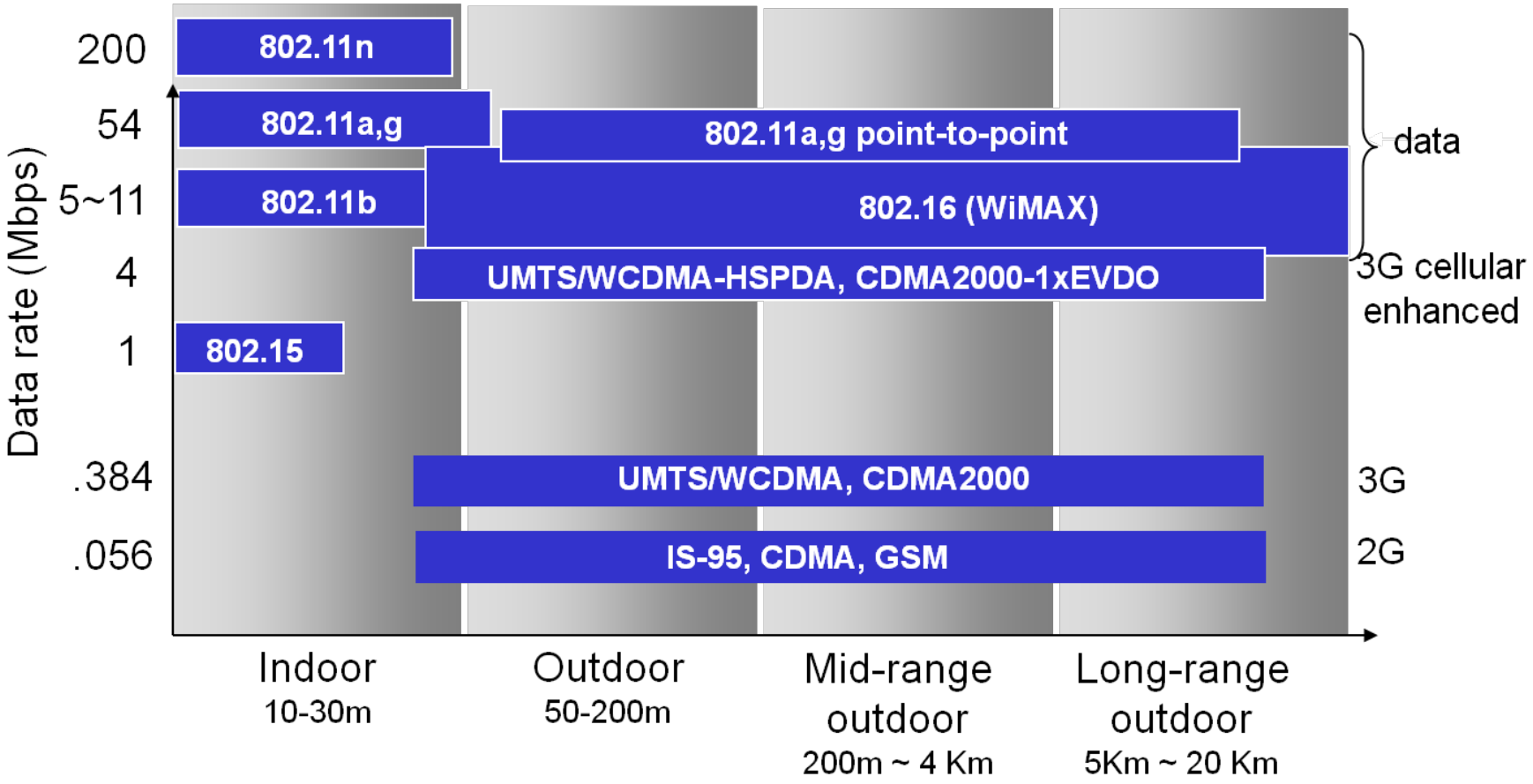
Elements of a wireless network



wireless link

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

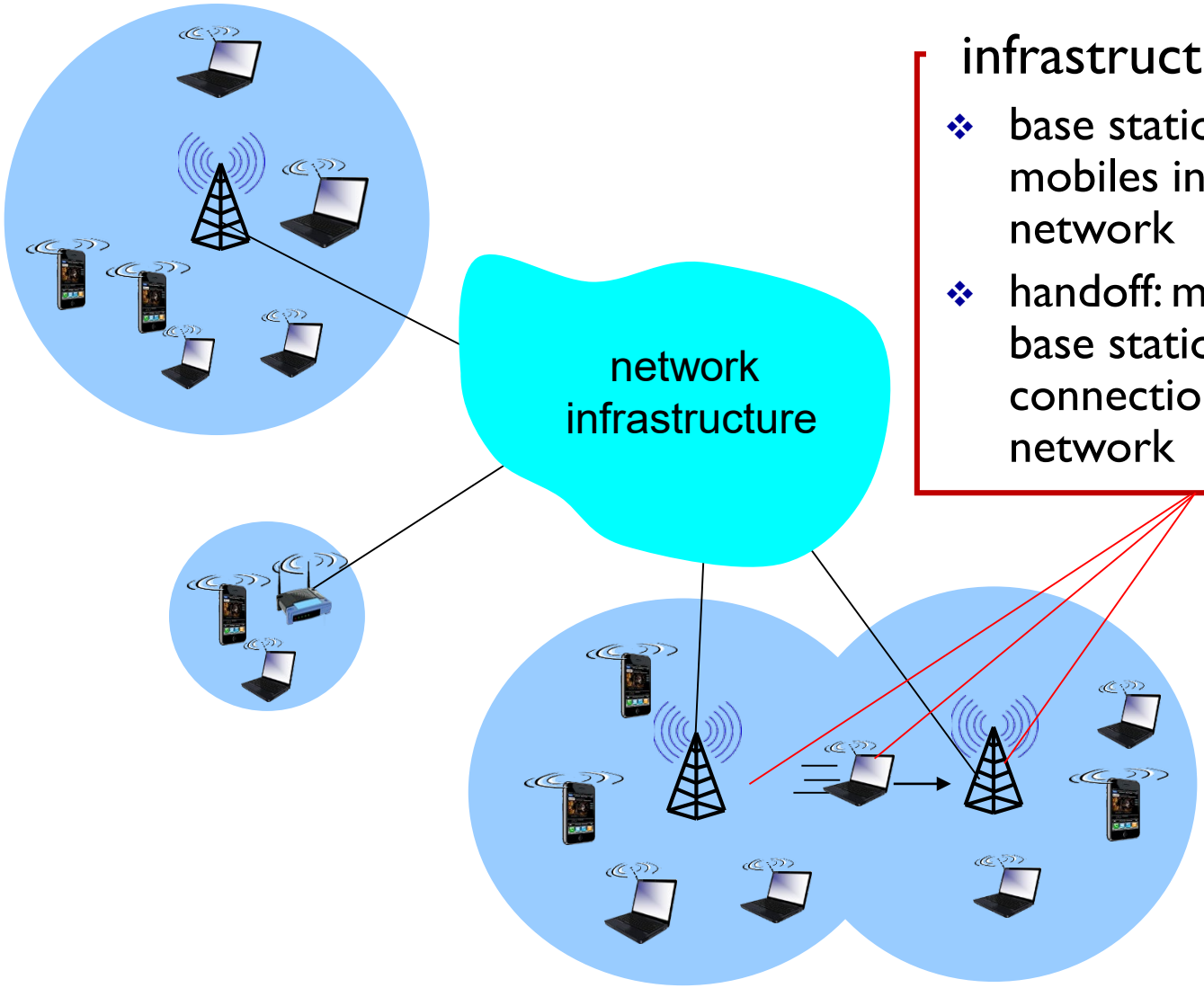
Various Wireless Link Standards



Two modes of operation

- Infrastructure mode: Base stations connect mobiles to wired network
- Ad-hoc mode: Wireless hosts organize themselves to communicate

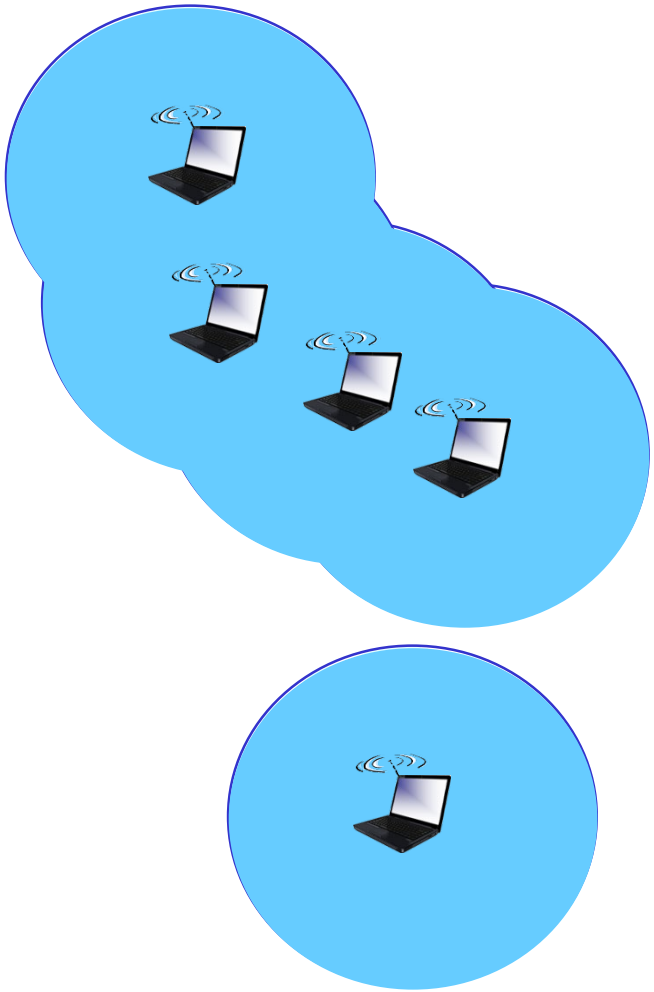
Infrastructure mode



infrastructure mode

- base station connects mobiles into wired network
- handoff: mobile changes base station providing connection into wired network

Ad-hoc mode

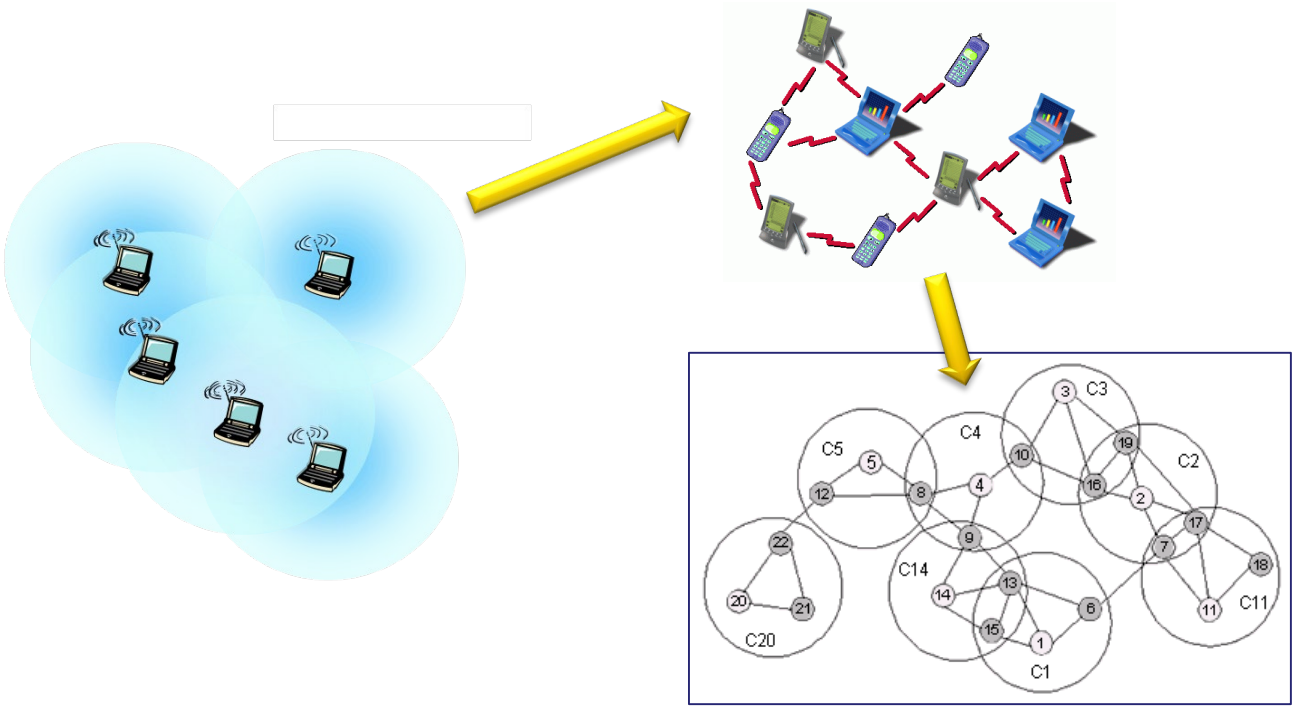


ad hoc mode

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

Ad-hoc Networking

- Peer-to-peer communication, no base stations
- Nodes organize themselves into a network: route among themselves



Wireless network taxonomy

	single hop	multiple hops
infrastructure (e.g., APs)	host connects to base station (WiFi, WiMAX, 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

Wireless link characteristics

- Three important differences from wired link …
  - Decreased signal strength: Radio signal attenuates as it propagates through matter (path loss)

Path loss/path attenuation

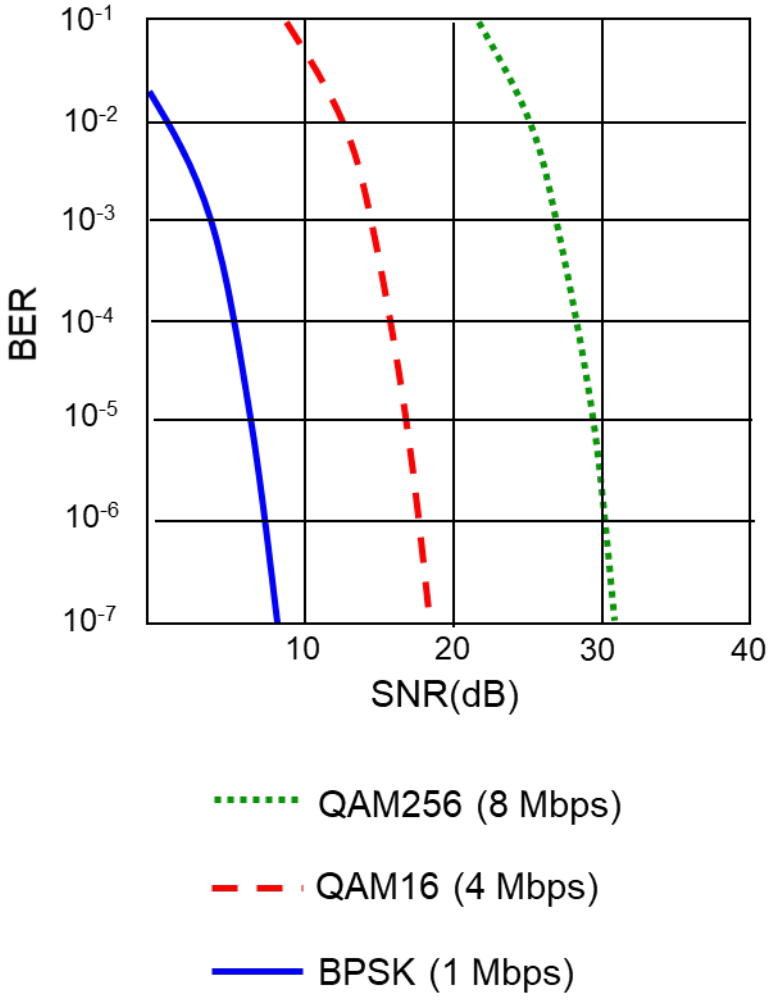
- Free Space Path Loss (FSPL):

$$FSPL = \left(\frac{4\pi df}{c}\right)^2$$

  - d = distance
  - λ = wave length (c/f)
  - f = frequency
  - c = speed of light
- Due to
  - Reflection, diffraction, absorption, terrain contours (urban, rural, vegetation), humidity

SNR and BER

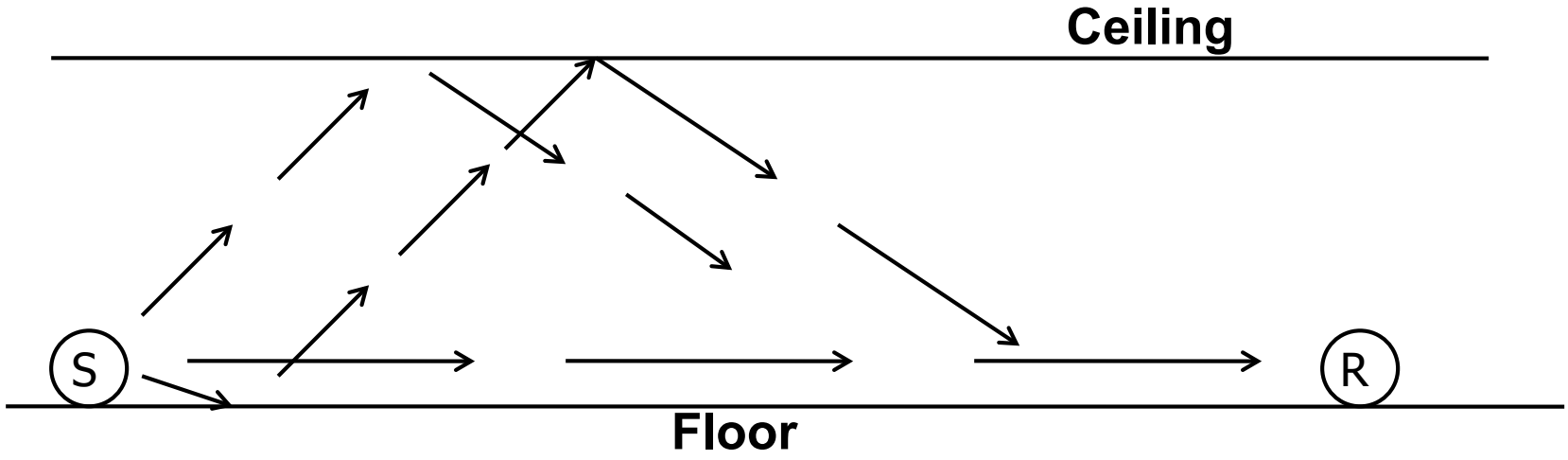
- SNR: Signal-to-noise ratio
  - Larger SNR makes it easier to extract signal from noise (good)
- BER: Bit error rate
- SNR vs. BER tradeoffs
  - Given physical layer: Increase power → increase SNR → decrease BER
  - Given SNR: Choose physical layer that meets BER requirement, giving highest throughput
  - SNR may change with mobility: Dynamically adapt physical layer



Wireless link characteristics

- Three important differences from wired link …
  - Decreased signal strength: Radio signal attenuates as it propagates through matter (path loss)
  - Multipath propagation: Radio signal reflects off objects ground, arriving ad destination at slightly different times

Multipath effects



- Signals bounce off surface and interfere with one another
- Self-interference

19

Wireless link characteristics

- Three important differences from wired link …
  - Decreased signal strength: Radio signal attenuates as it propagates through matter (path loss)
  - Multipath propagation: Radio signal reflects off objects ground, arriving ad destination at slightly different times
  - 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
- … make communication across (even a point-to-point) wireless link much more "difficult"

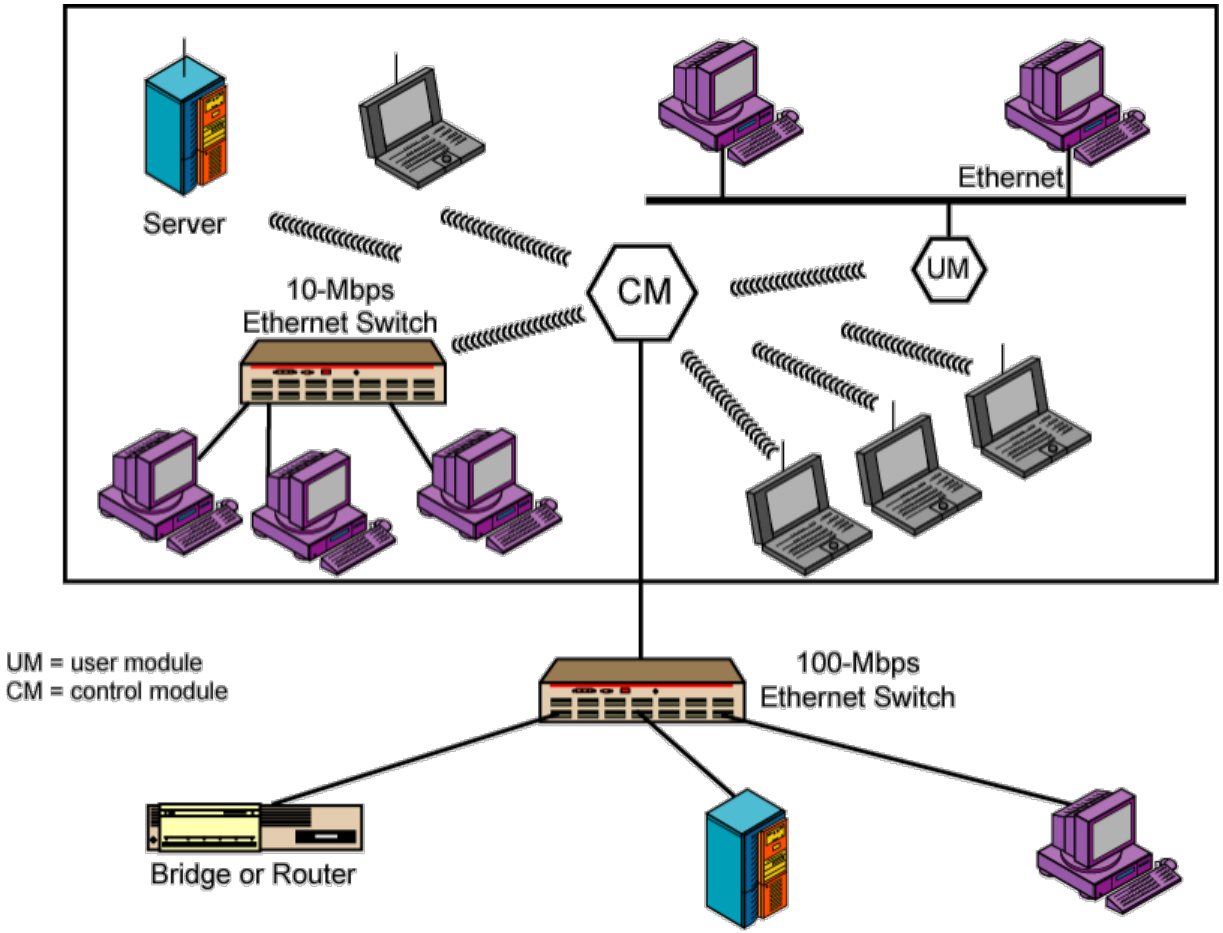
Wireless network characteristics

- Broadcast medium
  - Anybody in proximity can hear and interfere
- Cannot receive while transmitting
  - Our own (or nearby) transmission is deafening our receiver ⇒ Half-duplex
  - Recent work has shown that full duplex may also be possible
- Signals sent by sender don't always end up at receiver intact
- Multiple wireless senders and receivers create many problems
  - Multiple access issues (we've seen this before)
  - Hidden terminal problem

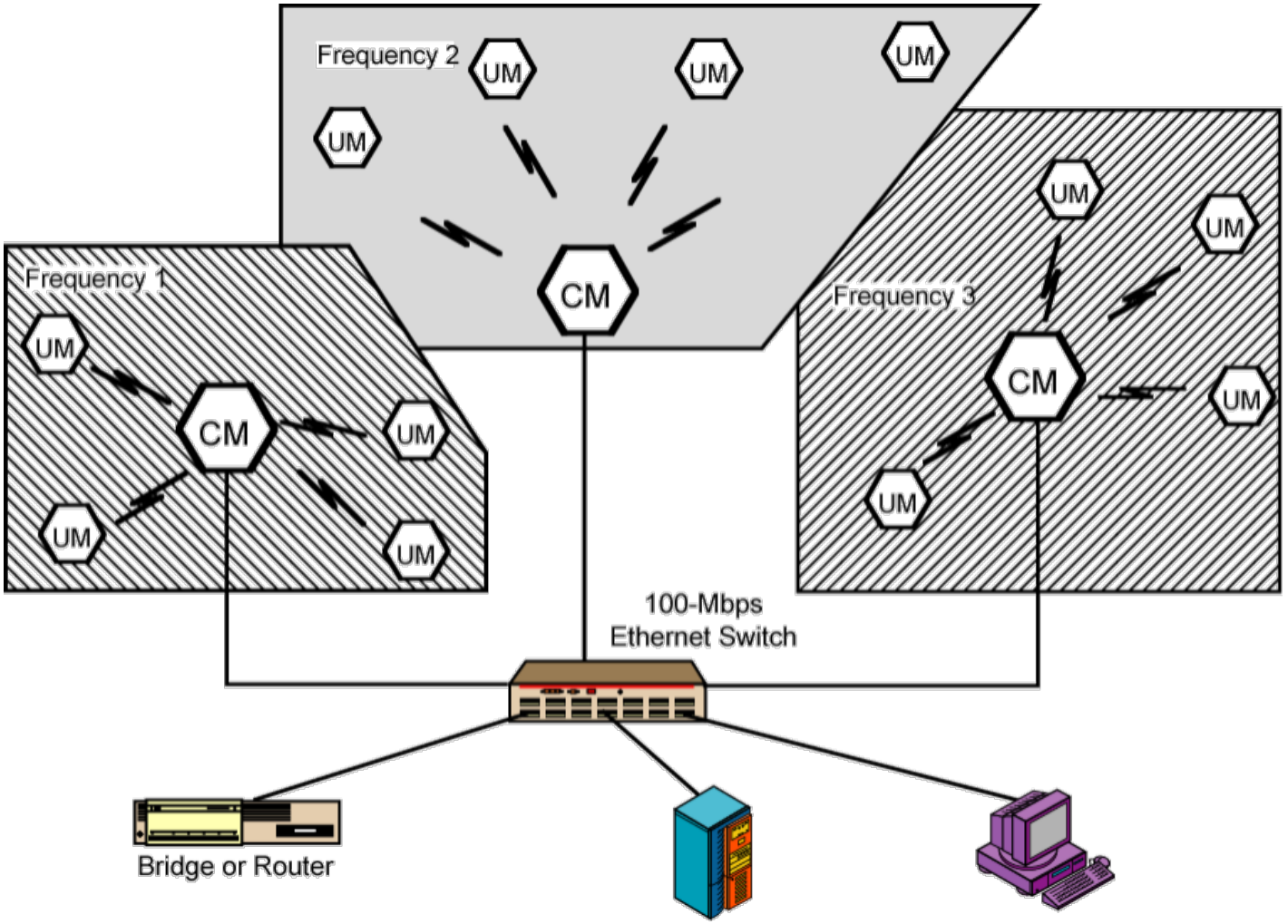
WiFi - IEEE 802.11 Wireless LANs

IEEE 802.11 Wireless LANs

- A single-cell configuration

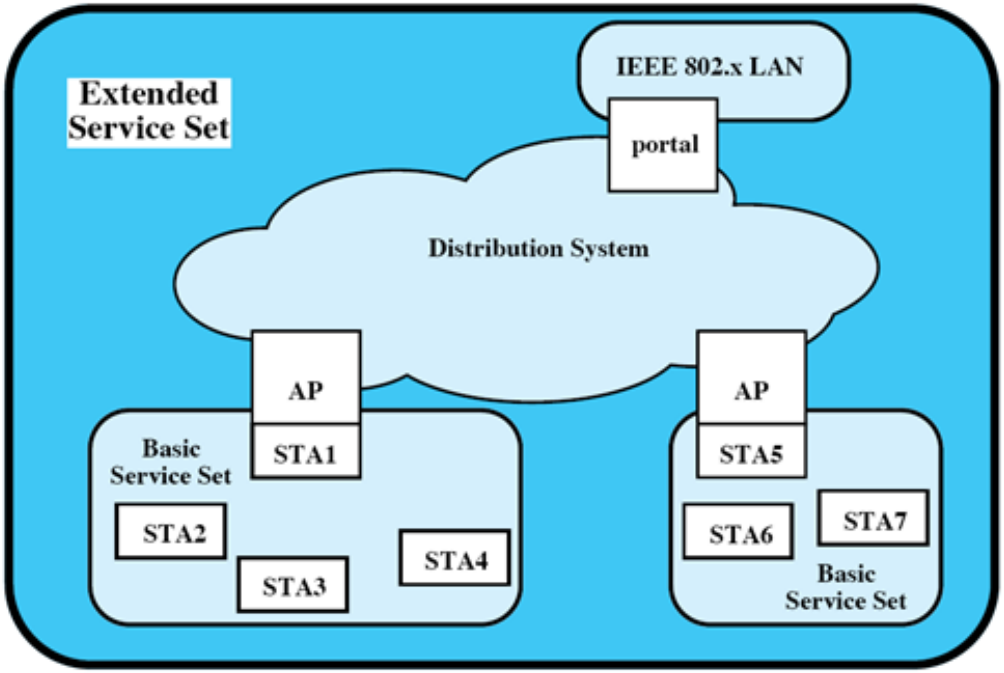


A Multi-Cell Configuration

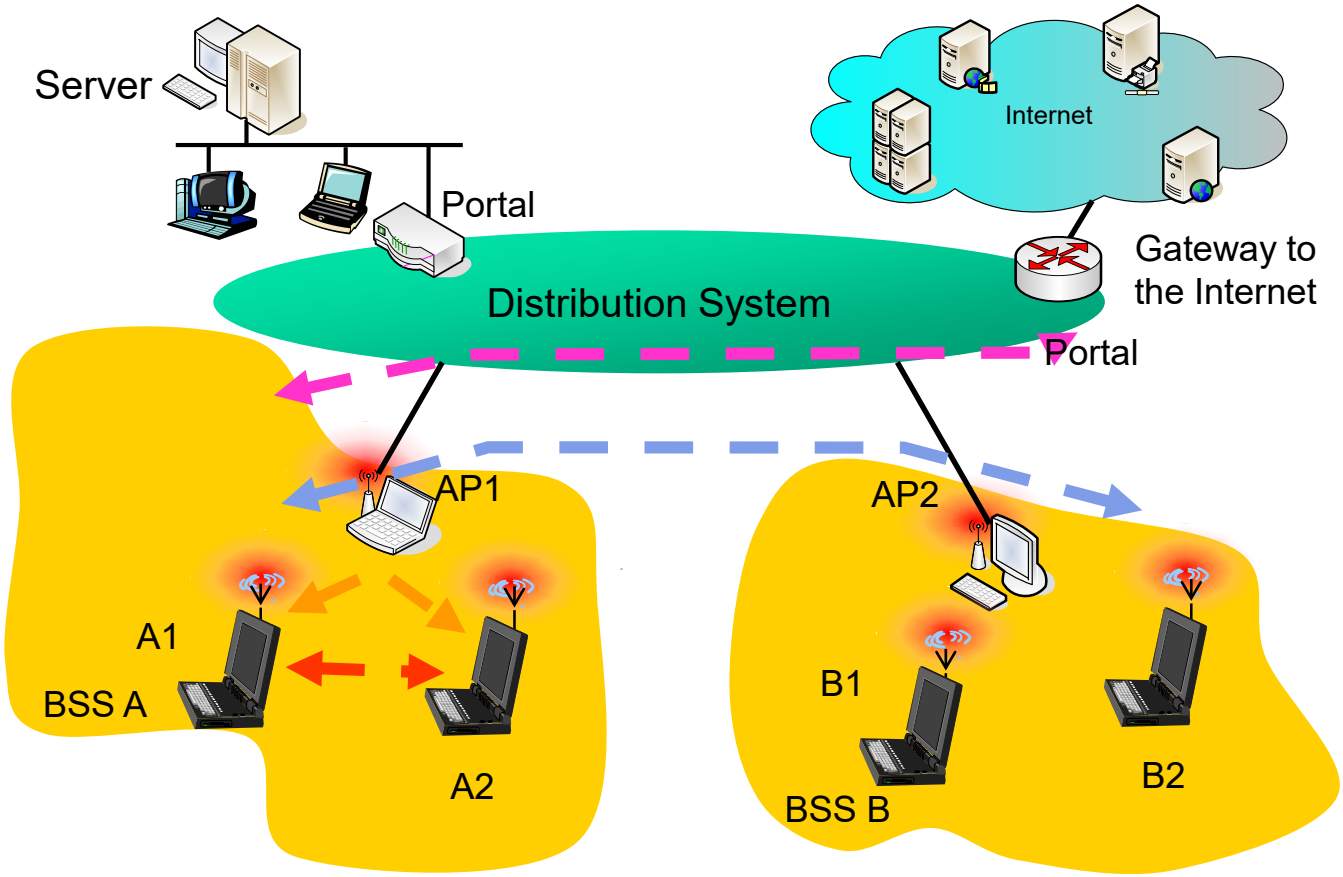


IEEE 802.11 Architecture

- Station: device with IEEE 802.11 conformant MAC and physical layer
- Access Point (AP):
  - Provides access to the distribution system via the wireless medium
- Basic Service Set (BSS)
  - A single cell coordinated by one access point (base station)
- Extended Service Set (ESS)
  - Multiple BSSs interconnected by Distribution System (DS)
  - DS can be a switch, wired network, or wireless network
  - An ESS appears as a single logical LAN
  - Portals (routers) provide access to Internet
- Distribution System (DS):
  - A system used to interconnect a set of BSSs and integrated LANs to create an (ESS)



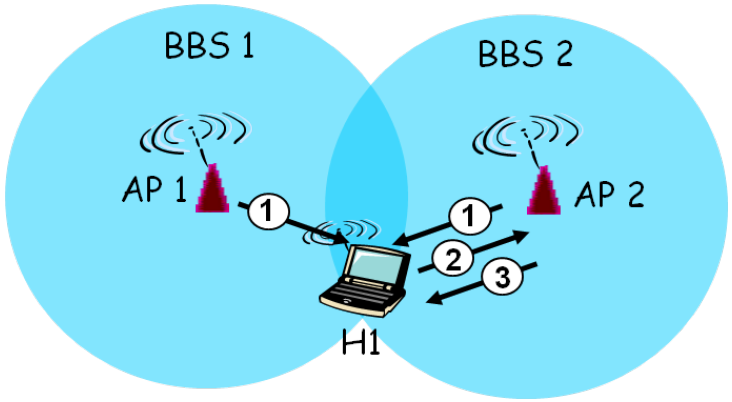
Possible Communications



802.11: Channels, association

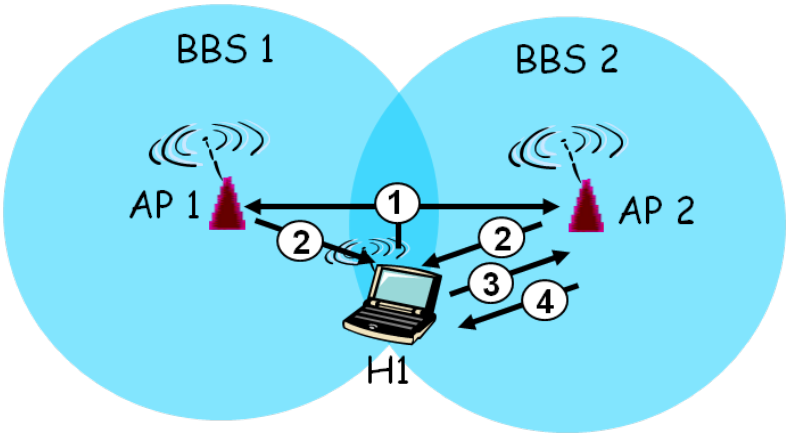
- 802.11b: 2.4GHz-2.485GHz spectrum divided into 11 channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
- Host: must *associate* with an AP
  - scans channels, listening for *beacon frames* containing 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

Scanning for Association



Passive Scanning:

- Beacon frames sent from Aps
- Association Request frame sent: H1 to selected AP
- Association Response frame sent: selected AP to H1

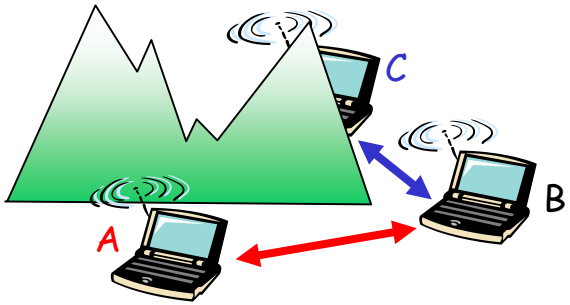


Active Scanning:

- Probe Request frame broadcast from H1
- Probe response frame sent from APs
- Association Request frame sent: H1 to selected AP
- Association Response frame sent: selected AP to H1

IEEE 802.11: Multiple Access

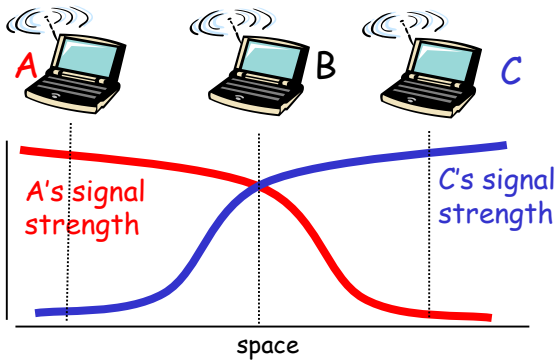
- Multiple wireless senders and receivers create additional problems (beyond multiple access)



Hidden terminal problem

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

A, C unaware of their interference at B



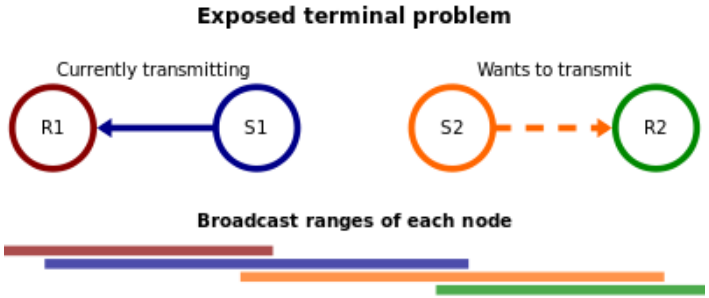
Signal fading problem

- B, A hear each other
- B, C hear each other

A, C can not hear each other interfering at B

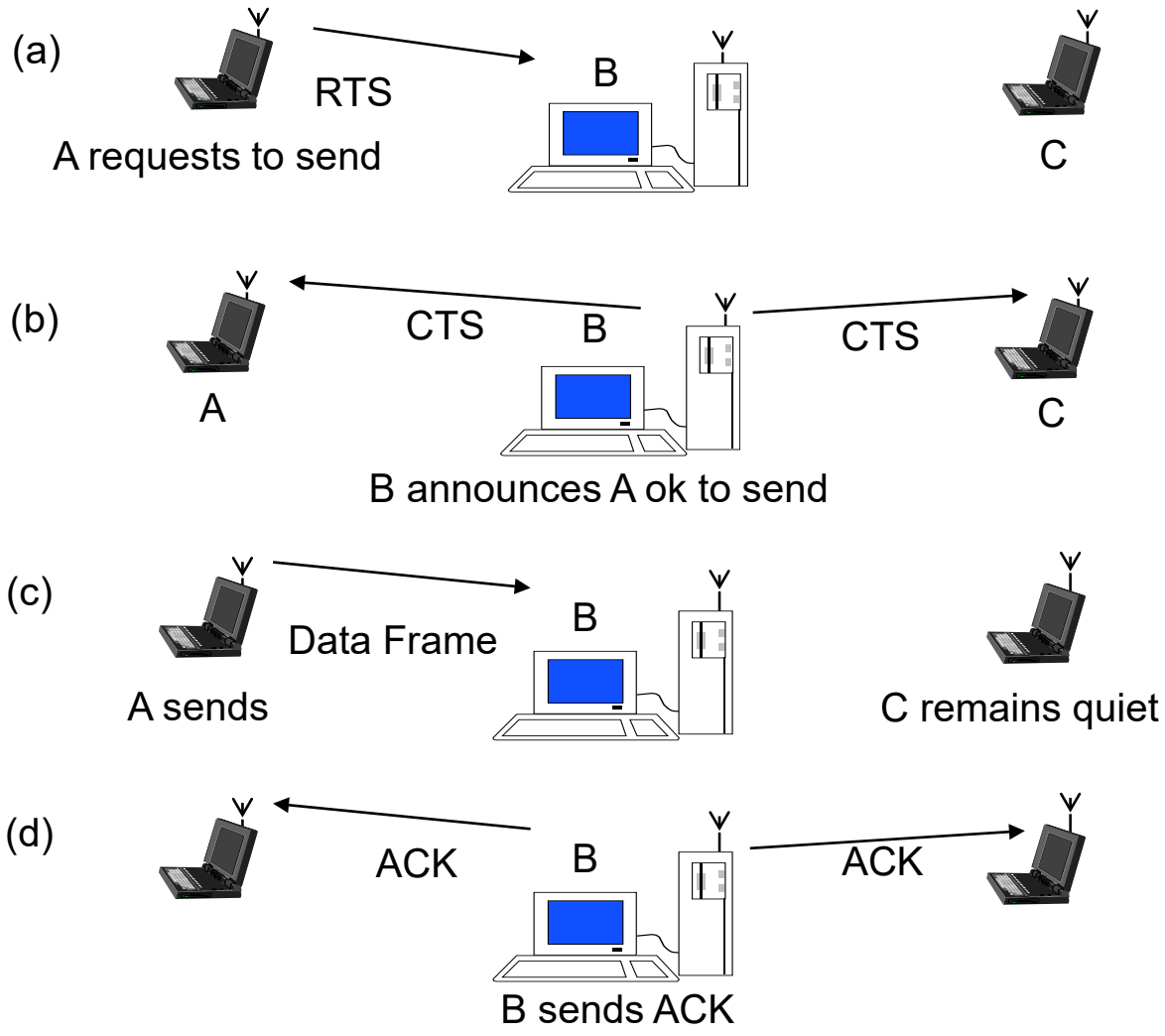
Exposed terminal problem

- S1, S2 hear each other
- S2 waits when it hears S1 transmitting
- But S1->R1 and S2->R2 can transfer simultaneously since they are not interference

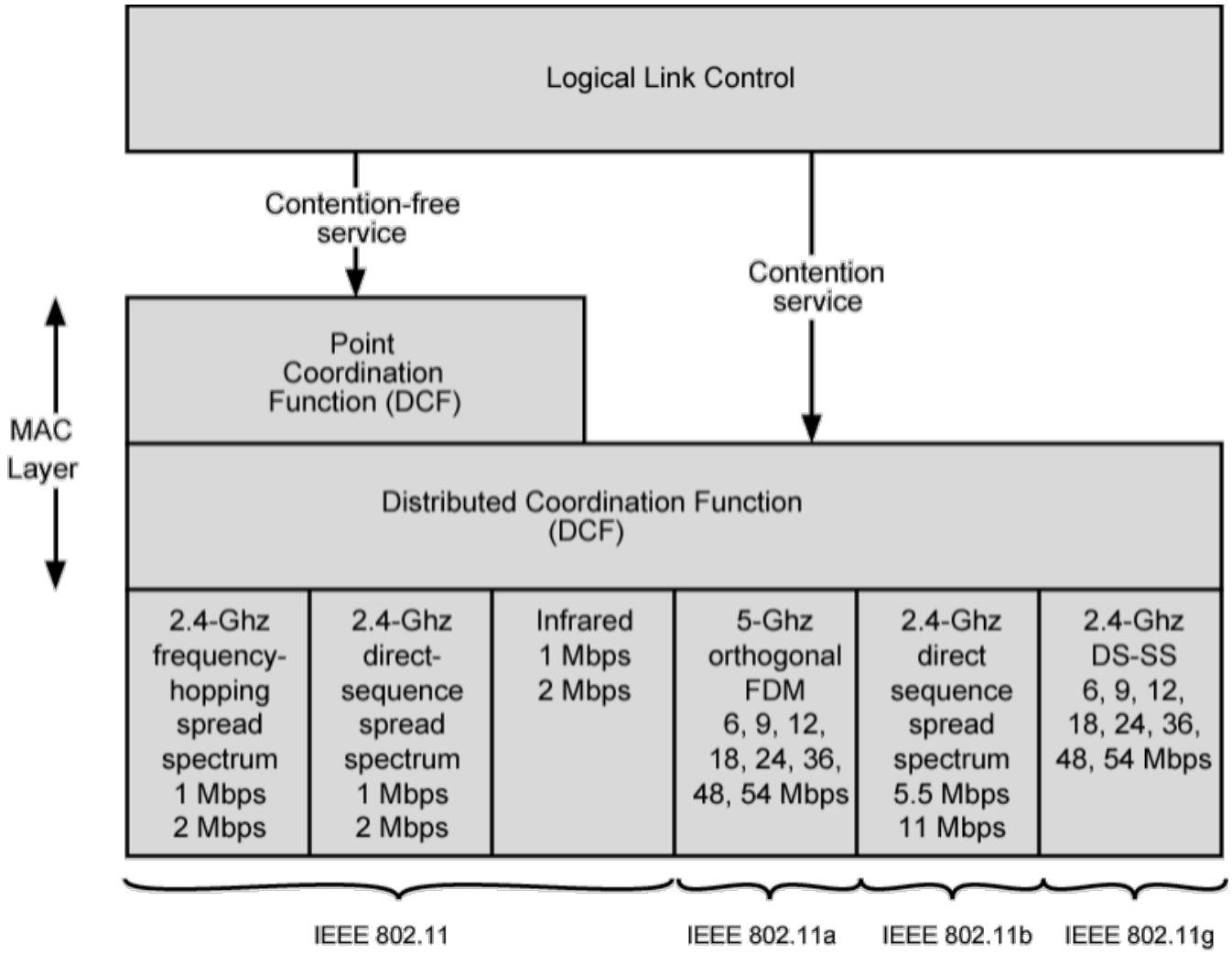


4 Frame Exchange

- Solving the hidden terminal problem: using **RTS/CTS**
- To enhance wireless reliability, 4-frame exchange may be used
  - Source issues a Request to Send (RTS) frame to destination
  - Destination responds with Clear to Send (CTS)
  - After receiving CTS, source transmits data
  - Destination responds with ACK
- Stations refrain from transmission to avoid collision
  - RTS alerts all stations within range of source that exchange is under way
  - CTS alerts all stations within range of destination
- RTS/CTS exchange is a required function, but can be disabled


(a)
RTS
B
A requests to send
C
(b)
CTS
B
CTS
A
C
B announces A ok to send
(c)
Data Frame
B
A sends
C remains quiet
(d)
ACK
B
ACK
B sends ACK

IEEE 802.11 Protocol Architecture

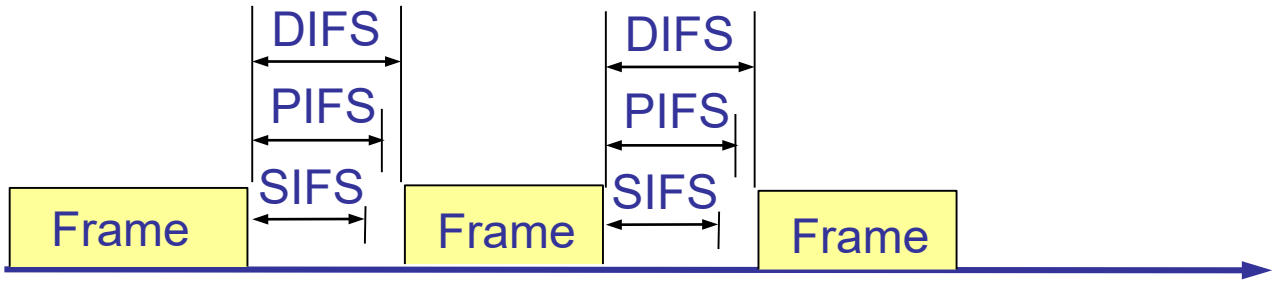


Media Access Control

- Distributed wireless foundation MAC (DWFMAC，分布式基础无线媒体访问控制)
  - Distributed access control mechanism
  - Optional centralized control on top
- The lower sub-layer is distributed coordination function **(DCF,分布式协调功能，分布式控制，用于传输异步数据，优先级最低)**
  - Contention algorithm to provide access to all traffic
  - CSMA/CA (collision avoidance)
- The upper is point coordination function **(PCF,点协调功能，集中式控制，用于发送实时数据，优先级仅次于控制帧)**
  - Centralized MAC algorithm, Contention free
  - Built on top of DCF

3-level Priority

- SIFS (Short Inter Frame Space)
  - Shortest IFS – highest priority
  - For all immediate responses
- PIFS (point coordination function IFS)
  - Mid-length IFS
  - Used by the centralized controller in PCF scheme when issuing polls
- DIFS (distributed coordination function IFS)
  - Longest IFS
  - Used for other asynchronous frames contending for access



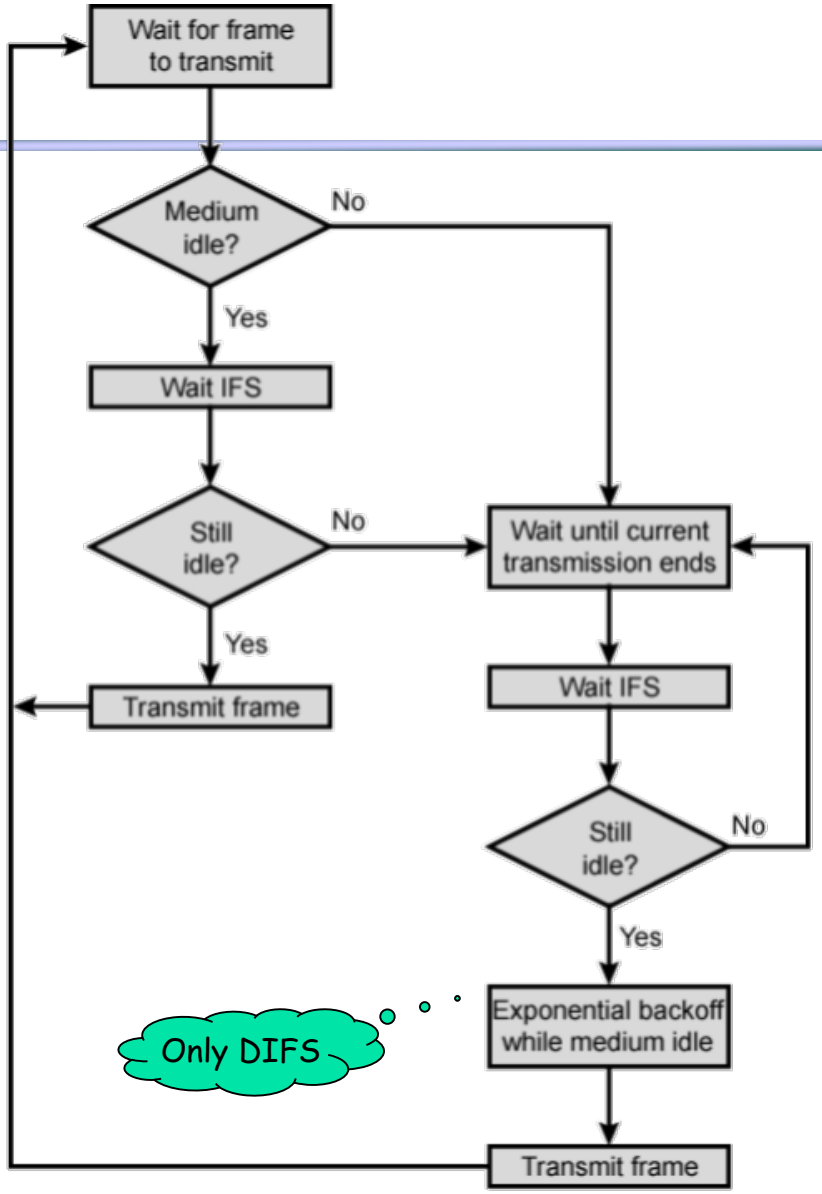
SIFS Use

- Acknowledgment (ACK)
  - Station responds with ACK after waiting SIFS gap
- Delivery of multiple frame LLC PDU
  - Station with multi-frame LLC PDU to transmit sends out 1st MAC frame using normal IFS
  - Each subsequent frames sent after SIFS
- Poll response
  - Response frame after poll
- Clear to Send (CTS)
  - Station can ensure data frame will get through by issuing RTS with normal IFS
  - Destination station should respond with CTS using SIFS if ready to receive

PIFS and DIFS

- PIFS used by centralized controller
  - Issuing polls
  - Takes precedence over normal contention traffic
  - Frames using SIFS have precedence over PCF poll
- DIFS used for all ordinary asynchronous traffic

IEEE 802.11 Medium Access Control Logic



Point Coordination Function (PCF)

- Polling by centralized polling master (point coordinator)
  - Uses PIFS (<DIFS) when issuing polls
  - Can seize medium and lock out all asynchronous traffic while it issues polls and receives responses

- Wireless network configured a number of stations with time-sensitive traffic are controlled by point coordinator
  - Point coordinator polls in round-robin to stations configured for polling
  - When poll issued, polled station may respond using SIFS

  - If point coordinator receives response, it issues another poll using PIFS
  - If no response during expected turnaround time, coordinator issues another poll

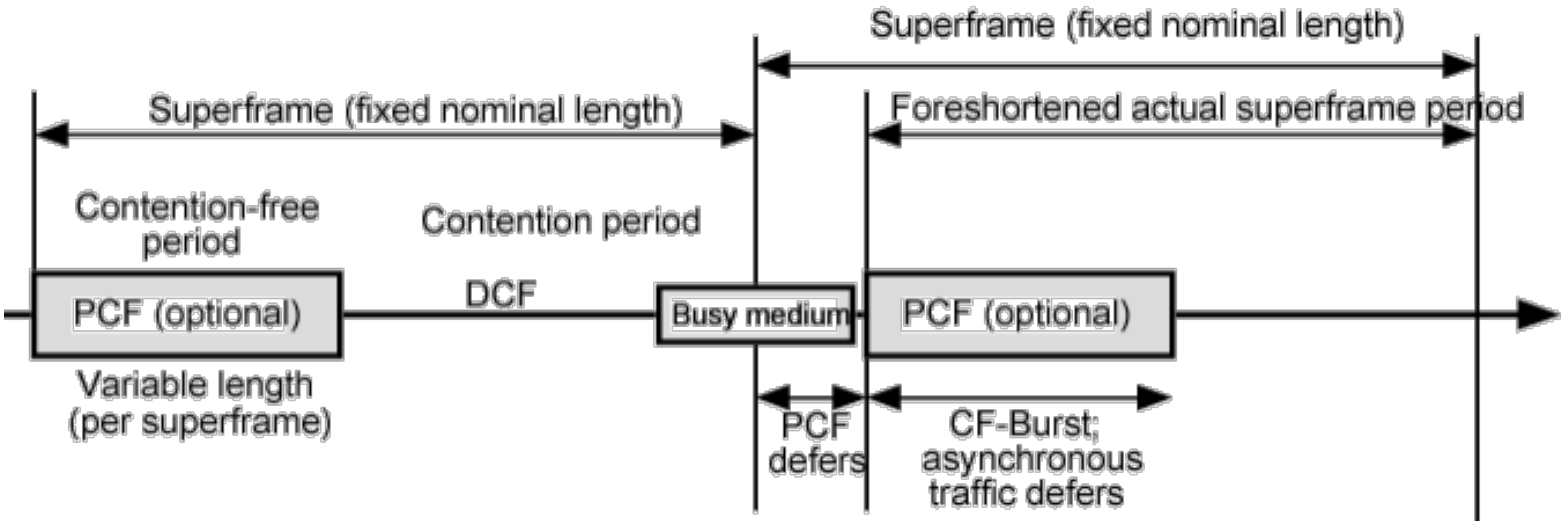
  - Repeat until current round ended

Super-frame

- Super-frame defined by PCF
  - During first part of super-frame interval, point coordinator polls round-robin to all polling stations
  - Remainder of super-frame allows contention period for asynchronous access
- At beginning of super-frame, point coordinator creates a contention-free period
  - Time varies because of variable frame size issued by responding stations
  - Rest of super-frame available for contention-based access
- At end of super-frame interval, point coordinator contends for access using PIFS
  - By beacon frame, results in super-frame period for next cycle

超级帧：
点协调器不断发布轮询，会封锁所有异步通信量。为了避免这种情况，在超帧时间的前一部分，由点协调器轮询，在超帧时间的后一部分，允许异步通信量争用接入。

IEEE 802.11 MAC Timing – PCF



Distributed Coordination Function

- The DCF sub-layer uses CSMA/CA (collision avoidance)
  - Station senses medium before transmitting
  - Don't collide with ongoing transmission by other station
- DCF includes delays
  - Inter-frame space (IFS), station wait for IFS before transmitting
  - Accounts for priority scheme
- No collision detection, why?
  - Difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
  - Transmitting station cannot distinguish incoming weak signals from noise and effects of own transmission
  - Can't sense all collisions in any case: hidden terminal, fading
  - *ACK* is used for success transmission

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

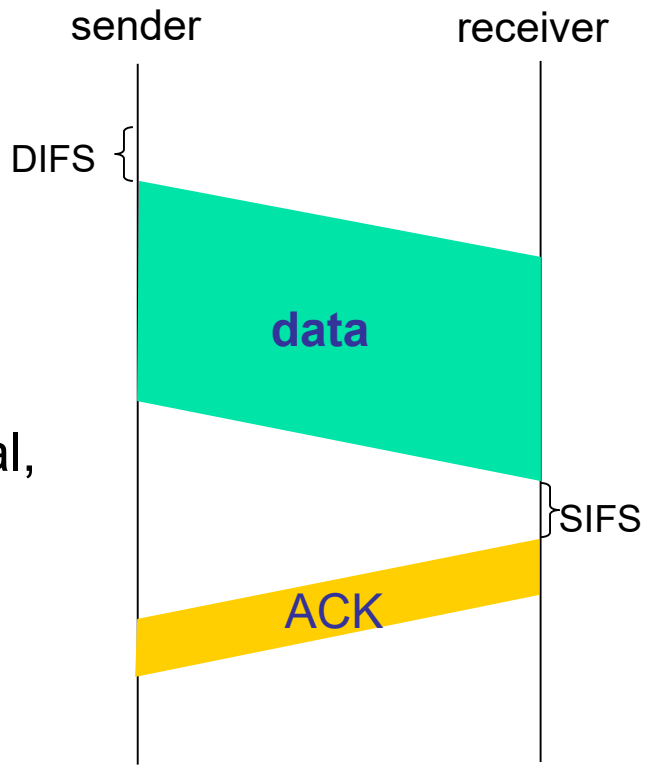
transmit when timer expires

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)



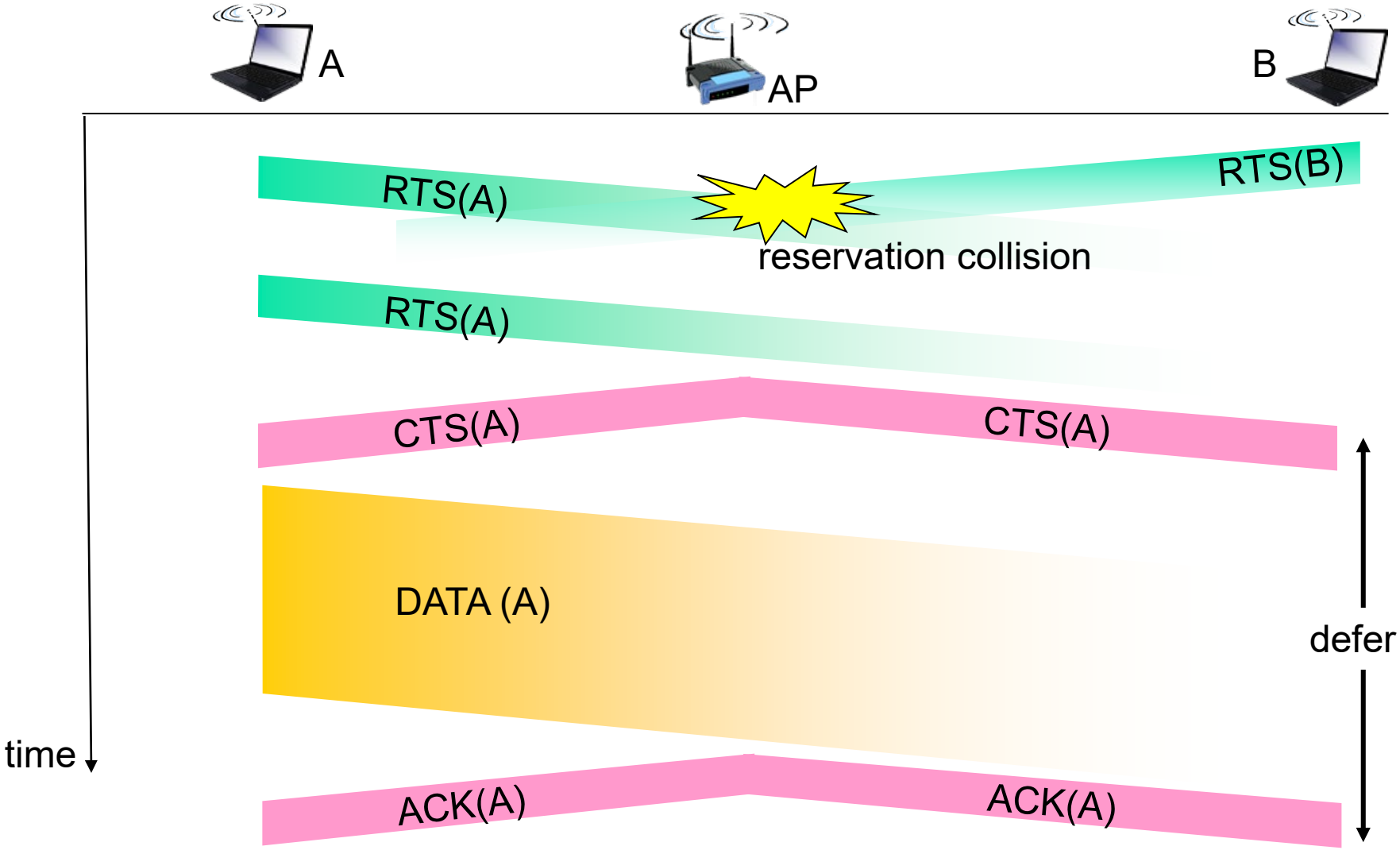
Avoiding collisions (more)

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

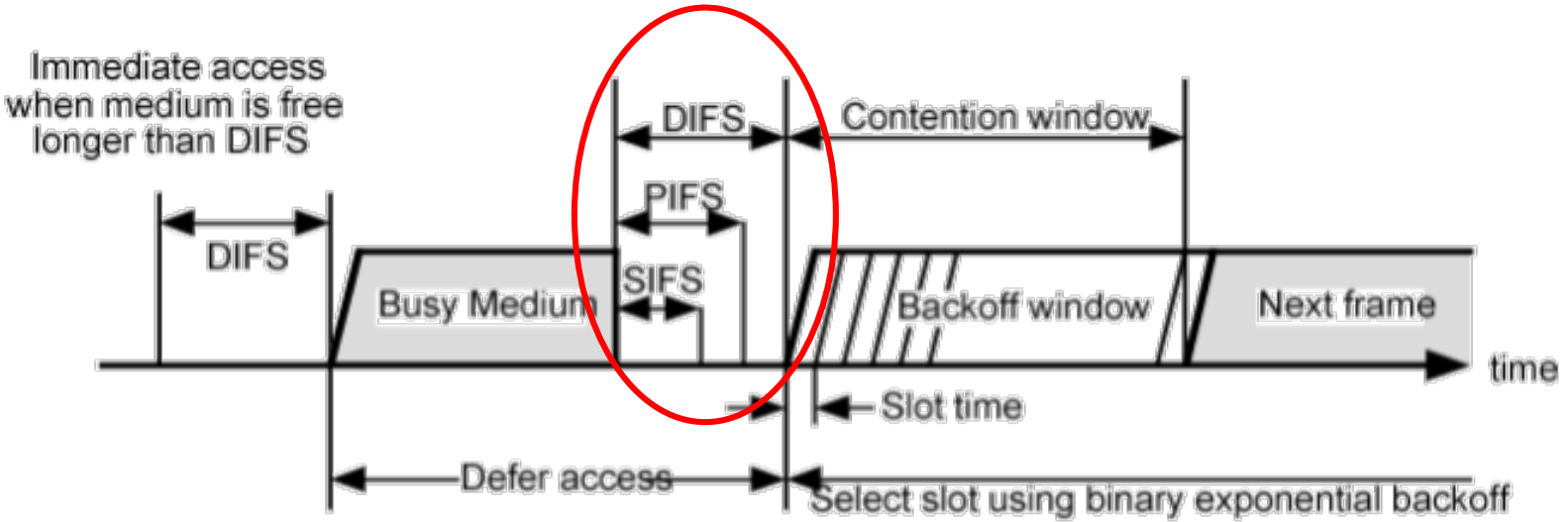
- sender first transmits *small* request-to-send (RTS) packets to BS using CSMA
  - RTSs may still collide with each other (but they're short)
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS exchange

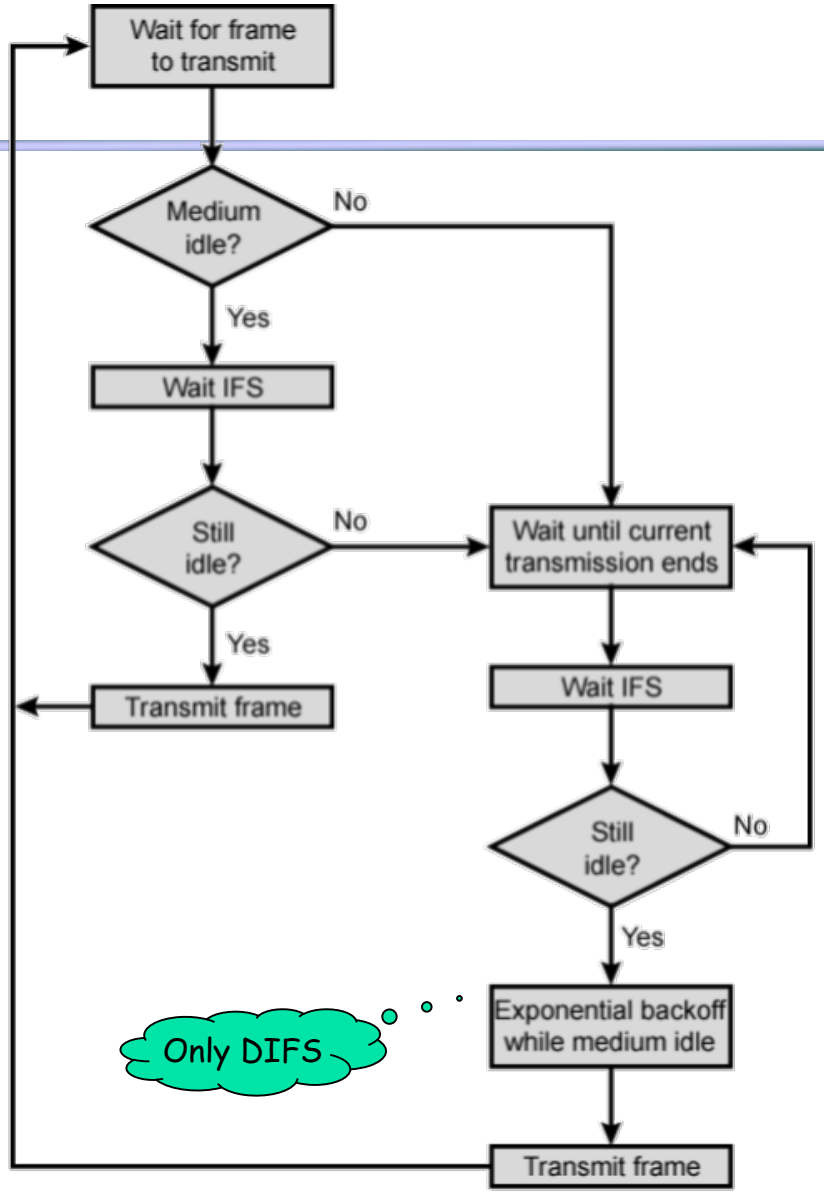


IEEE 802.11 MAC Timing – DCF

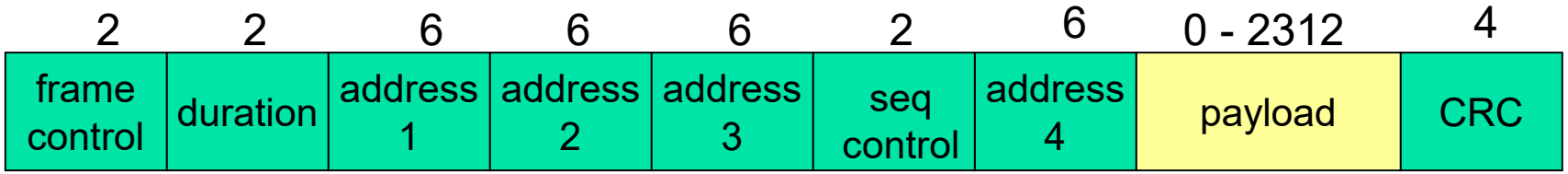


(a) Basic Access Method

IEEE 802.11 Medium Access Control Logic



802.11 frame: addressing



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

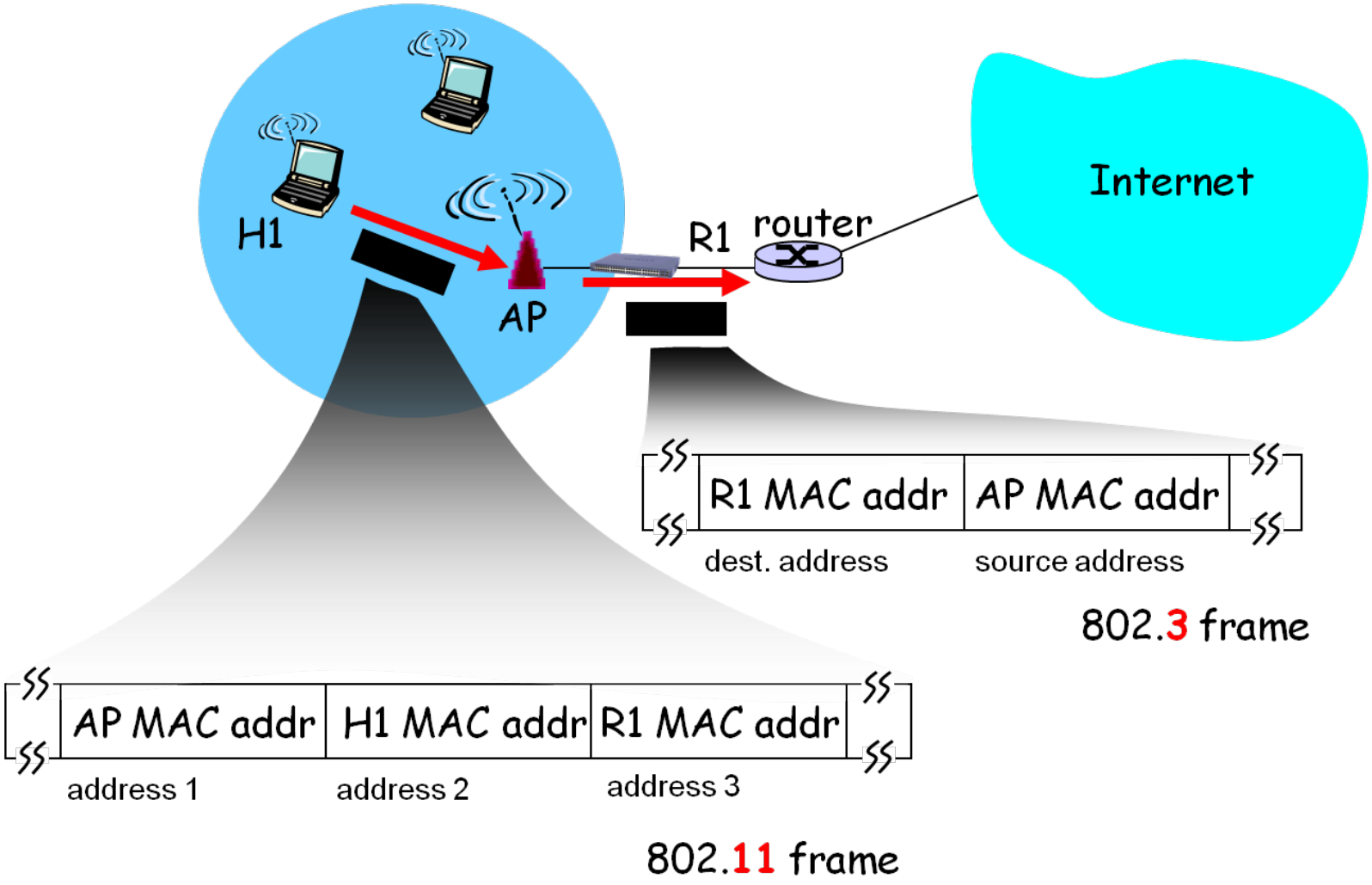
Address 2: MAC address of wireless host or AP transmitting this frame

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

Address 4: used only in ad hoc mode

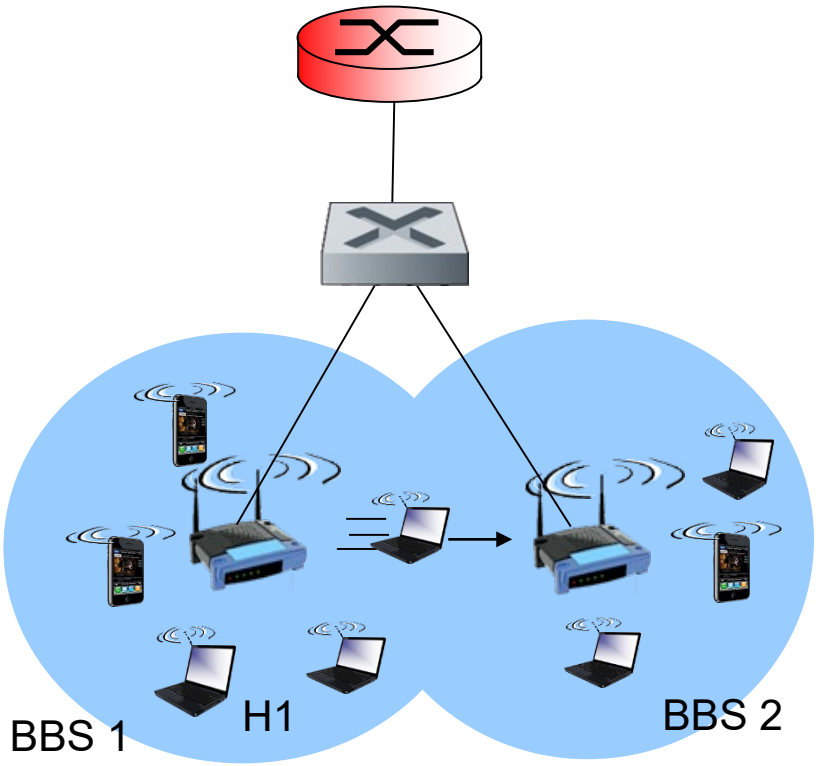
Why do we need Address 3?

Integrate 802.11 and 802.3 nets



802.11: mobility within same subnet

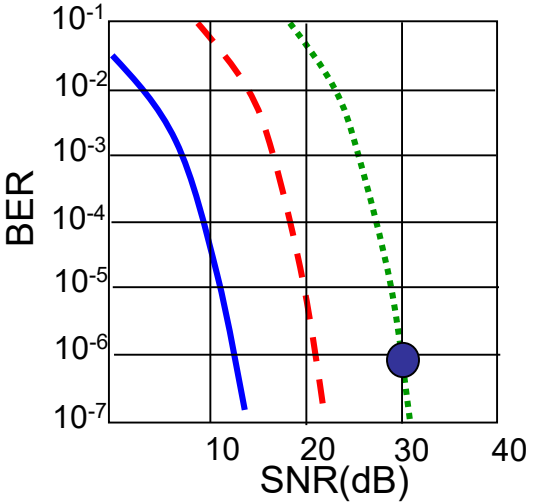
- H1 remains in same IP subnet: IP address can remain same
- switch: which AP is associated with H1?
  - self-learning (Ch. 5): switch will see frame from H1 and "remember" which switch port can be used to reach H1

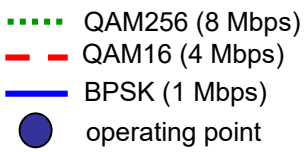


802.11: advanced capabilities

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 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
- 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

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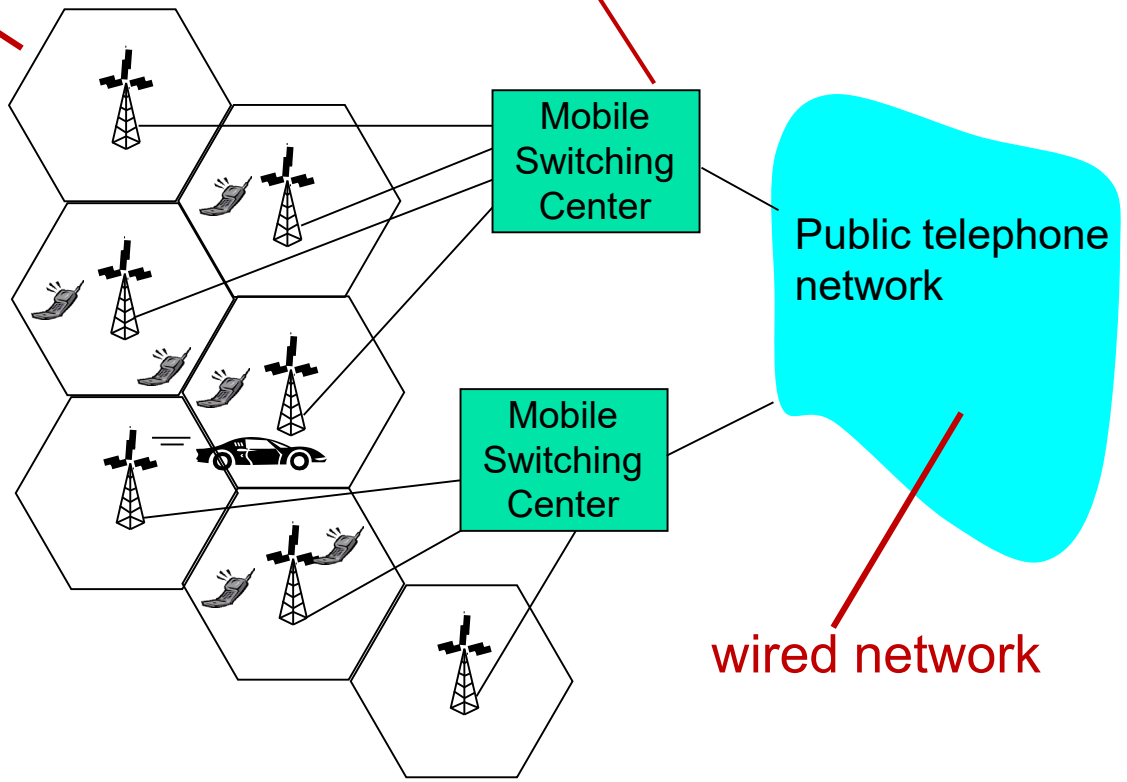
Cellular Network

Components of cellular network architecture

MSC
- connects cells to wired tel. net.
- manages call setup (more later!)
- handles mobility (more later!)

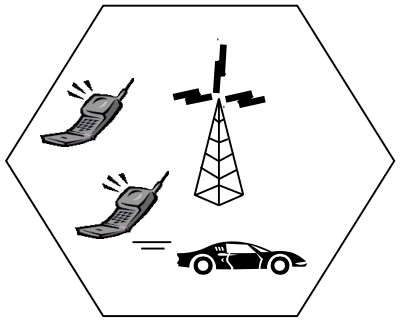
cell
- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS

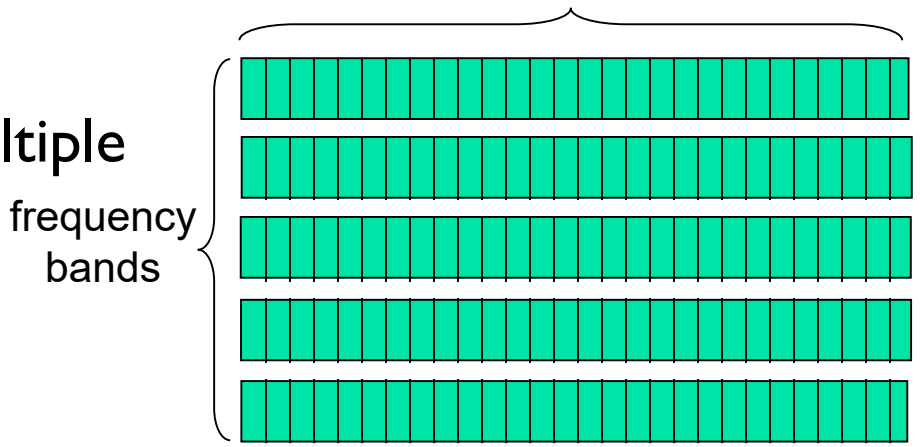


Cellular networks: the first hop

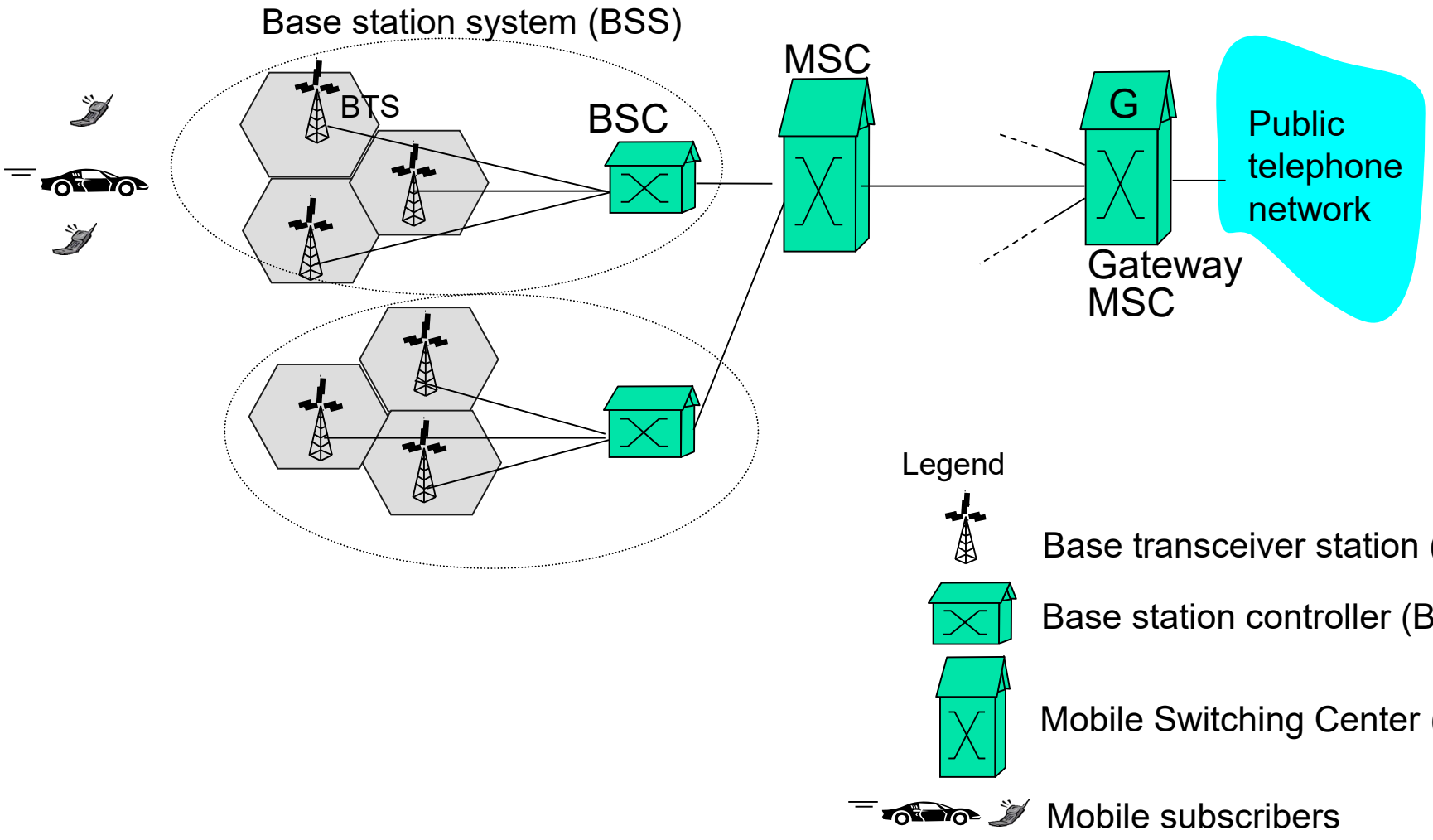
Two techniques for sharing mobile-to-BS radio spectrum

- combined FDMA/TDMA: divide spectrum in frequency channels, divide each channel into time slots
- CDMA: code division multiple access

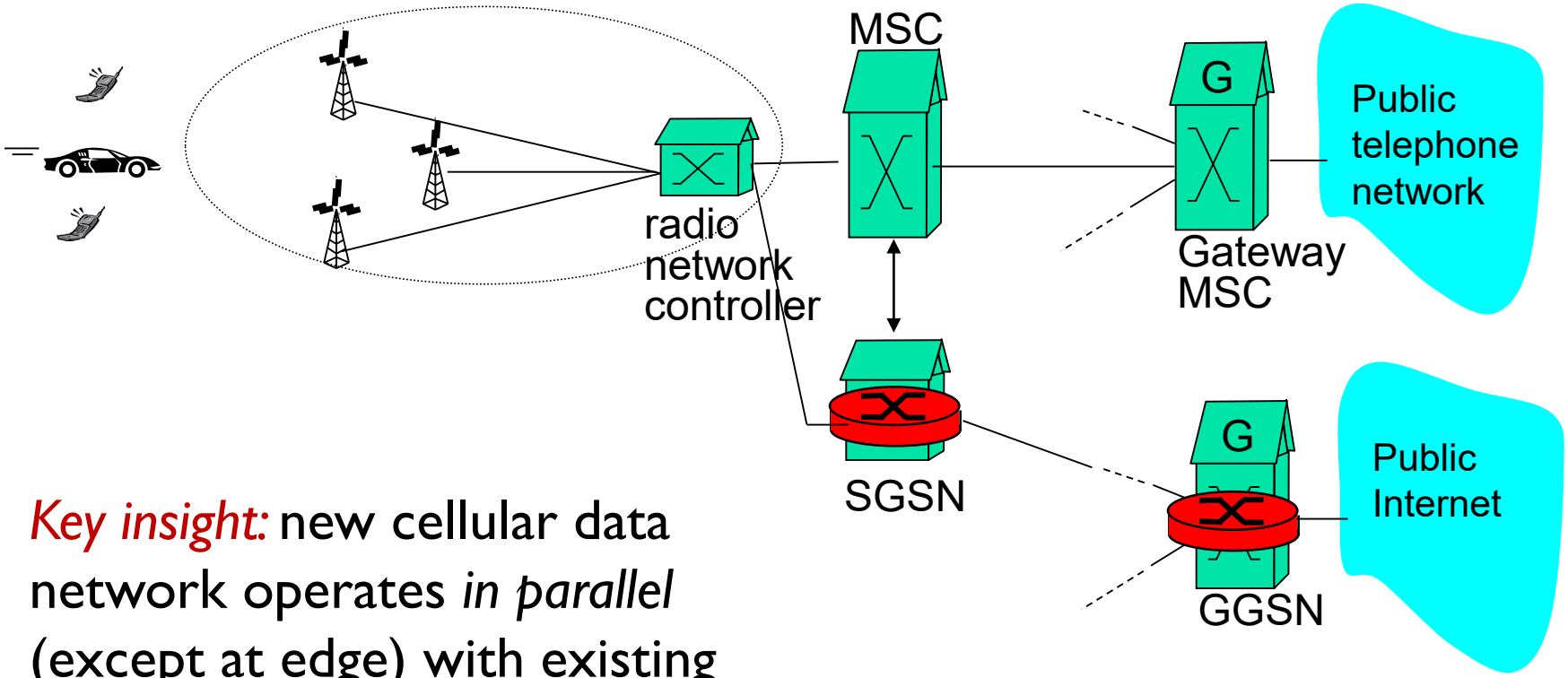




2G (voice) network architecture

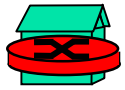


3G (voice+data) network architecture

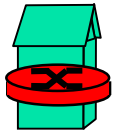


Key insight: new cellular data network operates *in parallel* (except at edge) with existing cellular voice network

- voice network unchanged in core
- data network operates in parallel

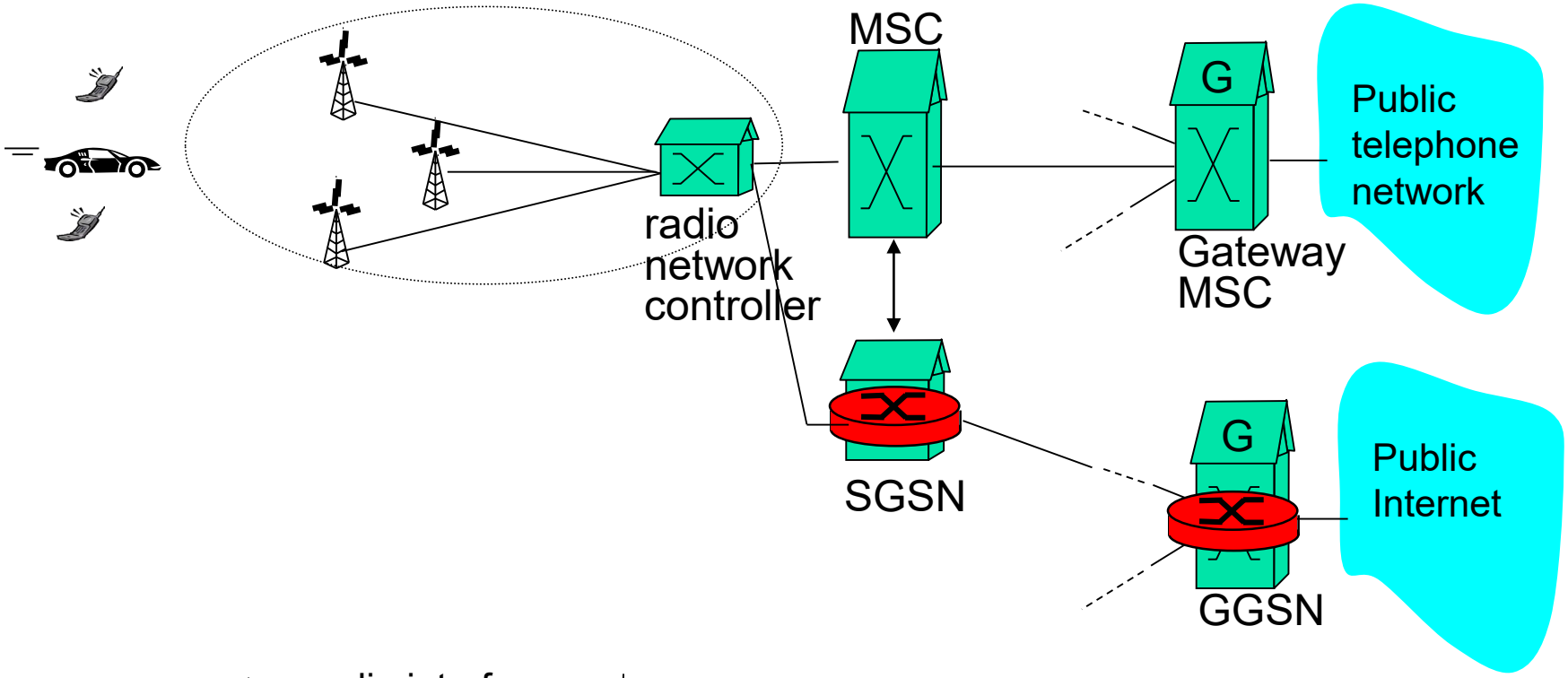


Serving GPRS Support Node (SGSN)



Gateway GPRS Support Node (GGSN)

3G (voice+data) network architecture



Summary

- 无线局域网的组成
- 802.11的服务
- 802.11的MAC协议：CSMA/CA
  - 与CSMA/CD作比较
- 三种优先级
- 点协同功能和分布式协同功能
- 解决隐藏终端问题
- 802.11的帧类型和帧格式
  - 与以太网帧格式比较

Homework

- 第7章：R7, P5, P6, P8