# ECE 356/COMPSI 356
# Computer Network Architecture

## Wireless Communications

Monday September 9, 2019

Monday September 16, 2019

# Recap

- Previously:
  - Network architectures
  - Physical layer
  - Link layer
- Readings for this lecture: **PD 2.7**

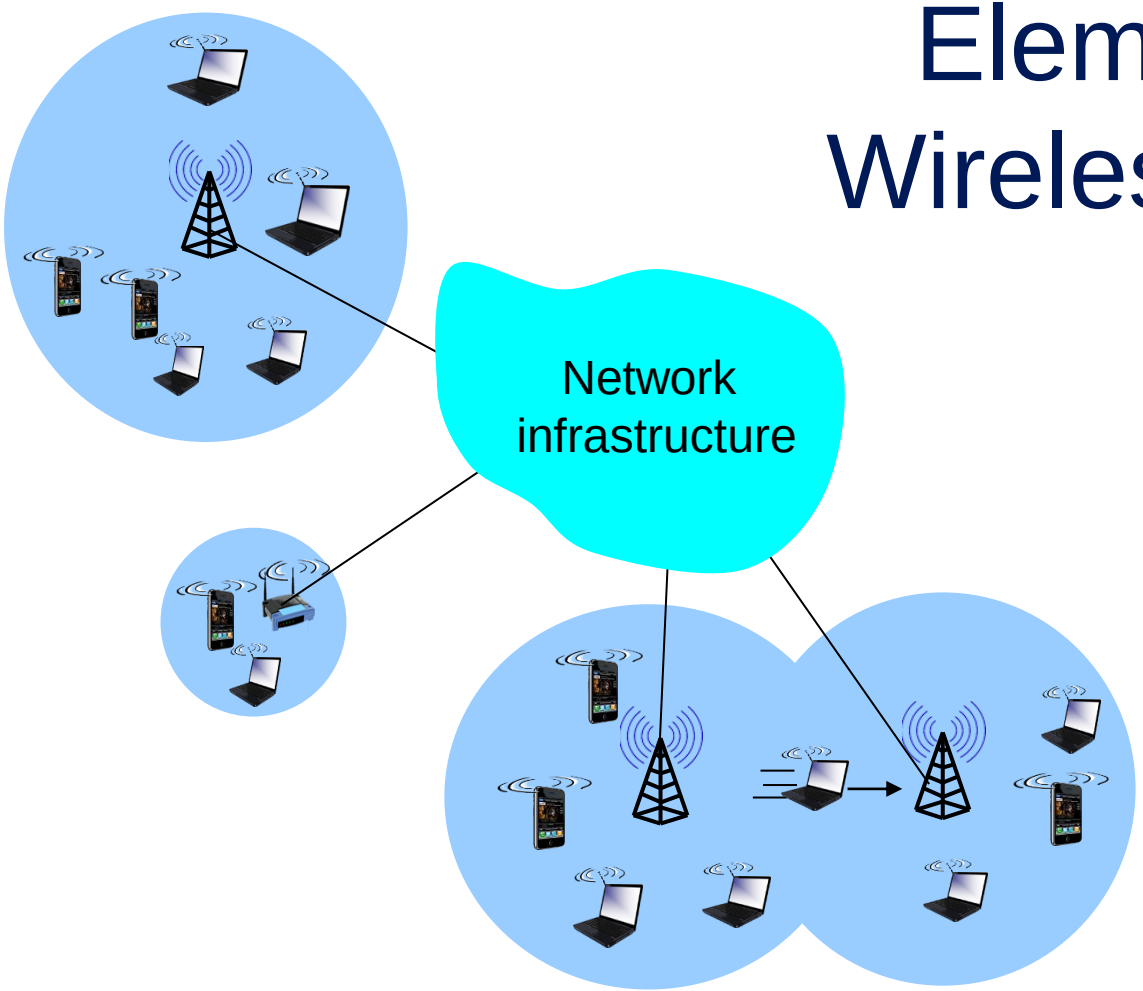
# What Did We Already Discuss About Wireless Communications?

- Some parts of spectrum are licensed
- Higher bit error rates than wired connections
- Interference from other devices
- Internet of Things: a frontier in networking

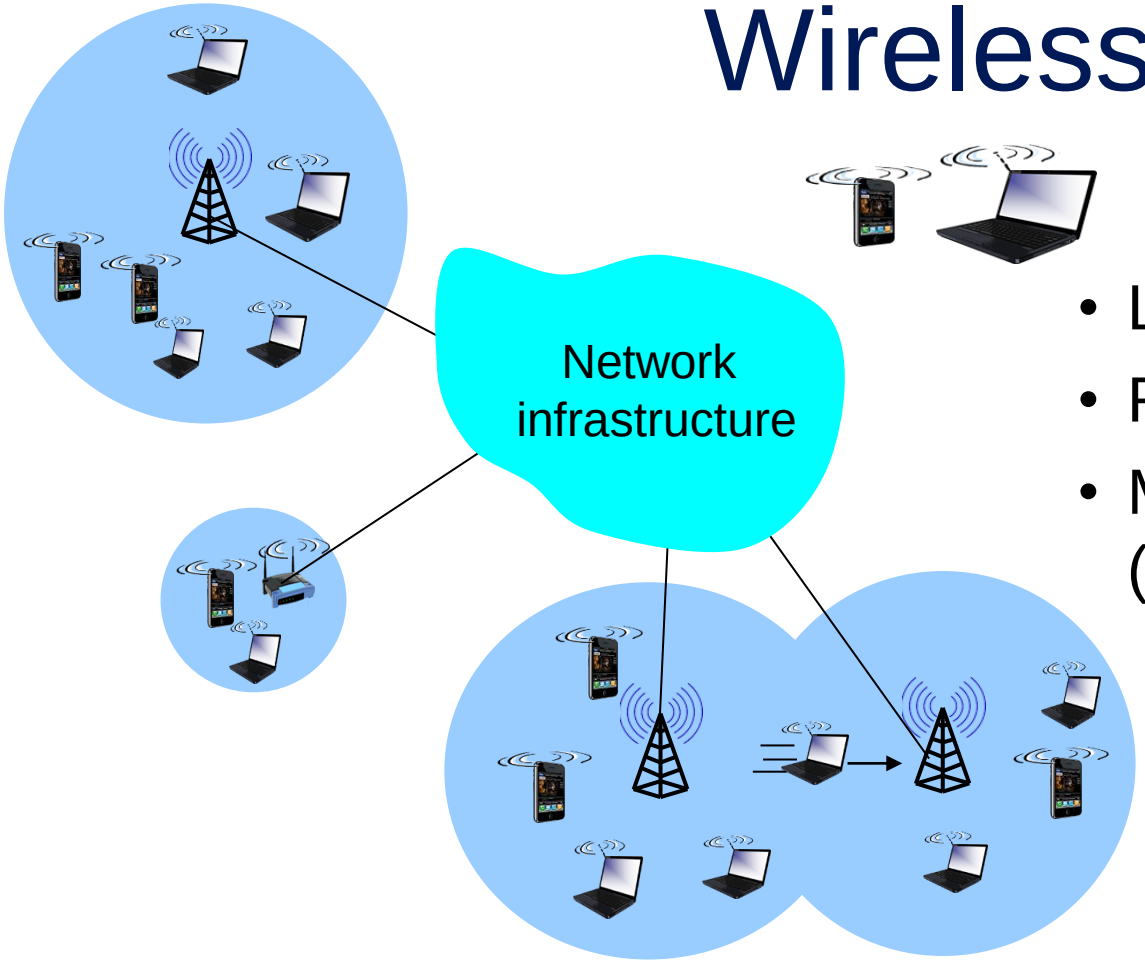
# Lecture Outline

- **Wireless network taxonomy**
- Wireless link characteristics
- CDMA
- 802.11: an introduction
- 802.11: advanced features
- Cellular communications

# Elements of a Wireless Network

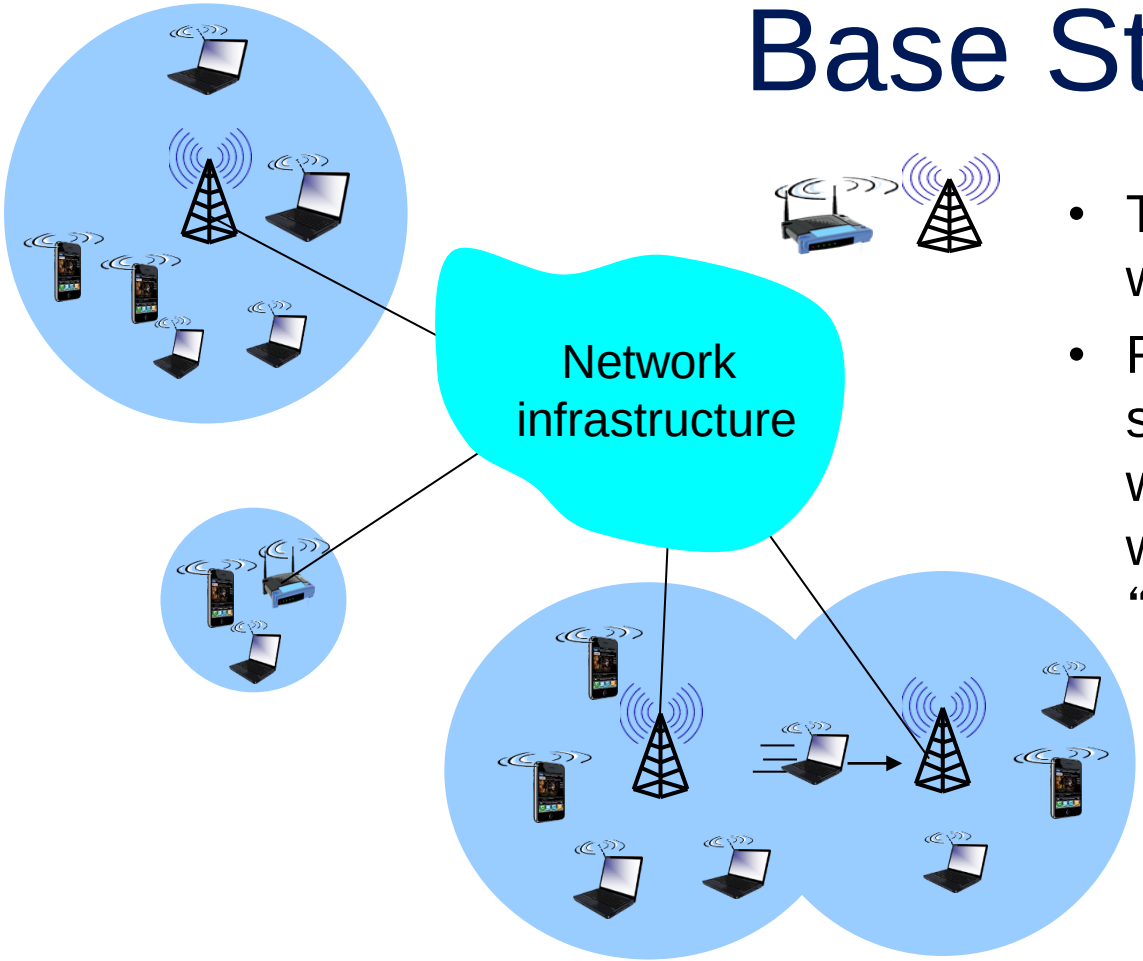


# Wireless Hosts



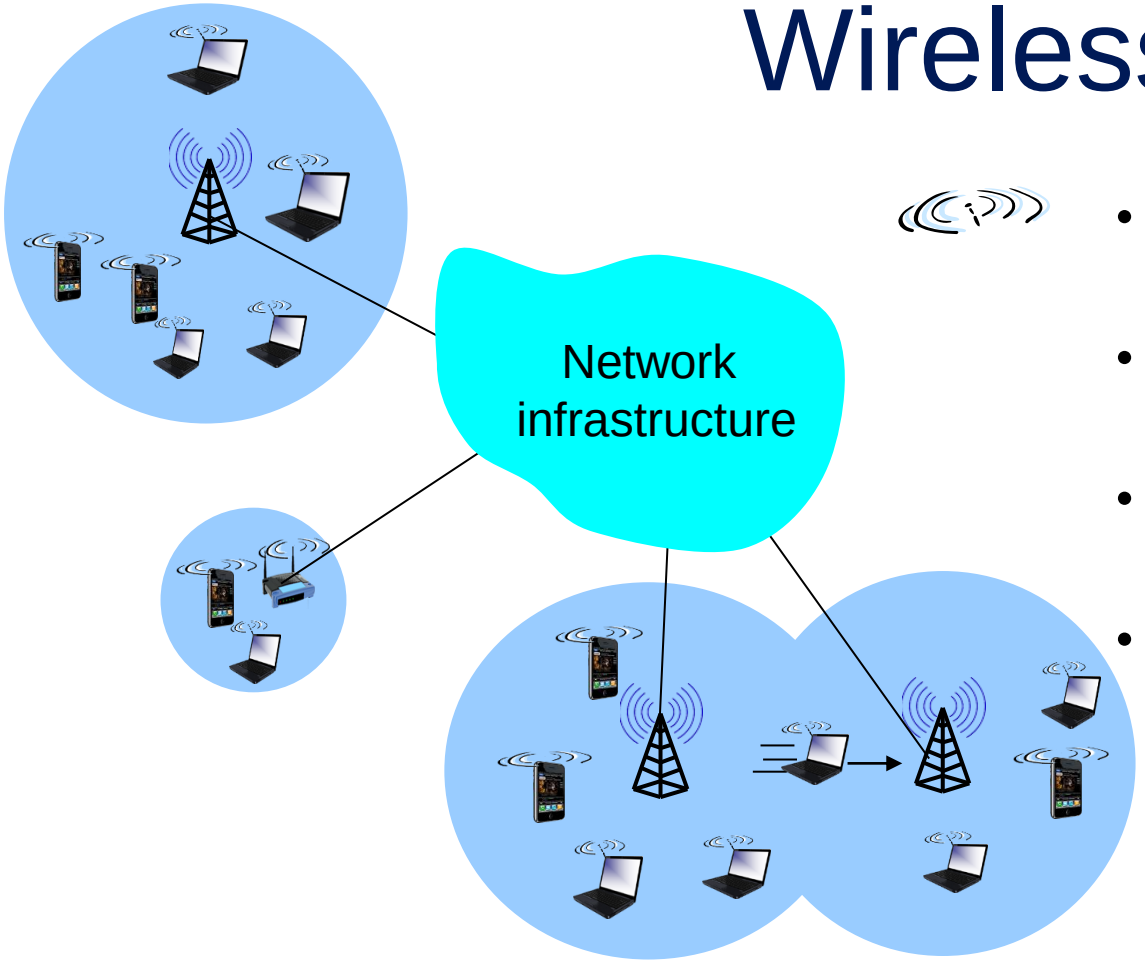

- Laptop, smartphone
- Run applications
- May be stationary (non-mobile) or mobile
  - ➢Wireless does *not* always mean mobility

# Base Stations



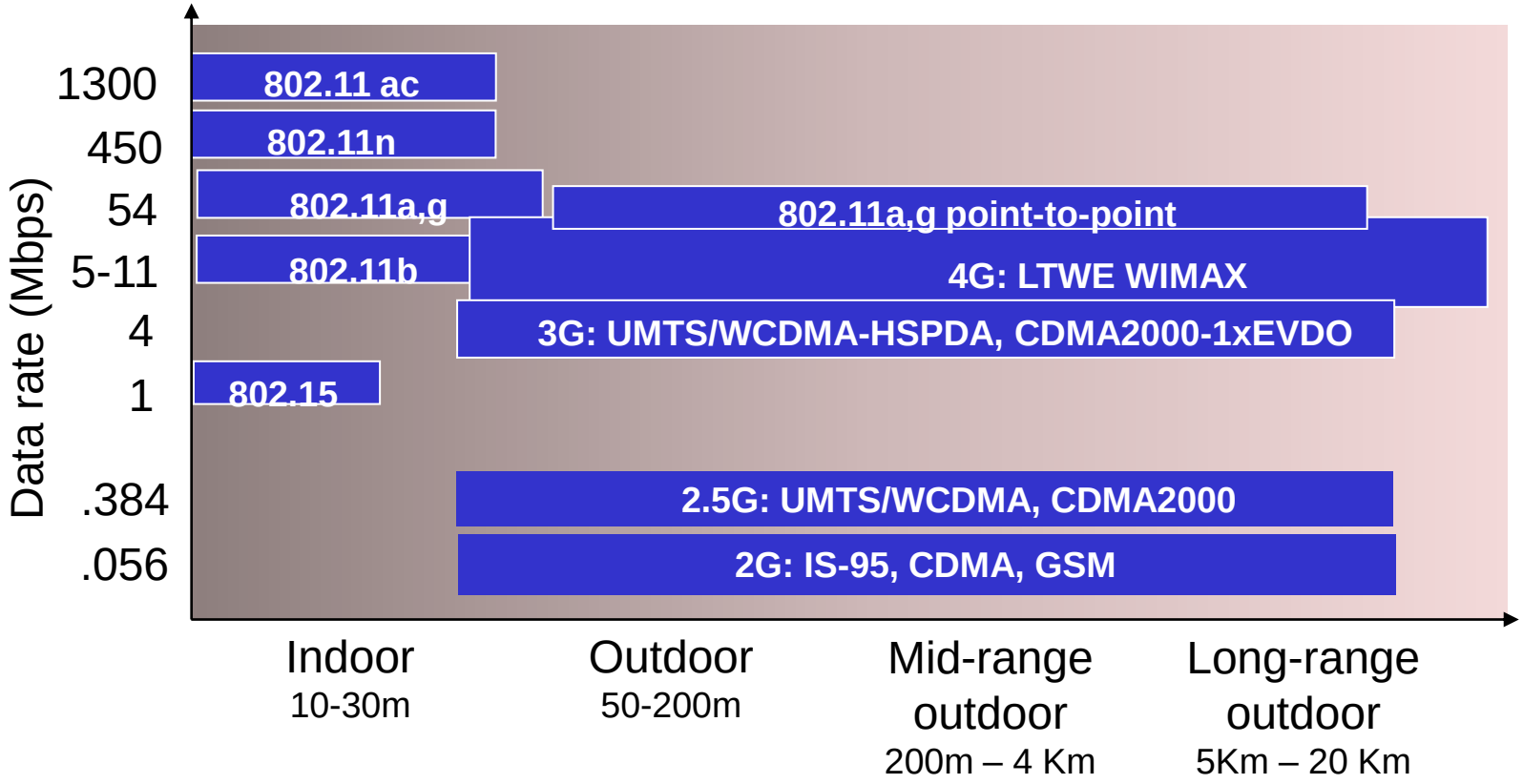

- Typically connected to wired network
- Relay - responsible for sending packets between wired network and wireless host(s) in its "area"
  - E.g., cell towers, 802.11 access points

# Wireless Link

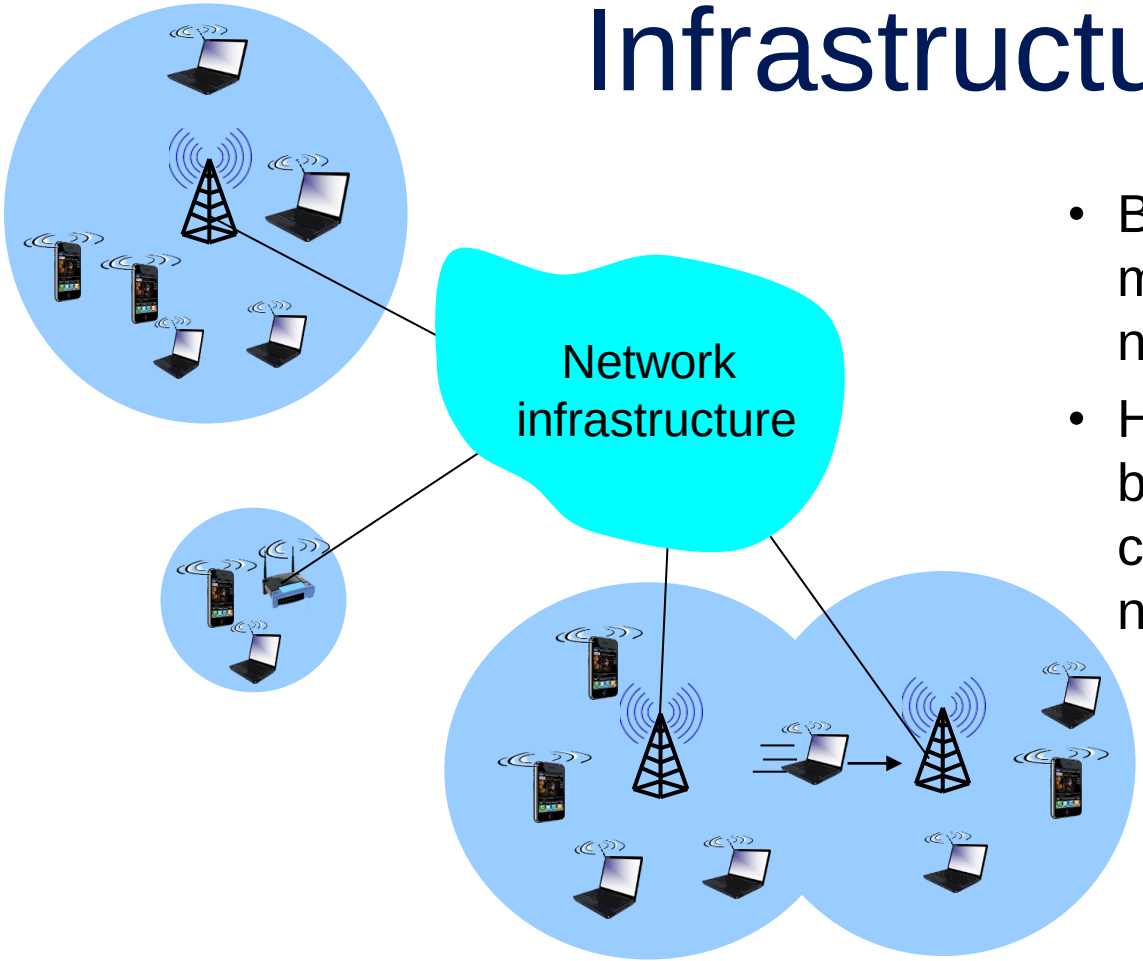



- Typically used to connect mobile(s) to base station
- Also used as backbone link
- Multiple access protocol coordinates link access
- Various data rates, transmission distances

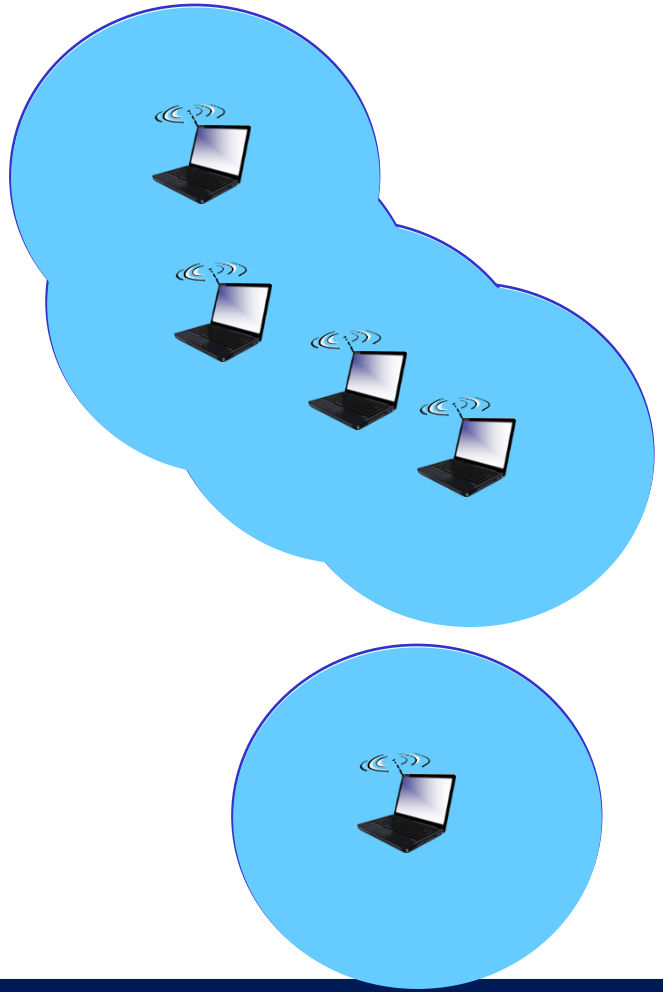
# Characteristics of Selected Wireless Links



# Infrastructure Mode




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

# 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 |

# Lecture Outline

- Wireless network taxonomy
- **Wireless link characteristics**
- CDMA
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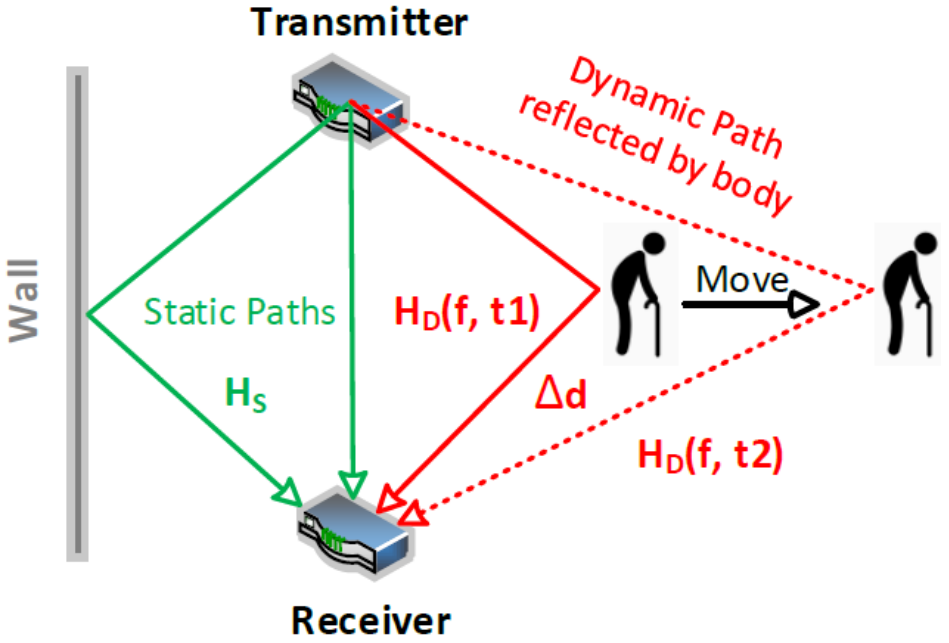
# Wireless Link Characteristics: Signal Strength and Interference

- Much more challenging than communicating over a wire
- *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., phones, microwaves)

# Wireless Link Characteristics: Multipath Propagation

- Radio signal reflects off objects and the ground, arriving at the destination at slightly different times
- Multipath changes over time



# Bit Errors Are More Common in Wireless Links

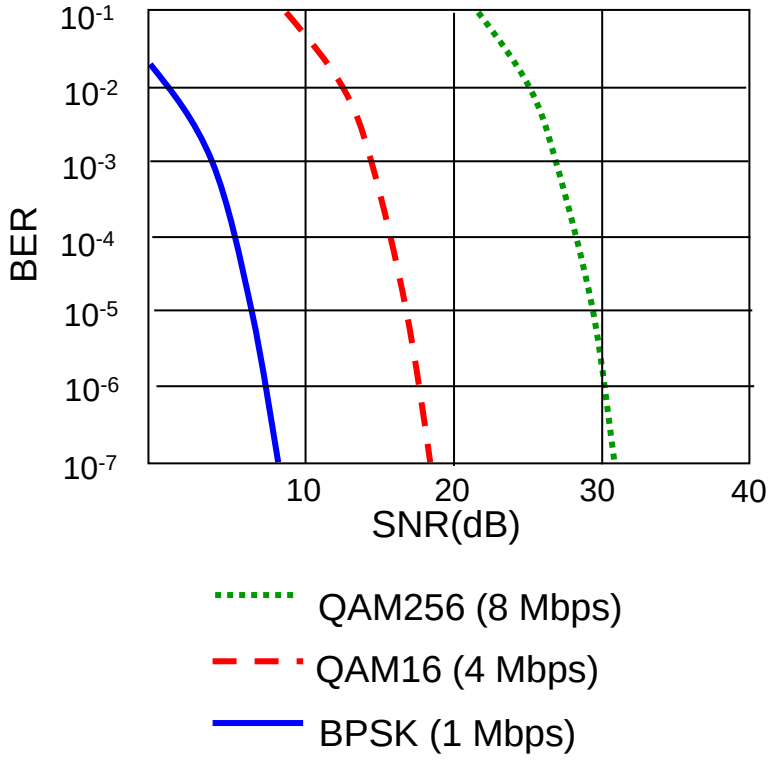
- Use both error detection codes and link-level reliable data transfer protocols that retransmit corrupted frames

# Bit Error Rate and Signal to Noise Ratio Revisited

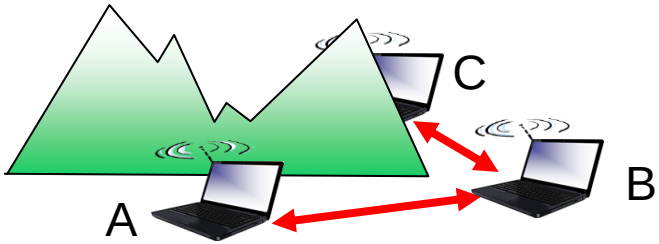
- BER: bit error rate
- SNR: signal-to-noise ratio
  - ➢ Larger SNR: easier to extract signal from noise
    - A good thing
  - ➢ Can improve SNR by increasing transmission power
    - Disadvantages: power consumption, interference
    - There are regulatory limits on how much transmission power can be increased

# 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*: modulation technique, rate

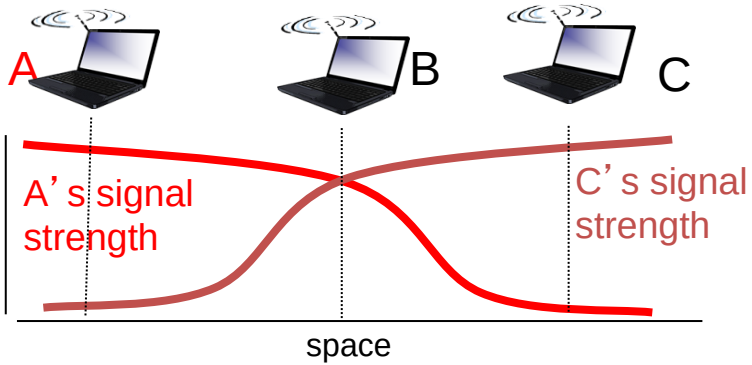


# Node “Visibility” Complications




## *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

# Homework Submission Requirements

- Submit a single pdf file with your NetID as the filename (do not submit multiple pictures)
- Use word or Latex to write the homework. You can insert handwritten graphs or tables for some questions
- Answer one question on one single page and compile them in order into one single pdf file
- Write down your NetID and name on the header of the first page

# Quiz 2 Answers

# Lecture Outline

- Wireless network taxonomy
- Wireless link characteristics
- **CDMA**
- 802.11: an introduction
- 802.11: advanced features
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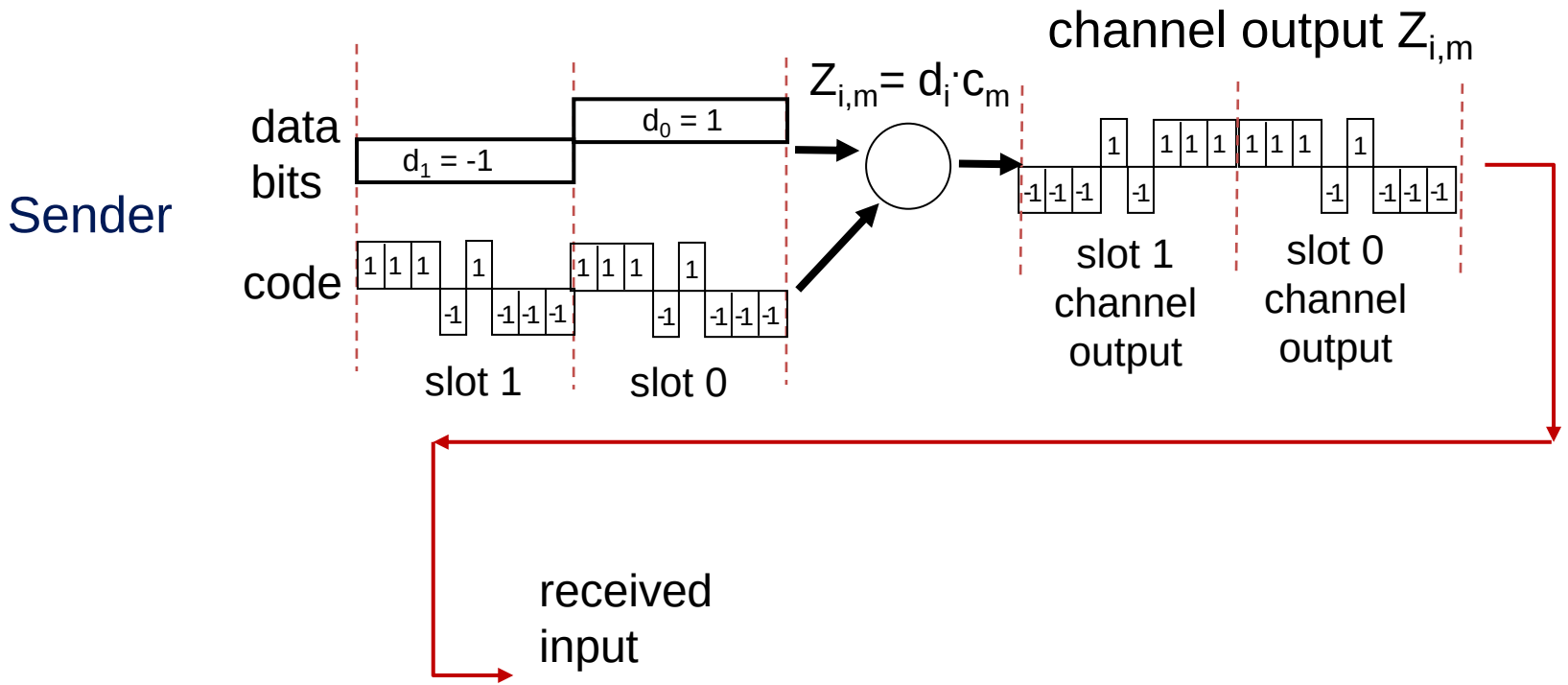
# Code Division Multiple Access (CDMA) (1/2)

- Channel partitioning protocol prevalent in wireless communications
- 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”)

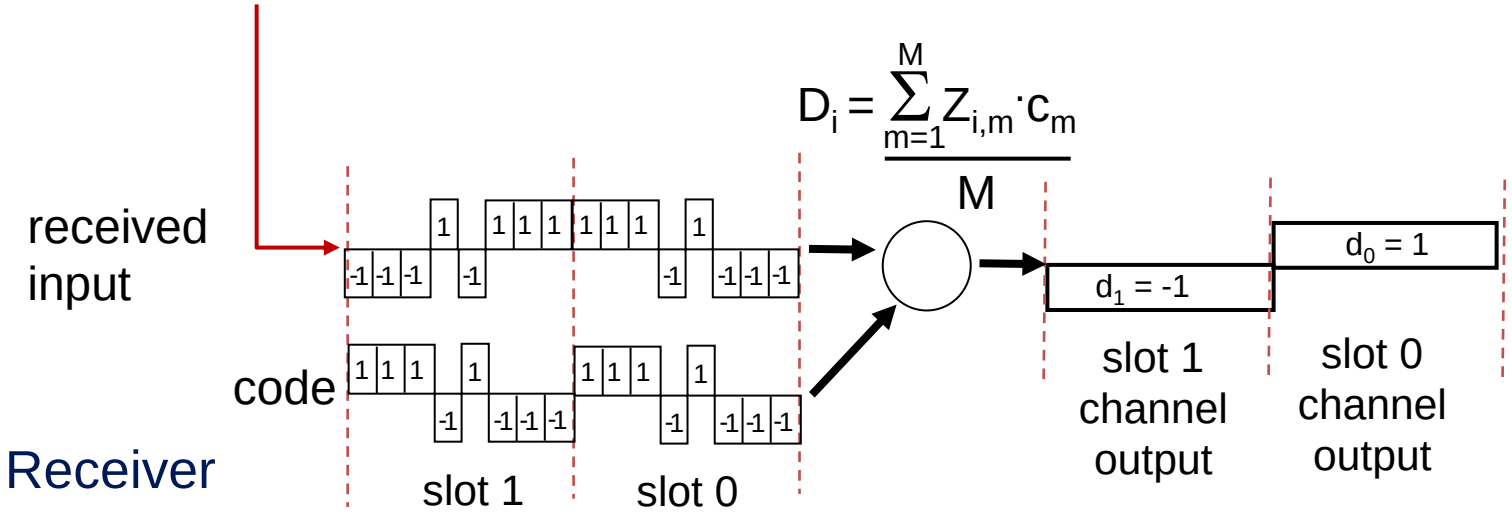
# Code Division Multiple Access (CDMA) (2/2)

- *Encoded signal* = (original data) X (chipping sequence)
  - Where chipping sequence is much faster than the bit rate
- *Decoding:* inner-product of encoded signal and chipping sequence

# CDMA Encode/Decode: Sender

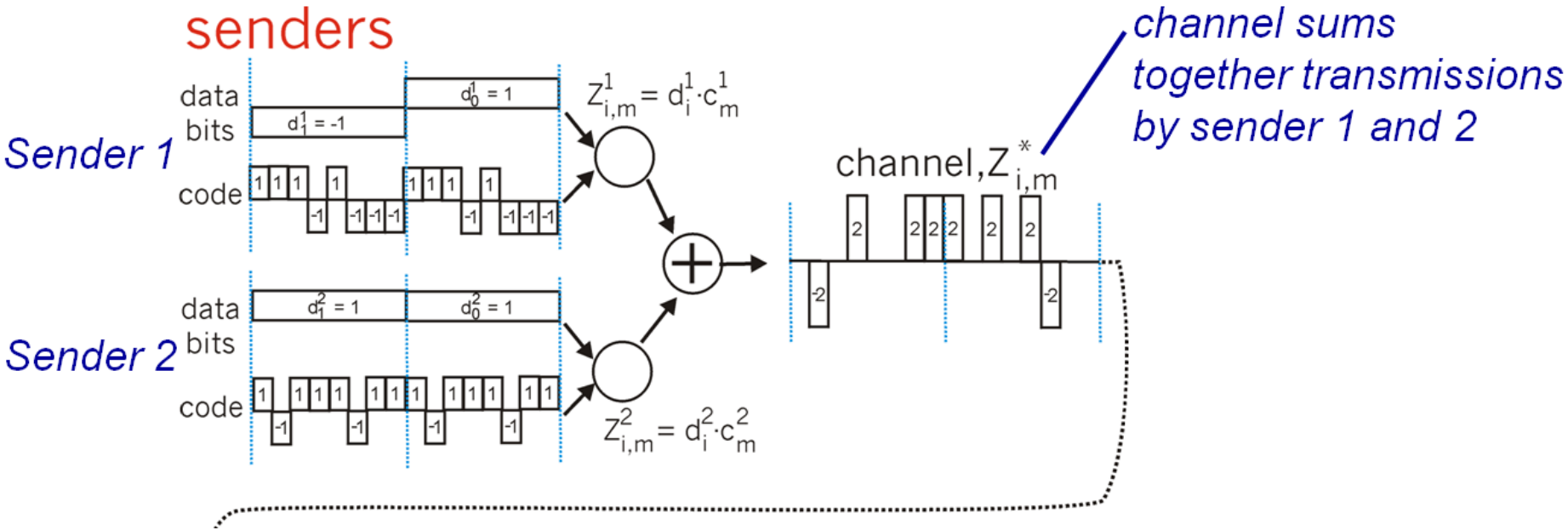


# CDMA Encode/Decode: Receiver

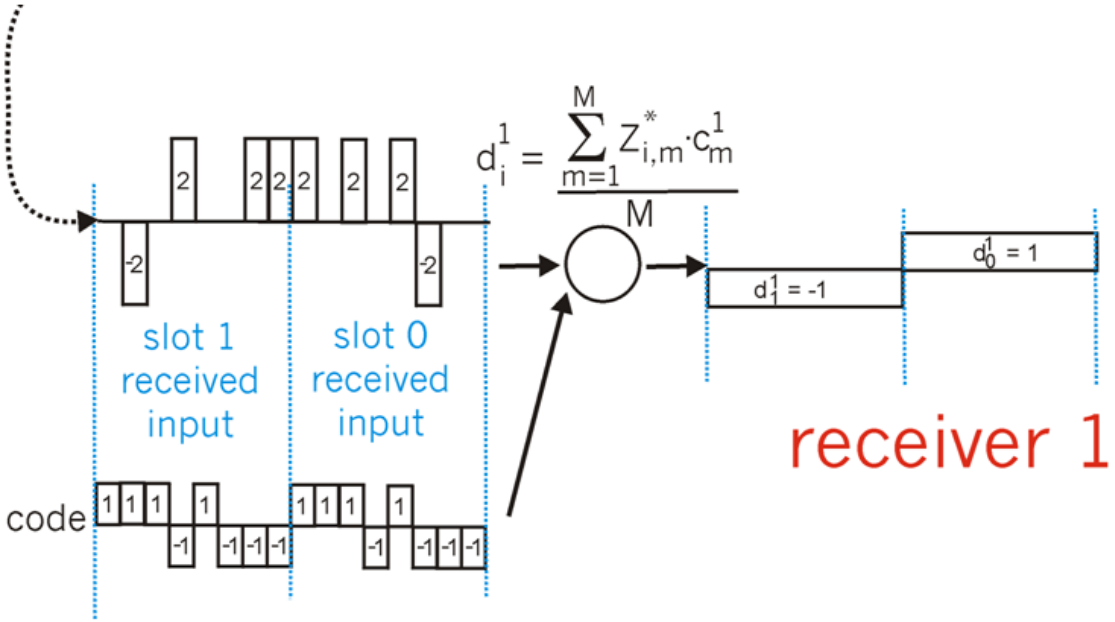


# CDMA: Two-sender Interference (1/2)

- Assume interference to be *additive*



# CDMA: Two-sender Interference (2/2)




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

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- Wireless network taxonomy
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# IEEE 802.11 Wireless LAN

- A collection of *link layer and physical layer* wireless protocols
  - First released in 1997, new variants released continuously after
  - Ubiquitous
- Nearly all protocols operate in unlicensed spectrum bands
- All use same multiple access technique
- All have base station and ad hoc network versions
- Aim to be backwards-compatible

# IEEE 802.11: Common Variants (1/2)

- 802.11b
  - 2.4 GHz
  - Up to 11 Mbps
- 802.11g
  - 2.4 GHz
  - Up to 54 Mbps

- But, 2.4 GHz is a busy frequency band



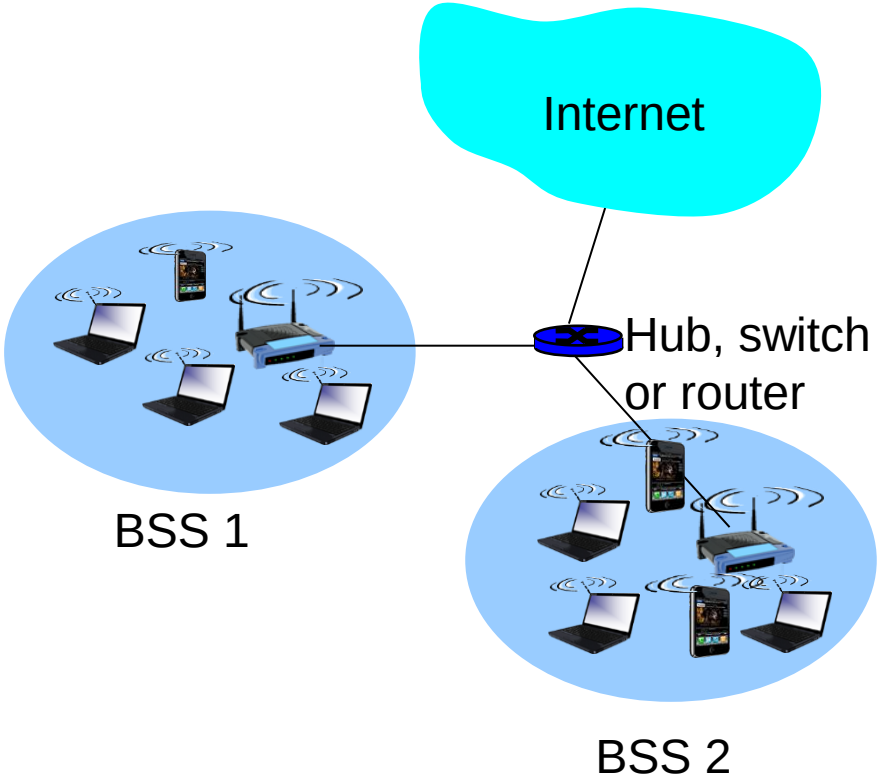
# IEEE 802.11: Common Variants (2/2)

- 802.11a
  - 5 GHz
  - Up to 54 Mbps
  - Lower effective range than 802.11b/g
- 802.11n
  - 2.4 GHz, 5 GHz
  - Multiple antennae
    - MIMO: multiple-input multiple-output antennas
  - Up to 200 Mbps

# IEEE 802.11: More Exotic Variants

- 802.11ad
  - 60 GHz: mmWave communications
  - Up to **7 Gbps**
    - 130x faster than 802.11b/g
  - Range of only 1-10 meters
  - Walls, obstacles a concern
- 802.11af
  - Senses unused TV bands between 54 and 790 MHz: "TV whitespace communications"
    - Increases communication range

# 802.11 LAN Architecture




- Wireless hosts communicate with a base station
  - Base station = access point (AP)
- Basic Service Set (BSS) (aka “cell”) contains:
  - In infrastructure mode: wireless hosts, base station
  - In ad hoc mode: hosts only

# 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

# 802.11 Host to AP Association: Which AP to Associate with?

- Hosts can associate with only one AP at a time
- Often receive signals from more than one AP
- How to select an access point is not specified in the standard
  - Left to device designers
- Usually host chooses an access point with the highest signal strength
  - Access point could be overloaded though

# 802.11 Multiple Access: Next Lecture

- Ethernet multiple access: Carrier Sense Multiple Access with Collision Detection
- 802.11 multiple access: Carrier Sense Multiple Access with Collision Avoidance

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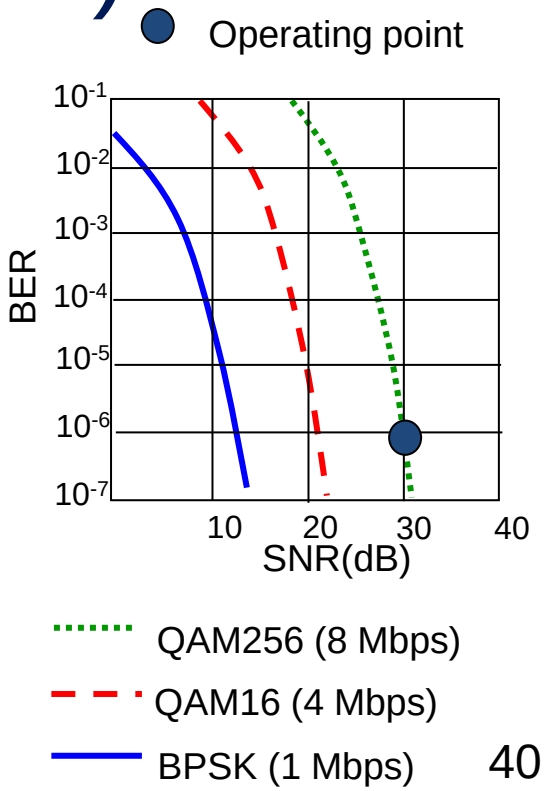
# 802.11 Advanced Features: Rate Adaptation (1/2)

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

# 802.11 Advanced Features: Rate Adaptation (2/2)

1. SNR decreases, BER increases as node moves away from base station
2. When BER becomes too high, switch to lower transmission rate but with lower BER

- Two frames in a row unacknowledged: drop the rate
- 10 frames in a row acknowledged: increase the rate



# 802.11 Advanced Features: 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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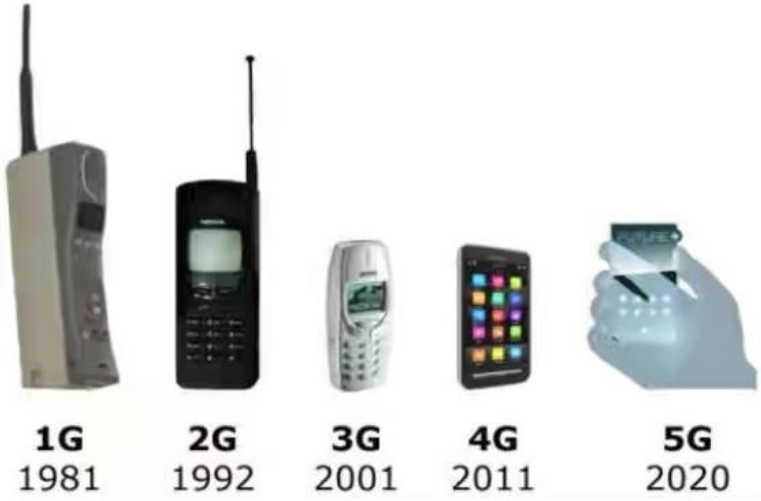
# Cellular Communications (1/2)



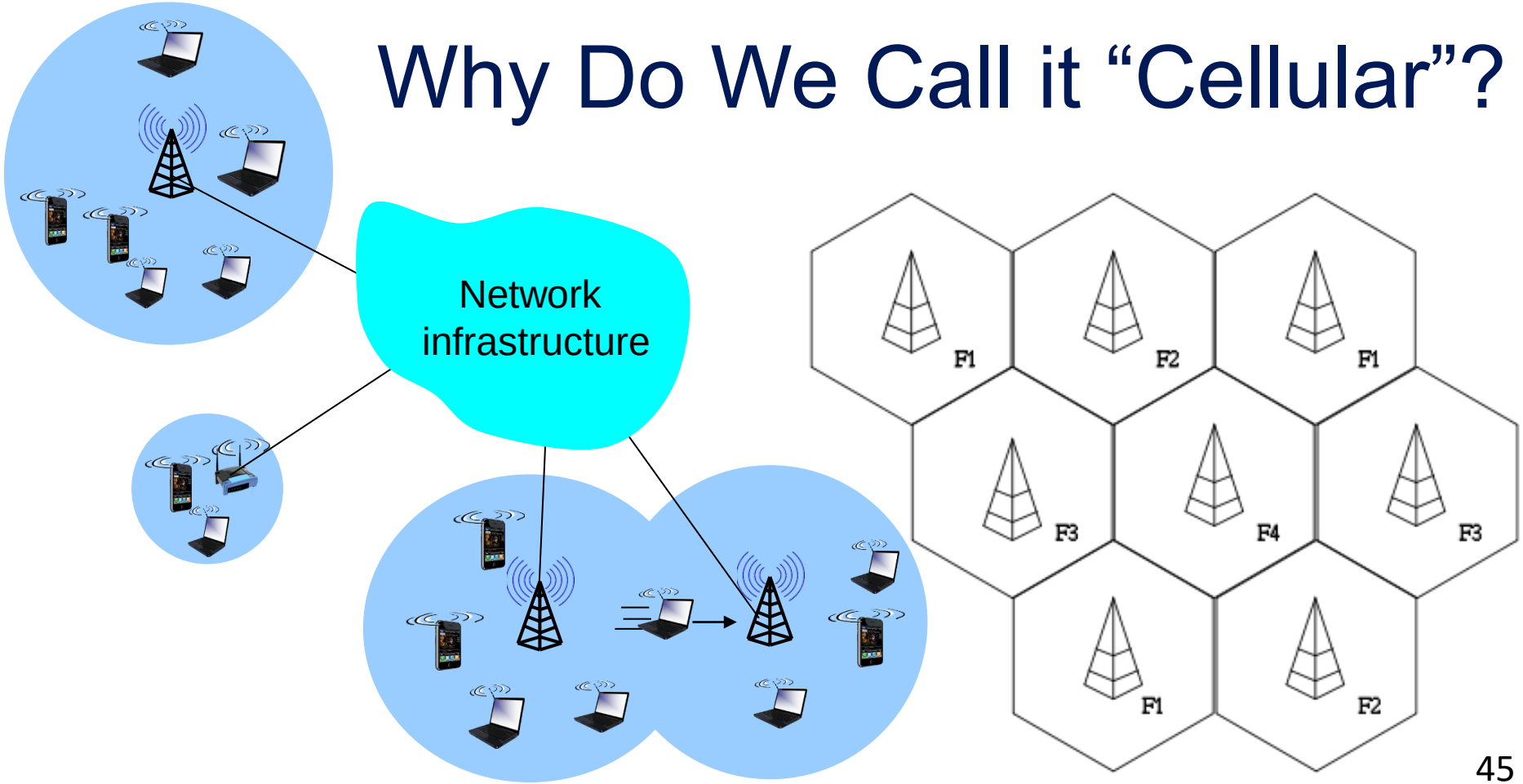

- Mobile devices communicate with a cellular base station
  - Traditionally: phones
  - Recently envisioned: low-end devices

- Started with supporting voice alone
- Now carry more data than voice

# Cellular Communications (2/2)

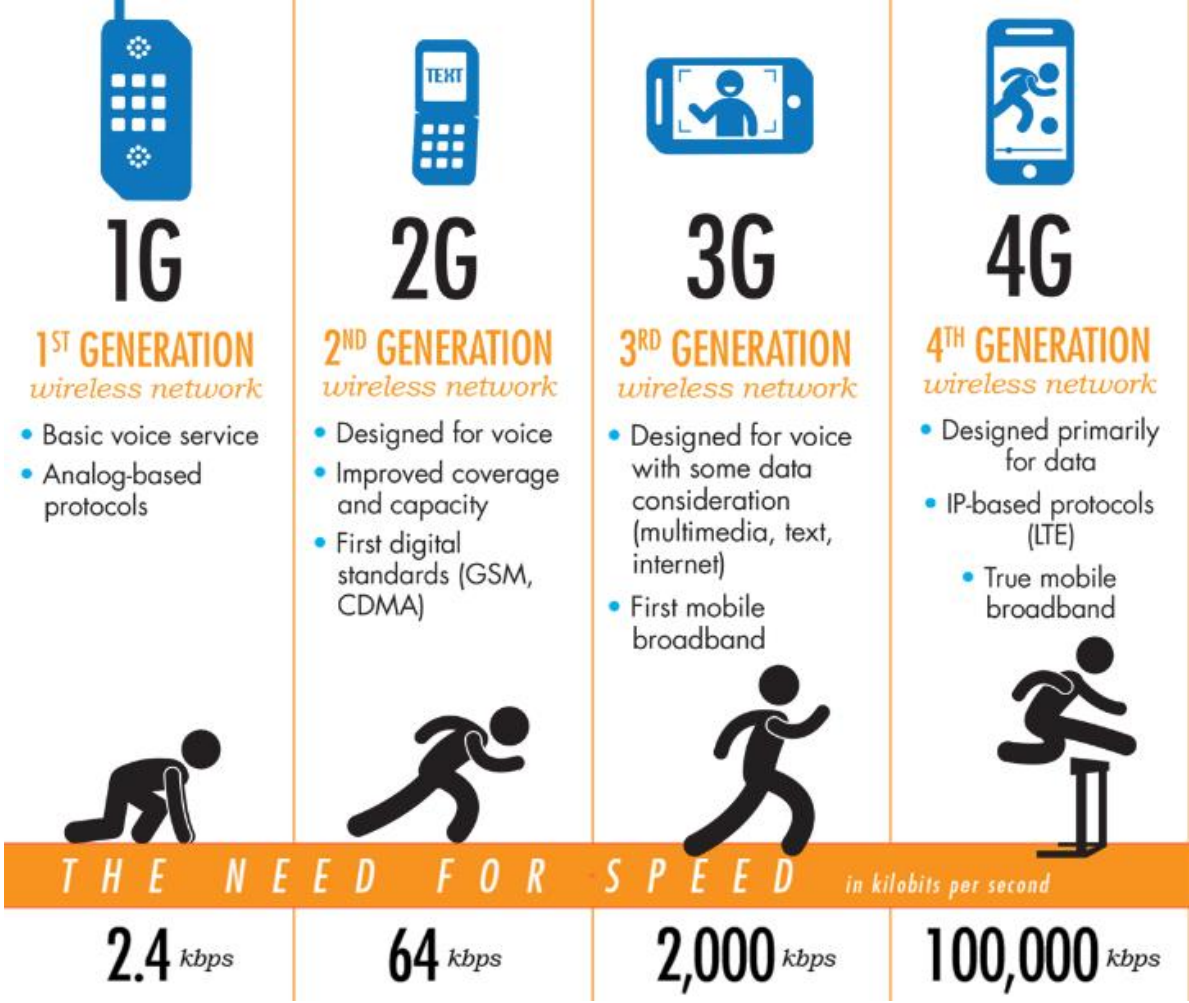
- Use licensed spectrum
  - Europe: mainly 900 MHz, 1800 MHz
  - North America: mainly 850 MHz, 1900 MHz
- Base stations form a wired network
- Phone is associated with one base station
- Leaving or entering a cell causes a handoff

# Why Do We Call it “Cellular”?

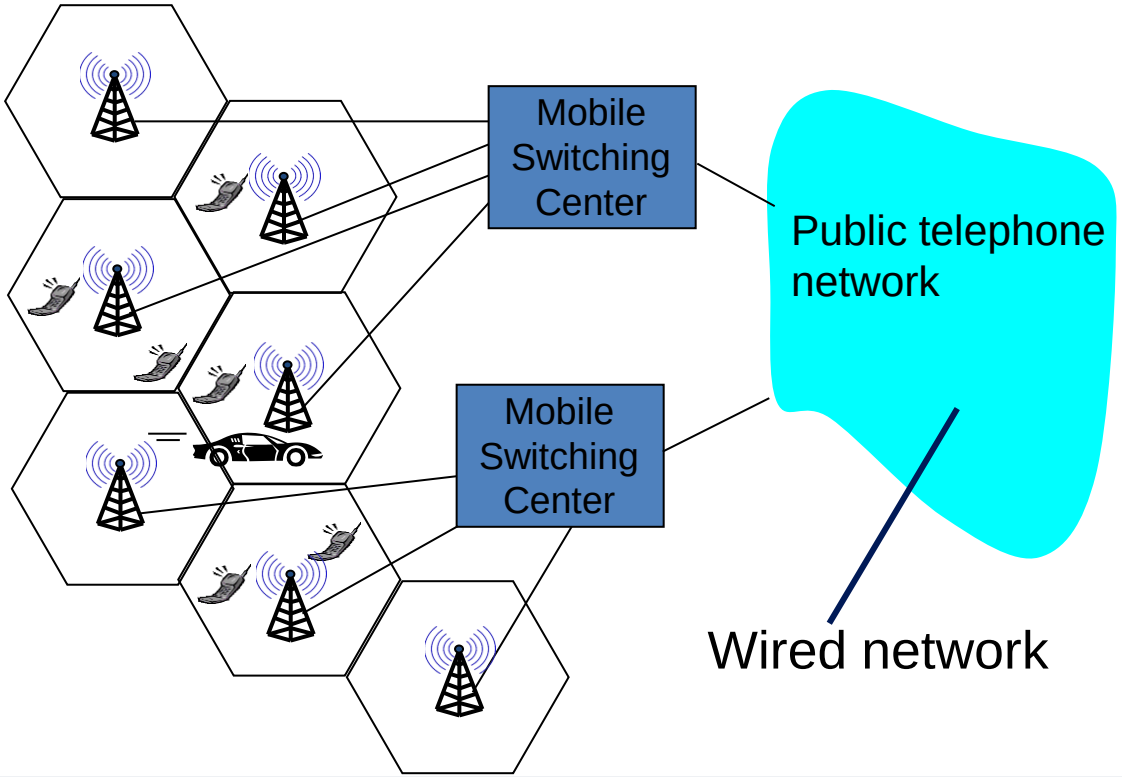


# Generations of Cellular Technology

- Define both last-hop and wired backbone behavior

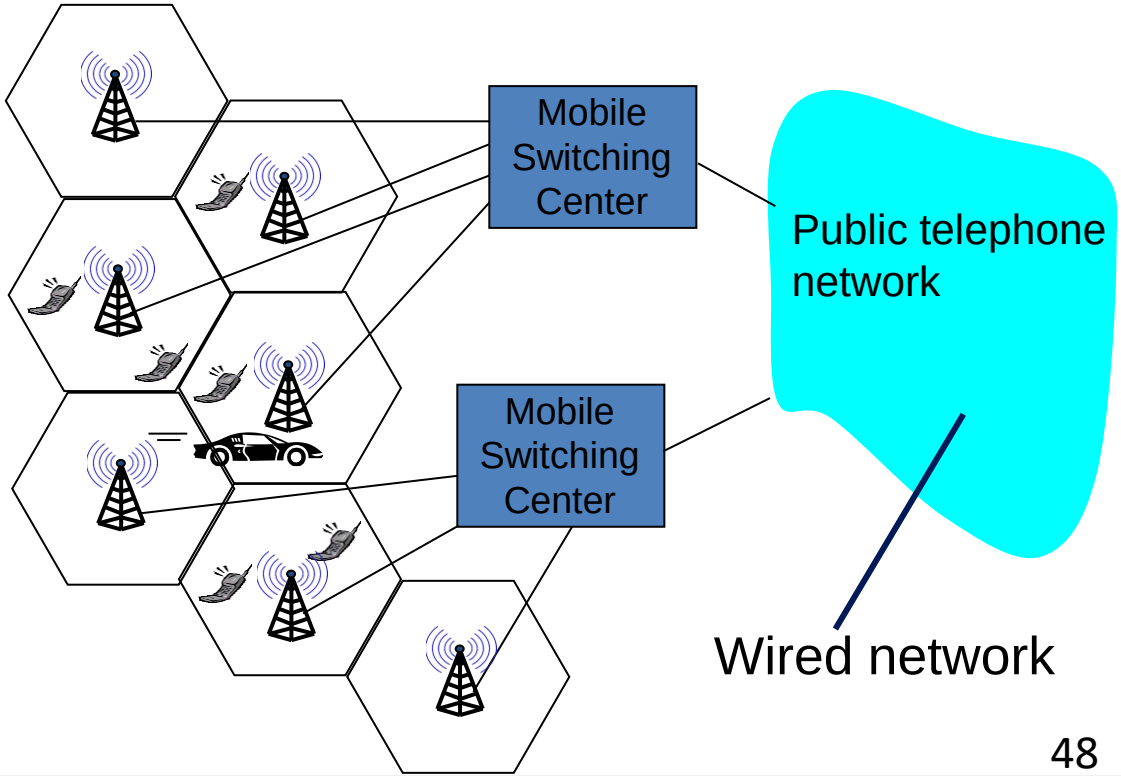



# Components of Cellular Network Architecture



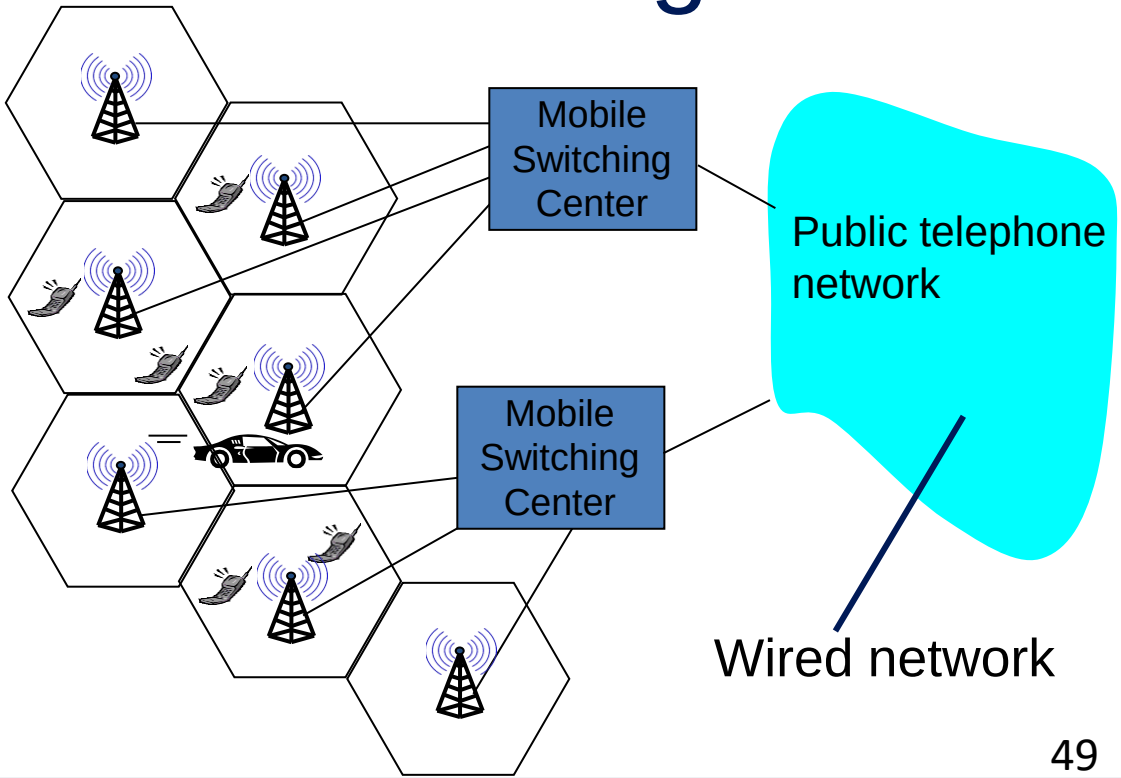
# Components of Cellular Network Architecture: Cells

- A cell covers a 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



# Components of Cellular Network Architecture: Mobile Switching Center

- Connects cells to wired telephone network
- Manages connection setup
- Handles mobility



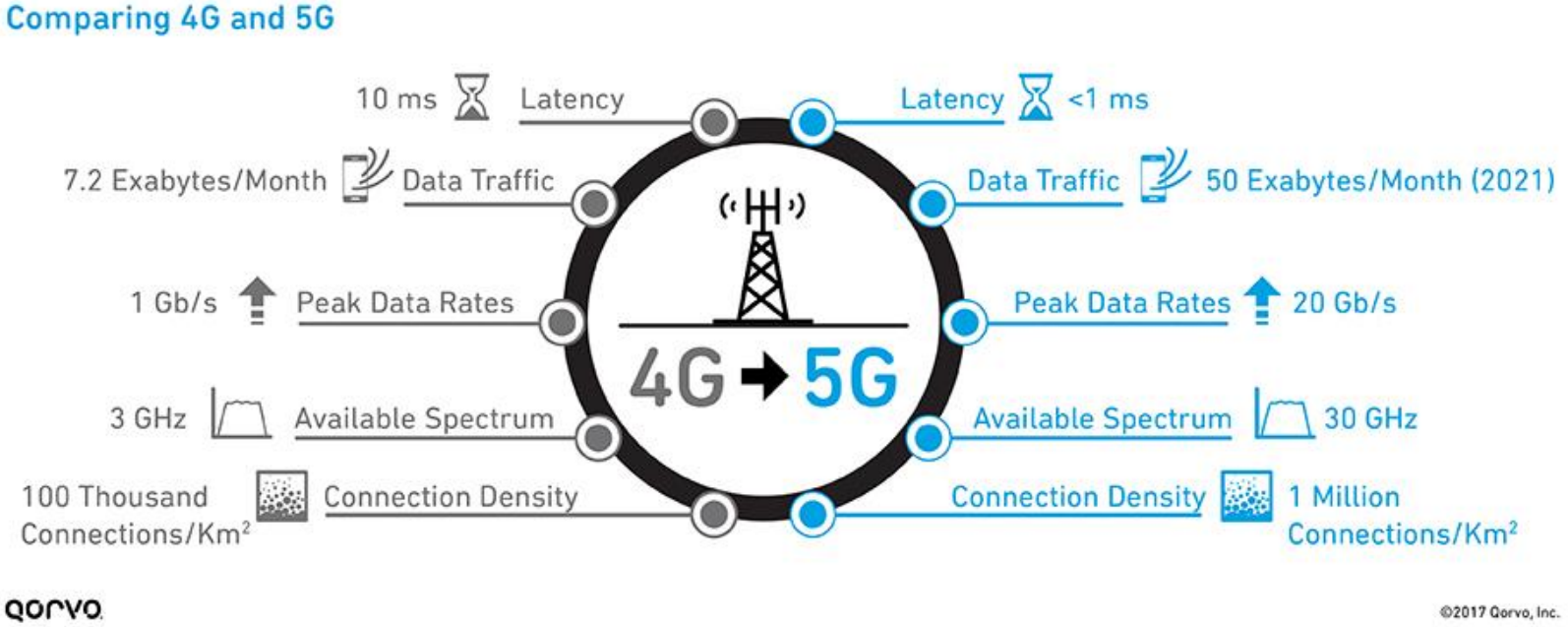
# 5G is Coming

- Several phone models already support 5G
  - Samsung Galaxy S10 5G
  - LG V50 THINQ
- Limited deployments ongoing world-wide
  - Limited regionally
  - Limited in capabilities
- Much more expected over the next couple of years
  - E.g., Germany expects 98% of households to have 5G access by 2022

# Current 5G Deployments in the US

| City \ Carrier | AT&T | Sprint | T-Mobile | Verizon |
|---|---|---|---|---|
| Atlanta | Live | Live | Live | Live |
| Boston | — | — | — | Planned |
| Charlotte | Live | — | — | Planned |
| Chicago | — | Live | — | Live |
| Cincinnati | — | — | — | Planned |
| Cleveland | — | — | — | Planned |
| Columbus | — | — | — | Planned |
| Dallas–Fort Worth | Live | Live | Planned | Planned |
| Denver | — | — | — | Live |
| Des Moines | — | — | — | Planned |
| Detroit | — | — | — | Live |
| Houston | Live | Live | — | Planned |
| Indianapolis | Live | — | — | Live |
| Jacksonville | Live | — | — | — |
| Kansas City | — | Live | — | Planned |
| Las Vegas | Live | — | Live | — |
| Little Rock | — | — | — | Planned |
| Los Angeles | Live | Live | Live | — |
| Louisville | Live | — | — | — |
| Memphis | — | — | — | Planned |
| Minneapolis–Saint Paul | — | — | — | Live |
| Nashville | Live | — | — | — |
| New Orleans | Live | — | — | — |
| New York | — | Live | Live | — |
| Oklahoma City | Live | — | — | — |
| Orlando | Live | — | — | — |
| Phoenix | — | Live | — | Live |
| Providence | — | — | — | Live |
| Raleigh | Live | — | — | — |
| Salt Lake City | — | — | — | Planned |
| San Antonio | Live | — | — | — |
| San Diego | Live | — | — | Planned |
| San Francisco | Live | — | — | — |
| San Jose | Live | — | — | — |
| Tampa | Live | — | — | — |
| Waco | Live | — | — | — |
| Washington | — | Live | — | Live |

# 5G Marketing



# 5G Requirements (1/2)

- 1 ms end-to-end round-trip latency
  - Compared to ~ 10 ms with 4G
- 1-10 Gbps connections to mobile hosts
  - 4G Verizon: 12 Mbps downlink, 5 Mbps uplink
  - Peak downlink ~ 50 Mbps: 20 – 200x slower than 4G
- 1000x bandwidth per unit area

# 5G Requirements (2/2)

- 10-100x number of connected devices
- (Perception of) 99.999% availability and 100% coverage
- First cellular generation designed for a diverse set of connected devices
  - Moving beyond a human browsing web on a smart phone
  - E.g., latency + reliability + number of connected devices: control applications, connected cars, connected sensors
  - E.g., latency + bandwidth: augmented and virtual reality

# 5G: Frequency Bands Used

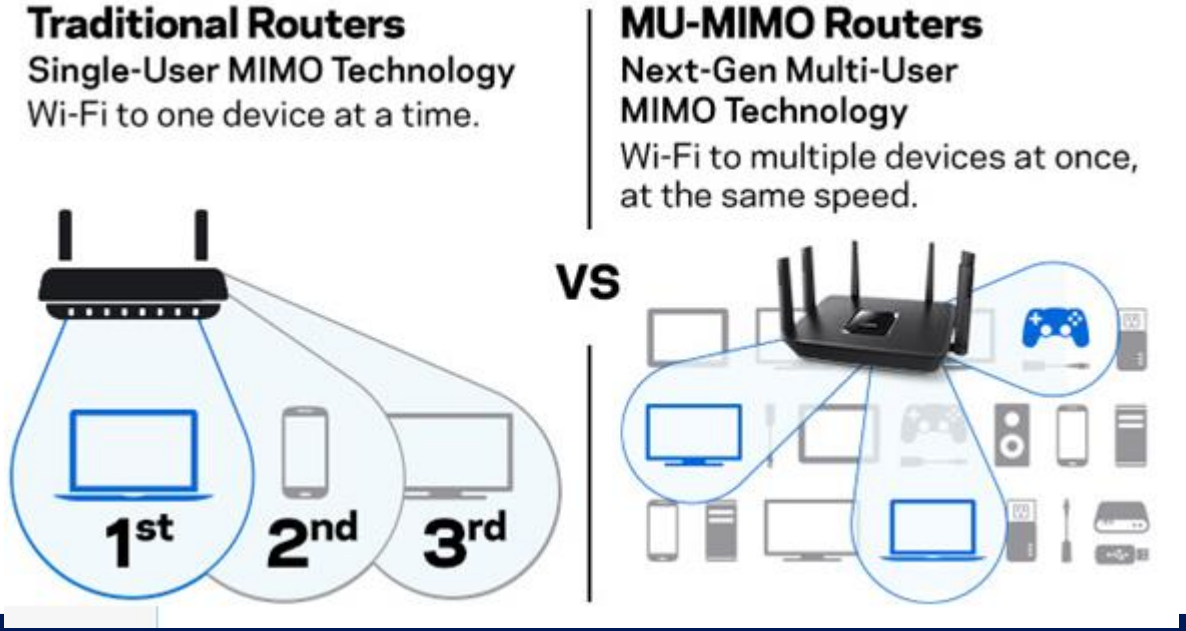
- Two different frequency bands
- < 6 GHz: typically 3.5 GHz
  - Behavior similar to previous cellular technology
- > 24 GHz: mmWave frequencies
  - In USA: 28 GHz Verizon, 38 GHz AT&T
  - Can use up to 300 GHz
  - Support *1,000 more devices* per meter than 4G

# mmWave Communication Requirements

- Need base stations every 10s – 100s of meters
  - ➢*Small cells*: femtocells, picocells
- Cannot easily go through solid objects
  - ➢Walls, trees, humans are problematic

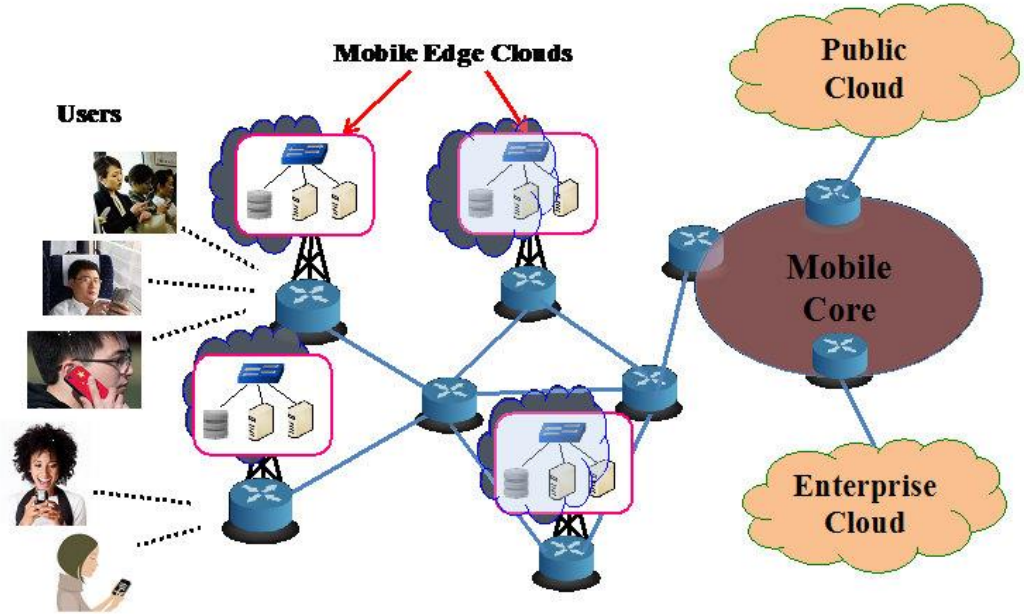
# 5G Technology Enhancements (1/2)

- Multiple antennas (Massive MIMO)
- Beamforming to direct waves at a target



# 5G Technology Enhancements (2/2)

- Edge computing
  - Computing capabilities attached to each base station



# Lecture Summary

- Wireless network taxonomy
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# Next Lecture

- Switching technologies