Semester Topics

- Network Interface Layer
  - Brief descriptions of existing network types
  - High-level description of Ethernet
- Internet Layer
  - Concentrate on IP
  - Talk a little about IPv6 (replacement technology)
- Transport Layer
  - Concentrate on TCP and UDP
- Applications (as time permits)
  - File transfer: FTP/TFTP
  - Email
  - Remote login: Telnet/RSH/SSH
  - X windows
  - WWW stuff

Class Scope

- To understand computer networking, we need an understanding of the hardware that it's built on
  - Electrical/theoretical characteristics covered in Electrical Engineering classes
    - Dr. Dill's data communication classes
  - Mechanical/practical characteristics
    - Covered in Tysko/Kruse/Ostermann's cs475/575 (Winter)
- In this class, we'll be touching briefly on these topics as needed
- For further information, check references

Two Network Communication Approaches

- Communication networks fall into two broad categories
  - Circuit-switched (connection-oriented)
    - Create a dedicated "path" between two entities that want to talk
    - Guaranteed capacity
      - Bandwidth
      - Delay
      - Others?
    - May not maximize utilization
    - Sometimes needed for real-time applications
      - Audio
      - Video
    - Call setup and teardown can be "expensive"
    - An example is the US phone system

Two Network Communication Approaches (continued)

- Packet-switched (connectionless)
  - Information broken into "packets"
  - Each packet "wanders" the network separately
  - Each packet includes identification of the destination
  - Each packet can be a different size
    - The maximum packet size is fixed
    - 1500 for slow Ethernet
    - approx 10,000 for "large" technologies
  - Motivation is to increase utilization
    - Many applications can share the capacity

- We'll concentrate on packet-switching, but will also discuss some circuit-switched technologies (like ATM)

Broad Characterization Of Packet Switched Networks

- Broad categorization
  - Packet switched networks tend to be categorized as:
    - Local Area Network (LAN)
    - Wide Area Network (WAN)
- Local Area Networks
  - Highest speed
  - Direct connection among computers
  - Large packet sizes
  - Limited distance
- Wide Area Networks (Long Haul Network)
  - Low to medium speed
  - Usually use special-purpose switches
  - Small to medium packet sizes
  - Unlimited distance

Example Local Area Network Ethernet

- 10M bits/sec CSMA/CD network over coaxial cable
- 100M bits/sec CSMA/CD network over twisted pair
  - Currently the most common
  - Uses star topology
- Cable is passive
  - All active electronics in attached hosts
- Length limited to 1500 meters (500 meters per cable segment)
  - 500 meter limitation is for "signal quality"
  - 1500 meter limitation provides collision detection guarantees
- Cards receive all packets, ignore those addressed to others
- IEEE standard known as 802.3

Gigabit Ethernet

- Aka "GigE"
- 1000M bits/sec CSMA/CD network
  - Normally "full duplex"
- Currently supported by many newer computers
  - Interconnections (hubs/switches) still relatively expensive
- Uses star topology
- Example cabling
  - Multi-mode fiber (550 meters)
  - Single-mode fiber (5 km)
  - CAT-5, Cat-5E, CAT-6, CAT-7 twisted pair (100 meters)
    - The RJ45 stuff

Fun With Physics
Ethernet

- Ethernet Signal Propagation (approx)
  $\frac{2}{3}c = \frac{2}{3} \times 3 \times 10^8 \frac{m}{sec}$
  $= 2 \times 10^8 \frac{m}{sec}$

- From end to end for a 500m cable
  $\frac{500m}{prop} = \frac{500m}{2 \times 10^8 \frac{m}{sec}}$
  $= 2.5 \times 10^{-6} sec = 2.5 \mu seconds$

- "Bit width" in seconds
  $10 Mbps = 10 \times 10^6 \frac{bits}{sec}$
  $= 1 \times 10^7 \frac{bits}{sec} = 1 \times 10^{-7} \frac{secs}{bit}$

- "Bit width" in metres
  $\frac{prop}{width} = 2 \times 10^8 \frac{m}{sec} \times 10^{-7} \frac{sec}{bit} = 20 \frac{m}{bit}$

Ethernet Repeater

- Hardware device that connects two Ethernet cable segments and makes them appear to be a single cable
- Repeats all packets from one cable to the other and vice versa
- Introduces delay of 1 bit-time
- Called "level 1" interconnect
- Usually called an "Ethernet Hub" these days
  - Can be very inexpensive, $30 (although hard to find these days)

Ethernet Bridge

- Hardware device that connects two Ethernet cable segments and makes them appear to be a single cable
- Repeats all packets from one cable to the other and vice versa
- Introduces delay of 1 packet-time
- Does not forward collisions or noise
- Does forward all broadcast packets
- Makes multiple Ethernets appear to be a single, large Ethernet
- Called "level 2" interconnect
- Usually called a "switch" these days

Modern Ethernet Switches

- Mixing 10Mb, 100Mb, and 1000Mb network connections requires bridges (switches) instead of repeaters (hubs)
- They're fairly inexpensive
  - 8 port 10/100 Ethernet switch perhaps $40
  - GigE capable switches are $10 to $20 more
  - Most modern switches auto-sense the connections so that you can "daisy chain" them without needing an Ethernet crossover cable or a switch to set
- "Managed Switches" are better
  - You can monitor them
  - Provide statistics for logging and/or debugging

Physical Network Addresses

- Each machine attached to a packet switch network is assigned a unique physical address
- Sender must supply destination address when transmitting a packet
- In most technologies, sender supplies source address as well
- Each technology defines its own address scheme
- Ethernet as an example
  - 48-bit address obtained when device is manufactured
  - All 1s address reserved for broadcast
  - One-half of the addresses reserved for multicast (a restricted form of broadcast); assigned by customer

Ethernet Frame Format

- After Xerox finished the original Ethernet Specifications, the IEEE standardized a slightly different version with a different header format
  - "With careful planning", the two versions can be run on the same wire
- Original Ethernet Specification

Preamble	Dest Addr	Source Addr	Frame Type	Frame Data	CRC
64 bits 8 octets	48 bits 6 octets	48 bits 6 octets	16 bits 2 octets	368-12000 bits 46-1500 octets	32 bits 4 octets

- IEEE Ethernet Specification

Pre.	Dest Addr	Source Addr	Length	DSAP	SSAP	Ctrl	Data	CRC
8 octets	2 or 6 octets	2 or 6 octets	2 octets	1 octet	1 octet	1-2 octets	variable	4 octets

How Adaptive Ethernet Bridge Uses Addresses

- Bridge begins with no knowledge of which machines connect to which wire; it forwards all packets
- Bridge watches **source** address in packets to form list of which machines reside on each side
- Bridge uses **destination** address and location list to decide whether to forward packet
- Bridge always forwards broadcast and multicast packets

Another LAN Example FDDI

- Architecture is a "ring" rather than a "bus"
  - Actually 2 rings
- Everything you send eventually comes back to you
- A sender looks at the data coming back to ensure that it wasn't "garbled"
- Originally for Optical Fiber, now also runs on "copper"
- Typically runs at 100 Mbps
- Contention for the wire is handled by a circulating "token"
- To send, a station waits for the token
  - Grab the token
  - Send your data
  - Re-insert the token
  - How does this compare to Ethernet?

FDDI Details

- Self healing
  - Lost tokens are recovered
  - Broken rings are spliced together
- Frame format
  - 16 bits of Preamble
  - 8 bits of Start Delimiter
  - 8 bits of Frame Control
  - 16 or 48 bits of destination address
  - 16 or 48 bits of source address
  - 0 to 240 bits of routing information
  - 32 bit Frame Check Sequence
  - 4 bits of End Delimiter
  - 12 or more bits of Frame Status
- Maximum frame size is 4500 octets

Example Network
Point-to-Point "Network"

- Direct connection between two machines
- Link-level protocol specifies
  - Data link (framing) format
  - Error detection/recovery scheme
- Various transmission media available
  - Twisted Pair, Coaxial Cable, Optical Fiber
  - Microwave/Satellite
  - Infrared
  - Radio Waves

Example Point-to-Point Network SLIP

- Often used between modems across phone lines
- SLIP provides no "addressing", all data is "from the guy at one end and to the guy at the other end"
- Defines two "magic" characters
  - END (decimal 192)
  - ESC (decimal 219)
- To send a packet of information, the sender sends the data followed by END
- What if the data itself contains END?
  - END is "escaped" in the data by sending ESC followed by (decimal 220) instead.
  - ESC is "escaped" in the data by sending ESC followed by (decimal 221) instead

Example Point-to-Point Network Point-To-Point Protocol (PPP)

- Also usually used between modems
- Supports addressing
- Supports multiple data types
  - TCP/IP
  - Appletalk
  - Novell
- Supports authentication
- Many other features

Example WAN ARPANET (1968-1989)

- Original wide area backbone around which TCP/IP was developed
- Initial funding from Defense Advanced Research Project Agency
- In existence 1968-1989
- Leased line interconnection among switching machines called Packet Switched Nodes (PSNs)
- Switches originally called IMPs
- Biconnected (no single point of failure)
- 56K bits/sec line speed

Example WAN
NSFNET (1987-1992)

- Funded by National Science Foundation
- Motivation: to connect all scientists and engineers
- Three-level hierarchy
  - Wide area backbone spanning geographic U.S.
  - Many mid-level (regional) networks that attach to backbone
  - Campus networks at lowest level
- 1992 Version
  - Leased connections provided by MCI
  - Switches provided by IBM
  - Reached 1 billion packets per day by November, 1992

Advanced Networks & Services

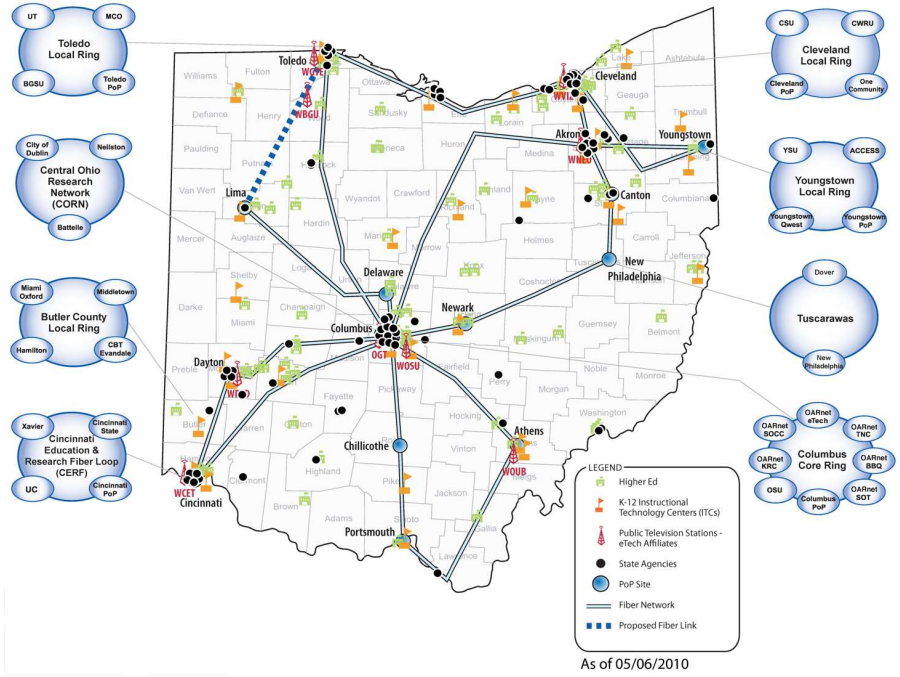
- National Science Foundation wanted out of the business of supporting networking
- ANS formed as not-for-profit corporation
  - Formed in late 1991 by MERIT, IBM, and MCI
    - MERIT had the operations experience
    - IBM supplied the hardware
    - MCI supplied the wires (optical fiber)
- Owns the current T3-speed (45 Mbps) backbone
- Was considered the first step toward commercialization and privatization of the Internet
- 1993 Version
  - Each leased connection operates at T3 speed
  - Built and owned by Advanced Networks & Services (ANS)

No More Backbone

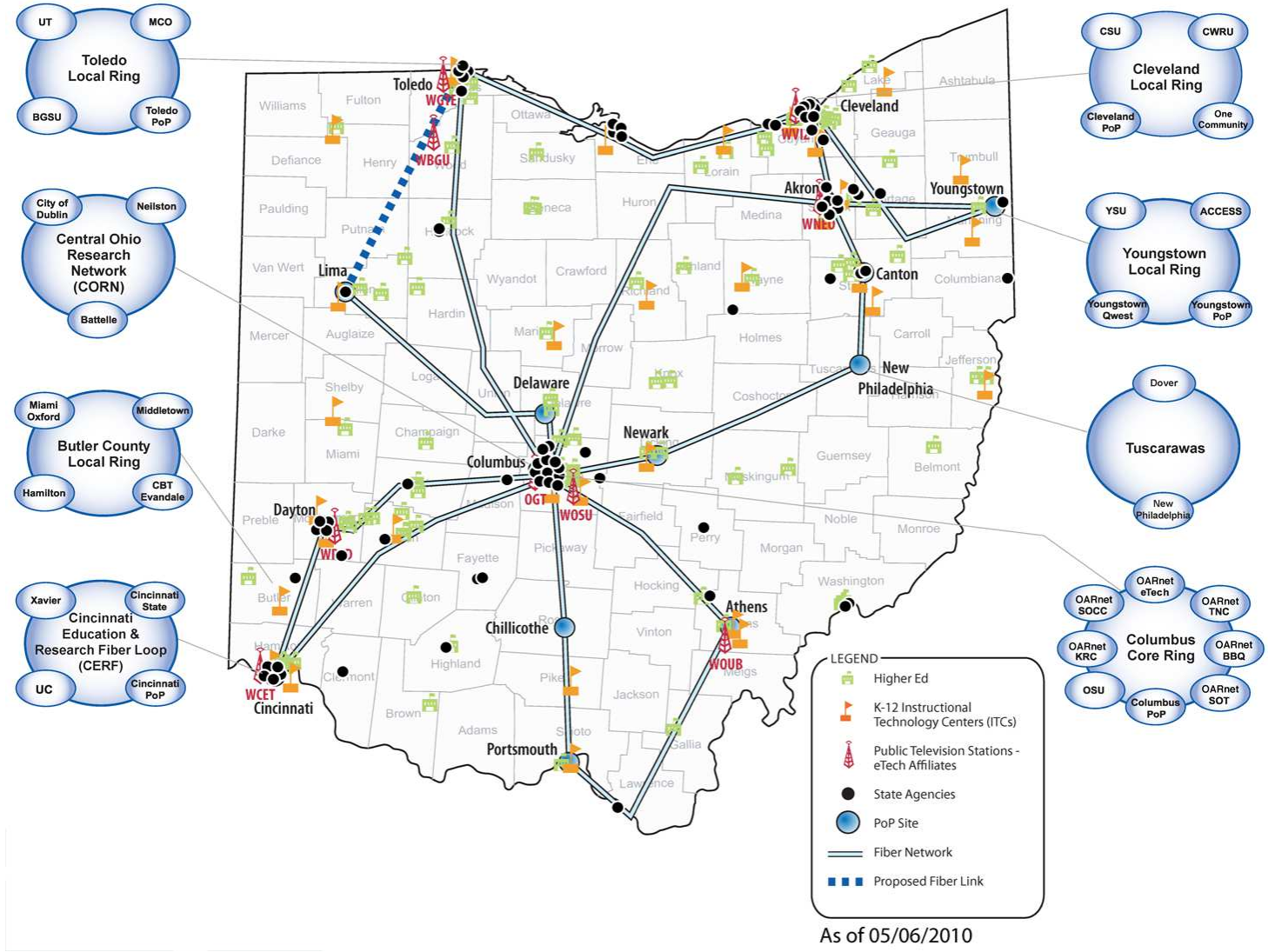
- Today, the notion of the "backbone network" is largely gone
- "The Internet" is a collection of regional/global network providers that join together at multiple locations
  - ATT
  - Sprint
  - MCI
  - Verizon
  - ...

Example Regional WAN OARNET (was briefly OSCnet)

- Ohio University currently gets its service from a regional ISP called OARNET (OSCnet)
  - Serves most of the Colleges in the state
  - Also serves NASA, etc...
  - Their *Third Frontier Network* currently consists of several rings run over 10Gbps optical fibers



Oarnet
Third Frontier Network



OU's Network Connection

- Our main provider is OARNET (now OSCnet)
- Two logically-separate connections
  - Internet II link to other Ohio campuses
    - Roughly 200 Mbps
  - Internet I link to the rest of the Internet
    - 450 Mbps
- Previously had a backup link for when OARnet was down
- Previously had "peering arrangements" with local access providers, now gone
  - Frognet
  - Time Warner

Common Communication Speeds Digital

- DS-0
  - The base unit of digital transmission capacity.
  - 1 communication channel = 1 simultaneous voice grade equivalent with a communication capacity of 64 thousand bits per second (64Kbps).
- DS-1
  - T1- The equivalent of 24 multiplexed voice grade channels (DS-0s). 1.5Mbps
- DS-2
  - T2 - 4 T1 channels. 6.3Mbps
- DS-3
  - T3 - 28 T1 channels. 45Mbps
- DS-4
  - T4 - 6 T3 channels. 274Mbps

Common Communication Speeds
Optical

- OC-1 - 51.84Mbps: 1 DS-3, 28 DS-1, 672 DS-0
- OC-3 - 155.52Mbps: 3 DS-3, 84 DS-1, 2016 DS-0
- OC-9 - 466.56Mbps: 9 DS-3, 252 DS-1, 6048 DS-0
- OC-12 - 622.08Mbps: 12 DS-3, 336 DS-1, 8064 DS-0
- OC-18 - 933.12Mbps
- OC-24 - 1244.16Mbps
- OC-36 - 1866.24Mbps
- OC-48 - 2488.32Mbps
- OC-96 - 4976.64Mbps
- OC-192 - 9953.28Mbps