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

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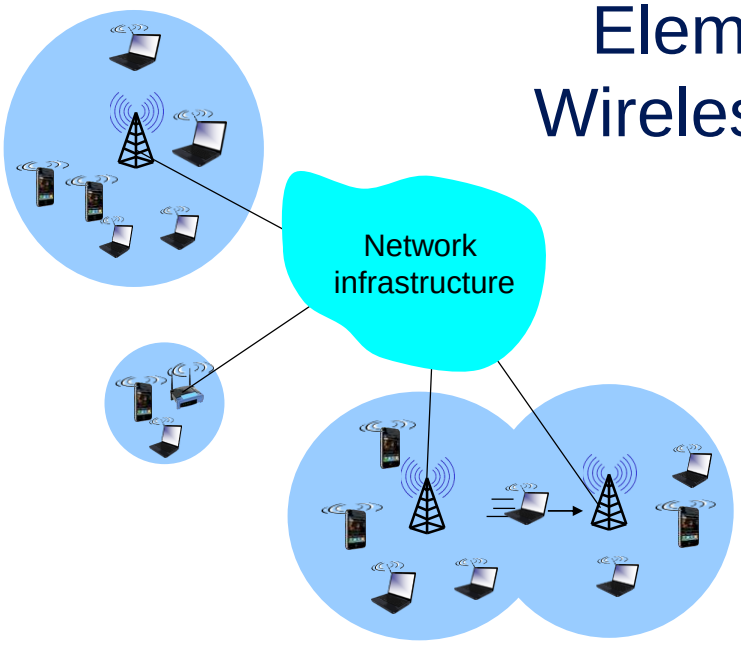
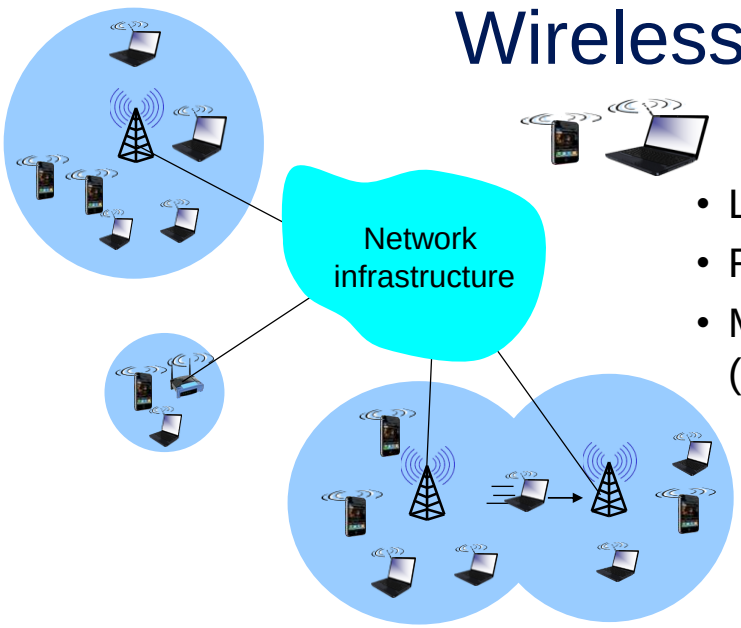
Lecture Outline

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

Elements of a Wireless Network

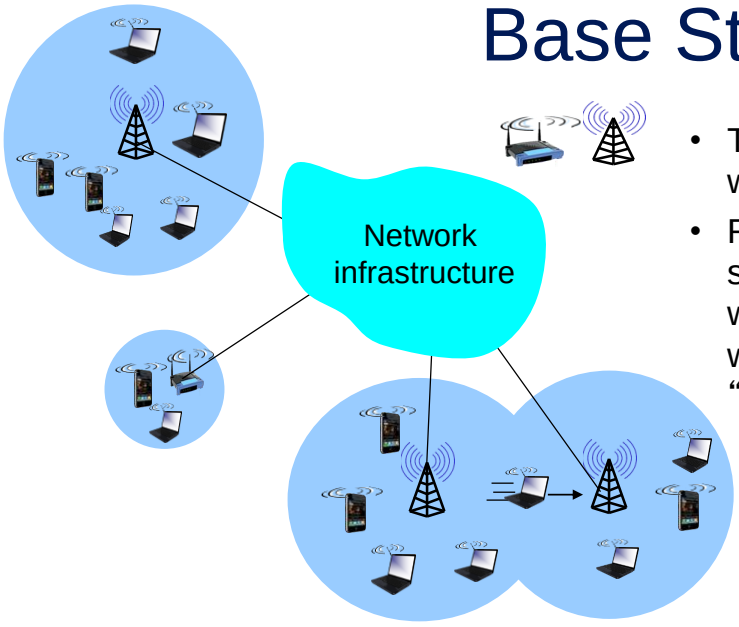


Wireless Hosts



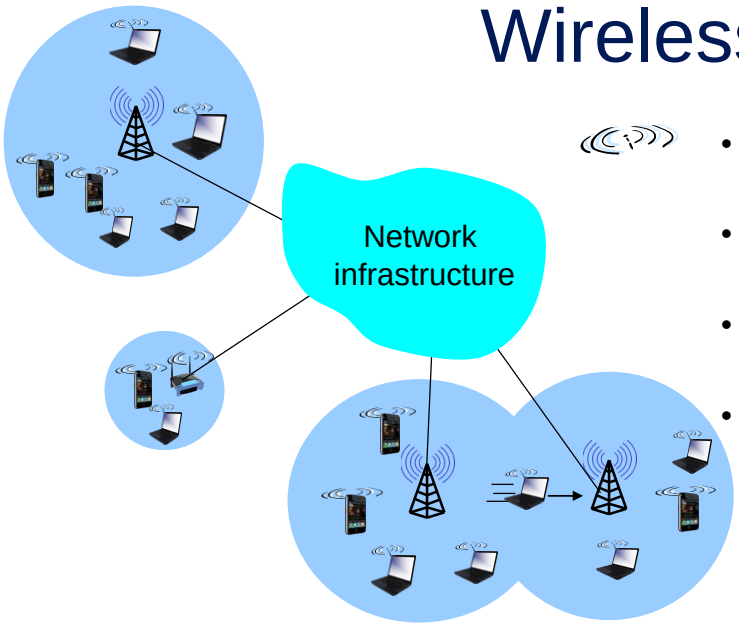
- Laptop, smartphone
- Run applications
- May be stationary (non-mobile) or mobile
  - Wireless does *not* always mean mobility

Base Stations



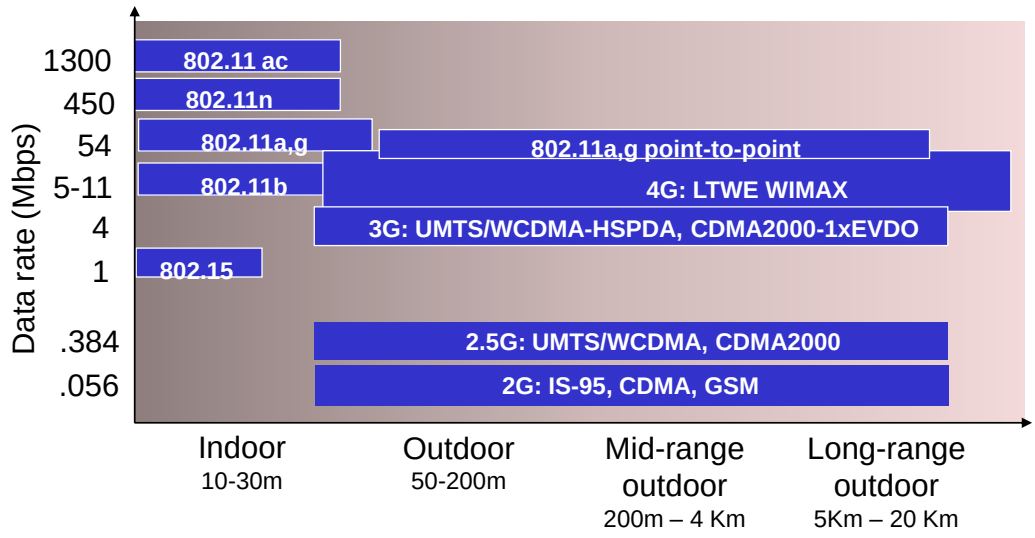
- Typically connected to wired network
- Relay - responsible for sending packets between wired network and wireless host(s) in its "area"
  - E.g., cell towers, 802.11 access points

Wireless Link

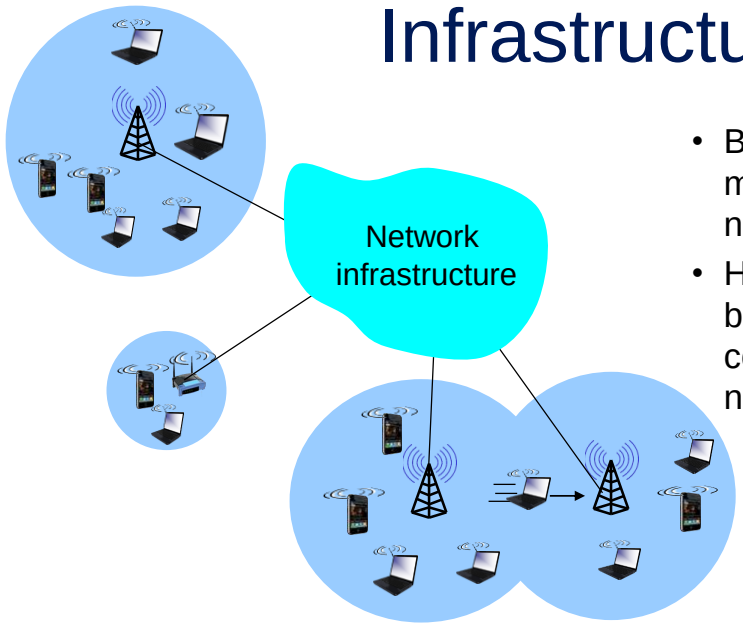


- Typically used to connect mobile(s) to base station
- Also used as backbone link
- Multiple access protocol coordinates link access
- Various data rates, transmission distances

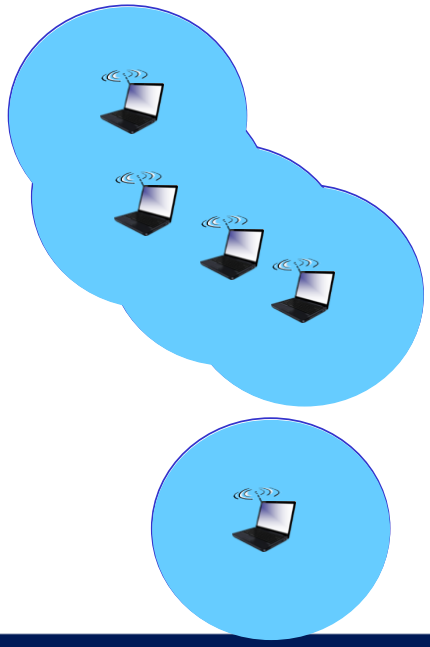
Characteristics of Selected Wireless Links



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

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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

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Lecture Outline

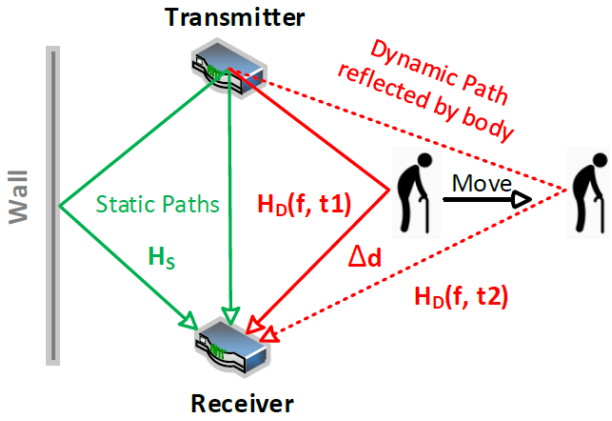
- Wireless network taxonomy
- **Wireless link characteristics**
- CDMA
- 802.11: an introduction
- 802.11: advanced features
- Cellular communications

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

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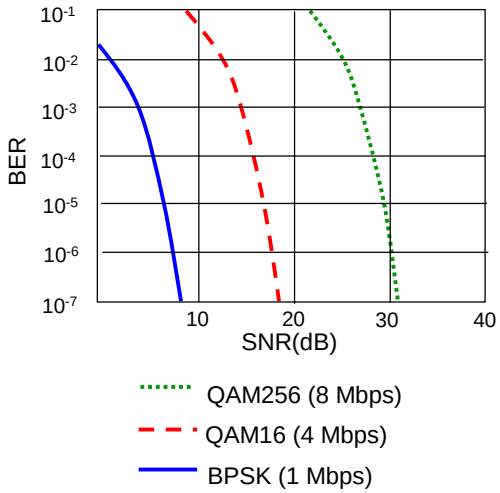
Bit Error Rate and Signal to Noise Ratio Revisited

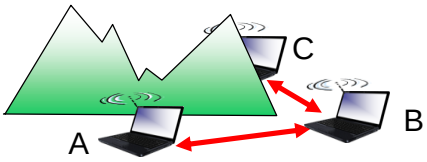
- BER: bit error rate
- SNR: signal-to-noise ratio
  - ➢ Larger SNR: easier to extract signal from noise
    - A good thing
  - ➢ Can improve SNR by increasing transmission power
    - Disadvantages: power consumption, interference
    - There are regulatory limits on how much transmission power can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

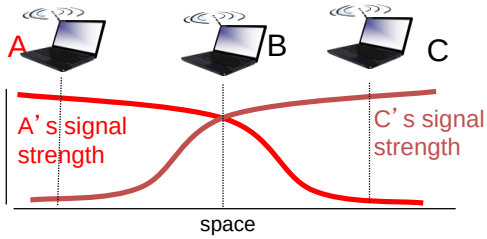


Node "Visibility" Complications



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

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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

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Quiz 2 Answers

Lecture Outline

- Wireless network taxonomy
- Wireless link characteristics
- **CDMA**
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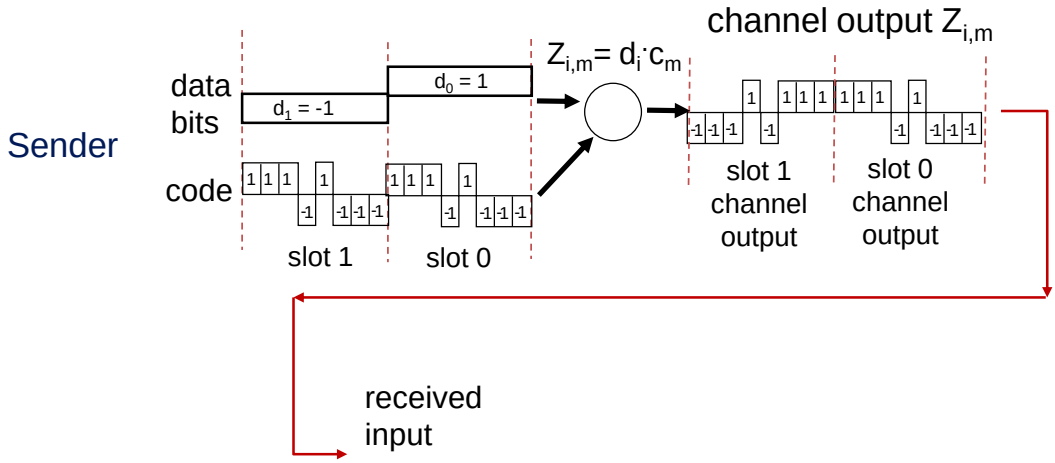
Code Division Multiple Access (CDMA) (1/2)

- 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")

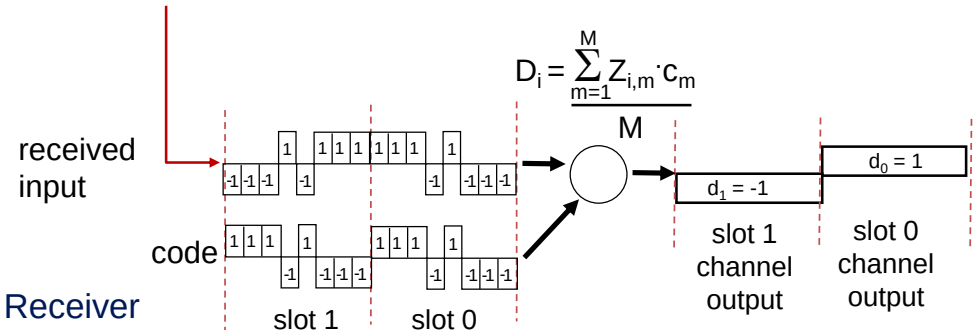
Code Division Multiple Access (CDMA) (2/2)

- *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

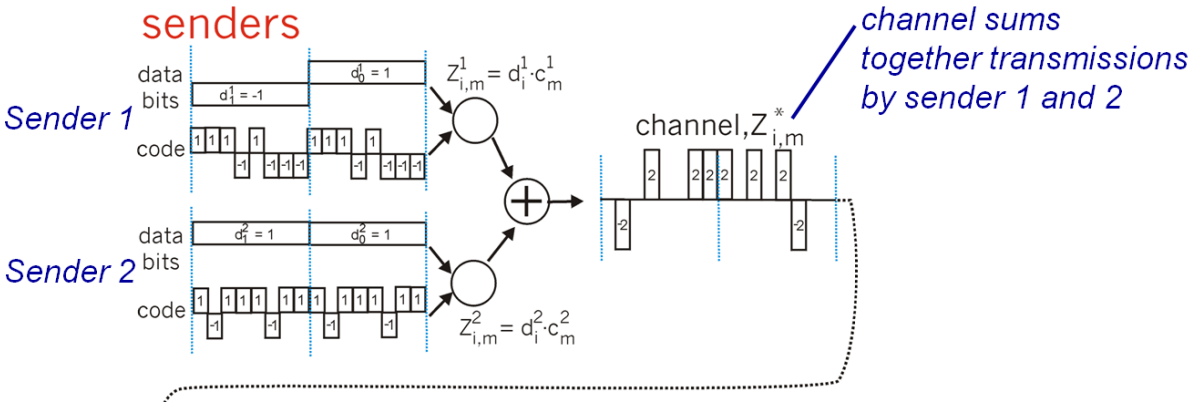


CDMA Encode/Decode: Receiver

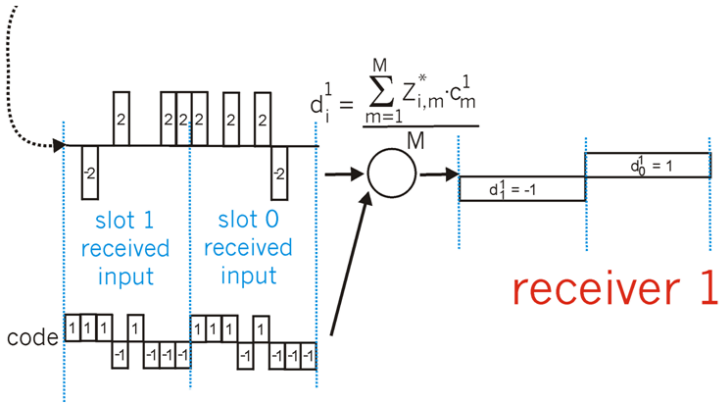


CDMA: Two-sender Interference (1/2)

- 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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- 802.11: advanced features
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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

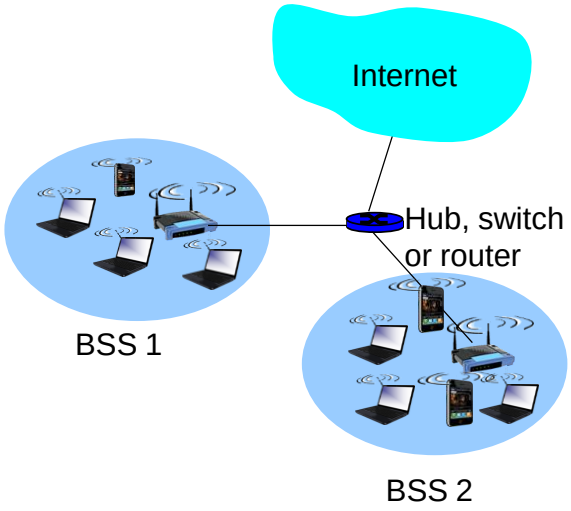
IEEE 802.11: Common Variants (2/2)

- 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

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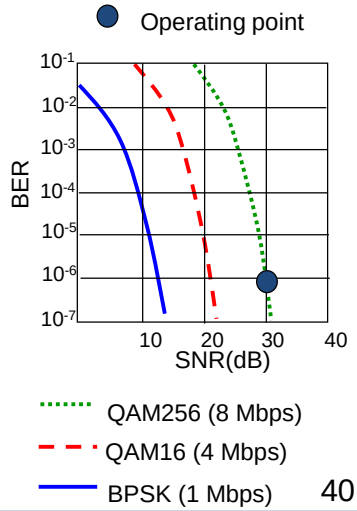
802.11 Advanced Features: Rate Adaptation (2/2)

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



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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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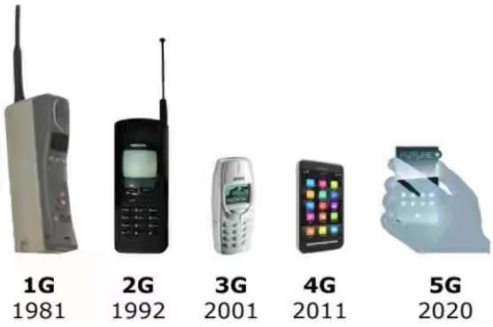
Cellular Communications (1/2)



- 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

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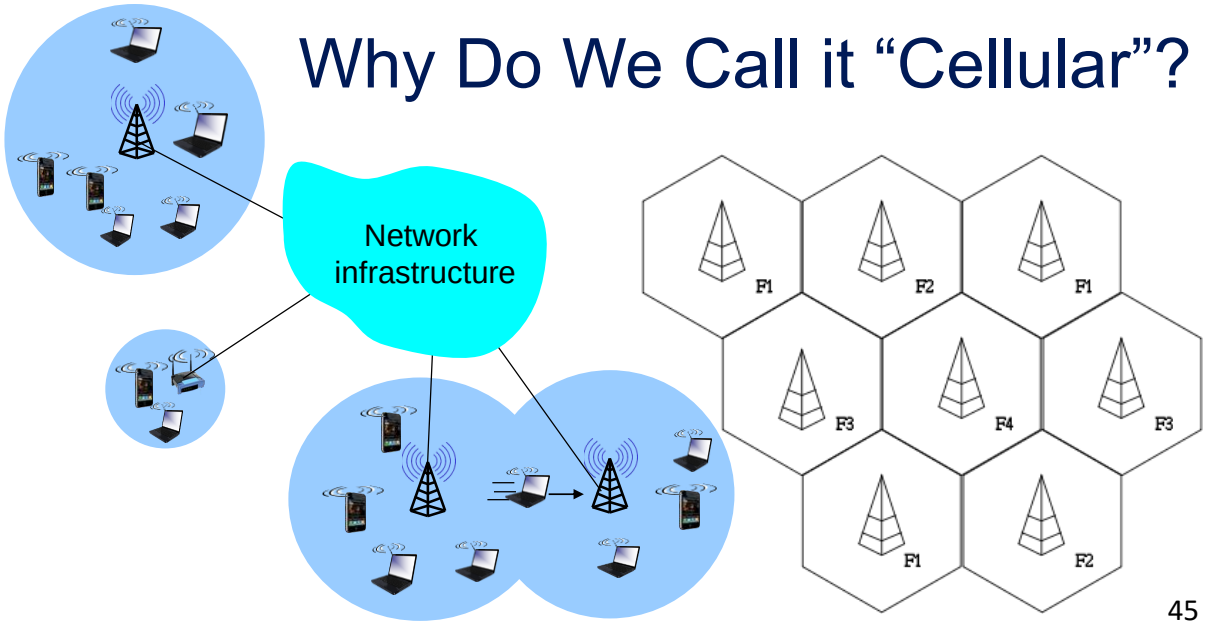
Cellular Communications (2/2)

- 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"?



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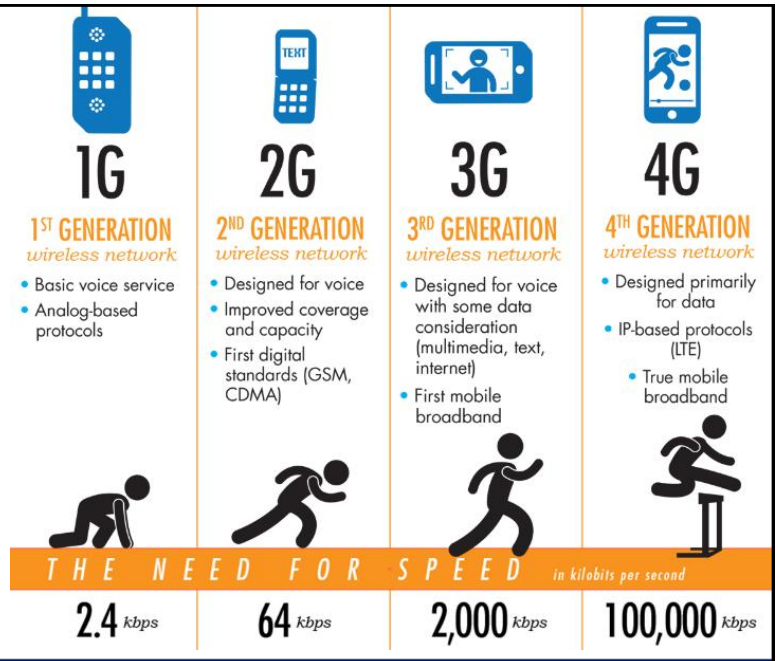
Generations of Cellular Technology

- Define both last-hop and wired backbone behavior



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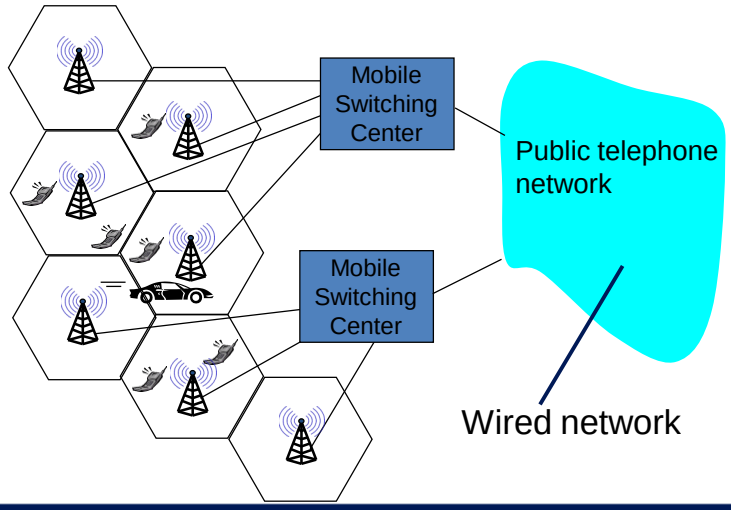
Components of Cellular Network Architecture



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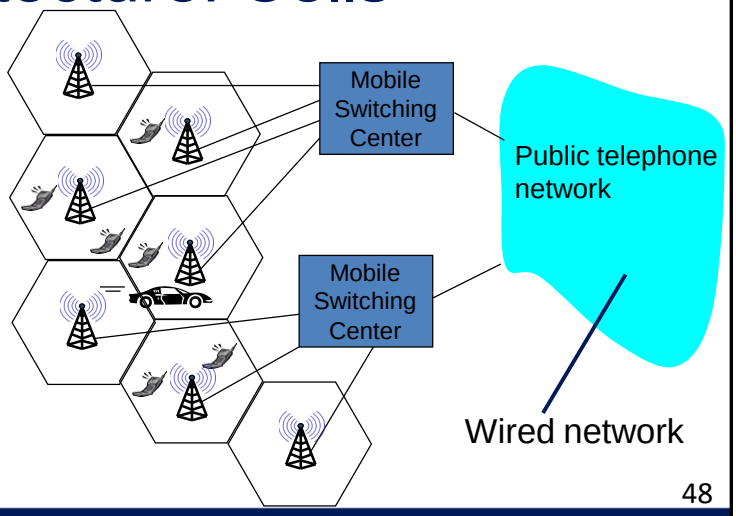
Components of Cellular Network Architecture: Cells

- 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



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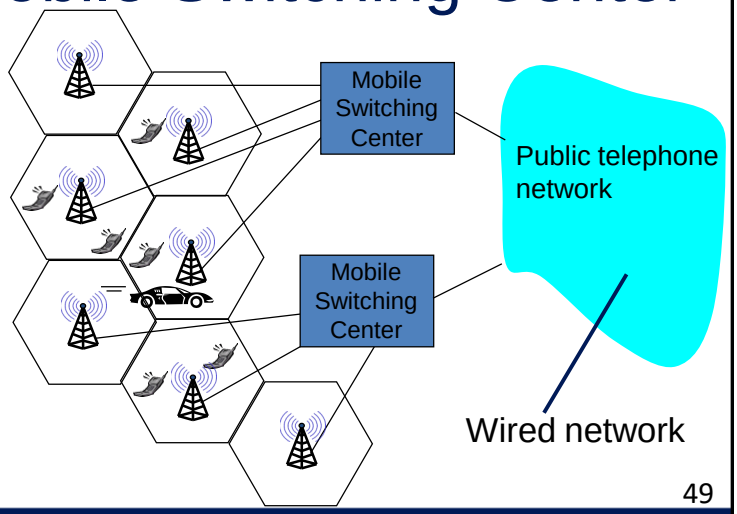
Components of Cellular Network Architecture: Mobile Switching Center

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



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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

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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

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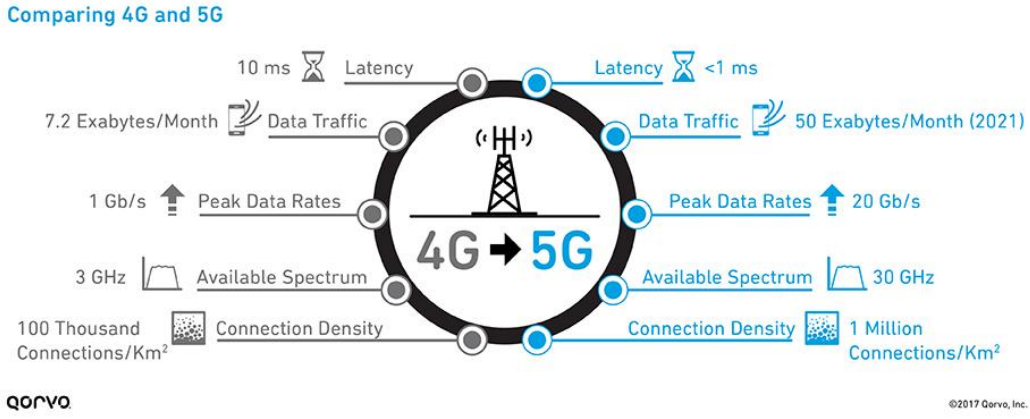
5G Marketing



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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 5G
- 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

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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

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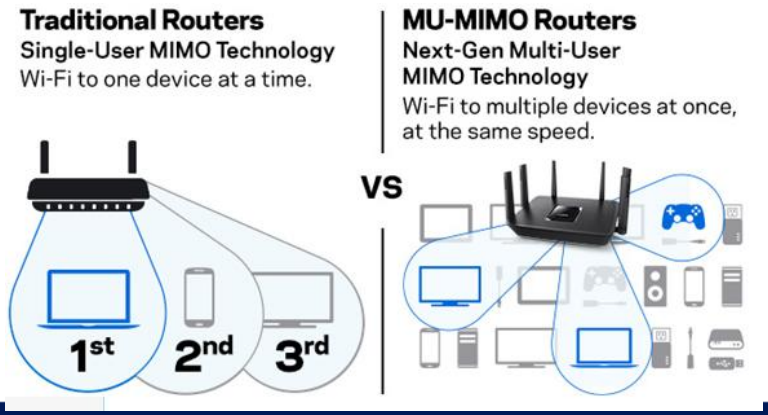
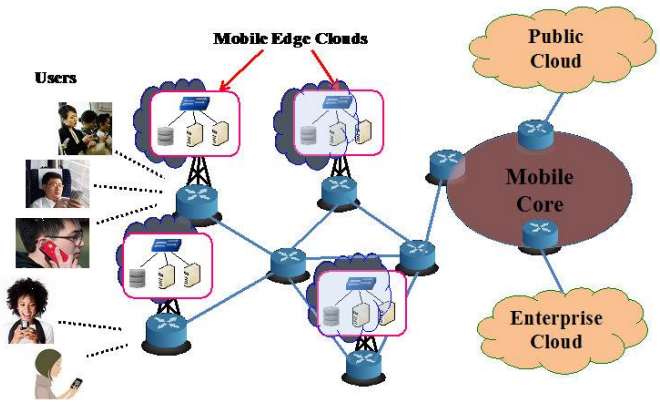
5G Technology Enhancements (1/2)

- 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