# Spectrum Sharing + Spectrum Policy + Limits

A high level overview for the
UW Community Networks Capstone 2021

# Radio Resources Review

Think back to the phy lecture and the network planning lecture...

What are some of the dimensions along which radio resources can be divided?

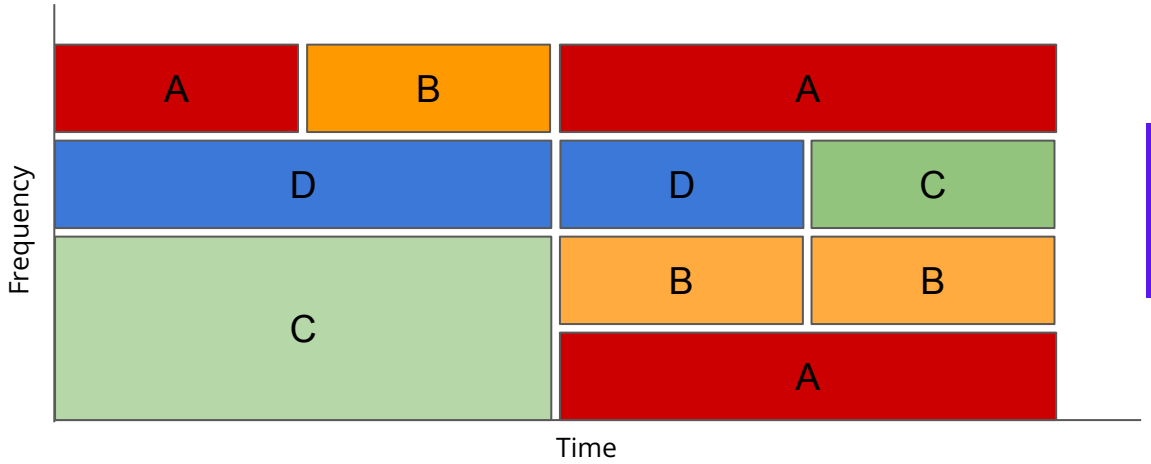
# Radio Resources Review

- Time
- Frequency
- Space
  - By extension “angle” with directional antennas and polarization
  - “6 degrees of freedom” full spatial orientation

Fundamentally that’s it for now… if you can figure out another way you could probably win a nobel prize + become fabulously wealthy!

# Reasoning about resources from a single TRx (Tx/Rx)

From the perspective of a single emitter, can draw out a time/frequency plot of radio resources. These are call “Resource Blocks” (RB’s) in cellular

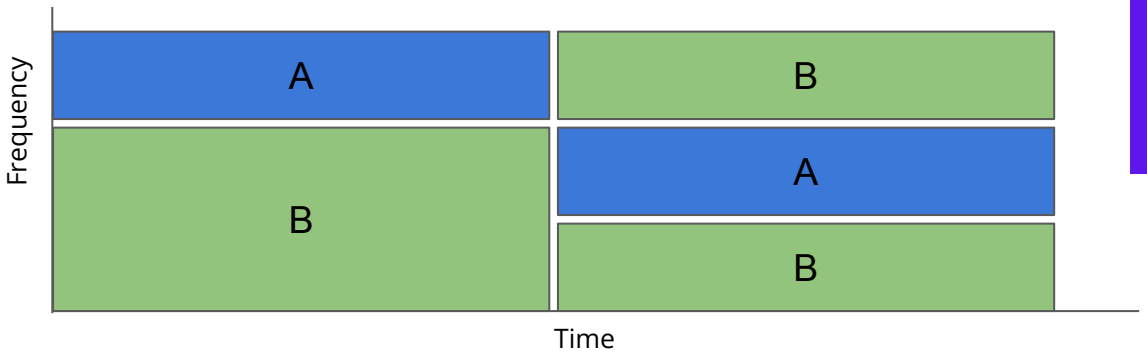



If multiple users can be served at the same time, this is called “multiple access”

Constraints in each waveform about how a schedule can be constructed, what can go where, spacing, duty cycle, etc.

# Airtime + Airtime Fairness

- The amount of data transmitted in a resource block depends on the “modulation” and “coding rate” used (“mod-cod”)
- Tradeoff between throughput and robustness!

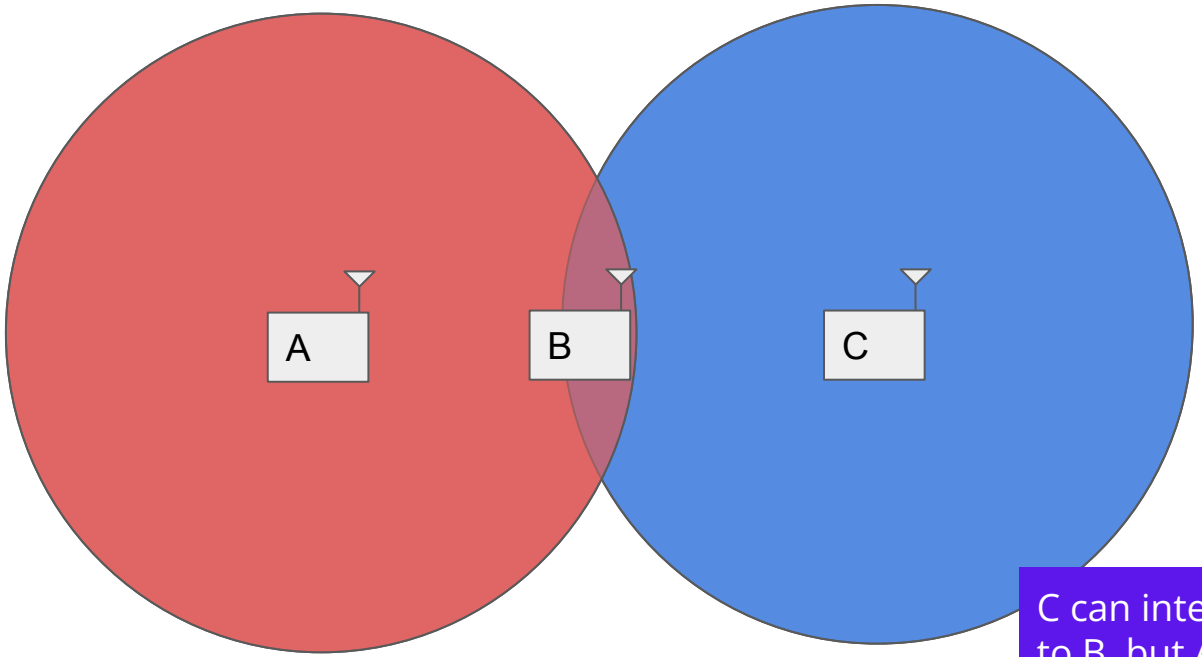



Achieving equal throughput may require more channel resources be dedicated to users with less ideal channel conditions!

Alternative conception of “fairness” where the constrained airtime is divided equally rather than the top-level throughput

# Coordination + Interference

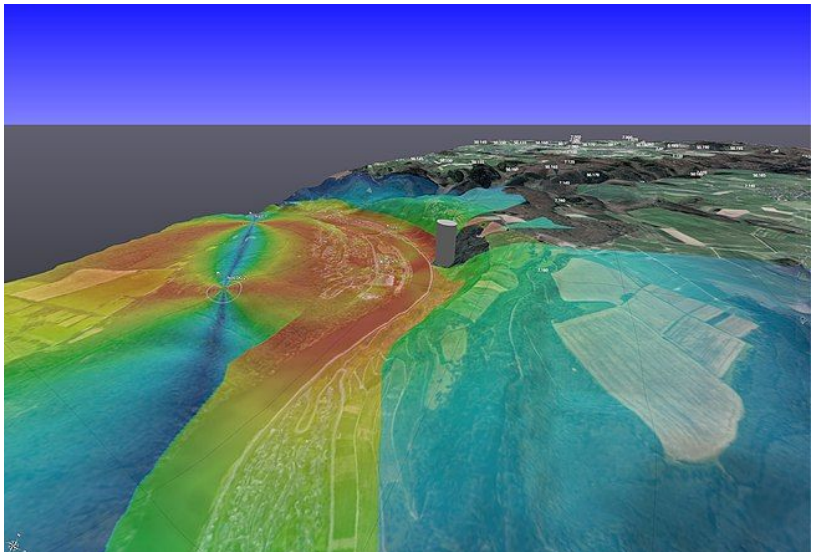
# A common example: “the hidden node”




C can interfere with A’s transmission to B, but A cannot sense C and C cannot sense A!

# Reasoning about Interference

- Remember that in the real world, coverage is not a neat circle or hexagon
  - “Neighbor Discovery” in LTE & 5G
- In addition to interference, can “contend” for channel access with other nodes using the same waveform
  - Determine “who’s turn to talk”
  - Nodes that can hear each other are in the same contention domain



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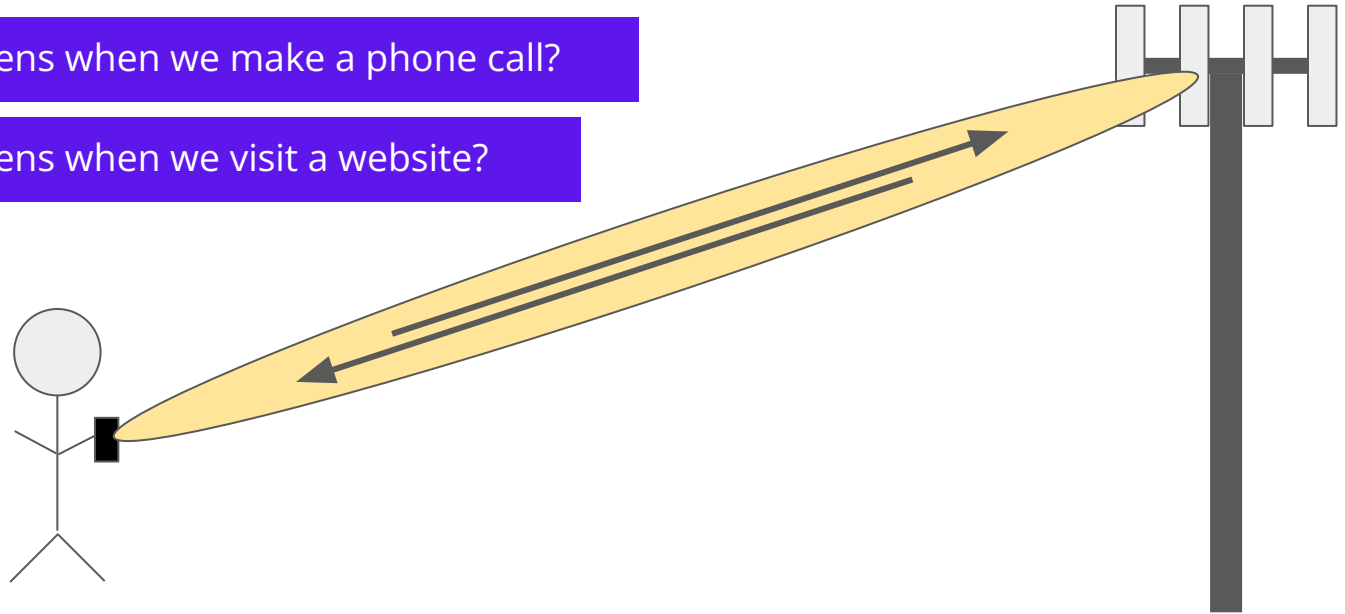
# Smarter Reuse

- In practice can be smarter for “N=1 frequency reuse”
  - pseudorandom sequences
  - orthogonal carriers
- Depends on the specific technology used
  - WiFi before 802.11ax was particularly bad about this, ax is okay
  - LTE is pretty good at it, as long as you have unique codes!
- Still adds to noise power and lowers capacity and sensitivity (aka range)

# The simplest link in the world...

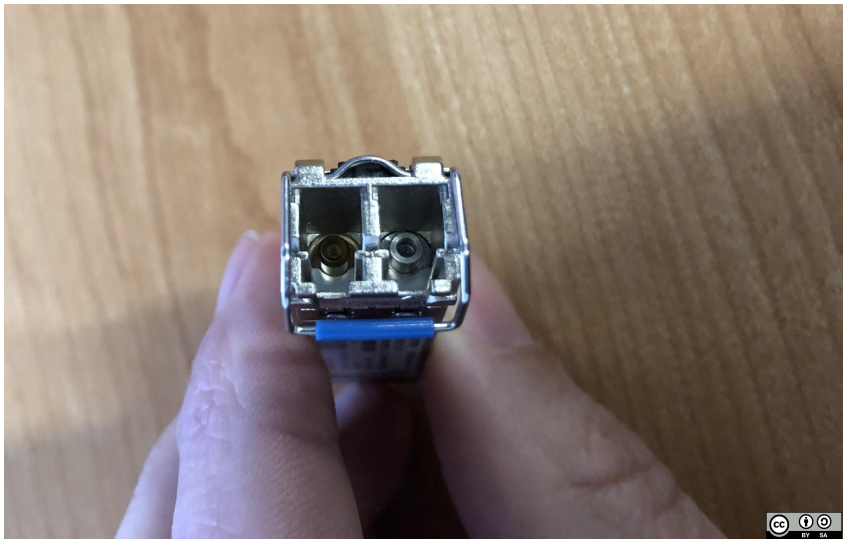
What happens when we make a phone call?

What happens when we visit a website?



# Duplexing

- Ideally we want “Full Duplex”, the ability to send and receive at the same time!
  - Trivial to do wires... just use two (or more) cables!
  - Ethernet + Fiber work this way and offer “full duplex”
- Can we do it with wireless?

# Full Duplex Radio

- Yes! Well… sort of… In theory…
  - We know exactly what we're transmitting, so even if it's received by our receiver, we can just "subtract it out!"
- Why might this be challenging in practice? DEMO

- Real Numbers (napkin math):
  - Typical LTE receive power for "5 bars" ~ -90dBm
  - Transmit power 30-40dBm typical…
    - That's 130dB of dynamic range you have to cancel just to get to 0 SNR!
    - Hearing a whisper at a rock concert is 80dB of dynamic range…
    - Hearing a whisper in front of a jet engine is 90dB…

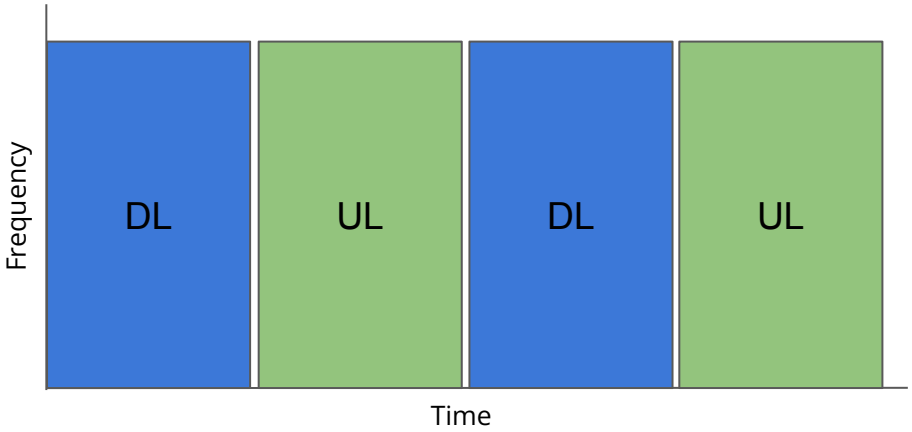
# Practical Radio Duplexing

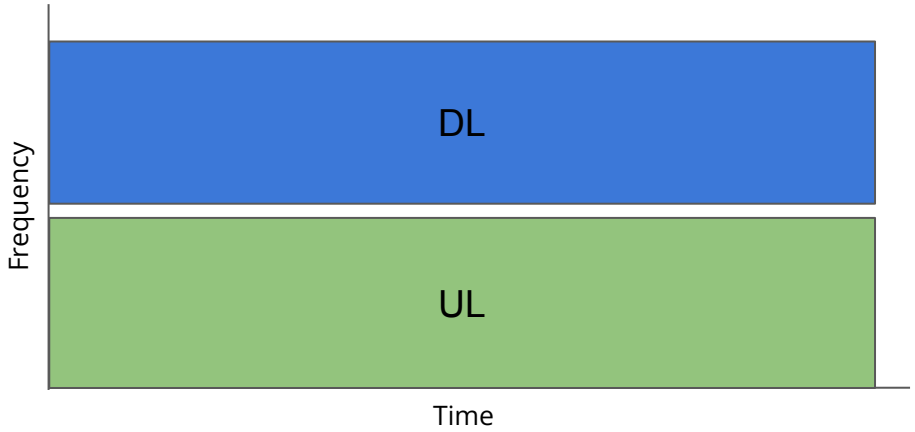
Most practical radios today are half duplex, can only receive when not transmitting

How can we get “full duplex behavior” with half duplex radios?

# TDD & FDD

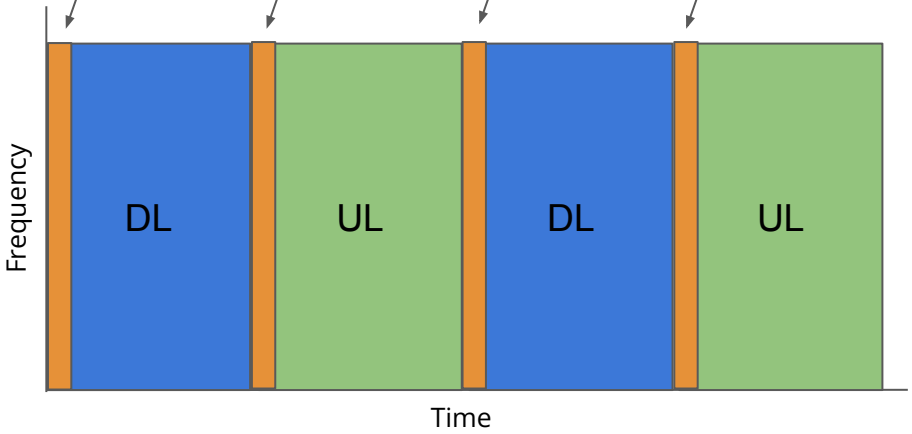
- At a single point in space, can divide between
  - **time** (“Time Division Duplex” → TDD)
  - **frequency** (“Frequency Division Duplex” → FDD)



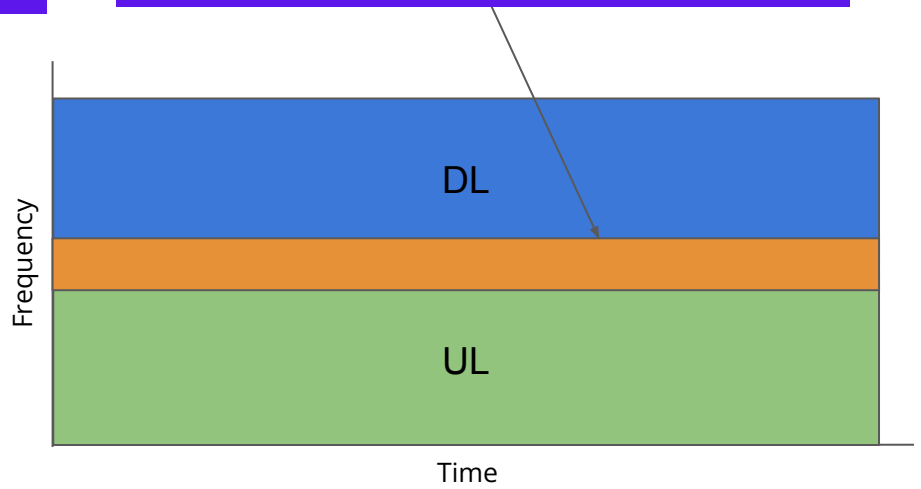



# TDD & FDD “Guards”

“Guard Time” based on ([cell size]/[speed of light]) + clock uncertainty




“Guard Band” based on how well you can build your RF filters



# TDD & FDD

Practical engineering + physics tradeoffs between either approach!

- Small group exercise, write down two advantages and two disadvantages of either approach

# Tradeoffs between TDD and FDD

**TDD**

+ Simpler hardware optimized for a single frequency
+ Variable Uplink/Downlink Radio
+ Symmetric channel between endpoints

- Wastes airtime “switching” between Tx and Rx while packets in flight
- Higher latency, might need to wait for next Tx opportunity

**FDD**

+ Lower latency, can transmit & receive at the same time (at least as a basestation)
+ No switching overhead, can time align all transmissions and receptions

- UL/DL ratio is fixed at spectrum planning time, might be hard to change dynamically!
- UL and DL have different properties
- Filter HW to isolate the different frequencies can be bulky + heavy, often limited to BTS only, not UE

Side question, why might most FDD “low bands” be assigned to uplinks?

# Which one is better?

**Actually a trick question…**

Depends on the application domain and traffic pattern!

Voice-optimized networks and band plans opted for FDD

Have drifted more towards TDD as networks more commonly used for data now!

Aside: “Carrier Aggregation” in LTE-A + 5G with multiple different TDD carriers can give some of the advantages of FDD with the flexibility of TDD

# Now finally to spectrum policy : )

Focus on the FCC since that's what I'm most familiar with, most other countries also have a central regulator that fills a similar role, although policies are region + country specific


Img: U.S. Government, Public domain, via Wikimedia Commons

# The FCC has a tough and complex job...

- Need to come up with a sharing plan for many types of RF users... scientific equipment, TV/radio broadcast, public safety radio, HAMs, digital comms, etc.

Img: Free-Photos, CC0, via Wikimedia Commons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# Policies ← → Bands

- To make it easier to reason about compatibility, the 3GPP defines “band numbers” mapping to a particular policy decision.
- Some bands are harmonized across countries, others are not
- Bands are “arbitrary” since they are representing “arbitrary” policy decisions
  - https://en.wikipedia.org/wiki/LTE_frequency_bands
  - https://en.wikipedia.org/wiki/5G_NR_frequency_bands
- Some bands are complete subsets of other bands : )

# Just because a band is allocated... is it used?

- “Whitespace Networks” and “Secondary Use”
  - Fundamental challenge is determining truly if the spectrum is used or not...
    - Remember that hidden node!
- Multiple approaches to whitespace networks
  - Sensing-based approaches
  - Coordination database-based approaches
  - More exotic distributed auctions, grants, etc.
- Common examples of whitespace-ish networks in practice are TVWS, CBRS, WiFi 6e

# A few case studies

# 800 MHz “Cellular”

- FDD band
  - UL 824-849MHz
  - DL 869-894MHz
- Started as cellular spectrum for analog “1G” phones in the ‘80s
- Continues to be used for mobile communication networks through 5G
  - 2G GSM-850
  - LTE “B5”
  - 5G-NR “n5”
- 800MHz band is shared with regional public safety systems
- Deets:
  - https://www.fcc.gov/wireless/bureau-divisions/mobility-division/800-mhz-cellular-service
  - https://www.fcc.gov/general/800-mhz-spectrum

# LTE 700 “digital dividend”

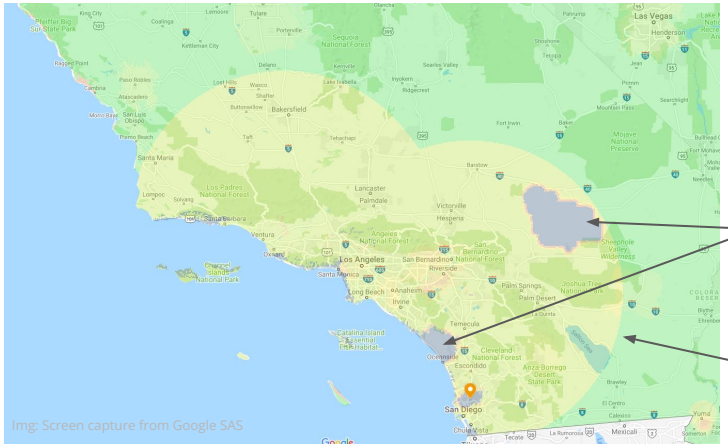
- 700MHz spectrum originally used for broadcast TV channels 52-69
  - With the transition to digital TV, transmissions were more efficient, allowing TV channels to fit in less bandwidth, freeing up the 700MHz band
  - FDD pairings in the blocks purchased by wireless carriers: 12, 10, or 22MHz blocks
  - Initially some restrictions based on adjacent TV channels (51), although addressed now
  - LTE b12,b13,b14,b17 and NR n12, n13, n14
- High Profile spectrum auction in 2008
  - Google was involved, placed a bid to trigger net neutrality provisions but did not win any licenses
- Used for LTE “coverage” cells by major carriers in the US (VZW, Tmo, ATT)
- Deets:
  - https://en.wikipedia.org/wiki/2008_United_States_wireless_spectrum_auction
  - https://www.fcc.gov/wireless/bureau-divisions/mobility-division/lower-700-mhz-service

# Wifi 5Ghz

- The “Unlicensed National Information Infrastructure” (UNII) band, UNII 1-4
- 775 MHz of bandwidth from 5150MHz - 5925MHz ... wow!
  - Unpaired (TDD) 20MHz channels
  - Different power limits based on the sub-band
- 475MHz (from 5250-5725) must avoid interference with radar through the “dynamic frequency selection” mechanism
  - Required sensing spec is too conservative, many false positives, often avoided now due to unreliability
- Despite the huge amount of spectrum, still prone to congestion in dense areas (apartments) with many uncoordinated users
- Deets:
  - https://en.wikipedia.org/wiki/List_of_WLAN_channels#5GHz
  - https://en.wikipedia.org/wiki/Unlicensed_National_Information_Infrastructure
  - https://www.fcc.gov/document/5-ghz-unlicensed-spectrum-unii

# CBRS-- hopefully you've heard enough about it already : )

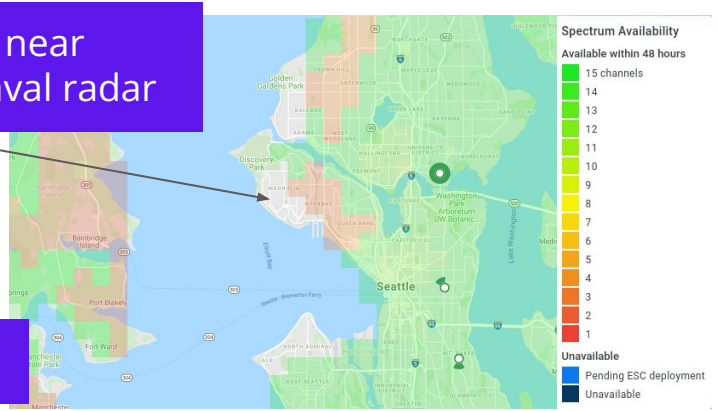
- "3-tier" system, mediated by a spectrum sharing database
- 150MHz from 3750MHz - 3800MHz
  - Unpaired (TDD) 10MHz allocations
- Spectrum database does channel modeling to make "optimal" allocations for all users, with priority given to incumbents and then PAL holders




No spectrum available near navigable water per naval radar

Military Bases

Satellite/Radar/Other?




Img: Screen capture from Google SAS

# WiFi 6Ghz “6e”

- If 775MHz of WiFi wasn’t enough, let’s add another 1200MHz…
  - UNII 5-8, 5925-7125MHz, Unpaired (TDD) 20MHz channels
- Must use 802.11ax or newer (“WiFi 6”), which has features to improve coexistence in dense deployments
- More strict power controls
  - Low power indoor operation for UNII 5-8
  - Standard power outdoor operation in UNII 5 and 7 only, must coordinate through a spectrum database
    - “Automatic Frequency Coordination” (AFC), works like CBRS, but only two levels!
- Deets:
  - https://docs.fcc.gov/public/attachments/FCC-20-51A1_Rcd.pdf
  - https://en.wikipedia.org/wiki/Wi-Fi_6

Fun Aside: How do you think they keep devices indoor only?

# So... what limits network scale?

- Raw throughput
  - Only so many bits you can fit “through the pipe”
- Contention overhead
  - Network gets less efficient the more you have to switch between different nodes
- Device management overhead
  - Static networks are lower overhead than dynamic networks, at the expense of mobility and flexibility... things humans like

Beyond spectrum:

- Addressing
- Human capacity to manage and understand the network
- Social ties + organizational structure
- A last thought on “Scaling Wisps”