Communication Protocols and Internet Architectures

Harvard University

Lecture #1

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Lecture Agenda

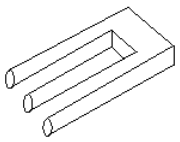
- Course Goals and Objectives
- Review of Course Syllabus & Logistics
- Network Building Blocks
- Network Standards
- Network Models, Services versus Protocols
- What is the Internet
- Real World Network Design Issues
- One Minute Wrap-Up

Course Goals

- This course will provide:
  * Tools, theories and a framework for understanding the constantly changing networked environment
  * In-depth technical understanding of current network architectures and protocols
  * Understanding of the design trade-offs that have to be made when designing, implementing and managing large networks
  * Appreciation of the evolution of communication networks and services: from POTS to IoT and the Cloud
- What this course is not about:
  * Programming specific network protocols
  * Installing specific communication products

What is Wrong with the Following Statements?

- "I was at a seminar and they explained that VLANs and switches are are how networks are built today so we don't need to worry about IPv6."
- "Doing a network design will take too long, we'll just use the Internet."
- "I just heard that we ran out of IP addresses and we all know that this means that the web will stop working sometime next spring."
- "Easy, the video will look great if you just use gigabit ethernet and 4G LTE."
- "Of course using QoS (or the TLA of the moment) solves the problem."
- "Don't worry, we have an extremely reliable network since it is built using nothing but fiber optics."



Course Logistics

Course Logistics

- Textbook and Readings – We have one required textbook. Links to other materials such as RFCs will be available on the web.
- Course work load -- minimum 12 hours/week
- Section meetings: please check the course website for details.
- The course website contains schedule information, late-breaking news, chat room and a discussion group. We will typically post three documents each week: the Lecture Handout, a Reading Assignment and Course Information Sheet.
- Please check the School web site for registration and other administrative details, and information about online courses (including tech support details.)

Course Logistics - part 2

If you are viewing this lecture online please have a copy of the syllabus.

- The syllabus contains the schedule and other information. Reading assignments will be distributed weekly.
- 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.
- There will be five homework assignments.
- Grades will be based on your performance on homework, the midterm and the final exam. ***It is very important that you do all of the homework assignments.***

Some Final Logistics

- The course website will have copies of the lecture handouts before the lecture is given.
- Please print and bring copies of the handouts to lecture if you want them. We will **not** provide copies of the handouts at lecture.
- A small number of the slides that I use in lecture will not be included in the handout.
- The use of any particular vendor, product or service is not intended as an endorsement by Harvard or the Instructor.
- **Most Important: What is a one minute wrap-up and why do we ask you to submit one each week?**

One Minute Wrap-Up

- Please complete this Wrap-Up at the end of each lecture.
- Please use the form on the course website.
- The form on the website is anonymous (but you can include your name if you wish.)
- 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?

What is a Network and how are networks different ?

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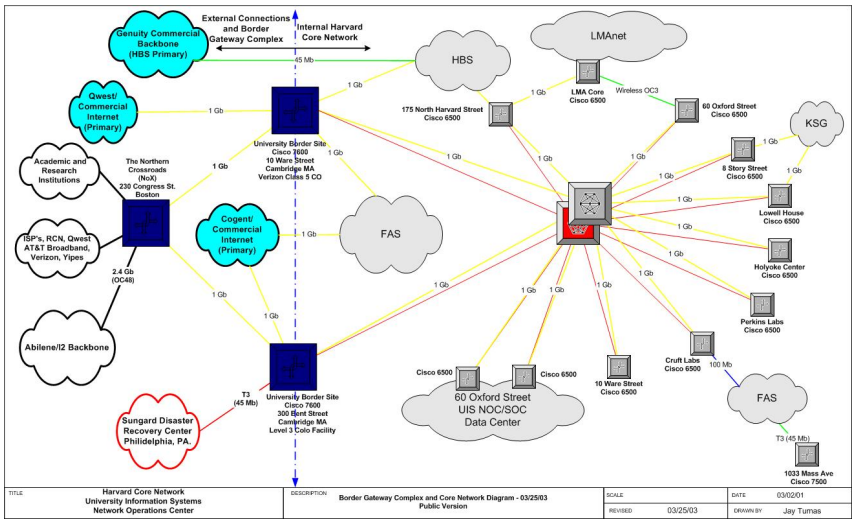
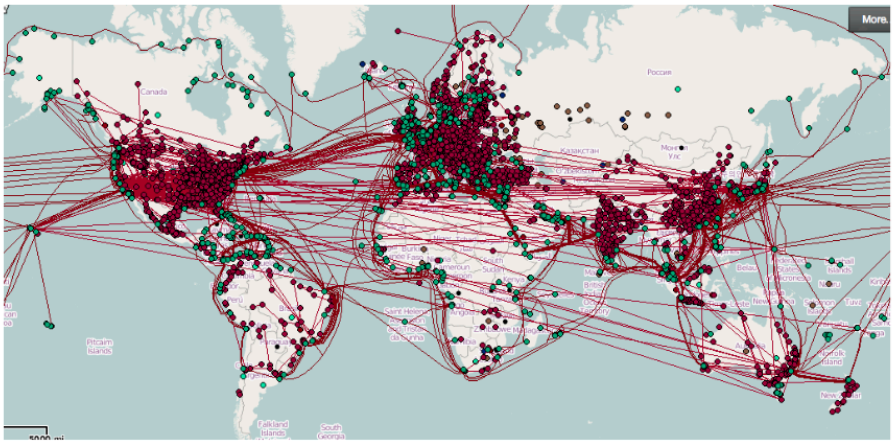
Harvard Core Network
Source and copyright is Harvard HUIT

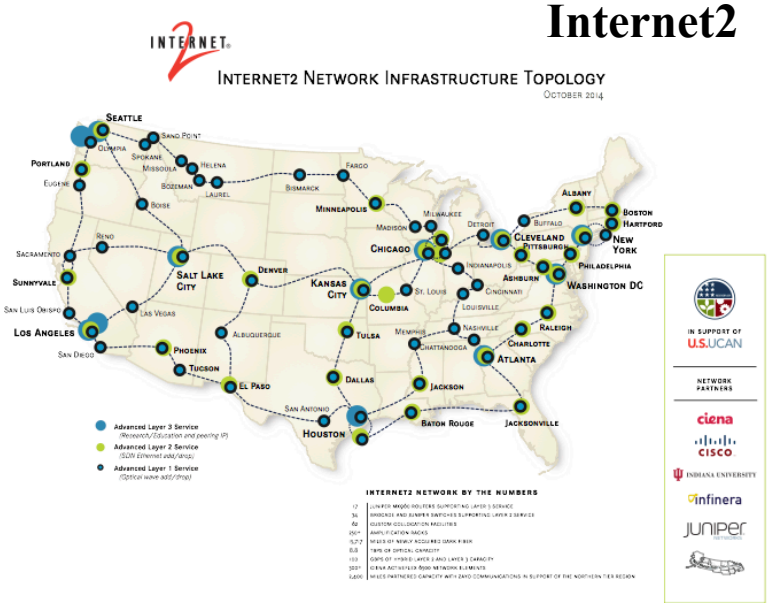


Internet Topology Diagram



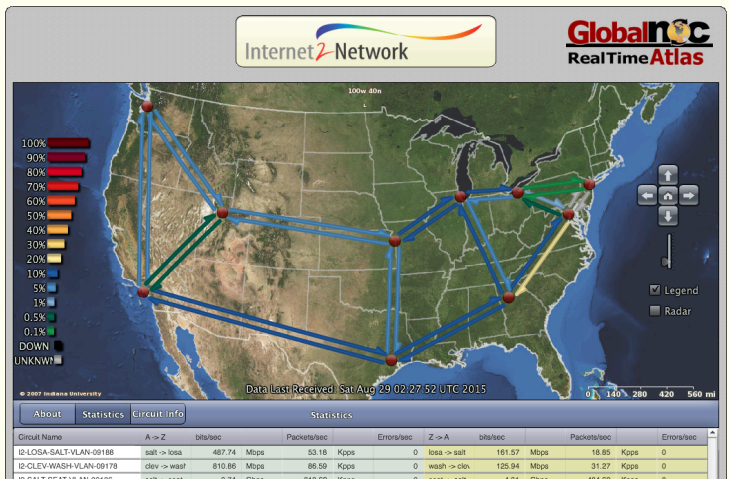
Source: internetatlas.org and Univ of Wisconsin, 2013

Internet2



Source and copyright is http://www.internet2.edu 2015

Internet2 Real Time Map



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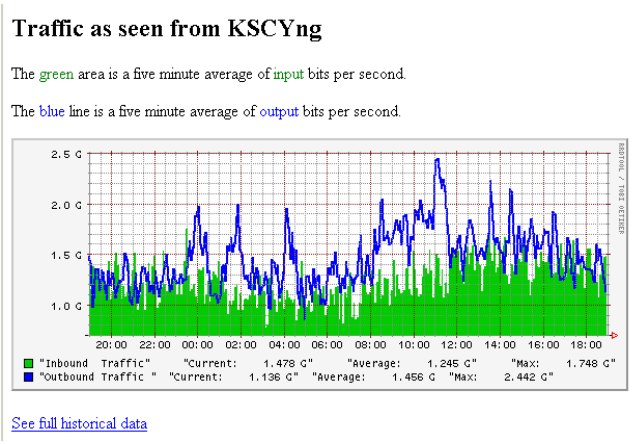
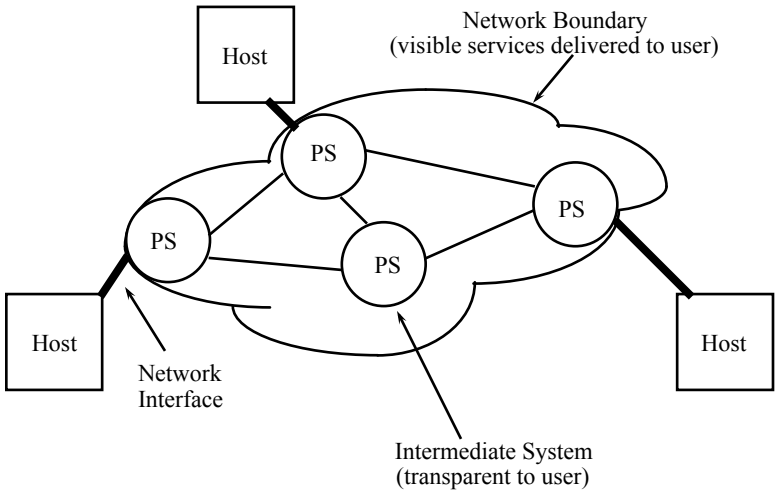


Source and copyright is http://abilene.internet2.edu/
Indiana University Abilene NOC Weathermap

Typical Network Operations Center (NOC)

Source and copyright is Clemson University

The Network "Cloud"



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

Evolution of Network Technology

Consider the evolution of each of the following network building blocks:

- Transmission
- Multiplexing
- Switching
- Signaling
- Interfaces and Protocols
- Network Management
- Network Applications: email, web, VoIP, Twitter, etc.
- Crypto and Security
- etc., etc.

Transmission and Multiplexing

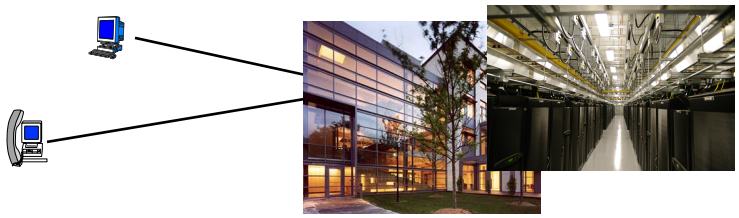
Transmission Media in the Network:

- "Sneaker Net" -- disk, memory stick, DVD, etc.
- Electrical -- copper pairs, coax cable, etc.
- Radio – cellular, wireless, 802.11, microwave, satellite, NFC
- Optical -- fiber, free-space optical with LED, infrared or laser

Each medium has its own noise, error rate, bandwidth, distance and attenuation characteristics, etc.

A Seemingly Simple Question?

What is the speed and the characteristics of the connection between your home and the Network?



The answer depends on a number of factors and what you mean by the Network.

Some Details about Transmission

- "Bandwidth" is the maximum frequency at which a signal on a given channel can change and still be intelligible at the far end
- The bandwidth of a channel puts both a theoretical and a practical limit on the data rate of the channel
- Bandwidth will be naturally limited by the physical characteristics of the medium, or artificially limited for other reasons
- Noise will limit the usable data rate of a channel. There are many sources of noise. The BER (bit error rate) of the channel and the packet loss of the system determines the practical, available data rate (as seen by the user.)
- Sophisticated signaling methods using multiple signal levels and data compression can maximize the data rate on a channel but cannot overcome the fundamental physical limits.
- What is the relationship between BER and packet loss?

What is Multiplexing and Why is it Used?

- Imagine you need to connect 24 users in Boston to 24 users in NYC and that each user needs 64kbps.

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2,700 Pair Telephone Cable – Before Multiplexing

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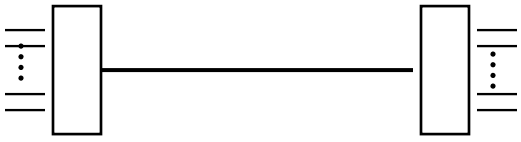
Multiplexing

- The division of a single physical channel into two or more logical channels. (Muxing is the basis of packet switching.)
- Users share a single physical channel and this provides for equipment and cost savings. The question is how to share it.
- Frequency Division Multiplexing is one option (radio, satellite)
- Time Division Multiplexing is another option
  - Slotted TDM - each user is assigned a particular slot (time interval) whether it is needed or not - this provides guaranteed delay and bandwidth. Also called fixed TDM.
  - Statistical TDM - each user requests access or enters a queue and waits for access to the shared medium. What about the queuing delay and resulting quality of service (QoS) in this case?
- Many other combinations possible

What About the 25th User?

- Assume your system was designed to support 24 users via time division multiplexing (TDM). Imagine now that you need to connect a 25th user between Boston and NYC.
- A couple of options exist, what are they?



Switching

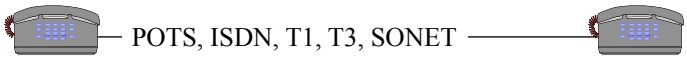
Switching

- 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

Circuit Switched versus Packet Switched Networks

- How did these two types of networks develop?
- How is a system designed for one used with the other?

Circuit Switched



Packet Switched

(POTS is Plain Old Telephone Service)

Circuit Switching – Establishing the Circuit

Wall Mounted
Crank Telephone
circa 1910

(POTS is Plain Old Telephone Service)

Telephone Switchboard circa 1930

By courtesy of] [The American Telephone and Telegraph Co.

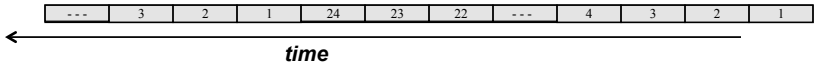
A LONG-DISTANCE TELEPHONE EXCHANGE.

Radio-telephone switchboard circa 1930. From the left the first four stations are to London, the next Ship to Shore, Buenos Aires, and Rio de Janeiro.

AT&T Photo

Evolution of Circuit Switched Networks

- Circuit switched networks evolved over 100 years to support telephone voice communications
  - Analog telephone service was the primary driver
  - Dedicated circuit (in the beginning it was a physical circuit, and then 70 years later, a virtual circuit) was put in place for the entire call
  - Virtual circuit approach developed for TDM, but still circuit switched
    - » 8KHz samples @ 8 bits = 64Kbps per voice call/channel
    - » Allows muxing of multiple calls, each at 64kbps, on a single physical circuit line (basis of T1/E1 and then much higher BW.)
    - » Continuous stream of bits sent for the duration of the phone call whether or not anyone was talking at that instant
    - » Emphasis was on reliable connection of a large number of continuous 64Kbps flows (phone conversations.)
    - » Most common system supported 24 simultaneous conversations



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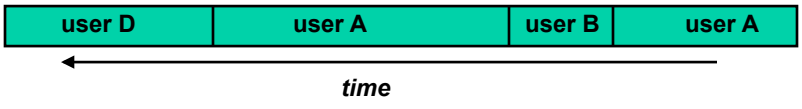
Evolution of Packet Switched Networks

- Packet Switching evolved to support computer to 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 utilize the entire capacity of the link, but for a very, very, very short period of time. This is not an easy concept to understand.



Carrying Data on a Packet Network (Simplified)

- Computers divide the data to be sent into packets.
- Computers try to use 100% of the available bandwidth at an instant in time to send the packet of data
- Hence, the utilization on the link is a very bursty. There is one burst of traffic for each packet that is sent.
- The bursty nature of traffic makes it is possible to share bandwidth and other network resources because each computer has a low average utilization
- If the network or link is not available now, the computer waits a short time (milliseconds) and tries again. This is not a problem for sending information like email.
- However, waiting for a network resource can be a problem for video and voice (as we will discuss later in the course.) This relates to Quality of Service (QoS.)

What is a standard, what is a protocol model, and who decides on them?

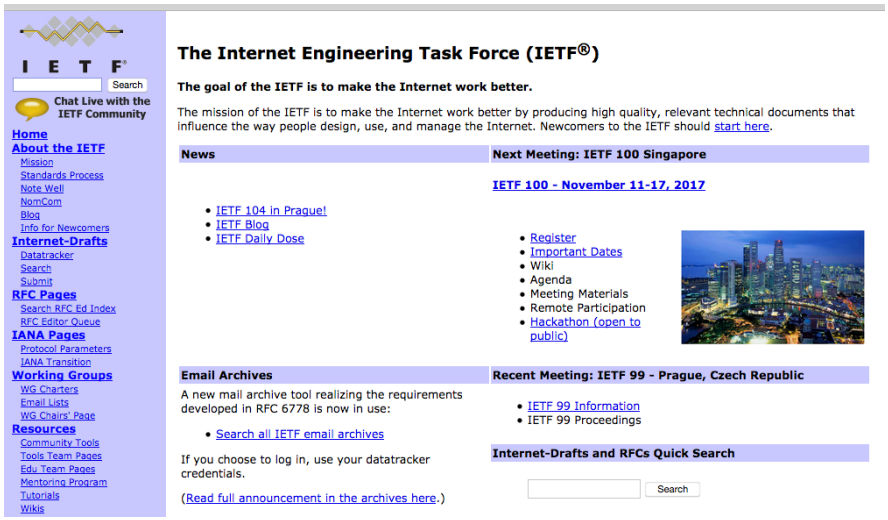
Who Establishes Protocols and Standards

- Standards bodies and other organizations:
  IETF, Internet Engineering Task Force, www.ietf.org
  ISO, International Organization for Standards
  ITU-T, International Telecommunication Union (was CCITT)
  NIST, National Institute for Standards and Technology
  IEEE, Institute of Electrical and Electronics Engineers
  W3C, World Wide Web Consortium
  plus ... EIA, ECMA, etc...
- Computer, software and communication companies
- Large users, user groups, industry groups, etc.

Things that need standardizing

- Types of connectors
- Physical media
- Signaling techniques
- Addressing
- Minimum and maximum size of packets (this is not obvious)
- Routing protocols and techniques
- Video and audio encoding techniques
- Division of management authority and responsibility
- Error detection techniques and recovery procedures
- Security issues
- All the APIs you work with
- etc., etc.

www.ietf.org



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Protocol Models and Layering

Why Layered Network Architectures?

- To help manage complexity
- To facilitate the building block approach to implementation & management

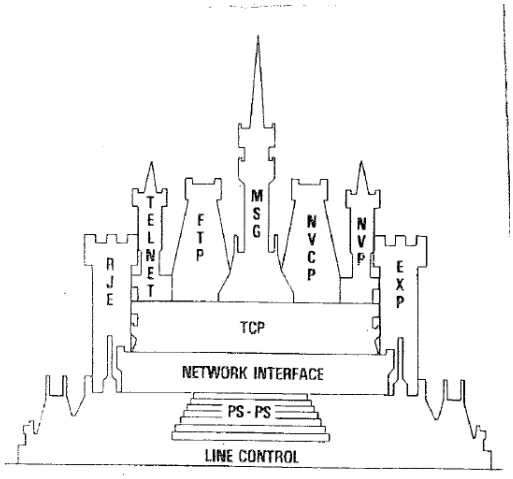
How Many Layers are Enough?

Depends on who's counting.

- OSI / ISO model "said" 7 about 30 years ago and this is still talked about today
- Internet model uses 5 and most systems are built using this approach. **This is the model we will use for this course.**

However, counting the number of layers is more art than science when you build systems in the real world.

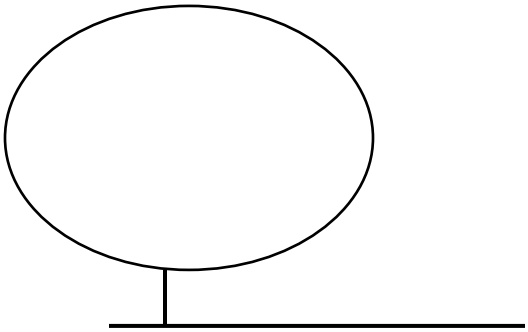
Protocol Model, circa 1974



Source: IEEE Tutorial on Communication Protocols

Communication Functionality versus the Model

You can divide up the functionality required in a communication system in many different ways.



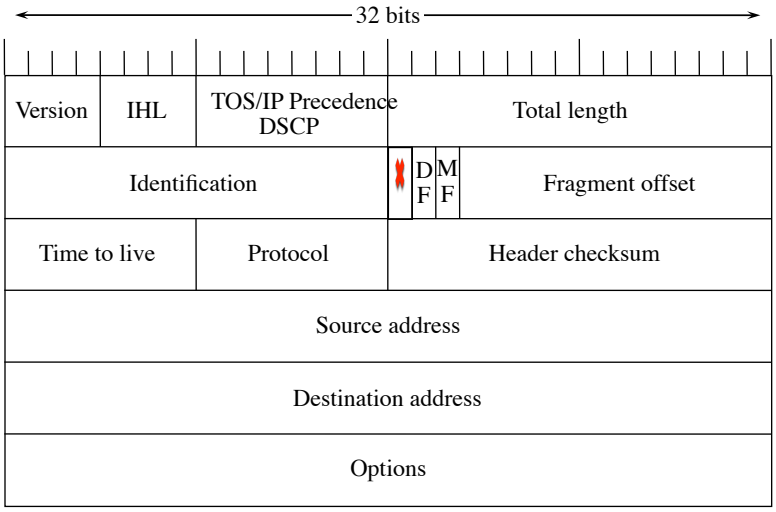
OSI 7 Layer Model

- Application
- Presentation
- Session
- Transport
- Network
- Data link
- Physical

5 Layer Internet Model also known as the TCP/IP Model

- Application layer
- Transport layer
- Internet layer (sometimes called the Network layer)
- Link layer (sometimes called Network Interface layer, or Data Link layer)
- Physical layer

IPv4 Packet Format

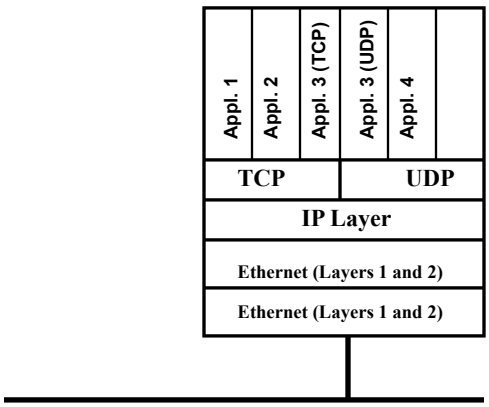


Protocol Encapsulation

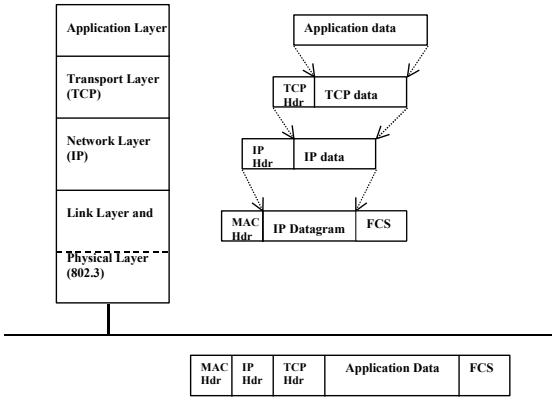
Encapsulation – 5 Layer Internet Model

- Application
- Transport
- Internet
- Data Link
- Physical

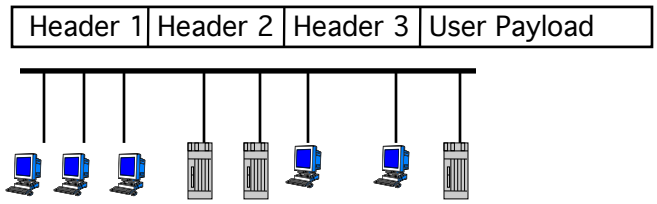
Five Layer Simplified Software Schematic



Protocol Encapsulation

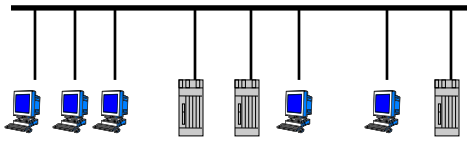


Encapsulation Results in Multiple Headers



What Does a Packet Look Like

What Does a Frame Look Like on an Ethernet?

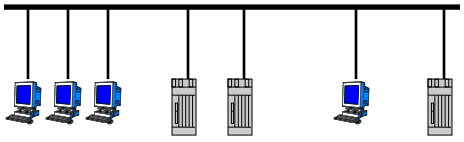


Ethernet Frame

(Sometimes incorrectly called a Packet)

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

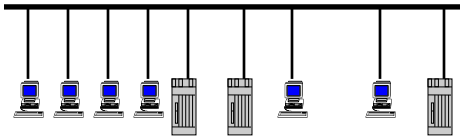
```
00 00 a7 11 57 dd 08 00 09 38 24 31 08 00 45 00 00 38 b3 ….
```



Ethernet Frame

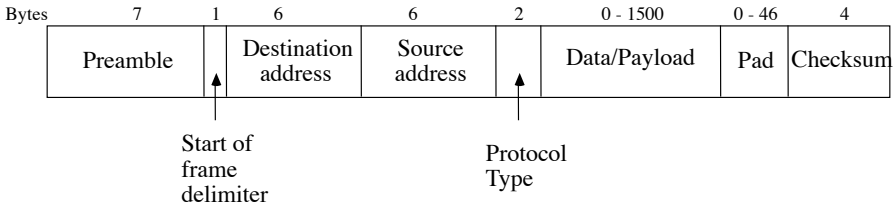
Byte Count **Content of Frame**

```
00 to 15: 00 00 a7 11 57 dd 08 00 - 09 38 24 31 08 00 45 00
16 to 31: 00 38 b3 e3 00 00 1e 06 - 8b 3e c6 04 69 c9 c6 04
32 to 47: 69 cf 05 bd 17 70 3a e4 - 44 b9 2c 0a 9e ad 50 18
48 to 63: 20 00 88 53 00 00 3d 11 - 11 04 11 80 11 02 34 a3
64 to 69: 00 76 34 0c 00 13
```

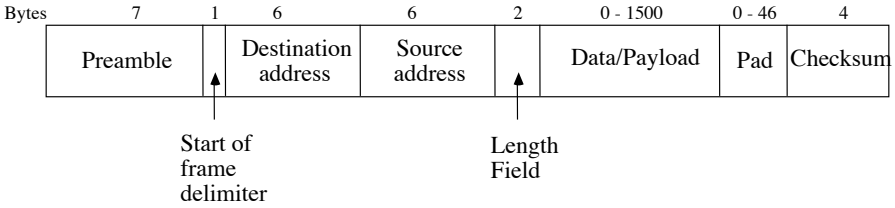


Ethernet and IEEE 802.3 Frame Formats

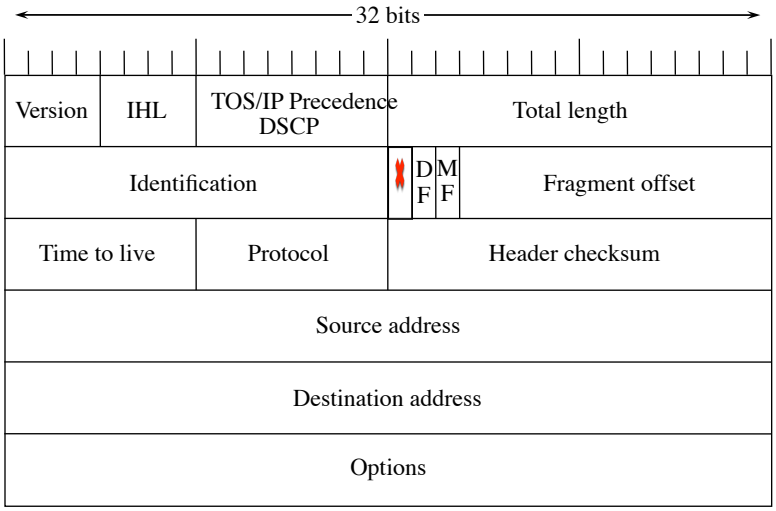
Ethernet



IEEE 802.3

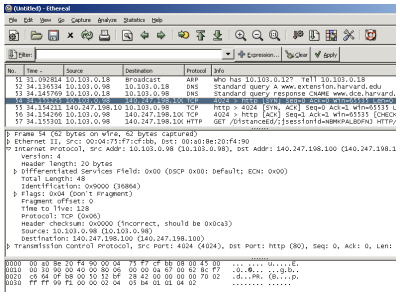


IPv4 Packet Header Format

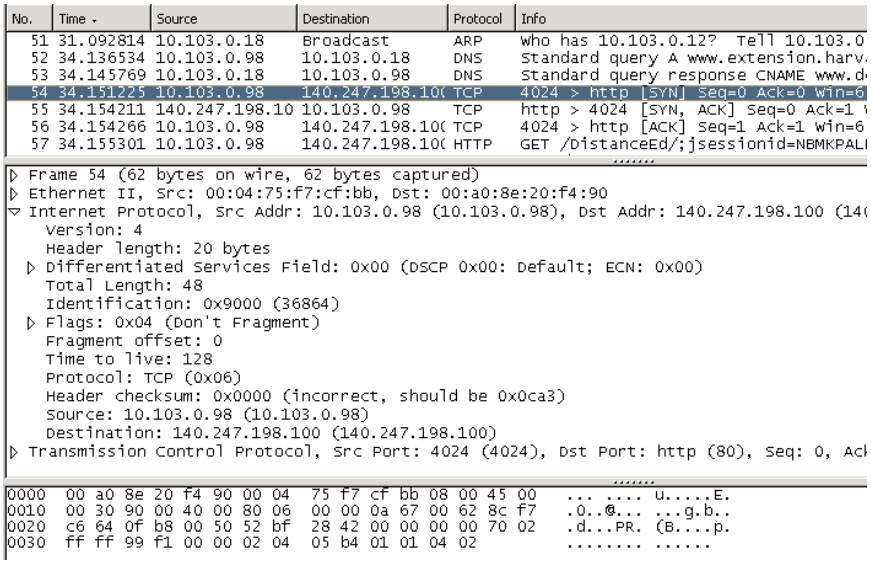


Network Packet Trace

- Network analysis tool is called Wireshark and it is available from www.wireshark.com
- Wiretapping or monitoring of any Harvard network traffic is strictly forbidden under all circumstances. See the Harvard Computer Policy & Responsibilities website for the details.
- Almost all organizations also have policies against the monitoring of corporate traffic.



Network Packet Trace

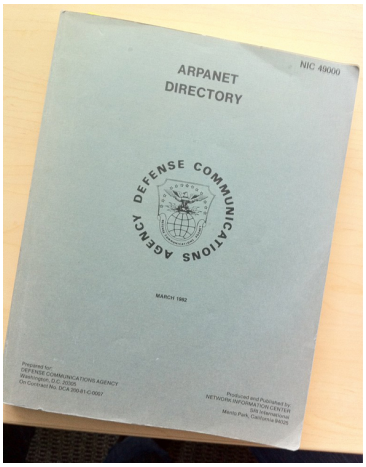


What is the Internet?

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

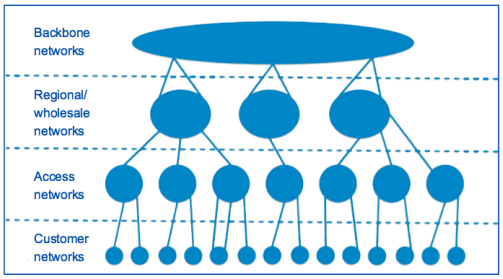


Figure 2 Traditional Internet hierarchical model

Straightforward Hierarchical Topology Early '90s

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

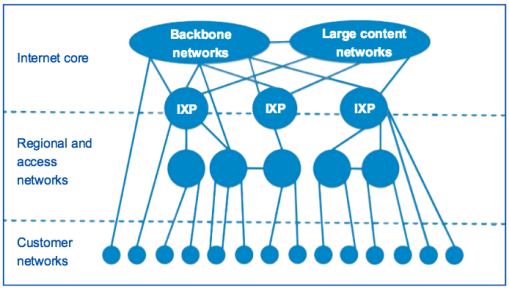
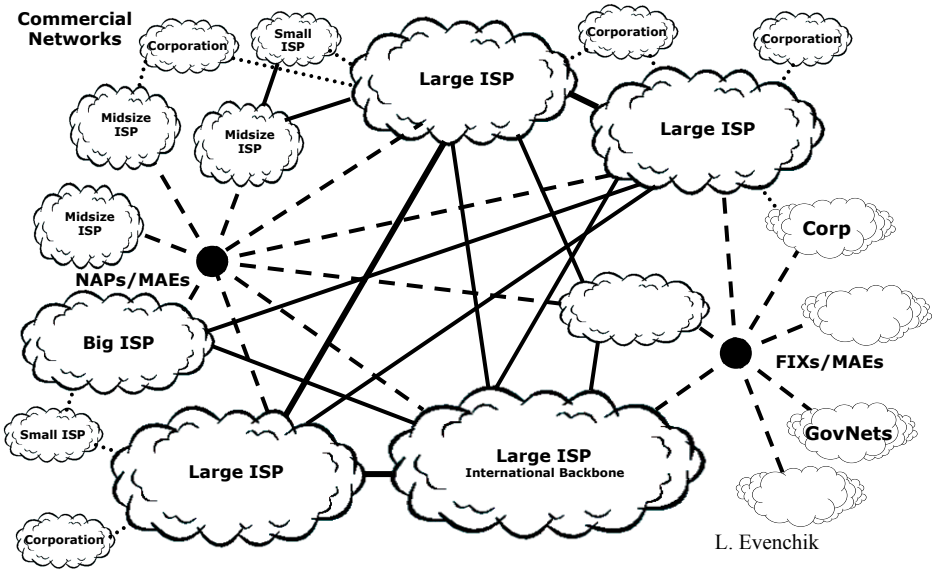


Figure 3 Flatter, more connected model

Source: ISOC Reports

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



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