Communication Protocols and Internet Architectures

Harvard University

Lecture #3

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ALIGHLSOD1701

Lecture Agenda

- Course Logistics
- Review and Q&A
- LAN Topologies and Building Blocks
- Ethernet and LAN Protocols
- Ethernet Switching
- Ethernet Configuration
- What is the Internet
- One Minute Wrap-Up

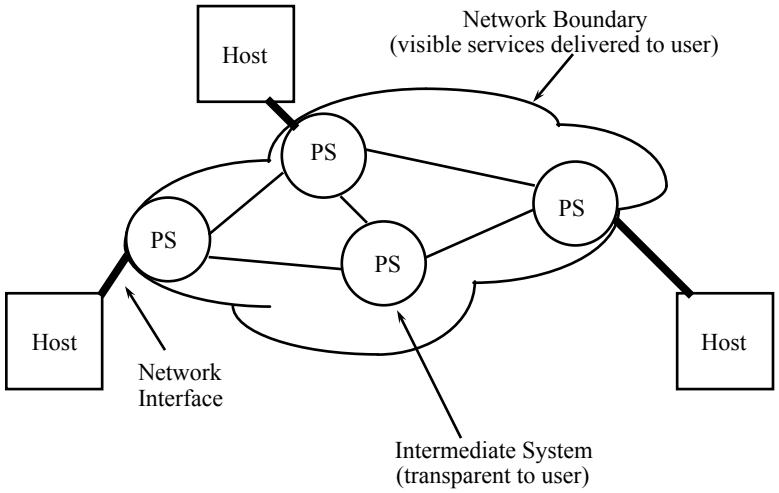
Course Logistics

Course Logistics

- Please contact the instructor if your homework is going to be late. Completing all of the homework is essential to understanding the course material, and not submitting a homework assignment will typically lower your grade in the course.
- There will be an online midterm exam and in-class, closed book final exam.
- If you live in New England, you must take the final exam at Harvard on the date it is scheduled. Distance students will need to have their exam proctored.
- **Please submit a one minute wrap-up after each lecture. Thank you!**

Q&A and
Some Things from Previous Lectures

The Network "Cloud"



Source: A Protocol for Packet Network Interconnection,
published in 1974, IEEE Transactions on Communication

Switching

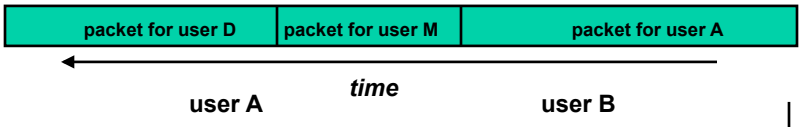
- Circuit Switching
- Message Switching (Telegraph, 1800s)
- Packet Switching
- Cell Switching (Used fixed size packets: ATM is the common example from the 1990s. Lots of development and dollars, but little deployment. Skip references in any readings.)
- Optical Switching
- .. and other options

When is switching used, and when is multiplexing used?

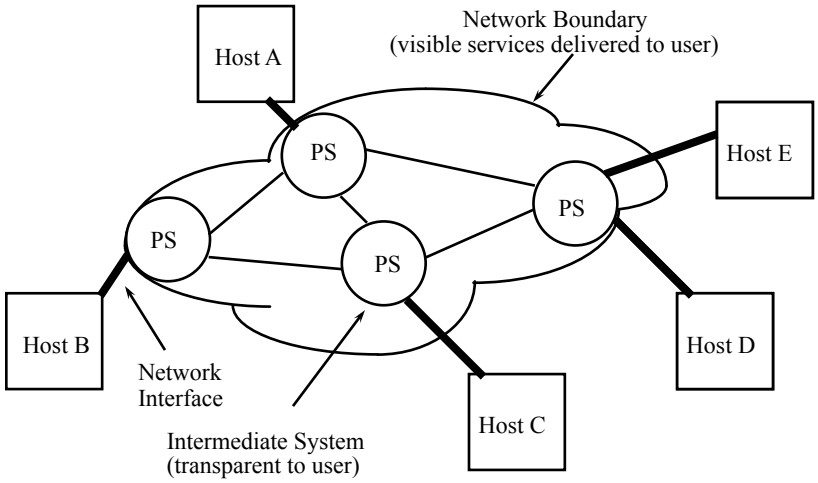
Packet Switching

- Packet Switching evolved to support computer communications
  - Separate data into packets
  - Move a packet of data from one computer to another
  - Allows for the resource sharing of the links and switches
  - Packet contains a header and a payload, and a minimum and maximum packet size (along with many other details) is set by the protocol
  - Emphasis is on efficiently moving blocks/packets of data with no errors

- ***Individual packets are directed out a particular port on the switch based on the address in the packet, and then the outbound packet utilizes the entire capacity of the link, but for a very, very, very short period of time. This is not an easy concept to understand.***



The Network "Cloud"



Source: A Protocol for Packet Network Interconnection, published in 1974, IEEE Transactions on Communication

Protocol Design 101

Protocol Design Issues for a Protocol Used in a Network with a Bus Topolgy

- Does the protocol need addressing?
- Can each station hear every other station? How should the protocol support this?
- Should the protocol be reliable?
- What else should be considered

SP3 Protocol Framework

- Service
  - The Service is a description of what the protocol does, not how it is done. This should be a few sentences long.
- Purpose
  - The Purpose describes the specific functionality that the protocol provides and how it is accomplished. Examples are flow control, error detection, error correction, etc.
- Packets
  - The Packet layout determines how the various bits and fields within the packet are defined, assembled and used.
- Procedures
  - The Procedures describe the various packet exchanges and the reason for each exchange.

SP3 - Service
What type of Service does the protocol provide?

The Service is a short description of what the protocol does, not how it is done. For example, a link layer protocol could provide any of the following services

- Reliable service, including sequenced delivery. This is commonly known as connection-oriented service.
- Reliable service, but not with sequenced delivery.
- Unreliable service. This is known as connectionless or datagram service. (IP, UDP)
- Unreliable service, but with the sequenced delivery of messages. (RTP is an example of this.)
- Are there more?

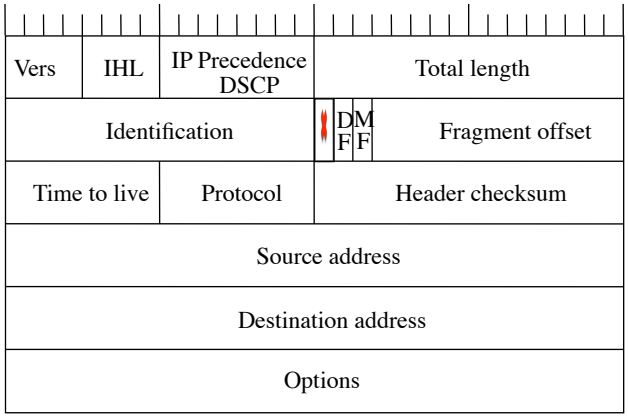
SP3 – Purpose

What specific functionality does the protocol provide and how does it do it?

- Addressing
- Multiplexing
- Sequencing
- Error control - two parts to this, detection and correction
- Flow control
- Option negotiation
- Encryption
- Fragmentation and reassembly
- *plus many others...*

SP3 Packet

What do the fields in this IPv4 packet header do?



SP3 – Procedures

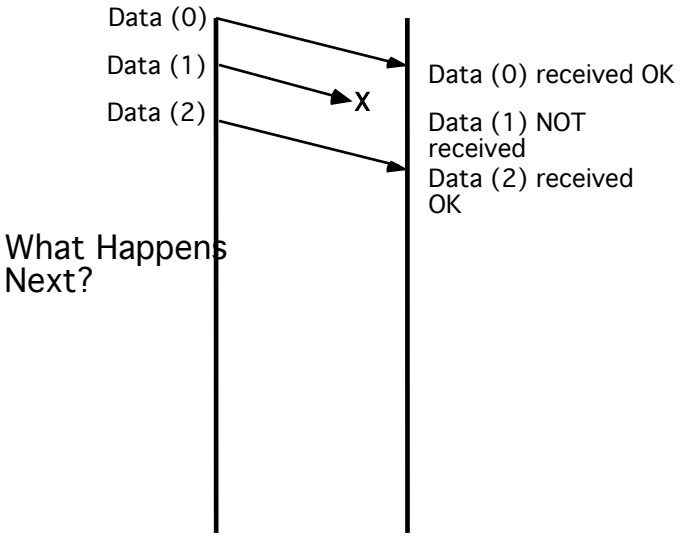
What Procedures does a protocol use to implement the following functionality:

- Connection Establishment or Initialization
- Data Transfer
- Connection Release or Disconnect
- Error Handling (of many different types)

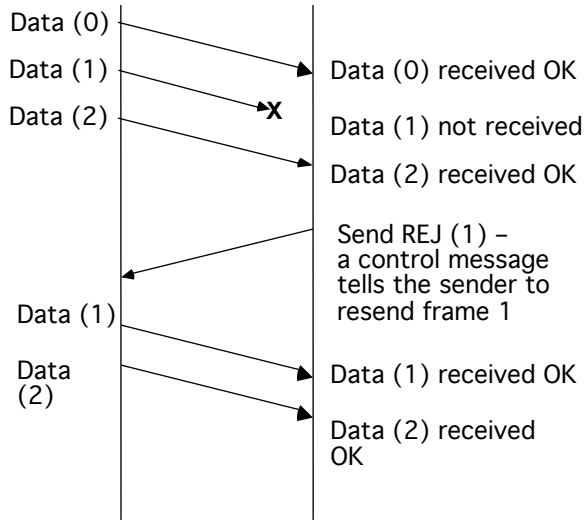
Addressing

- Should addresses have local or global significance?
- How should addresses be structured?
- How many addresses are needed in a packet or frame given that they can have local or global significance?
- How are addresses assigned?
- Can addresses be private?
- What is the difference between an address, a name, and a route?

The Sliding Window - Error Control

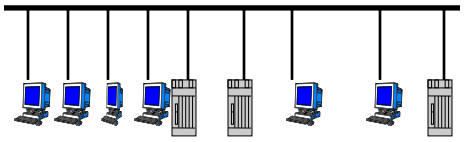


The Sliding Window - Error Control

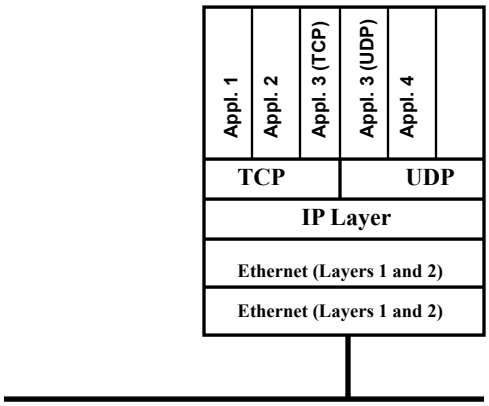


Local Area Networks

What is a LAN?



LANs, WANs, PANs, etc. reside in Layers 1 and 2 of the Five Layer Model



Classic Network Topologies

- Point to Point (pt-to-pt)
- Star
- Bus
- Ring
- Mesh

Notes:

- This list describes the topology, not the type of media or the protocol
- A separate question is whether the topology and media support broadcast (or multicast)

Characteristics of LANs versus WANs

- What are the important distinctions between a LAN and a WAN (Wide Area Network)?
- If distance or physical topology distinguishes the two types of networks, what are the implications of these differences?
- What is not an important difference between them from a protocol design standpoint?

Characteristics of LANs versus WANs

- Network reach (i.e., distance, physical layout)
- Physical media - wired, RF, optical
- Ownership, control and management
- Cost structure
- Bandwidth
- Error rate
- plus others

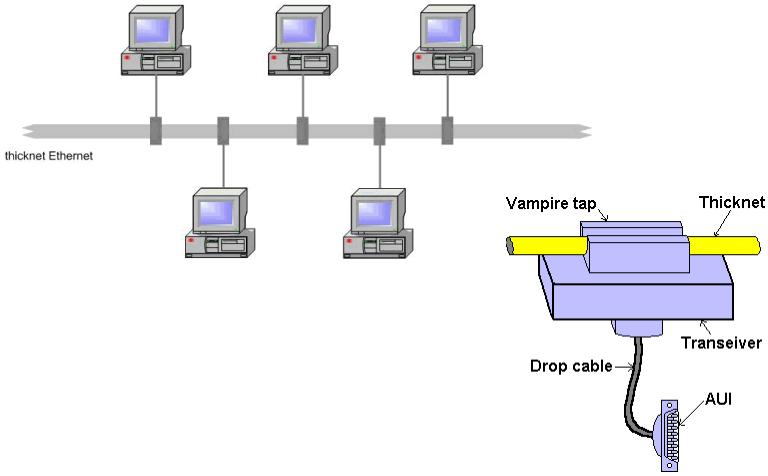
LAN Building Blocks

- System wiring
- Network interfaces: wired and wireless
- LAN protocol stack (MAC/LLC, 802.11 a/b/g/n/etc.)
- Ethernet hubs, switches (bridges) and routers (Hubs are very rarely used today and bridge is the older name for an ethernet switch. Gateway is the older name for router.)
- Network layer and transport layer protocols
- OS support
- End user applications
- Network management systems
- and many more of course

Ethernet Topology and Wiring

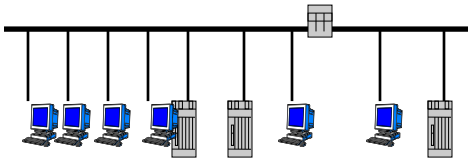
- Ethernet was originally designed as a shared bus topology
- Ethernet media
  - ***Historical –*** *Original Ethernet standard used thick coax with vampire taps. Then "Thin" ethernet used coax cable TV style (BNC) connectors. Standards are 40 years old.*
  - Unshielded Twisted Pair (UTP) for 10/100/1000BaseT
  - Optical fiber cable connections
  - Wireless (multiple variations)
  - LED lighting options in development
- Ethernet Hubs – **Old technology**, **rarely used,** but important to understand, 10/100 mbps
  - Implementation creates a single shared topology bus, but it looks like a physical star topology
  - End stations see a single logical LAN segment, as though there were a single shared bus

Original Ethernet Coax Based Network

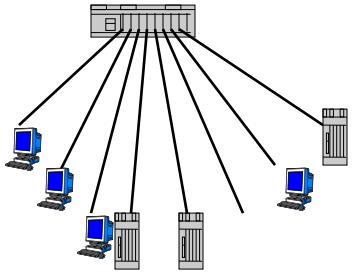


Source and copyright unknown

Ethernet Topologies - 1

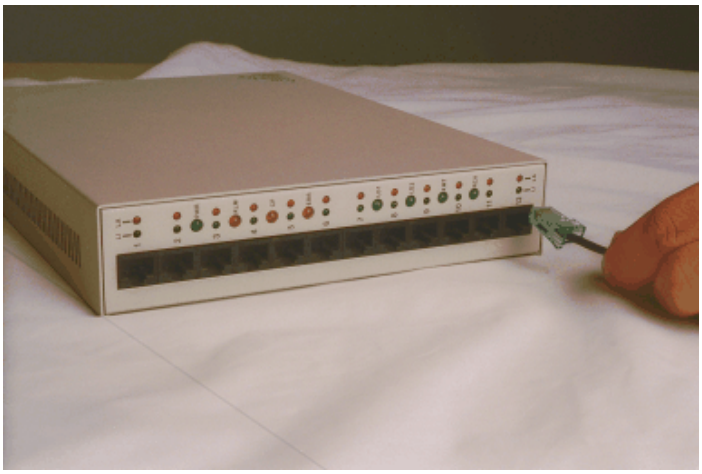


Classic (OLD) Bus Wiring with Coax & Repeater



Comparable Topology with 10/100/1000 BaseT

Ethernet Hub, Switch or Router - Photo #1
All devices look pretty much the same today.



Source and copyright - D. Comer Instructor's Resource CD

Ethernet Switch or Router - Photo #2
All devices look pretty much the same today.

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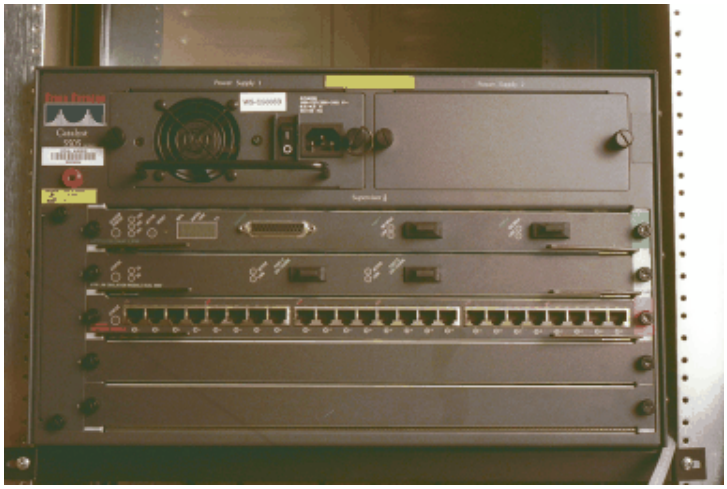
Ethernet Switch or Router - Photo #3
All devices look pretty much the same today.



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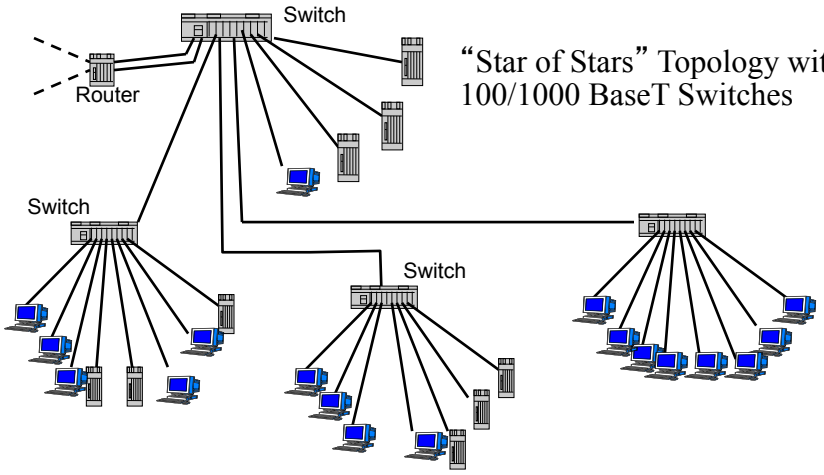
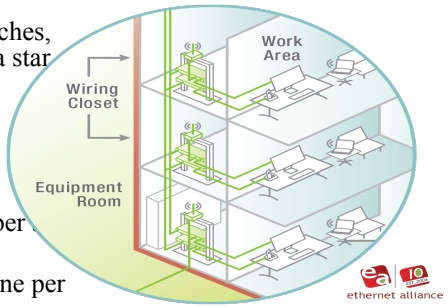
Typical Ethernet Topology



"Star of Stars" Topology with 100/1000 BaseT Switches

LAN Wiring Design and Implementation (2)

- Wiring Topology
  - Devices connected via ethernet switches, but the layout is typically drawn as a star bus
  - Star of stars topology is common implementation in buildings
- Wiring Building Blocks
  - Wiring Components – UTP wire, fiber, patch panels, connectors, etc.
  - Horizontal distribution (typically done per floor for larger buildings)
  - Communication closets or wiring closet for the switches on a single floor.
  - Vertical distribution connects together different floors and also connect to main equipment room
  - Connection to WAN called a Demarc



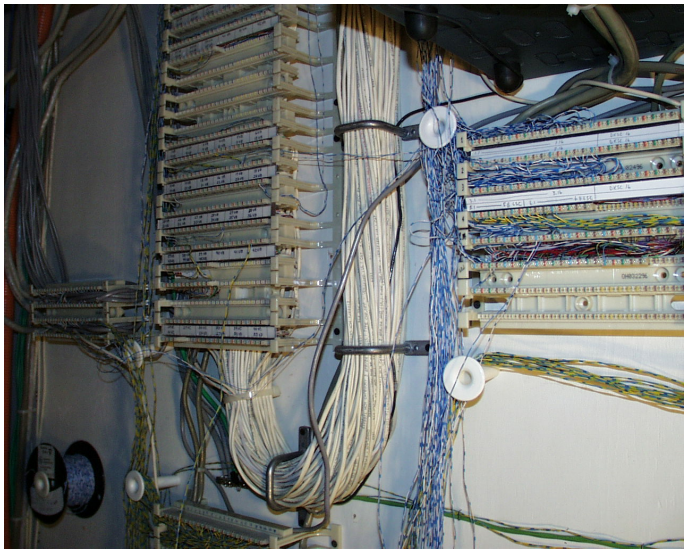
Graphic from Ethernet Alliance

LAN Wiring Design and Implementation (2)

- There are EIA and IEEE standards for ethernet wiring. In addition to these standards, there are important building codes, fire codes, and electrical codes that must be followed. The specific safety and building codes depend on where you live.
- System Administration and Management of all the wires and devices is still a very difficult problem.
- Wireless networks reduce the number of wires, but remember that wireless access points must be connected to the building's equipment room and this is done via UTP or fiber. In other words, wireless networks still require wired connections.

Old Style Telephone Facilities are (Unfortunately) Still Used for Data

Telco and Data Building Wiring - 1



Typical Building Wiring -2

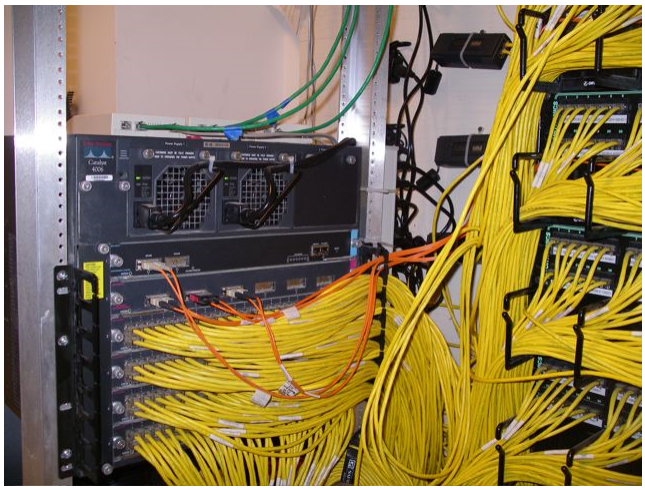
The computers have been upgraded but not the wiring

Well Designed Building Wiring

The switch (in rack on right) has been upgraded but not the wiring

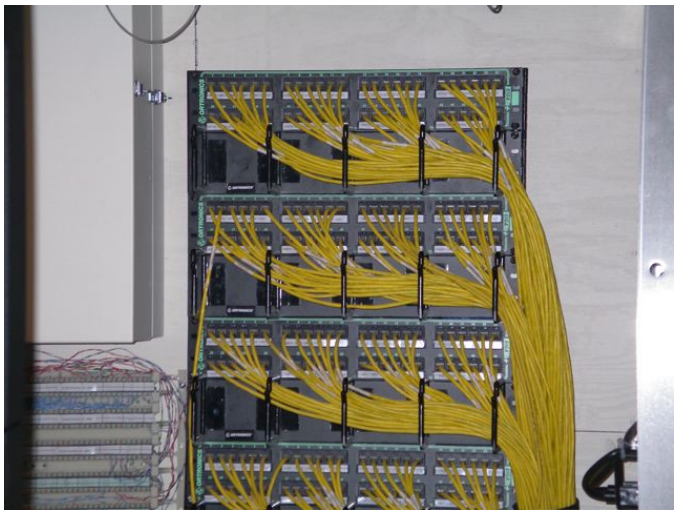
Wiring and Switch

The switch (in rack) has been upgraded but not the wiring



1,000s of Wires in a Typical Building

Well Managed Patch Panel



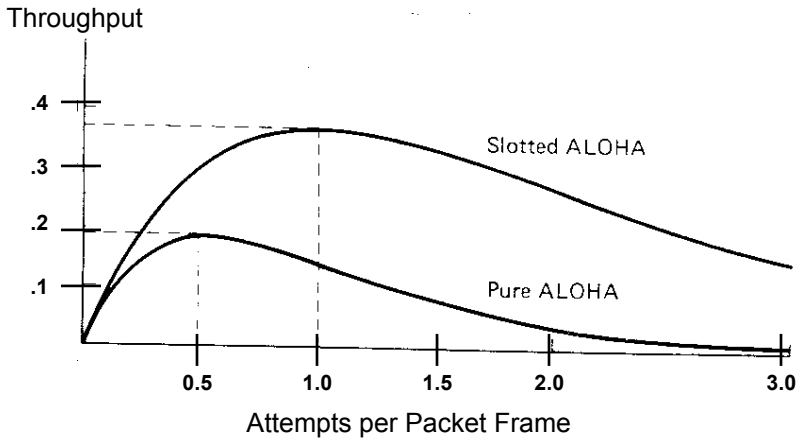
Typical Wireless Access Point

Channel Allocation for a Shared Multi-Access Channel

The Channel Allocation Problem

- Objective is to share a single multi-access channel in a fair way among multiple stations
- Options include static versus dynamic assignment of channel, and centralized versus distributed management of the channel
- ALOHA protocol and slotted ALOHA are important for both historical and practical reasons. ALOHA was developed in Hawaii 50 years ago and it was the basis for the wired ethernet standard.
- The performance and stability of CSMA/CD and follow-on protocol still used today in wired and wireless ethernet is important to understand since resource sharing continues to be an important problem.

Throughput Versus Offered Traffic



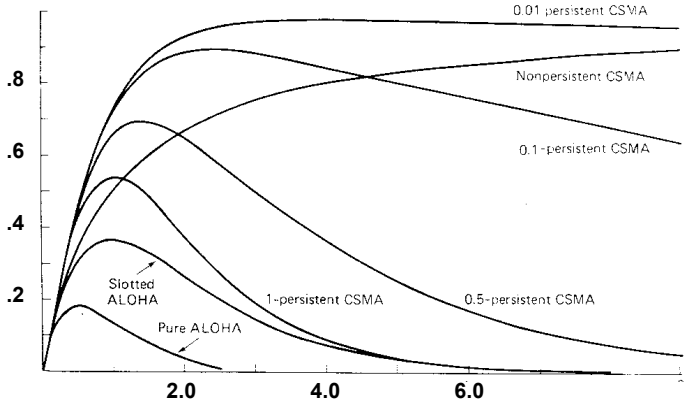
(Source and copyright 2003
Tanenbaum Computer Networks, Fig. 4-3)

Ethernet Medium Access Control

- Classic Ethernet LAN is a broadcast media
- Medium Access Control uses CSMA/CD
  - All stations broadcast on same channel
  - Stations listen for clear channel before sending
  - Sending stations listen for collision
  - Colliding stations back off and wait for a random time before retransmitting, they repeat this a few times
  - Collisions increase as number of active stations increase
- It is still important to understand CSMA/CD even though hubs should never be used today to build LANs since wireless LANs continue to share a single channel. (LANs today use Ethernet switches which have one device per port.)

Channel Utilization Comparison

(Not on an exam)



(Source and copyright 2003 Tanenbaum Computer Networks, Fig. 4-4)

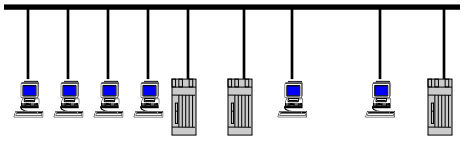
Is ethernet reliable or unreliable?

Ethernet Frame Format

Ethernet Frame
(improperly called a Packet)

Frame starts here … . . . . . and continues off the page….

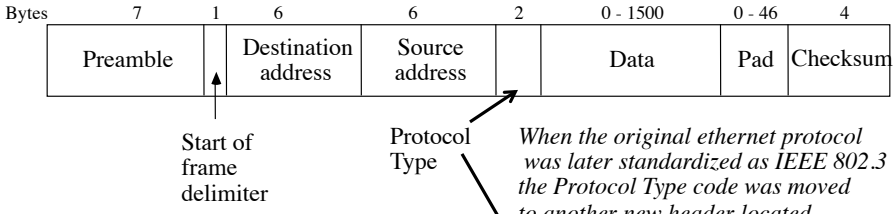
```
00 00 a7 11 57 dd 08 00 09 38 24 31 08 00 45 00 00 38 b3 ….
```



Ethernet and IEEE 802.3 Frame Formats

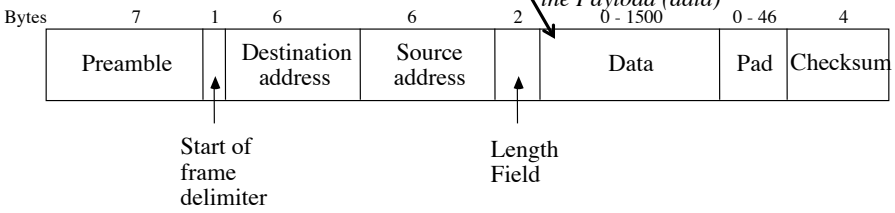
(There are two compatible formats used today for wired ethernet)

Ethernet – *We will focus on this format.*

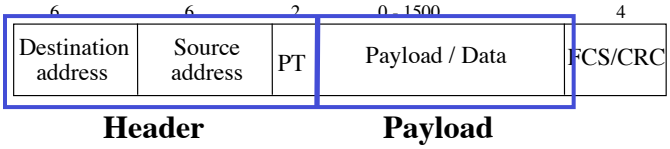


When the original ethernet protocol was later standardized as IEEE 802.3 the Protocol Type code was moved to another new header located after the length field and before the Payload (data)

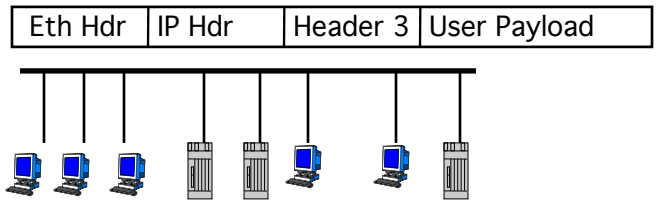
IEEE 802.3



Typical Representation of the Ethernet Frame Format and the One We Will Use in Class



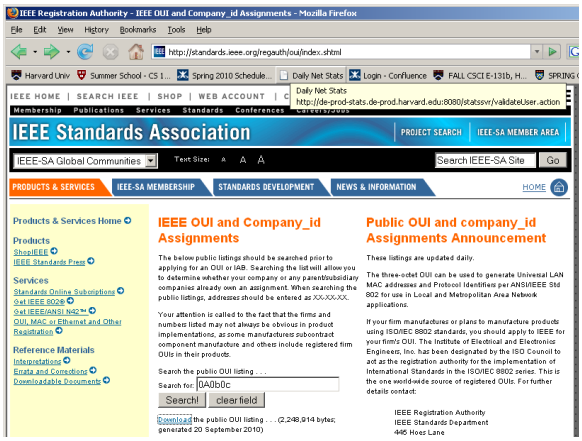
Encapsulation – Ethernet and IP Headers



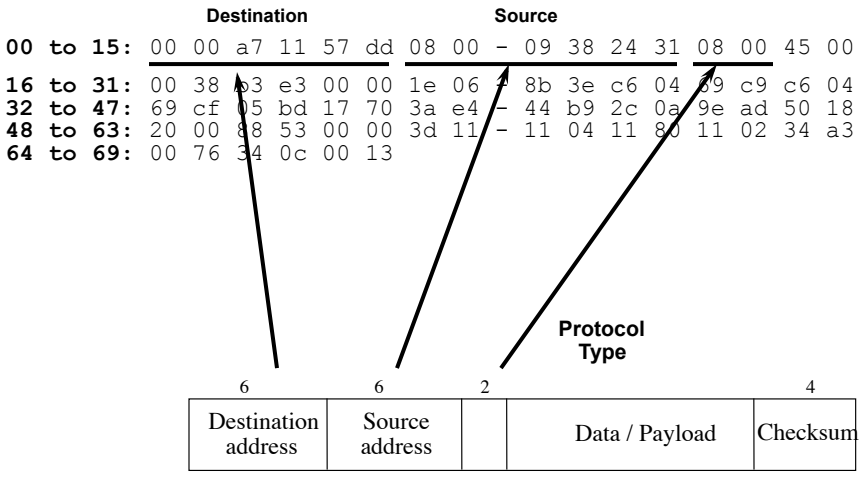
Ethernet 802 Addresses

- Frame contains both source and destination addresses
- Address is 48 bits including Multicast and G/L bits
- 24 bits are OUI (Organizationally Unique Idenitifier)
- Other 24 bits are unique within a given OUI
- Broadcast address is all ones
- There are many different multicast addresses
- Bit ordering issues are nontrivial, but fortunately, all handled by the chips today.
- *The IEEE now refers to the OUI as a MAC Address Block Large (MA-L), but we will continue to call it the OUI*

OUI Standardized by IEEE
http://standards.ieee.org/

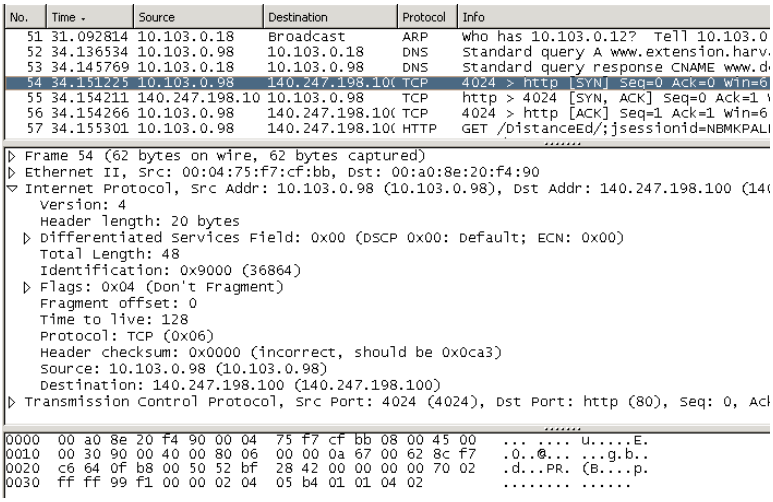


Ethernet Frame



Ethernet Trace

Remember that Harvard policy forbids monitoring or capturing network traffic

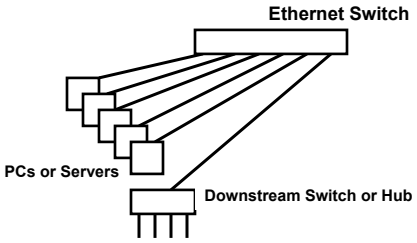


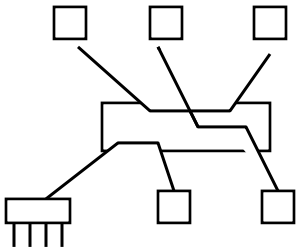
Ethernet Switching

Repeater/Hub versus Bridge/Switch versus Router

- Hub/Repeater (Should not be used to build networks)
  - Improved distance
  - End stations see one physical LAN
  - Single broadcast domain, single collision domain
- Switch/Ethernet Switch/ historical name was bridge
  - End stations see one logical LAN
  - Protocol insensitive
  - Single broadcast domain, multiple collision domains
- Router (sometimes called a L3 Switch)
  - Protocol sensitive (at layer 3)
  - Traffic isolation
  - Multiple broadcast domains, multiple collision domains
  - End stations see multiple networks and of course, multiple LANs

Ethernet Switch Topology



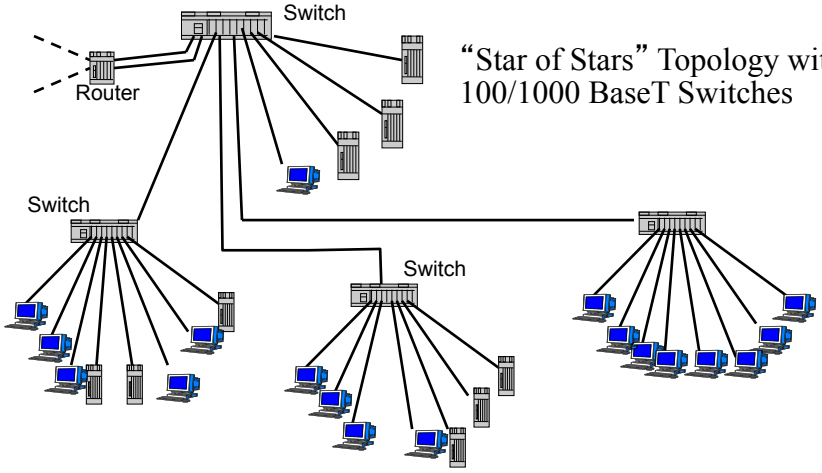


A switch uses the same wiring approach as a hub

BUT

Multiple parallel paths are provided by the switch.

Typical Ethernet Topology



"Star of Stars" Topology with 100/1000 BaseT Switches

Ethernet Switch Functionality

- Implements frame filtering and forwarding to improve network performance (no shared link from switch to host)
- Can also implement the Spanning Tree Protocol to prevent broadcast storms when switches are connected in a loop. STP is important but we do not study this protocol in this course due to a lack of time.
- Implements Network Control and Management

Historical Note:
The first ethernet switches were called ethernet bridges and they had two ports. The large bridges twenty years ago had eight or maybe sixteen ports. Switches today can have 100s of ports.

Switch Filtering and Forwarding

- Receive a frame on a port
- Discard frame if bad checksum
- Learn (or re-learn) that the station with the source MAC address of the frame is located "off that port." Update switch table of address and port information.
- Look at destination MAC address and if it is a broadcast, forward frame out all ports (except the port it arrived on.)
- Look at destination MAC address and if not in table, forward frame out all ports (except the port it arrived on.)
- Look at destination MAC address and if found in the switch table then forward the frame out the specified port (unless it is the port it arrived on.)

Ethernet Switching Implementation

We are posting a previously recorded lecture on this topic; this material is an important part of this course.

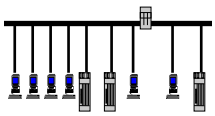
Ethernet: Some Real World Details

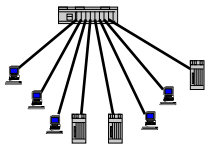
Gigabit Ethernet

- Gigabit (1Gbps) ethernet was first used as a high speed backbone link to interconnect core switches and routers. It is now a standard feature on almost all devices.
- 1000Base-T runs over UTP and uses the same ethernet frame format.
- Gigabit ethernet over fiber has different distance constraints depending upon the type of fiber. This allows for ethernet based campus networks, and carriers use it to provide ethernet based access networks.
- 10-Gigabit ethernet fiber connections are common, and 40 and 100 Gigabit are available, and 400/800 Gig is in development. This of course is not the end of the ethernet story.

Half Duplex versus Full Duplex Ethernet

Unfortunately, this is still a problem today!





Original Ethernet and 10BaseT are half-duplex protocols

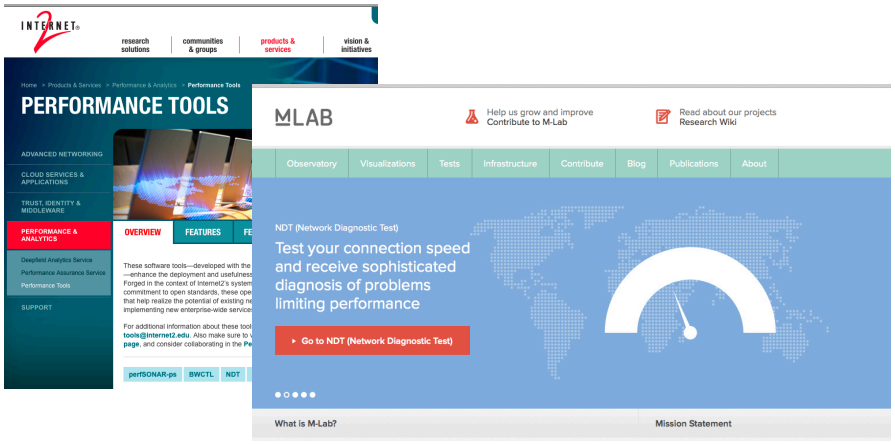
100BaseT ethernet implemented with switches is almost always full-duplex, but there was an option for half-duplex in the standard. Unfortunately, this means that configuration problems can occur.

There is a significant error rate when the switch port and host are not configured exactly the same way. Why do you think this is the case? how could you figure it out?

Fortunately, gigabit ethernet is only FDX.

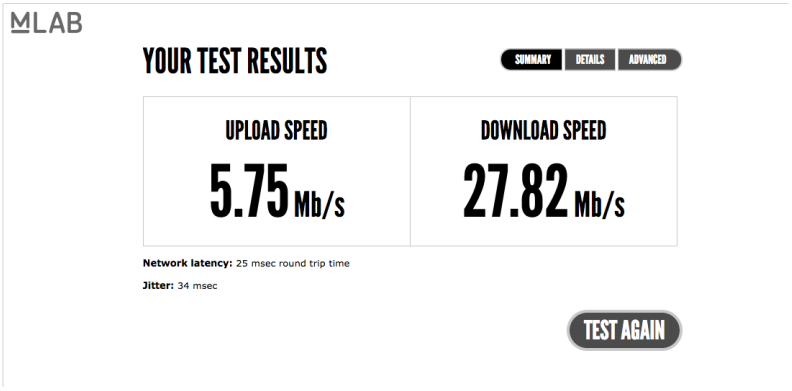
Network Diagnostic Tool (NDT)

http://www.internet2.edu/performance/ndt
https://www.measurementlab.net/

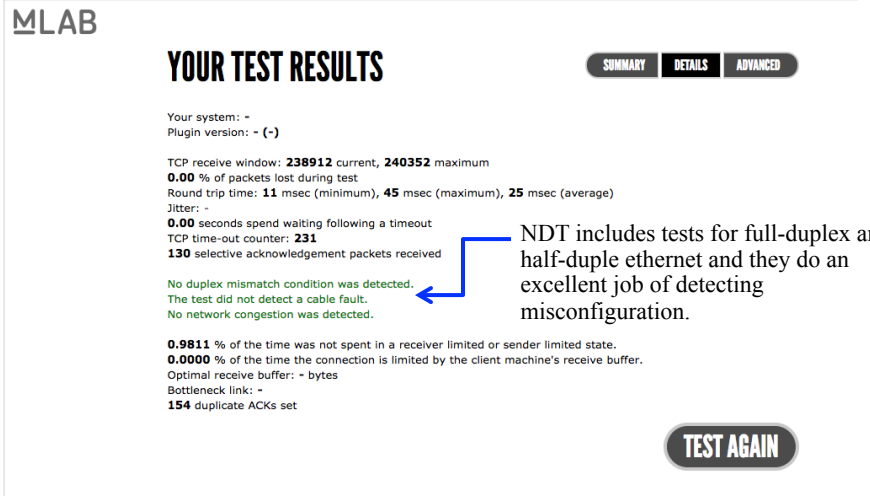


Network Diagnostic Tool (NDT)

Network Diagnostic Tool (NDT) results from
http://www.measurementlab.net/



Network Diagnostic Tool (NDT) results from
https://www.measurementlab.net/



NDT includes tests for full-duplex and half-duple ethernet and they do an excellent job of detecting misconfiguration.

Typical LAN Performance

Argonne web100 based Network Diagnostic Tool (NDT)

Located at Argonne National Laboratory, Argonne, Illinois U.S.A.; 1000 Mbps (Gigabit Ethernet) network connection

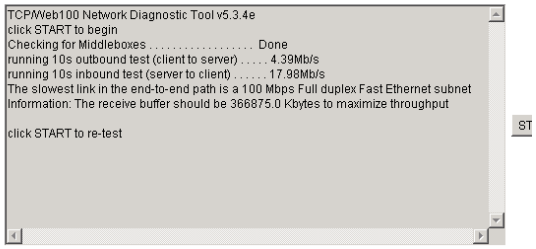
This java applet was developed to test the reliablity and operational status of your desktop computer and network connection. It does this by sending data betwee determine:

- The slowest link in the end-to-end path (Dial-up modem to 10 Gbps Ethernet/OC-192)
- The Ethernet duplex setting (full or half);
- If congestion is limiting end-to-end throughput.

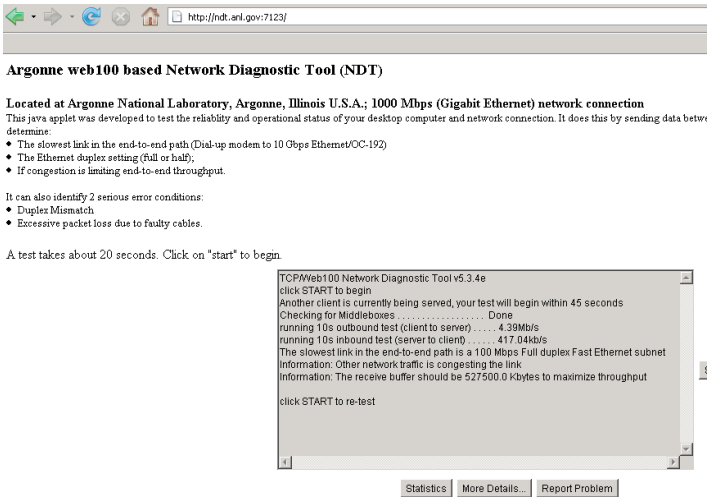
It can also identify 2 serious error conditions:

- Duplex Mismatch
- Excessive packet loss due to faulty cables.

A test takes about 20 seconds. Click on "start" to begin.



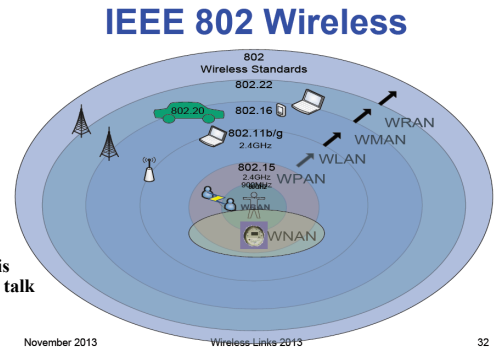
LAN FDX/HDX Performance Problem



802.11 and Wireless Networks

Wireless Networks

- As you know there are a multitude of different types of wireless networks and multiple generations for each type: cellular (1G, 2G, 3G, 4G, LTE, etc), 802.11a/b/g/n/etc, Bluetooth, satellite, 802.15, 802.16, "white space", NFC, LED, etc, etc.



Source and Copyright is D. Eastlake from IETF talk on wireless Nov. 2013

Wireless Networks

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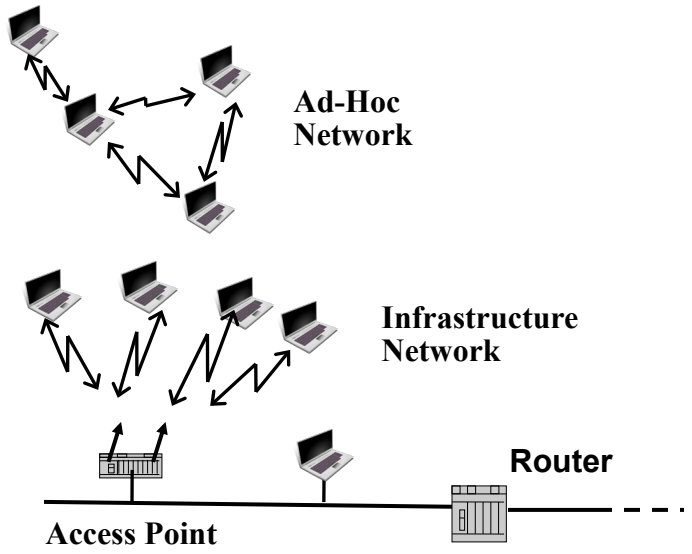
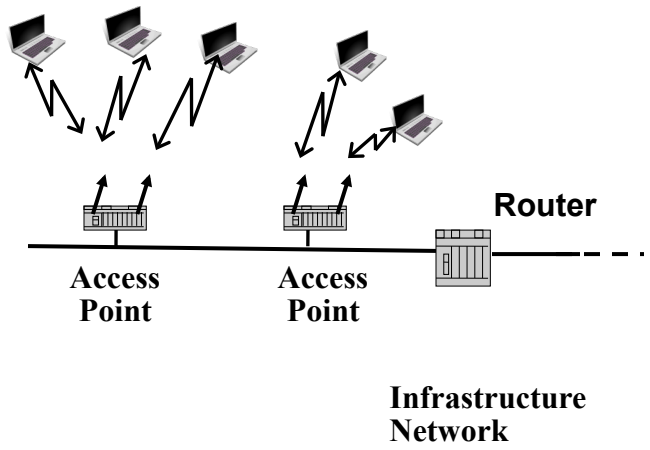
- Each type of wireless network has a different topology and uses the RF spectrum differently. This means that they each have a different data rate, error rate, broadcast mechanism, distance limitation, etc.
- Channel contention and how the channel is managed are critical issues and distinguish one type of system from another. This is not a new issue, consider Aloha.
- We will look at 802.11 and briefly compare it to what we know about 802.3. We'll revisit this topic after we study TCP performance.

802.11 Network Topologies



802.11 Distribution System and Network



802.11 Technical Characteristics

- **Wireless ethernet has a higher error rate than wired ethernet. This is important to know and remember when talking about network performance!**
- CSMA/CA – Carrier Sense Multiple Access with Collision Avoidance
  - Includes the use of ACK frames
- Optional use of RTS/CTS packets to minimize collisions
- 802.11 frame format is different than 802.3 frame
- 802.11 includes management and control protocols (which 802.3 does not include)
- The typical home AP (access point) also includes switch, router and NAT functionality.
- TCP makes the assumption that lost packets are the result of congestion. What does this mean when there are both wired and wireless networks? We'll discuss this in a later lecture.

There are Many Different Versions of 802.11

TABLE I

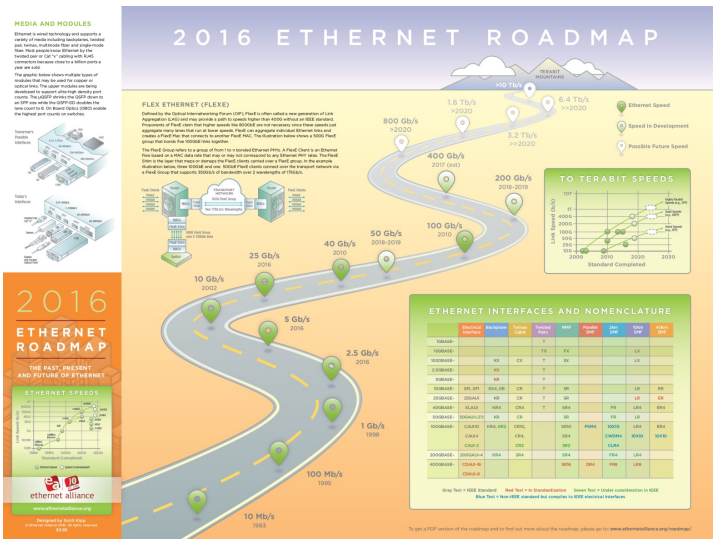
THE EVOLUTION OF THE 802.11 STANDARDS

Protocol	Year Introduced	Maximum Data Transfer Speed	Frequency	Highest Order Modulation	Channel Bandwidth	Antenna Configurations
802.11a	1999	54 Mbps	5 GHz	64 QAM	20 MHz	1×1 SISO
802.11b	1999	11 Mbps	2.4 GHz	11 CCK	20 MHz	1×1 SISO
802.11g	2003	54 Mbps	2.4 GHz	64 QAM	20 MHz	1×1 SISO
802.11n	2009	65 to 600 Mbps	2.4 or 5 GHz	64 QAM	20 and 40 MHz	Up to 4×4 MIMO
802.11ac	2012	78 Mbps to 3.2 Gbps	5 GHz	256 QAM	20, 40, 80 and 160 MHz	Up to 8×8 MIMO; MU-MIMO

Source: http://www.dtig.net/wireless-802-11ac-whats/ retrieved Sept. 19, 2016

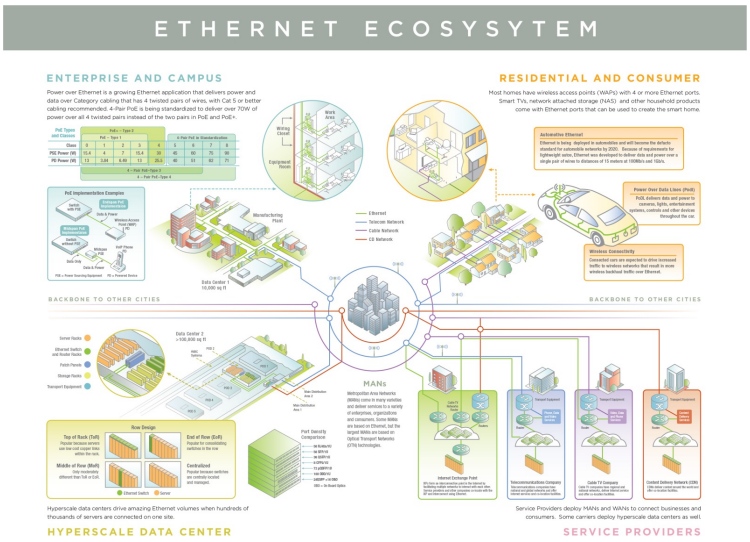
Ethernet Future

Ethernet Alliance Roadmap (1)
source http://www.ethernetalliance.org/roadmap/



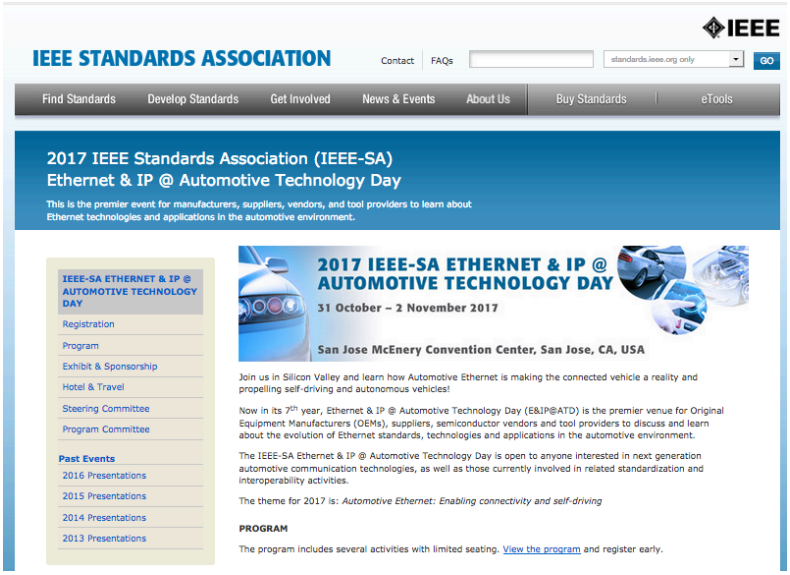
Ethernet Alliance Roadmap (2)

source http://www.ethernetalliance.org/roadmap/



Industry-Specific Ethernet Group

Source https://standards.ieee.org/events/automotive/index.html

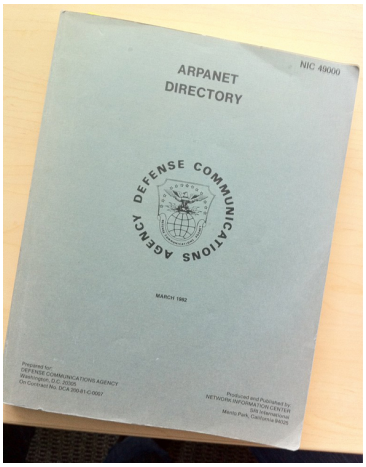


What is the Internet?

An Extremely and Overly Simple Approach to Understanding its Complexity

Internet History
The Internet Directory: March 1982

(400 pages, 20 names per page)



What is the Internet

- A network of networks with a couple billion users
- With large national and international ISPs (Internet Service Providers) as the core networks
- With regional ISPs connected to national ISPs
- With local ISPs connected to national/regional ISPs
- All ISPs exchanging inbound and outbound traffic with other ISPs across public and/or private peering points.
- With billions of users connected to customer networks at the outer edge, that then connect to one or more of the ISPs.
- All using the TCP/IP suite of protocols

Changes in Internet Topology

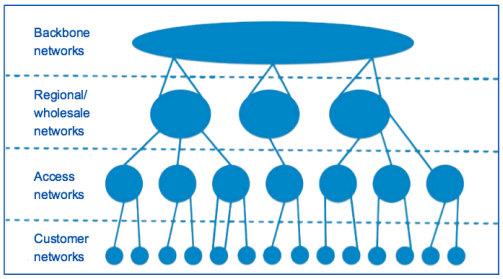


Figure 2 Traditional Internet hierarchical model

Straightforward Hierarchical Topology Early '90s

Mesh or Highly Connected Topology Today, Both ISPs and Others Provide Connectivity as well as Content

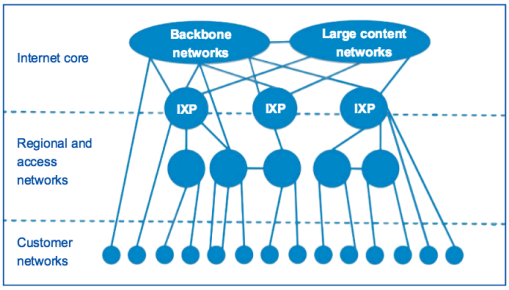
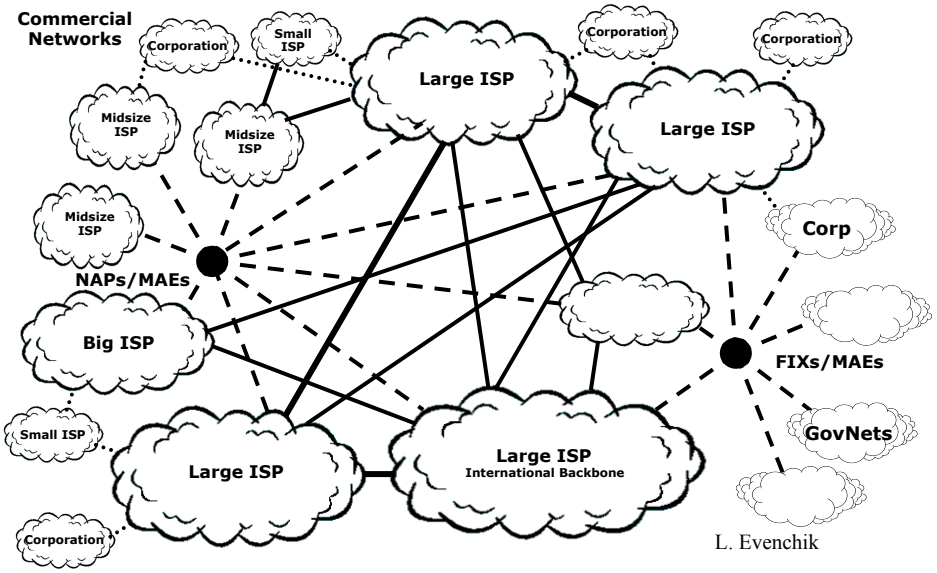


Figure 3 Flatter, more connected model

Source: ISOC Reports

The Current Internet (Very, Very, Very, Very... Simplified Topology)



L. Evenchik

Internet Trace from Harvard to MIT

```
fas% traceroute www.mit.edu
traceroute to DANDELION-PATCH.MIT.edu (18.181.0.31),40 byte packets
 1  scmr-gw.fas.harvard.edu (140.247.30.1)  1 ms  1 ms  1 ms
 2  sc-gw.fas.harvard.edu (140.247.6.2)  1 ms  1 ms  0 ms
 3  camgw1-fas.harvard.edu (140.247.20.1)  1 ms  2 ms  1 ms
 4  192.5.66.18 (192.5.66.18)  2 ms  1 ms  1 ms
 5  192.5.66.50 (192.5.66.50)  1 ms  1 ms  1 ms
 6  192.5.66.41 (192.5.66.41)  1 ms  2 ms  1 ms
 7  192.5.66.34 (192.5.66.34)  1 ms  2 ms  1 ms
 8  MIT-MEDIAONE.MIT.EDU (18.95.0.1)  30 ms  2 ms  2 ms
 9  W20-RTR-FDDI.MIT.EDU (18.168.0.8)  3 ms  3 ms  3 ms
10  DANDELION-PATCH.MIT.EDU (18.181.0.31)  2 ms *  4 ms
fas%
```


Internet Trace to Oxford University

```
fas% traceroute www.oxford.edu
traceroute to www.OXFORD.edu (163.1.0.45), 30 hops max, 40 byte packets
 1  scmr-gw.fas.harvard.edu (140.247.30.1)  1 ms  1 ms  1 ms
 2  sc-gw.fas.harvard.edu (140.247.6.2)  1 ms  1 ms  0 ms
 3  camgw1-fas.harvard.edu (140.247.20.1)  0 ms  0 ms  1 ms
 4  192.5.66.18 (192.5.66.18)  2 ms  1 ms  1 ms
 5  192.5.66.9 (192.5.66.9)  2 ms  2 ms  2 ms
 6  12.127.80.125 (12.127.80.125)  3 ms  3 ms  3 ms
 7  br2-a3110s1.cb1ma.ip.att.net (12.127.5.10)  3 ms  3 ms  3 ms
 8  br3-h20.wswdc.ip.att.net (12.127.15.177)  12 ms  13 ms  11 ms
 9  gr1-a3100s1.wswdc.ip.att.net (192.205.31.185)  13 ms  13 ms  13 ms
10  - 15 …. multiple hops in ALTER.NET, only a few shown in this slide
16  - 21 …. multiple hops in.Teleglobe.net, only a few shown in this slide
22  external-gw.ja.net (128.86.1.40)  145 ms  145 ms  143 ms
23  london-core.ja.net (146.97.251.58)  152 ms  142 ms  145 ms
24  146.97.251.82 (146.97.251.82)  150 ms  148 ms  149 ms
25  noucs2.backbone.ox.ac.uk (192.76.35.2)  152 ms  155 ms  150 ms
26  wwwtest.ox.ac.uk (163.1.0.45)  152 ms  150 ms  152 ms
fas%
```

One Minute Wrap-Up

- Please do this Wrap-Up at the end of each lecture.
- Please fill out the form on the website.
- The form is anonymous (but you can include your name if you want.)
- Please answer three questions:
  - What is your grand "Aha" for today's class?
  - What concept did you find most confusing in today's class?
  - What questions should I address next time
- **Thank you!**

Thank You!

ALIGHLSOD1701