

# **EECS 489**

# **Computer Networks**

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*Material with thanks to Aditya Akella, Sugih Jamin, Philip Levis, Sylvia Ratnasamy, Peter Steenkiste, and many other colleagues.*

# Agenda

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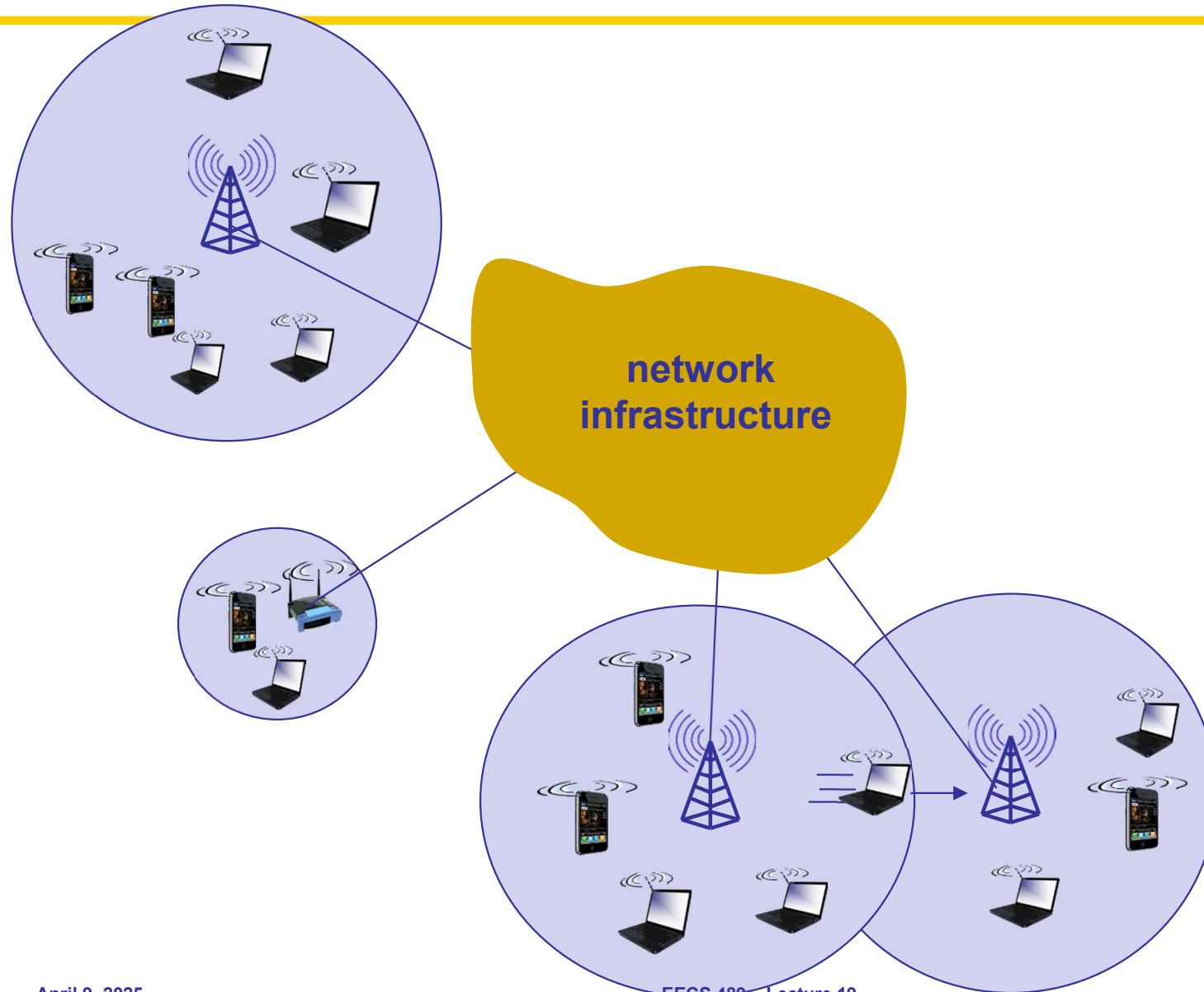
- ❑ Wireless network basics
- ❑ 802.11 Wireless LAN

# Recap: Random access MAC protocols in broadcast media

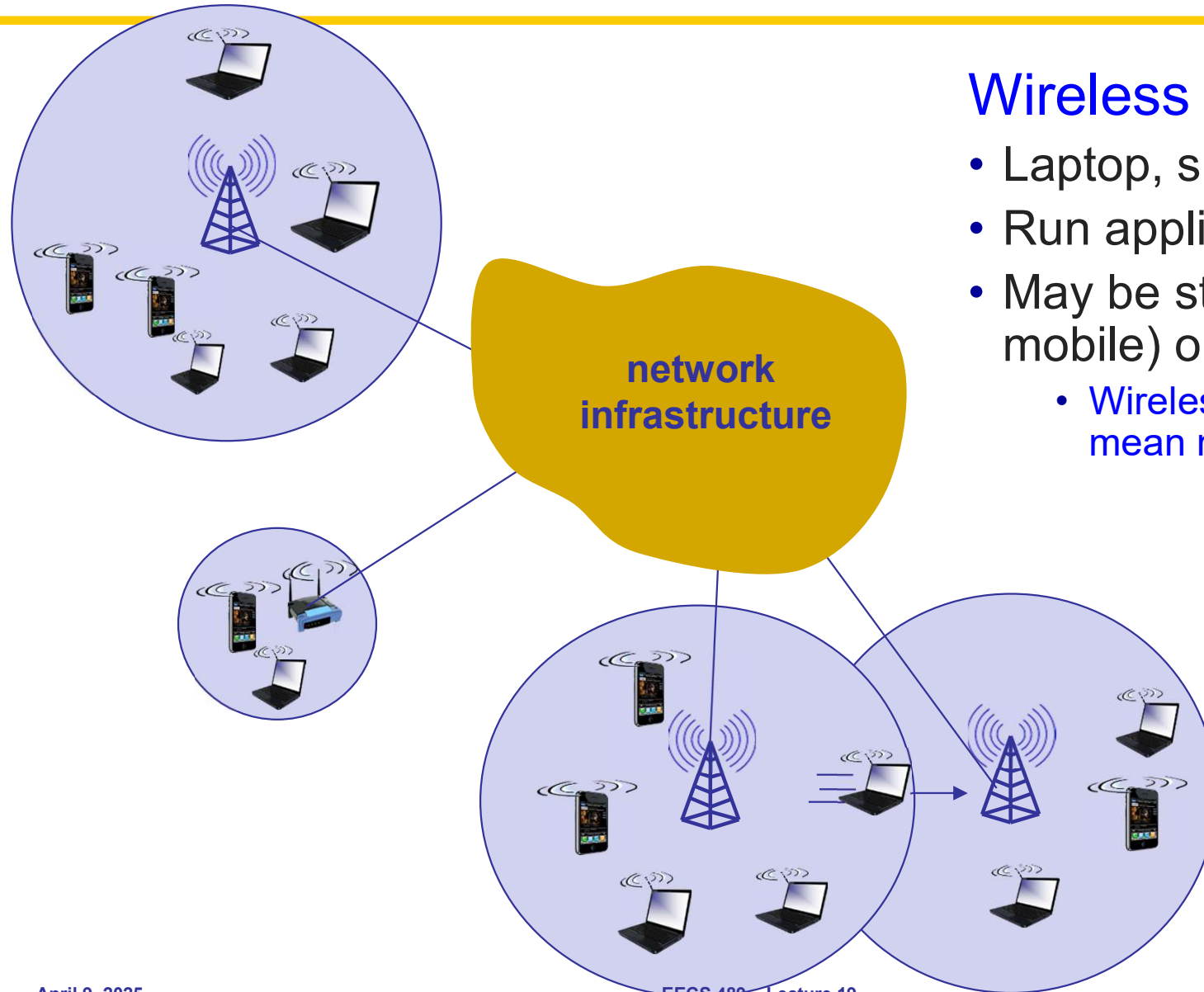
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- ❑ When node has packet to send
  - Transmit at full channel data rate **w/o** coordination
- ❑ Two or more transmitting nodes  $\Rightarrow$  collision
  - Data lost
- ❑ Random access MAC protocol specifies
  - How to detect and recover from collisions
- ❑ Examples
  - ALOHA and Slotted ALOHA
  - CSMA, CSMA/CD, CSMA/CA (wireless)

# Elements of a wireless network



# Elements of a wireless network



## Wireless hosts

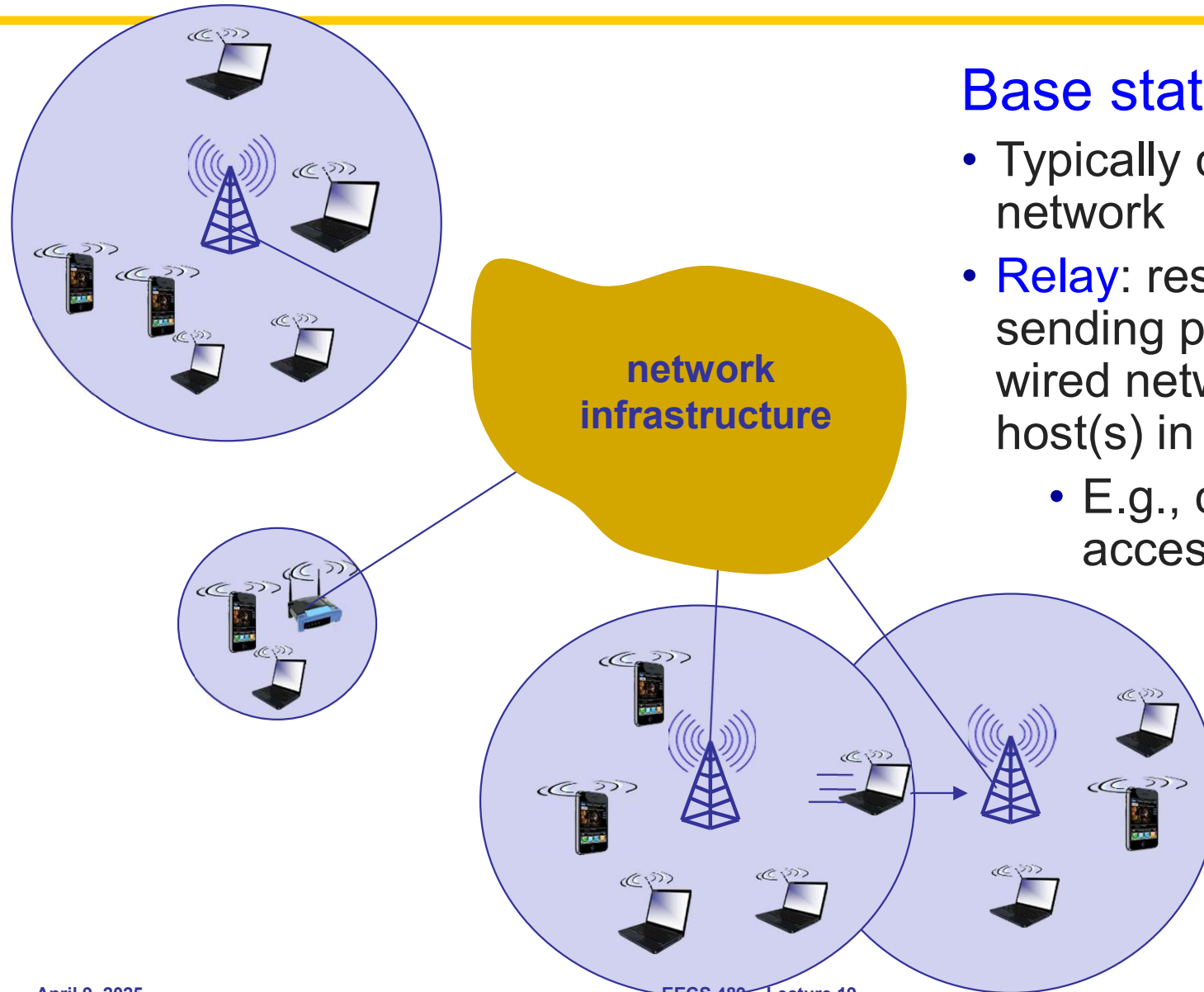
- Laptop, smartphone
- Run applications
- May be stationary (non-mobile) or mobile
  - Wireless does *not* always mean mobility

# Wireless vs. mobile

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- ❑ Wireless networks deal with communication over wireless links
- ❑ Mobility deals with handling mobile users that change 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

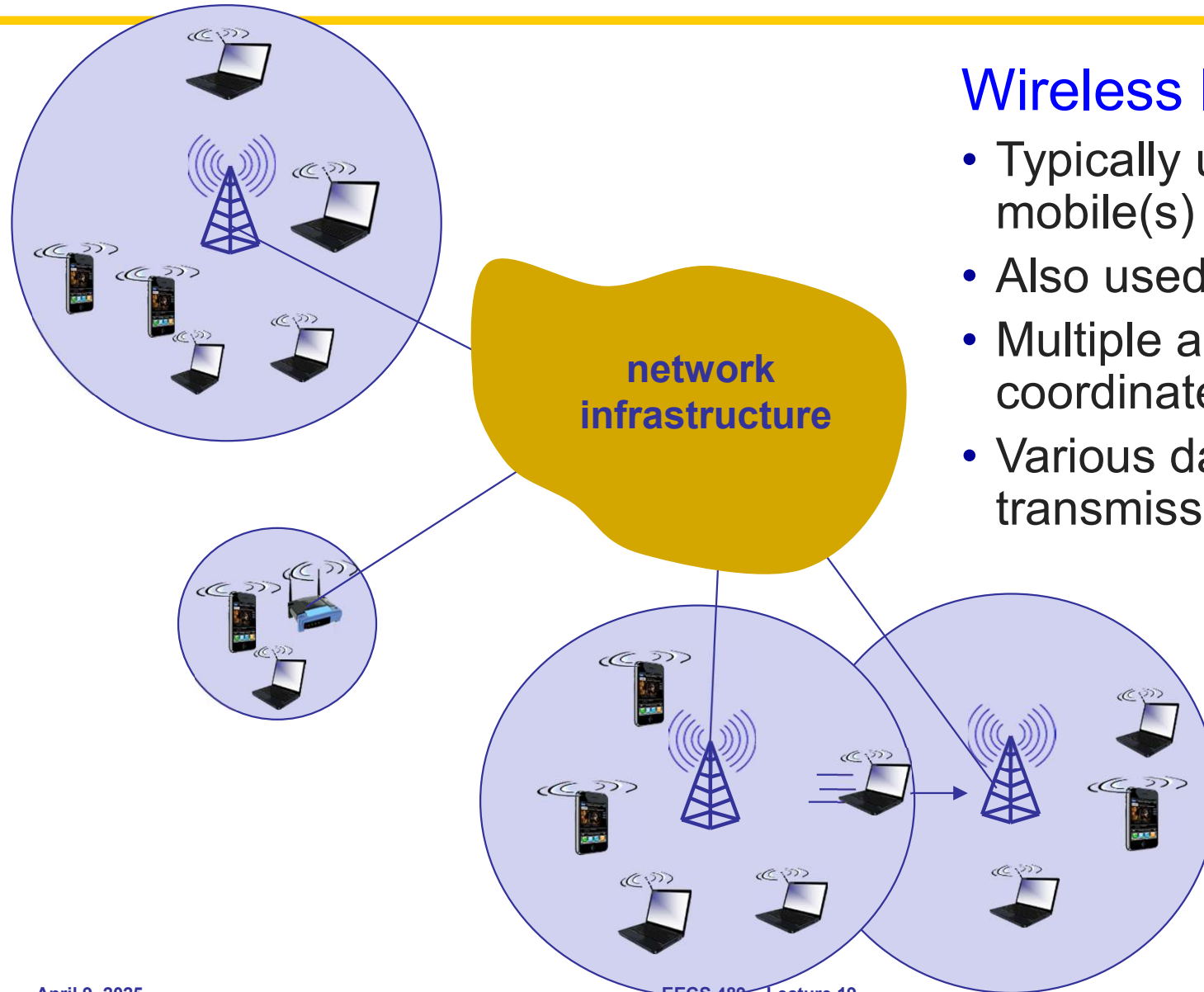
# Elements of a wireless network



## 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 (AP)

# Elements of a wireless network

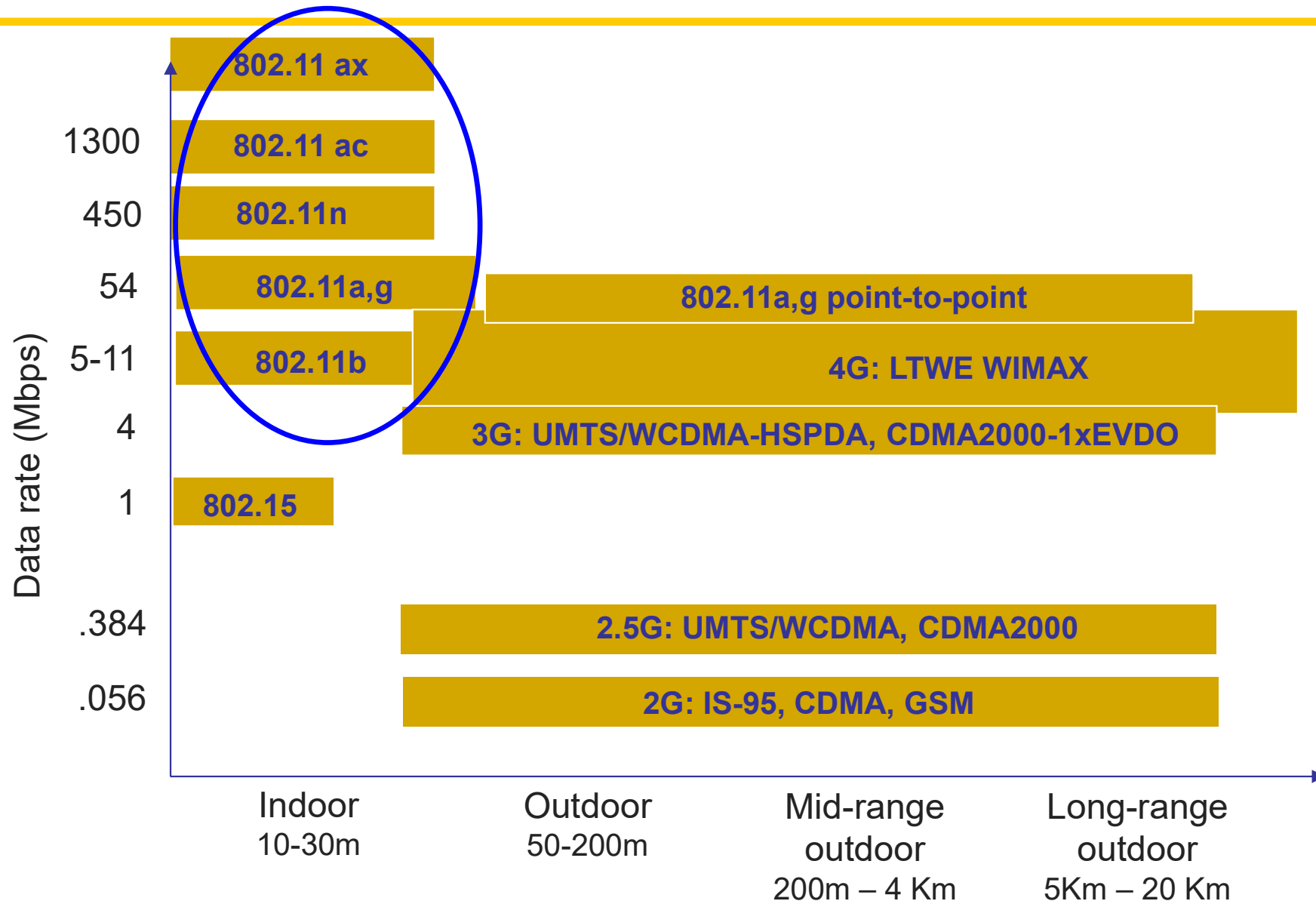


## Wireless link

- 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



# Characteristics of selected wireless links



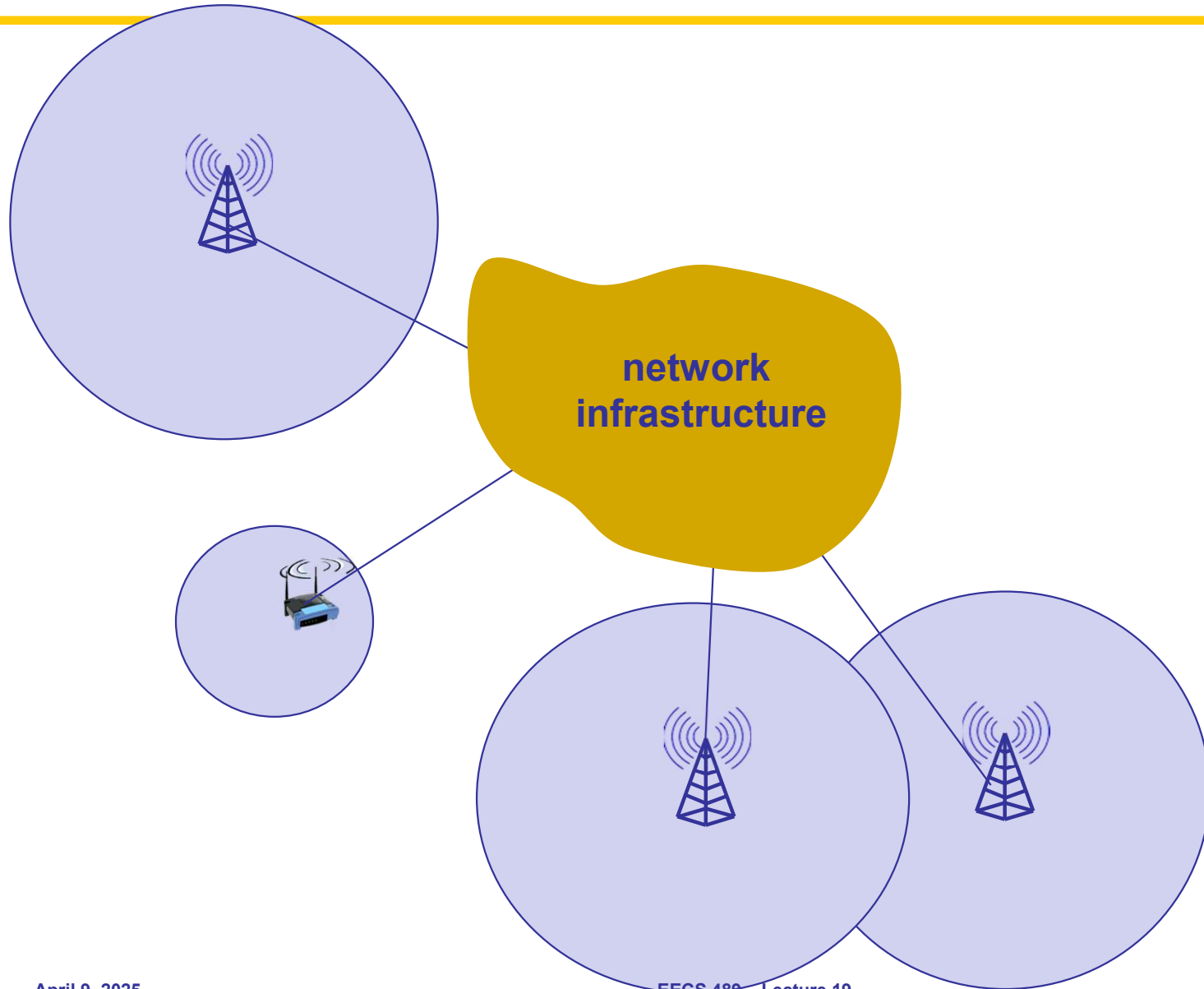
# Two modes of operation

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

# Infrastructure mode

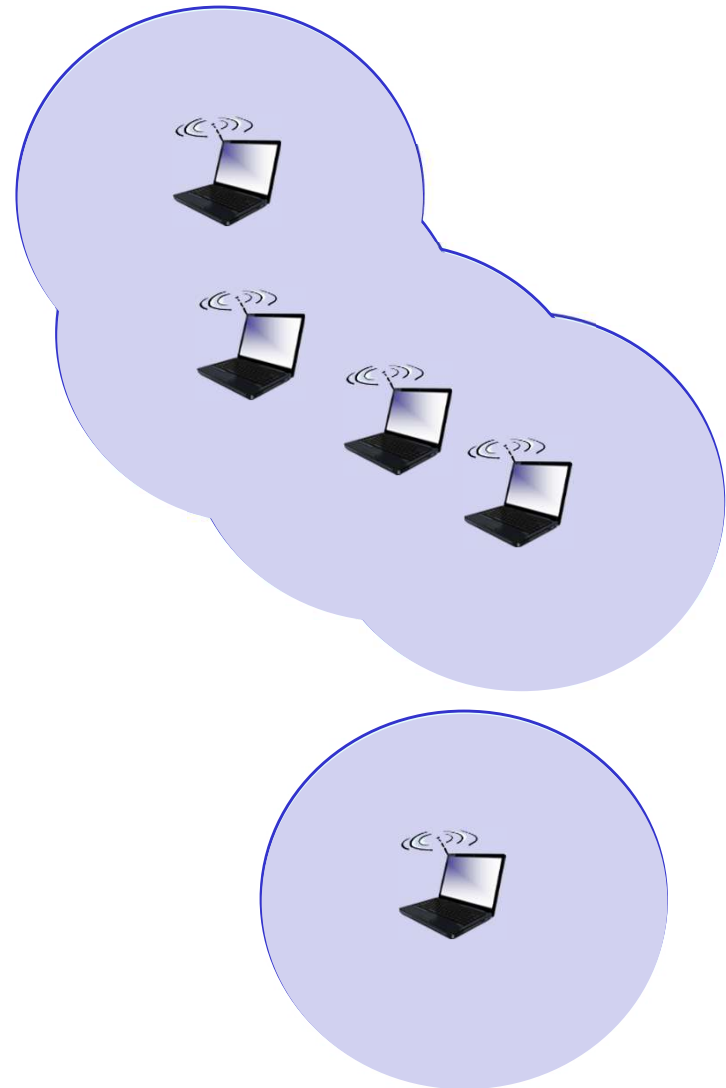
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# Ad-hoc mode

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- ❑ No base station
- ❑ Nodes can only transmit to other nodes within link coverage
- ❑ Nodes **organize themselves** into a network: route among themselves



# Wireless network taxonomy

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	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: <i>mesh net</i>
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

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

# Path loss/path attenuation

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- Free Space Path Loss (FSPL):

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

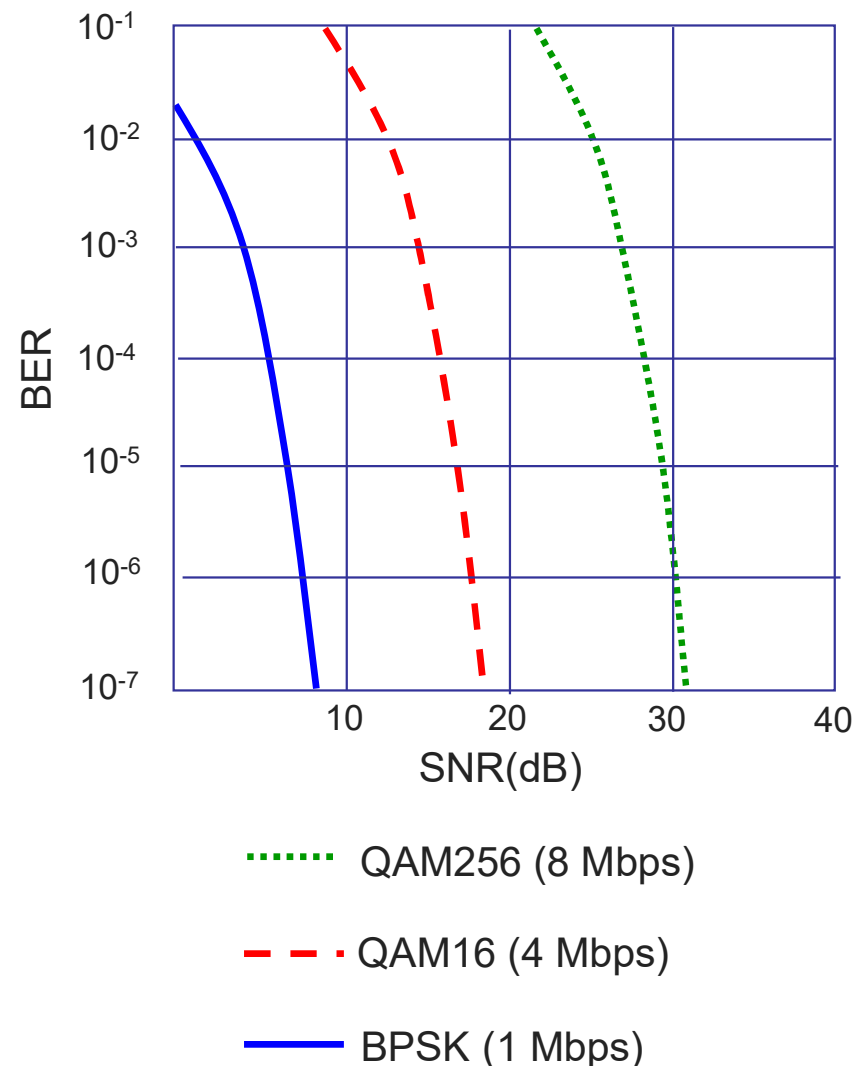
- d = distance
- $\lambda$  = wave length (c/f)
- f = frequency
- c = speed of light

- 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





# Dealing with bit errors

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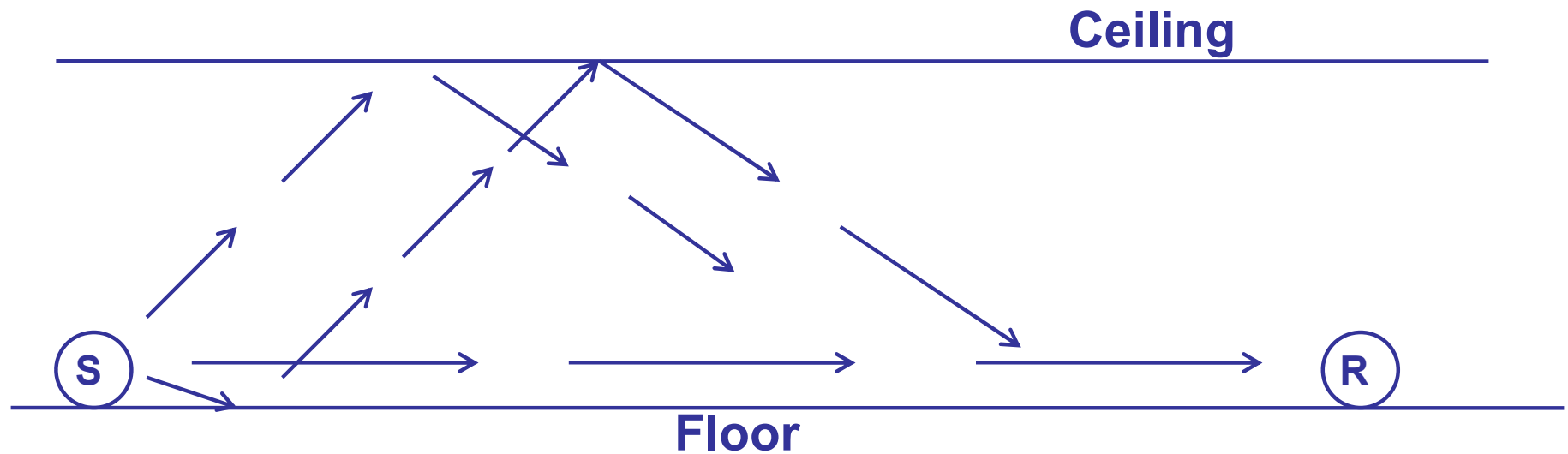
- ❑ Wired vs. wireless links: most loss due to congestion vs. higher, time-varying BER
- ❑ Dealing with high wireless bit-error rates
  - Sender could increase transmission power
    - » Needs hi energy (bad for battery-powered hosts)
    - » Creates more interference with other senders
  - Stronger error detection and recovery
    - » More powerful error detection/correction codes
    - » Link-layer retransmission of corrupted frames
  - Many TCP alternatives/extensions for wireless
    - » TCP Westwood uses Explicit Loss Notification (ELN)

# Wireless link characteristics

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- 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 at destination at slightly different times

# Multipath effects



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

# Wireless link characteristics

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- 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 at 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

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- ❑ 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 is possible
- ❑ Signals sent by sender don't always end up at receiver intact

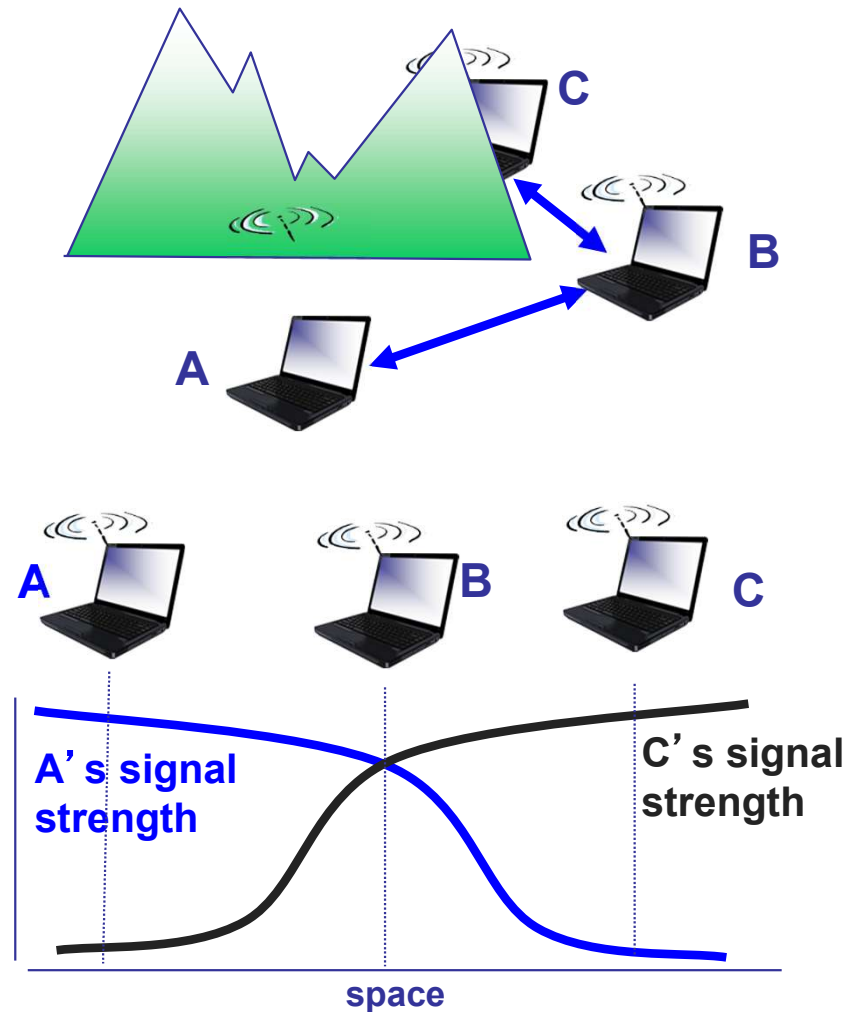
# Wireless network characteristics

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- Multiple wireless senders and receivers create many problems
  - Multiple access issues (we've seen this before)
  - Hidden terminal problem

# Hidden terminal problem

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



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**5-MINUTE BREAK!**

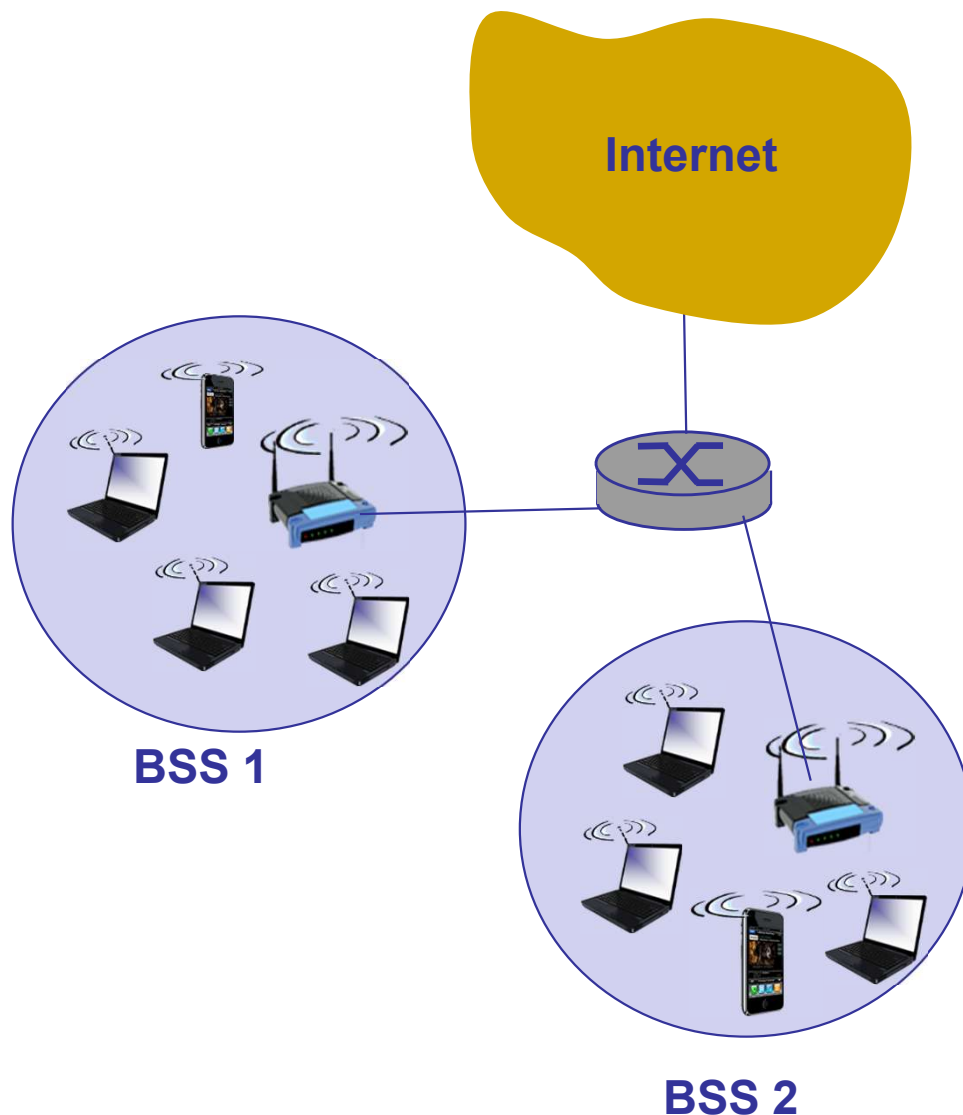


# 802.11 wireless LAN (aka WiFi)

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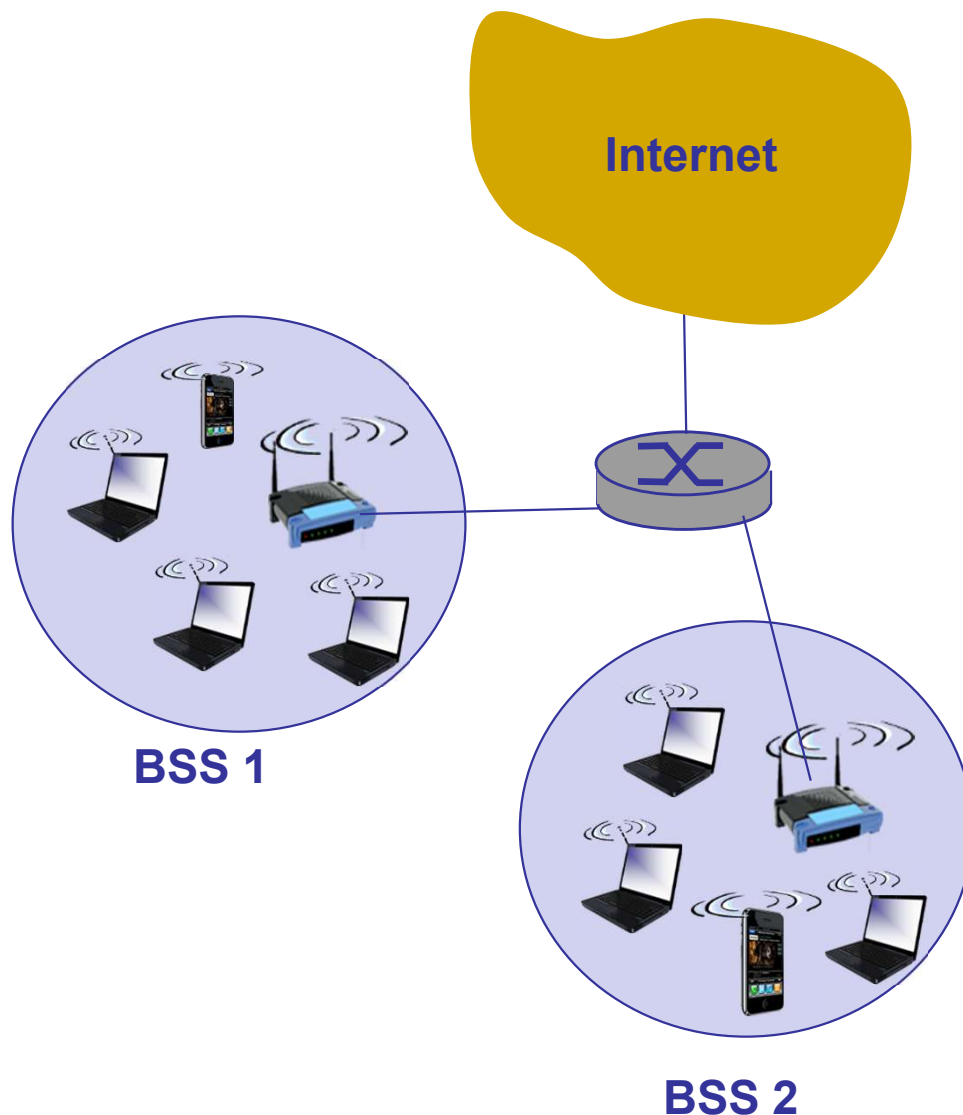
- Many variations
  - 802.11b, 802.11a, 802.11g, 802.11n, 802.11a\*
- All use CSMA/CA for multiple access
- All have infrastructure and ad-hoc modes

# 802.11 LAN architecture



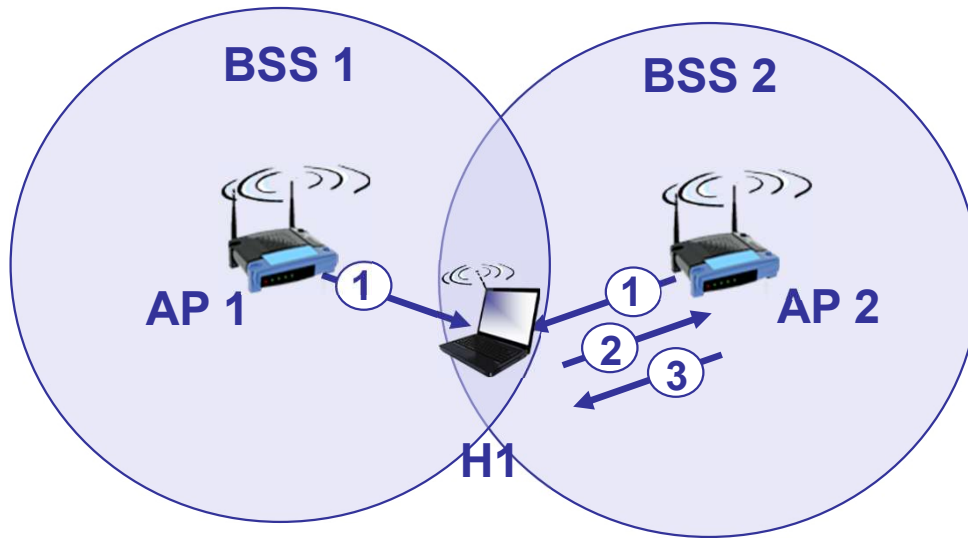
- ❑ Wireless host communicates with base station
  - **Base station** = access point (AP)
- ❑ **Basic Service Set (BSS)** (aka “cell”) in infrastructure mode contains
  - Wireless hosts
  - Access point (AP): base station
- ❑ Ad-hoc mode: hosts only

# 802.11 LAN architecture



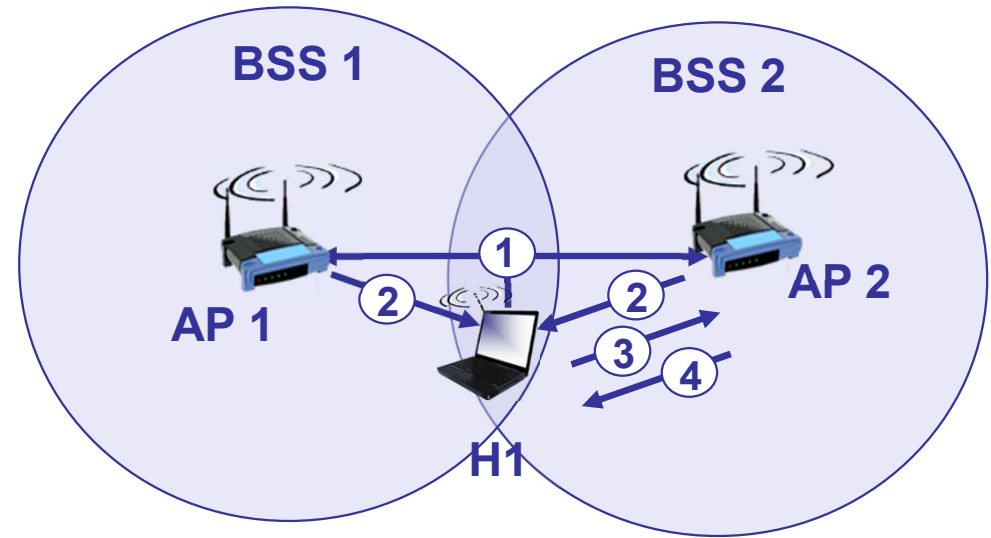
- ❑ Designed for limited area
- ❑ AP is set to specific channel
  - Broadcast beacon messages with SSID (Service Set Identifier) and MAC Address periodically
- ❑ Hosts scan all the channels to discover the AP's
  - Host **associates** with AP

# 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 from H1 to selected AP
4. Association Response frame sent from selected AP to H1

# 802.11 multiple access

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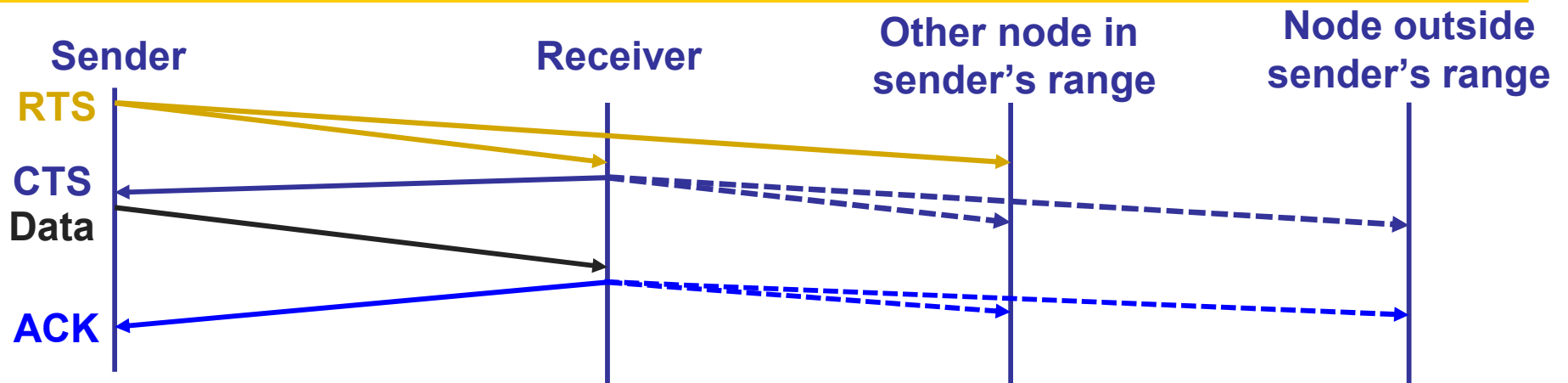
- 802.11 CSMA: sense before transmitting
  - Don't collide with ongoing transmissions by others
- 802.11 has no collision detection!
  - Difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
  - Can't sense all collisions in any case: hidden terminal, fading
- **Avoid collisions:** CSMA/CA
  - CA: Collision Avoidance

# Basic collision avoidance

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- Carrier sense:
  - When medium busy, choose random interval
  - Wait that many idle timeslots to pass before sending
- When a collision is inferred, retransmit with binary exponential backoff (like Ethernet)
  - Use ACK from receiver to infer “no collision”
  - Use exponential backoff to adapt contention window

# CSMA/CA



□ Before every data transmission

- Sender sends a Request to Send (RTS) frame with the length of transmission and the destination
- Receiver respond with a Clear to Send (CTS) frame
- Sender sends data
- Receiver sends an ACK

□ If sender doesn't get a CTS back, it assumes collision

# RTS/CTS

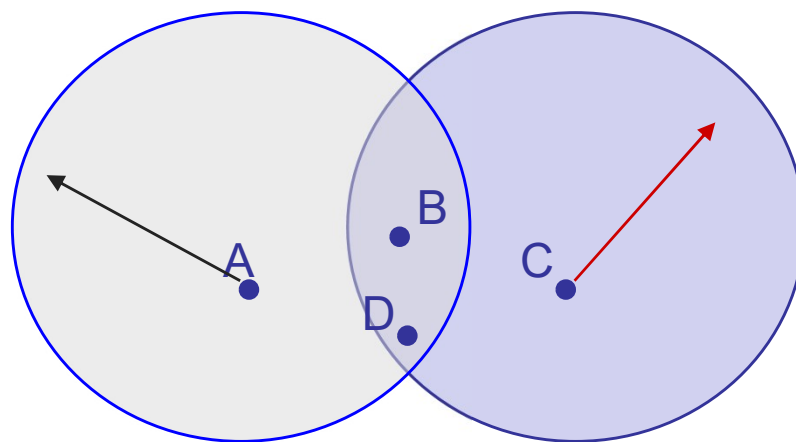
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- ❑ Works by reserving the channel using short frames before transferring much longer DATA frame
  - Explicitly reserving the channel enables avoidance
- ❑ Required to avoid hidden terminals
  - Hidden terminals will hear CTS from the receiver



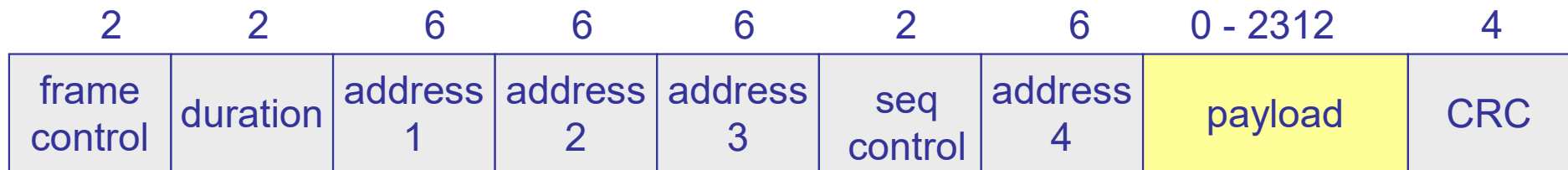
# Preventing collisions altogether

- Frequency Spectrum partitioned into several channels
  - Nodes within interference range can use separate channels



- Now A and C can send without any interference!
- Aggregate Network throughput doubles

# 802.11 frame: Addressing



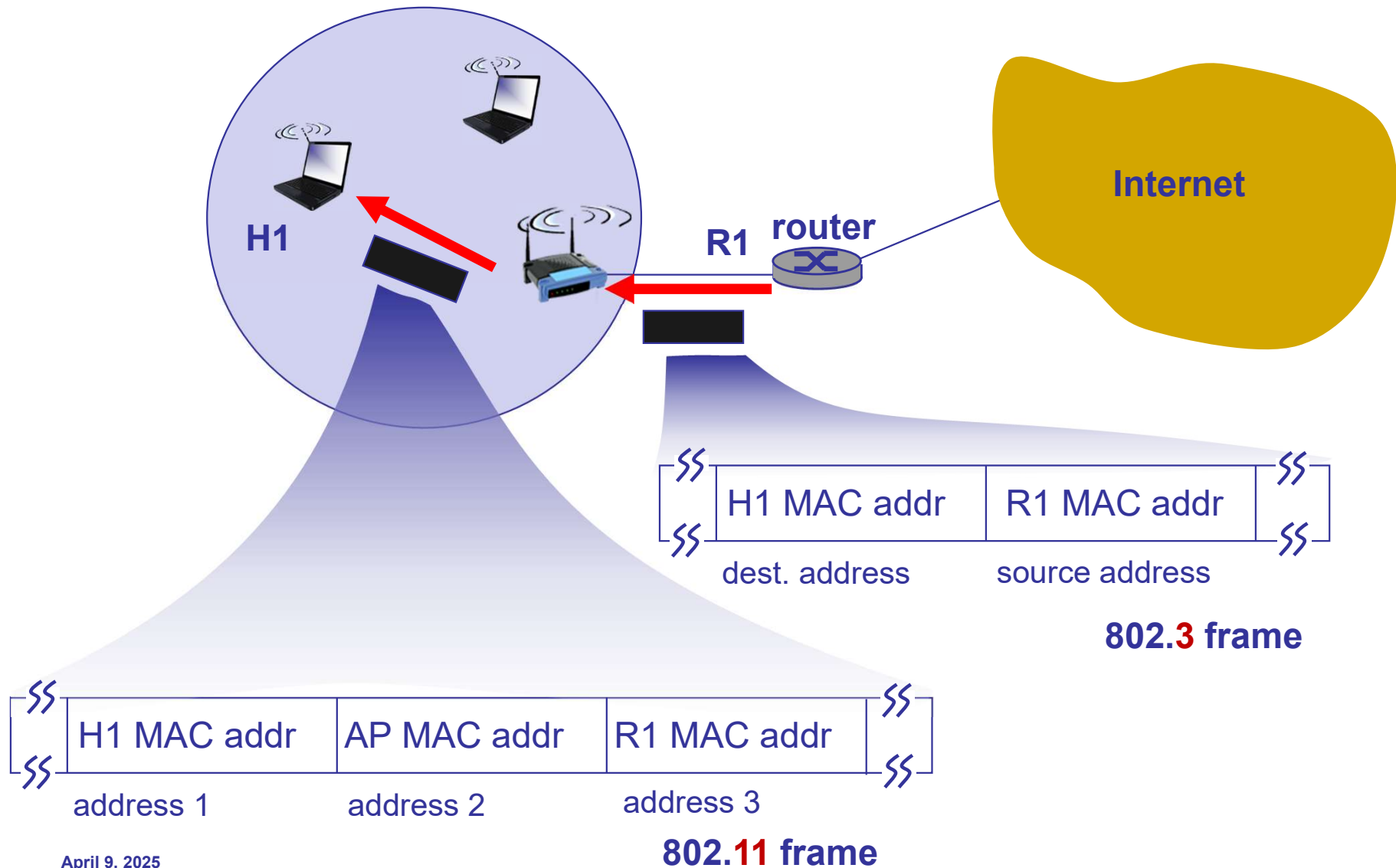
Address 1: MAC address of wireless host or AP to receive this frame

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

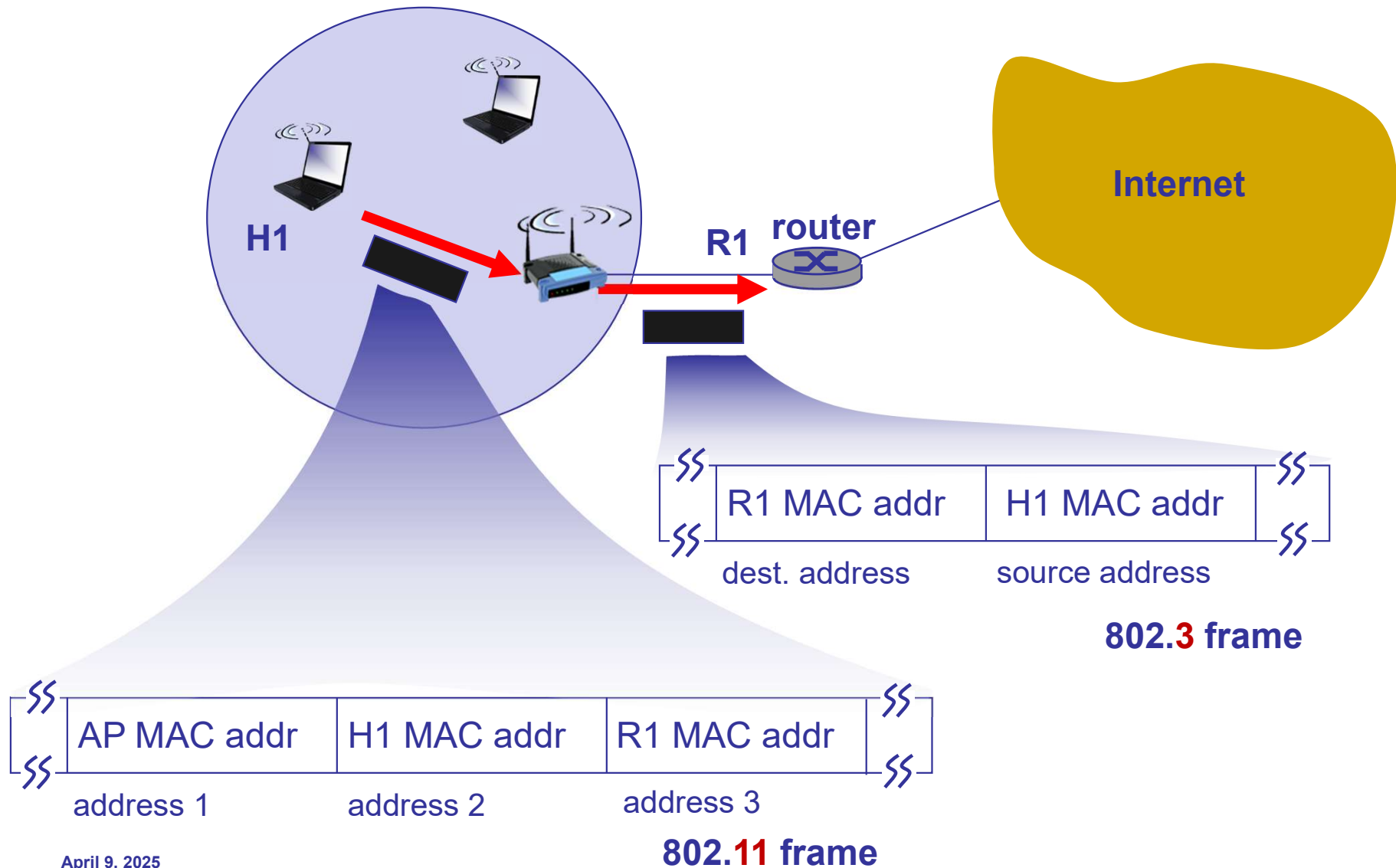
Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

# Why do we need Address 3?

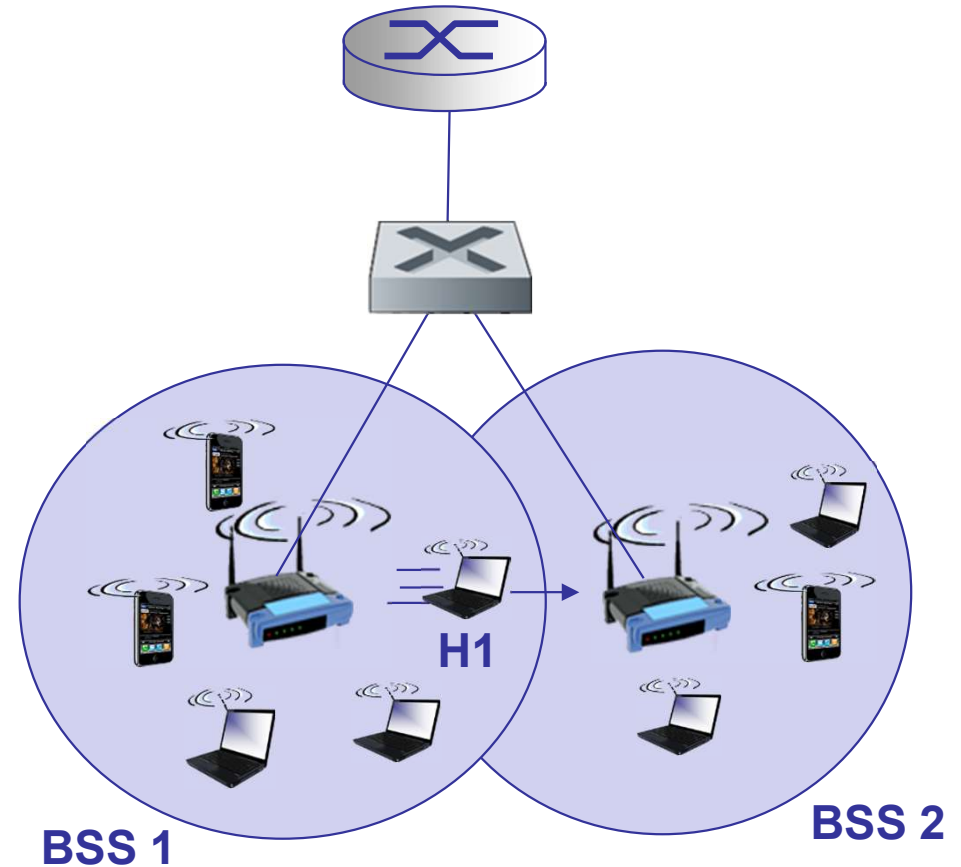


# Why do we need Address 3?



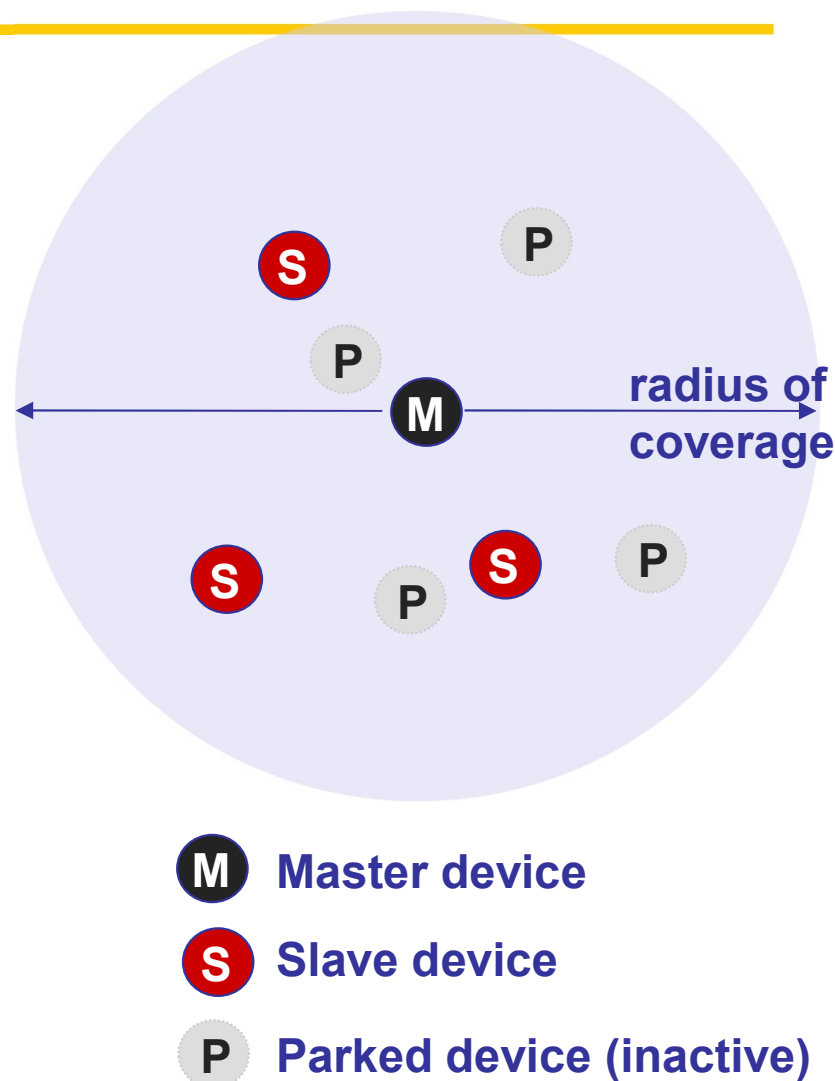
# 802.11: Mobility within same subnet

- H1 remains in same IP subnet: IP address can remain same
- Switch: which AP is associated with H1?
  - Self-learning: Switch will see frame from H1 and “remember” which switch port can be used to reach H1



# 802.15: Personal Area Network (PAN)

- 802.15: evolved from Bluetooth specification
- 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



# Summary

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- ❑ Wireless networking introduces more challenges than wired networks
  - Interference, attenuation, multipath, hidden terminals, etc.
- ❑ CSMA/CD doesn't work because collision detection is difficult
  - Instead, CSMA/CA is used that avoid collisions by reserving the channel a priori