# Computer Networks

## Fall 2011

https://jingyu.dyndns.org/~jzhou/courses/F11.Networks/

Tuesday 10:00 – 11:40 AM or 14:00 – 15:40 PM

# Outline

- *Administrative trivia's*
- What is a network protocol?
- A brief introduction to the Internet: past and present
- Summary

# Personnel

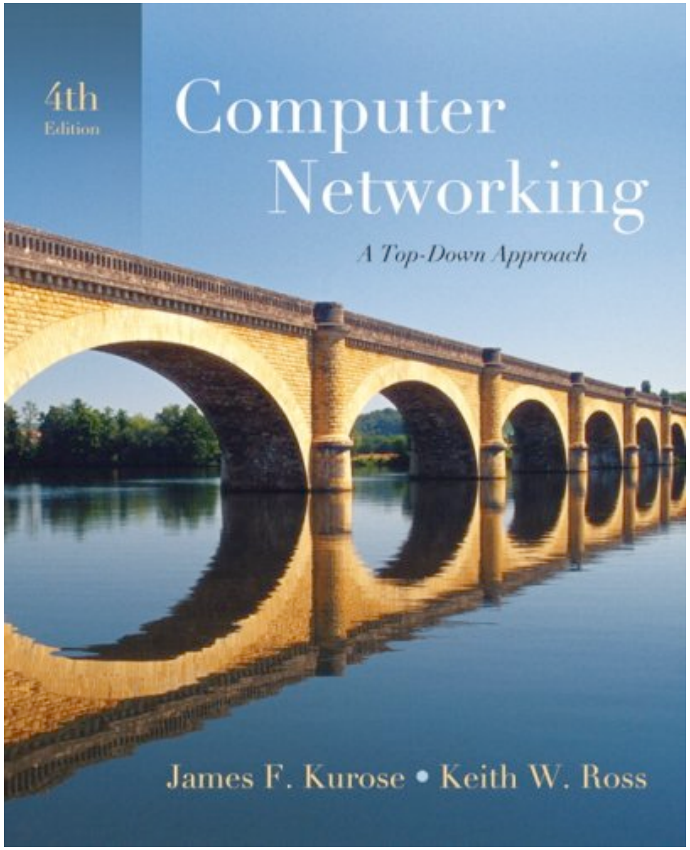
- Instructor 周憬宇
  - Office: 1104 Software Building, Minhang Campus
  - Phone: (21) 3420-4125
  - Email: zhou-jy@cs.sjtu.edu.cn

- Teaching assistant
  - Wu, Jiewei <wujayway AT gmail.com>, SE-5501
  - Wang, Peng <peng_wp AT 163.com>
  - Qiu, Shuang <qshhnkf AT gmail.com>, SE-5406
  - Dou, Xianzheng <dozenow AT 163.com>

# Textbook

- Textbook
  - *Computer Networking: A Top-Down Approach Featuring the Internet, 4th ed.*, by Kurose and Ross

- Reference books
  - *Computer Networks* by A. Tanenbaum
  - *Computer Networks, A Systems Approach* by L. Peterson and B. Davie
  - *TCP/IP Illustrated, Volume 1: The Protocols* by W. Richard Stevens
  - Java Network Programming, 3/e by Elliotte Harold
  - *Unix Network Programming: Networking APIs: Sockets and XTI (Volume 1)* by W. Richard Stevens



# Grading

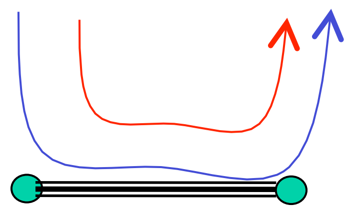
- Grades
  - Homework and projects: **45%**
  - Labs and class participation: **15%**
  - Final exam: **40%**
- Late policy
  - Assignments are due at **11:59 PM** on the due date
  - The deadline for any assignment can be extended with a **10% penalty per day**
  - Assignments will **NOT** be accepted **72** hours after the due date
- Cheating: NOT tolerated! Zero for the assignment!

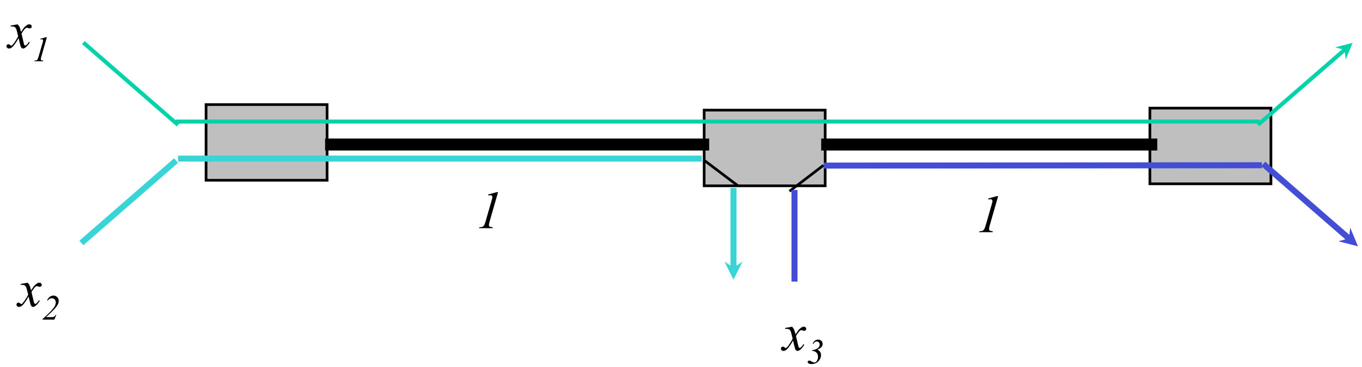
# Goals of This Course

- Learn networking principles, e.g.,
  - Distributed resource allocation
  - Distributed, asynchronous autonomous routing selection
  - Distributed multiple access
  - Foundation of application adaptation
  - Security
- See how the principles apply to the Internet
  - Its philosophy, architecture, protocols, and challenges
  - Network applications
- Learn network programming

# Example: Distributed Network Resource Allocation

- Question: how to allocate network resources to users fairly, efficiently?





# Maximize Throughput

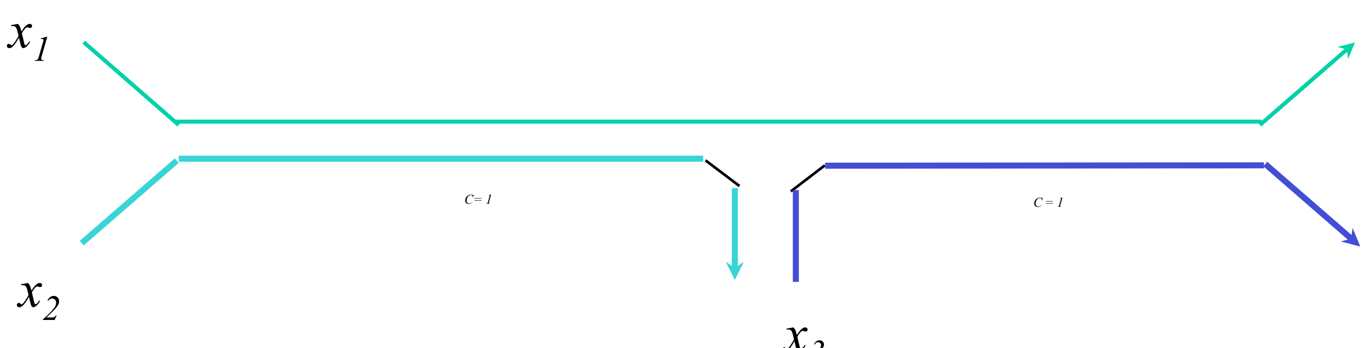
$$\max_{x_f \geq 0} \quad \sum_f x_f$$

$$\text{subject to} \quad x_1 + x_2 \leq 1$$

$$x_1 + x_3 \leq 1$$

Optimal: $x_1 = 0$

$x_2 = x_3 = 1$



# Max-min Fairness

- Max-min fairness: maximizes the throughput of the flow receiving the minimum (of resources)
  - Justification: John Rawls, A Theory of Justice (1971)
    - http://en.wikipedia.org/wiki/John_Rawls
  - This is a resource allocation scheme used in ATM and some other recent proposals

# Max-Min

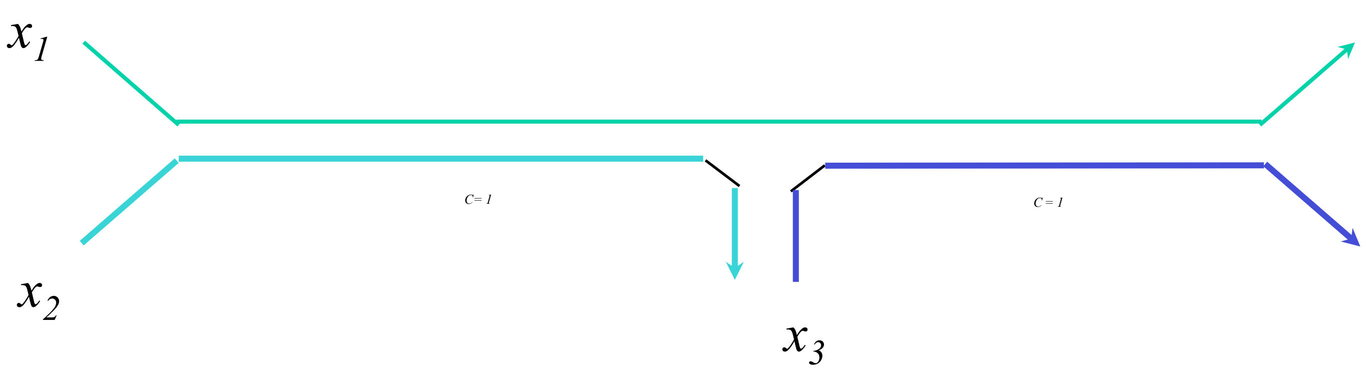
$$\max_{x_f \geq 0} \quad \min\{x_f\}$$

subject to

$$x_1 + x_2 \leq 1$$

$$x_1 + x_3 \leq 1$$

- Optimal: $x_1 = x_2 = x_3 = 1/2$



# Network Resource Allocation Using Utility Functions

- A set of flows $F$
- If $x_f$ is the rate of flow $f$, then the utility to flow $f$ is $U_f(x_f)$, where $U_f(x_f)$ is a concave utility function.
- Maximize aggregate utility, subject to capacity constraints

$$
\begin{array}{ll}
\text{max} & \displaystyle\sum_{f \in F} U_f\left(x_f\right) \\
\text{subject to} & \displaystyle\sum_{f : f \text{ uses link } l} x_f \le c_l \text{ for any link } l \\
\text{over} & x \ge 0
\end{array}
$$

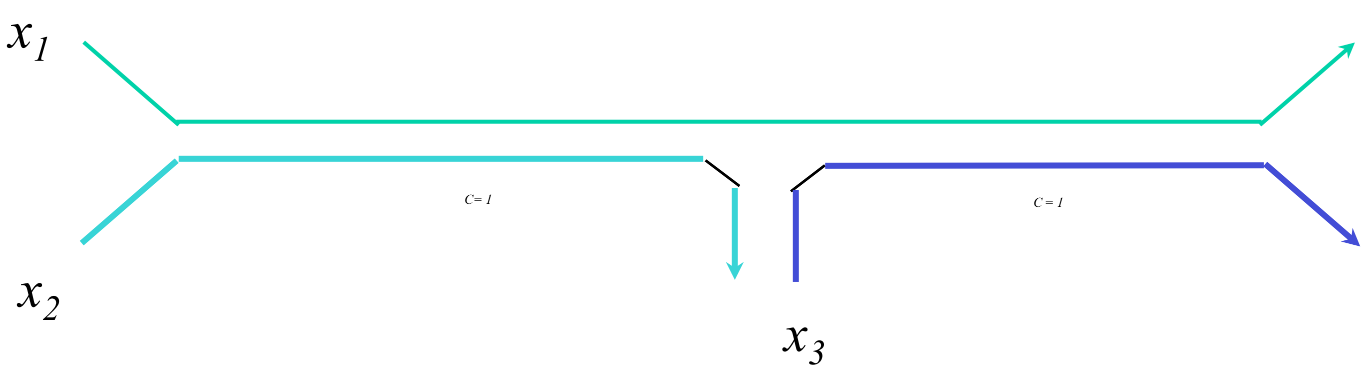
# Proportional Fairness

$$\max_{x_f \geq 0} \quad \sum_f \log x_f \qquad U_f(x_f) = \log(x_f)$$

$$\text{subject to} \quad x_1 + x_2 \leq 1$$

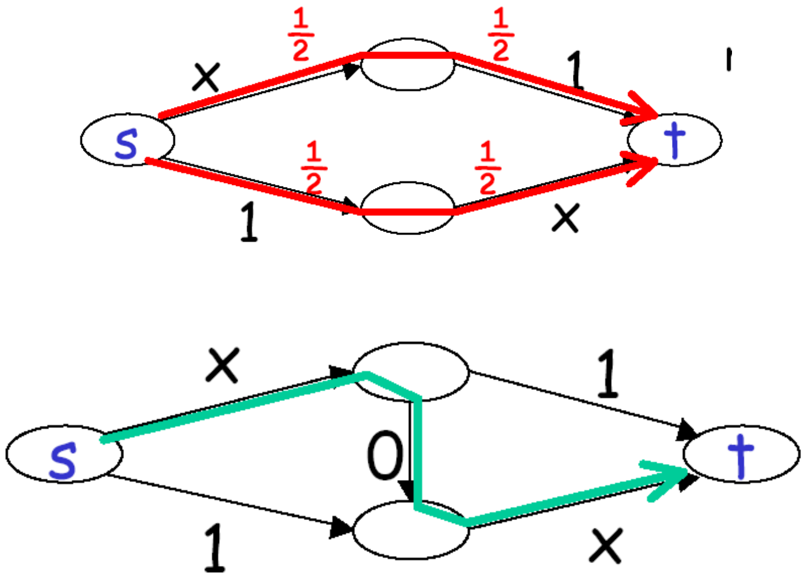
$$x_1 + x_3 \leq 1$$

- Optimal: $x_1 = 1/3$
  $x_2 = x_3 = 2/3$



# Sometimes Adding More Resource Means Lower Performance

- E.g., flow with capacity 1 from s to t




Braess's paradox

Source Korea has a case where traffic actually improves after destruction of a major highway.

# Topics

- Networking architecture and design principles

- Applications
  - Application paradigms
  - HTTP/Web, Email, DNS, P2P

- Transport
  - Transport services
  - Reliability; distributed resource allocation
  - Transport protocols: TCP/UDP

# Topics (cont.)

- Network
  - Network services
  - Distributed, asynchronous, autonomous routing algorithms; scalable router design
  - IP/IPv6; mobile IP; cellular networks
- ~~Link and physical~~
  - ~~Multiple access; queueing analysis; capacity analysis~~
  - ~~Ethernet, 802.11, CDMA, bluetooth~~
- ~~Multimedia networking~~
  - ~~Principle of application adaptation; scheduling/QoS~~
  - ~~Audio/video applications~~
- ~~Network security~~
  - ~~Security primitives; keys; attacks and countermeasures; SSL~~

Questions?

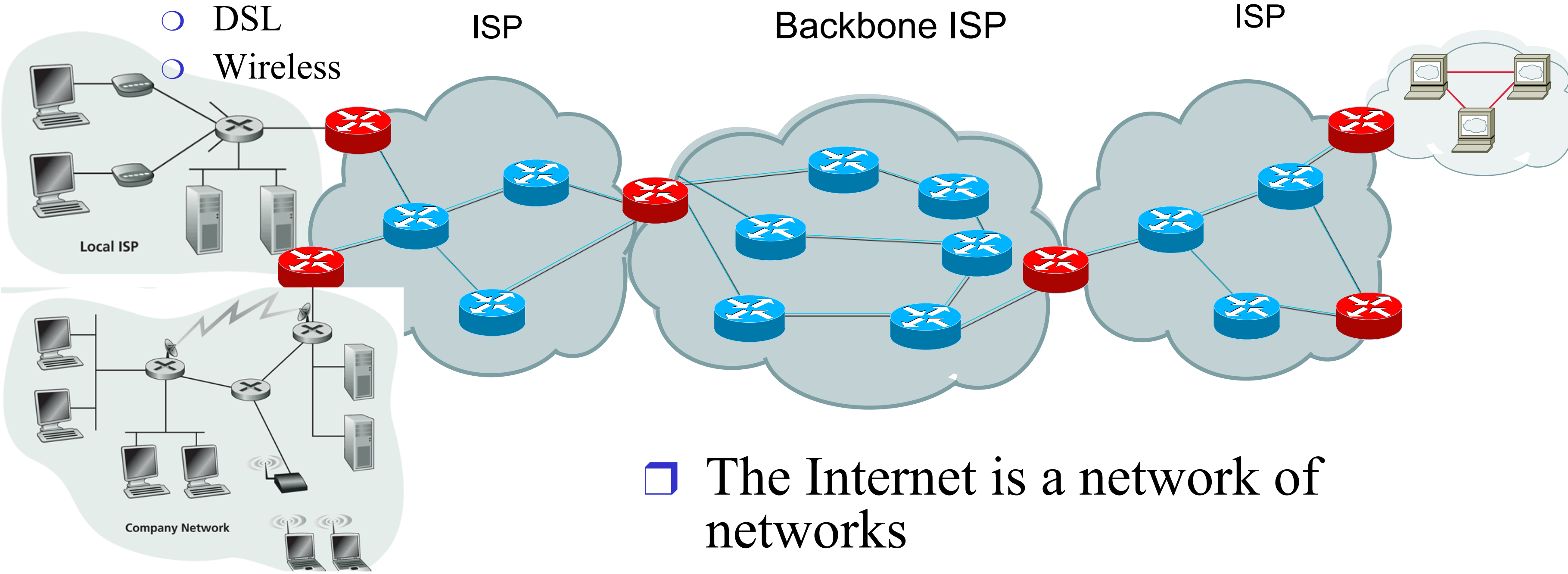
# Outline

- Administrative trivia’s
- *What is a network protocol?*
- A brief introduction to the Internet: past and present
- Summary

# Internet Physical Infrastructure

Residential access

- Cable
- Fiber
- DSL
- Wireless



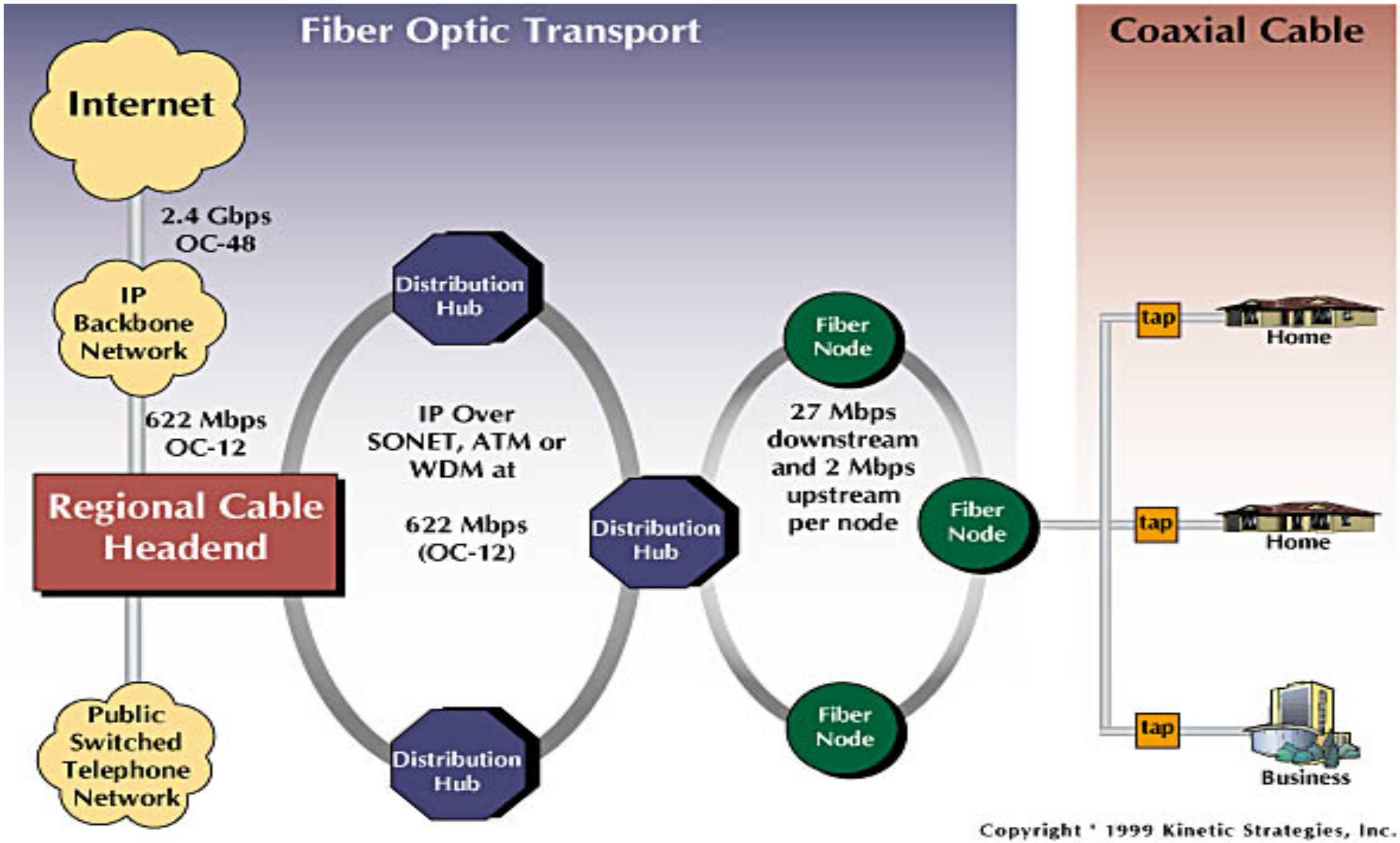

Campus access, e.g.,

- Ethernet
- Wireless

- The Internet is a network of networks
- Each individually administrated network is called an Autonomous System (AS)

# Access: Cable

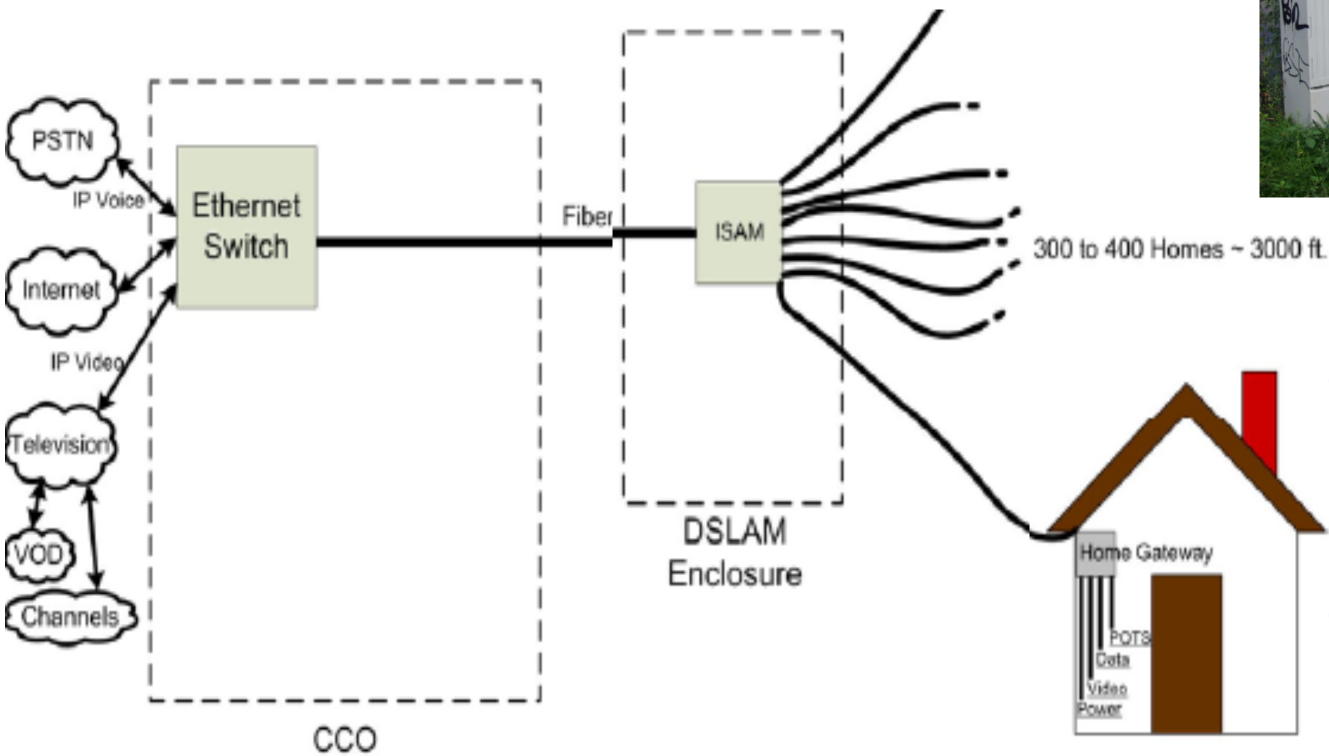
Also called Hybrid Fiber-coaxial Cable (HFC)




- Fiber node: 500 - 1K homes
- Distribution hub: 20K - 40 K homes
- Regional headend: 200 K - 400 K homes

# Access: DSL

- Compared with FTTP, copper from cabinet (DSLAM) to home



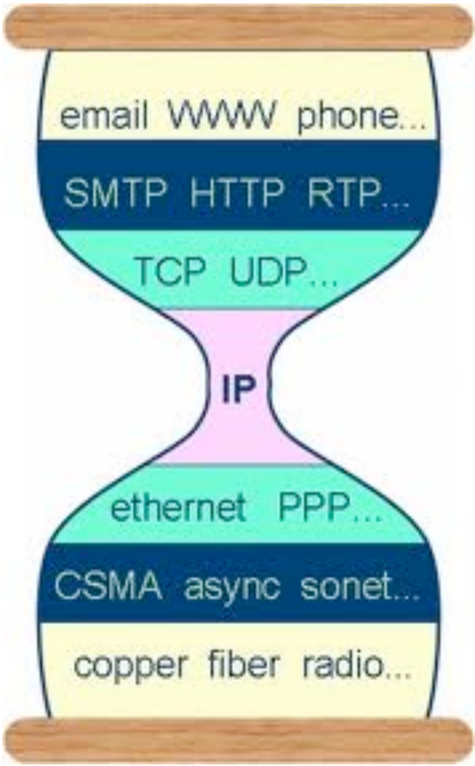

DSLAM

# DSL Services to Customers

- Up to 25 Mbps per customer
- Currently a few Mbps downstream, and a few Mbps upstream
- Voice
  - Converted to standard telephone signal at Home Gateway

# Networking: A Layering Approach

- Network is a very complex system
  - Many different hardware devices and technologies
  - Many different applications
- Internet design follows a layered approach
  - Functionalities are divided into different layers
  - Each layer speak the same "language", i.e., protocol

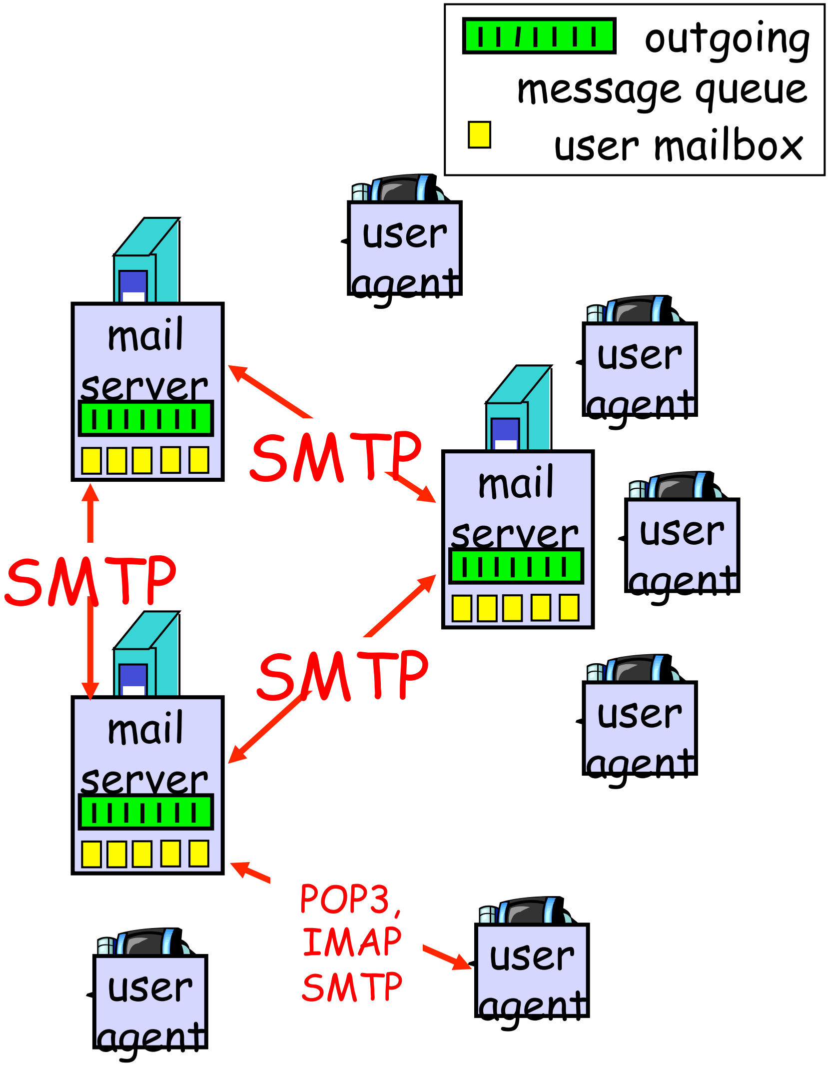


# What is a Network Protocol?

- A **network protocol** defines the format and the order of messages exchanged between two or more communicating entities, as well as the actions taken on the transmission and/or receipt of a message or other events.

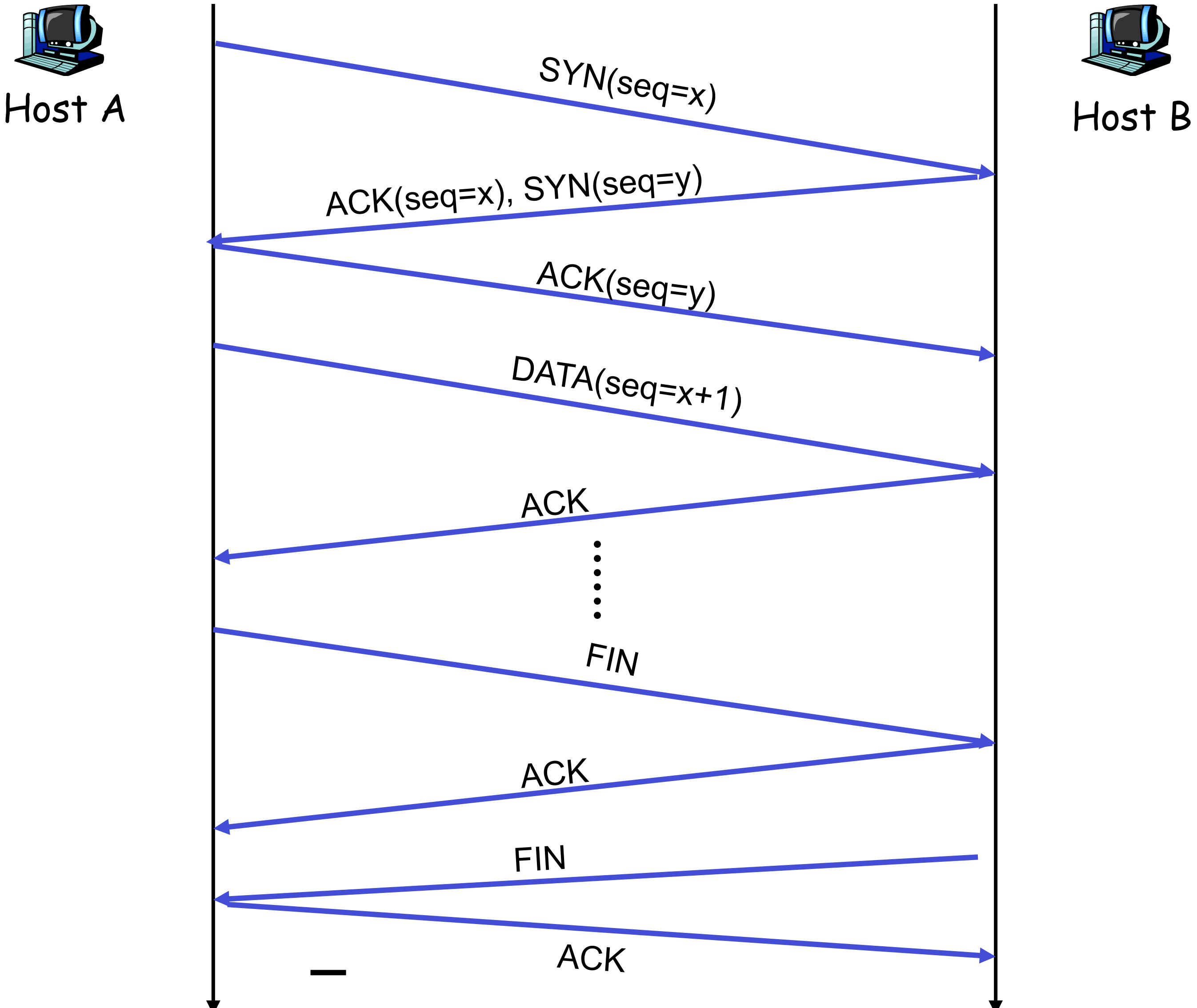
# Example Protocol: Simple Mail Transfer Protocol (SMTP)

- Messages from a client to a mail server
  - HELO
  - MAIL FROM: <address>
  - RCPT TO: <address>
  - DATA
    <This is the text end with a line with a single .>
  - QUIT
- Messages from a mail server to a client
  - status code
    - The first digit of the response broadly indicates the success, failure, or progress of the previous command.
      - 1xx - Informative message
      - 2xx - Command ok
      - 3xx - Command ok so far, send the rest of it.
      - 4xx - Command was correct, but couldn't be performed for some reason.
      - 5xx - Command unimplemented, or incorrect, or a serious program error occurred.
  - content




**Command: %telnet mail.cs.sjtu.edu.cn smtp**

# Example: TCP Reliability



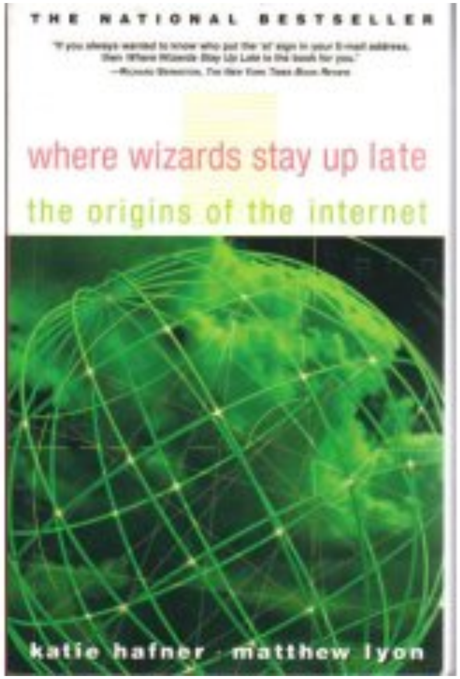
# Internet Standardization Process

- All standards of the Internet are published as RFC (Request for Comments)
  - E.g., the SMTP protocol is specified in RFC821
  - But not all RFCs are Internet Standards: http://zoo.cs.yale.edu/classes/cs433/readings/interestingrfcs.html
- A typical (but not the only) way of standardization:
  - Internet draft
  - RFC
  - Proposed standard
  - Draft standard  (requires 2 working implementations)
  - Internet standard (declared by Internet Architecture Board)
- David Clark, 1992:

  **We reject: kings, presidents, and voting. We believe in: rough consensus and running code.**

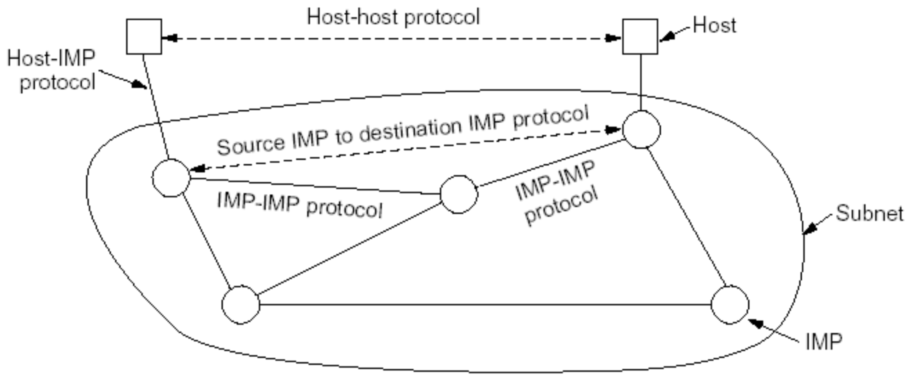
# Outline

- Administrative trivia’s
- What is a network protocol?
- *A brief introduction to the Internet*
  - *Past*
  - Present
- Summary



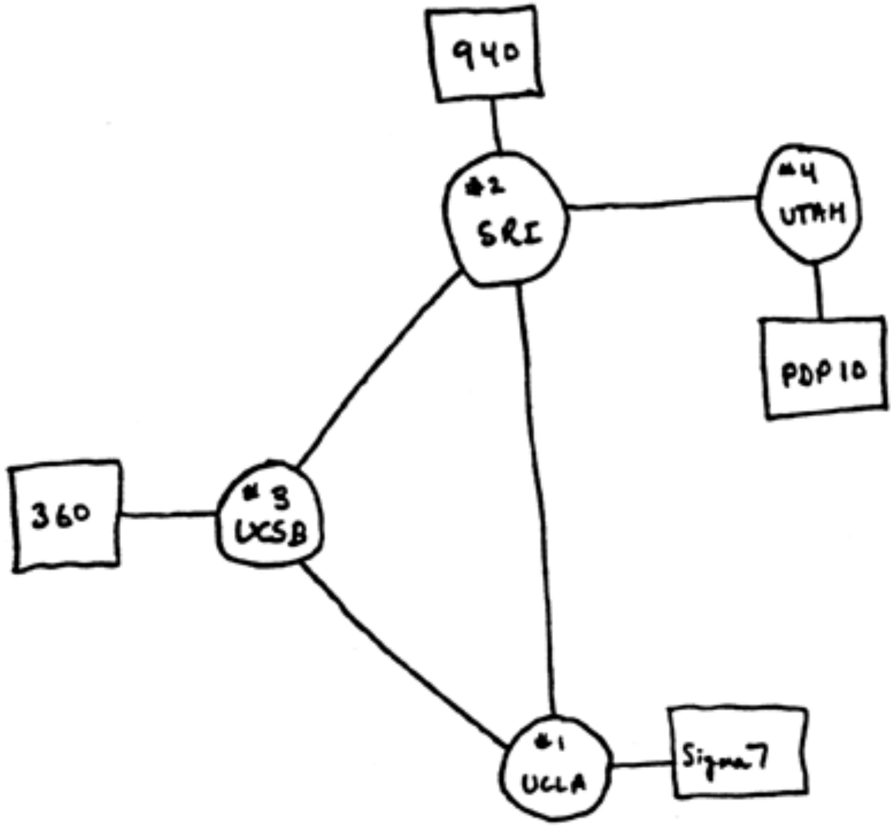
# A Brief History of the Internet: Packet Switching and ARPANET

- **1957**
  - USSR launched Sputnik; US DoD formed Advanced Research Projects Agency (ARPA)
- **1961**
  - First paper by Len Kleinrock on packet switching theory
- **1964**
  - Paul Baran from RAND on design of packet switching networks
- **1965-1968**
  - ARPANET plan
  - 3 independent implementation
  - Bolt Beranek and Newman, Inc. (BBN), a small company, was awarded Packet Switch contract to build Interface Message Processors (IMPs) US Senator Edward Kennedy congratulating BBN for getting contract to build "interfaith" message processors

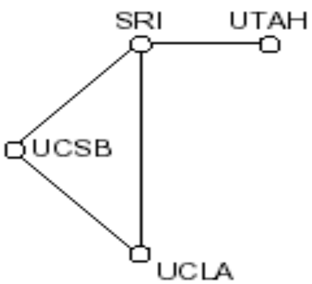


# Initial ARPANET

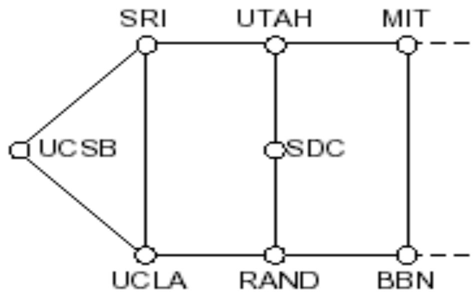
- 1969
  - ARPANET commissioned: 4 nodes, 50kbps



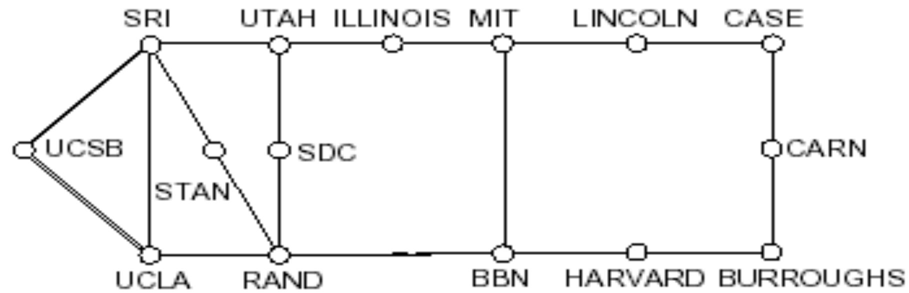
# Initial Expansion of the ARPANET



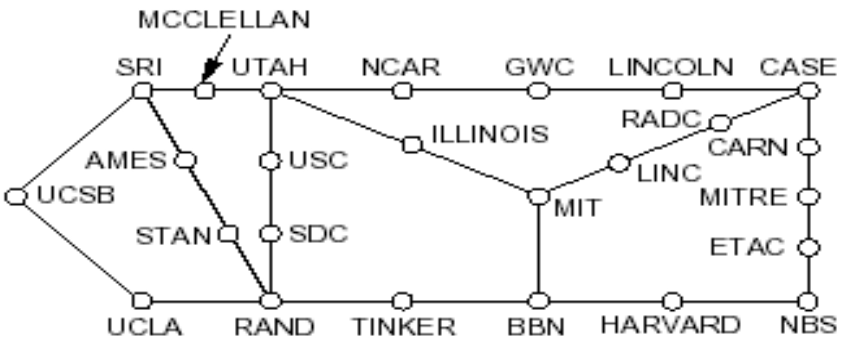
Dec. 1969



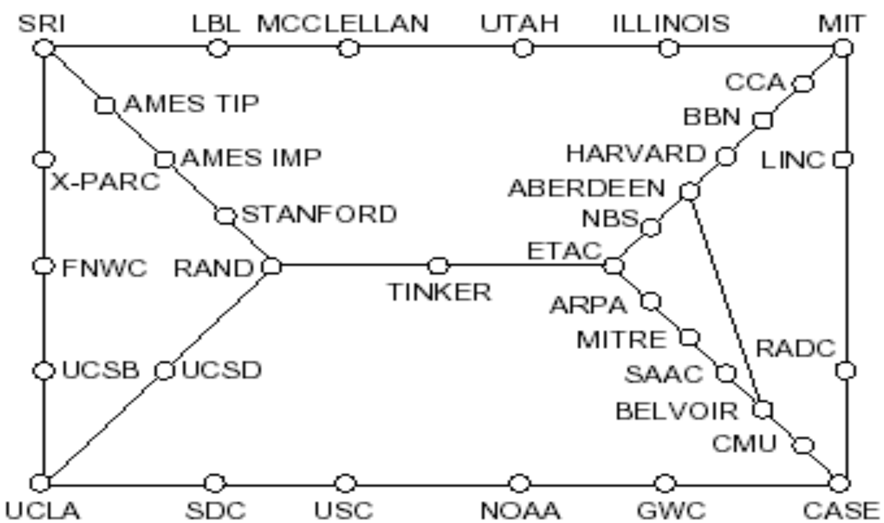
July 1970



Mar. 1971



Apr. 1972



Sept. 1972

RFC 527: ARPAWOCKY; RFC 602: The Stockings Were Hung by the Chimney with Care

# The Internet Becomes a Network of Networks

- 1970: ALOHAnet, the first packet radio network, developed by Norman Abramson, Univ of Hawaii, becomes operational

- 1973: Bob Kahn poses Internet problem---how to connect ARPANET, packet radio network, and satellite network

- 1974: Vint Cerf, Bob Kahn publish initial design of TCP (NCP) to connect multiple networks
  - 1978: TCP (NCP) split to TCP/IP
  - 1983: TCP (NCP) converted to TCP/IP (Jan. 1)

# Growth of the Internet

- 1986: NSF builds NSFNET as backbone, links 6 supercomputer centers, 56 kbps; this allows an explosion of connections, especially from universities
- 1987: 10,000 hosts
- 1988: NSFNET backbone upgrades to 1.5Mbps
- 1989: 100,000 hosts

RFC 1121: Act One – The Poem

WELCOME by Leonard Kleinrock

We've gathered here for two days to examine and debate
And reflect on data networks and as well to celebrate.
To recognize the leaders and recount the path we took.

We'll begin with how it happened; for it's time to take a look.
Yes, the history is legend and the pioneers are here.
Listen to the story - it's our job to make it clear.
We'll tell you where we are now and where we'll likely go.
So welcome to ACT ONE, folks.
Sit back - enjoy the show!!

# Web and Commercialization of the Internet

- 1990: ARPANET ceases to exist
- 1991: NSF lifts restrictions on the commercial use of the Net; Berners-Lee of European Organization for Nuclear Research (CERN) released World Wide Web
- 1992: 1 million hosts (RFC 1300: Remembrances of Things Past)
- 1994: NSF reverts back to research network (vBNS); the backbone of the Internet consists of multiple private backbones
- Today: backbones run at 10 Gbps, some updated to 40 Gbps, ~500 mil computers in 150 countries

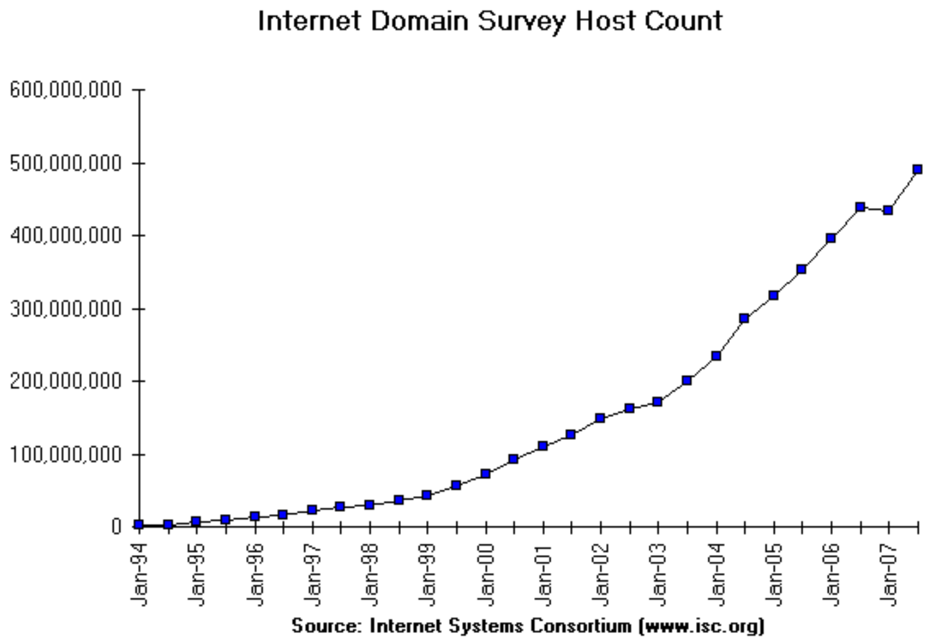
For a link of interesting RFCs, please see
http://zoo.cs.yale.edu/classes/cs433/readings/interestingrfcs.html

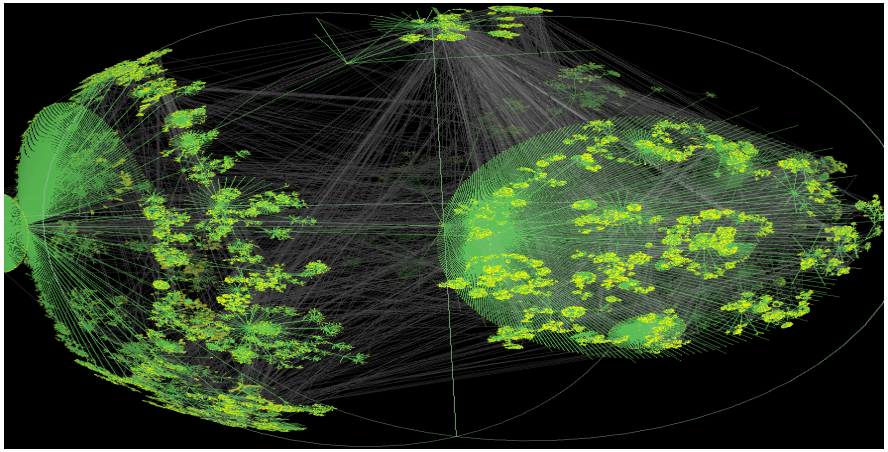
For more on Internet history, please see http://www.zakon.org/robert/internet/timeline/

# Growth of the Internet in Terms of Number of Hosts

**Number of Hosts on the Internet:**

| | |
|---|---|
| Aug. 1981 | 213 |
| Oct. 1984 | 1,024 |
| Dec. 1987 | 28,174 |
| Oct. 1990 | 313,000 |
| Jul. 1993 | 1,776,000 |
| Jul. 1996 | 19,540,000 |
| Jul. 1999 | 56,218,000 |
| Jul. 2004 | 285,139,000 |
| Jul. 2005 | 353,284,000 |
| Jul. 2006 | 439,286,000 |
| Jul. 2007 | 489,774,000 |



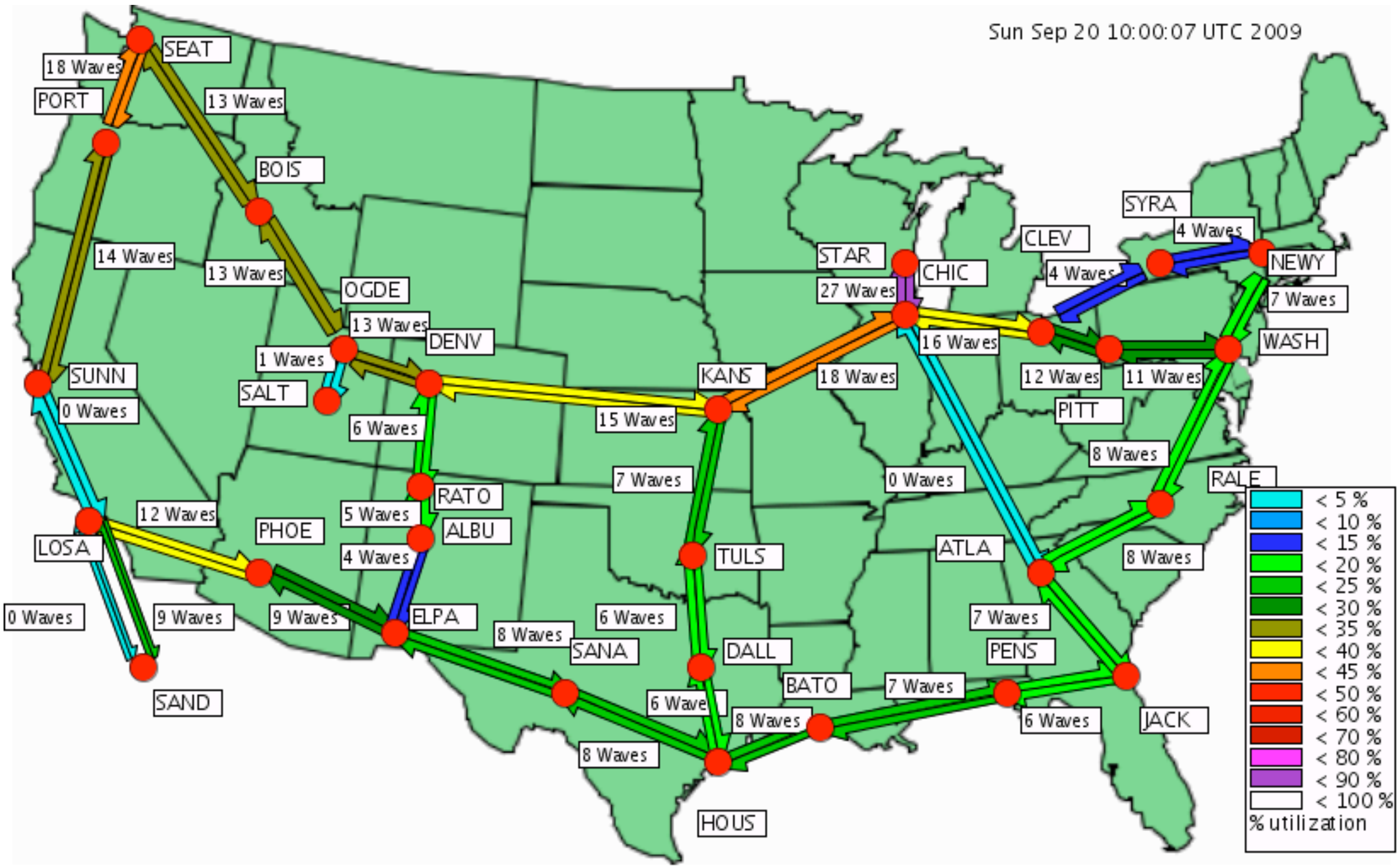



CAIDA router level view

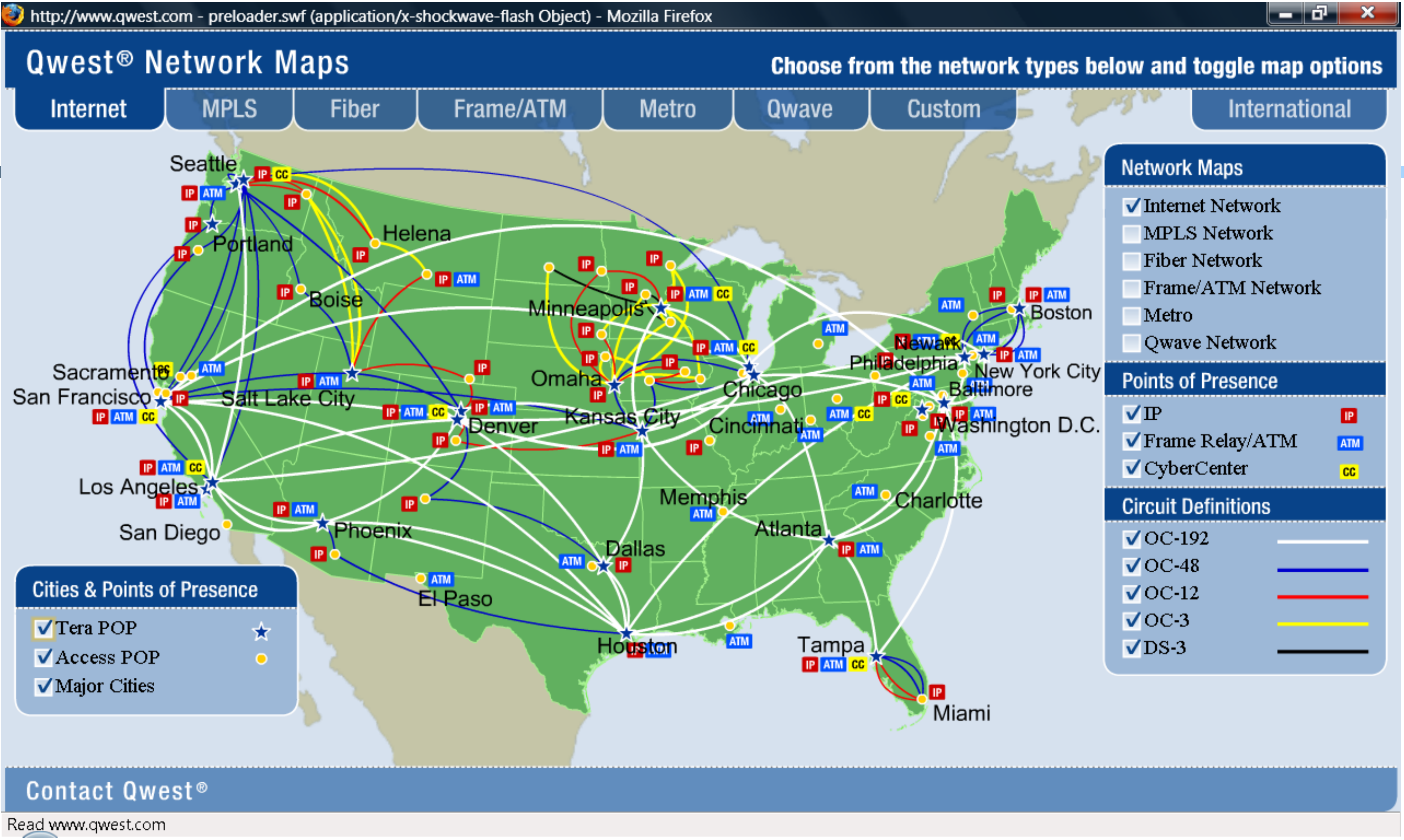
# Outline

- Administrative trivia's
- What is a network protocol?
- *A brief introduction to the Internet*
  - past
  - *present*
- Summary

# Abilene I2 Backbone



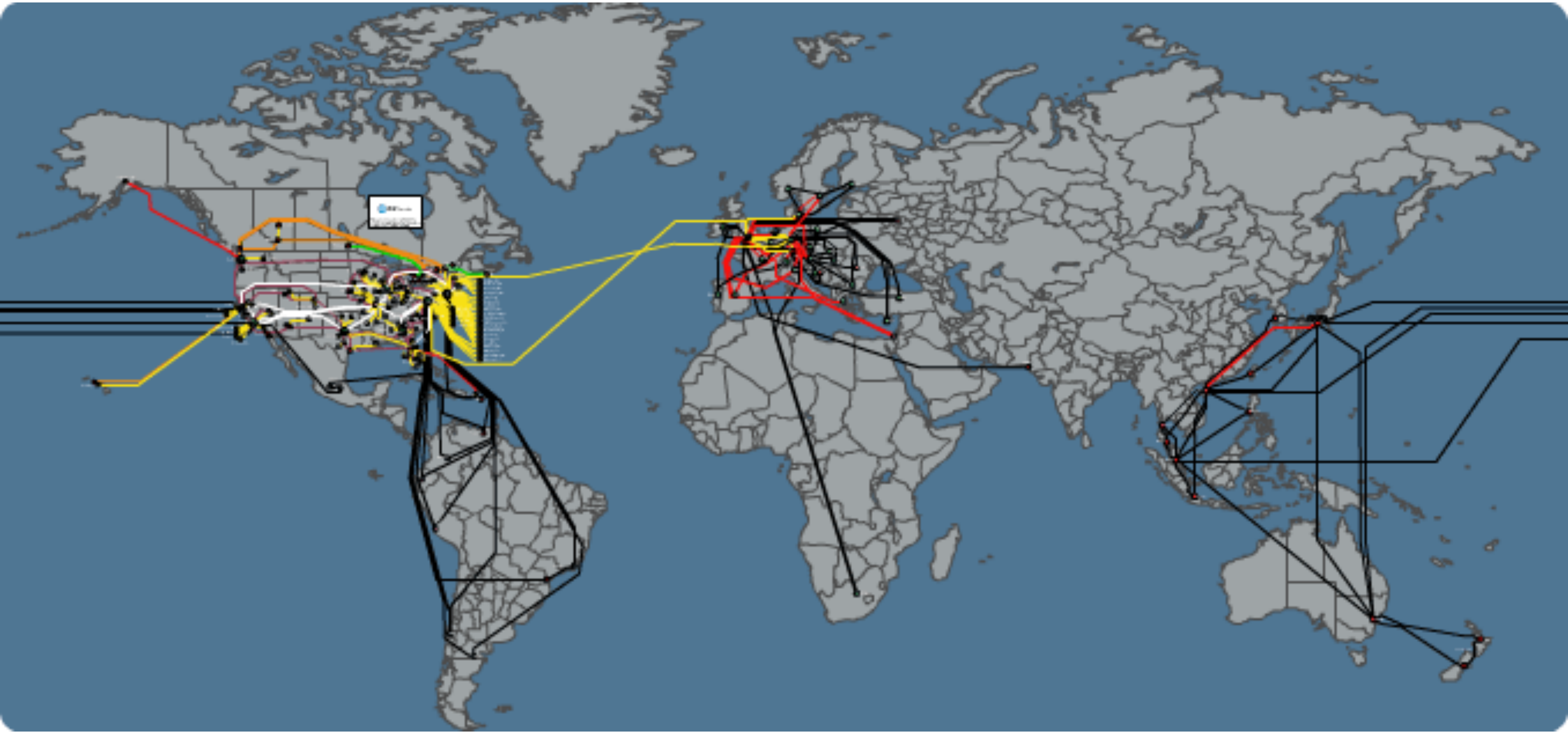

http://weathermap.grnoc.iu.edu/NLR_Layer1-internal_jpg.html




http://www.qwest.com/largebusiness/enterprisesolutions/networkMaps/preloader.swf

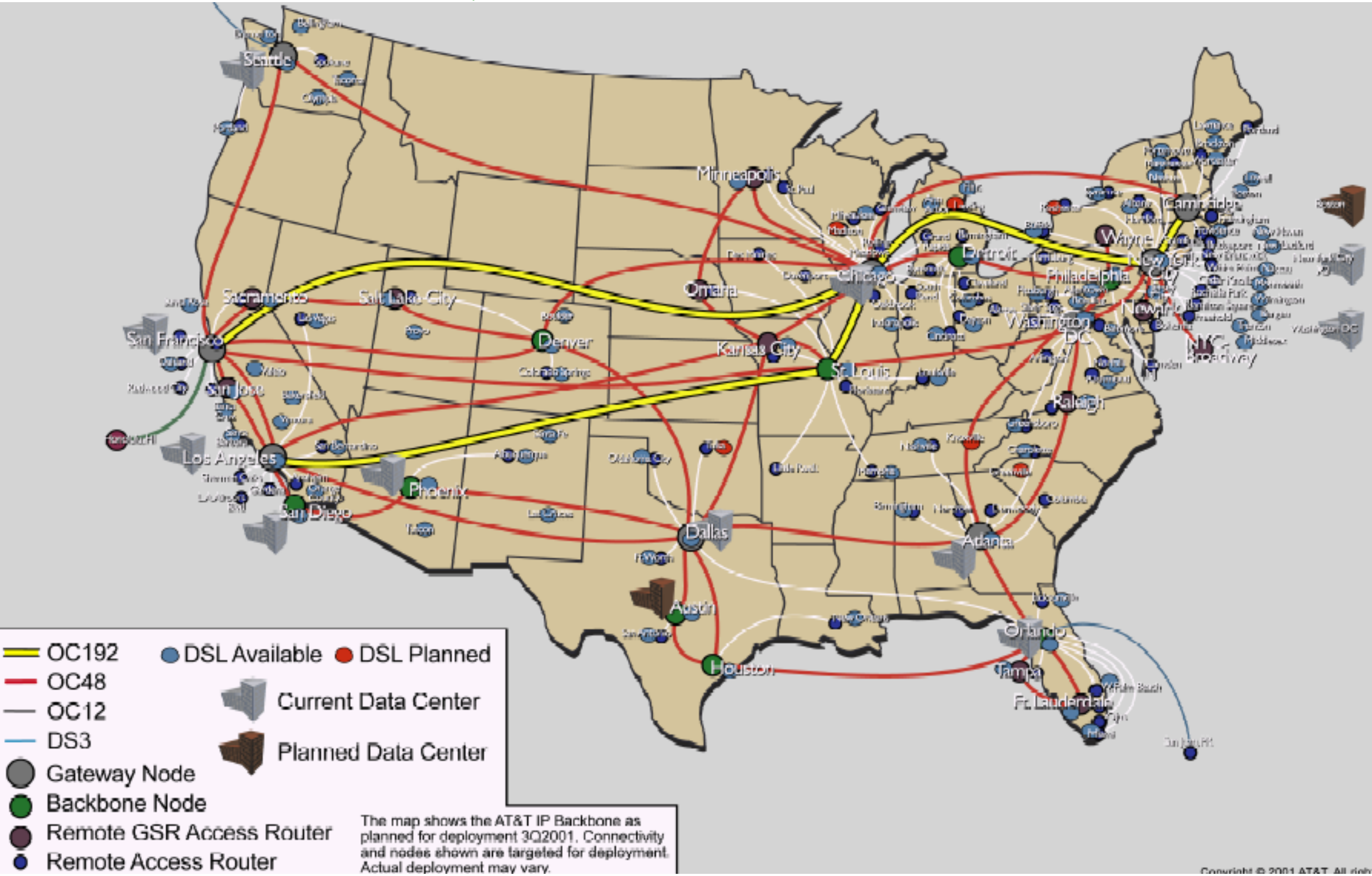
## Qwest Backbone Map

# ATT Global Backbone IP Network



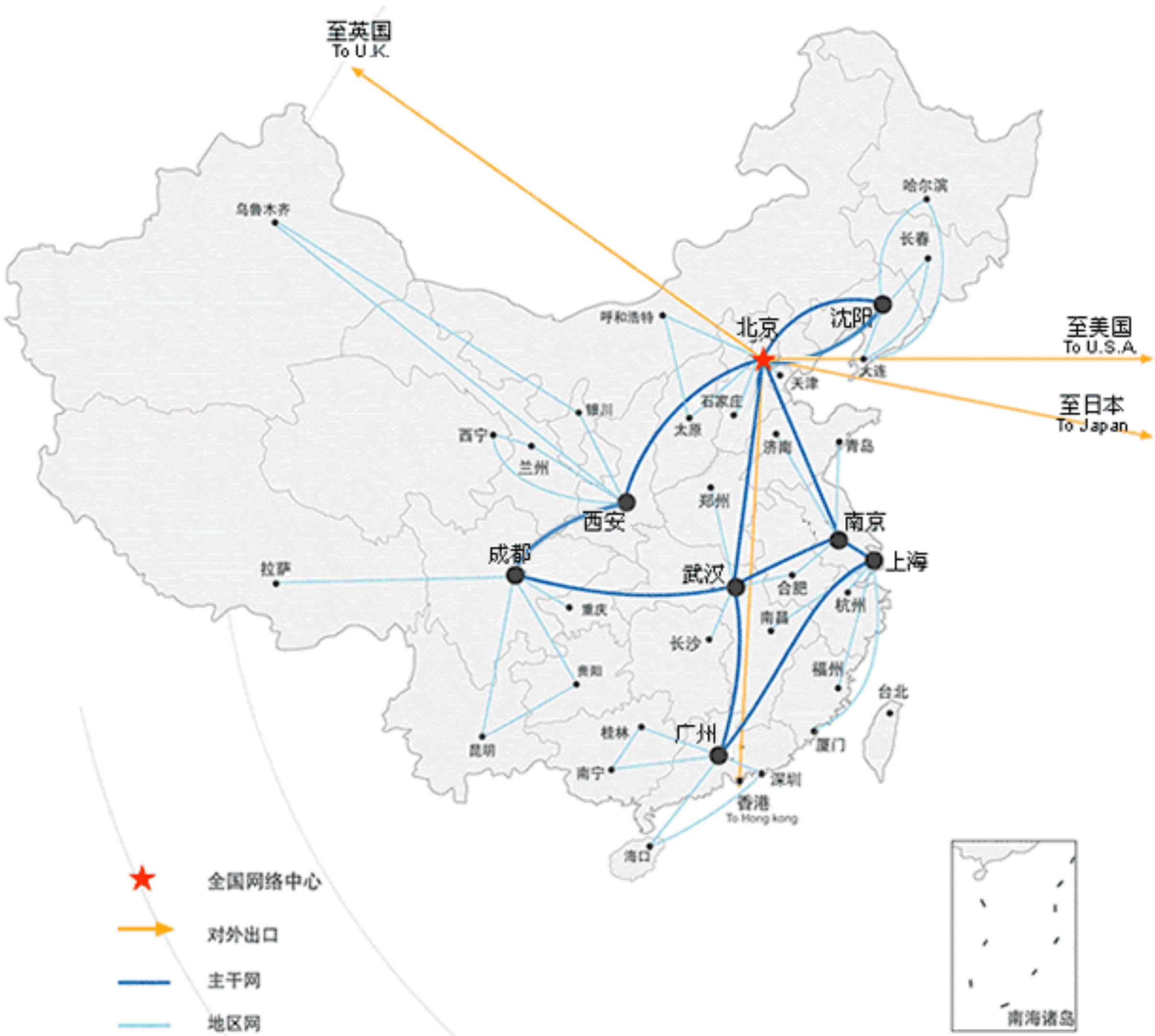
From http://www.business.att.com

# AT&T USA Backbone Map

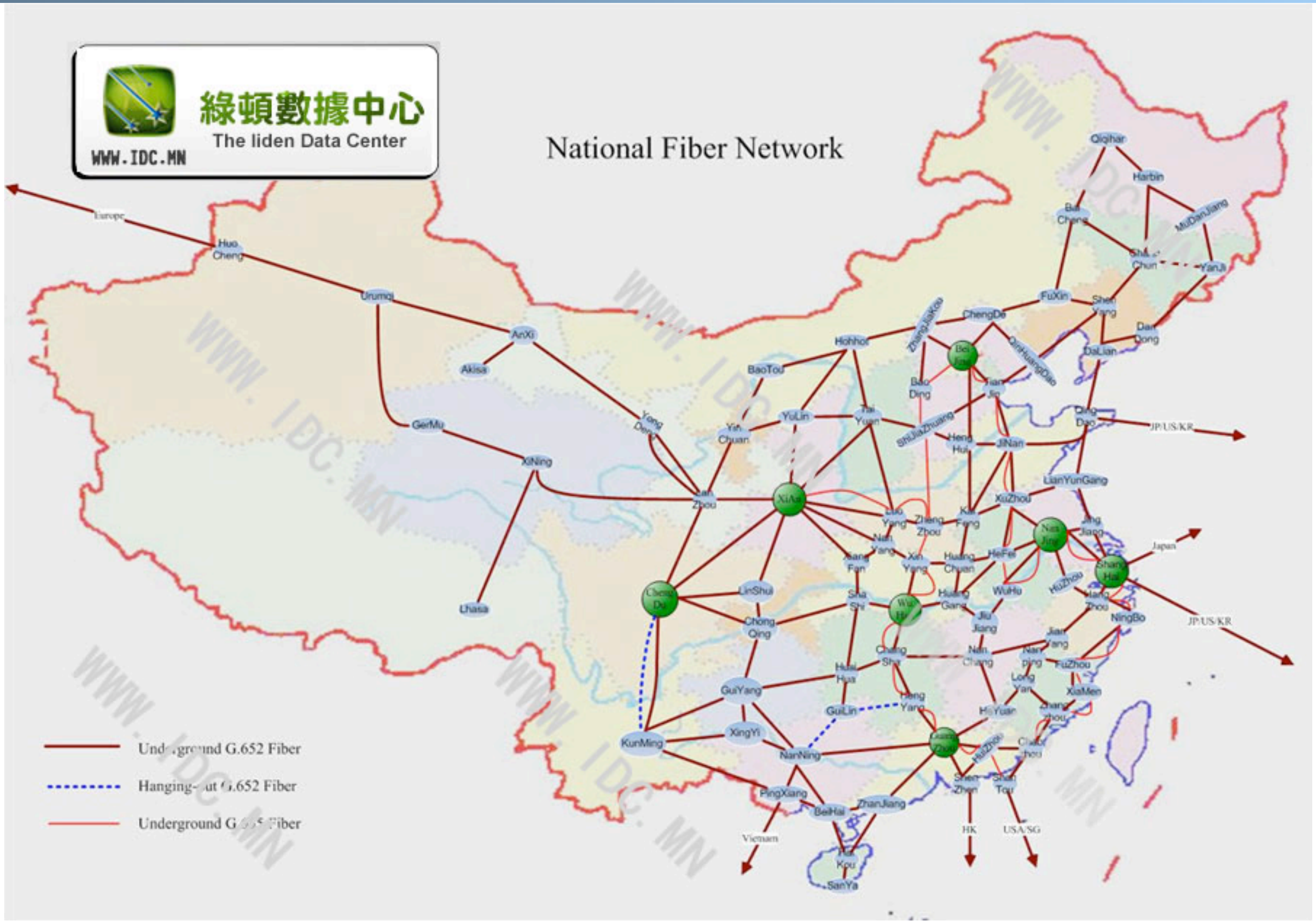



From AT&T web site.

# CERNET Topology

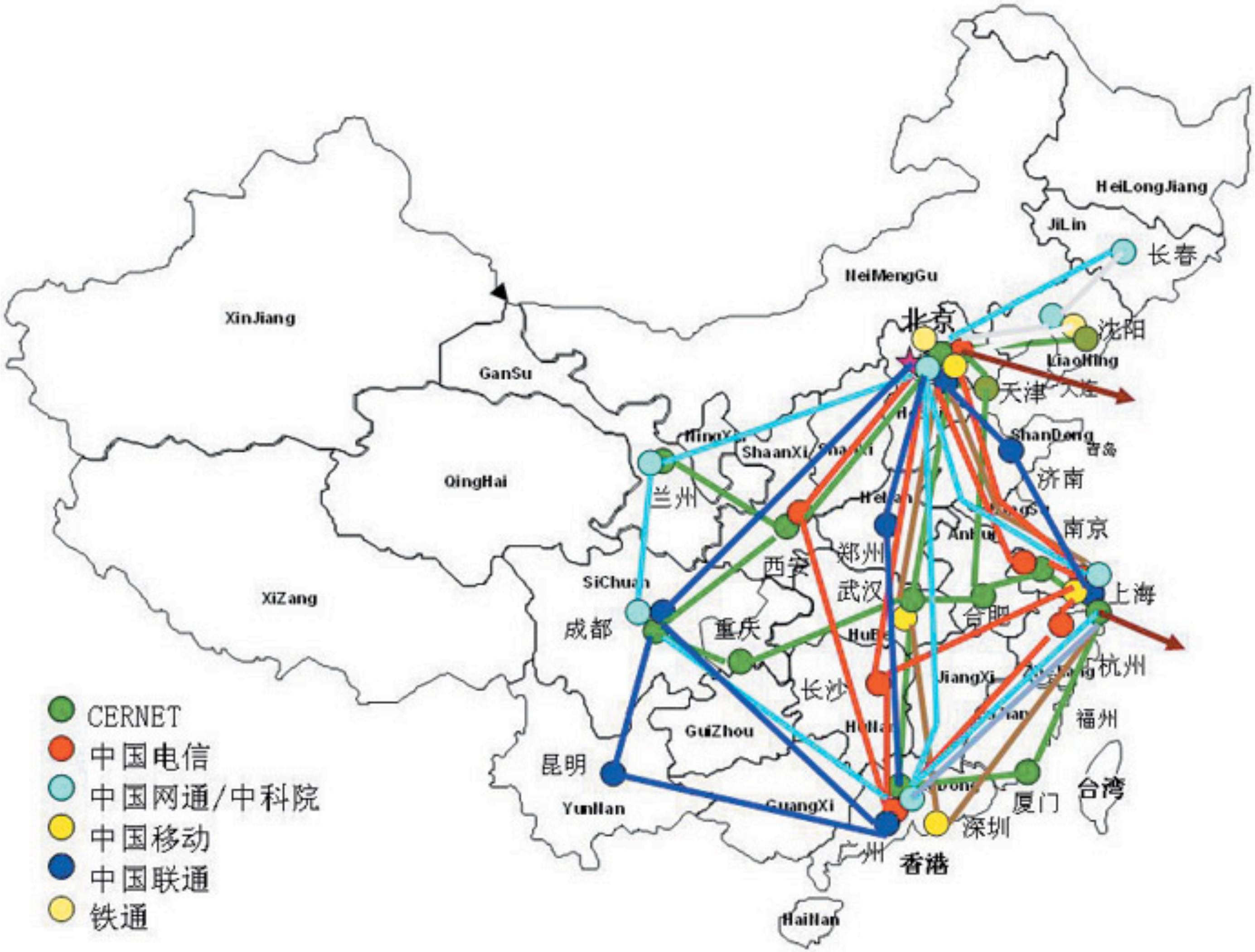


# Chinanet Topology

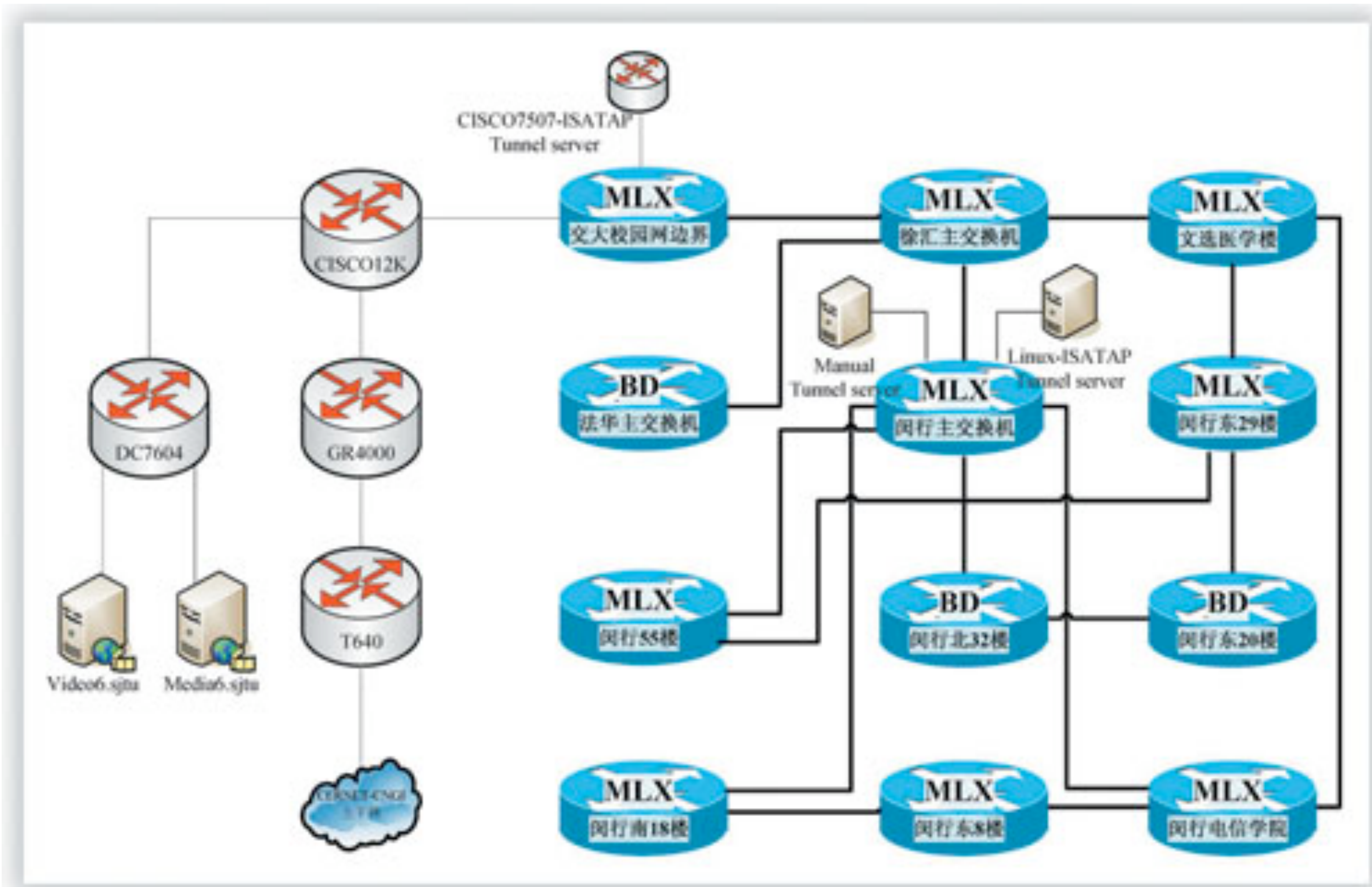



核心层：北京、上海、广州、沈阳、南京、武汉、成都、西安等8个城市

# China Next Generation Internet (CNGI)



# SJTU CNGI Topology



# Summary

- Course administration
- A protocol defines the format and the order of messages exchanged between two or more communicating entities, as well as the actions taken on the transmission and/or receipt of a message or other events.
- The past:
  - Facts:
    - The Internet started as ARPANET in late 1960s
    - The initial link bandwidth was 50 kbps
    - The number of hosts at the end of 1969 was 4
  - Some implications of the past:
    - ARPANET is sponsored by ARPA → design should survive failures
    - The initial IMPs were very simple → keep the network simple
    - Many networks → need a network to connect networks
- Current:
  - The number of hosts connected to the Internet is about 490 millions
  - The backbone speed of the current Internet is about 10 Gbps
  - The Internet is roughly hierarchical where ISPs interconnect at PoP and NAP

# Observing the Internet

- Read the manual of ping and traceroute, and try them

  $ /bin/ping <machine_name>

  $ /usr/sbin/traceroute <machine_name>

- Look at the web sites of the routers you see through traceroute

- Use Wireshark to capture packets

# Preview

- We have only looked at the topology/connectivity of the Internet
  - A communication network is a mesh of interconnected devices

- *A* fundamental question: how is data transferred through a network?

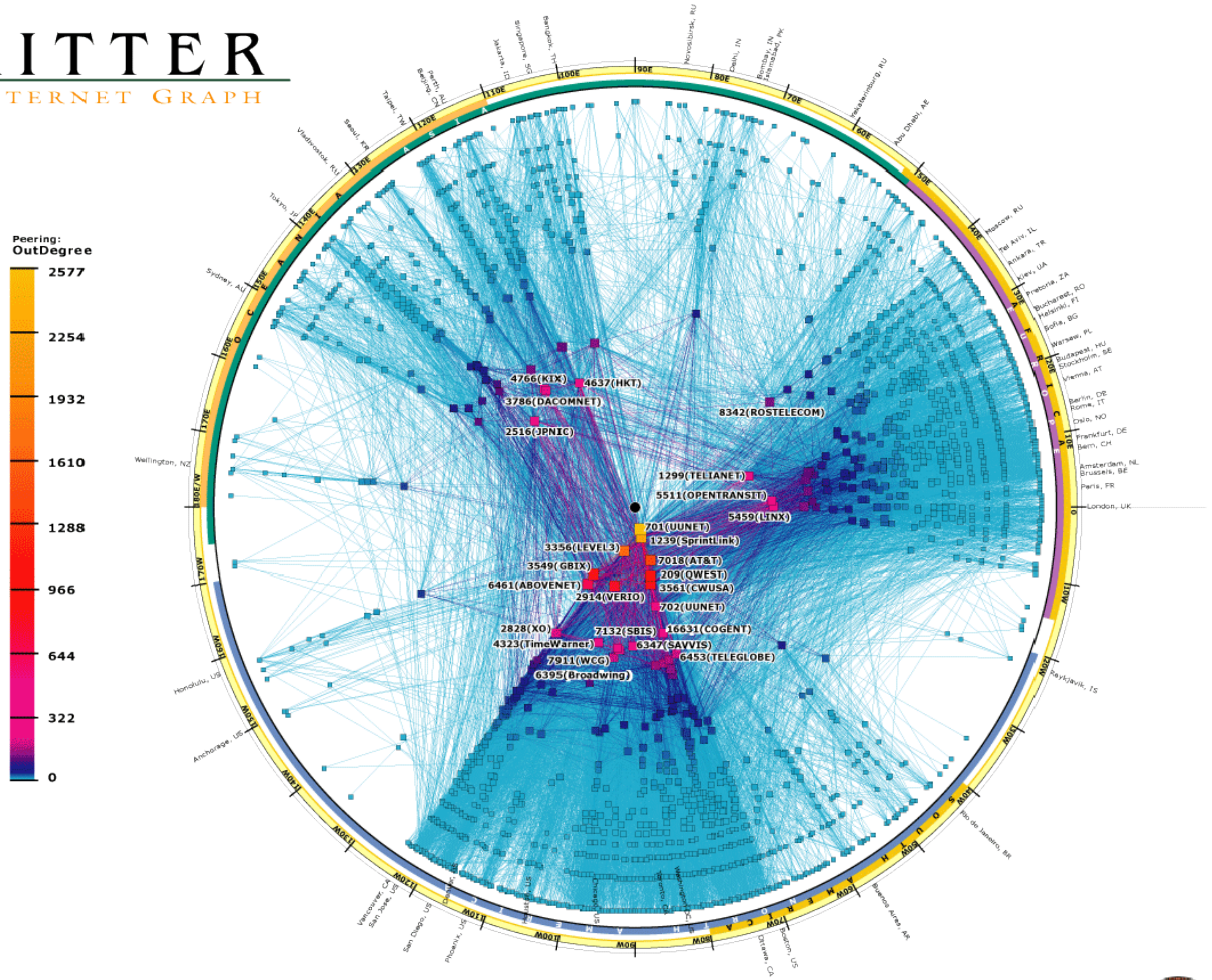
# Backup Slides

# Challenge of the Internet: Characterizing Internet Topology



SKITTER

AS INTERNET GRAPH




cooperative association for internet data analysis ○ san diego supercomputer center ○ university of california, san diego
9500 gilman drive, mc0505 ○ la jolla, ca 92093-0505 ○ tel. 858-534-5000 ○ http://www.caida.org/

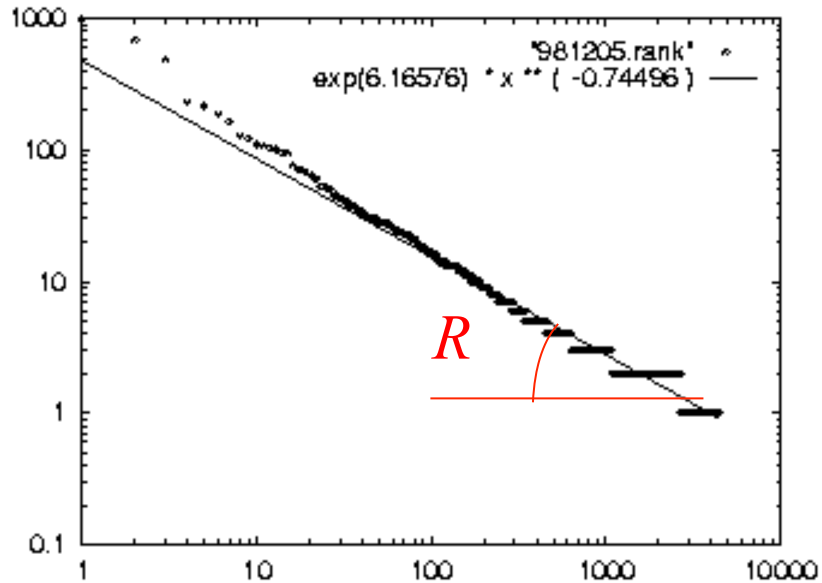
CAIDA is a program of the University of California's San Diego Supercomputer Center (UCSD/SDSC)
CAIDA's topology mapping projects are supported by DARPA, NCS, NSF, WIDE and CAIDA members

# Challenge of the Internet: Power Law?

- Some researchers found that the Internet AS connectivity graph satisfies Power Law
- Does it really satisfy power law? If so, why?

Exponent = slope

*R = -0.74*




Dec' 98

Rank: nodes in decreasing outdegree order

Note that the plot is a line in log-log scale