ECE 435 – Network Engineering
Lecture 22

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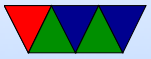
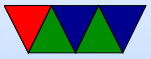
Announcements

- Project status reports
- HW#10 will be posted

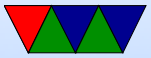


Wireless



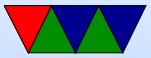
Why Wireless?

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



Wireless LAN

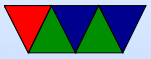
- What does WiFi mean? Nothing really.
- 802.11. Started in 1990, no standard until 1997
- Operates in fixed ISM bands
  - Industrial/Scientific/Medical
  - No license needed
  - 900MHz, 2.4GHz, 5GHz
  - What issues come up with these bands?
    Microwave oven? Cordless phones, Bluetooth
  - Until 2002 ISM usage had to be spread spectrum



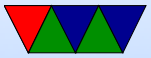
Wireless LAN Standards

- All of the various 802.11 have been sort of merged together, but people use the old letters out of habit
- Original 802.11 (1997) 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.

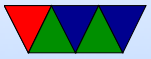


- frequency-hopping spread spectrum (FHSS)
  rapidly switch signal among a bunch of different frequencies in a pseudo-random fashion. Harder to jam, causes less interference?
  Initial seed, dwell time
- 802.11b (1999) 5.5Mbps and 11Mbps
  - HR-DSSS (High Rate Direct Sequence Spread Spectrum)
  - Walsh-Hadamard codes (error correction)
  - actually came to market before 802.11a
  - In the 2.4GHz frequency band, no licensing

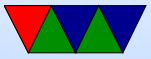


- Various channels, 22MHz wide. Not all available in all countries. Some channels overlap.
- In the US have channels 1 through 11, but 1, 6, 11 are only non-overlapping ones

- 802.11a (1999) 1.5 - 54Mbps
  - Not compatible with B, 54Mbps in 5GHz band
  - 5GHz less crowded, but signal doesn't go as far
  - 48 data channels 4 syc
  - OFDM (Orthogonal Frequency Division Multiplexing) Data is sent on multiple channels in parallel
- 802.11g (2003) 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) 54Mbps - 600Mbps
  - MIMO (multiple input/multiple output antennas)
  - Can do spatial multiplexing, two antennas broadcast on same frequency by aiming signal
- 802.11ad – 7Gbps, 60GHz freq
- 802.11af – white wi-fi, super wi-fi, operates in vacant UHF/VHF TV bands. Receiver uses GPS to find out where it is and what channels are free
- Many more



Wireless Frames

FC	Duration	Addr 1	Addr 2	Addr 3	SEQ	Addr 4	Body	FCS
2	2	6	6	6	2	6	0-2312	4

- Frame format
  - Frame Control (2 bytes)

    Protocol Version (2 bits) [only 0 in practice]

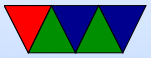
    Type (2 bits): data, control, management

    Subtype (4 bits) [rts,cts]

    ToDS/FromDS(1,1) (going to or from the cell)

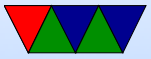
    MF (1) more fragments to follow

    Retry(1)

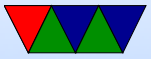


Power Management(1) (into or out of sleep)
More(1) [more coming]
W(1) WEP [encryption]
O(1) frames must be in-order

- Duration/ID (2 bytes) – how long will occupy channel
- Addr1 (6 bytes) Receiver
- Addr2 (6 bytes) Transmitter
- Addr3 (6 bytes) Base Station Source?
- Sequence control (2 bytes) Frame (12) and fragment (4)
- Address4 (6 bytes) Base Station Dest?

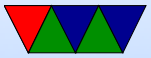


  - Frame body (0-2312)
  - FCS Checksum (4 bytes)
- Addr3/Addr4 optional, usually if bridge.
- Management frames: similar to data frame, restricted to one cell
- Control frames: Short, only two addresses, no data, no sequence, often just RTS/CTS/ACK



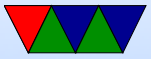
Wireless Network Topology

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



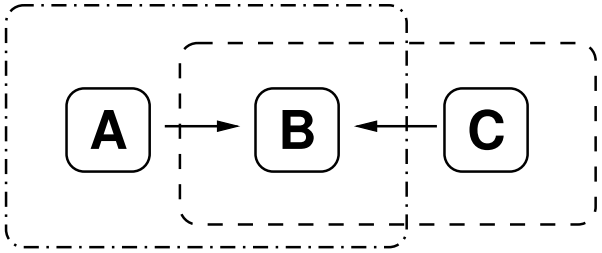
Service Sets

- 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

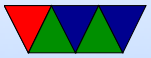


802.11 – Why not just Ethernet over the Air

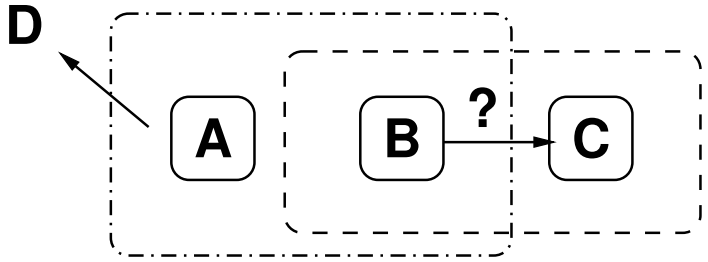
- Hidden station/terminal problem A in range of B, B in range of C, but A cannot see C. If A and C transmit at same time, they'll not get collision, only way of knowing is if not get ACK.



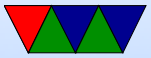
- Exposed station problem. A and C not overlap, but B



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

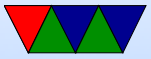


- To deal with this, Distributed Coordination Function (DCF) and point coordination function (PCF)



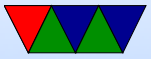
DCF – Distributed Coordination Function

- Basic DCF
  - No central control
  - Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)
  - Different from Ethernet CSMA/CD (D=detection)
  - Every time ready to transmit, looks to see if can transmit (listen to see if channel clear)
  - If clear, waits DIFS (inter frame) time and transmits

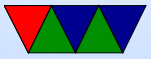


- If busy, waits until clear. Then it will wait a random backoff time before starting. Why? Multiple transmitters might have all been waiting and they would all instantly collide once clear.
- There is a short inter-frame interval (SIFS) which gives time for receiver to transmit an ACK packet.
- If source does not get an ACK, then it backs off and retries

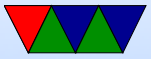
- Optional RTS/CTS mode
  - Before sending data, sends short RTS (request to send) packet



  - Receiver responds with short CTS (clear to send)
  - Data only sent if CTS sent properly
  - All stations can see both CTS *and* RTS, this and hopefully avoids collisions.
  - There's a duration field too to hint how long it will take
  - ACK at end
- Fragmentation – the longer the packet, the more likely it is to lose bits to interference. So split things up into smaller chunks likely to get through
- DCF not optimal, can take 60us to transmit ACK, wheras

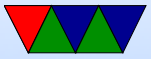


a 54MB connection could have send 3k of data in same time.



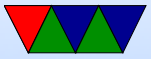
PCF – Point Coordination Function

- PCF provides central control. A point coordinator in the AP periodically transmits a beacon to announce a contention-free period (CFP). Stations keep quiet.
- Sort of like time-division multiplexing
- Guaranteed a certain fraction of bandwidth
- For power saving, base station can tell receiver to go to sleep, and buffer packets for it until wakes up
- Can combine PCF and DCF in same cell.



Does my router use PCF or DCF

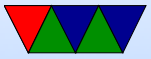
- It appears that most use DCF, PCF is somewhat uncommon
- There is 802.11e which enhances this to Enhanced distributed channel access (EDCA)
- Introduces HCF (Hybrid Coordination Function)
- Still most are using DCF



Wireless Services

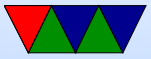
Must provide 9 services

- intracell for dealing with things outside of a cell
  - Association – allow stations to connect to base stations. When arriving announce its identity and capability
  - Disassociation – either side may break the association, should do it before shutting down
  - Reassociation – can change preferred base station, useful for handover (but best-effort)



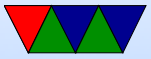
- Distribution – determines best way to route frames
- Integration – in case frame needs to be sent through a non-802.11 network

- Intercell
  - Authentication – check password
  - Deauthentication – to leave network
  - Privacy – encryption
  - Data delivery – modeled on Ethernet, no guarantees frames will get in



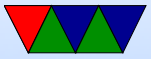
Encryption

- WEP – Wired Equivalent Privacy
  - Used RC4 and CRC32
  - Deprecated 2004
  - Meant to be 64 bit, originally 40 but due to export limitations
  - Later 128-bit. Can enter in hex or ASCII chars
  - Can be cracked fairly quickly these days (10 mins on a laptop)
- WPA – Wi-Fi Protected Access (WPA)

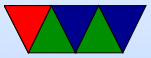


- 802.11i – Temporal Key Integrity Protocol (TKIP)
- 64 or 128 bit encryption key
- TKIP replace CRC, harder to crack, RC4
- WPA-personal Pre-shared key, AKA the password. 128 bits derived from 256 bits. If ASCII, PBKDF2 applied and then SSID used as salt (to prevent rainbow tables)
- WPA-enterprise is more complicated key setup

- WPA2 Wi-Fi Protected Access II (WPA2)
  - 4-way handshake (recent issues with that on many Linux machines), Ironically had issues for too closely following IEEE standard

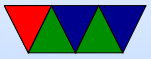


- AES?
- WPA3 – 2018
  - 802.11-2016
  - Simultaneous Authentication of Equals instead of pre-shared key



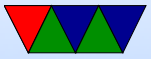
Authenticated

- Three states: not authenticated, authenticated but not associated, authenticated and associated
- device sends probe requests. Advertise data rates and what version of 802.11 supported. BSSID of ff:ff:ff:ff:ff:ff so all access points that hear it will respond
- if an access point (AP) supports a common data rate, it will respond with SSID, data rate, encryption mode, etc
- device chooses an access point and authenticates.

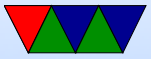


Originally this would have been WEP, but deprecated so often happens in open and usually succeeds. Device sends a 802.11 open authentication frame, seq 0x01

- AP responds saying open with seq 0x02
- if AP receives frames other than auth or probe from device, responds with a deauth to make it start over
- A device can be authenticated to multiple APs but only associated with one
- device determines who to associate with and requests

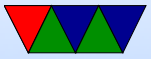


- AP responds and creates association ID
- once associated then WPA/WPA2 has to happen still before data can flow

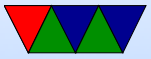


Security Issues

- Packet sniffing
- Easier to tap into a network undetected. Long range antennas
- Malicious association – go into an area with own access point that machines will connect to
- MAC spoofing, set your MAC to an existing machines
- Denial of Service – flood the router so it can't respond



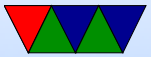
- Deauthentication attack– continually spoof an "I'm leaving" packet from all MAC addresses on network
- Hide you SSID? How effective is that?
- Encryption breaking, see long list of issues on WPA wikipedia page



Transmission Power

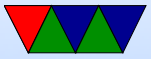
- 802.11b signal typically around 32mW
- Often use dBmW (often shorted dBm) where 0dBm=1mW
- 1dBm = 0.001258925W
- Convert -68 dBm to Watts
  - $P = 1W * 10^{P_{dBm}/10}/1000$
  - -68 dBm = 160pW

- Convert 1W to dBm



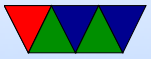
- $P_{dBm} = 10 * log_{10}(1000 * P_W/1W)$
- 1W = 30dBm

- Juno space probe (13 Oct 2016)
  - 8.4GHz, received -135.75dBm (2.7e-20kW) 18kb/s



Channels

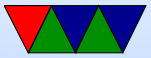
- 802.11b, DSSS 2.4GHz, 2412MHz as first channel, 14 channels 5MHz apart 1-14.
- 802.11g same as 802.11b when talking to b, but a modes when talking to other g
- 802.11a 5GHz band, channels 1-199 starting at 5005MHz 5MHz apart
- CMSA/CA – uses RTS/CTS. 802.11g needs to do this if 802.11b present, slowing things down 20-50%



Linux Interface

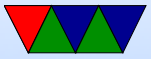
- iwconfig
- iwlist scanning

```
wlan0     IEEE 802.11abg  ESSID:"Whatever"
          Mode:Managed  Frequency:2.452 GHz
                        Access Point: 00:1C:10:11:B4:C6
          Bit Rate=54 Mb/s   Tx-Power=200 dBm
          Retry short limit:7   RTS thr:off   Fragment thr:off
          Encryption key:XXXXX
          Power Management:off
          Link Quality=42/70  Signal level=-68 dBm
          Rx invalid nwid:0  Rx invalid crypt:0  Rx invalid frag:0
          Tx excessive retries:0  Invalid misc:0   Missed beacon:0
```



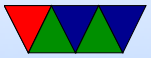
Bluetooth

- Personal Area Network (PAN)



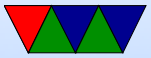
Bluetooth Applications

- Headsets
- Wireless controllers (Wii, PS3)

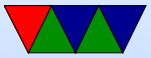


Bluetooth

- 1994 Ericsson. With IBM, Intel, Nokia and Toshiba formed a SIG.
- Named after Harald Blaatand (Bluetooth II (940-981) a Viking king who "united" (conquered) Denmark and Norway. Unite various standards.
- Symbol is runes for HB.
- Get rid of cables, specifically serial cables
- Interferes with 802.11
- IEEE came in an decided to take standard and make it

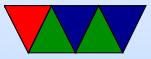


802.15.1 but no longer maintains it



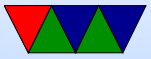
Bluetooth Architecture

- Basic unit: piconet, master node and up to seven *active* slave nodes within 10m
- Many can exist in an area, and can be connected by a bridge. Connected piconets are called a scatternet
- There can also be up to 255 “parked” nodes in a picnoet
- When parked, can only respond to activation on beacon
- Hold and siff?



- Slaves designed to be cheap, so dumb. Master is smart and runs them. slave/slave communication not possible

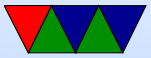
- Master broadcasts clock 312.5us. Master transmits in even, slave in odd.



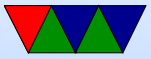
Bluetooth Applications – Profiles

Bluetooth V1.1 has 13 different application protocols.

- Required
  - generic access – link management
  - service discovery – discovering services
- Serial port
  - Object exchange
- Networking
  - LAN access
  - Dial-up

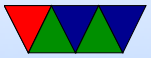


  - Fax
- Telephony
  - Cordless phone
  - Intercom
  - Headset
- File exchange
  - Object push
  - File transfer
  - Synchronization

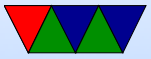


Bluetooth Layering

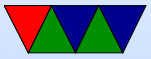
- Radio layer
  - 2.4GHz, 10 meters. 79 channels of 1MHz.
  - Frequency shift keying, 1 Mbps but consumed by overhead
  - Frequency hopping spread spectrum, 1600 hops/sec dwell of 625 usec. All nodes in piconet hop at once, with master controlling this (PRNG) 1,3, or 5 slots/packet
  - Interferes with 802.11. Bluetooth hops faster so causes



more trouble.
  - power output class: 100mW class 1, 2.5mW class 2, 1mW class 3.
- Baseband layer
  - Asynchronous Connection-less link (ACL) packet-switch data at irregular info, no guarantees. one per slice
  - Synchronous Connection Oriented (SCO) – for real time data.
  - Three per slave. Error correction. Each can send 64kpbs PCM audio

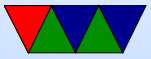


- L2CAP layer
  - accept packets of 64kB and break into frames.
  - Handles multiplexing.



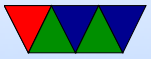
Bluetooth Frames

- Several different formats
- 72 bits access (identify master, as can be in range of multiple)
- 54 bit header
  - (addr(3) frame type(4), flow [buffer full](1), Ack (1) seq(1) checksum(8)
  - This is repeated 3 times.
  - Majority wins (redundancy, cheap small protocol)
- Data 0-2744 bits. SCO always 240 bits.



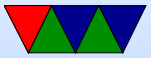
Bluetooth 1.1 (2002)

- First stable version
- Gaussian Freq-shift Keying (GFSK). Smooths signal instead of abrupt 1/0 transition
- 1Mbps peak in theory



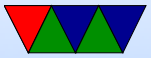
Bluetooth 1.2

- Adaptive frequency hopping, skip busy frequencies
- Up to 721kbps
- eSCO allow retransmitting corrupted packets, at expense of audio latency
- HCI host controller interface, three wire



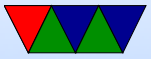
Bluetooth 2.0 (2004)

- 2.0
  - EDR = Enhanced Data Rate
  - BR/EDR 2 and 3Mbps
  - Pi/4 DQPSK – differential quadrature phase-shift keying
- 2.1
  - Secure simple pairing
  - Extended inquiry response



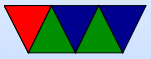
Bluetooth 3.0 (2009)

- Up to 25Mbps "HS" (high speed)
- Alternative MAC, bluetooth set up connection but 802.11 used to transmit data?



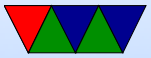
Bluetooth 4.0 (Bluetooth Low Energy) (2010)

- Entirely new stack, designed for low power rapid setup links
- 40 2MHz channels, 1Mbit/s
- Max power 10mW
- Not backwards compatible, but same frequency range
- New profiles



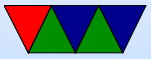
Bluetooth 5.0 (2017)

- Internet of things
- 2MBit/s



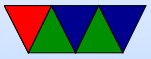
Setting up Connections

- In discoverable mode, will transmit name, class, services, etc on demand
- Has unique 48 bit number but that's rarely seen
- Bonding/Pairing – to avoid people stealing info from your device, require some sort of user interaction to connect for the first time. Before 2.1 it was a 16-byte pin code
- Secure simple pairing, pub key crypto



Security

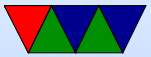
- Prior to 2.1 security can be turned off, and only good for 23.5 hours



Linux Bluetooth

- Competing implementations (bluez, Affix)
- Install bluez
- bluetoothctl

```
[NEW] Controller B8:27:EB:05:9D:BB pi3 [default]
[bluetooth]# exit
[DEL] Controller B8:27:EB:05:9D:BB pi3 [default]
root@pi3:/home/vince# bluetoothctl
[NEW] Controller B8:27:EB:05:9D:BB pi3 [default]
[bluetooth]# scan on
```



```
Discovery started
[CHG] Controller B8:27:EB:05:9D:BB Discovering: yes
[bluetooth]# power on
Changing power on succeeded
[bluetooth]# scan on
Failed to start discovery: org.bluez.Error.InProgress
[bluetooth]# scan on
Failed to start discovery: org.bluez.Error.InProgress
[NEW] Device 64:8A:44:9D:DC:FD 64-8A-44-9D-DC-FD
[NEW] Device D3:E8:9D:CA:71:63 D3-E8-9D-CA-71-63
[CHG] Device D3:E8:9D:CA:71:63 RSSI: -89
```