CEG7450: Advanced Computer Networks

- Instructor
  - Dr. Bin Wang (use Pilot to send email, 491 Joshi)

- Lecture time:
  - Section 1 9:05-10:00, MWF
  - Section 2 11:15-12:10, MWF
  - Online section

- Office hour 12:30-1:15pm MWF or walk-in
- Office hour online section: email
- Class Web page
  - pilot.wright.edu

Reading Assignments

- [SRC84] J. Saltzer, D. Reed, and D. Clark, "End-to-end Arguments in System Design". ACM Transactions on Computer Systems (TOCS), Vol. 2, No. 4, 1984, pp. 195-206.

- Review paper [Jac88], due a week from today.

Overview

- Administrative trivia
- Overview and history of the Internet
- A taxonomy of communication networks
- Router architecture in packet-switching networks

Goals of this Course

- Understand how the Internet works in more depth
- Get familiar with current Internet research efforts
- Appreciate what is good research
  - problem selection
  - solution & research methodology
- Apply what you learned in small scale class projects

What Do You Need To Do?

- A class term paper + lab projects
- Paper reading and reviews
- Final exam

Term Paper

- Investigate new ideas and solutions in a small scale research or survey
  - define the problem or topic
  - execute the research
  - write up and present your research (if time permits)
- Ideally, best papers will become conference papers

Term Paper: Steps

- I'll distribute a list of topics
  - you can either choose one of these topics or come up with your own
- Pick your topic and submit a one page proposal describing:
  - the problem you are solving or doing a survey on
  - your plan of attack with milestones and dates
  - any special resources you may need
- A midterm report of your progress
- Final project presentation (optional, if time permits)
- Submit term papers

Paper Reviews

- Goal: summarize main ideas and concepts in research papers
- Number: up to two papers per class
- Length: one page per paper
- Contents
  - main points intended by the author
  - points you particularly liked/disliked
  - potential for improvement if applicable
  - other comments (writing, conclusions…)
- Submission:
  - hardcopy submission

Grading

Term paper + lab projects	40%
Final exam	40%
Paper reading & reviews	20%

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

Overview

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- Overview and history of the Internet
- A Taxonomy of Communication Networks
- Router Architecture in Packet-Switching Networks

What is a Communication Network? (from end system point of 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 is a Communication Network? Infrastructure Centric View

- Electrons and photons as communication medium
- Links: fiber, copper, satellite, …
- Switches: mechanical/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, ...

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
- 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

Types of Networks

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

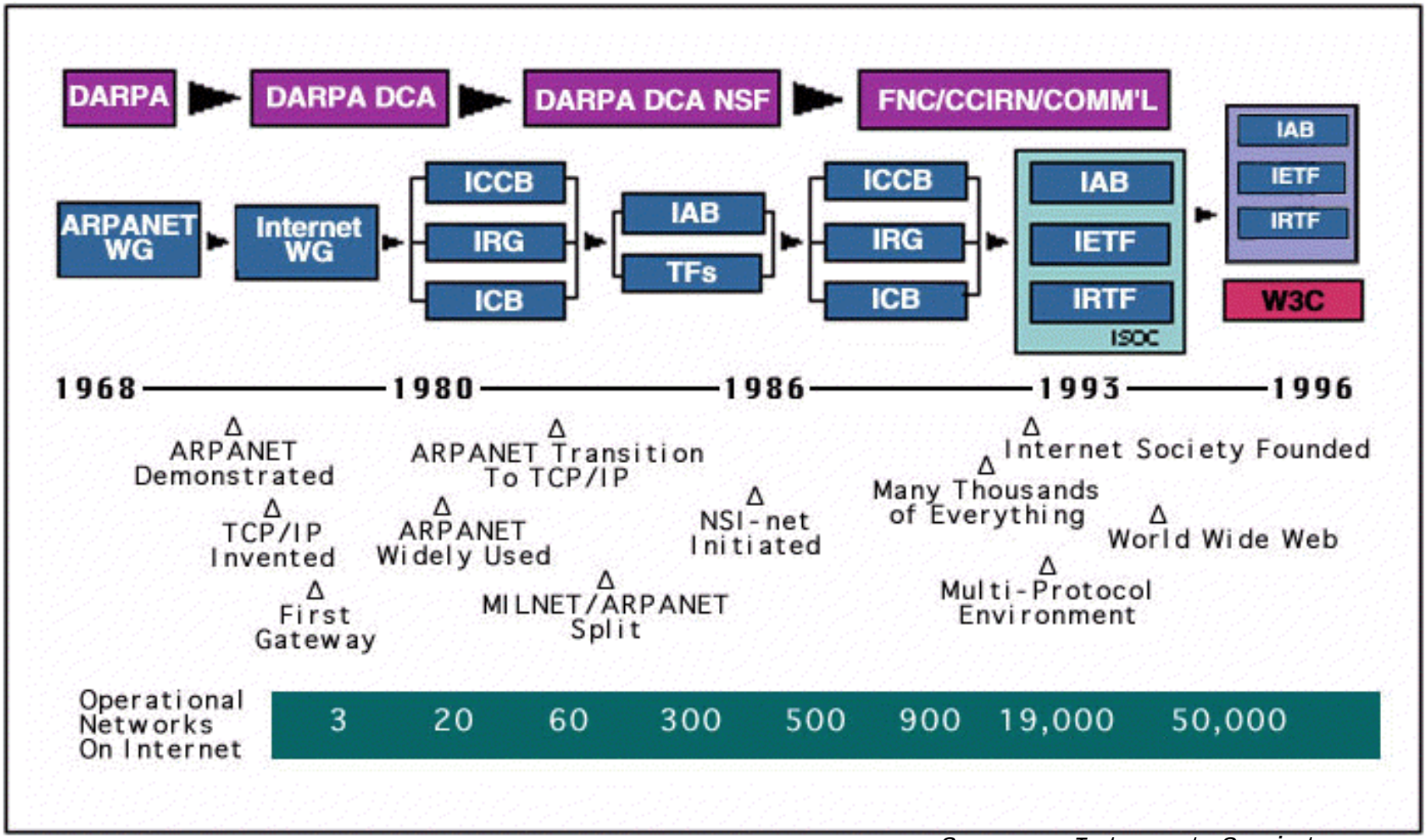
The Internet

- Global scale, general purpose, heterogeneous-technologies, public 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, 100s millions computers in 150 countries

Time Line of the Internet

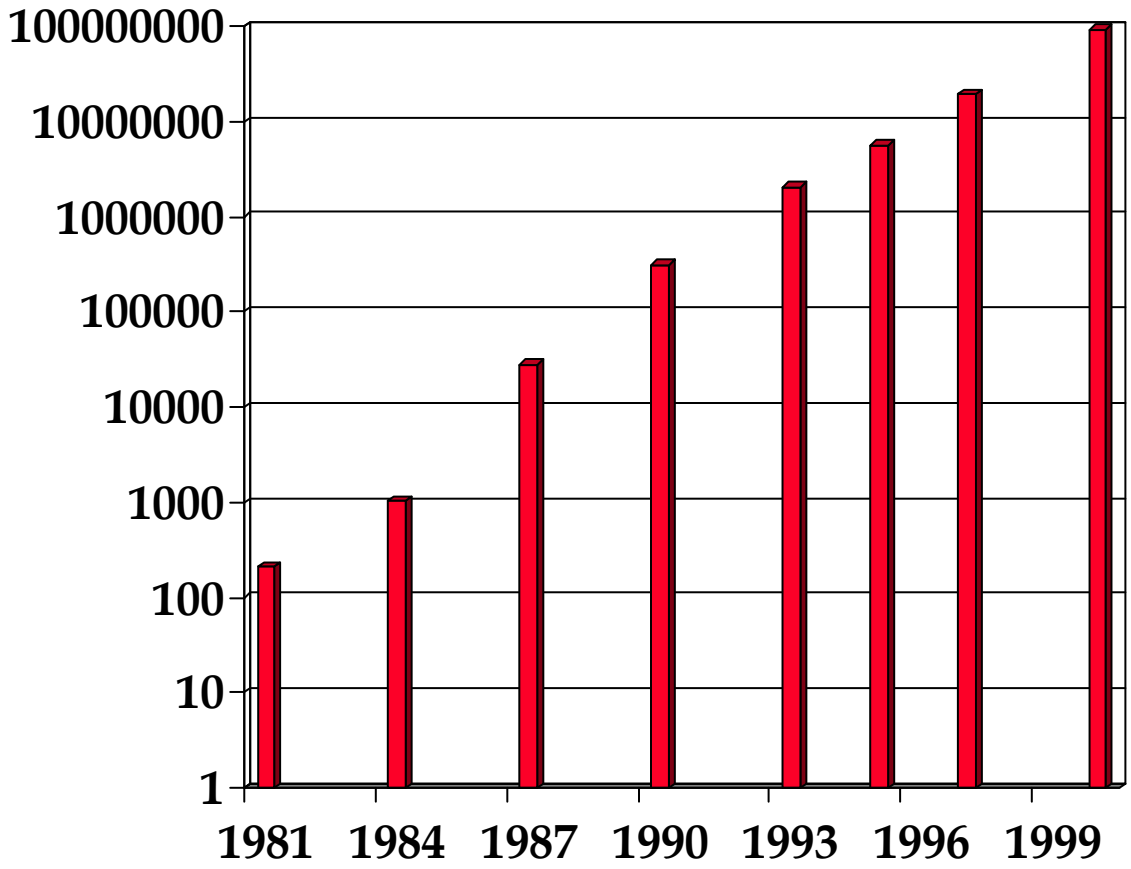


•*Source: Internet Society*

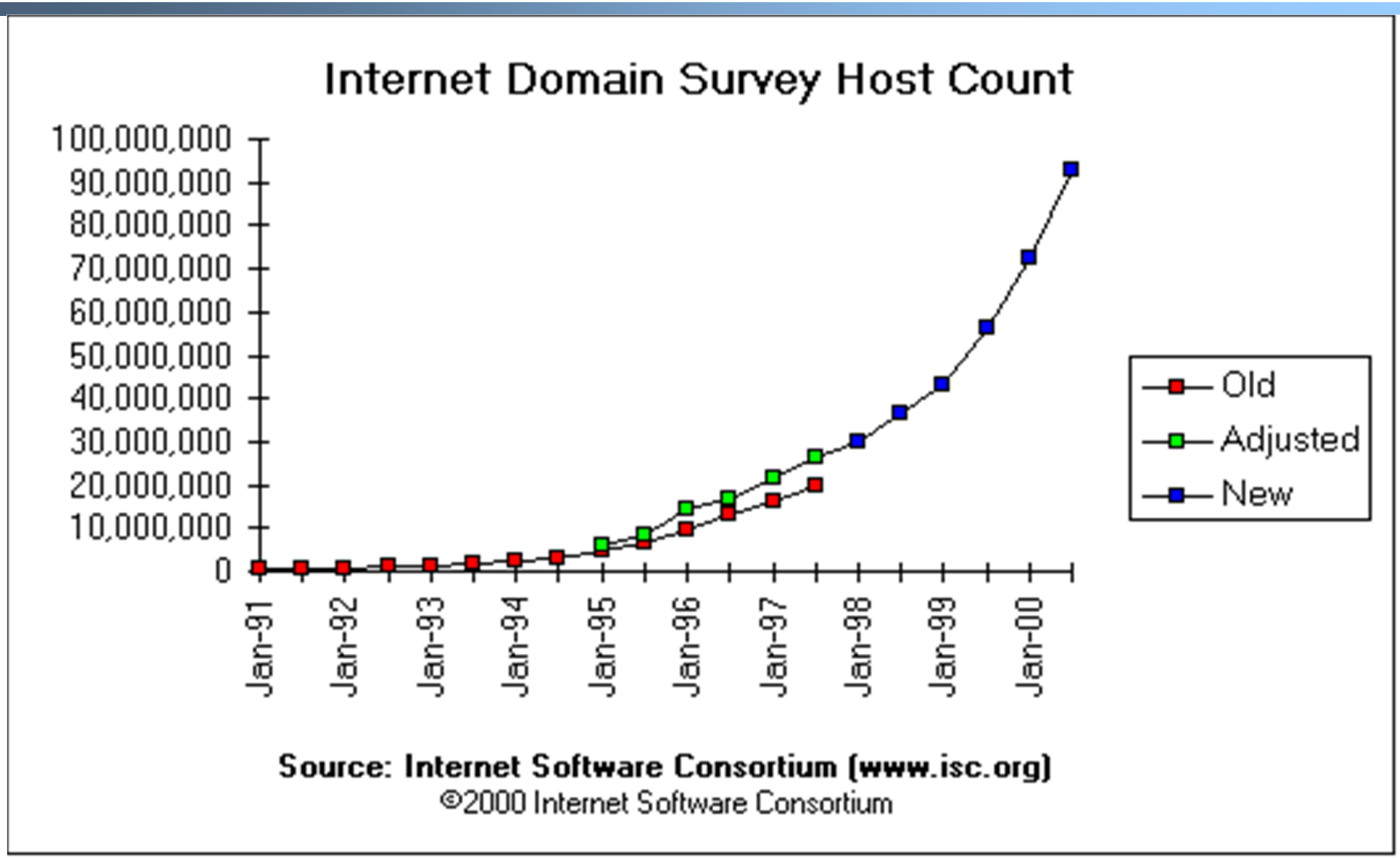
Growth of the Internet

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

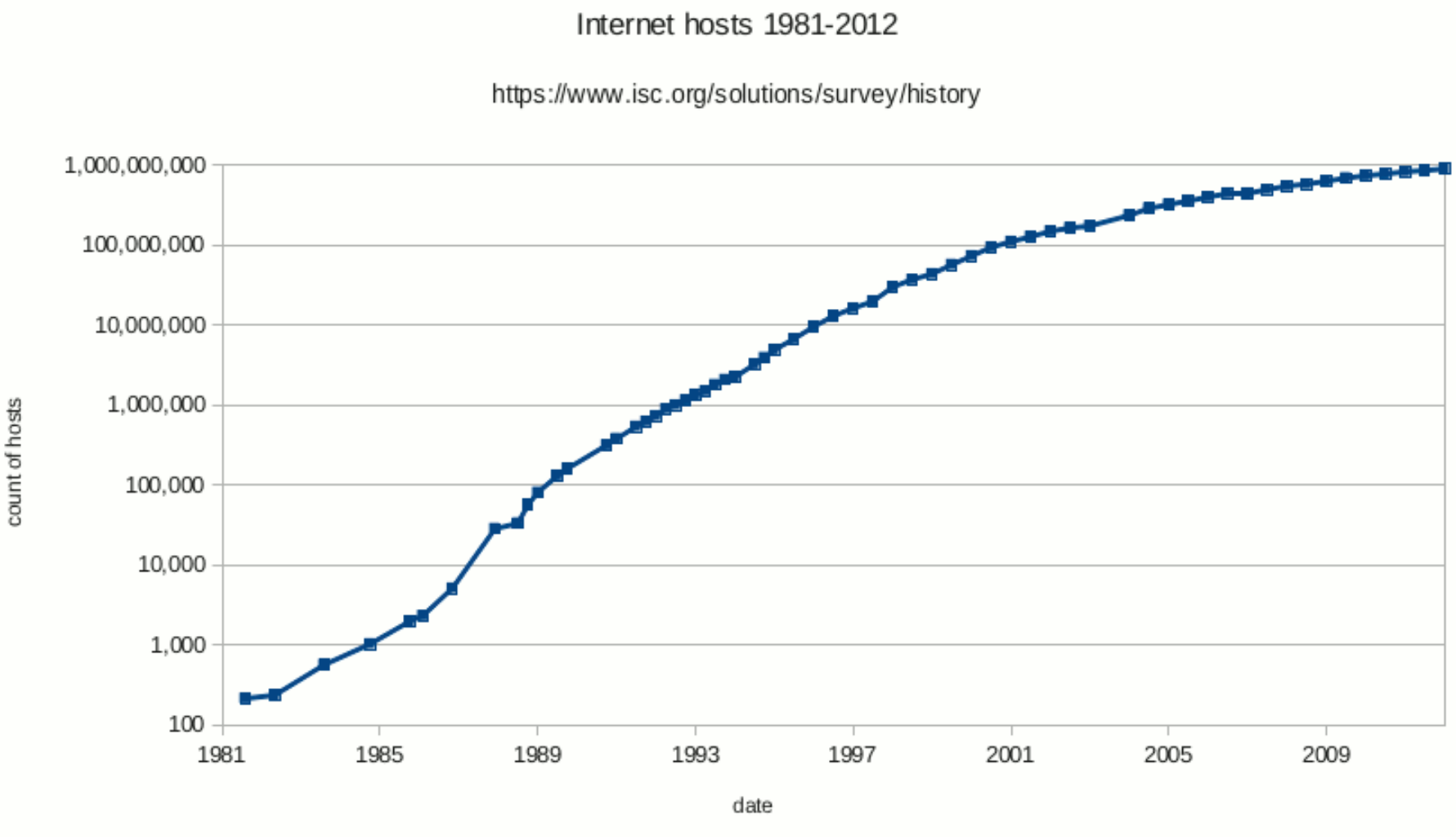
Aug. 1981	213
Oct. 1984	1,024
Dec. 1987	28,174
Oct. 1990	313,000
Oct. 1993	2,056,000
Apr. 1995	5,706,000
Jul. 1997	19,540,000
Jul. 2000	93,047,785

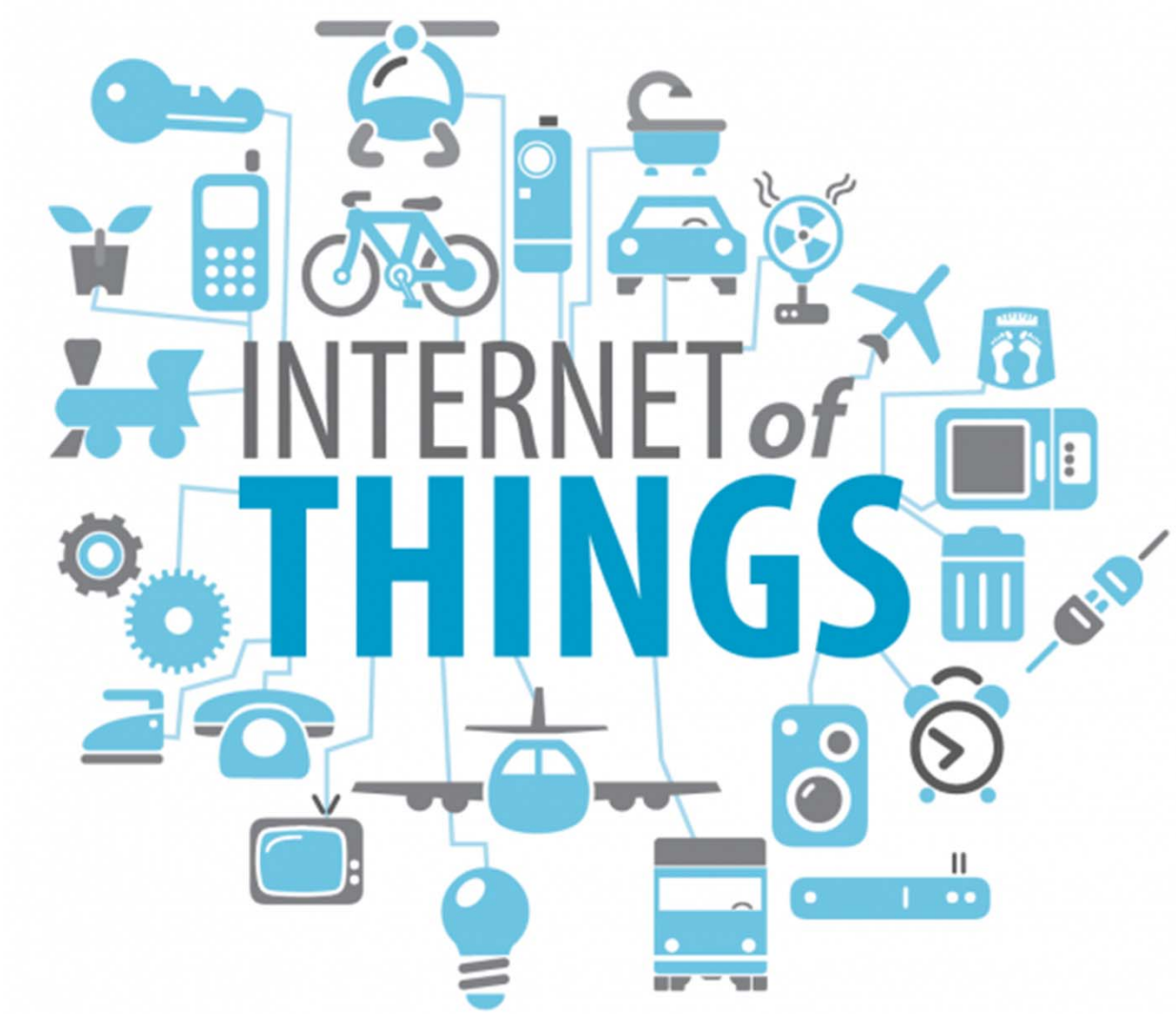


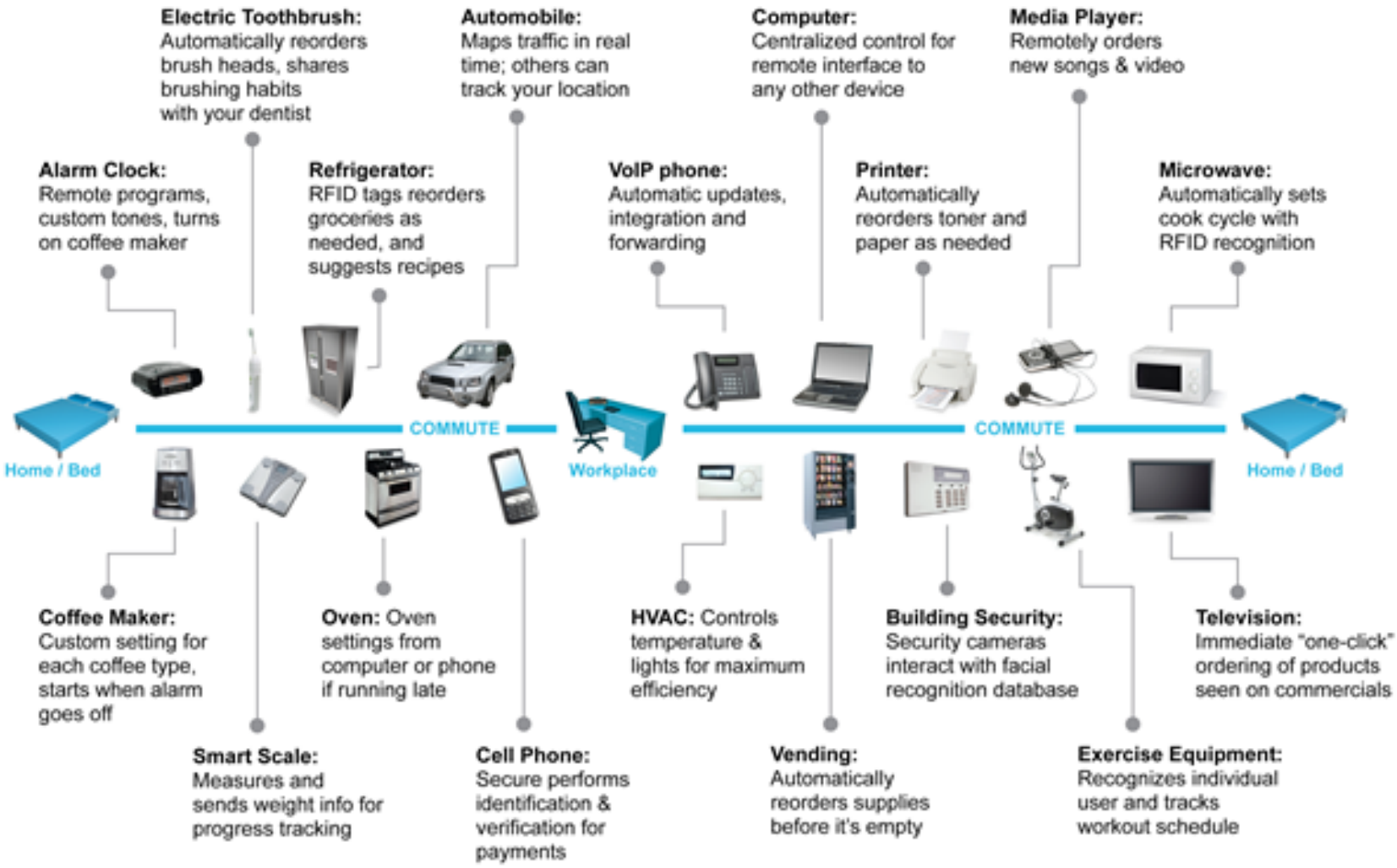
Recent Growth (1991-2000)

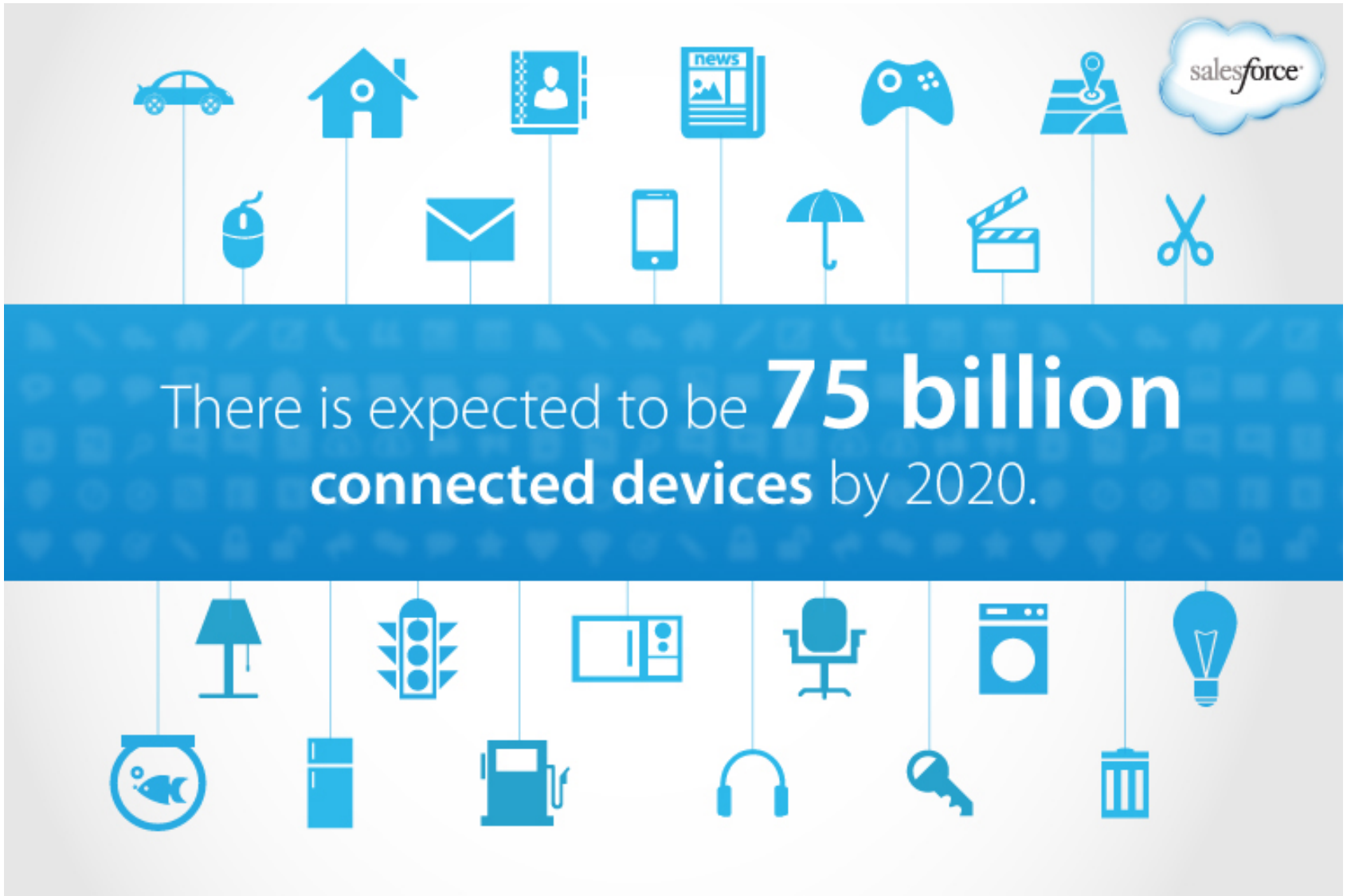


Recent Growth (1981-2012)




INTERNET of
THINGS


Electric Toothbrush: Automatically reorders brush heads, shares brushing habits with your dentist
Automobile: Maps traffic in real time; others can track your location
Computer: Centralized control for remote interface to any other device
Media Player: Remotely orders new songs & video
Alarm Clock: Remote programs, custom tones, turns on coffee maker
Refrigerator: RFID tags reorders groceries as needed, and suggests recipes
VoIP phone: Automatic updates, integration and forwarding
Printer: Automatically reorders toner and paper as needed
Microwave: Automatically sets cook cycle with RFID recognition
COMMUTE
COMMUTE
Home / Bed
Workplace
Home / Bed
Coffee Maker: Custom setting for each coffee type, starts when alarm goes off
Oven: Oven settings from computer or phone if running late
HVAC: Controls temperature & lights for maximum efficiency
Building Security: Security cameras interact with facial recognition database
Television: Immediate "one-click" ordering of products seen on commercials
Smart Scale: Measures and sends weight info for progress tracking
Cell Phone: Secure performs identification & verification for payments
Vending: Automatically reorders supplies before it's empty
Exercise Equipment: Recognizes individual user and tracks workout schedule


news
salesforce
There is expected to be 75 billion
connected devices by 2020.

Who is Who on 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 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. 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 (1990's)
    - replacing radio, CD, TV?
  - Blog, p2p, youtube

Today's Vision

- Everything is digital: voice, video, music, pictures, live events
- Everything is on-line: bank statements, medical records, books, airline schedules, weather, highway traffic, toaster, refrigerator …
- Everyone is connected: doctor, teacher, broker, mother, son, friends, enemies

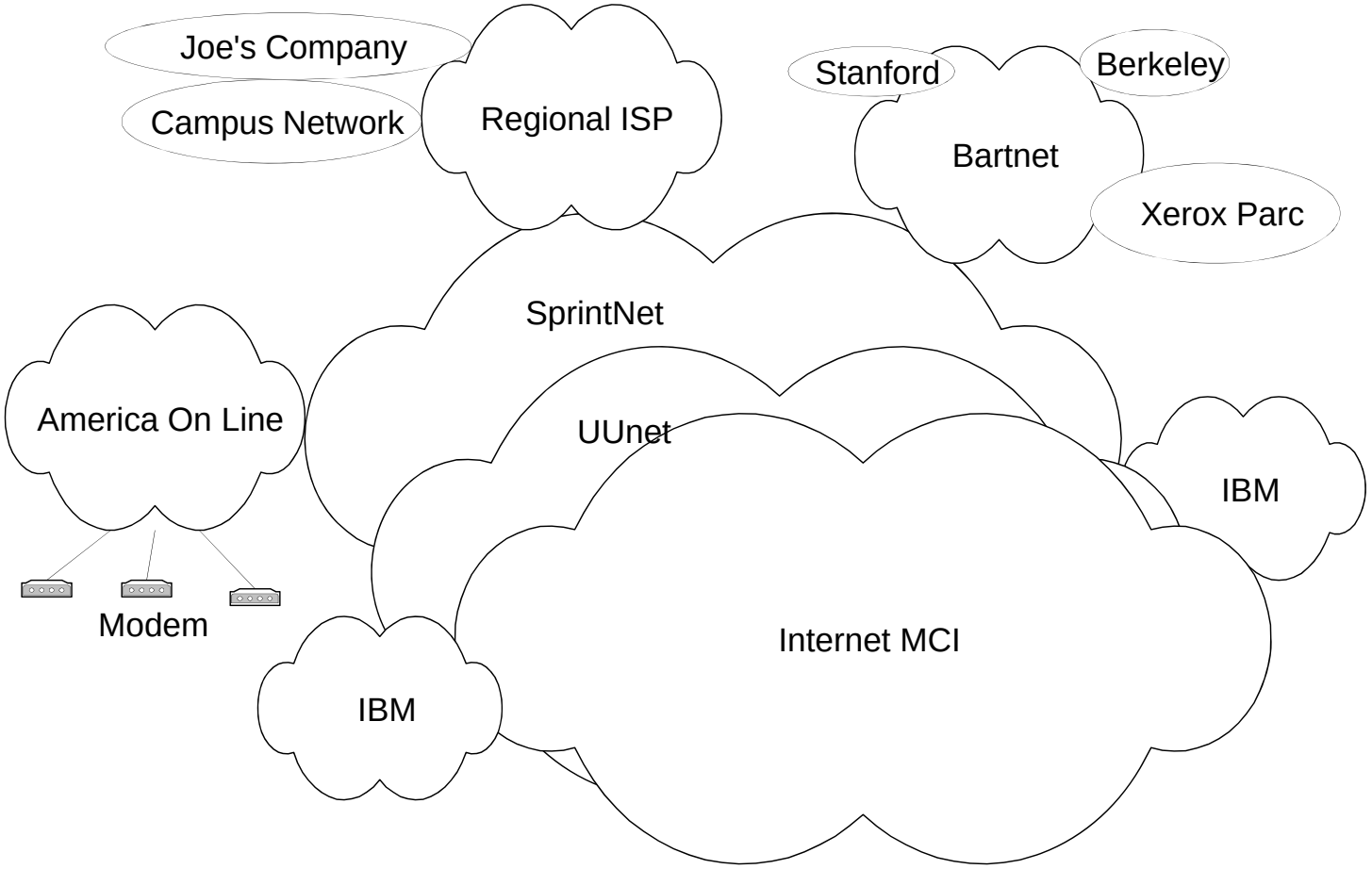
What is Next?

- Electronic commerce
  - virtual enterprise
- Internet entertainment
  - interactive sitcom
- World as a small village
  - community organized according to interests
  - enhanced understanding among diverse groups
- Electronic democracy
  - little people can voice their opinions to the whole world
  - little people can coordinate their actions
  - bridge the gap between information haves and have not's
- Electronic terrorism
  - attackers can bring the whole world to its knee

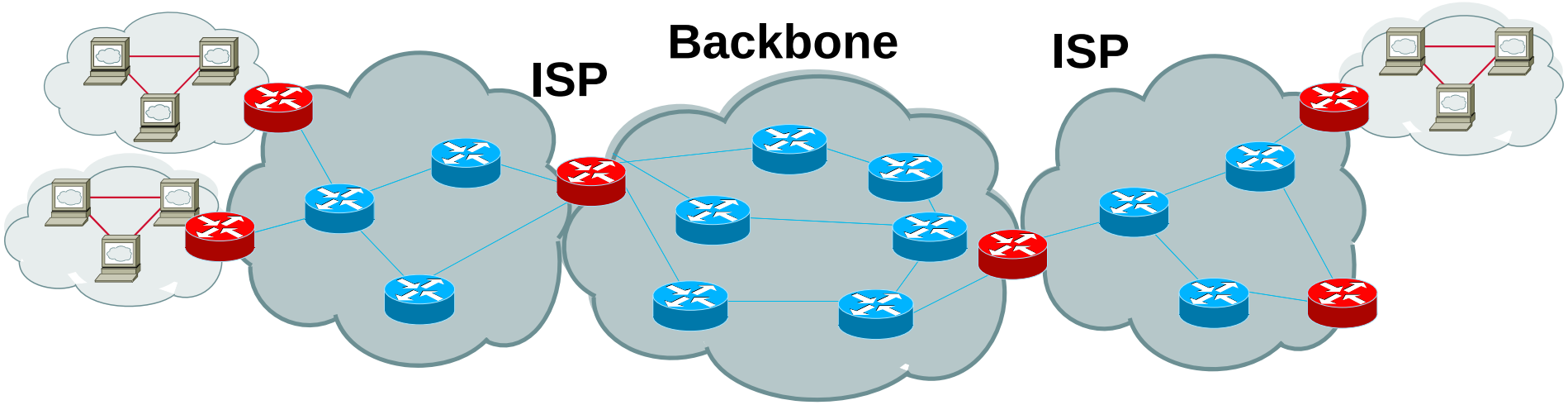
Industrial Players

- Telephone companies
  - own long-haul and access communication links, customers
- Cable companies
  - own access links
- Wireless/Satellite companies
  - alternative communication links
- Utility companies: power, water, railway
  - own right of way to lay down more wires
- Medium companies
  - own contents
- Internet Service Providers
- Equipment companies
  - switches/routers, chips, optics, computers
- Software companies

Commercial Internet after 1994

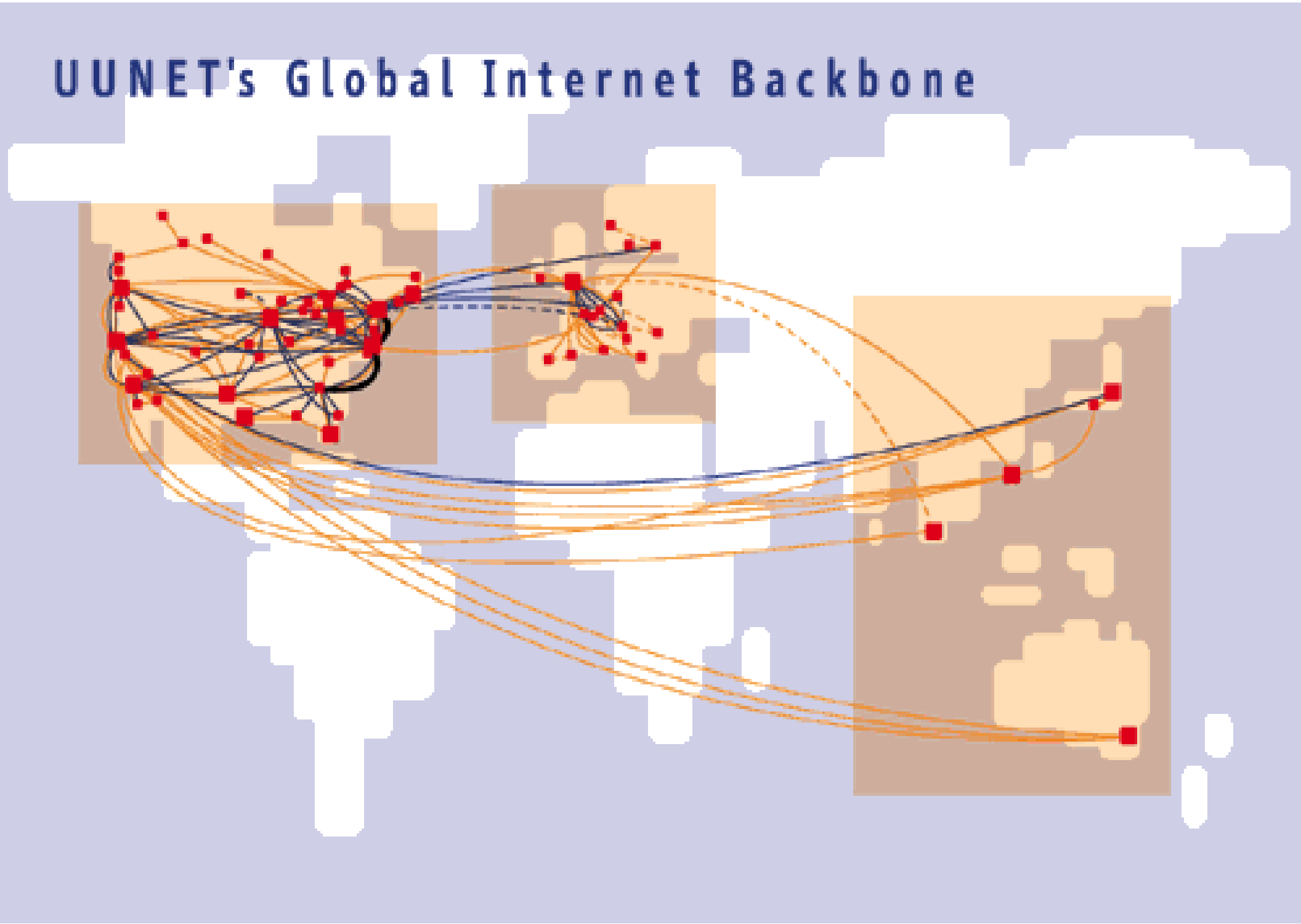


Internet Physical Infrastructure

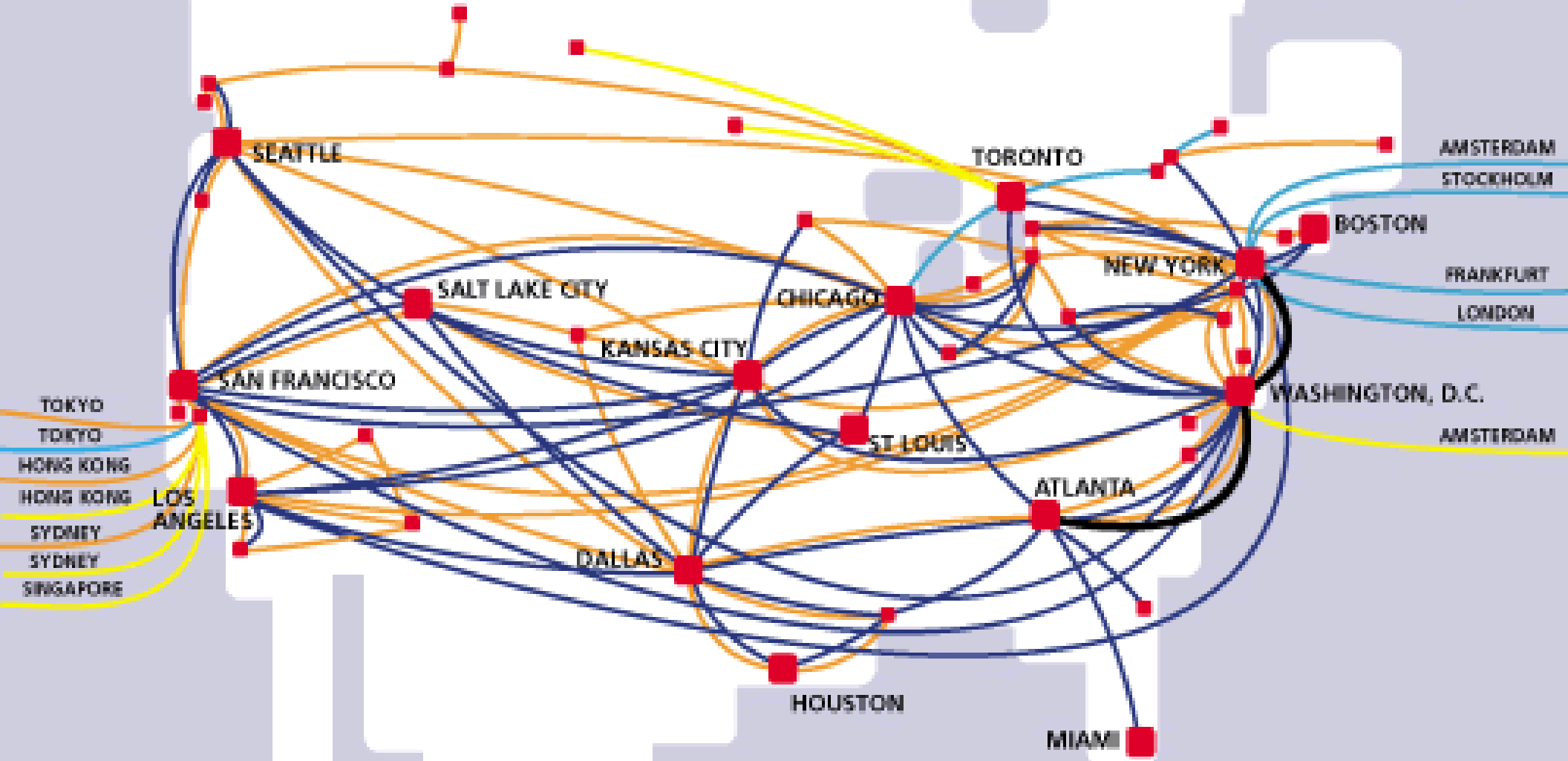


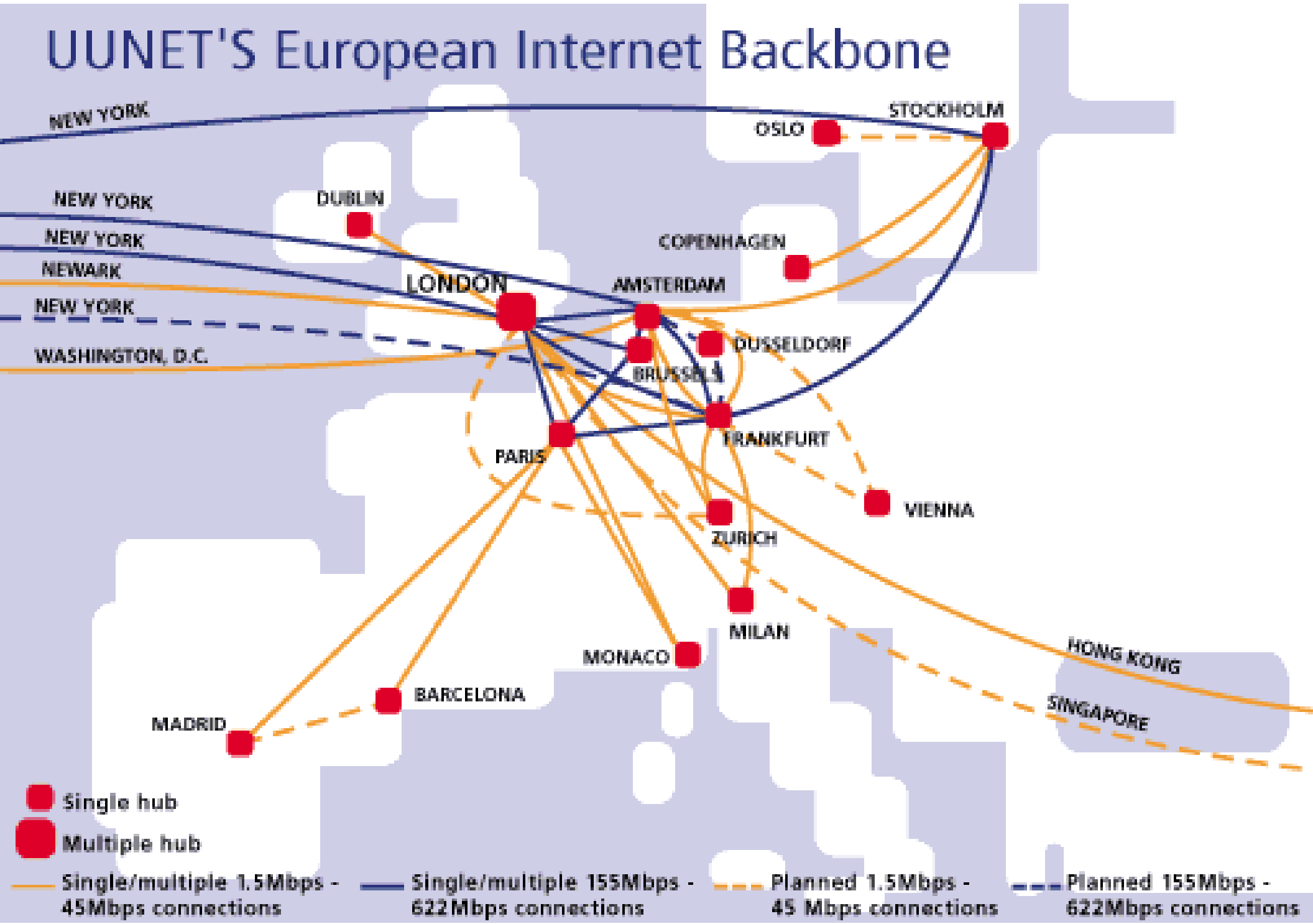
- Residential Access
  - Modem
  - DSL
  - Cable modem
  - Satellite
- Enterprise/ISP access, Backbone transmission
  - T1/T3, DS-1 DS-3
  - OC-3, OC-12, OC-192
  - ATM vs. SONET, vs. WDM
- Campus network
  - Ethernet, ATM
- Internet Service Providers
  - access, regional, backbone
  - Point of Presence (POP)
  - Network Access Point (NAP)

UUNET's Global Internet Backbone



UUNET'S North American Internet Backbone




UUNET'S European Internet Backbone
NEW YORK
STOCKHOLM
OSLO
NEW YORK
DUBLIN
NEW YORK
COPENHAGEN
NEWARK
LONDON
AMSTERDAM
NEW YORK
DUSSELDORF
WASHINGTON, D.C.
BRUSSELS
FRANKFURT
PARIS
VIENNA
ZURICH
MILAN
MONACO
HONG KONG
BARCELONA
SINGAPORE
MADRID
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

Links for Long Haul Transmission

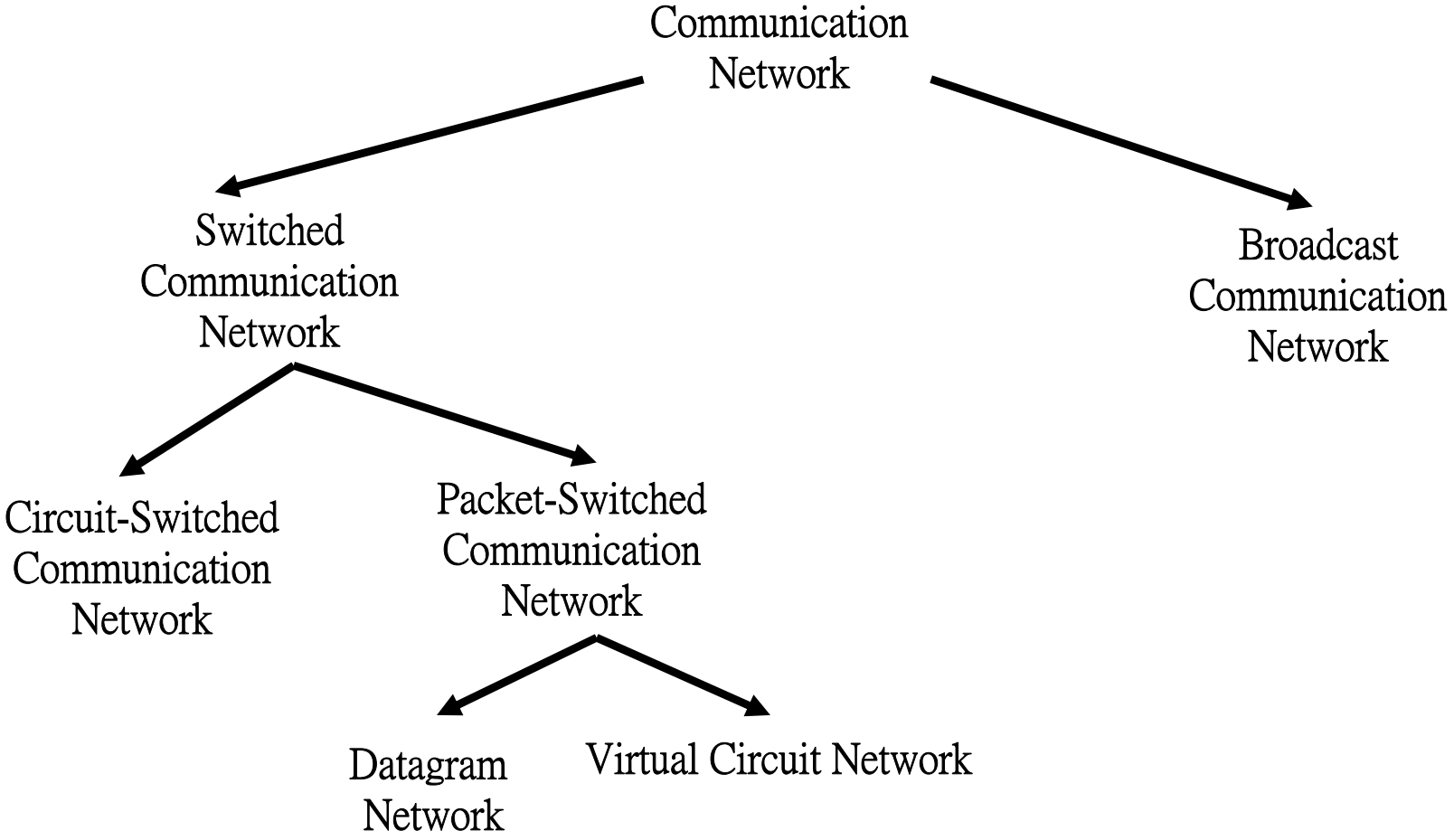
- Types of links
  - T1/DS1: 1.544 Mbps
  - T3/DS3: 44.736 Mbps
  - STS-1/OC-1: 51.850 Mbps
  - STS-3/OC-3: 155.2 Mbps
  - STS-12/OC-12: 622.080 Mbps
  - STS-48/OC-48: 2.488 Gbps
  - STS-192/OC-192: 9.953 Gbps
- Higher levels of services offered commercially
  - Frame Relay
  - ATM
- Possibilities
  - IP over SONET
  - IP over ATM
  - IP over Frame Relay
  - IP over WDM

Overview

- Administrative trivia
- Overview and history of the Internet
- A Taxonomy of Communication Networks
- Router Architecture in Packet-Switching 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

A Taxonomy of Communication Networks

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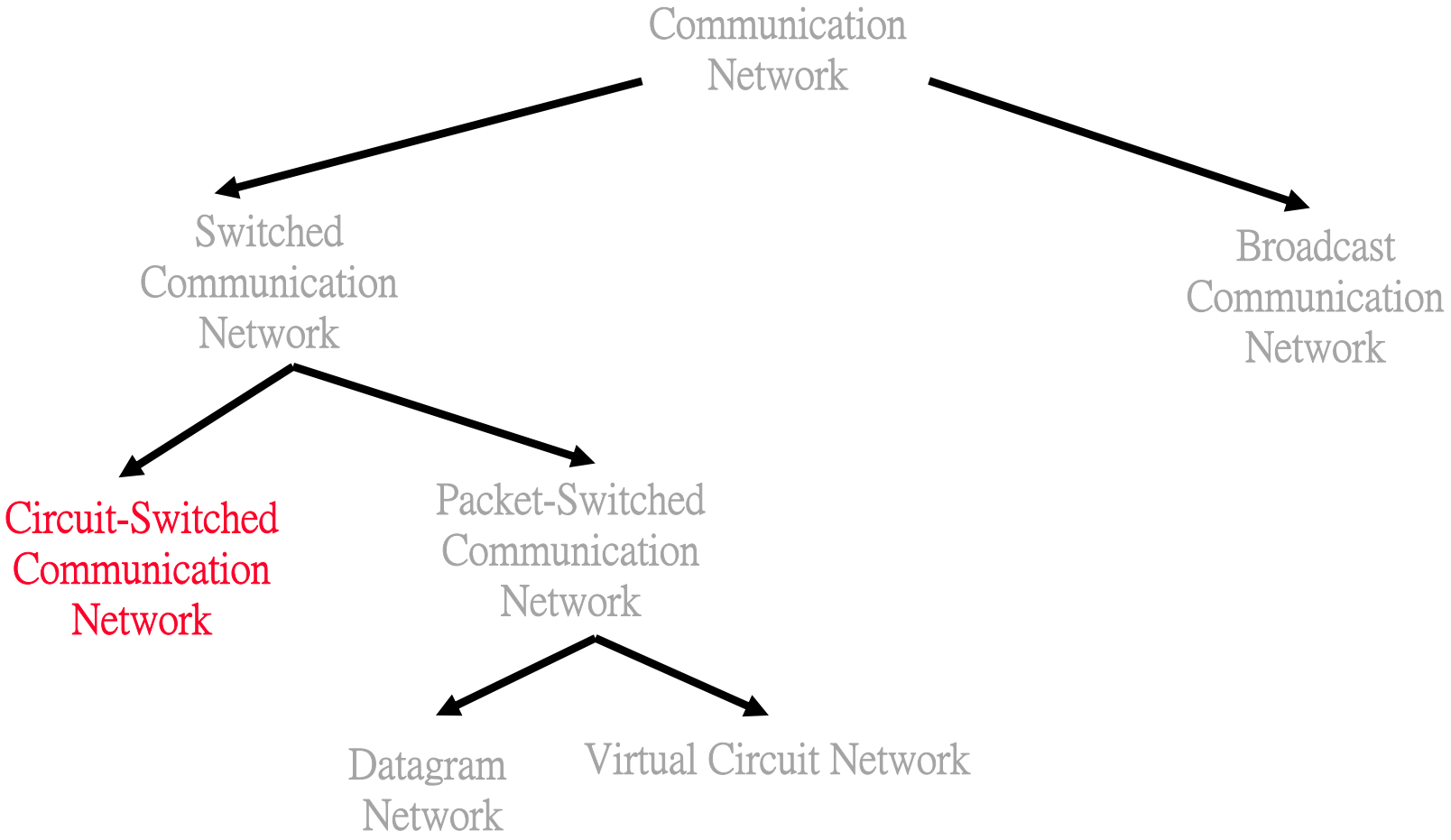
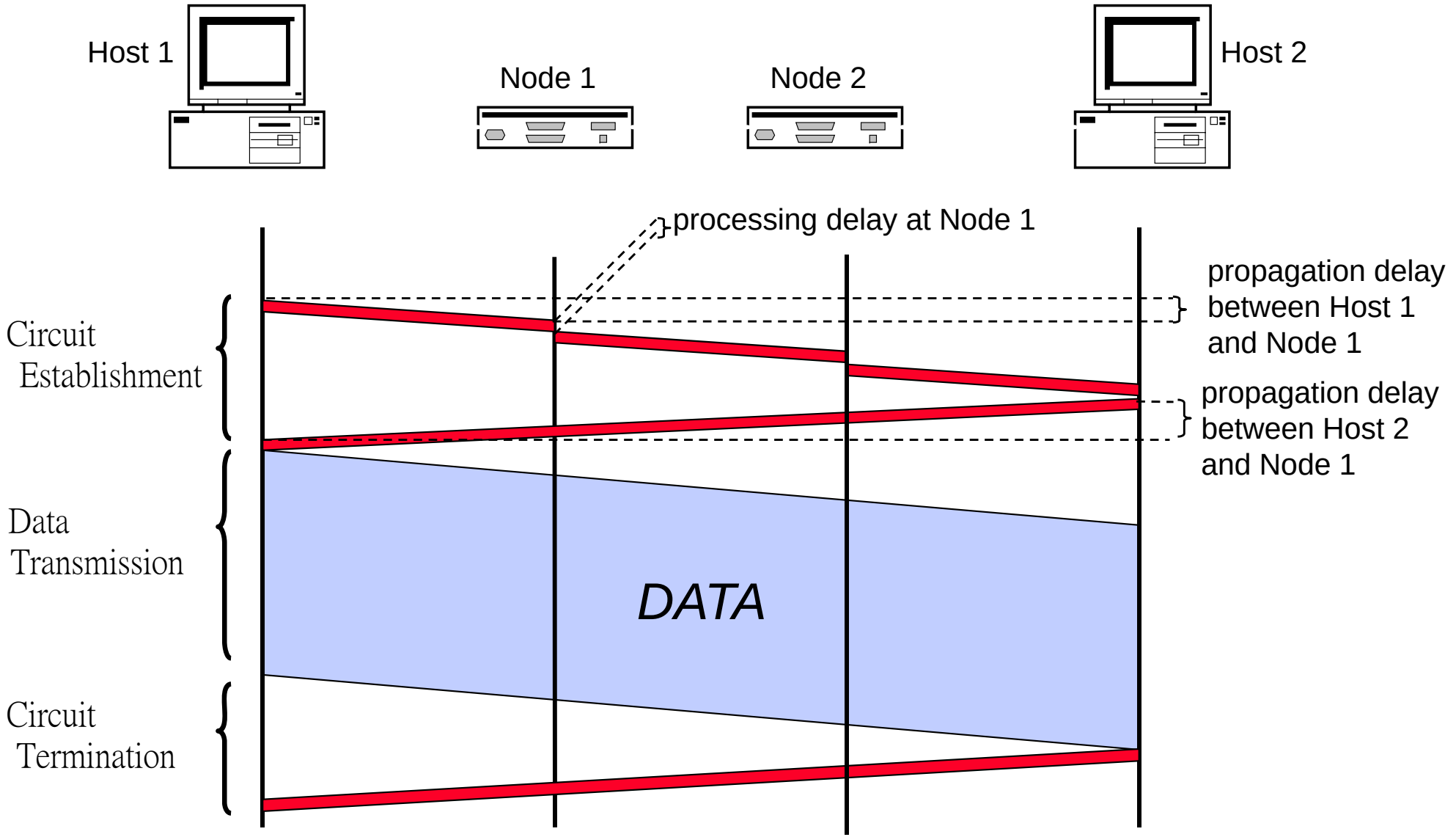


Circuit Switching

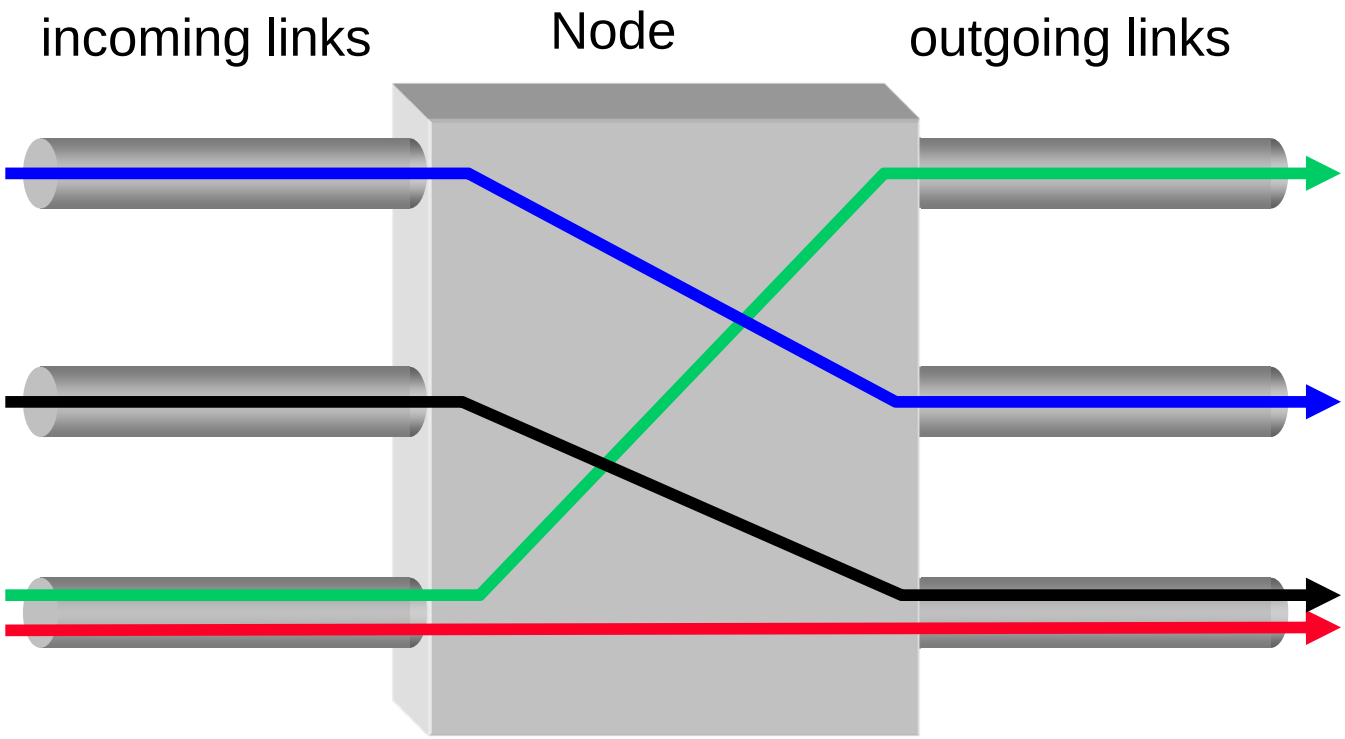
- Three phases
  1. circuit establishment
  2. data transfer
  3. circuit termination
- If circuit not available: “Busy signal”
- Examples
  - Telephone networks
  - ISDN (Integrated Services Digital Networks)

Timing in Circuit Switching

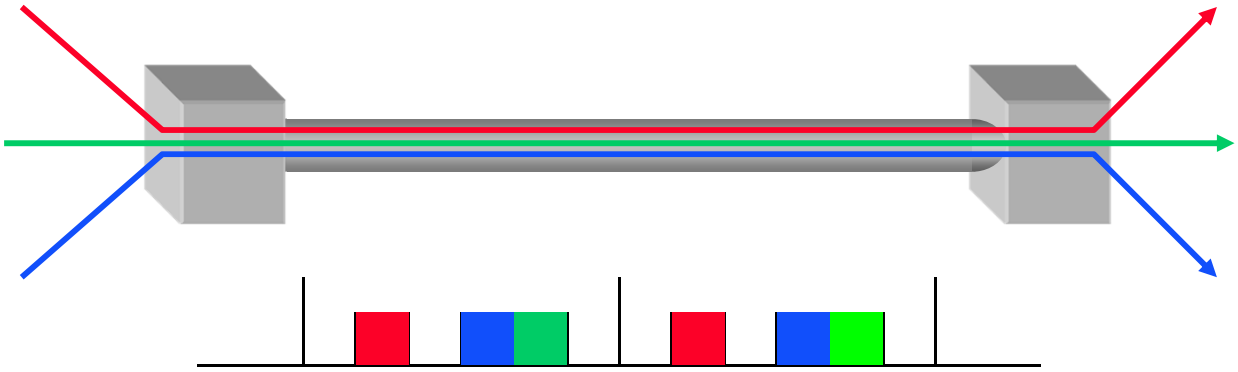


Circuit Switching

- A node (switch) in a circuit switching network



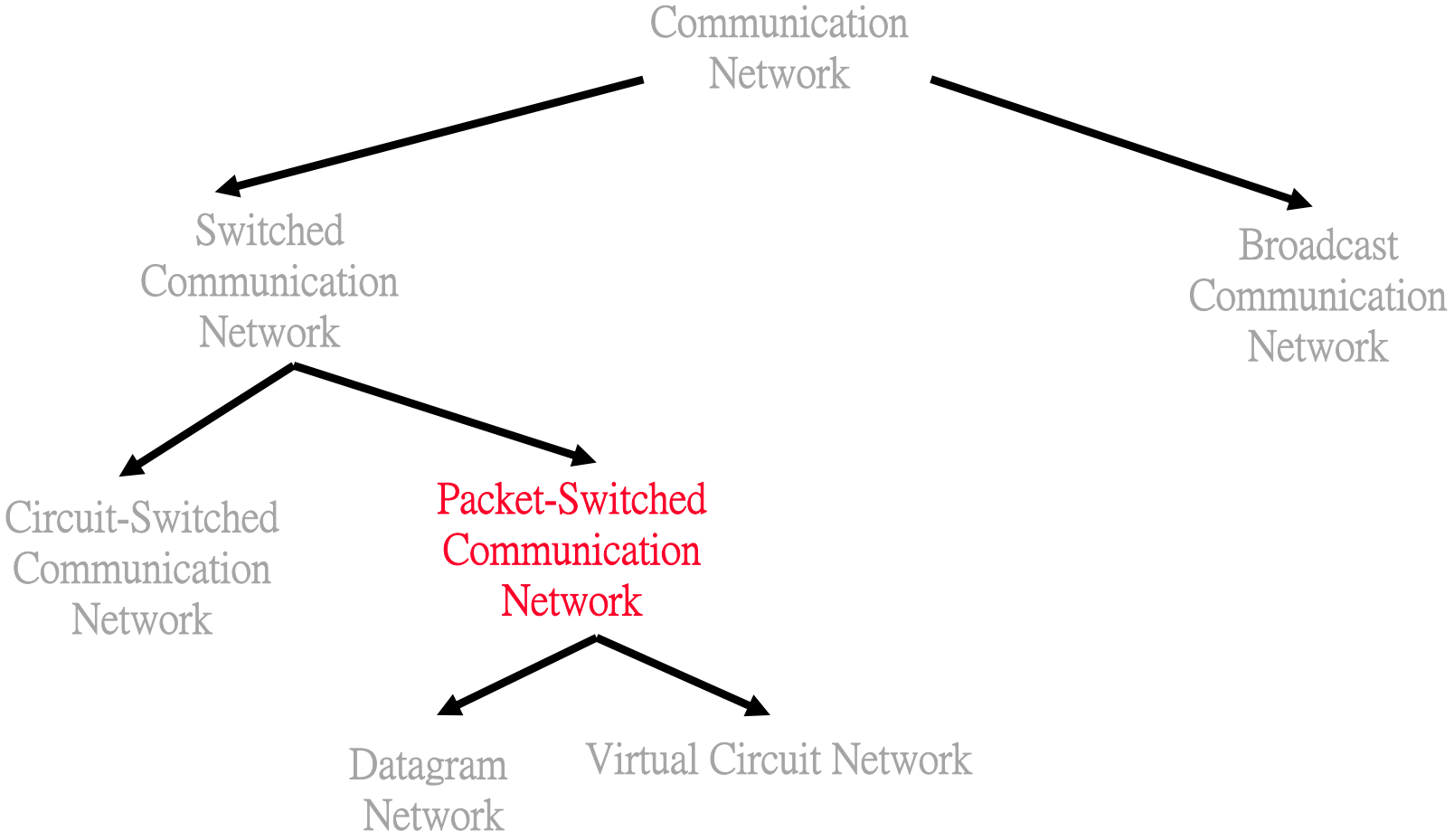
Circuit Switching: Multiplexing/Demultiplexing



- 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
  - how to do this?

A Taxonomy of Communication Networks

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



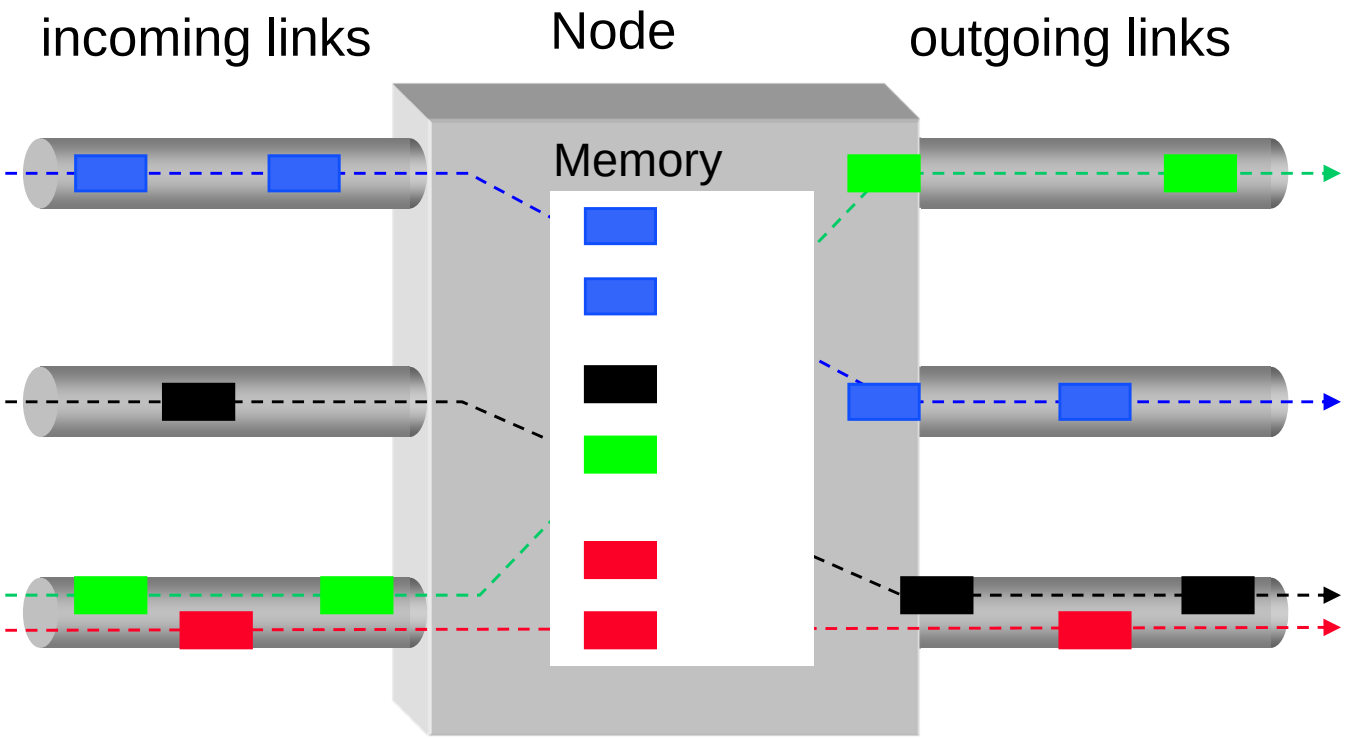
Packet Switching

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

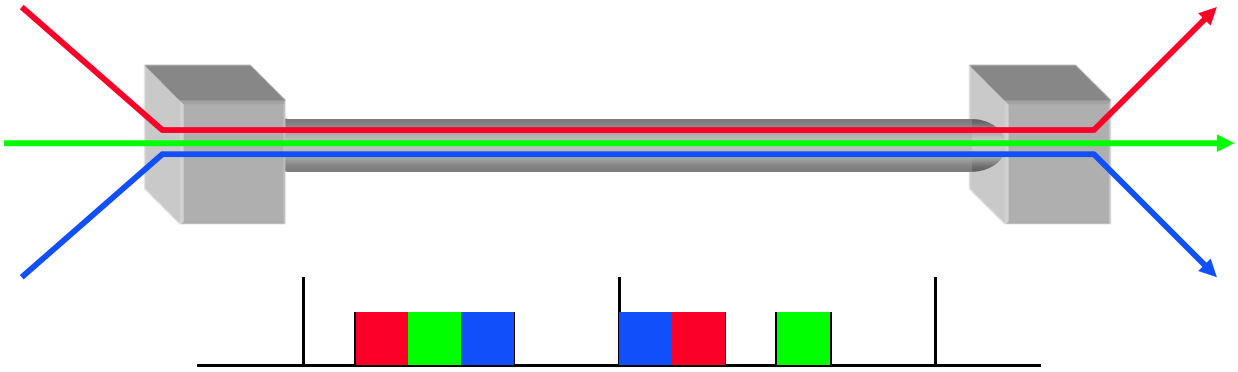
  - Header and Trailer carry control information (e.g., destination address, check sum)
- Each packet is passed through the network from node to node along some path (**Routing**)
- At each node the entire packet is received, stored briefly, and then forwarded to the next node (**Store-and-Forward Networks**)
- Typically no capacity is allocated for packets

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

A Taxonomy of Communication Networks

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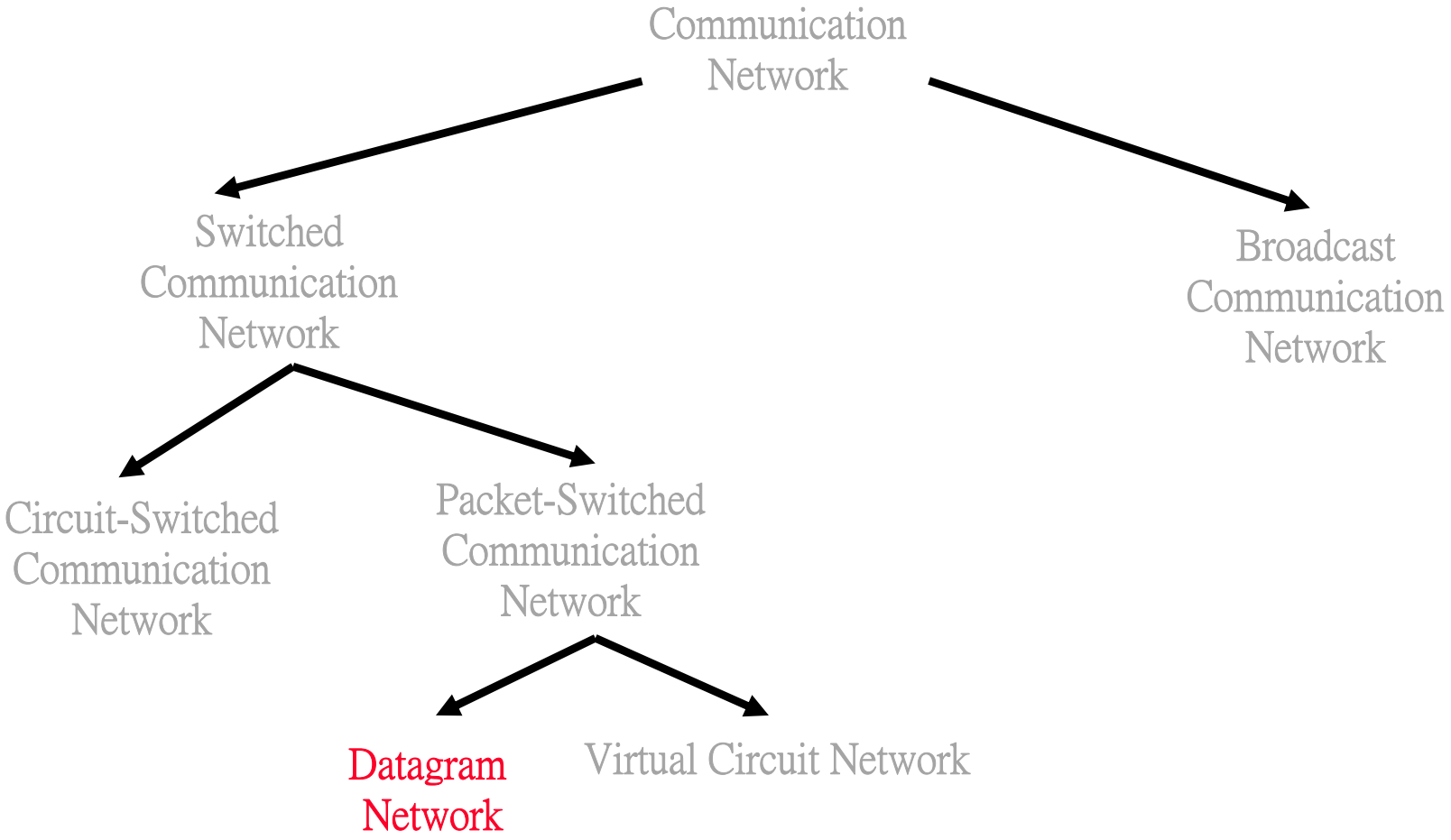
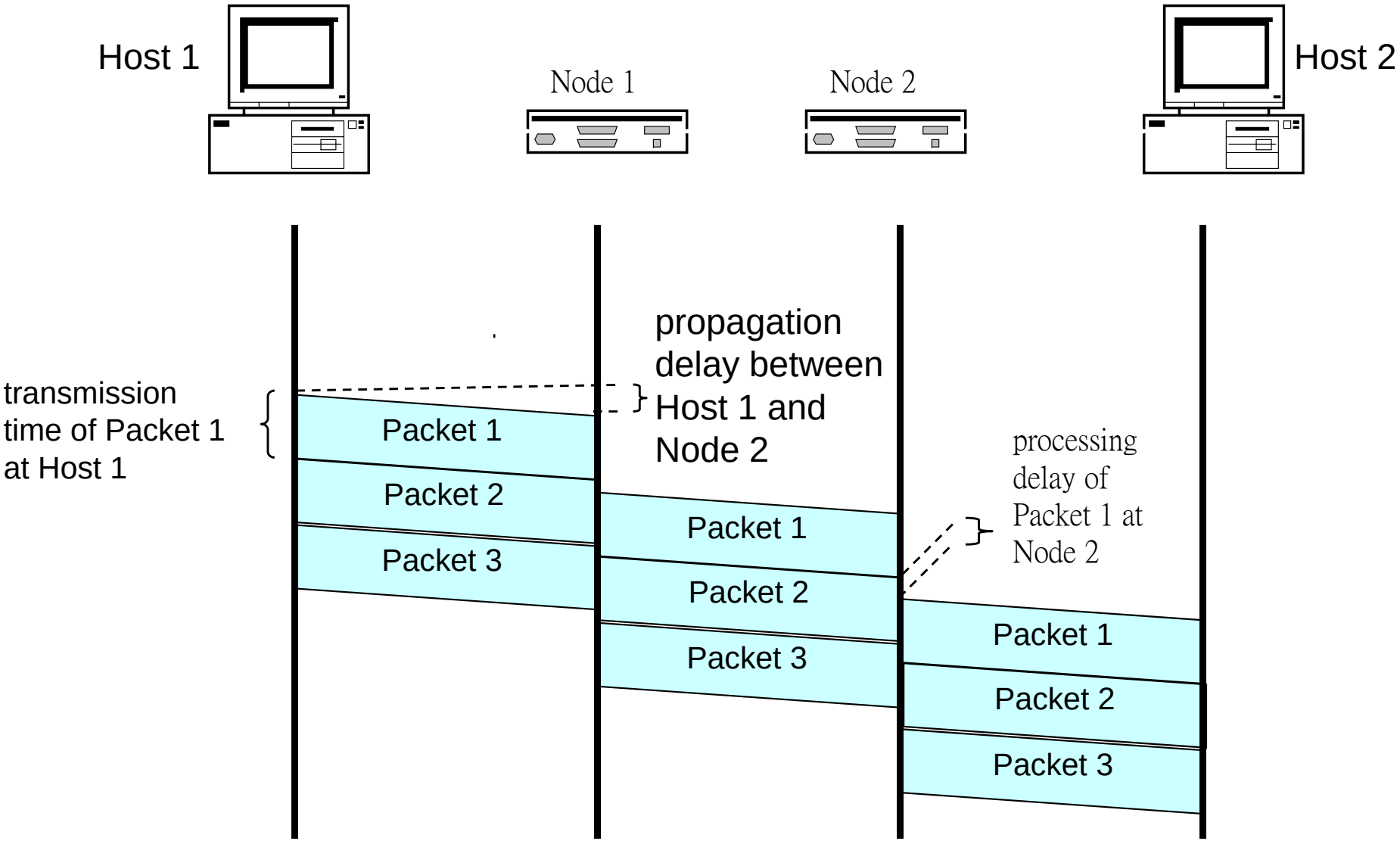


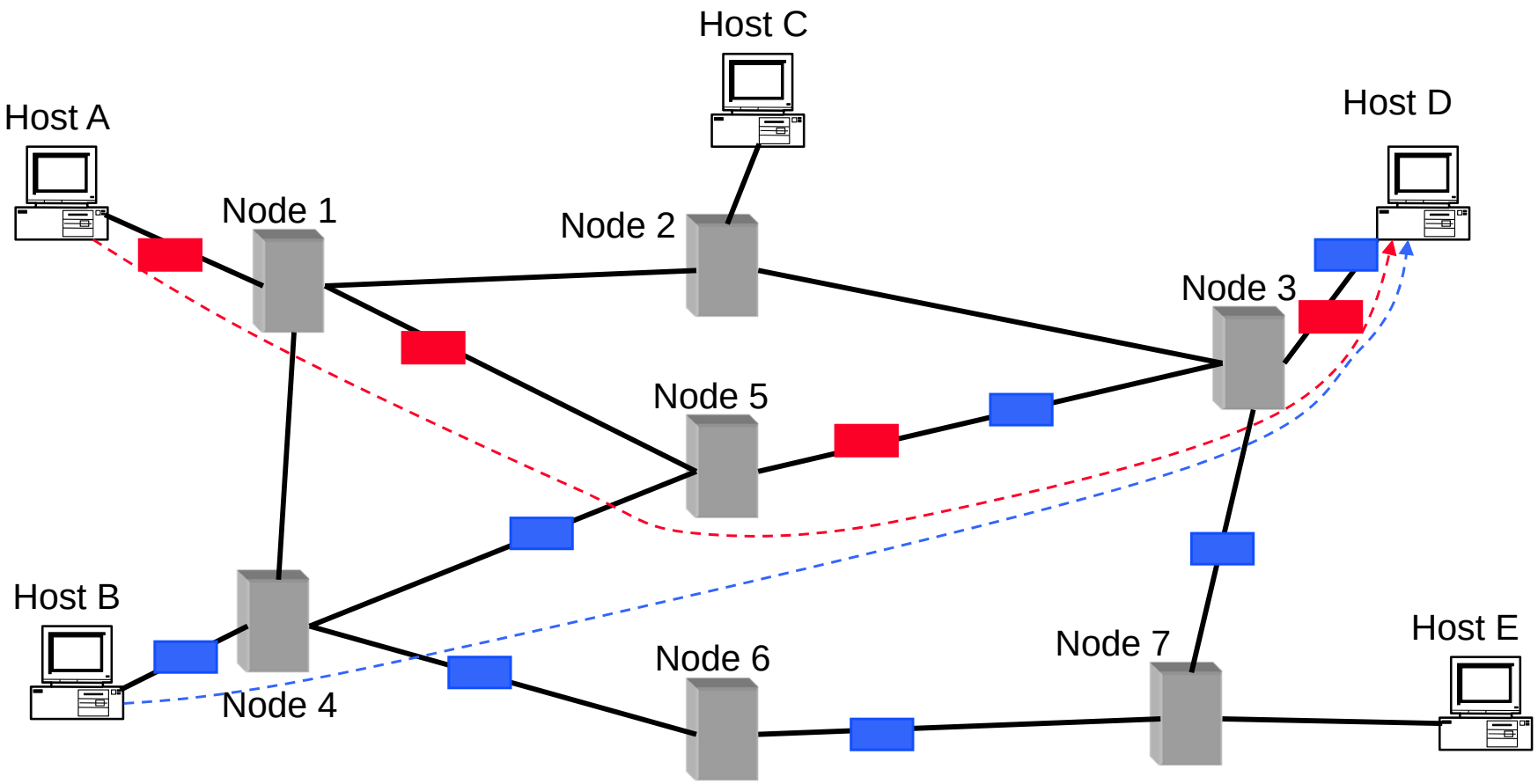
Datagram Packet Switching

- 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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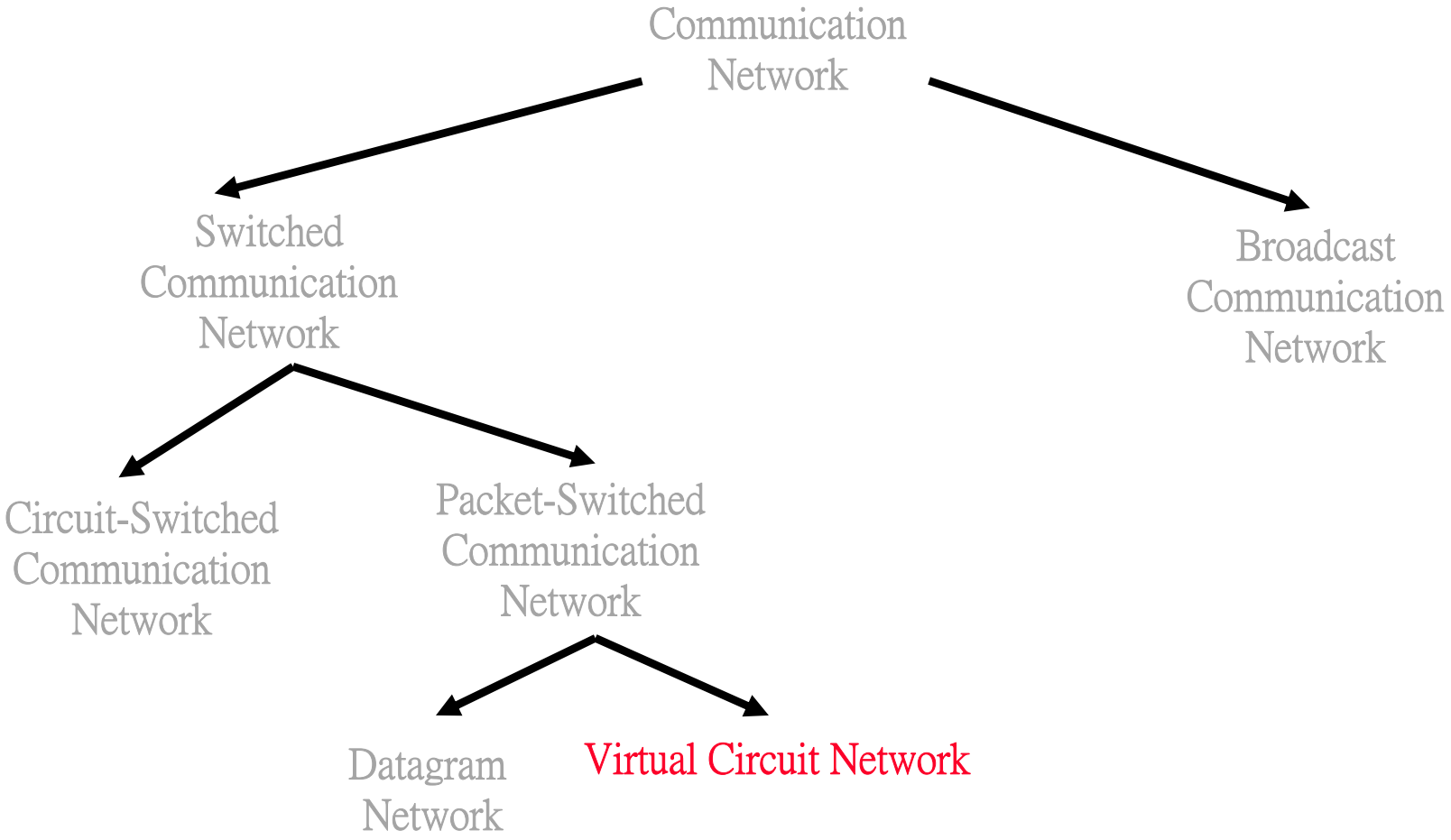


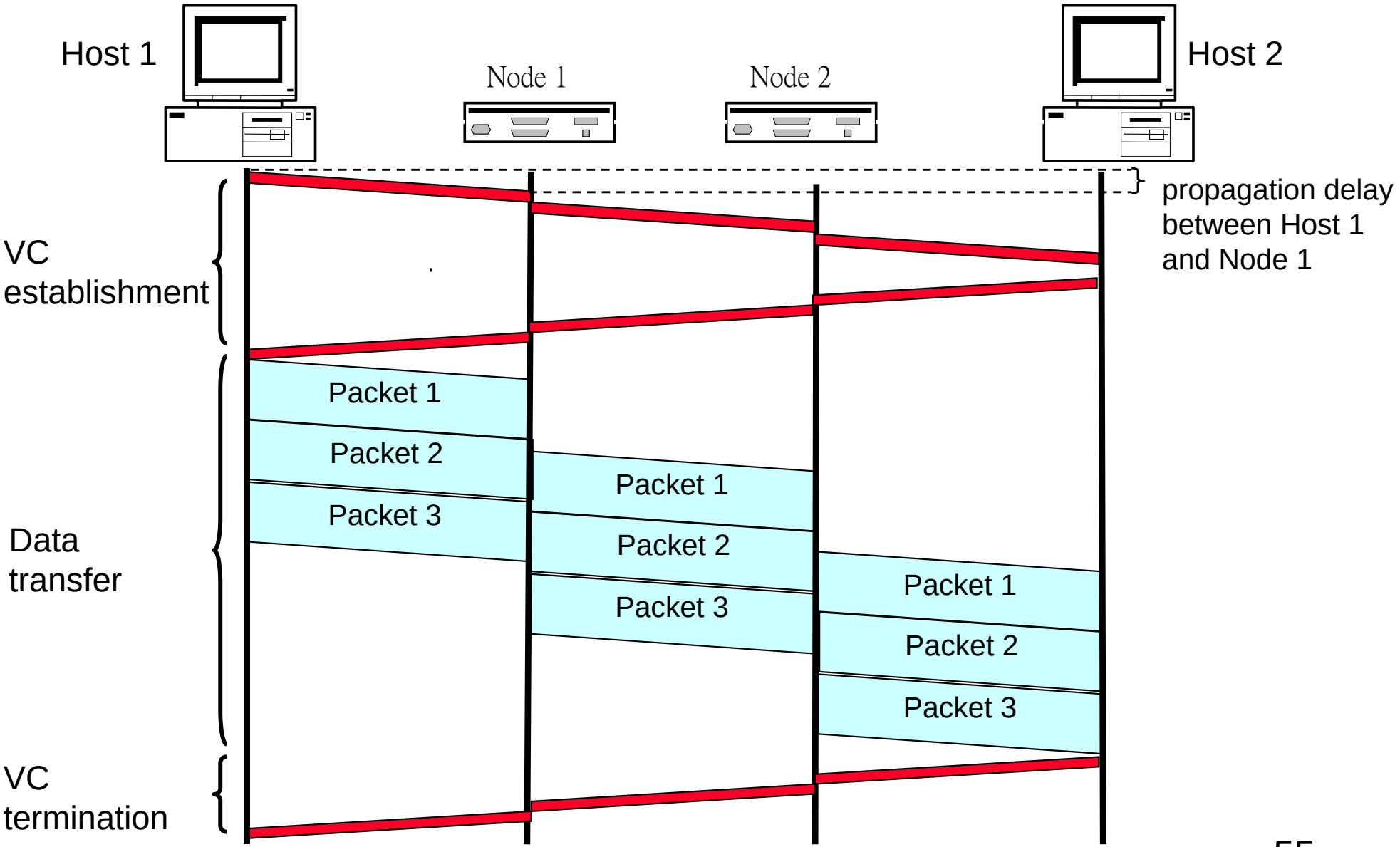
Virtual-Circuit Packet Switching

- “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

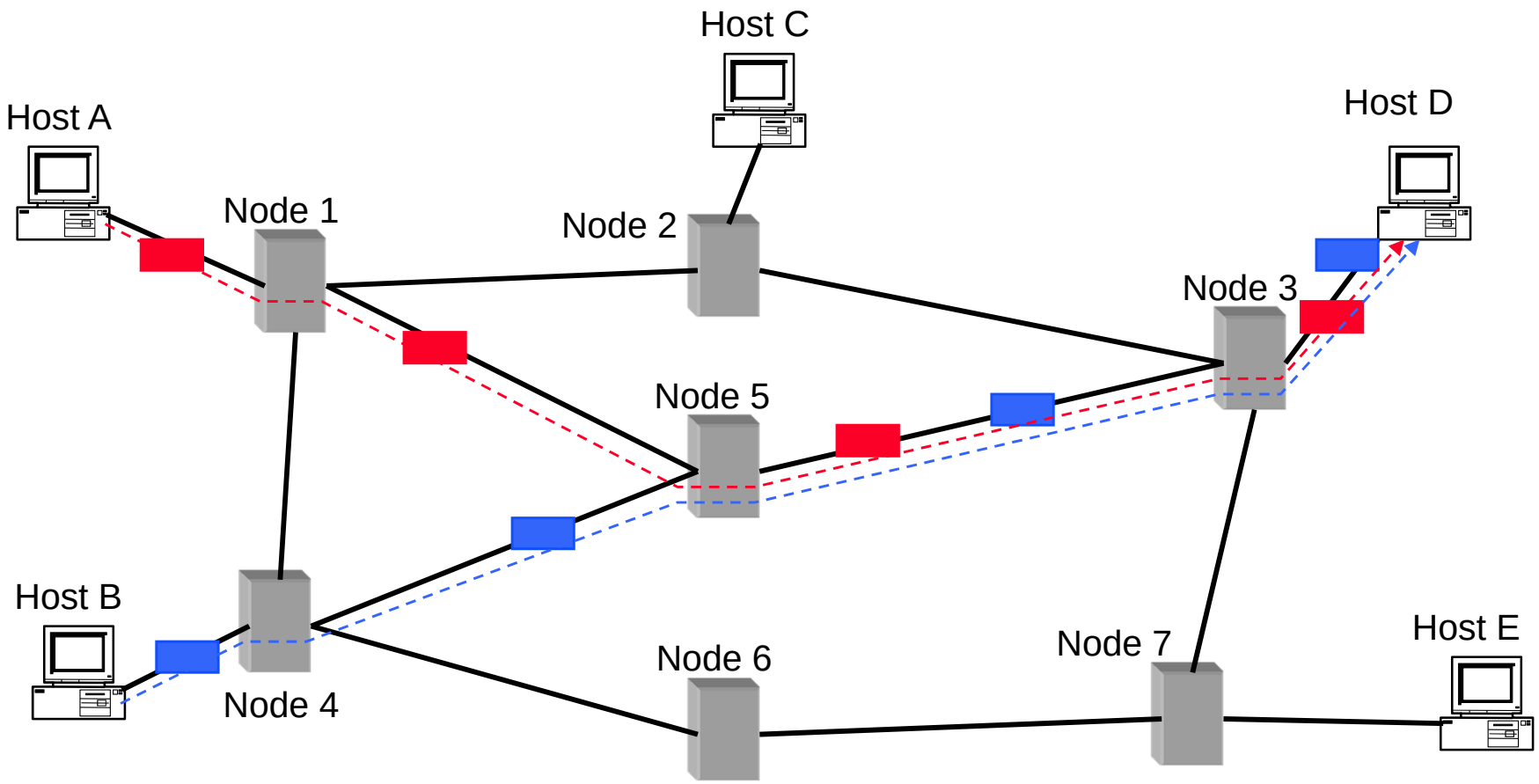
Virtual-Circuit Packet Switching

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

Timing of Virtual Circuit Packet Switching



Datagram Virtual Circuit 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 peek 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

Overview

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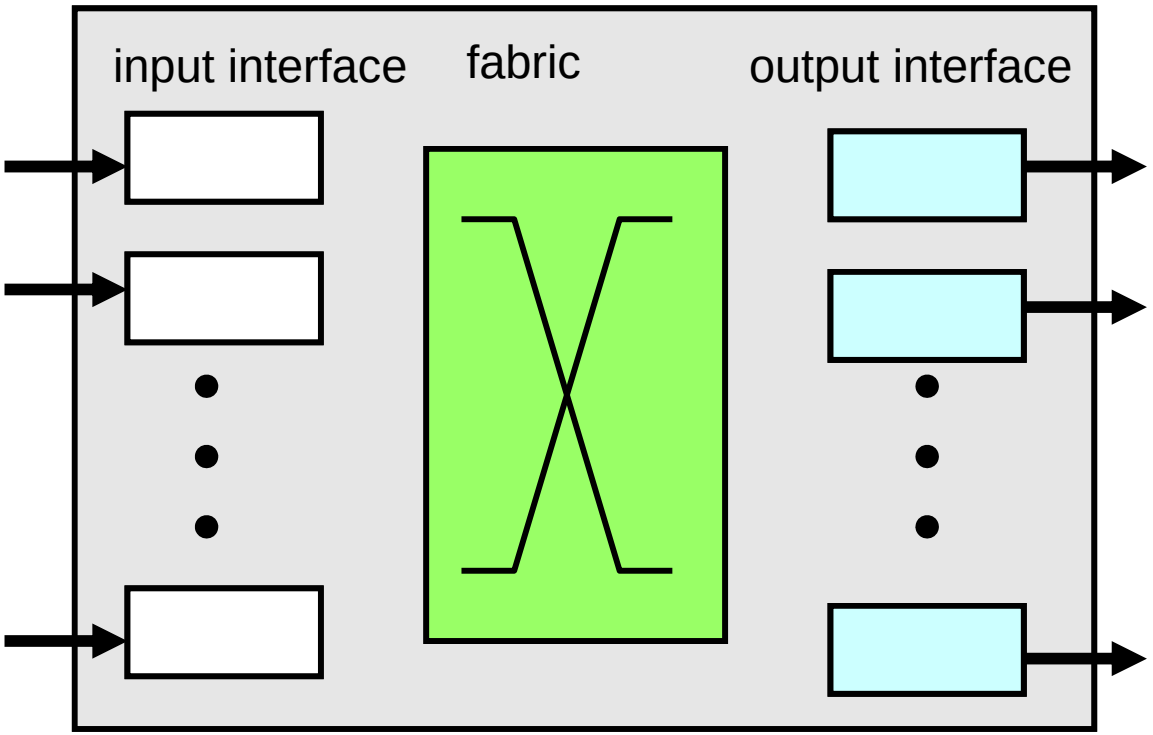
Router Architecture in Packet Switching Networks

- Set of input and output interfaces interconnected by a high speed fabric

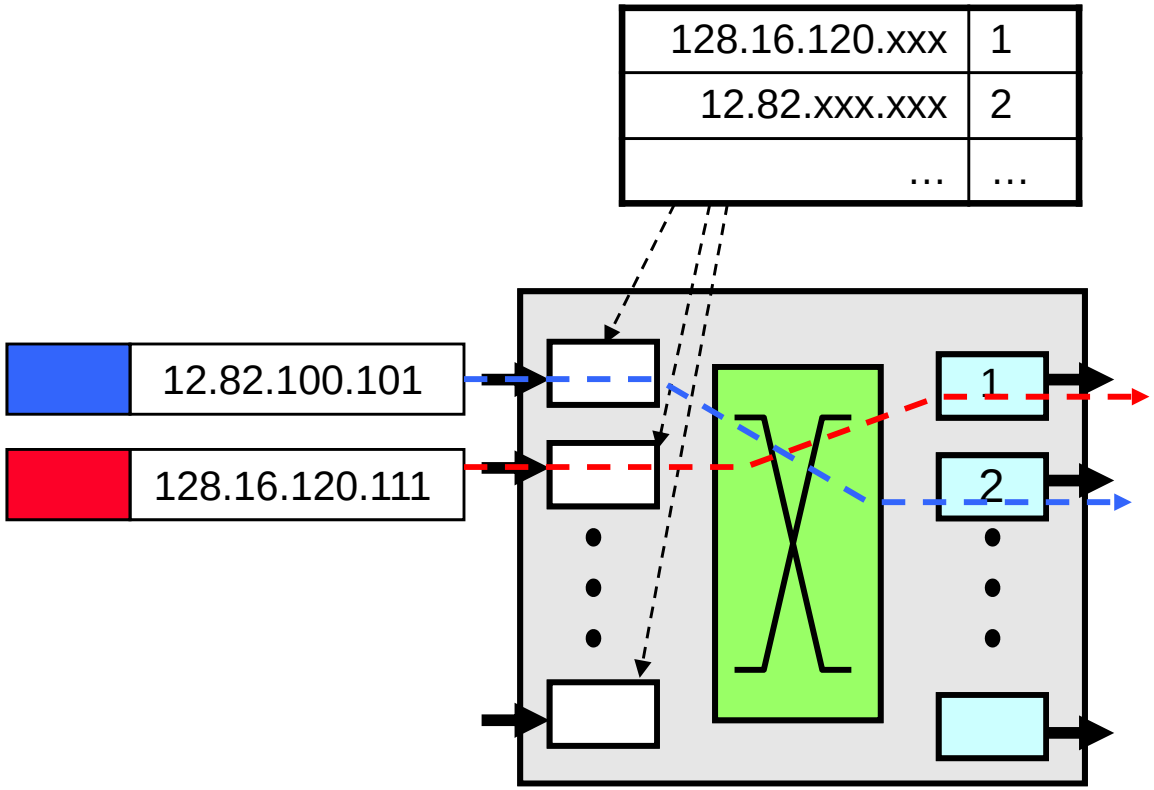


Data and Control Paths

- Data Path: all operations performed by a router on a packet as the packet propagates to its destination
  - forwarding, buffer management, scheduling
- Control Path: all operations required to set and maintain state in a router – state required to process packets on the data path
  - routing protocols, signaling

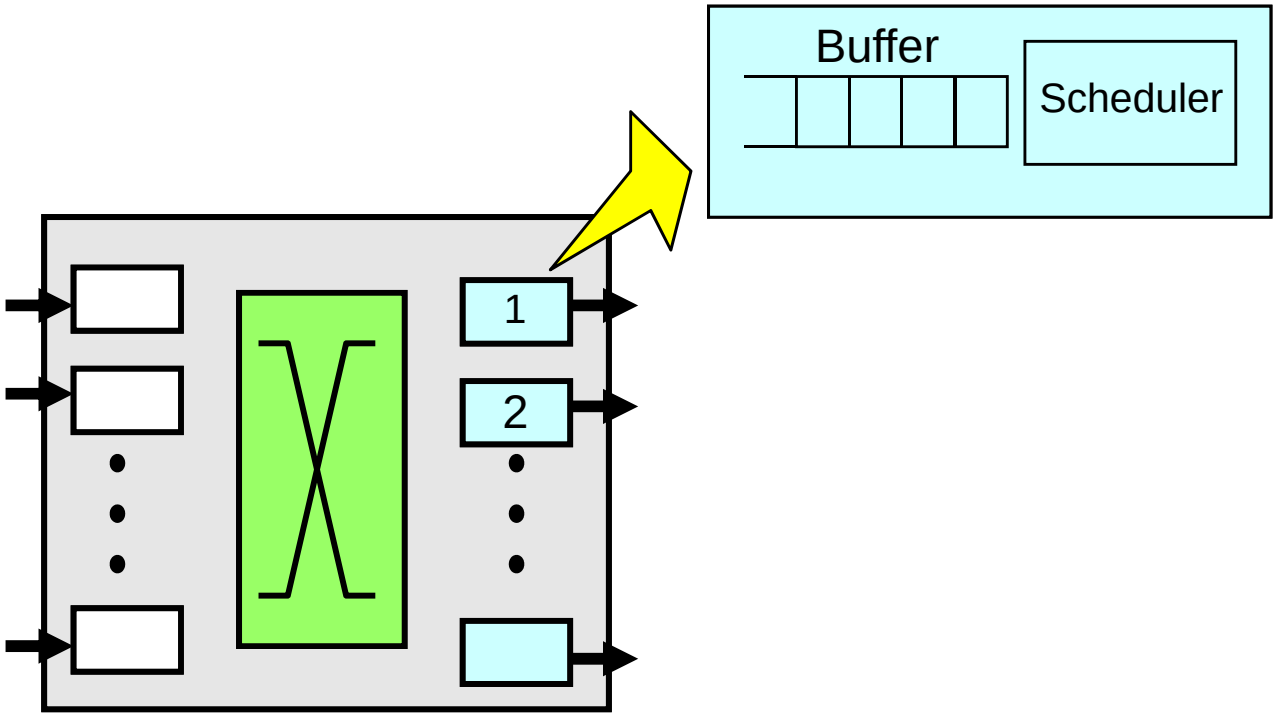
Typical Functions Performed by Input Interface on Data Path

- Packet forwarding: decide to which output interface to forward each packet based on the information in packet header



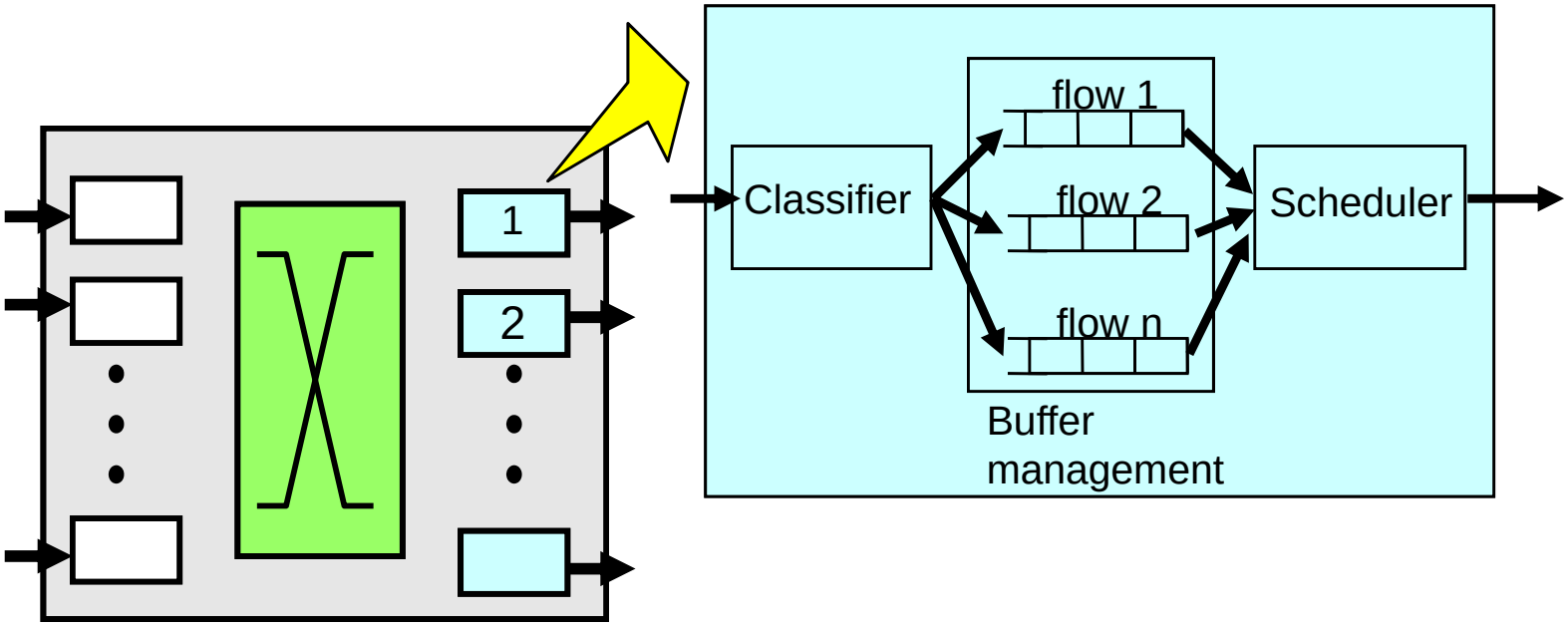
Typical Functions Performed by Output Interface

- Buffer management: decide when and which packet to drop
- Scheduler: decide when and which packet to transmit



Typical Functions Performed by Output Interface

- Packet classification: map each packet to a predefined flow
  - use to implement more sophisticated services (e.g., QoS)



- Flow: a subset of packets between any two endpoints in the network

Control Path

- Routing protocol: compute and set up routing tables
- Signaling protocol: set-up reservations and flow state along the path to achieve better services (e.g., delay and bandwidth guarantees)

Summary

- Course administrative trivia
- Internet history and trivia
- Classification of communication networks
- Router architecture

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

Network Protocols

- Specify any function that requires cooperation between two or more network entities
  - specify the format of the information that is sent/received among routers and end-systems
  - specify timings and the actions that a node has to take when it receives special messages or special events occur