# ECE 435 – Network Engineering
# Lecture 20

Vince Weaver

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

vincent.weaver@maine.edu

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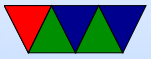
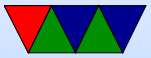
# Announcements

- HW#9 (Ethernet) was posted
- Don't forget project status update due April 13th (next Thurs)



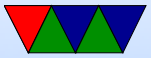
# Project Status

- Summary of topic
- What HW/SW you'll be using
- On track to finish
- Say if you're willing to present early (Tuesday vs Thursday)



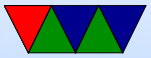
# Classic 10Mbps is too slow!

- 10Mbps not fast enough! What can we do?
- FDDI and Fibrechannel (fast optic-ring), too expensive
- Can we just multiply all speeds by 10? Or else come up with some completely new better thing?
- IEEE decided to just keep everything same, just faster 802.3u 1995
- The other group went off and made 802.12 100BaseVG (which failed)

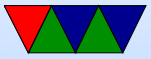


# "Fast" Ethernet (100Mbps)

- 100BASE-TX most common
- BASE means baseband, that it's not modulated on a carrier
- Bit time from 100nsec to 10nsec
- Uses twisted pair/switches, no coax
  - To use cat3 100BASE-T4 wiring needed 4 twisted pair and complex encoding, no Manchester, ternary
  - To use cat5 wiring 100BASE-TX. Two twisted pair, one to hub, one from.

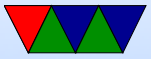


- The pairs are differential pairs, like USB



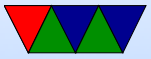
# "Fast" Ethernet (100Mbps)

- Often split between MAC (media access controller) and PHY (physical interface).
- Card configures the PHY via the MII (media independent interface)
- Goal was you could have same card but interchangeable PHY (twisted pair, fiber, etc)
- MII interface
  - 4bit bus
  - Interface requires 18 signals, only two can be shared if



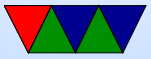
multiple PHY

- So RMII (reduced) was designed. Clock doubled, only 2-bit bus. Fewer signal wires.

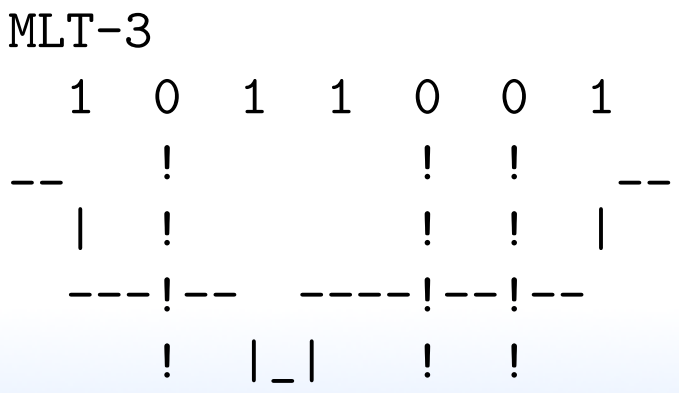


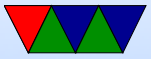
# 100BASE-TX

- 2 pairs inside cat5 cable
- One pair 100MB each direction, full duplex
- 100m distance
- Raw bits (4 bits wide at 25MHz at MII) go through 4B/5B encoding clocked at 125MHz
- 4B/5B means 4 bits encoded as 5, this allows at least two transitions per 5 bits, allows special patterns for end frame or error
- TX then goes through MLT-3 encoding



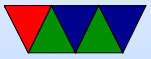
- MLT-3 has three voltages, -1, 0, +1
- Cycles through them -1, 0, +1, 0, repeats
- For a 1, it transitions to next, for a 0, no transition
- 31.25MHz, much like copper version of FDDI (CDDI/TP-PMD)
- Needs an encoding that limits numbers of consecutive zeros



# 4B/5B Encoding

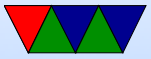
- At least two transitions per 5-bit code
- Provides DC equalization and spectrum shaping
  (what does that mean? This is cut-and-pasted a lot)



# 4B/5B Encoding (layout)

| hex | 4B | 5B |
|---|---|---|
| 0 | 0000 | 11110 |
| 1 | 0001 | 01001 |
| 2 | 0010 | 10100 |
| 3 | 0011 | 10101 |
| 4 | 0100 | 01010 |
| 5 | 0101 | 01011 |
| 6 | 0110 | 01110 |
| 7 | 0111 | 01111 |
| 8 | 1000 | 10010 |
| 9 | 1001 | 10011 |
| A | 1010 | 10110 |
| B | 1011 | 10111 |
| C | 1100 | 11010 |
| D | 1101 | 11011 |
| E | 1110 | 11100 |
| F | 1111 | 11101 |

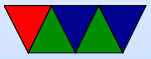
| Control Char | 5B | meaning |
|---|---|---|
| H | 00100 | halt |
| I | 11111 | idle |
| J | 11000 | start #1 |
| K | 10001 | Start #2 |
| L | 00110 | Start #3 |
| Q | 00000 | Quiet |
| R | 00111 | Reset |
| S | 11001 | Set |
| T | 01101 | End (terminate) |



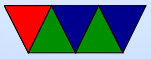
# Gigabit Ethernet

- Two task forces working in 1998/1999
- 802.3z 1998 (fiber), 802.3ab 1999 (copper)
- Could still use hub, problem was the CSMA/CD restriction.
  - About 200m for 100Mbps.
  - For Gb would have been 20m which is not very far.
  - Carrier extension: hardware transparently pads frames to 512 bytes

    Wasteful, 512 bytes to send 64 bytes of data

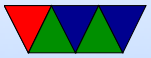


- Frame bursting: allow sender to sends sequence of multiple frames grouped together
- Better solution is just use full duplex
- 1000Base-SX (fiber)/LX (fiber)/CX (shielded)/T (cat 5), more



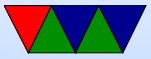
# Gigabit Ethernet – Fiber

- No Manchester, 8B/10B encoding.
- Chosen so no more than four identical bits in row,
- No more than six 0s or six 1s
- need transitions to keep in sync

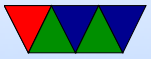


# Gigabit Ethernet – 1000BASE-T

- 5 voltage levels, 00, 01, 10, 11, or control. So 8 bits per clock cycle per pair,
- 4 pairs running at 125MHz, in two directions, so 1GBps
- simultaneous transmission in both directions with adaptive equalization (using DSPs)
  - Actually can send and receive at same time on one pair
  - Basically, when you send the values add up
  - However if you send 1 1 0 1 an you notice on the line

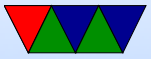


0 2 0 2 you can figure out the other side sent -1 1 0 1
  - Slightly tricky because voltage loss on line
- 5-level pulse-level modulation (PAM-5) [technically 100BASE-TX is PAM-3]. Diagram? looks sort of like a sine wave as cycle through the voltages.
- four-dimensional trellis coded modulation (TCM) 6dB coding gain across the four pairs
  Trellis coding also provides error correction
- Autonegotiation of speed. Only uses two pairs for this, can be trouble if pairs missing.



# Gigabit Ethernet – Other

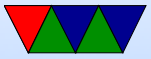
- Try to balance 0s and 1s? keep DC component low so can pass through transformers?
- Fast enough that computers at time had trouble saturating such a connection
- Jumbo Frames? 9000 byte?



# Even Faster Ethernet

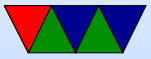
http://www.theregister.co.uk/2017/02/06/decoding_25gb_ethernet_and_beyond/

- Misquote: Not sure what the network will be like in 30 years, but they will call it Ethernet.



# 10Gb Ethernet

- 10Gb: 802.3ae-2002. Full duplex, switches only
- Need Cat6a or Cat7 for links up to 100m
- Expensive. Lots of kind.
- 10GBASE-T, 802.3an-2006 100m over cat6a, 55m Cat6
- additional encoding overhead, higher latency
- Tomlinson-Harashin precoding (THP), PAM15 in two-dimensional checkerboard DSQ128 at 800Msymbol/s



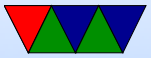
# 2.5Gb Ethernet

- 2.5Gb: 802.3bz (Sep 2016?)
- Like 10Gb but slower. Can't run 10Gb over Cat5e

- Power over Ethernet (for using on wireless access points)

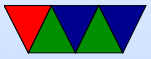
- Power with signal overlaid on top.

- 2.5Gb on Cat 5e, 5Gb on Cat6



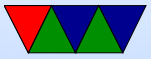
# 25Gb Ethernet

- 25Gb, 802.3by. 25GBASE-T, 50GBASE-T. Available, if copper only a few meters
- Introduced as 10GB not fast enough, but 40GB too expensive
- SFP28 transceivers, both optical and copper

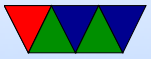


# 40Gb Ethernet

- 40GBASE-T twisted pair 40GBit/s 30m. QFSP+ connectors, like Infiniband
- Terabit? still under discussion
- 802.3ba – 2010 – 1m backplane, 100m multi-mode fiber, 10km single-mode fiber
- 802.3bg –
- 802.3bq – 2016 – 4-pair balanced twisted pair 30m
- QSFP+ transceivers, quad small form-factor pluggable, four 10GB lanes

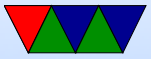


- 802.3ba-2010, 802.3bg-2011, 802.3bj-2014, 802.3bm-2015



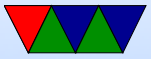
# 100Gb Ethernet

- 4 lanes of 25GB



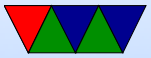
# Terabit Ethernet?

- Maybe someday?
- Still under discussion



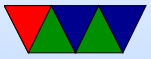
# Energy Efficiency

- 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



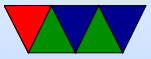
# Autonegotiation

- How figure out line speed and duplex
- Series of pulses sent along periodically
- If not received for 150ms, link is detected as down
- Encoded in the 16-bit series of pulses is the speed / duplex available

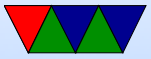


# Auto-sensing vs Auto-negotiation

- 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
- 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

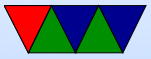


- Duplex – try to cause a collision



# Auto-negotiation

- Similar to link integrity test pulses (LIT) unipolar positive-only pulses, 100ns
- That's how sense link
- For negotiation, fast-link pulse, 16-bit pattern describes link
- duplex, if it can't see a negotiation defaults to half-duplex as it's safe?



# What does your machine have

- skylake machine:

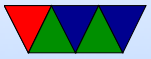
```
[   18.240021] e1000e: eth0 NIC Link is Up 1000 Mbps Full Duplex, Flow Control: Rx/Tx
```

- Raspberry Pi:

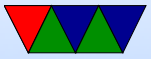
```
[   77.110505] smsc95xx 1-1.1:1.0 eth0: link up, 100Mbps, full-duplex, lpa 0xC5E1
```

- 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])
```

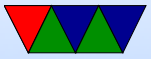


```
[    3.929838] tg3 0000:03:00.0 eth0: RXcsums[1] LinkChgREG[0] MIirq[0] ASF[1] TSOcap[1]
[    3.938174] tg3 0000:03:00.0 eth0: dma_rwctrl[76180000] dma_mask[64-bit]
[   13.758613] IPv6: ADDRCONF(NETDEV_UP): eth0: link is not ready
[   15.404905] tg3 0000:03:00.0 eth0: Link is up at 100 Mbps, full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

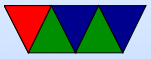


# Linux OS Support

- 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?