ECE 435 – Network Engineering
Lecture 29

Vince Weaver

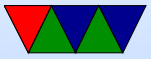
https://web.eece.maine.edu/~vweaver

vincent.weaver@maine.edu

9 April 2025

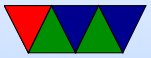
Announcements

- Project status reports due next Friday 18th (more info on that next time)
- Don't forget HW#10 due Friday
- Might be slightly late to class Friday depending on how the Student Symposium Judging goes



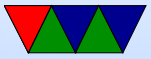
HW#8 Review – IPv6 Addresses

- 2607:f8b0:4009:0801:0000:0000:0000:200e – OK
- 2607:f8b0:4009:801::200e – OK
- 2607:f8b0::4009:801::200e – can you have two colons?
- 123.45.67.18 – ipv4



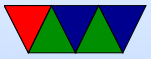
HW#8 Review – IPv6 Packet

```
0x000e:  6002 2618 :
 6 = IPv6
 00 = traffic class
 2618 = flow label
0x0012:  0031 =        payload length, 49
0x0014:  11 =          next header = 0x11, UDP
0x0015:  40 =          hop limit 0x40, 64
0x0016:  2610 0048 0100 08da 0230 18ff feab 1c39
                       source address
0x0026:  2001 4860 4860 0000 0000 0000 0000 8844
                       destination address
```



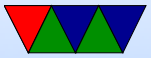
HW#8 Review – Traceroute

- internet2
- bost/hart/newy probably boston, hartford, new york
- lon2.uk London
- janet is british academic network
- 6→7 across ocean
- 80ms = ?? speed of light
- 80e-3s 3e8m/s = 24000km? 5500km = 1/4 speed of light?



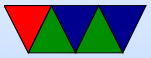
HW#8 Review – Traceroute6

- different hops? IP6 different? random chance
- hop 5→6
- Washington? internet 2?
- Abilene was the predecessor to internet2
- fra.de Frankfurt Germany probably not France
  ams.nl probably Amsterdam in Netherlands
- latency 133ms rather than 106ms

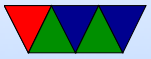


HW#8 Review – Anycast / Multicast

- Anycast: things where can load balance local. DNS. Google / facebook. CDNs
- Multicast: less load on server to just send one packet, instead of millions. Also better for bandwidth/congestion

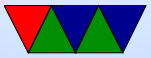


Wireless



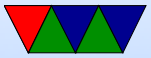
Why Wireless?

- Pros
  - Use anywhere
  - No wires
- Cons
  - Less reliability, noise
  - Less power availability
  - Less security



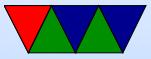
Wireless LAN

- 802.11. Started in 1990, no standard until 1997
- Operates in fixed ISM bands
  - Industrial/Scientific/Medical, no license needed
  - 900MHz, 2.4GHz, 5GHz
  - What issues come up with these bands?
    Microwave oven? Cordless phones, Bluetooth
  - Until 2002 ISM usage had to be spread spectrum
  - Up to 1W transmission power (50mW typical)



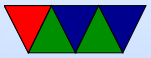
Wireless LAN Standards

- All of the various 802.11 have been sort of merged together, but people use the old letters out of habit



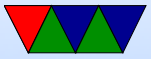
Wi-Fi

- What does Wi-Fi mean? Wireless Fidelity?
  Or Empty Marketing Term?
- Retroactively numbers given to older protocols
  - 802.11 = Wi-Fi 0
  - 802.11b = Wi-Fi 1
  - 802.11a = Wi-Fi 2
  - 802.11g = Wi-Fi 3
  - 802.11n = Wi-Fi 4
  - 802.11ac = Wi-Fi 5
  - 802.11ax = Wi-Fi 6/6E
  - 802.11be = Wi-Fi 7



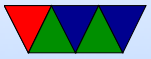
802.11 (1997) (Wi-Fi 0)

- Original, 1 or 2MBps, 2.4GHz, three implementations
  - infrared(?)
  - direct-sequence spread spectrum (DSSS)
    Takes a signal and spreads it along a wider frequency band but adding pseudo-random noise, then subtracting out at the other side.
  - frequency-hopping spread spectrum (FHSS)
    rapidly switch signal among a bunch of different frequencies in a pseudo-random fashion. Harder to



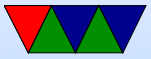
jam, causes less interference?

Initial seed, dwell time



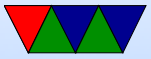
802.11b (1999) (Wi-Fi 1)

- 5.5Mbps and 11Mbps
- HR-DSSS (High Rate Direct Sequence Spread Spectrum)
- Walsh-Hadamard codes (error correction)
- actually came to market before 802.11a
- In the 2.4GHz frequency band, no licensing
- Various channels, 22MHz wide. Not all available in all countries. Some channels overlap.
- In the US have channels 1 through 11, but 1, 6, 11 are only non-overlapping ones



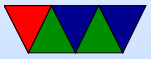
802.11a (1999) (Wi-Fi 2)

- 1.5 - 54Mbps
- Not compatible with B, 54Mbps in 5GHz band
- 5GHz less crowded, but signal doesn't go as far (7x less than b)
- OFDM (Orthogonal Frequency Division Multiplexing) Data is sent on multiple channels in parallel
- 52 channels: 48 data channels 4 pilot subcarriers



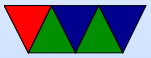
802.11g (2003) (Wi-Fi 3)

- 54Mbps, 2.4GHz
- Uses OFDM like 802.11a, but in the 2.4GHz band
- Backward compatible with b, which slows it down



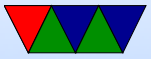
802.11n (2009) (Wi-Fi 4)

- 54Mbps - 600Mbps
- MIMO (multiple input/multiple output antennas)
- Can do spatial multiplexing, two antennas broadcast on same frequency by aiming signal



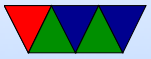
802.11ac (2009) (Wi-Fi 5)

- Most common currently (2022?)
- Wider channels, 80MHz-160MHz (vs 40MHz)
- 256 Quadrature Amplitude Modulation (QAM)
- MU-MIMO (multi-user MIMO)
- Usually 433Mbps to 2.16Gbps (theoretical max with stationary receiver and lots of antennas 7Gbps)
- Up to 8 MIMO streams (spatial?)
- Downlink multi-user MIMO (4 clients), with 4 antennas
- Beam forming



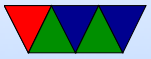
Aside on QAM

- I gloss over a lot here what's going on at physical layer
- Quadrature Amplitude Modulation is when there are two carrier waves, each 90 degrees out of phase from each other, and the data is modulated on top
- Often the frequency is much faster than the data being sent

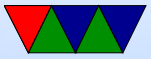


802.11ax (2019) (Wi-Fi 6)

- 2.4/5/6GHz
- Up to 11Gbps? (1Gbps more typical)
- high efficiency?
- Wi-Fi 6E
  - Extension that uses the “6 GHz” band 5.925 - 7.125GHz
  - 1.2GHz of spectrum (old one only 400MHz)
  - Indoors this is fine, stopped by walls
  - Outdoors might conflict with other users of the band,

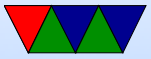


so has to do automatic frequency co-ordination where it checks database before using frequency



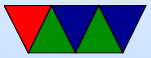
802.11be (20??) (Wi-Fi 7)

- To be released soon(?) They said late 2024 but still not out yet as of 2025
- 2.4/5/6GHz
- Up to 40Gbps?
- 4096-QAM



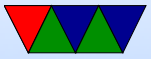
More obscure 802.11 variants

- WiGig (802.11ad/aj/ay)
  - 7Gbps
  - 60GHz (45GHz in china) freq (frequency that high short distance 1-10m, limited to inside room)
- White Wi-fi, Super Wi-fi (802.11af)
  - operates in vacant UHF/VHF TV bands.
  - Receiver uses GPS to find out where it is and what channels are free
- Many more



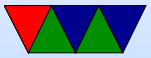
Terminology

- Station = device on wireless network
- Access Point (AP)



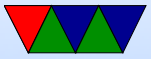
Wireless Network Topology

- Ad-hoc mode – peer to peer
- Distribution / Infrastructure mode – many to access point (AP) which has a wired connection
- In infrastructure mode all access goes through the AP



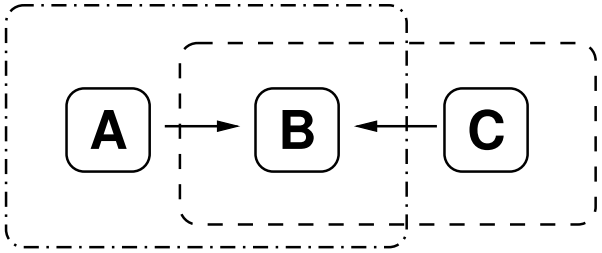
Service Sets

- A basic service set (BSS) is a group of nodes that all recognize each other
- An extended service set (ESS) is a group of overlapping BSSes with APs that are connected together
- An AP keeps the BSSes in line by periodically transmitting beacon frames

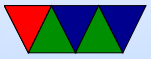


802.11 – Why not just Ethernet over the Air

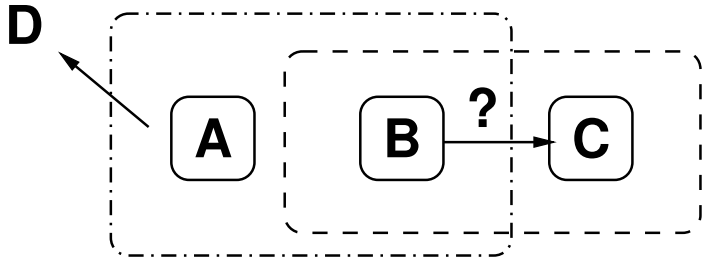
- Hidden station/terminal problem A in range of B, B in range of C, but A cannot see C. If A and C transmit at same time, they'll not get collision, only way of knowing is if not get ACK.



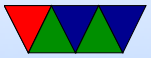
- Exposed station problem. A and C not overlap, but B



does not know this so it sees A transmitted to D and doesn't transmit to B even though it wouldn't cause collision.

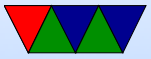


- To deal with this, Distributed Coordination Function (DCF) and point coordination function (PCF)



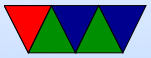
First some Timing Notes

- Network Allocation Vector (NAV), send along estimated time for how long things will take, other stations see this
- Interframe Spacing, 4 types
  - Short (SIFS)
  - PCF (PIFS)
  - DCF (DIFS)
  - EIFS



Also Note on Transmitter

- Half-duplex (full more expensive)
- Multiple frequency? Does each need own antenna?



Notes on BSSID

- Each AP can handle more than one network group (i.e. guest, tempest, etc)
- BSSID (basic service set identifier)
- Each BSSID has 48-bit MAC. Randomly generated, with "local" bit set
- AP supposed to filter on this so only frames destined to correct BSS handled properly. Book stresses not everyone does this right.