ECE 435 – Network Engineering
Lecture 30

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Announcements

- HW#10 posted, due Friday
- Project status reports due Friday 17th

Project Status

- Project status reports due Friday (April 17th)
- See pdf on website for full details
- One sentence description of project topic
- What HW/SW you'll be using
- Briefly describe any progress made
- On track to finish
- Say if you're willing to present early (Monday / Wednesday / Friday) (bonus points if early)
  Note in theory Wednesday is Maine Day

Energy Efficient Ethernet

- How much power does Ethernet use?
  - 10/100Mbit 0.1-0.3W
  - Gigabit 0.5W-1W
  - 10 Gigabit 4W?
- Energy Efficient Ethernet (EEE) IEEE 802.3az (2010)
- Turn off when connection not up
- Use less power on shorter cables
- Low-power mode when idle

Auto-Sensing / Auto-Negotiation

- You maybe notice if you have wired Ethernet that your Operating System can sense when you unplug the cable
- It also can auto-detect what speed your switch can operate at
- How can it do this?

Old 10BASE-T – NLP

- Original 10BASE-T had something called "Link Integrity Test" (LIT) with the implementation being "Normal Link Pulses" (NLP)
- Ethernet cards if they haven't transmitted or received in a while send a 100ns pulse every 16ms
- It's a unipolar positive-only pulse
- If no pulse or frame received within 50m-150ms it means link is down

Auto-Negotiation

- Starting with Fast Ethernet and then Gigabit things got more complex, and mandatory
- Instead have a Fast Link Pulse (FLP) of 17-33 pulses sent 125us apart, still 16ms apart
- This is used to send 16-bits of data which contains
  - Supported speed
  - Full or Half duplex
  - For gigabit can indicate more data in next 16-bit page
- Only two pairs used for negotiation so can have trouble

if one of other pairs broken, it looks like a good link but isn't

Auto-negotiation vs Auto-Sending

- When you connect, each side sends list of what it supports
- Problem, if they have the same list will they pick the same to use? Not always
- If somehow doesn't send list, has to guess, passively, Auto-Sending
  - This is difficult, why fast Ethernet uses auto-negotiating rather than auto-sensing
  - need to detect speed, and duplex

- Speed – look at 1010101010 at start of frame
- Duplex – try to cause a collision

Other things to Investigate

- IEEE 1588 Precision Time Protocol (PTP)
- Synchronized Ethernet (SyncE)

What does your machine have

- skylake machine:

```
[   18.240021] e1000e: eth0 NIC Link is Up 1000 Mbps Full Duplex, Flow Control: Rx/Tx
```

- Raspberry Pi:

```
[   77.110505] smsc95xx 1-1.1:1.0 eth0: link up, 100Mbps, full-duplex, lpa 0xC5E1
```

- Haswell machine:

```
[    3.907651] tg3 0000:03:00.0 eth0: Tigon3 [partno(BCM95761) rev 5761100]
 (PCI Express) MAC address f0:92:1c:f5:e8:f3
[    3.919115] tg3 0000:03:00.0 eth0: attached PHY is 5761
 (10/100/1000Base-T Ethernet) (WireSpeed[1], EEE[0])
```

```
[    3.929838] tg3 0000:03:00.0 eth0: RXcsums[1] LinkChgREG[0] MIirq[0] ASF[1] TSOcap[1]
[    3.938174] tg3 0000:03:00.0 eth0: dma_rwctrl[76180000] dma_mask[64-bit]
[   13.758613] IPv6: ADDRCONF(NETDEV_UP): eth0: link is not ready
[   15.404905] tg3 0000:03:00.0 eth0: Link is up at 100 Mbps, full duplex
[   15.411479] tg3 0000:03:00.0 eth0: Flow control is on for TX and on for RX
```

Linux OS Support

- When frame comes in, interrupt comes in
- Allocates sk_buff copies in
- Old: net_if_rx() interrupt, net_rx_action() interrupt/polling
- net_if_receive_skb()
- passes it to proper net level (ip_recv(), ip_ipv6_recv(), arp_recv()

- for send
- `net_tx_action()`
  `dev_queue_xmit()` and then deallocate `sk_buff`
- `qdisc_run()` selects next frame to transmit and calls `dequeue_skb()`

Other Wired Connections

- Note: all high-speed copper interconnects have similar issues to Ethernet
- Low speeds (i2c, SPI, etc) just plain NRZ
- Faster like USB are?
  Step up for each generation
- PCIe?

Ethernet on Spaceships?

- Traditionally satellites and such use MIL-STD-1553, from 1975, 1Mbit/s
- Newer ones might use powerlink real-time ethernet (?)

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?
- Note possibly uses OFDMA like cell-phones? multiple can transmit/receive at once? (instead of or in addition to CSMA-CA?)
- 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 (2025) (Wi-Fi 7)

- Finally released July 2025 after some delay
- 2.4/5/6GHz
- Up to 40Gbps?
- 4096-QAM

802.11bn (202??) (Wi-Fi 8)

- ?

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