CS589: Advanced Computer Networks

- Instructor
  - Z. Morley Mao (zmao@umich.edu, 4629 CSE)
- Lecture time: TuTh, 10:30-12:30 PM
- Location: 1018 DOW
- Office hour:
  - TuTh 1-2PM
  - email for appointment

Topics Covered

- Internet design philosophies and principles
- Internet routing characterization, Internet AS relationships
- Routing security
- ISP traffic engineering
- Critical network infrastructure services
- Network security: IDS, worms, and honeypots
- CDNs, Peer to peer and overlay networks, DHTs
- Wireless networking, meshed networks, mobile systems
- Sensor networking
- Network measurements
- Network security
- Network models
- Network algorithmics: building fast networks
- Networking in challenging environments
- Data center networking

Interesting new/hot topics

- A research agenda for Web 2.0
- Architectural support for security or availability
- Computing in the cloud: what role for networking research?
- Ensuring correctness for distributed protocols
- Evolution of storage area networks
- Lessons drawn from failed research, and controversial or disruptive topics
- Measurement and management of metro-area WiFi networks
- Network coding: hype or reality?
- Power as a first-class design property; "green" protocols/implementations
- Protocol design for optical switching
- The future role of network processors
- Third-world networking challenges
- Understanding the economics of operational costs
- Unique challenges of massive multi-player game systems
- Validation of measurement-based research: what are our standards?

Lecture Overview

- Administrative trivia
- Course overview
- Self introduction, student introduction
- Overview and history of the Internet
- A Taxonomy of Communication Networks

Administrative Trivia

- Course Web page:
  - http://www.eecs.umich.edu/courses/eecs589
  - Linked from my home page: http://www.eecs.umich.edu/~zmao
  - Check it periodically to get the latest information
- Please come prepared for each class
  - Reading summaries are due before each class
  - Attendance is important
- Assignments are done individually, unless otherwise noted
- Research project are encouraged to be done in groups (at most 3 people)

Goals of this Course

- Critical examination of current topics of computer networks
  - What assumptions are no longer valid
  - What are the new research problems to look at
- Understand solutions in context
  - Goals
  - Assumptions
- Learning how to do research in systems
  - Paper review, writing, and presentation
- Appreciate what is good research
  - Problem selection
  - Solution & research methodology
  - Presentation
- Apply what you learned in a class project

What Do You Need To Do?

- A research-oriented class project
- Paper readings, selective book chapters
- Lead at least one class discussion
- 2-3 assignments

Research Project

- Investigate new ideas and solutions in a class research project
  - Define the problem
  - Execute the research
  - Work with your partner
  - Write up and present your research

- Ideally, best projects will become conference papers (e.g., SIGCOMM, INFOCOM, MOBICOM, Sensys, Mobisys, IMC)

Research Project: Steps

- I'll distribute a list of projects
  - You can either choose one of these projects or come up with your own
- Pick your project, partner, and submit a one page proposal describing:
  - The problem you are solving
  - Your plan of attack with milestones and dates
  - Any special resources you may need
- A midterm presentation of your progress (>10 minutes)
- Final project presentation (>30 minutes)
- Submit project papers

Paper Reviews

- Goal: synthesize main ideas and concepts in the papers
- Number: about two papers per class
- Length: no more than half page per paper
- Content
  - Main points intended by the author
  - Points you particularly liked/disliked
  - Other comments (writing, conclusions…)
- Submission:
  - Submit each review via on lecture day in class
  - See class web page for details

Grading

Term project	50%
Assignments	20%
Paper presentation	10%
Reading summaries	10%
Class discussion	10%

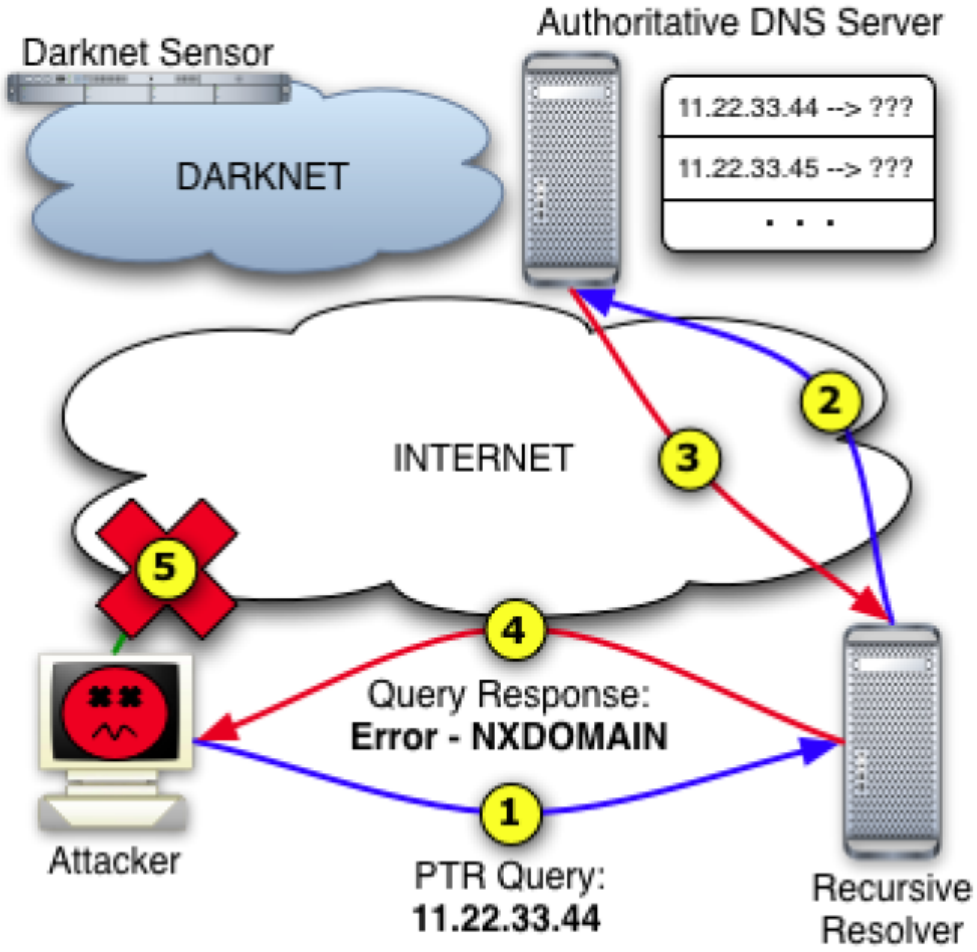
- This is a graduate networking class: more important is what you realize/learn than the grade

Self Introduction

- Faculty in the software lab
- Past and ongoing research:
  - Internet routing, BGP
    - How to protect the Internet routing systems better?
  - Network measurement
    - How do we know how well networks are doing?
  - Content distribution networks
  - Intrusion detection systems
  - Network troubleshooting, debugging
  - Network configuration management, provisioning
  - Denial of service attacks
  - General interest: Internet networks, routing systems, network security.

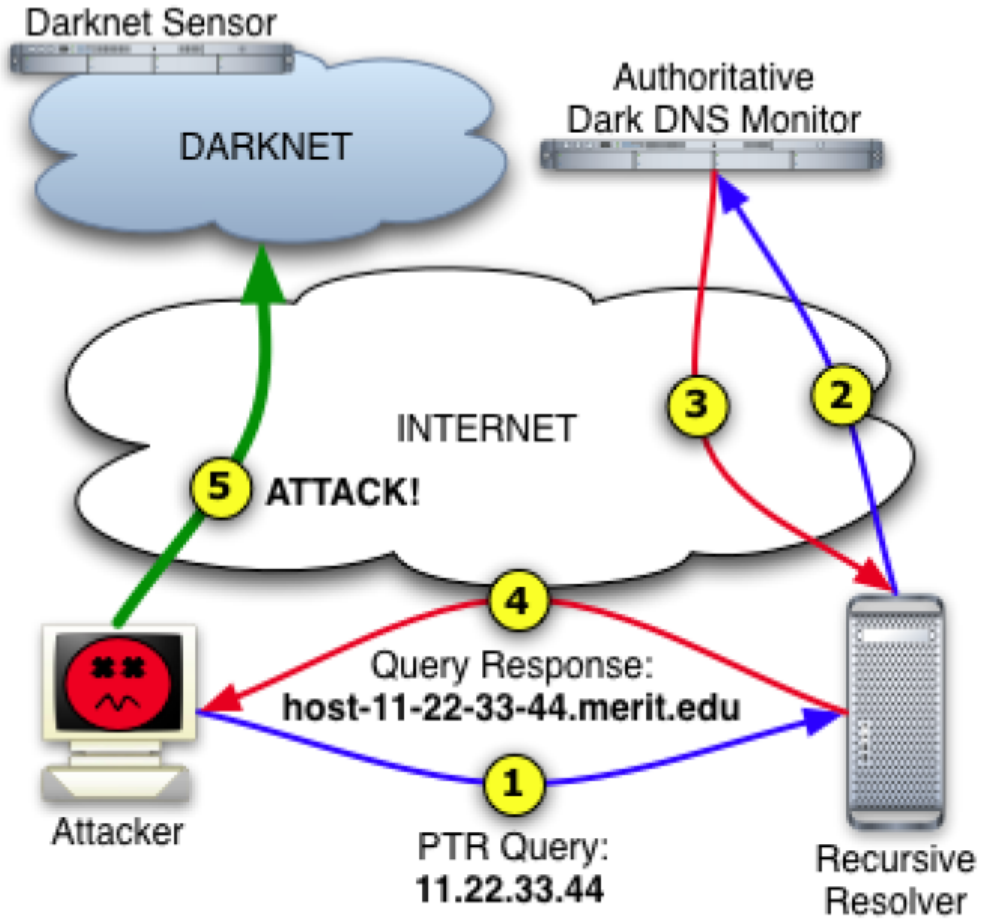
Example research project 1: dark DNS

Improperly Delegated

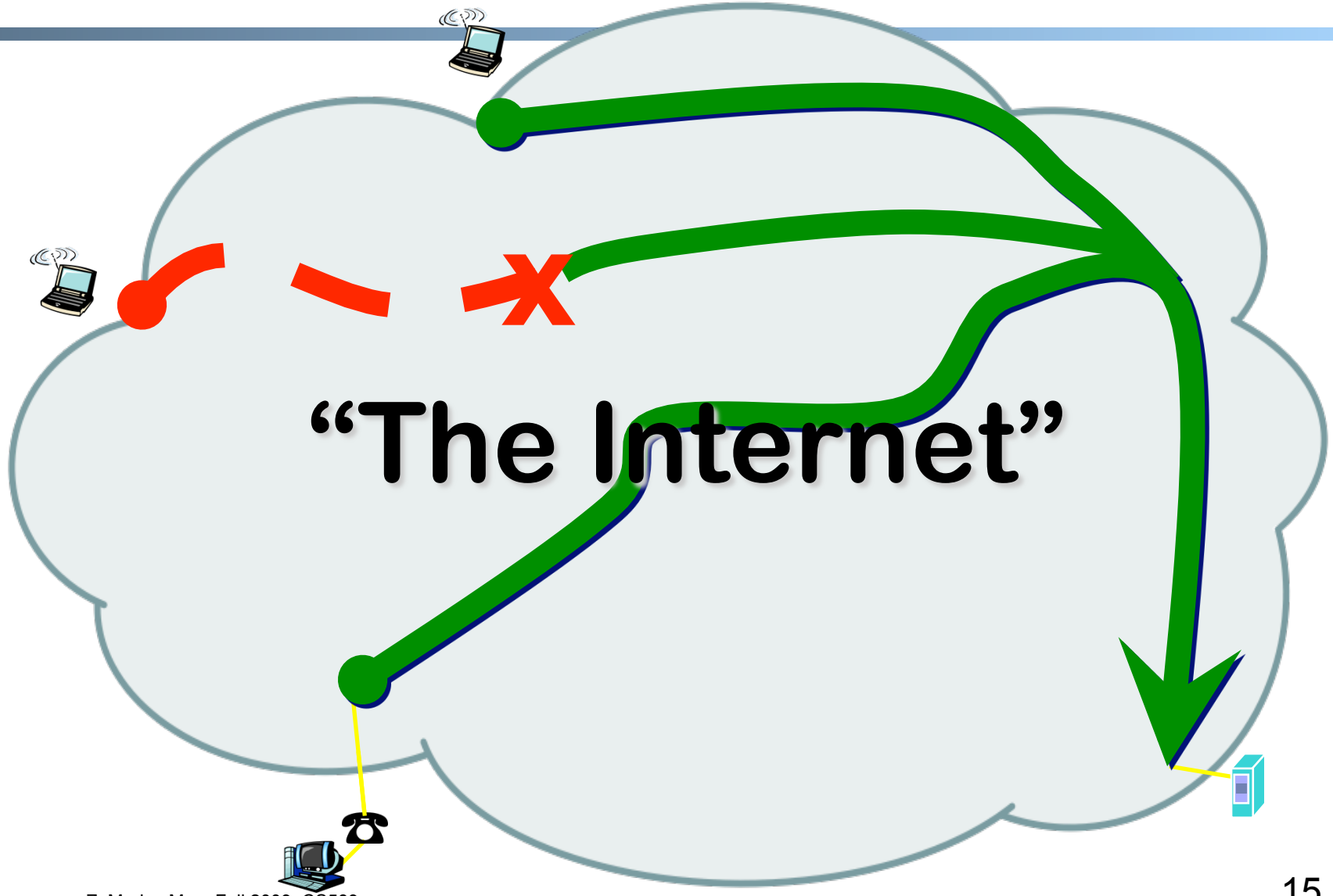


Dark DNS

Properly Delegated



Example research project 2: Testing the reachability of (new) address space



Testing reachability

- We can identify regions in the Internet that do not have reachability
- It is possible to achieve a reasonable coverage of the Internet
- We don’t only check reachability: we also detect places where there is "non-optimal" connectivity

Example research project 3: On the Impact of Route Monitor Selection

- Use of route monitoring
  - Dynamic properties:
    - Routing instability monitoring
    - IP prefix hijacking detection
  - Static properties:
    - AS topologies
    - Prefix to origin AS mappings
  - Inference of important network properties
    - AS relationships

Student introduction

- Please introduce yourself: name, standing, research area (for grad students)
- Say a few words about what you think you would like to learn about computer networks
- And what you think are “unsolved” problems in computer networks

Some unsolved problems…

- QoS
  - Networks are not fast enough
  - Networks do not satisfy application requirements
  - Networks are not robust, highly available
- Security
  - There are attacks every where on the Internet
  - Hosts are easily compromised
- We still don't have ubiquitous access
- New technologies: can networks take advantage of them?
  - Dual core, new algorithms (machine learning, statistical techniques, optimization)

Overview

- Administrative trivia
- Overview and history of the Internet
- A Taxonomy of Communication Networks

What is a Communication Network? (End system view)

- Network offers a service: move information
  - Bird, fire, messenger, truck, telegraph, telephone, Internet …
  - Another example, transportation service: move objects
    - horse, train, truck, airplane ...
- What distinguish different types of networks?
  - The services they provide
- What distinguish the services?
  - Latency
  - Bandwidth
  - Loss rate
  - Number of end systems
  - Service interface (how to invoke?)
  - Other details
    - Reliability, unicast vs. multicast, real-time, message vs. byte ...
  - **What services are missing from today's Internet?**

What is a Communication Network? (Infrastructure Centric View)

- Electrons and photons as communication medium
- Links: fiber, copper, satellite, …
- Switches: electronic/optical, crossbar/Banyan
- Protocols: TCP/IP, ATM, MPLS, SONET, Ethernet, PPP, X.25, FrameRelay, AppleTalk, IPX, SNA
- Functionalities: routing, error control, congestion control, Quality of Service (QoS)
- Applications: FTP, WEB, X windows, ...
- New “infrastructures”:
  - Wireless access points, NATs, firewalls, caches, traffic shapers, or middleboxes
  - Anything you can think of?

Types of Networks

- Geographical distance
  - Local Area Networks (LAN): Ethernet, Token ring, FDDI
  - Metropolitan Area Networks (MAN): DQDB, SMDS
  - Wide Area Networks (WAN): X.25, ATM, frame relay
  - Caveat: LAN, MAN, WAN may mean different things
    - service, network technology, networks
- Information type
  - Data networks vs. telecommunication networks
- Application type
  - Special purpose networks: airline reservation network, banking network, credit card network, telephony
  - General purpose network: Internet
  - Private networks or virtual private networks (VPNs)

Types of Networks

- Right to use
  - private: enterprise networks
  - public: telephony network, Internet
- Ownership of protocols
  - proprietary: SNA
  - open: IP
- Technologies
  - terrestrial vs. satellite
  - wired vs. wireless
- Protocols
  - IP, AppleTalk, SNA

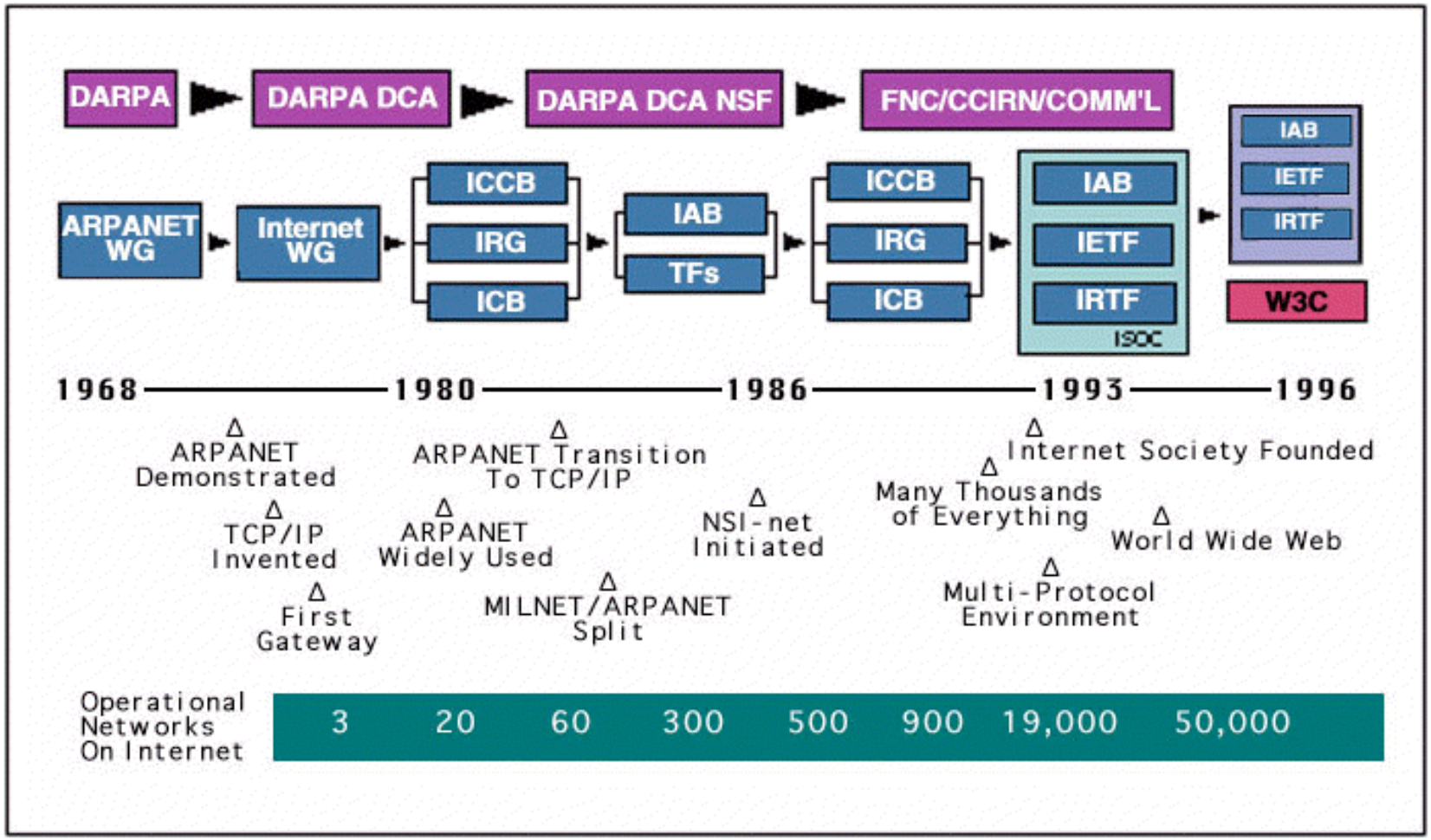
The Internet

- Global scale, general purpose, heterogeneous-technologies, public, computer network
- Internet Protocol
  - Open standard: Internet Engineering Task Force (IETF) as standard body
  - Technical basis for other types of networks
    - Intranet: enterprise IP network
- Developed by the research community

History of the Internet

- 70's: started as a research project, 56 kbps, < 100 computers
- 80-83: ARPANET and MILNET split,
- 85-86: NSF builds NSFNET as backbone, links 6 Supercomputer centers, 1.5 Mbps, 10,000 computers
- 87-90: link regional networks, NSI (NASA), ESNet(DOE), DARTnet, TWBNet (DARPA), 100,000 computers
- 90-92: NSFNET moves to 45 Mbps, 16 mid-level networks
- 94: NSF backbone dismantled, multiple private backbones
- Today: backbones run at 10 Gbps, 10s millions computers in 150 countries
- Internet organically evolved!

Time Line of the Internet

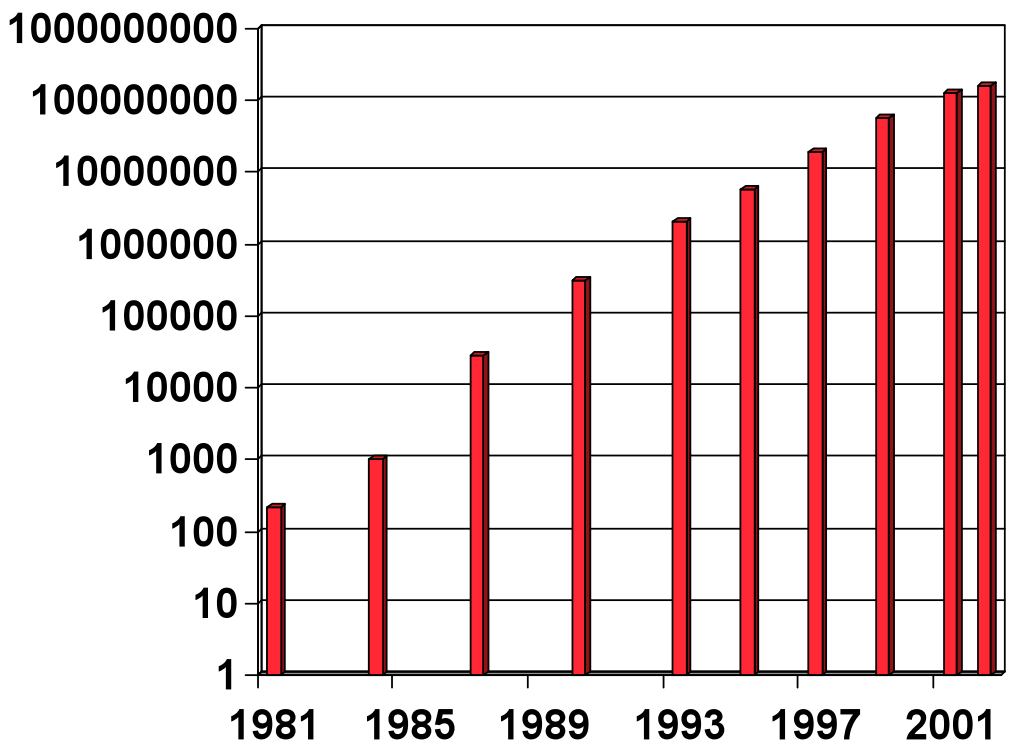


• *Source: Internet Society*

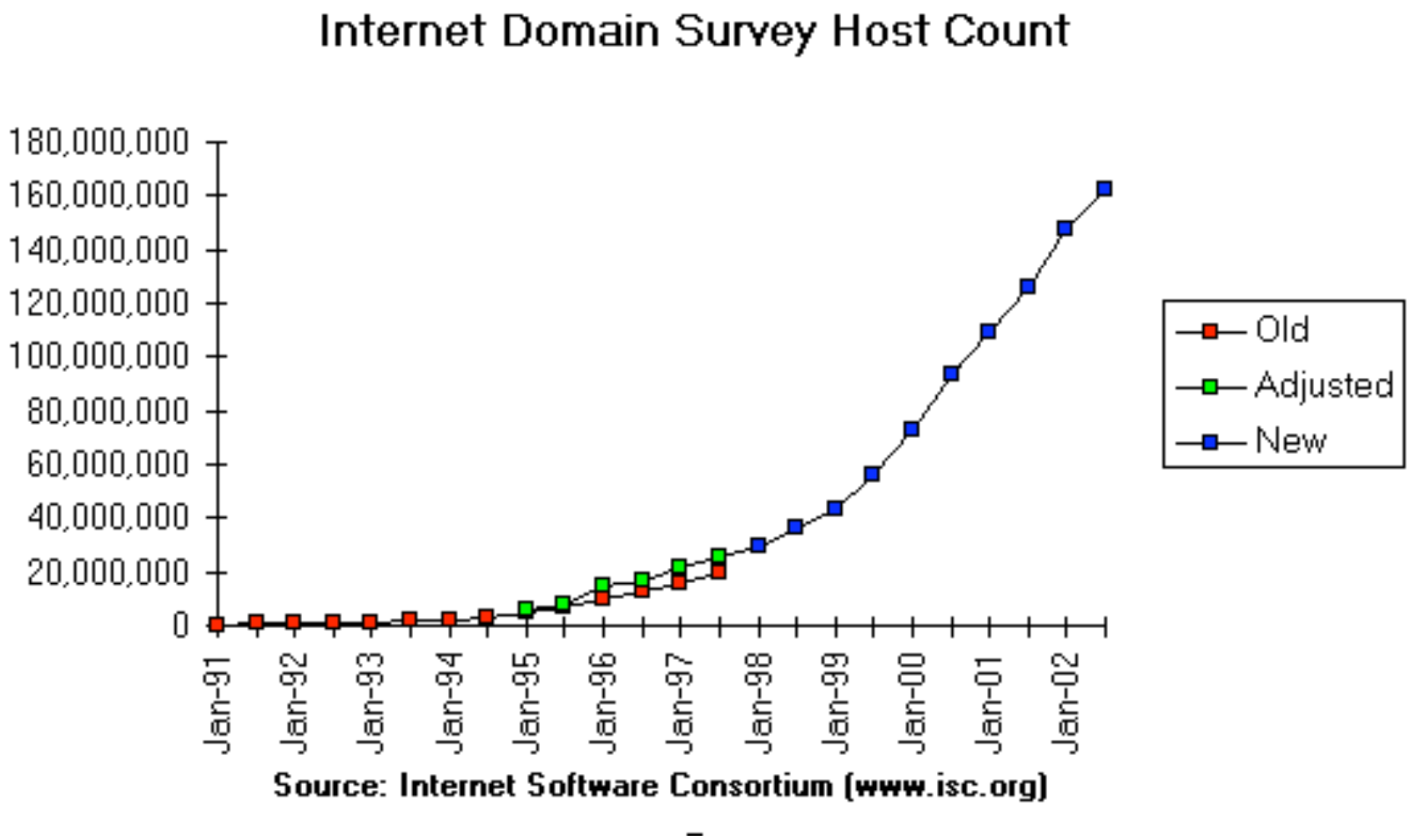
Growth of the Internet

- **Number of Hosts on the Internet:**

Aug. 1981	213
Oct. 1984	1,024
Dec. 1987	28,174
Oct. 1990	313,000
Oct. 1993	2,056,000
Apr. 1995	5,706,000
Jul. 1997	19,540,000
Jul. 1999	56,218,000
Jul. 2001	125,888,197
Jul. 2002	162,128,493



Recent Growth (1991-2002)



Who is Who in the Internet ?

- **Internet Engineering Task Force (IETF):** The IETF is the protocol engineering and development arm of the Internet. Subdivided into many working groups, which specify Request For Comments or RFCs.
- **IRTF (Internet Research Task Force):** The Internet Research Task Force is a composed of a number of focused, long-term and small Research Groups.
- **Internet Architecture Board (IAB)**: The IAB is responsible for defining the overall architecture of the Internet, providing guidance and broad direction to the IETF.
- **The Internet Engineering Steering Group (IESG)**: The IESG is responsible for technical management of IETF activities and the Internet standards process. Standards. Composed of the Area Directors of the IETF working groups.

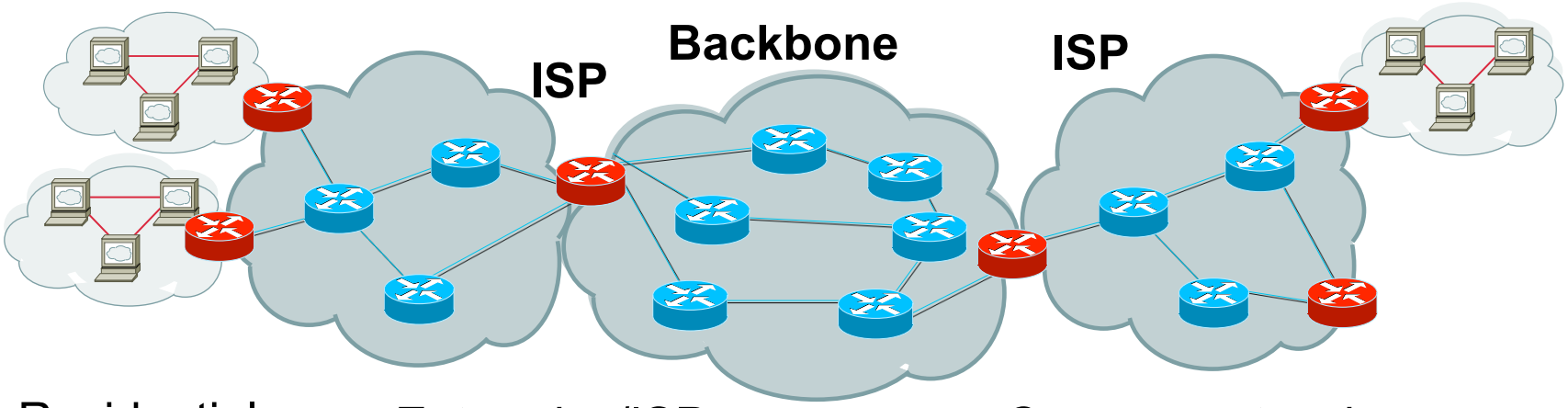
Internet Standardization Process

- All standards of the Internet are published as RFC (Request for Comments). But not all RFCs are Internet Standards !
  - available: http://www.ietf.org
- A typical (but not only) way of standardization is:
  - Internet Drafts
  - RFC
  - Proposed Standard
  - Draft Standard (requires 2 working implementation)
  - Internet Standard (declared by IAB)
- David Clark, MIT, 1992: "We reject: kings, presidents, and voting. We believe in: rough consensus and running code."

Services Provided by the Internet

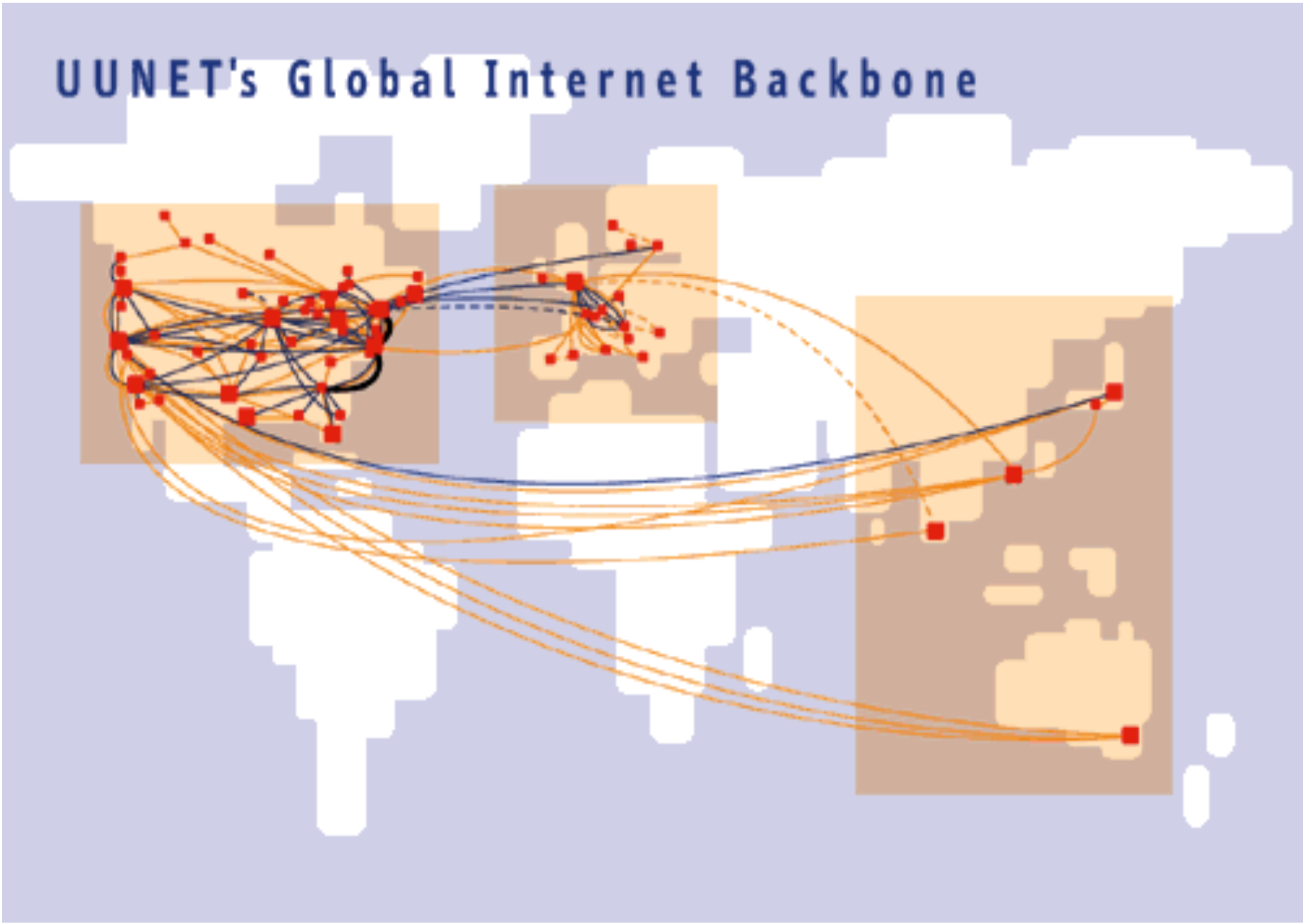
- Shared access to computing resources
  - Telnet (1970's)
- Shared access to data/files
  - FTP, NFS, AFS (1980's)
- Communication medium over which people interact
  - Email (1980's), on-line chat rooms, instant messaging (1990's)
  - Audio, video (1990's)
    - Replacing telephone network?
- A medium for information dissemination
  - USENET (1980's)
  - WWW (1990's)
    - Replacing newspaper, magazine?
  - Audio, video (2000's)
    - Replacing radio, CD, TV?

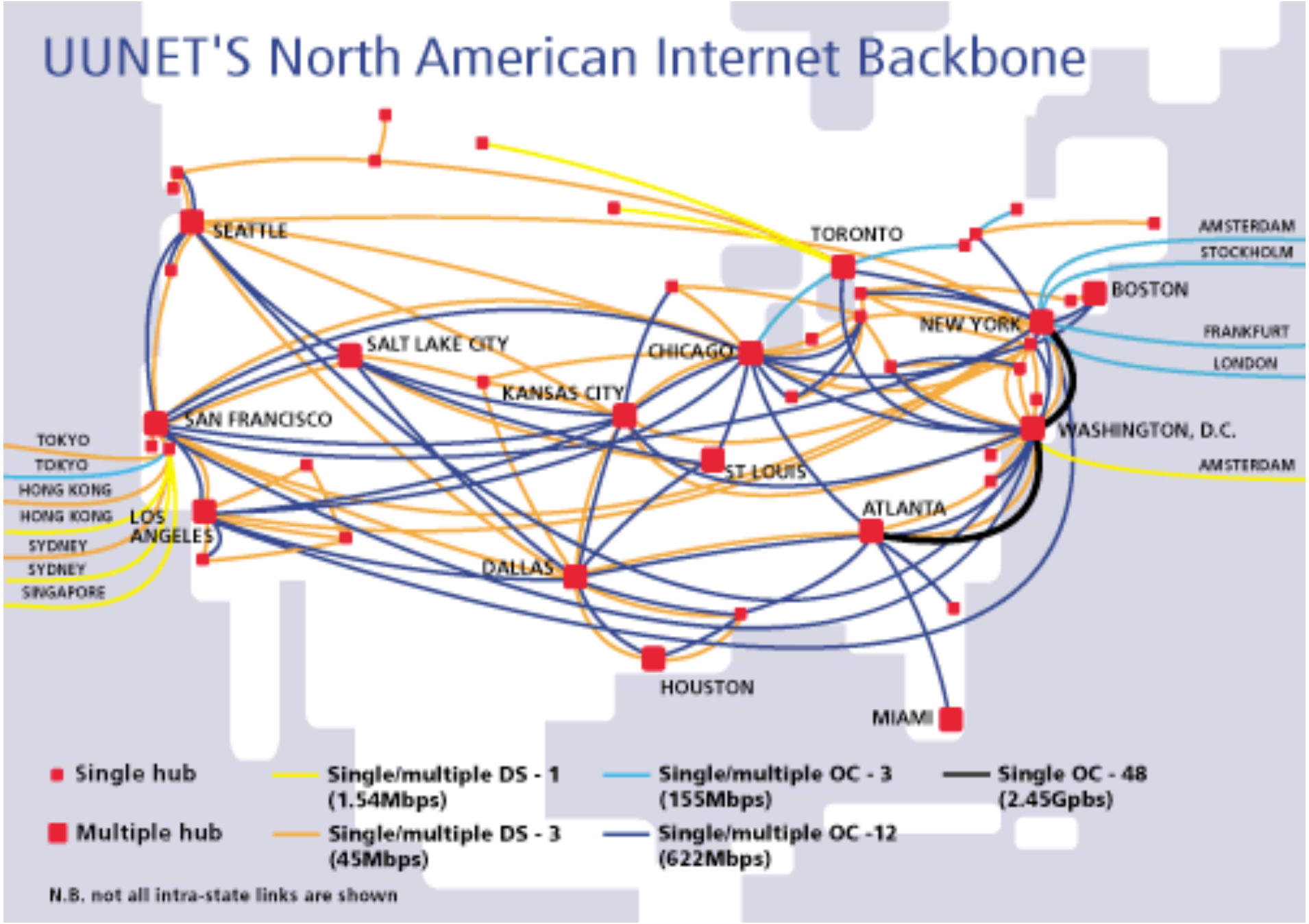
Internet Physical Infrastructure

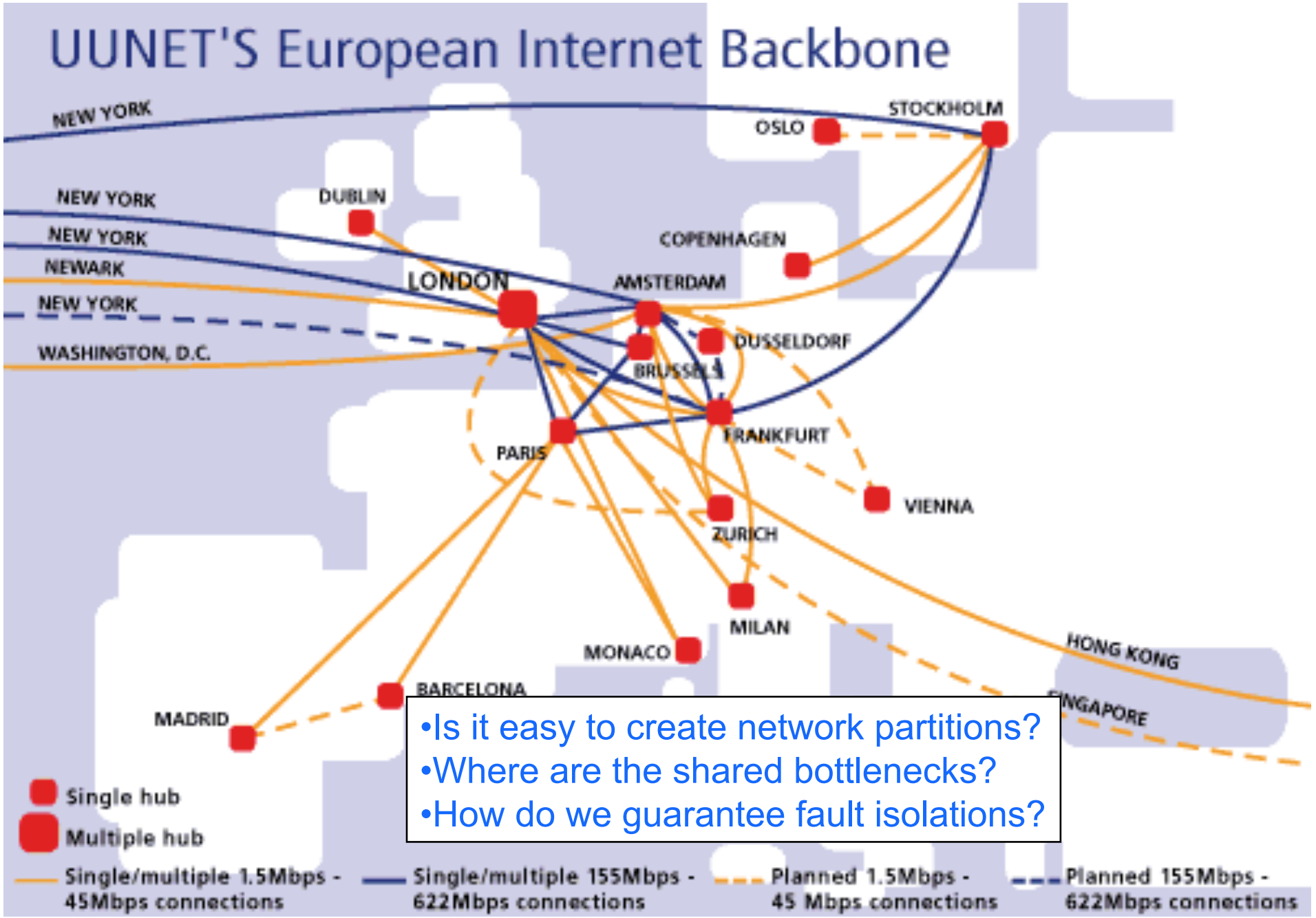


- Residential Access
  - Modem
  - DSL
  - Cable modem
  - Satellite
- Enterprise/ISP access, Backbone transmission
  - T1/T3, DS-1 DS-3
  - OC-3, OC-12
  - ATM vs. SONET, vs. WDM
- Campus network
  - Ethernet, ATM
- Internet Service Providers
  - access, regional, backbone
  - Point of Presence (POP)
  - Network Access Point (NAP)

Where do you think the **bottleneck** is on today's Internet?


UUNET's Global Internet Backbone


UUNET'S North American Internet Backbone
SEATTLE
TORONTO
AMSTERDAM
STOCKHOLM
BOSTON
NEW YORK
FRANKFURT
LONDON
SALT LAKE CITY
CHICAGO
KANSAS CITY
SAN FRANCISCO
WASHINGTON, D.C.
AMSTERDAM
TOKYO
TOKYO
HONG KONG
HONG KONG
SYDNEY
SYDNEY
SINGAPORE
LOS ANGELES
ST LOUIS
ATLANTA
DALLAS
HOUSTON
MIAMI
Single hub
Multiple hub
Single/multiple DS - 1 (1.54Mbps)
Single/multiple DS - 3 (45Mbps)
Single/multiple OC - 3 (155Mbps)
Single/multiple OC -12 (622Mbps)
Single OC - 48 (2.45Gpbs)
N.B. not all intra-state links are shown

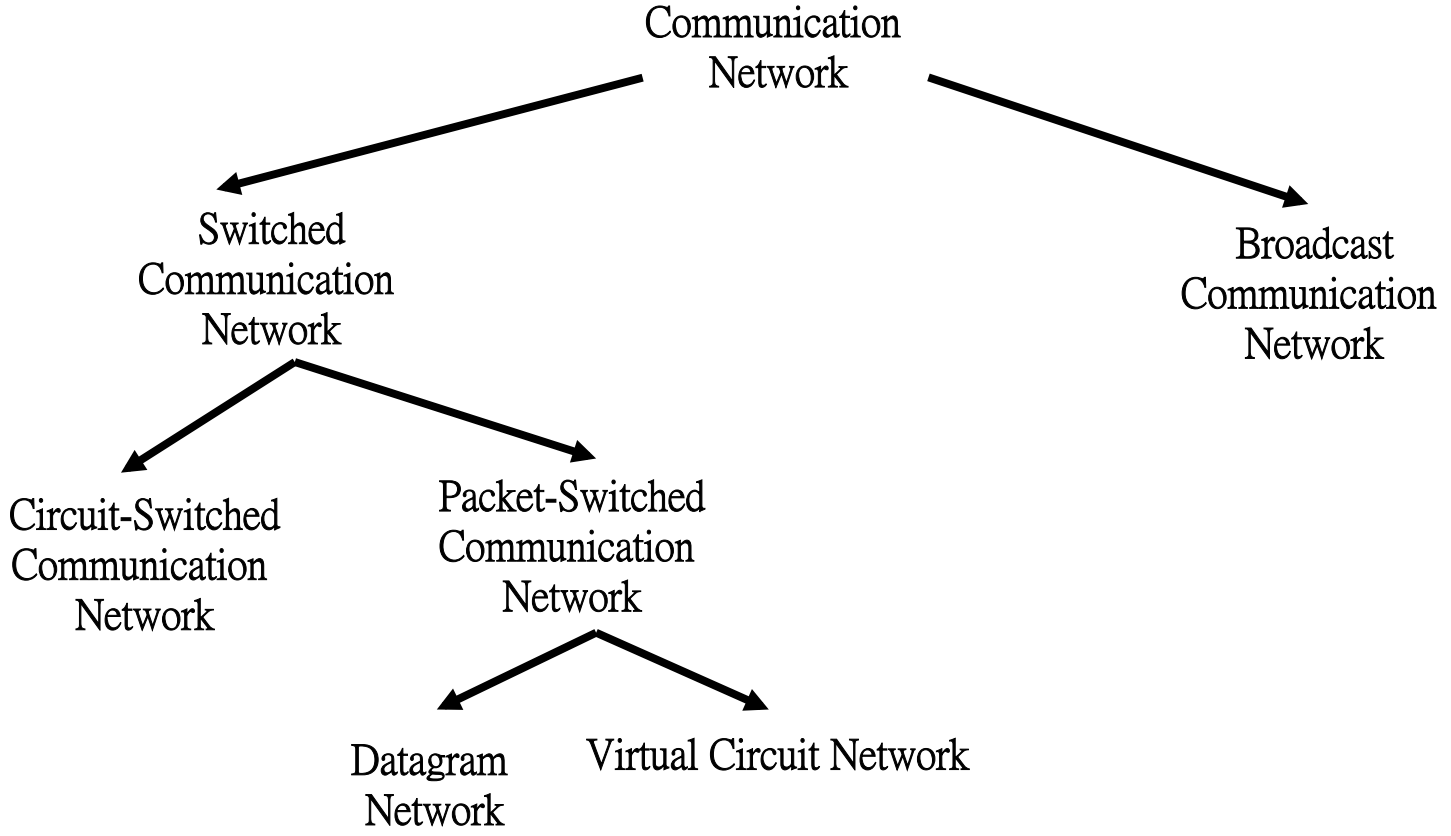

UUNET'S European Internet Backbone
NEW YORK
STOCKHOLM
OSLO
NEW YORK
DUBLIN
NEW YORK
NEWARK
COPENHAGEN
LONDON
AMSTERDAM
NEW YORK
DUSSELDORF
WASHINGTON, D.C.
BRUSSELS
FRANKFURT
PARIS
VIENNA
ZURICH
MILAN
MONACO
HONG KONG
BARCELONA
MADRID
•Is it easy to create network partitions?
•Where are the shared bottlenecks?
•How do we guarantee fault isolations?
Single hub
Multiple hub
Single/multiple 1.5Mbps - 45Mbps connections
Single/multiple 155Mbps - 622Mbps connections
Planned 1.5Mbps - 45 Mbps connections
Planned 155Mbps - 622Mbps connections

Overview

- Administrative trivia
- Overview and history of the Internet
- A Taxonomy of Communication Networks

A Taxonomy of Communication Networks

- Communication networks can be classified based on the way in which the nodes exchange information:



Broadcast vs. Switched Communication Networks

- Broadcast communication networks
  - information transmitted by any node is received by every other node in the network
    - examples: usually in LANs (Ethernet, Wavelan)
  - Problem: coordinate the access of all nodes to the shared communication medium (Multiple Access Problem)

- Switched communication networks
  - information is transmitted to a sub-set of designated nodes
    - examples: WANs (Telephony Network, Internet)
  - Problem: how to forward information to intended node(s)
    - this is done by special nodes (e.g., routers, switches) running routing protocols
  - New technologies: optical packet switching!

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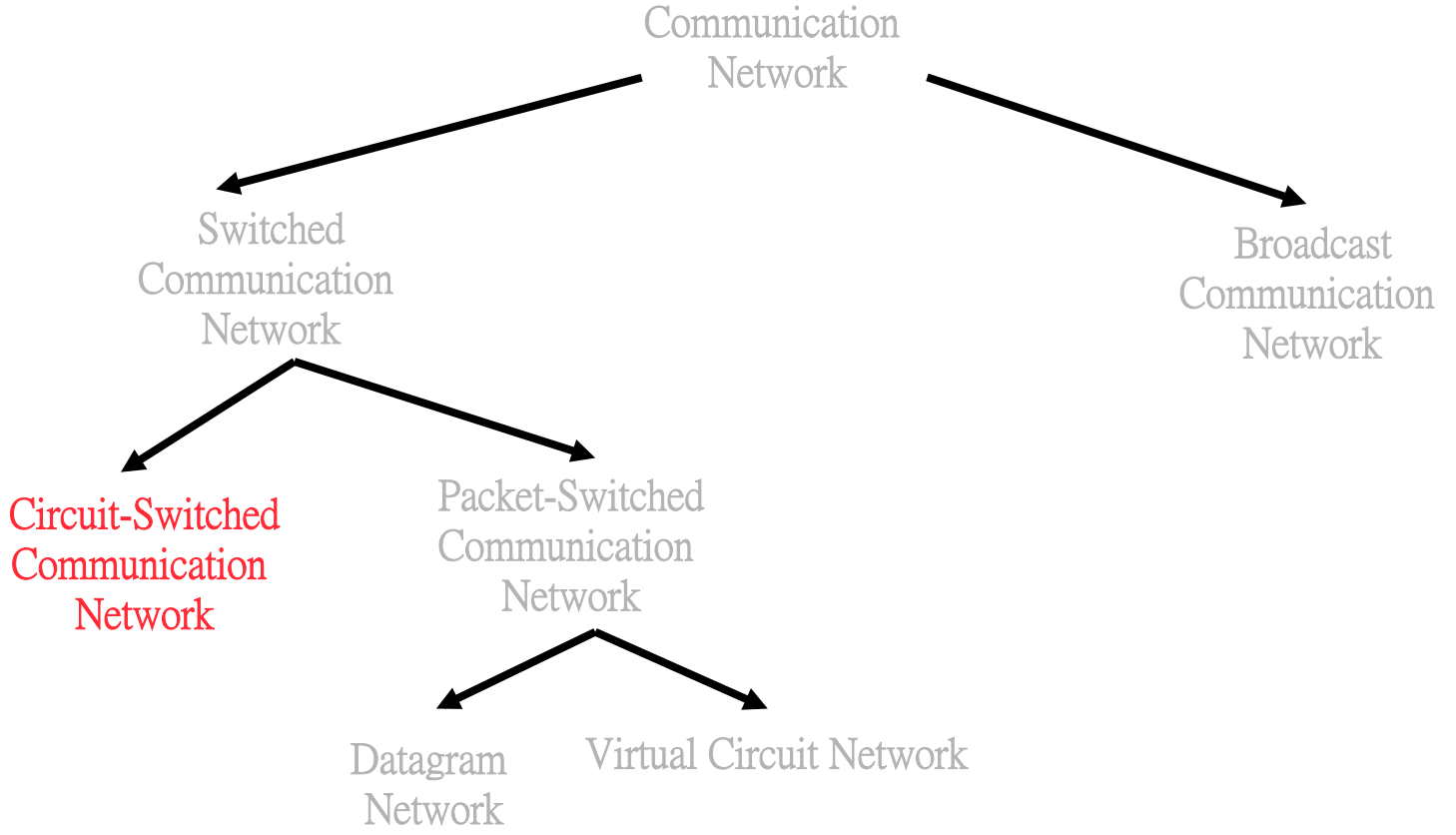
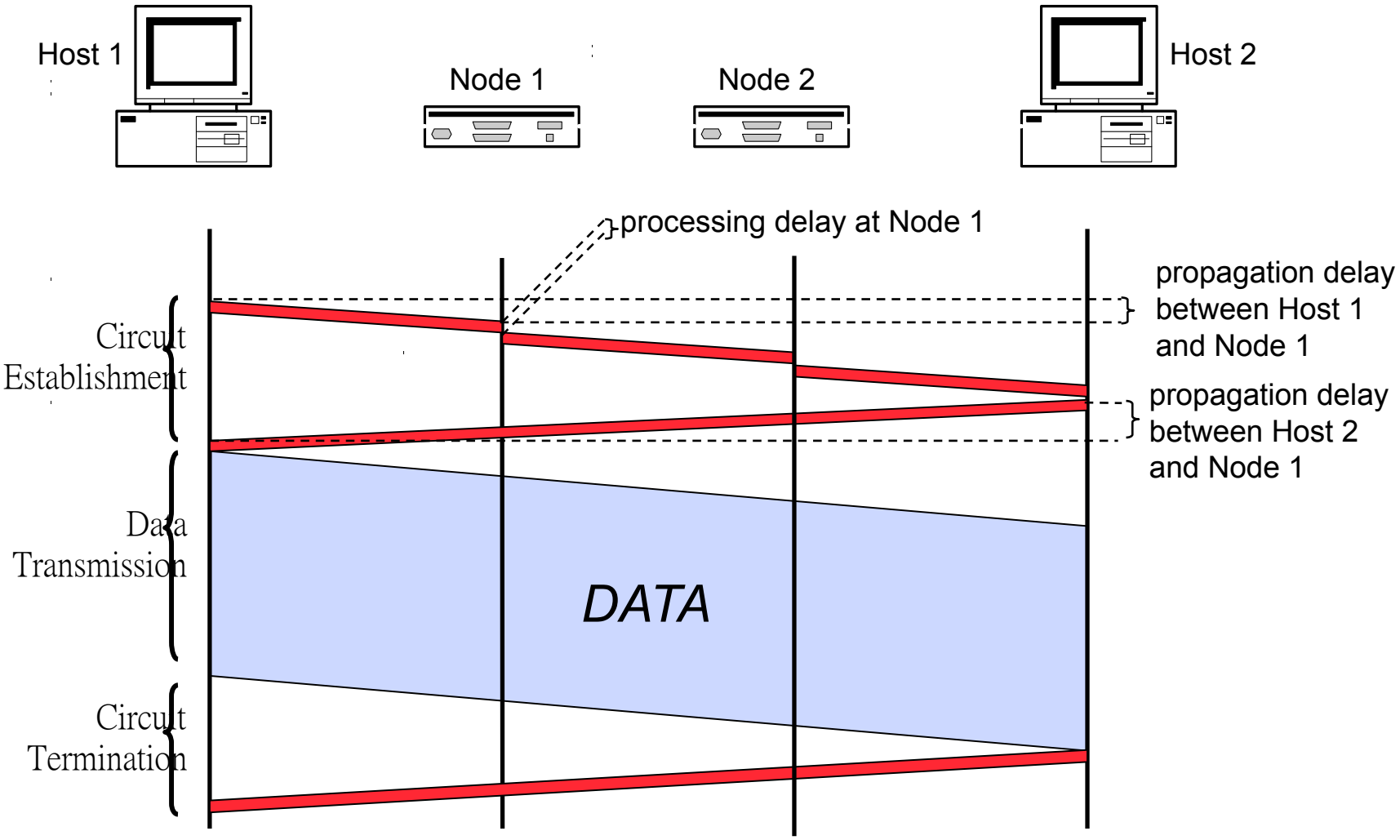


Circuit Switching

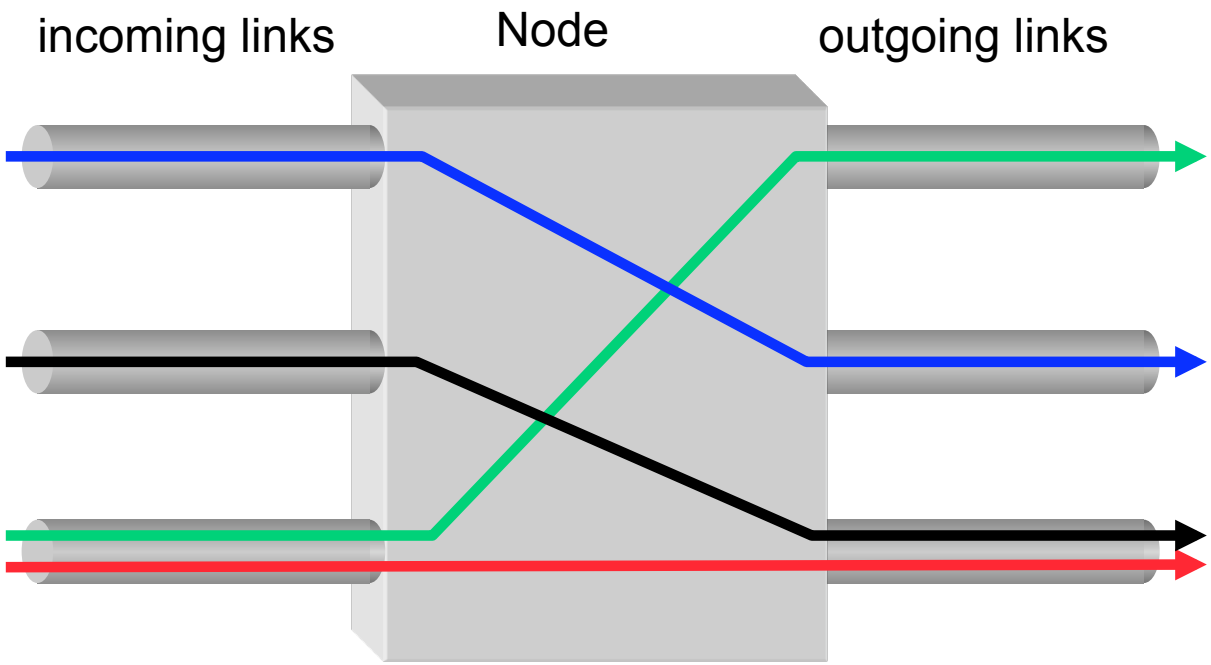
- Three phases
  1. circuit establishment
  2. data transfer
  3. circuit termination
- If circuit not available: “Busy signal”
- Examples
  - Telephone networks
  - ISDN (Integrated Services Digital Networks)

Timing in Circuit Switching



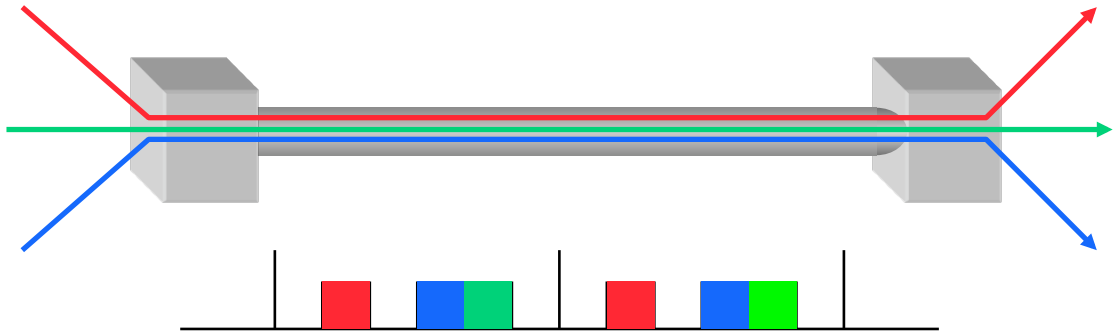
Circuit Switching

- A node (switch) in a circuit switching network



Switches and routers are very complicated!
-new requirements for today's routers: ability to filter traffic at line speed
graceful degradation under attacks, anything else?

Circuit Switching: Multiplexing/ Demultiplexing



- Time divided in frames and frames divided in slots
- Relative slot position inside a frame determines which conversation the data belongs to
- Needs synchronization between sender and receiver
- In case of non-permanent conversations
  - Needs to dynamic bind a slot to a conservation

A Taxonomy of Communication Networks

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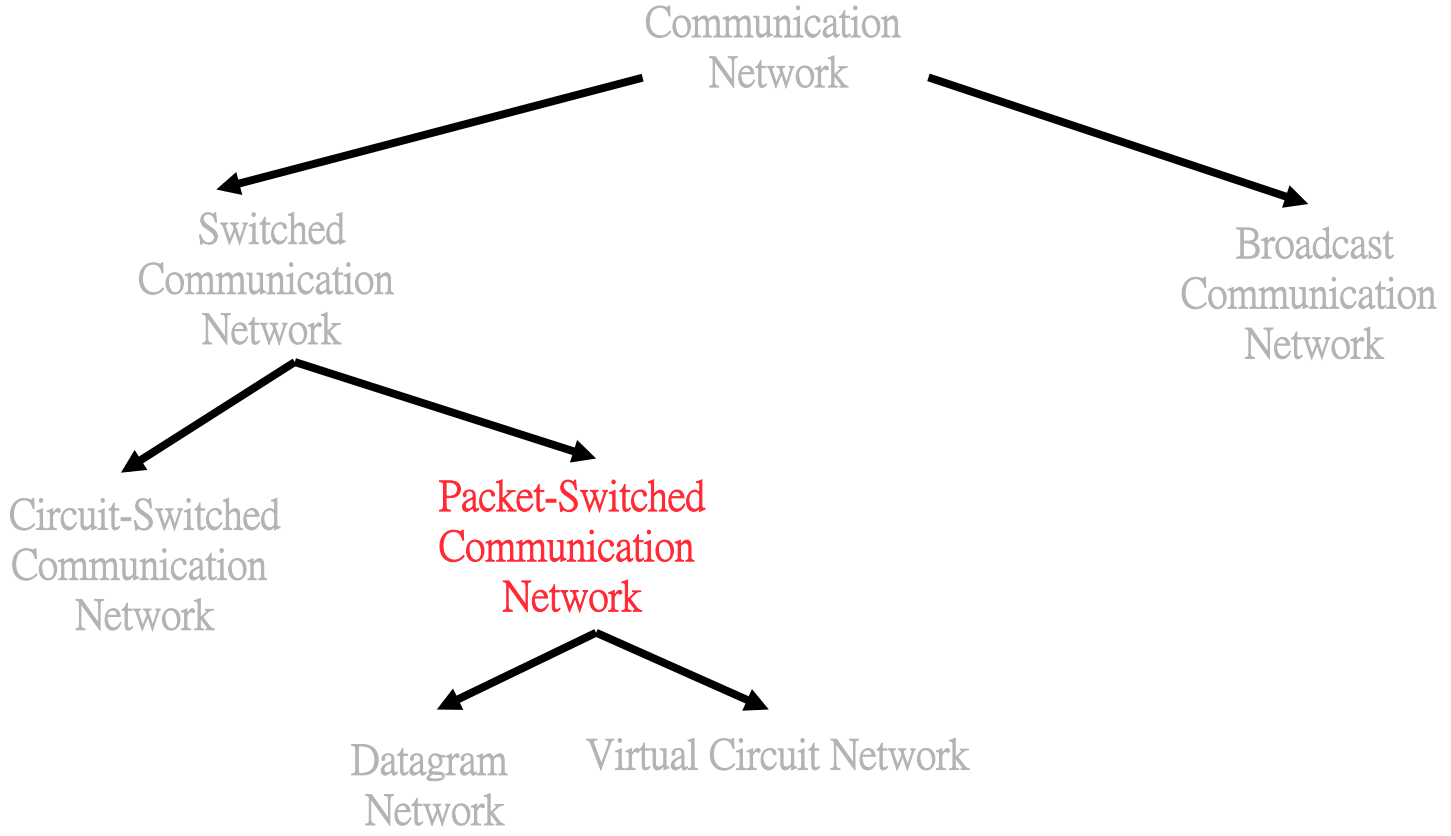


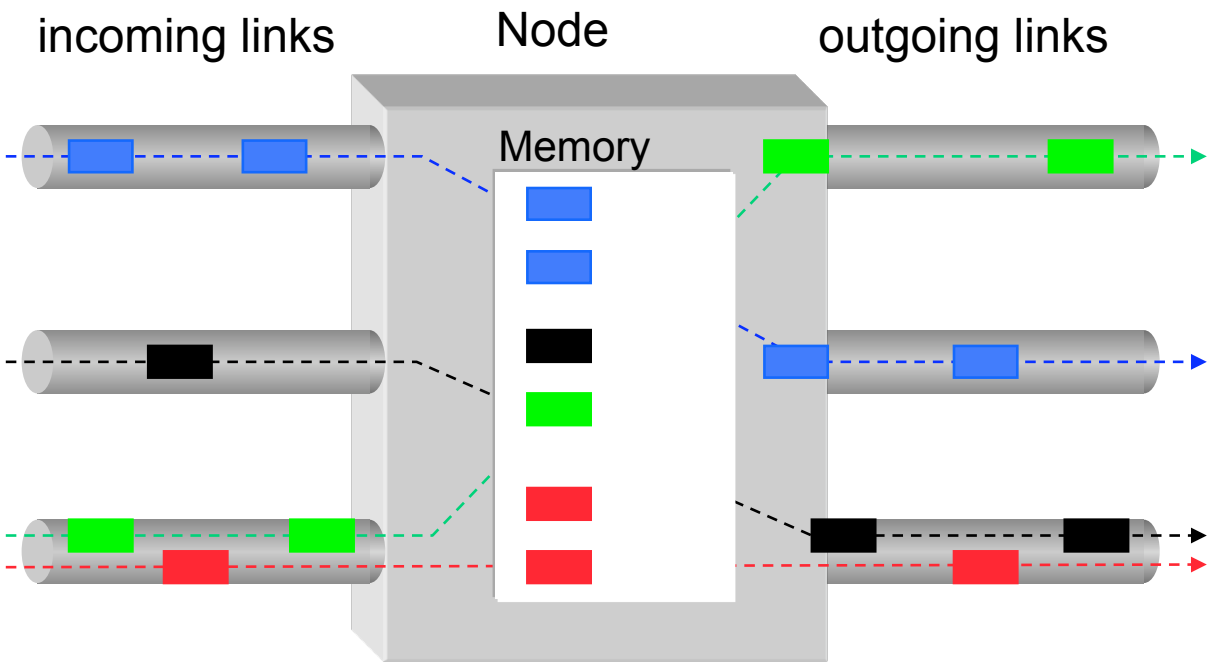
Packet Switching

- Data are sent as formatted bit-sequences, so-called packets.
- Packets have the following structure:

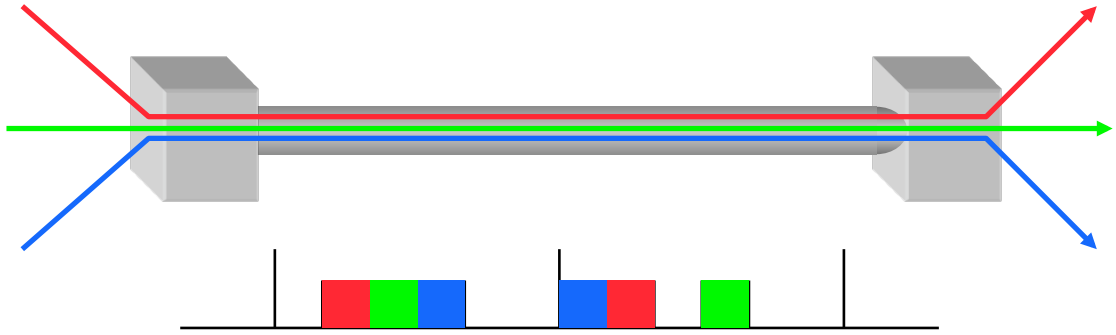
  - Header and Trailer carry control information (e.g., destination address, check sum)
- Each packet is passed through the network from node to node along some path (**Routing**)
- At each node the entire packet is received, stored briefly, and then forwarded to the next node
  - (**Store-and-Forward Networks**)

Packet Switching

- A node in a packet switching network



Packet Switching: Multiplexing/ Demultiplexing



- Data from any conversation can be transmitted at any given time
- How to tell them apart?
  - use meta-data (header) to describe data

Research issues: defense against DDoS attacks, malicious traffic behavior.

A Taxonomy of Communication Networks

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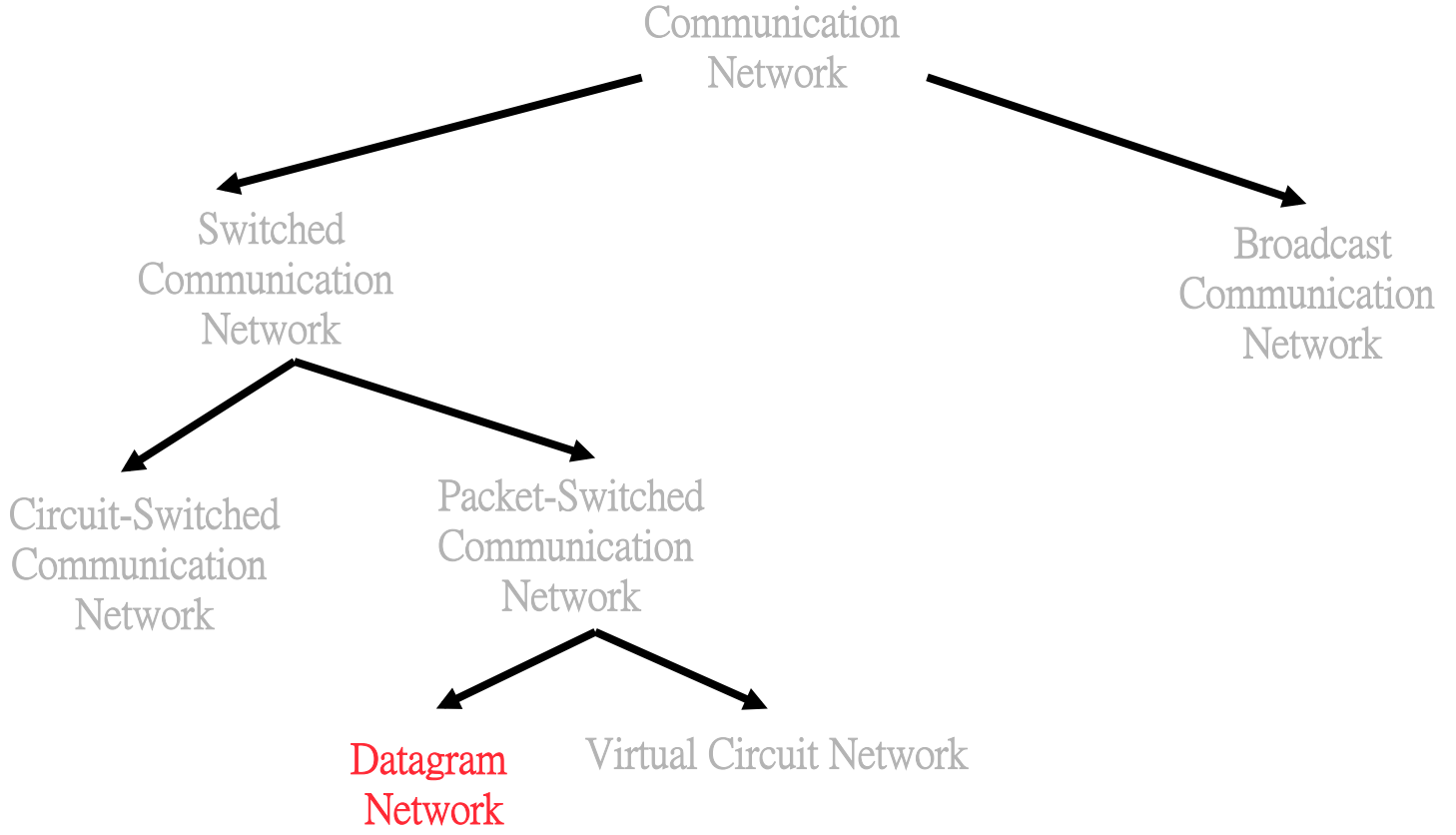
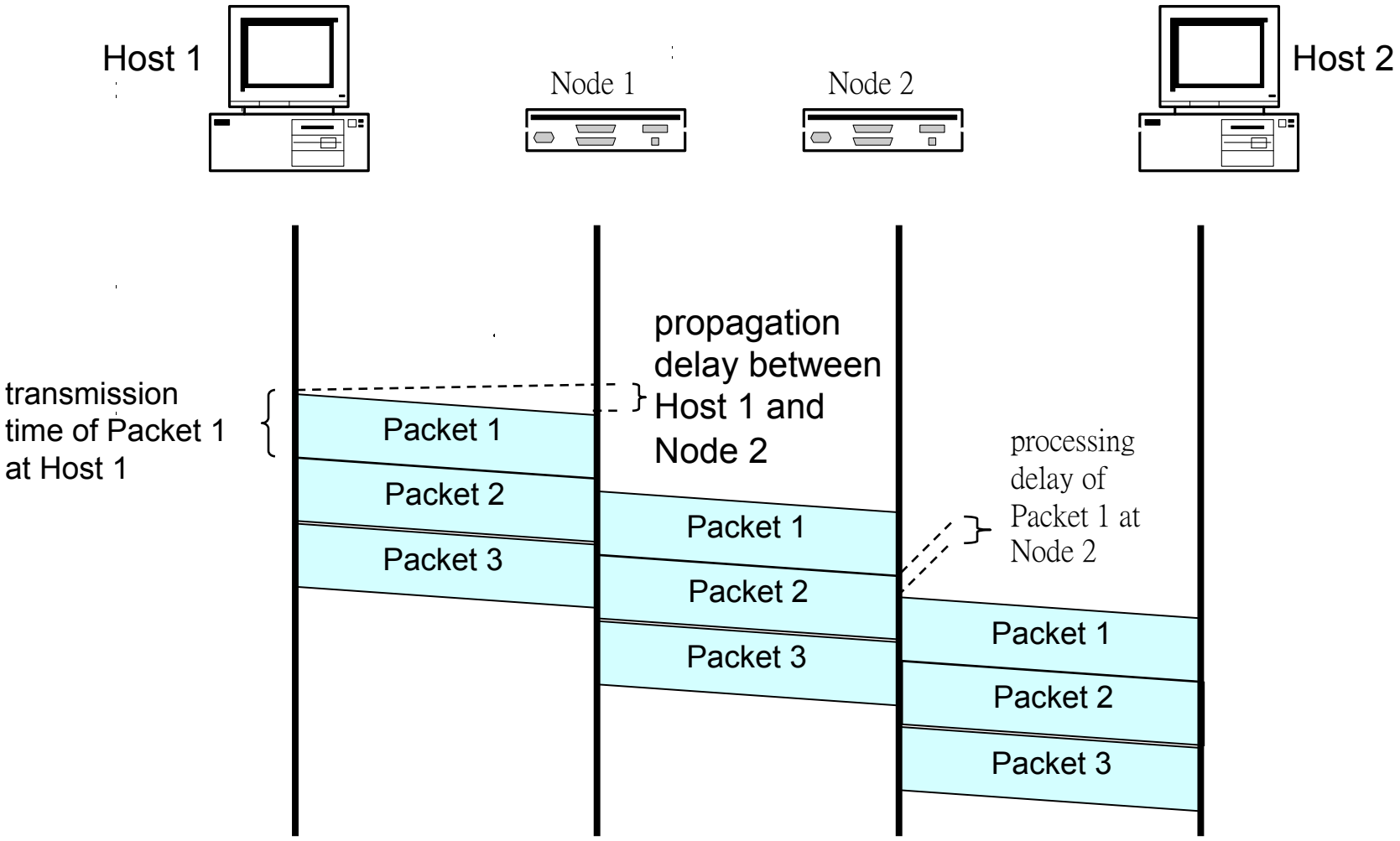


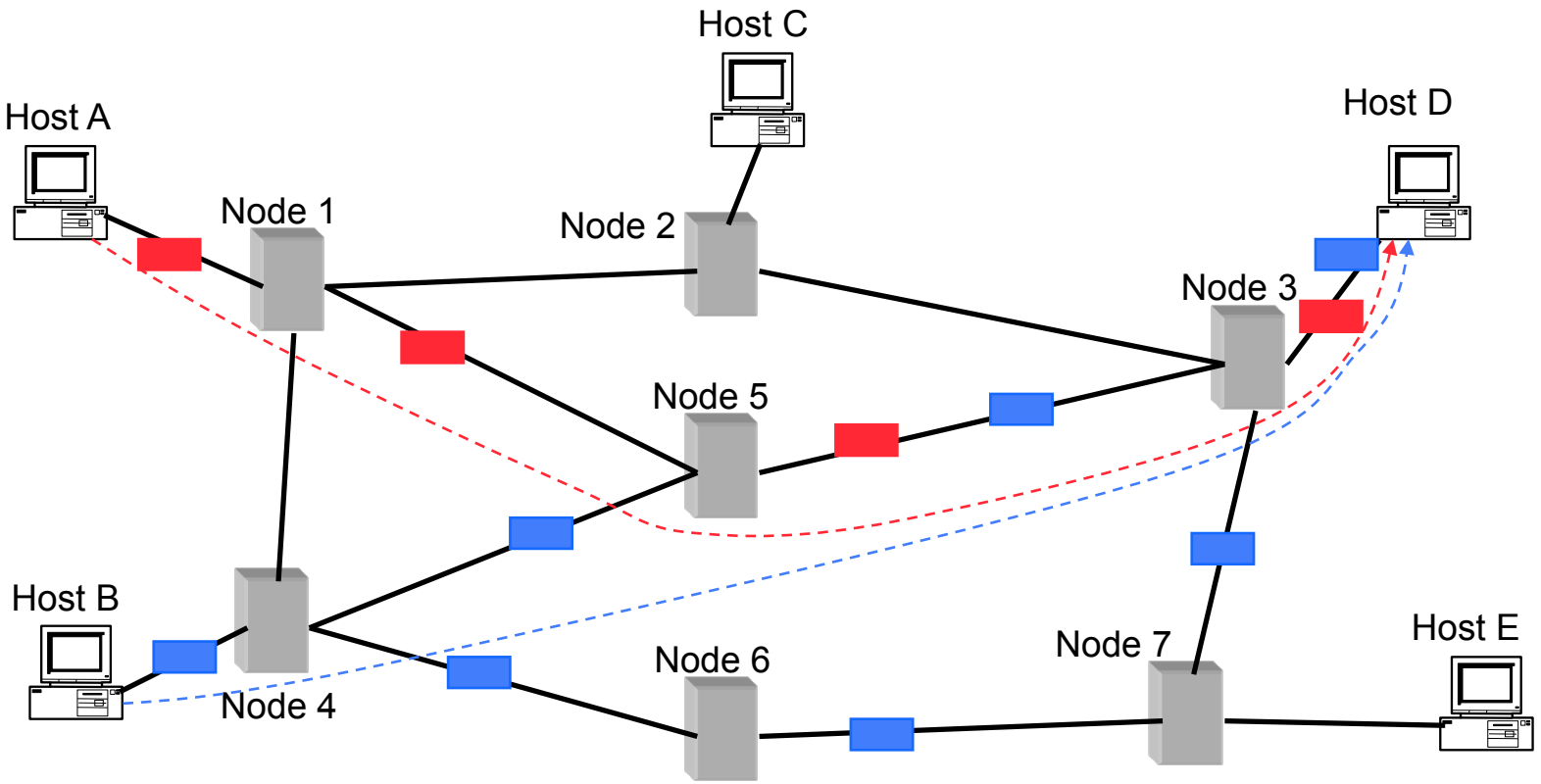
Datagram Packet Switching

- Each packet is independently switched
  - each packet header contains destination address
- No resources are pre-allocated (reserved) in advance
- Example: IP networks

Timing of Datagram Packet Switching



Datagram Packet Switching



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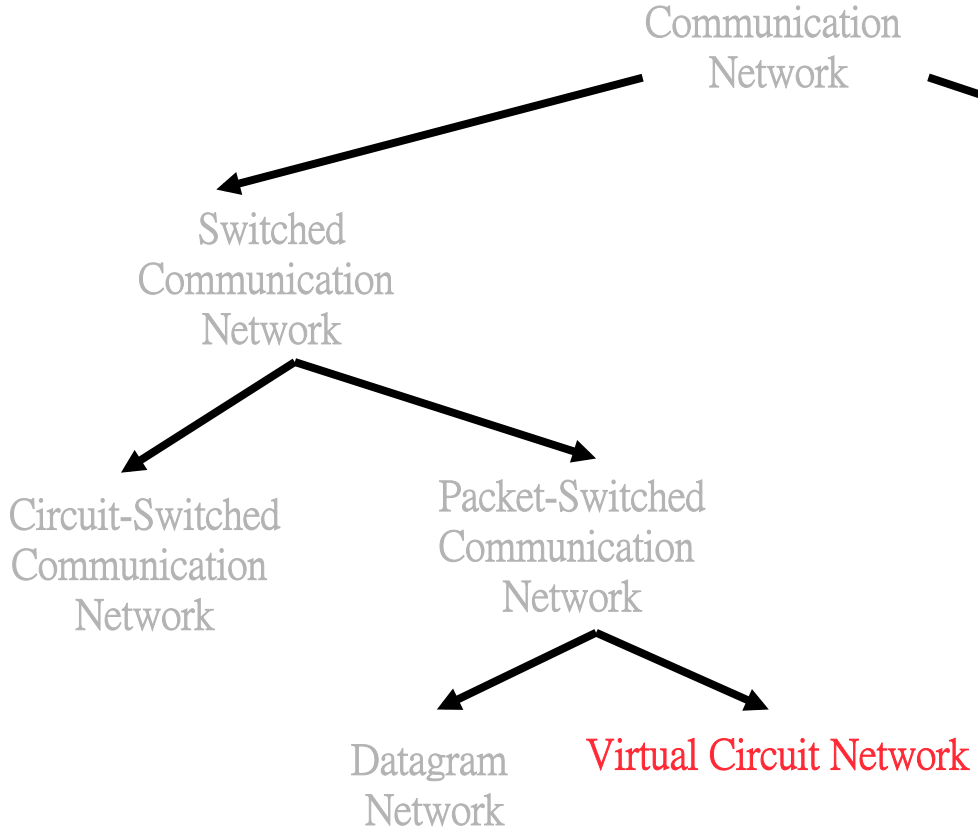


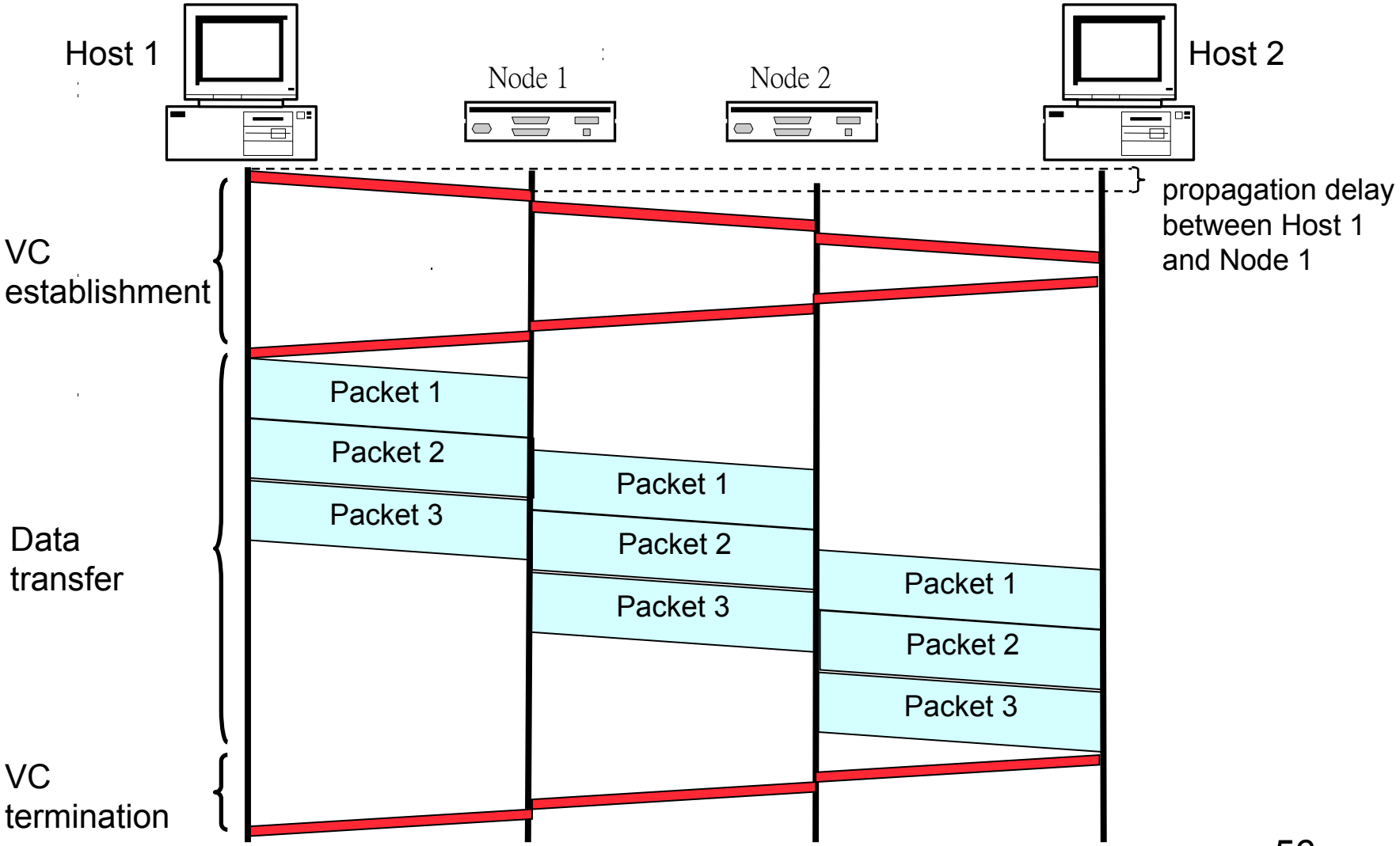
Virtual-Circuit Packet Switching

- Hybrid of circuit switching and packet switching
  - data is transmitted as packets
  - all packets from one packet stream are sent along a pre-established path (=virtual circuit)
- Guarantees in-sequence delivery of packets
- **However**: Packets from different virtual circuits may be interleaved
- Example: ATM networks

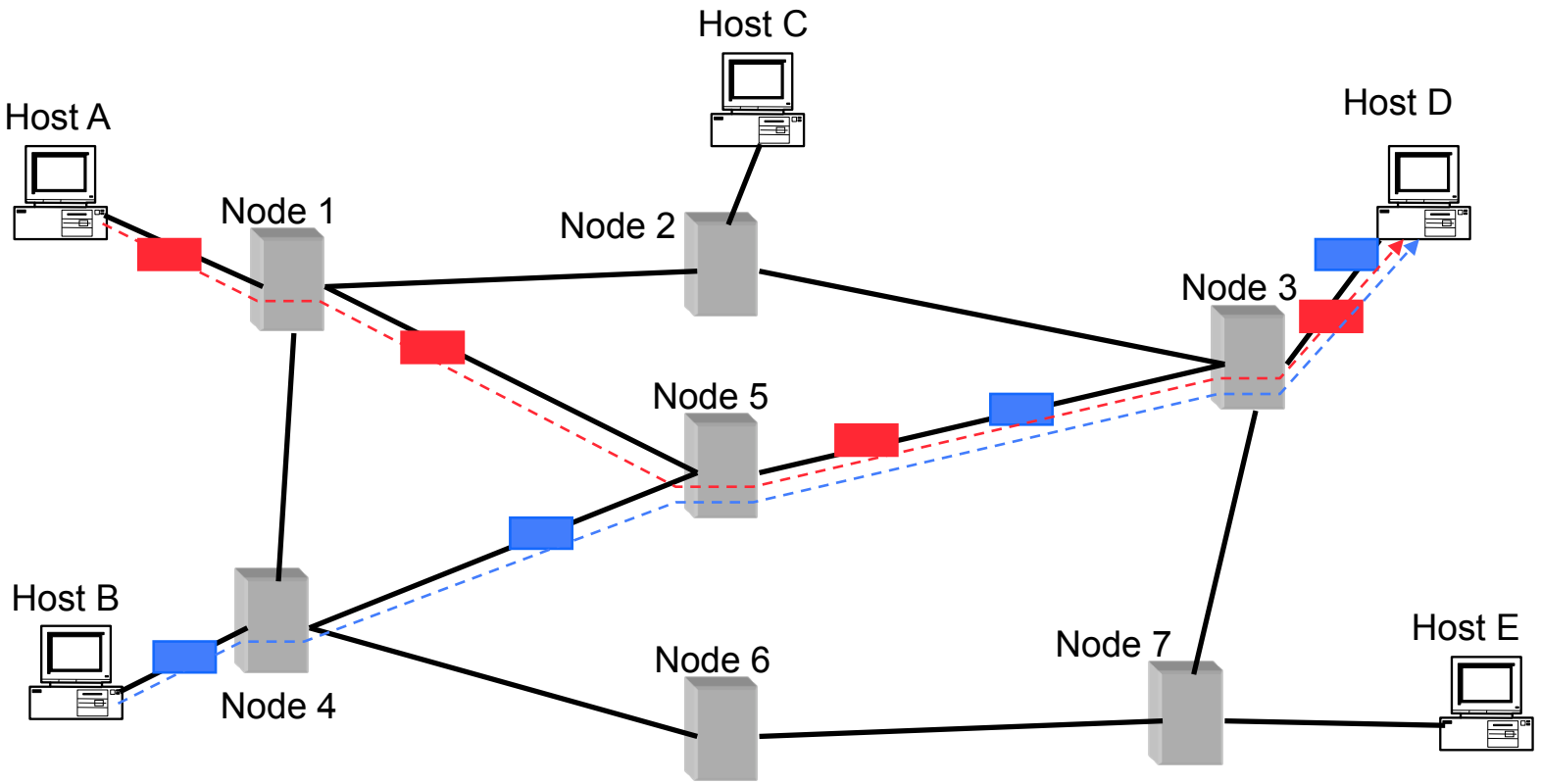
Virtual-Circuit Packet Switching

- Communication with virtual circuits takes place in three phases
  1. VC establishment
  2. data transfer
  3. VC disconnect
- Note: packet headers don't need to contain the full destination address of the packet

Timing of Datagram Packet Switching



Datagram Packet Switching



Packet-Switching vs. Circuit-Switching

- Most important advantage of packet-switching over circuit switching: Ability to exploit statistical multiplexing:
  - efficient bandwidth usage; ratio between peak and average rate is 3:1 for audio, and 15:1 for data traffic
- However, packet-switching needs to deal with congestion:
  - more complex routers
  - harder to provide good network services (e.g., delay and bandwidth guarantees)
- In practice they are combined:
  - IP over SONET, IP over Frame Relay

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Towards a two-tier internet

The egalitarian nature of the internet is under threat, argues internet law professor Michael Geist.

"Internet service providers (ISPs) always seem to get the first call when a problem arises on the internet.

Services offering calls over the internet could be disadvantaged

Lawmakers want them to assist with investigations into cyber crime, parents want them to filter out harmful content, consumers want them to stop spam, and copyright holders want them to curtail infringement.

cnet NEWS.COM http://www.news.com/

Bots slim down to get tough

By Dawn Kawamoto
http://news.com.com/Bots+slim+down+to+get+tough/210

Story last modified Wed Nov 16 11:53:00 PST 2005

Malicious makers of bots are finding big is not always better when it comes to avoiding detection, according to a security expert.

Over the past two years, the average network of bots, or compromised PCs commandeered by remote attackers, has dropped from more than 100,000 to an average of 20,000, Mark Sunner, MessageLabs's chief technology officer, said during Tuesday's annual Security Roundtable Webcast.

c|net NEWS.COM http://www.news.com/

Crocodile hunter's death clogs Web sites

Flash crowd effect

By Reuters
http://news.com.com/Crocodile+hunters+death+clogs+Web+sites/2100-1026_3-6112121.html

Story last modified Tue Sep 05 05:13:31 PDT 2006

In death as in life, iconic TV naturalist Steve Irwin captivated millions worldwide and clogged the Internet as fans from Guam to Glasgow reacted with disbelief to news that "The Crocodile Hunter" was dead.

Some Web sites groaned to a halt within hours of the first reports on Monday that Irwin had been killed by a stingray's barb through his chest in a freak diving accident off Australia's northeast coast.

Web measurement company Hitwise said Irwin's death was the biggest news event read by Australians on the Internet since two Australian miners were trapped by a mine collapse in southern Tasmania state in late April.

"We noticed that the Web site www.crocodilehunter.com increased in popularity quite substantially. It became the No. 1 entertainment personality Web site in Australia on Monday and in the United States it also became the third-most popular," Hitwise Asia-Pacific marketing director James Borg told Reuters.

Australian news Web sites struggled to keep up with demand.

The Australian Broadcasting's site (www.abc.com.au) had to temporarily shut down, posting a notice on Monday that it was experiencing higher than normal traffic.

It resumed soon after in a low-bandwidth format to cope with hundreds of thousands of hits.

Newspaper Web sites also wobbled but kept up with demand.

A spokesman for The Sydney Morning Herald's site, www.smh.com.au, said it had experienced a "huge" 40 percent spike in page impressions compared with the previous week's average weekday number of about 500,000.

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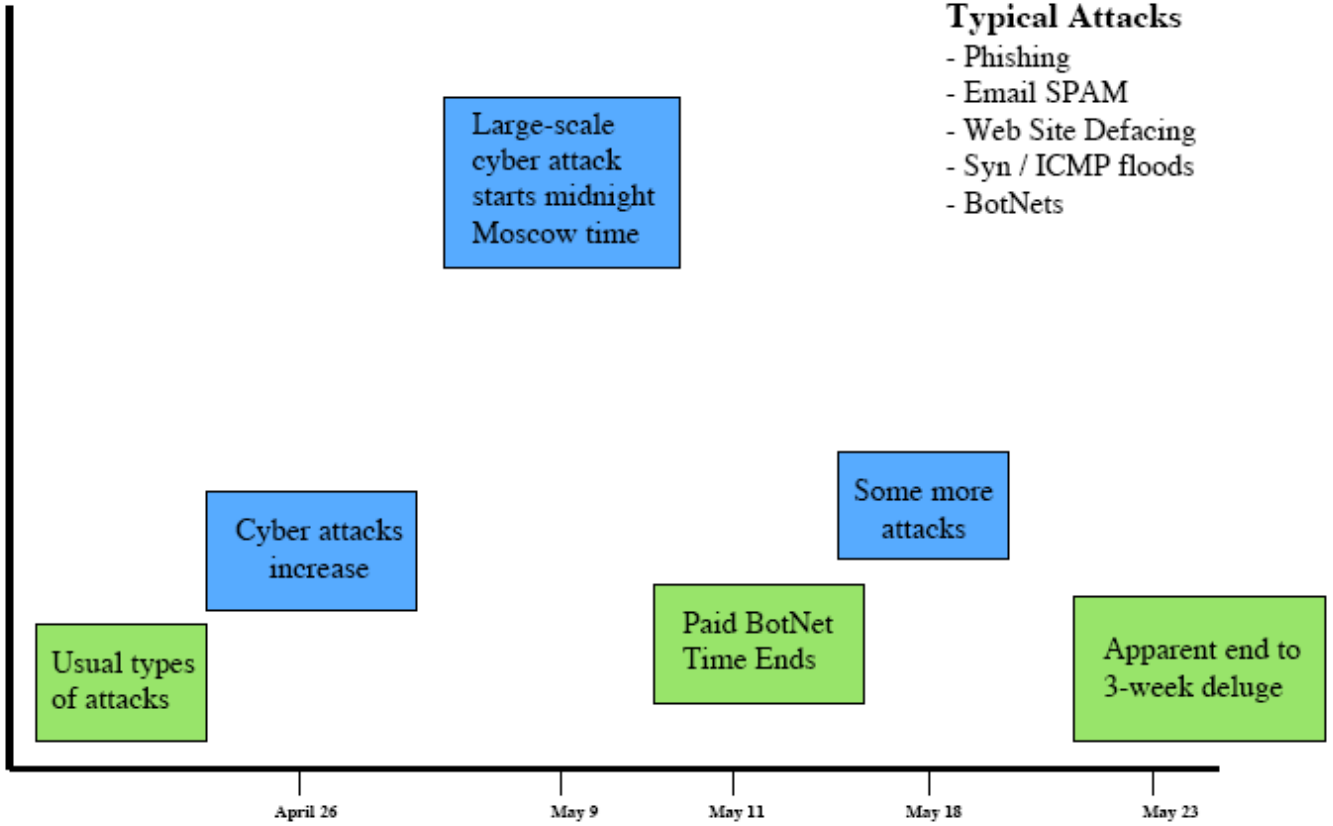
While Russia
are embroiled
dispute since the collapse of the Soviet Union, a row that erupted at the end of



Photograph: Timur Nisametdinov/AP

Summary

- Course administrative trivia
- Internet history and trivia

- Rest of the course a lot more technical and (hopefully) exciting