Lecture 03
Data Link Layer

CS433 – Wireless Protocols for IoT

Branden Ghena – Spring 2026

Materials in collaboration with
Pat Pannuto (UCSD) and Brad Campbell (UVA)

Administrivia

- Hw: Background
  - Goal: brush up on some embedded systems and networks background
  - Due tonight. Don't waste a slip day on this
  - Submit on Gradescope

- Lab: Wireshark
  - Goal: familiarize yourself with Wireshark
    - Install it, do some basic scanning, explore a little

  - See you all in lab tomorrow!
    - Friday 11:00-12:30 pm in Frances Searle 3320

Partnership survey

- Labs (after this first one) will be in groups of three

- I posted a form for recording groups on Ed Discussion
  - You can also submit without a full group, and I’ll help match!

- Tomorrow in labs, you can all do a little networking to find people you might want to work with

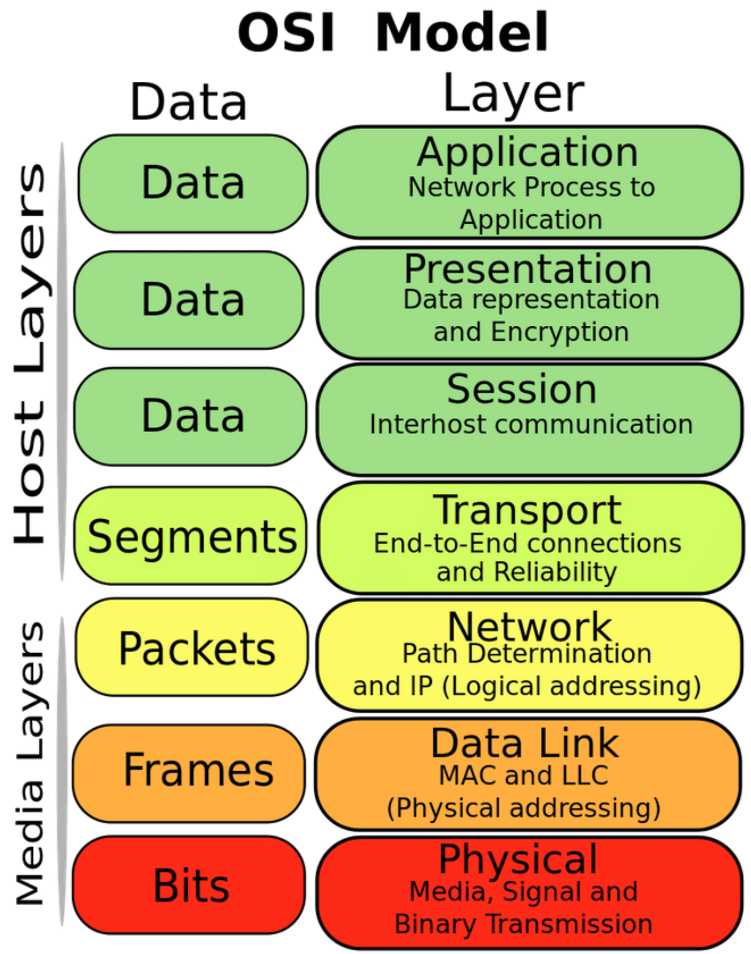
Today's Goals

- Finish Physical Layer topics
- Overview of concerns for the Data link layer
  - Speak the "lingo" of wireless communication
  - Present technology aspects that we will return to in specific protocols
- Describe Medium Access Control mechanisms
- If we have time: BLE Intro and Background

Review: OSI model of communication layers

- Transport
  - Sending data between applications
  - TCP and UDP
- Network
  - Sending data between networked computers
  - IP
- Data Link
  - Sending collections of bits
  - Ethernet, WiFi
- Physical
  - Sending individual bits
  - Ethernet, WiFi

Open Systems Interconnection (OSI)



Review: A programmer's view of the internet

1. Hosts are mapped to a set of 32-bit **IP addresses**
    - 129.105.7.30

2. The set of IP addresses is mapped to a set of identifiers called Internet **domain names**
    - 129.105.7.30 is mapped to moore.wot.eecs.northwestern.edu

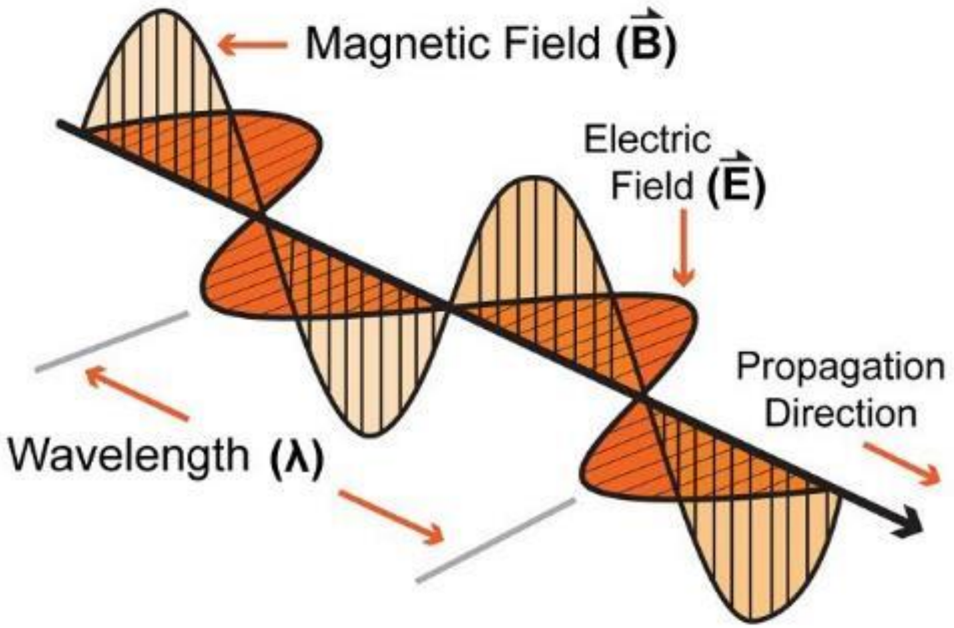
3. A process on one Internet host can communicate with a process on another Internet host over a **connection**

Review: Signal qualities

1. Signal strength
   - The amount of energy transmitted/received

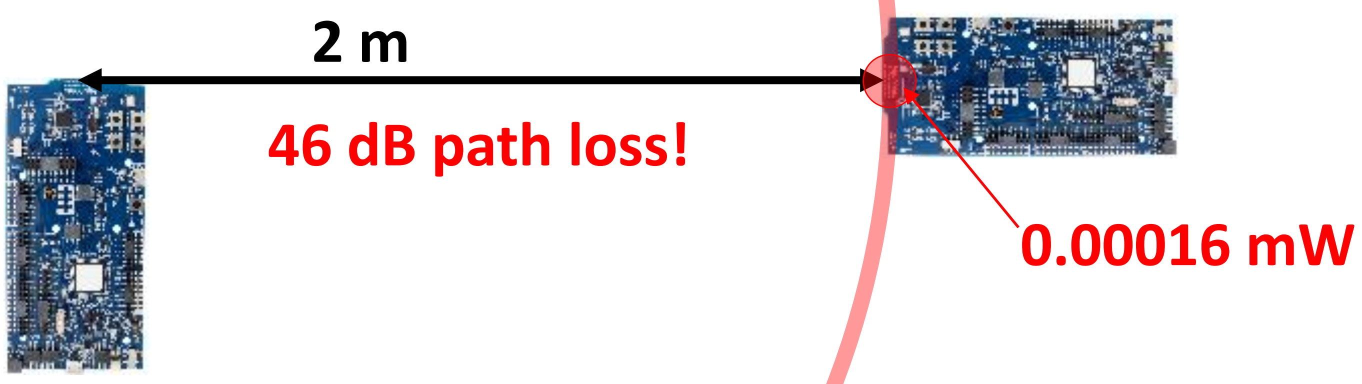
2. Signal frequency and bandwidth
   - Which “channel” the signal is sent on

3. Signal modulation
   - How data is encoded in the signal



Review: Signal strength

- We will use the nrf52840 in lab:
  - Max BLE transmit power for nRF52840: 8 dBm (6.31 mW)
  - Min BLE receive sensitivity for nRF52840: -95 dBm (316.2 fW)



Big Idea: many RF factors are interconnected

- Energy, Distance, Throughput, and Reliability are all interconnected in communication

- Protocols make choices of some and get the results on the others

- To get more distance, choose one or more:
  - Increase energy
  - Communicate slower
  - Accept a higher error rate

Outline

- Physical Layer
  - Overview
  - Signal Strength
  - **Signal Frequency and Bandwidth**
  - Signal Modulation
- Data Link Layer
- BLE Background

Signal qualities

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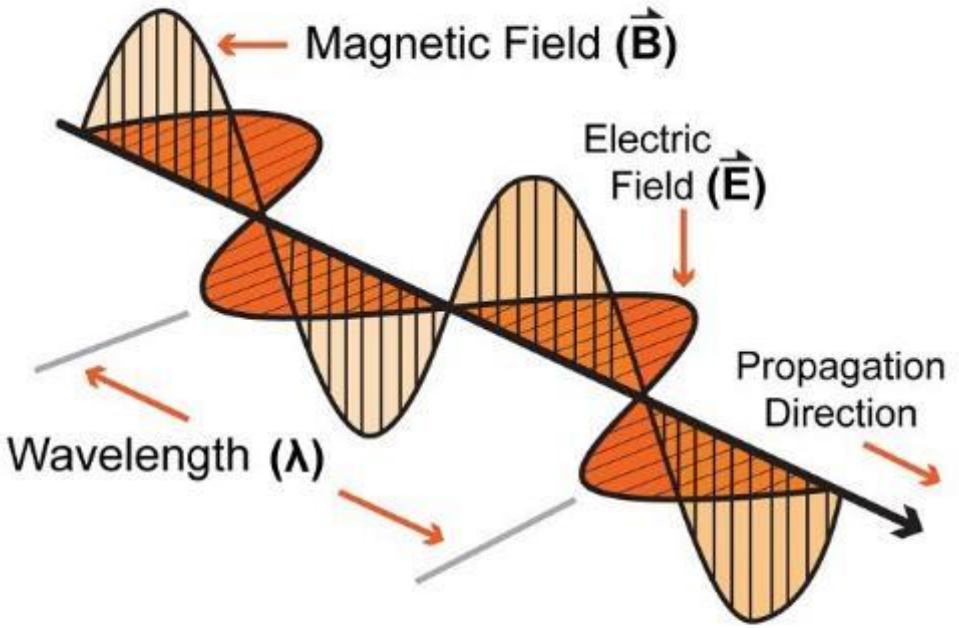
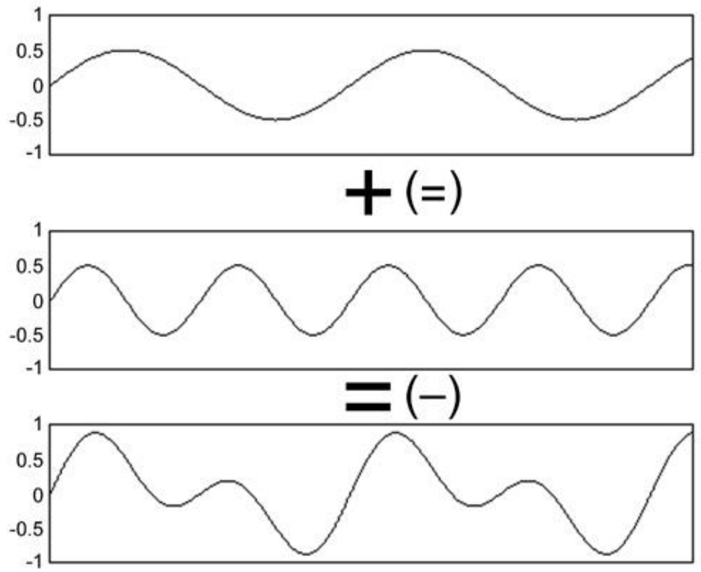
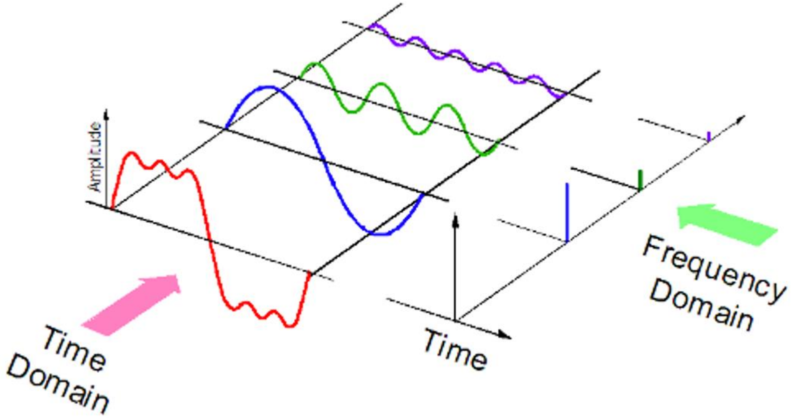


Sum of sinusoids can be reversed

- RF signals are fundamentally sinusoids of electromagnetic energy

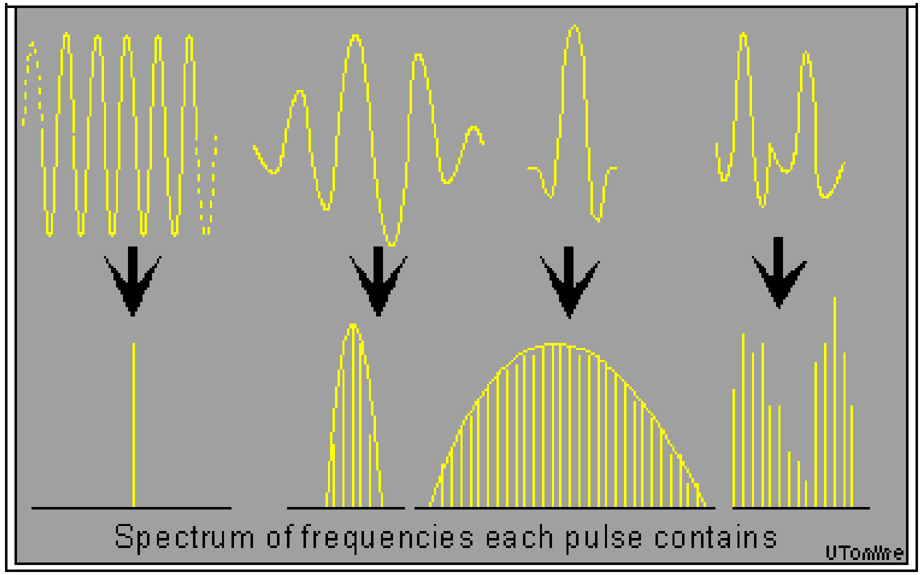
- Sinusoids at different frequencies can be combined and pulled apart again later
  - Particularly, it's relatively easy for hardware to determine if there's energy present on a given frequency
  - Although very close frequencies might be difficult to disentangle





Complex waveforms have a center frequency and a width

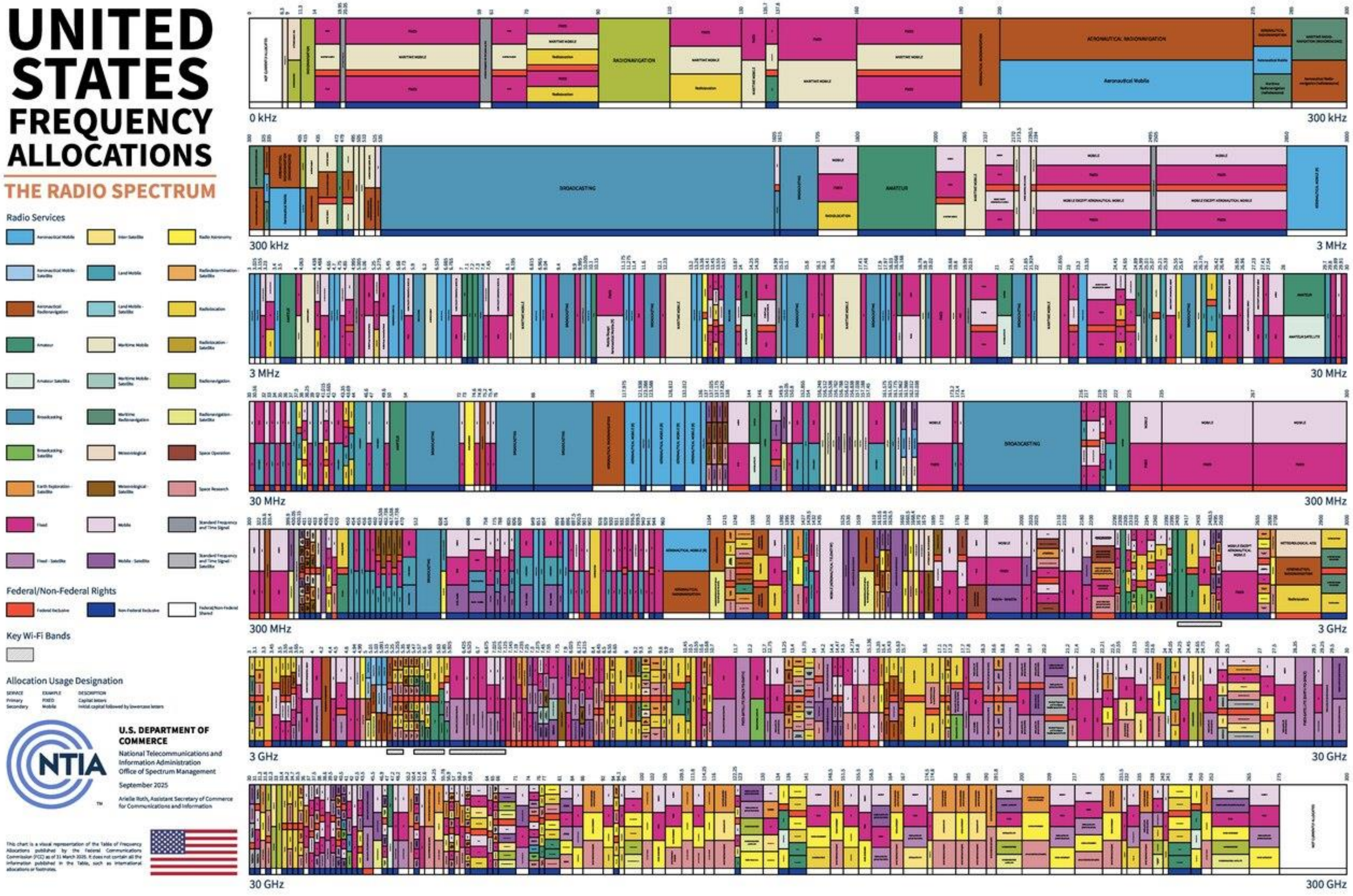
- A pure sinusoid is energy at exactly one frequency
  - But no data



- A messy sinusoid with data layered on top of it has nearby energy
  - There's a center of the signal energy
  - Plus some amount of width, which depends on how complicated the data layered on top is and what the data rate is

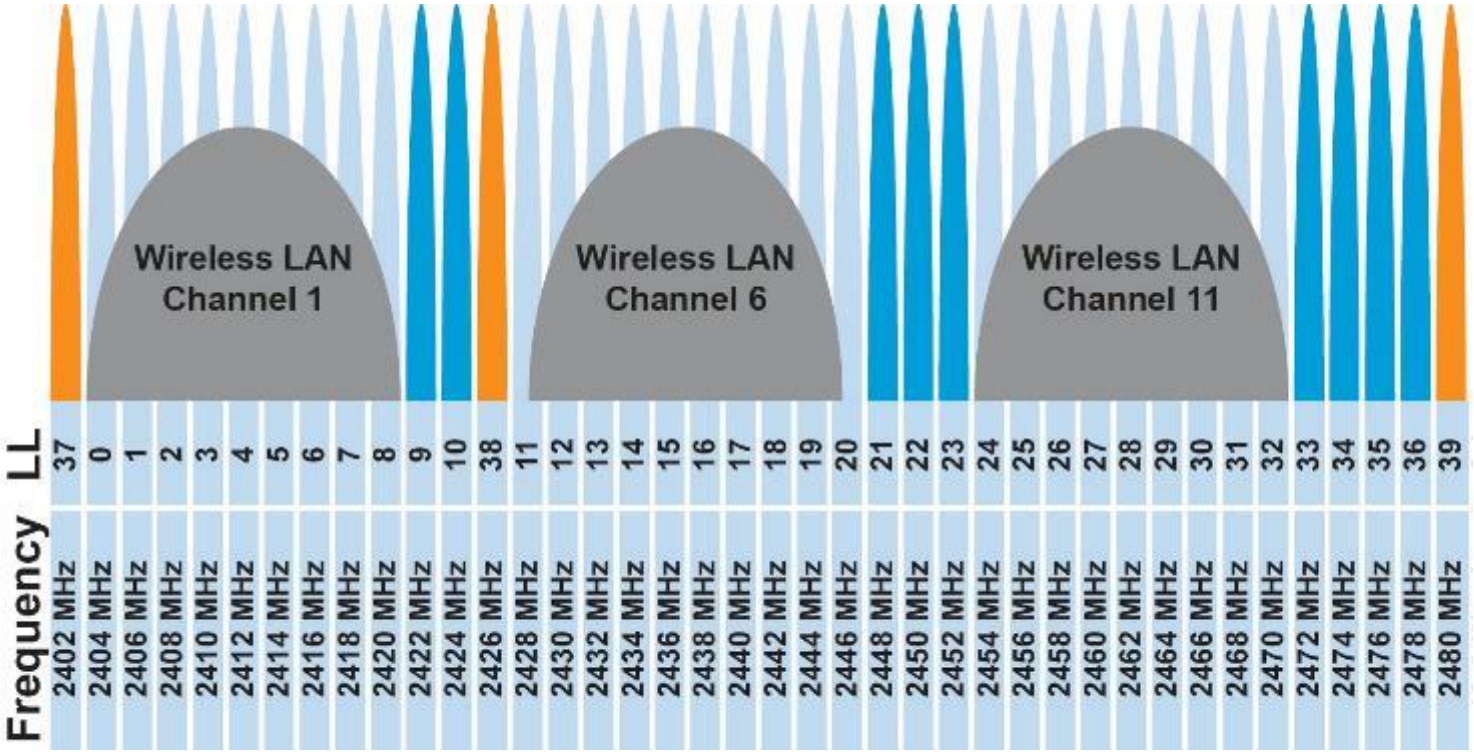
  - Adding data on top of a signal inherently sums sinusoids, using bandwidth

Wireless spectrum is allocated to specific uses



Unlicensed bands are where IoT thrives

- 902 MHz – 928 MHz
  - LPWANs
- 2.4 GHz to 2.5 GHz
  - WiFi, BLE, Thread
- 5 GHz
  - Faster WiFi



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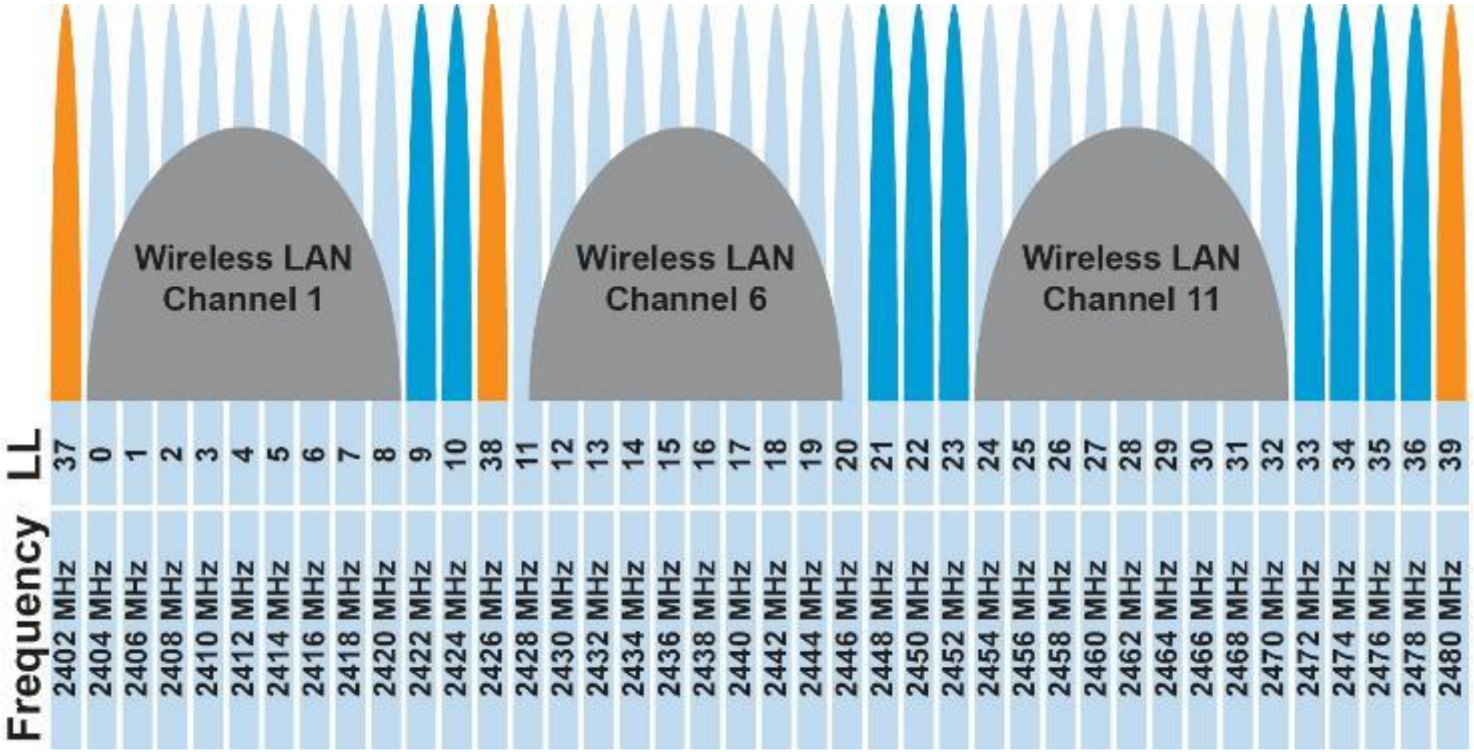

- Cellular uses licensed bands at great cost
  - **Why?**

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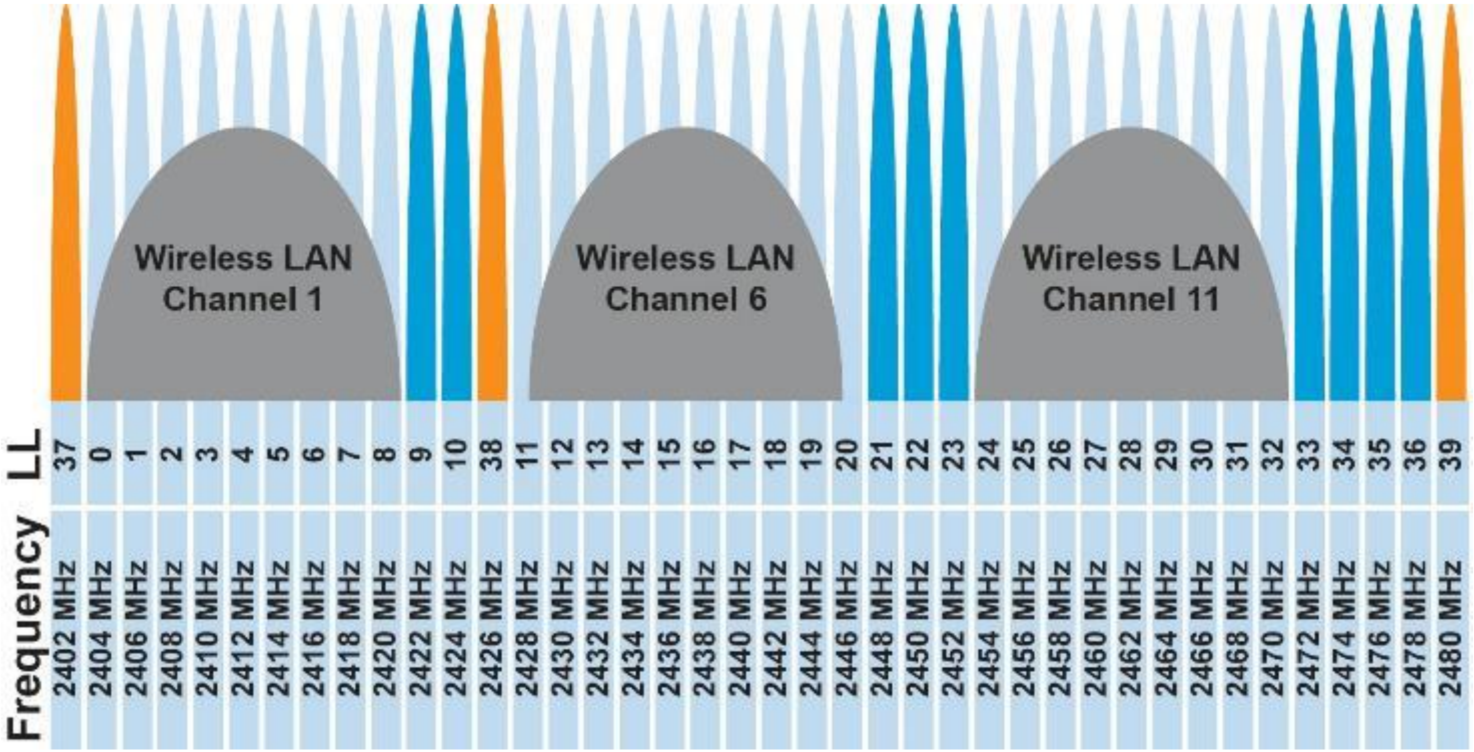
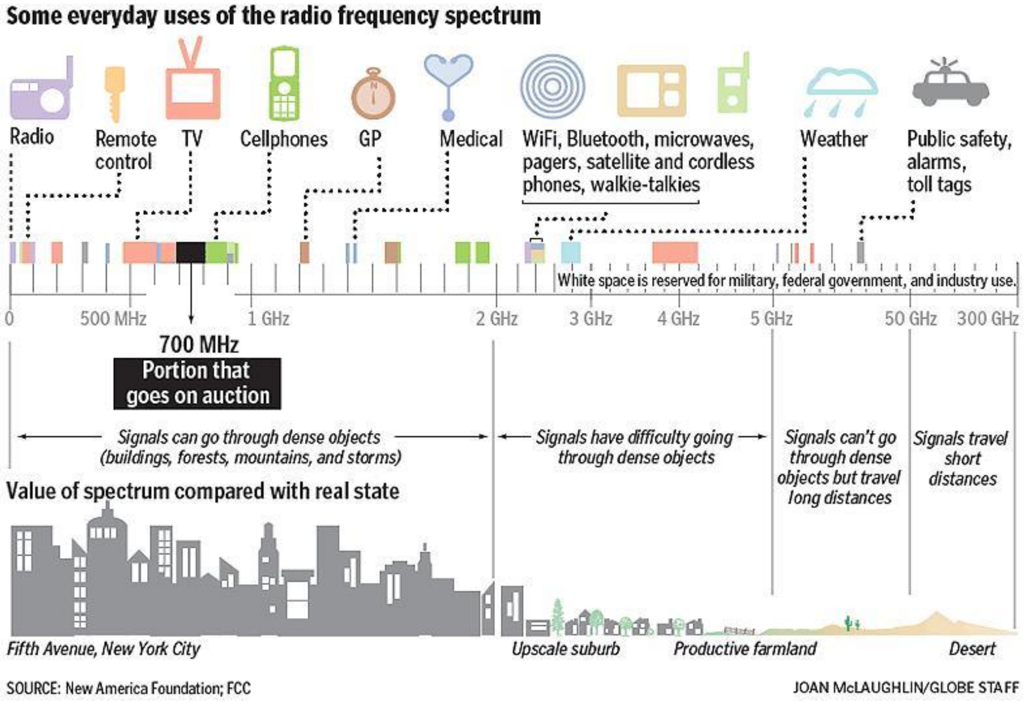


- 5 GHz
  - Faster WiFi
- Cellular uses licensed bands at great cost
  - **Why? No interference from other users**

Wireless spectrum is limited…and valuable

- FCC auctions blocks in US

- August 2020
  - 70 MHz in 3.5 GHz spectrum
  - $4.6 billion
- February 2021
  - 300 MHz in 3.7-9 GHz spectrum
  - $81 billion



FCC NEWS from the Federal Communications Commission

Media Contact:
Will Wiquist, (202) 418-0509
will.wiquist@fcc.gov

For Immediate Release

FCC CONCLUDES FIRST 5G MID-BAND SPECTRUM AUCTION

3.5 GHz Spectrum Will Promote Innovation and Advance U.S. Leadership in 5G

WIRELESS

T-Mobile pays $304M to fill in holes in its 2.5 GHz spectrum

By **Linda Hardesty** · Sep 1, 2022 5:39pm

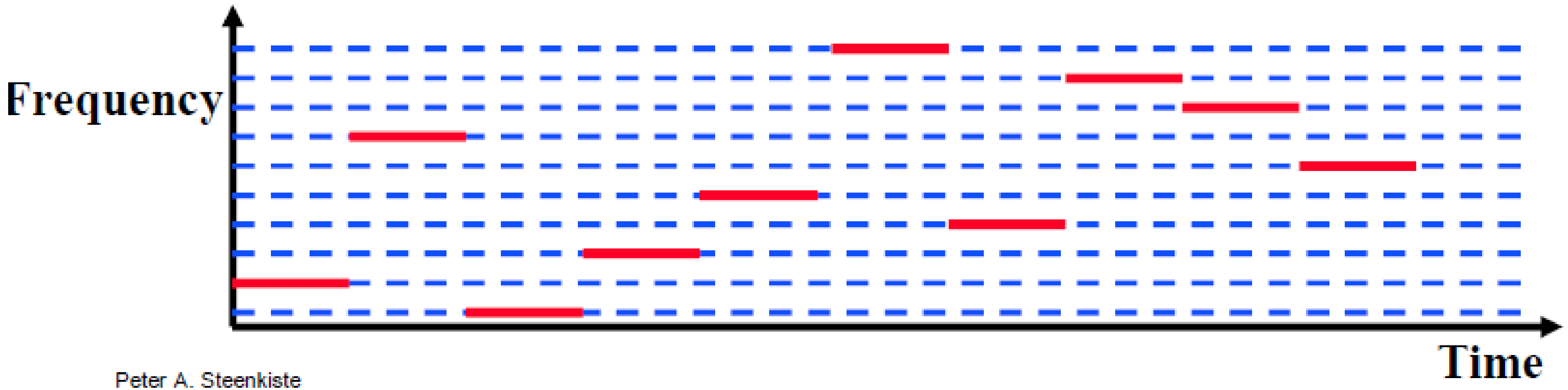
T-Mobile | 2.5 GHz | spectrum auction

https://www.fiercewireless.com/wireless/t-mobile-pays-304m-fill-holes-its-25-ghz-spectrum

Frequency Hopping Spread Spectrum

- Transmitter hops through a sequence of transmit channels
  - Spend some "dwell time" on each channel before hopping again
  - Receiver must know the hopping pattern

- Avoid causing or receiving prolonged interference



Peter A. Steenkiste

Sidebar: inventor of FHSS – Hedy Lamarr

- Actress, inventor, and all-around badass
  - Designed FHSS with George Antheil during WWII based on music ideas
  - Idea: torpedo control can’t be easily jammed if it jumps around

- https://en.wikipedia.org/wiki/Hedy_Lamarr#Inventing_career

- More modern comparison: imagine Scarlett Johansson invented a new wireless technology

Frequency and Data Rate

- Which can send data faster (more bits/second)?
  - Signal at 2 GHz frequency with 1 MHz of bandwidth
  - Signal at 20 GHz frequency with 1 MHz of bandwidth

Frequency and Data Rate

- Which can send data faster (more bits/second)?
  - Signal at 2 GHz frequency with 1 MHz of bandwidth
  - Signal at 20 GHz frequency with 1 MHz of bandwidth
  - **They are identical!**

- Data rate is a function of bandwidth and power (not frequency)
  - Shannon-Hartley Theorem: $C = B \log_2(1 + \frac{S}{N})$
    - C – channel capacity in bits per second
    - B – bandwidth
    - S/N – signal to noise ratio (measure of signal power)

Frequency and Range

- Oof. This gets a little tricky

- Does frequency affect range: yes and no
  - Identical energy would mean identical range regardless of frequency
  - BUT
  - Lower frequencies use larger antennas
  - Larger antennas collect more energy
  - More energy allows for farther range

- Also, RF waves may or may not be affected by obstacles
  - Depends on wavelength (frequency) with obstacles much smaller than the wavelength having a minimal effect
    - Low frequencies can diffract around obstacles
  - Also depends on the materials of the obstacle

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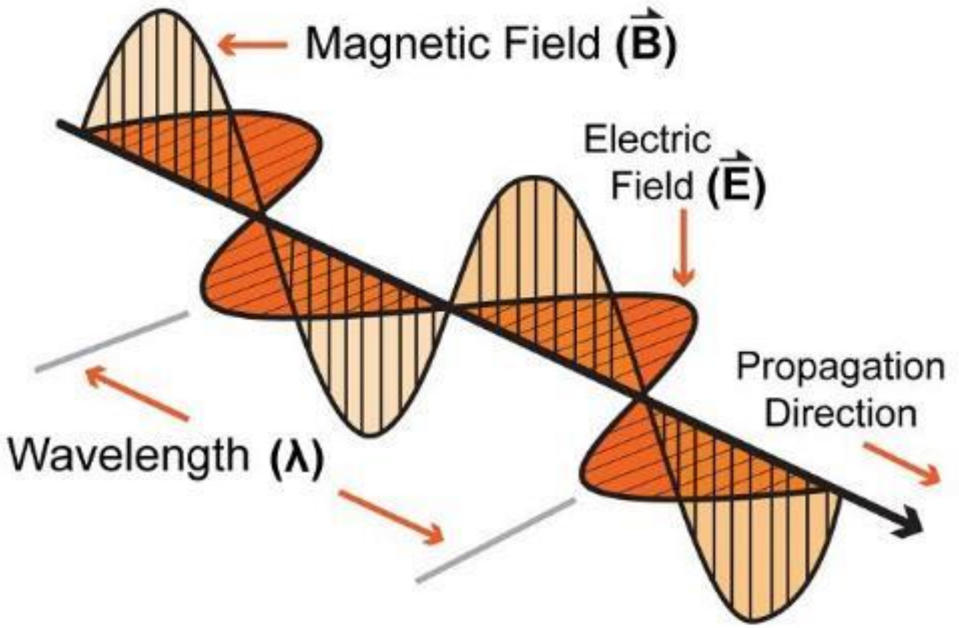
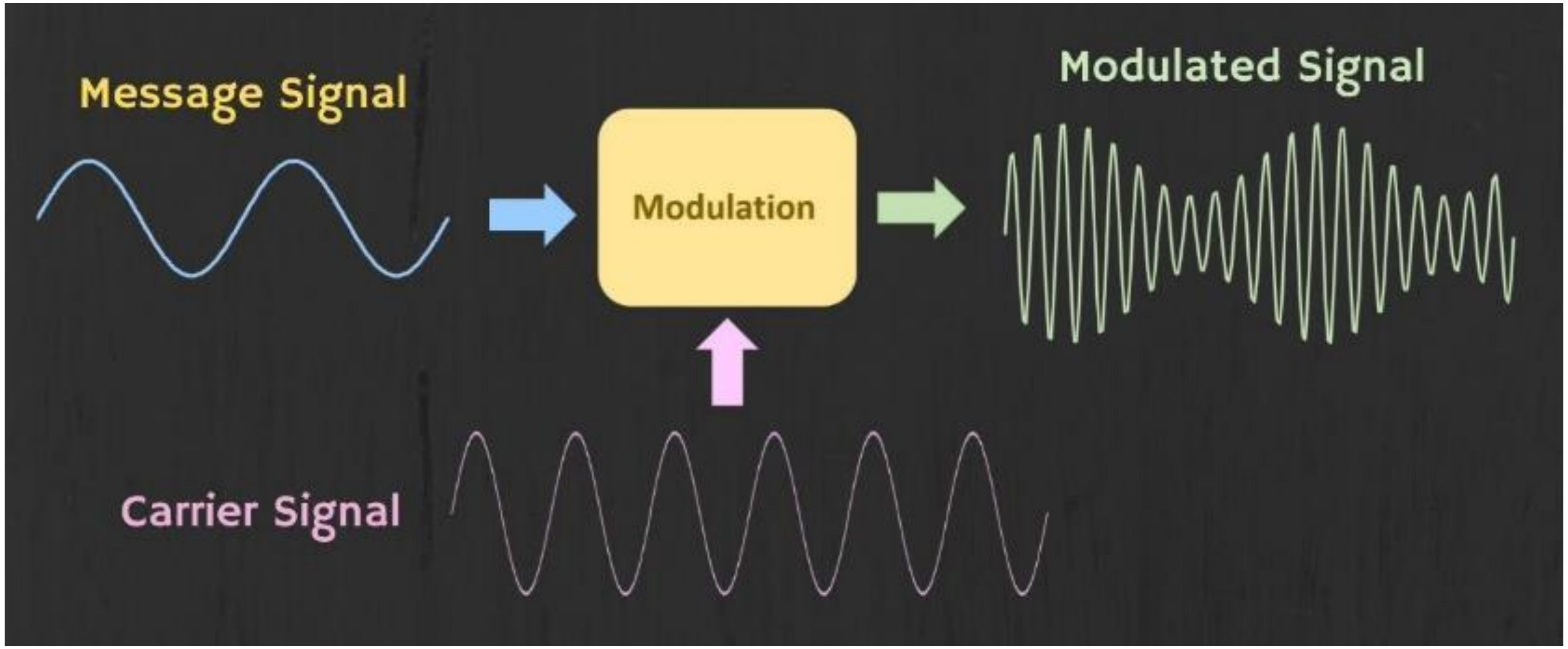


Modulation

- Encoding signal data in an analog “carrier” signal
  - Carrier signal defines the frequency
  - Modulation scheme + data define bandwidth required

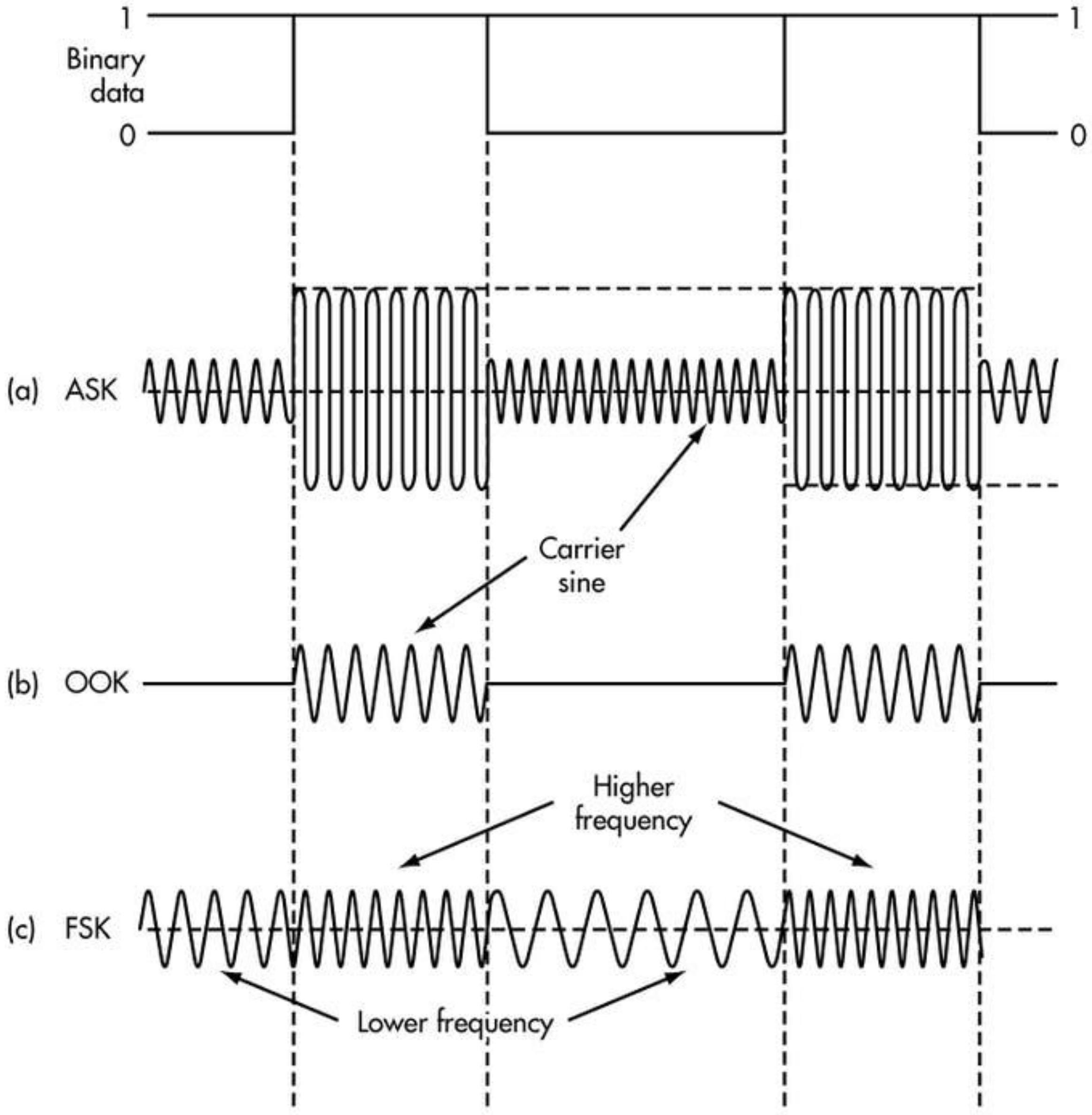


Modulation types

- Encoding binary data on a signal

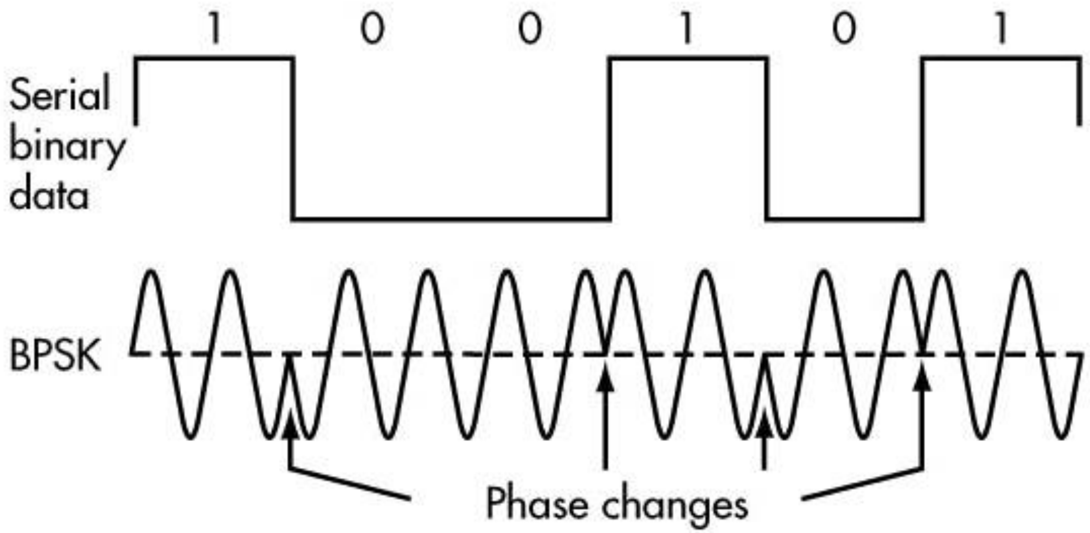
- Amplitude-shift Keying (ASK)
  - Modify amplitude of carrier signal
  - On-Off Keying (OOK) is an extreme example

- Frequency-shift Keying (FSK)
  - Modify frequency of carrier signal



Modulation types

- Phase-shift keying (PSK)
  - Modify phase of carrier signal
  - Often differential:
    the change signifies data



- More complicated possibilities exist
  - QAM (Quadrature Amplitude Modulation) combines amplitude and phase shift keying
    - Allows for more than one bit per “symbol”

Modulation tradeoffs

- Various tradeoffs between different modulation schemes
  - Bandwidth requirements, transceiver hardware, immunity to noise, etc.

- ASK (amplitude) is simple but susceptible to noise
  - Noise exists in the real world

- FSK (frequency) is relatively simple and robust to noise, but uses more bandwidth
  - Bandwidth is limited, but this modulation is still commonly used

- PSK (phase) energy efficient and robust, but more complex hardware
  - More expensive hardware, but very commonly used

Break + Video

- Excellent explanation of modulation techniques: https://youtu.be/0faCad2kKeg?si=kK6l0g63XGVPdut9&t=240
    - Listen for 3.5 minutes until 7:30 in the video

    - “How Cell Service Actually Works” by Wendover Productions

Outline

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- **Data Link Layer**
- BLE Background

Data Link Layer

- Framing
  - Combine arbitrary bits into a "packet" of data
- Logical link control
  - Manage transfer between transmitter and receiver
  - Error detection and correction
- Media access
  - Controlling which device gets to transmit next
- Inherently coupled to PHY and its decisions

Framing

- Typical packet structure
  - Preamble - Existence of packet and synchronization of clocks
  - Header - Addresses, Type, Length
  - Data - Payload plus higher layer headers (e.g. IP packet)
  - Trailer - Padding, CRC

Preamble	Destination Address	Source Address	Type and Length	Data	CRC

- Possible wireless considerations
  - Control information for Physical Layer
  - Ensure robustness for header
  - Explicit multi-hop routing
  - Possibly different data rates for different parts of packet

Error control: detection and recovery

- Detection: only detect errors
  - Make sure corrupted packets get discarded
  - Cyclical Redundancy Checks
    - Detect single bit errors
    - Detect “burst” errors of several contiguous bits
- Recovery: also try to recover from small bit errors
  - Forward error correction
  - Retransmissions
  - Far more important for wireless because the cost of transmission is higher

Medium Access Control

- How does a network determine which transmitter gets to transmit?

- Remember: the wireless medium is inherently broadcast
  - Two simultaneous transmitters may lose both packets

Analogy: wireless medium as acoustic

- How do we determine who gets to speak?
  - Two simultaneous speakers also lose both "transmissions"

- **Task:** Break into groups of 5 students each
  - In two minutes I'm going to ask each group a question
  - Everyone in the group needs to answer as quickly as possible

  - Rules:
    1. If two people talk at the same time the group loses
    2. Every group must use a unique method
       - I'll have each group explain what their method was after they use it
       - So be creative and have multiple options ready to go

Analogy: wireless medium as acoustic

- How do we determine who gets to speak?
  - Two simultaneous speakers also lose both “transmissions”

- Eye contact (or raise hand) -> out-of-band communication
- Wait until it’s quiet for some time -> carrier sense multiple access
- Strict turn order -> time division multiple access
- Just speak and hope it works -> ALOHA
- Everybody sing at different tones -> frequency division multiple access (stretching the metaphor)
- Everyone speak in different languages -> code division multiple access (sort of, but not really)

- Others?

MAC protocol categorization

Medium Access Control Protocols

$$\overbrace{\hspace{10em}}$$

Contention-Based Protocols

- ALOHA
- CSMA

Contention-Free Protocols

- FDMA
- TDMA
- CDMA

MAC protocol categorization

Medium Access Control Protocols

Contention-Based Protocols

ALOHA

CSMA

Contention-Free Protocols

FDMA

TDMA

CDMA

ALOHA

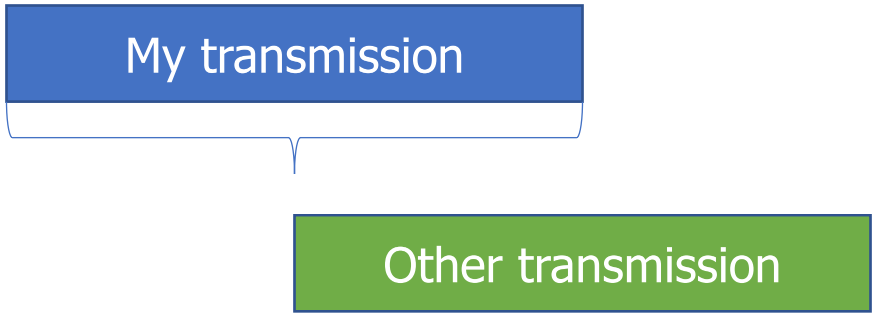
- ALOHAnet (1971)
  - University of Hawaii – Norman Abramson
  - First demonstration of wireless packet network

- Rules
  1. If you have data to send, send it

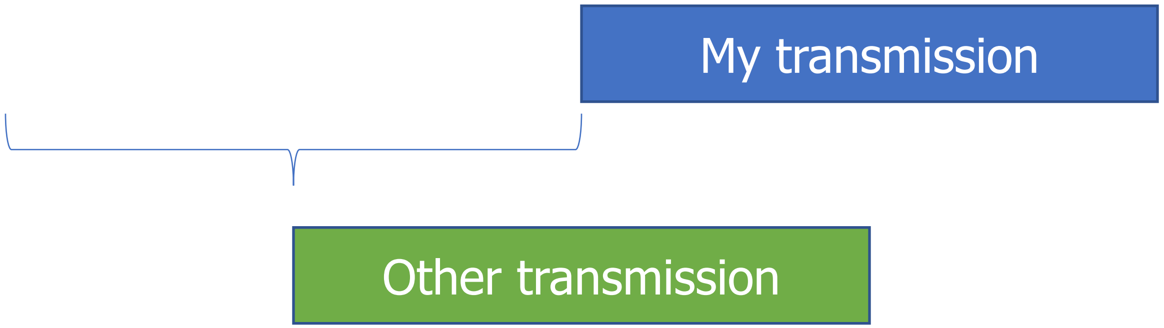
- Two (or more) simultaneous transmissions will collide and be lost
  - Wait a duration of time for an acknowledgement
  - If transmission was lost, try sending again “later”
    - Want some kind of exponential backoff scheme here

Packet collisions

- Each packet transmission has a window of vulnerability
  - Twice the on-air duration of a packet
  - Transmissions during the packet are bad

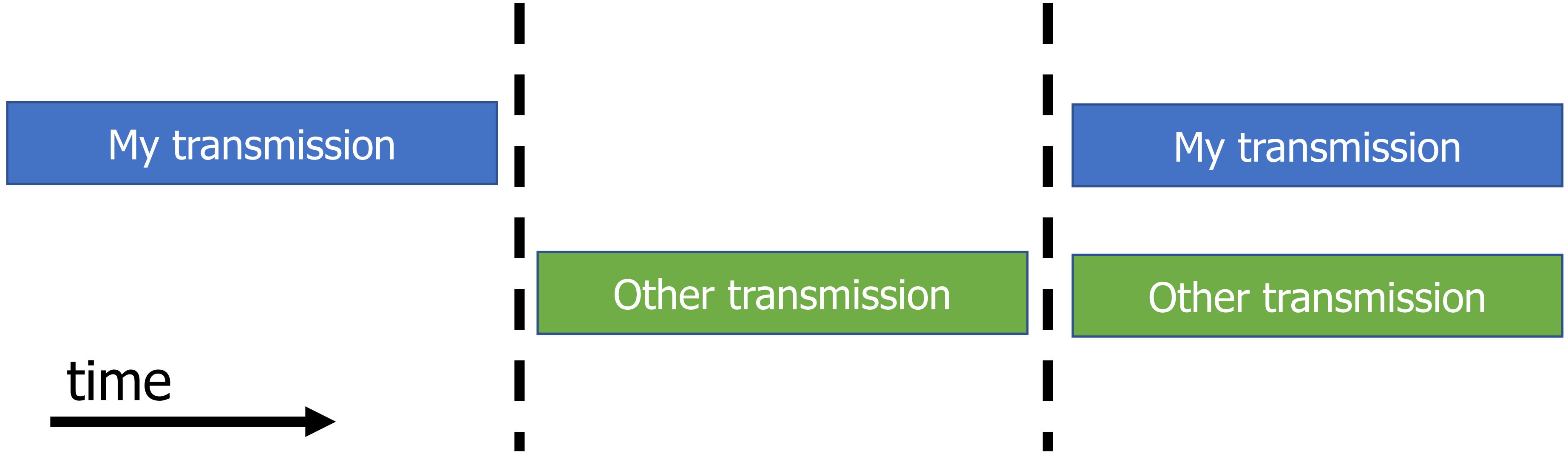


  - Transmissions before packet can also be bad



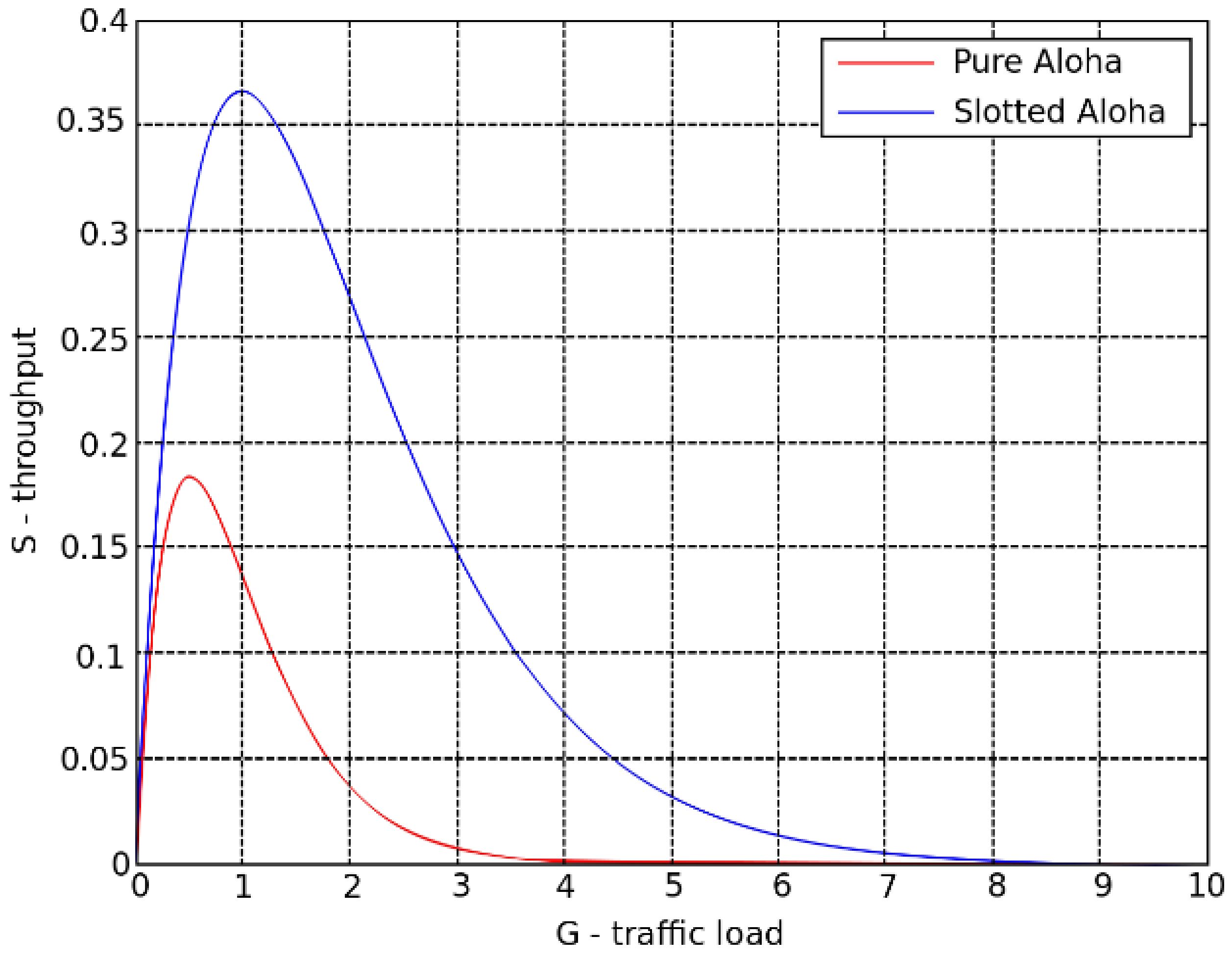
Slotted ALOHA

- Split time into synchronized “slots”
- Any device can transmit whenever it has data
  - But it must transmit at the start of a slot
  - And its transmission cannot be longer than a slot
  - Removes half of the possibilities for collisions!
    - At the cost of some synchronization method



ALOHA throughput

- It can be shown that traffic maxes out at
  - ALOHA: 18.4%
  - Slotted ALOHA: 36.8%
- Assuming Poisson distribution of transmission attempts
- Slotted throughput is double because the “before” collisions can no longer occur



Capture effect

- Actually, two packets at once isn't *always* a total loss
  - The louder packet can still sometimes be heard if loud enough

- How much louder?
  - Ballpark 12-14 dB

- When does this work?
  - Depends on the radio hardware
  - Louder packet first almost always works
  - Louder packet second *sometimes* works

MAC protocol categorization

Medium Access Control Protocols

Contention-Based Protocols

ALOHA

CSMA

Contention-Free Protocols

FDMA

TDMA

CDMA

CSMA/CA – Carrier Sense Multiple Access with Collision Avoidance

- First listen for a duration and determine if anyone is transmitting
  - If idle, you can transmit
  - If busy, wait and try again later

- “listen before send”

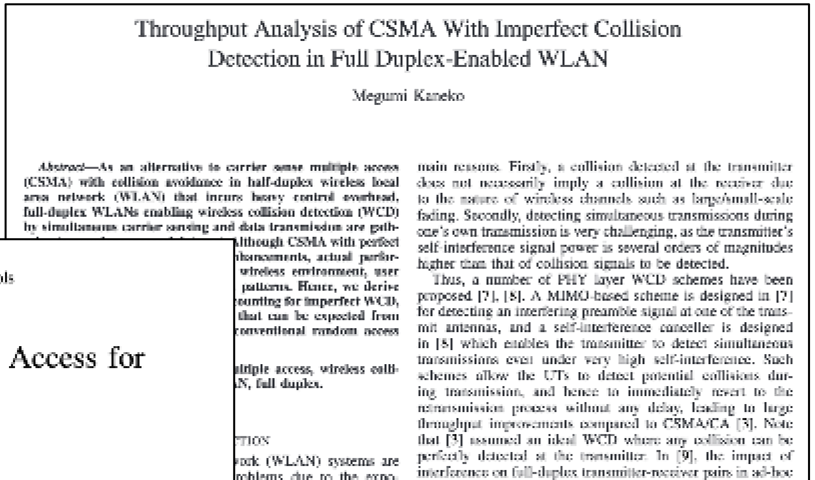
- Can be combined with notion of slotting
  - If current slot is idle, transmit in next slot
  - If current slot is busy, follow some algorithm to try again later

CSMA/CD – CSMA with Collision Detection

- Detect collisions during your own transmission
  - Works great on wired mediums (Ethernet, I2C)

- Very challenging for wireless systems
  - Transmit and receive are usually the same antenna
  - Receiving while transmitting would be drowned out by transmission
    - Remember: TX at 8 dBm and RX at -95 dBm

  - Area of active research!

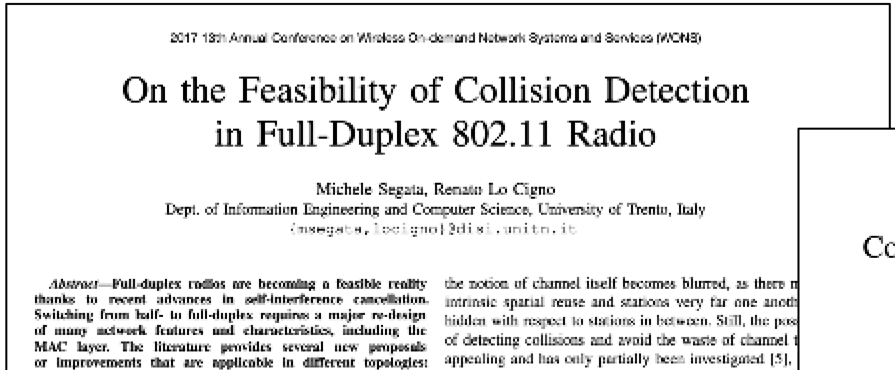

Throughput Analysis of CSMA With Imperfect Collision Detection in Full Duplex-Enabled WLAN

Megumi Kaneko

Abstract—As an alternative to carrier sense multiple access (CSMA) with collision avoidance in half-duplex wireless local area network (WLAN) that incurs heavy control overhead, full-duplex WLANs enabling wireless collision detection (WCD) by simultaneous carrier sensing and data transmission are gath-

main reasons. Firstly, a collision detected at the transmitter does not necessarily imply a collision at the receiver due to the nature of wireless channels such as large/small-scale fading. Secondly, detecting simultaneous transmissions during one's own transmission is very challenging, as the transmitter's self interference signal power is several orders of magnitudes higher than that of collision signals to be detected.

Thus, a number of PHY layer WCD schemes have been proposed [7], [8]. A MIMO-based scheme is designed in [7] for detecting an interfering preamble signal at one of the transmit antennas, and a self-interference canceller is designed in [8] which enables the transmitter to detect simultaneous transmissions even under very high self-interference. Such schemes allow the UTs to detect potential collisions during transmission, and hence to immediately revert to the retransmission process without any delay, leading to large throughput improvements compared to CSMA/CA [3]. Note that [3] assumed an ideal WCD where any collision can be perfectly detected at the transmitter. In [9], the impact of interference on full-duplex transmitter-receiver pairs in ad-hoc


2017 13th Annual Conference on Wireless On-demand Network Systems and Services (WONS)

On the Feasibility of Collision Detection in Full-Duplex 802.11 Radio

Michele Segata, Renato Lo Cigno
Dept. of Information Engineering and Computer Science, University of Trento, Italy

Abstract—Full-duplex radios are becoming a feasible reality thanks to recent advances in self-interference cancellation. Switching from half- to full-duplex requires a major re-design of many network features and characteristics, including the MAC layer. The literature provides several new proposals or improvements that are applicable in different topologies:

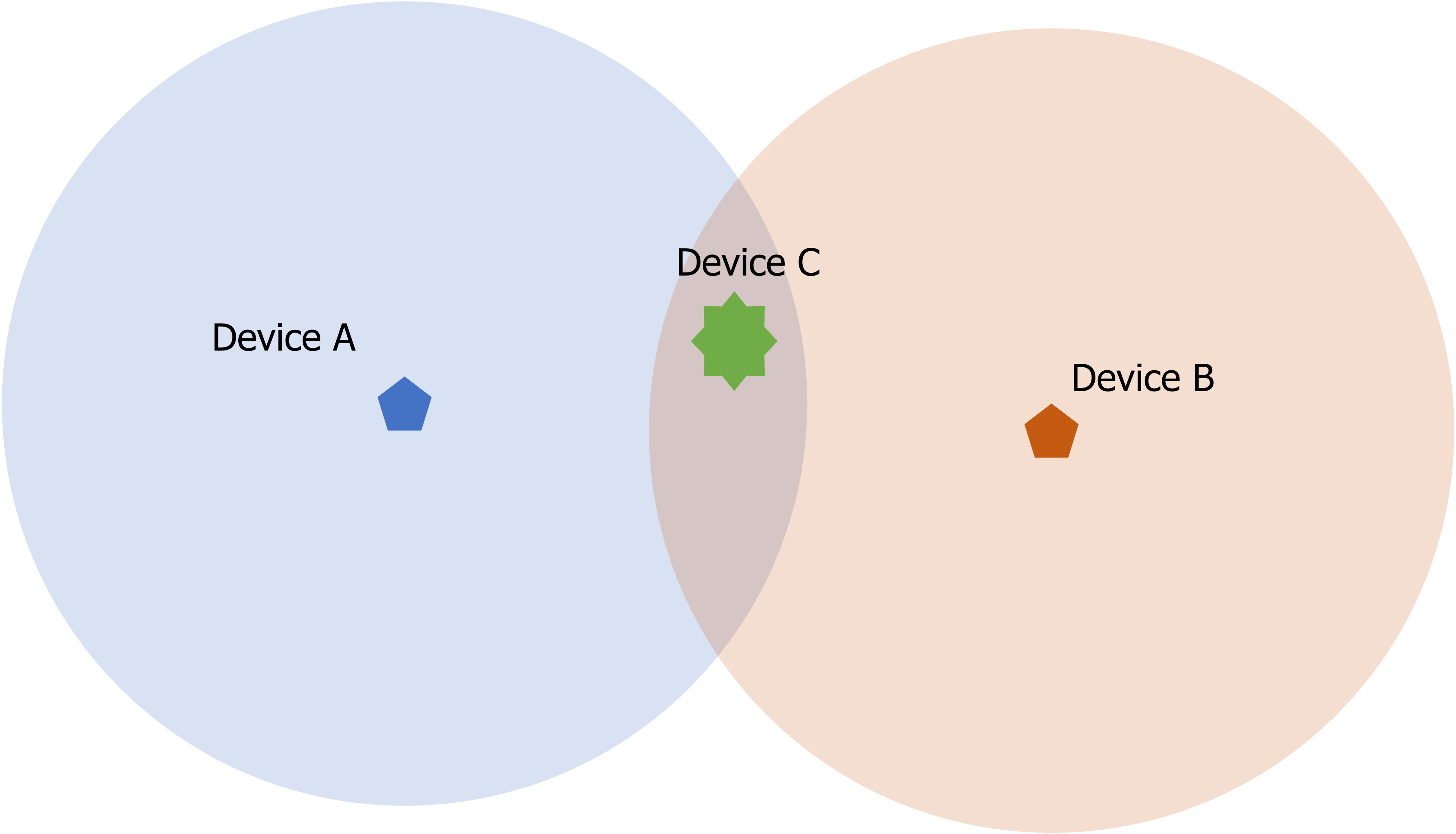
the notion of channel itself becomes blurred, as there intrinsic spatial reuse and stations very far one anoth hidden with respect to stations in between. Still, the pos of detecting collisions and avoid the waste of channel t appealing and has only partially been investigated [5],


2014 IEEE 22nd International Conference on Network Protocols

Concise Paper: Semi-Synchronous Channel Access for Full-Duplex Wireless Networks

Xiufeng Xie and Xinyu Zhang
University of Wisconsin-Madison
Email: {xiufeng.xyzhang}@ece.wisc.edu

Hidden terminal problem



CSMA with RTS/CTS

- Hidden terminal problem means that two transmitters might never be able to detect each other's transmissions

- A partial solution
  - When channel is idle, transmitter sends a short Request To Send (RTS)
  - Receiver will send a Clear To Send (CTS) to only one node at a time
  - RTS collisions are faster and less wasteful than hidden terminal collisions
  - Downside: overhead is high for waiting for CTS when contention is low
    - Not always worth it

MAC protocol categorization

Medium Access Control Protocols

- Contention-Based Protocols
  - ALOHA
  - CSMA
- Contention-Free Protocols
  - FDMA
  - TDMA
  - CDMA

Contention-free access control protocols

- Goal: split up communication such that devices will never conflict

- Can be predetermined or reservation-based
  - Devices might request to join the schedule and be given a slot
    - Devices lose their slot if it goes unused for some amount of time
    - Reservations often occur during a dedicated CSMA contention slot
  - Assignment of schedules can be complicated

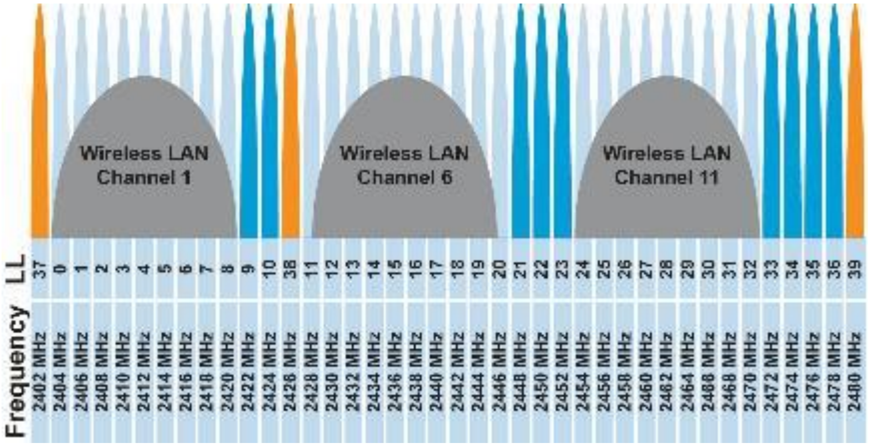
- Really efficient at creating a high-throughput network
  - Assuming they are all following the same protocol
  - Otherwise, interference can be very problematic

FDMA – Frequency Division Multiple Access

- Split transmissions in frequency
  - Different carrier frequencies are independent
  - Fundamentally how RF spectrum is split
  - Usually in conjunction with another scheme (but not always)

- Technically, each device uses a separate, fixed frequency
  - Walkie-talkies

- Conceptually, how RF channels work
  - WiFi networks pick different bands
  - 802.15.4 picks a channel to communicate on



TDMA – Time Division Multiple Access

- Split transmissions in time
  - Devices share the same channel

- Splits time into fixed-length windows
  - Each device is assigned one or more windows
  - Can build a priority system here with uneven split among devices

- Requires synchronization between devices
  - Often devices must listen periodically to resynchronize
  - Less efficient use of slots reduce synchronization
    - Large guard windows. E.g. 1.5 second slot for a 1 second transmission

CDMA – Code Division Multiple Access

- Split transmissions in ‘codes’
  - Not new; original applications in radar and early satellite communications

- Analogy: Multiple speakers in the same room all in different languages
  - [The human brain is crazy good at ignoring what it doesn’t understand ☺]

- Requires signal power coordination
  - [everyone needs to speak ~the same volume]
  - Can be hard in uncontrolled / dynamic environments

- Also can be more performant with highly synchronized clocks
  - i.e. if the code clock is known to both devices

Break + Question

- What is an advantage of Aloha over TDMA?

Break + Question

- What is an advantage of Aloha over TDMA?

  - Simplicity! It’s really easy to implement Aloha

  - No required centralization
    - TDMA time schedule needs to be decided by something
    - That thing is “in charge”
    - Aloha can be entirely distributed

Real-world protocol access control

- ALOHA
  - BLE advertisements
  - Unlicensed LPWANs: Sigfox, LoRaWAN

- CSMA
  - WiFi (slotted, CSMA/CA)

- TDMA
  - BLE connections
  - Cellular LPWANs: LTE-M and NB-IoT

Outline

- Physical Layer
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  - Signal Frequency and Bandwidth
  - Signal Modulation
- Data Link Layer
- **BLE Background**

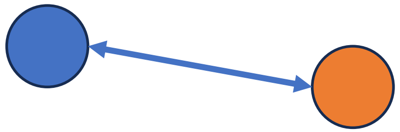
Bluetooth Low Energy Resources

- Good walkthrough of BLE:
  - https://www.silabs.com/documents/public/user-guides/ug103-14-fundamentals-ble.pdf

- [5.2 specification] [4.2 specification] (link to PDF download)
  - Also: [Supplement v9]

- I used a mix of 5.2 and 4.2 for this
  - Will talk about BLE 5 and BLE 6 differences as part of next lecture

Basics of Bluetooth Low Energy (BLE)



- Direct device-to-device communication
  - Usually: Computer to Thing
  - Smartphone to device, Laptop to device, etc.

- Focus on making the "Thing" really low energy
  - Push energy-intensive requirements onto "Computer"

- Devices (Computer or Thing) are servers with accessible fields
  - Not the traditional send-explicit-packets interface you might be expecting
  - Lower layers are still exchanging packets to make it work

A note on outdated notation

- Master/Slave paradigm
  - Master is the “Computer” and is in charge of interaction
  - Slave is the “Device” and has little control over interaction parameters
  - Really common notation in EE side of the world.
    - Not intended to be harmful, but also literally inconsiderate.

- Field is changing for the better. It’s going to take some time.
  - **Central/Peripheral**
  - Device/Peripheral
  - Controller/Peripheral
  - Master/Minion
  - Primary/Secondary

BLE development

- Protocol development
  - Research product
  - Specification
  - Hardware support
  - Usefulness and iteration

- Bluetooth Low Energy
  - Research in early 2000s: Bluetooth Low End Extension and Wibree
  - Specification in 2009: Bluetooth version 4.0
  - Hardware support in 2011/12: iPhone 4s, nRF51 series microcontrollers
  - 4.1 and 4.2 (2014), 5.0 (2016, first in phones 2017, really 2019 though)

Bluetooth has a long history — the IoT is near-exclusively BLE (Bluetooth 4.0+) as opposed to Bluetooth Classic (<4.0)

Year	Bluetooth Standard	Data Rate	Modulation	Notes
1999	V1.0	1 Mb/s	GFSK	• The Bluetooth 1.0 Specification is released by the Bluetooth SIG
2003	V1.2	1 Mb/s	GFSK	• First FDA-approved Bluetooth medical system. Bluetooth product shipments grow to 1 million/week
2004	V2.0 + EDR	1 Mb/s 2 Mb/s 3 Mb/s	GFSK π /4–DQPSK 8-DPSK	• Introduction of Enhanced Data Rate (EDR) for faster data transfer. • Bluetooth product shipments surpasses to 3 million/week
2007	V2.1 + EDR	1 Mb/s 2 Mb/s 3 Mb/s	GFSK π /4–DQPSK 8-DPSK	• Introduction of secure simple pairing (SSP) and extended inquiry response (EIR) for Bluetooth devices
2009	V3.0+HS	1 Mb/s 2 Mb/s 3 Mb/s	GFSK π /4–DQPSK 8-DPSK	• Introduction of AMP (Alternative MAC/PHY) and the addition of 802.11 as a high-speed transport with data transfer speeds up to 24 Mbit/s.
2010	V4.0 (Smart)	1 Mb/s 2 Mb/s 3 Mb/s	GFSK π /4–DQPSK 8-DPSK	• Introduction of Bluetooth Low Energy protocol and AES encryption
2013	V4.1	1 Mb/s 2 Mb/s 3 Mb/s	GFSK π /4–DQPSK 8-DPSK	• MWS (Mobile Wireless Standard) Coexistence • SIG membership surpasses 20,000 companies
2014	V4.2	1Mb/s 2Mb/s 3Mb/s	GFSK π /4–DQPSK 8-DPSK	• Smart sensor allows flexible internet connectivity • Increased privacy (Le Privacy 1.2 and LE Secure Connections) • LE Data Length Extension increases data throughput with packet capacity increase of 10x compared to previous versions.

Bluetooth Specification

- Problem: a bit overwhelming…
  - 5.2 spec: **3256 pages**
  - We only care about Vol 6: Low Energy Controller
    - Part A: Physical Layer Specification
    - Part B: Link Layer Specification
    - CSS: Part A: Data Types Specification
    - So ~250 pages

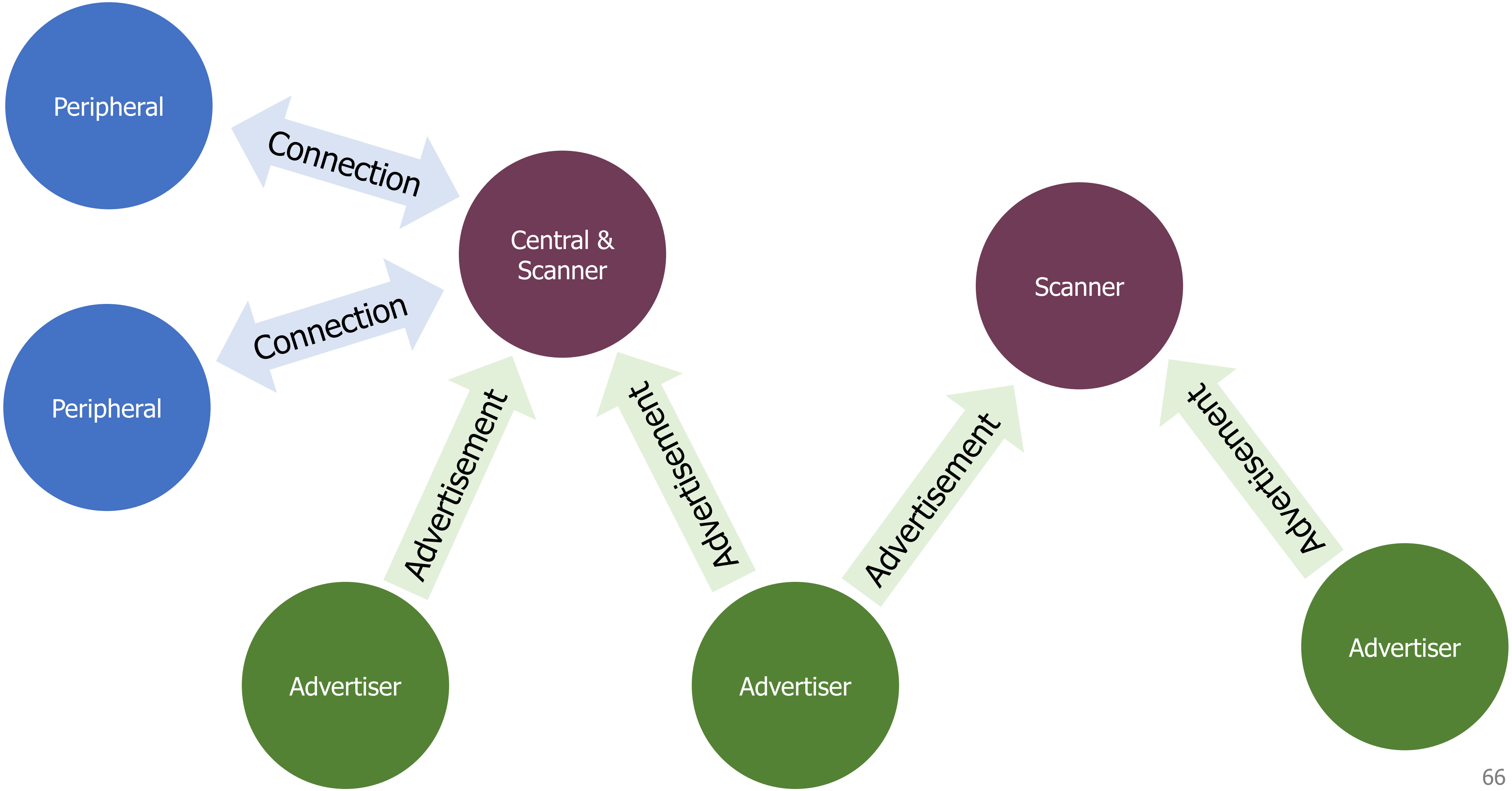
- Tip: be willing to just ignore things when skimming specs
  - 5.2 spec covers BLE and Bluetooth Classic and a bunch of upper layer stuff that we never have to care about

BLE mechanisms

- Advertising
  - Discovery
  - Advertisements – broadcast messages indicating device details
  - Ephemeral, uni-directional communication from Advertiser to Scanner(s)
  - ALOHA access control

- Connections
  - Interaction
  - Bi-directional communication between Peripheral and Central
  - Maintained for some duration
  - TDMA access control

BLE network topology



Multiple roles at the same time

- Topology picture is a simplification of roles

- A single device can have multiple roles simultaneously
  - Scanning and Advertising simultaneously
  - Peripheral and Scanner and Advertiser simultaneously
  - Peripheral and Scanner and Central and Advertiser simultaneously
    - Getting a bit out of hand though

- One Peripheral can even be connected to multiple Centrals
  - Not in the original design though: you'll find old docs saying you can't
  - And it's not a normal use-case for BLE

Break + Check your understanding

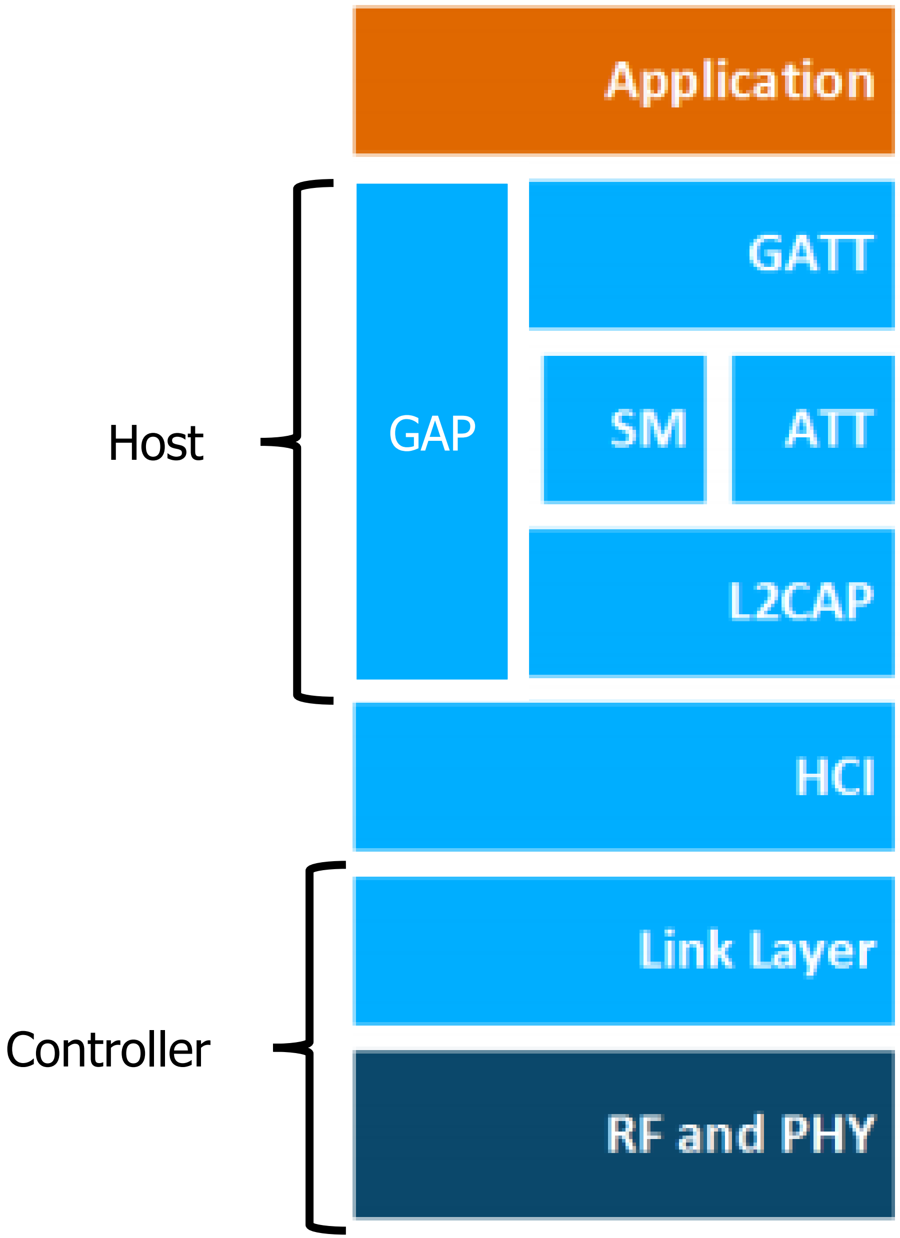
- Which roles is each device likely to have?
  - Keyboard
  - Laptop
  - Smartphone

Break + Check your understanding

- Which roles is each device likely to have?
  - Keyboard
    - Advertiser and Peripheral
  - Laptop
    - Scanner and Central
  - Smartphone
    - Advertiser, Peripheral, Scanner, and Central

BLE Layers

- Host – Configuration and Server
  - GAP – Generic Access Profile
    - Configure advertising
  - GATT – Generic ATTribute profile
    - Configure connections
- HCI - Host Controller Interface (sigh)
- Controller - Communication
  - Link Layer – send packets
  - RF and PHY – send bits



Outline

- Physical Layer
  - Overview
  - Signal Strength
  - Signal Frequency and Bandwidth
  - Signal Modulation
- Data Link Layer
- BLE Background