Computer Networks

Amir Mahdi Sadeghzadeh, Ph.D.

Course information

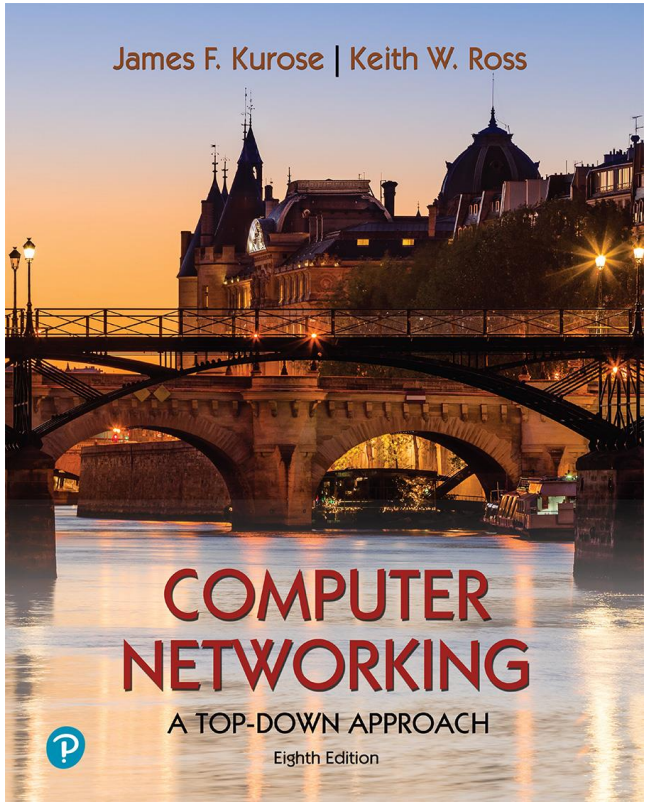
- Course Number: 40443-1
  - Time: Sun-Tue 15-16:30
  - Rooms: CE-102 & https://vc.sharif.edu/ch/amsadeghzadeh
- Instructor
  - Amir Mahdi Sadeghzadeh (amsadeghzadeh@gmail.com)
    - Office: CE-704
    - Lab: CE-502
    - Office hours: by appointment and through email
- Course Website: https://quera.org/course/add_to_course/course/20780/
  - Syllabus, Lecture slides, Discussions, Assignments, etc

Course information

- TAs
  - Zahra Moteshaker Arani(Head TA)
  - Mohammad Reza Mirbagheri(Head TA)

References

- Main reference
  - James Kurose and Keith Ross, Computer Networking - A Top-Down Approach, 8th edition



- Optional reference
  - Computer Networks: A Systems Approach (Fifth Edition), by Larry L. Peterson, Bruce S. Davie.

Course outline

- Computer Networks and the Internet
- Application Layer
- Transport Layer
- The Network Layer: Data Plane
- The Network Layer: Control Plane
- The Link Layer and LANs

Pre-requisite

- Probability and Statistics
- Operating Systems

Assignments and Project

- There are 4 or 5 Assignments
- There is a project at the end of semester

- Late policy
  - All students have 10 free late days for the assignments
  - You can distribute them as you want across your HWs
  - No more than 3 days for each homework
  - All subsequent late submissions will accrue a 24% penalty per 24 hours

Assignments and Project

- Ethics statement
  - Please read Sharif CE Department Ethics Statement
  - Every student must solve every homework by themselves
    - You may discuss the homeworks with your friends, but when you finally solve it, every line of your solution or code (except libraries that have been okayed by course staff) must be written by you
    - Your solution must be yours
  - Use of Language Learning Models (LLMs) such as ChatGPT or any similar artificial intelligence-based tools for the completion of homework assignments is strictly prohibited.
    - Any evidence of using such models for homework will be considered a violation of academic integrity and may result in disciplinary action.

Quiz

- A quiz every two weeks on Saturdays
  - Each quiz has 10 questions
  - At the end of semester, the lowest quiz score will be dropped

Grading Policy

- Homework (20%)
- Project (10%)
- Quiz (10%)
- Midterm (25%)
- Final (35%).

welcome to the course!

The Internet: a "nuts and bolts" view

Billions of connected computing *devices*:

- *hosts = end systems*
- running *network apps* at Internet's "edge"

Packet switches: forward packets (chunks of data)

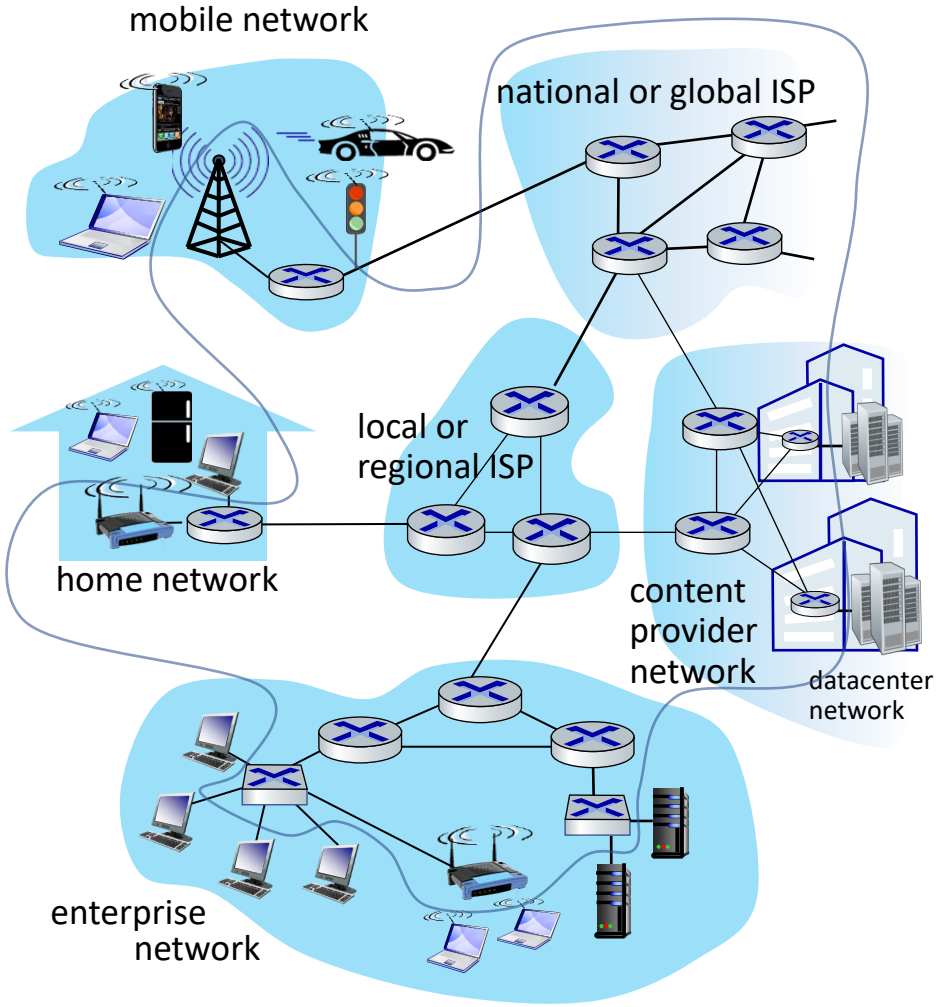
- *routers, switches*

Communication links

- fiber, copper, radio, satellite
- transmission rate: *bandwidth*

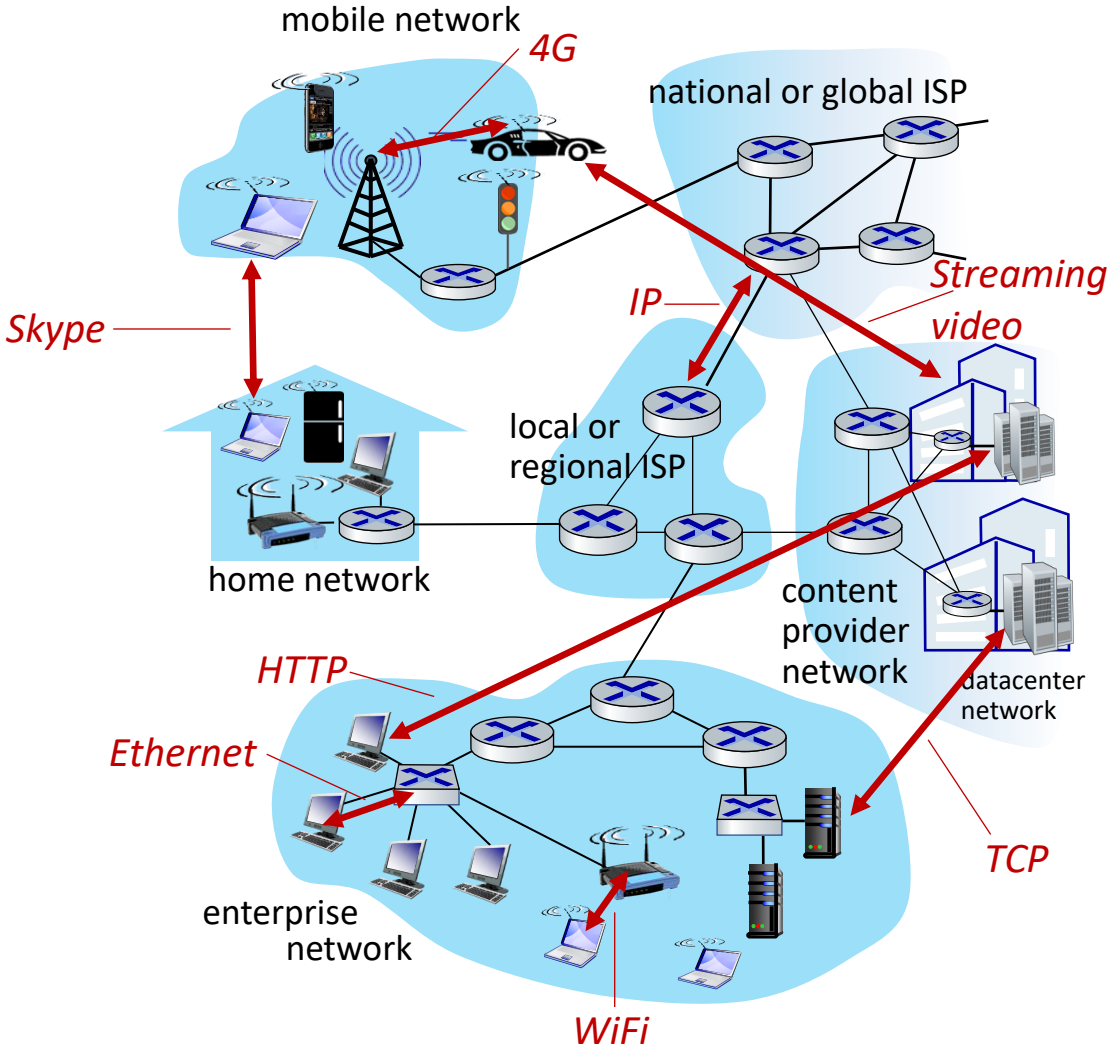
Networks

- collection of devices, routers, links: managed by an organization



The Internet: a "nuts and bolts" view

- *Internet:* "network of networks"
  - Interconnected ISPs
- *protocols* are *everywhere*
  - control sending, receiving of messages
  - e.g., HTTP (Web), streaming video, Skype, TCP, IP, WiFi, 4/5G, Ethernet
- *Internet standards*
  - RFC: Request for Comments
  - IETF: Internet Engineering Task Force



What's a protocol?

Human protocols:

- "what's the time?"
- "I have a question"
- introductions

Rules for:

… specific messages sent

… specific actions taken when message received, or other events

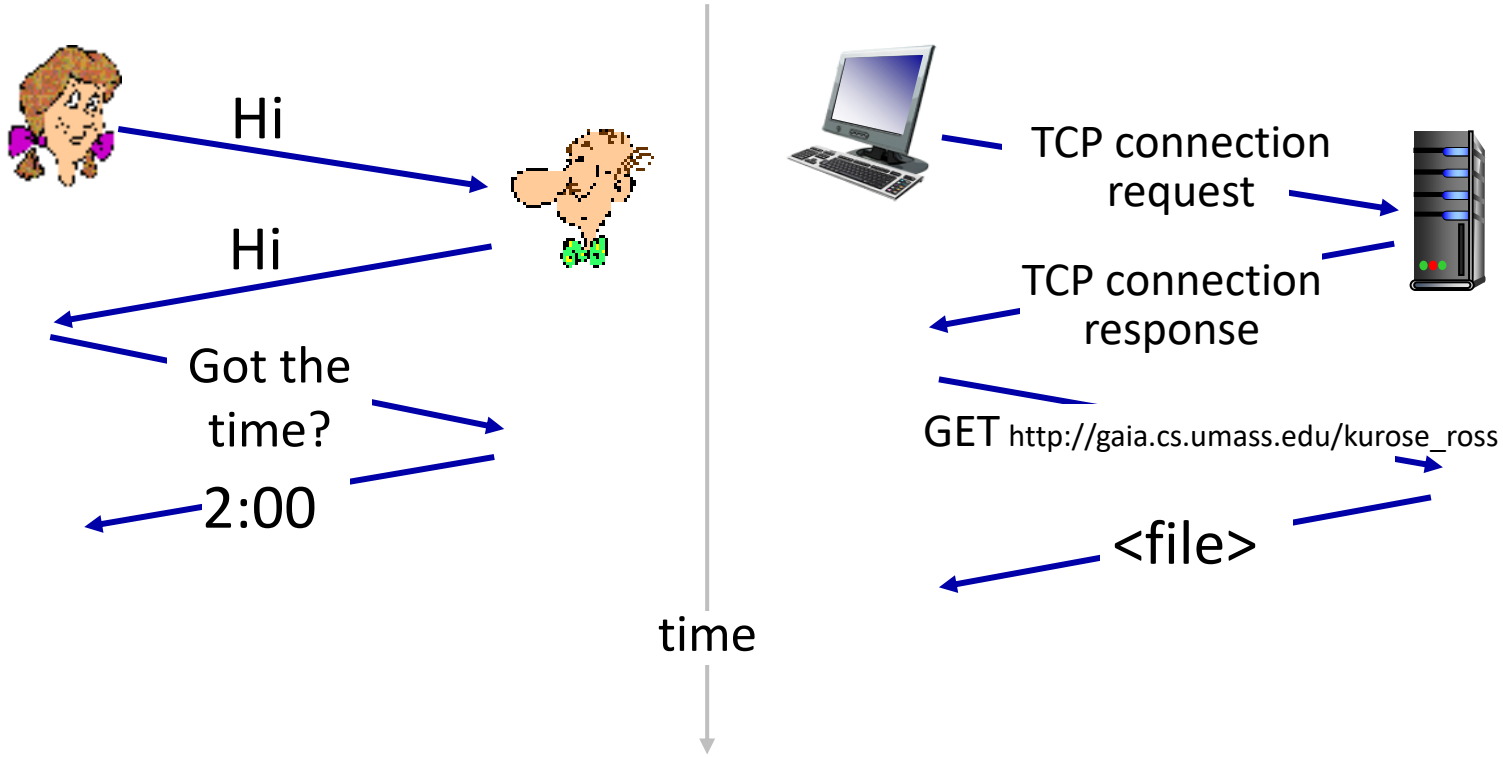
Network protocols:

- computers (devices) rather than humans
- all communication activity in Internet governed by protocols

Protocols define the format, order of messages sent and received among network entities, and actions taken on message transmission, receipt

What's a protocol?

A human protocol and a computer network protocol:



Q: other human protocols?

History of the Internet!

The roots of the internet

- The origins of the Internet are rooted in the USA of the 1950s.
  - The Cold War

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- Both superpowers were in possession of deadly nuclear weapons, and people lived in fear of long-range surprise attacks.
  - The US realized it needed a communications system that could not be affected by a Soviet nuclear attack.

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  - The Cold War
- Both superpowers were in possession of deadly nuclear weapons, and people lived in fear of long-range surprise attacks.
  - The US realized it needed a communications system that could not be affected by a Soviet nuclear attack.
- At this time, computers were large, expensive machines exclusively used by military scientists and university staff.

Elliott/NRDC 401 Computer MkI, c.1953
4 meters in length and weigh over a ton.

Supercomputers

- The first supercomputers were designed to simulate explosions, crack codes and consolidate surveillance data.
- They were difficult to use, unconnected to other machines, vulnerable to attack and accessible to only a few people.

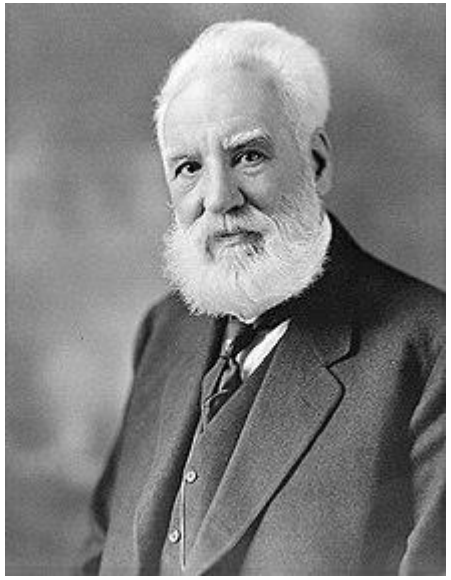
ARPA

- President Dwight D. Eisenhower formed the Advanced Research Projects Agency (ARPA) in 1958, bringing together some of the best scientific minds in the country.
  - In response to the Soviet launching of Sputnik 1 in 1957.
  - Their aim was to help American military technology stay ahead of its enemies.
    - Among ARPA's projects was a remit to test the feasibility of a large-scale computer network.
  - The name of the organization first changed from its founding name, ARPA, to DARPA, in March 1972

Origins of the Internet

History of the Telephone Network

- During the 1870's, two well known inventors both independently designed devices that could transmit sound along electrical cables. Those inventors were Alexander Graham Bell and Elisha Gray.



Alexander Graham Bell

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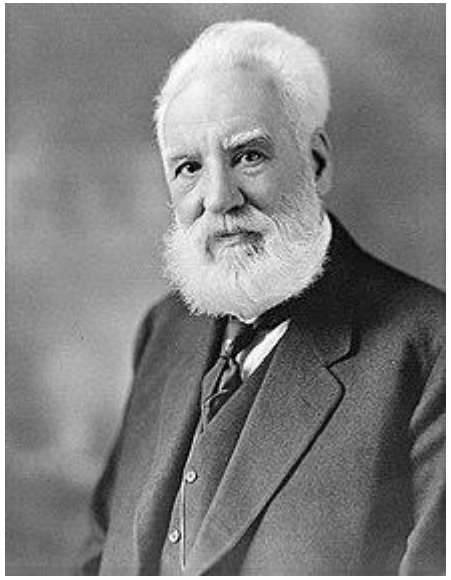
- 1878 - The workable exchange was developed, which enabled calls to be switched between subscribers rather than having direct lines.



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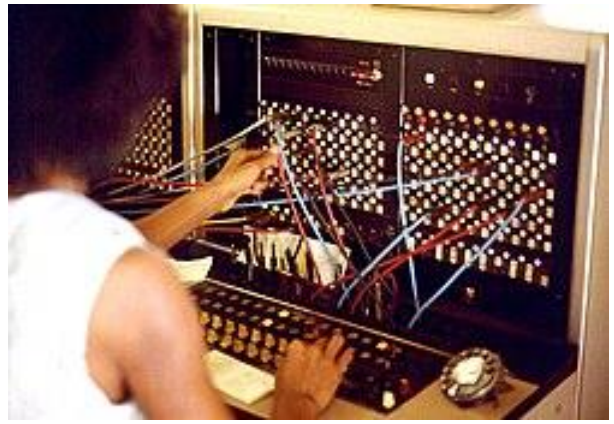

A telephone operator manually connecting calls with cord pairs at a telephone switchboard

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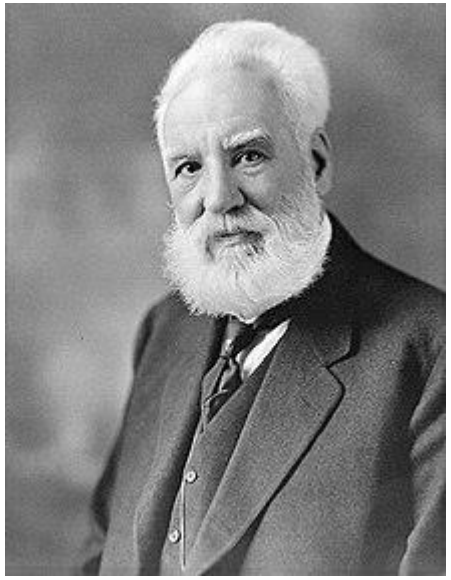

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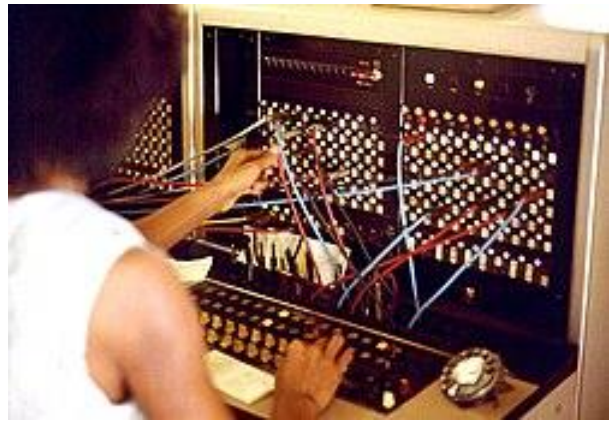

- 1879 - Subscribers began to be designated by numbers and not their names.

History of the Telephone

- 1891 - First automatic dialing system invented by a Kansas City undertaker.
  - He believed that crooked operators were sending his potential customers elsewhere. It was his aim to get rid of the operators altogether.

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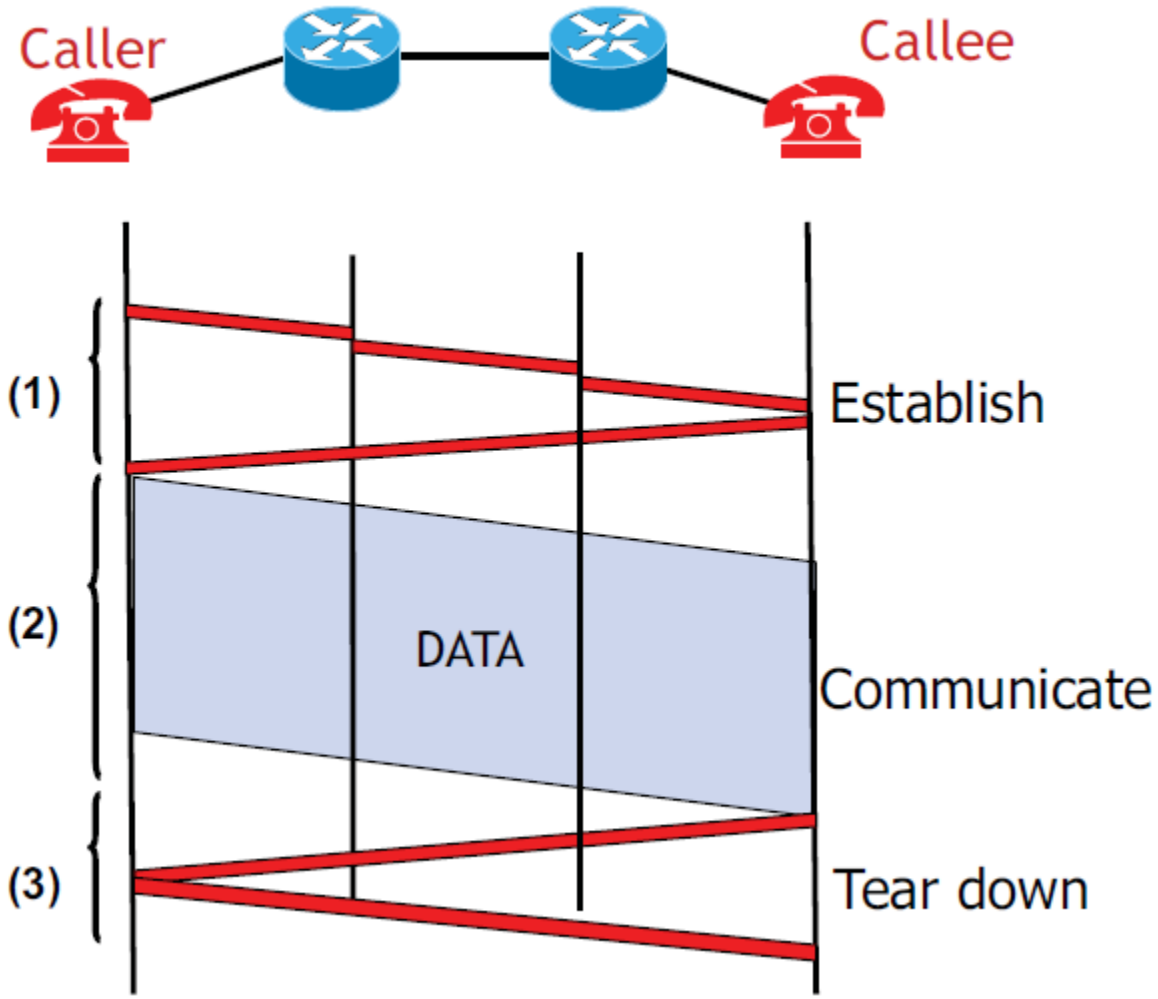
- 1918 - It was estimated that approximately ten million Bell system telephones were in service throughout the U.S.

- 1936 - Research into electronic telephone exchanges began and was eventually perfected in the 1960's with the electronic switching system (SES).

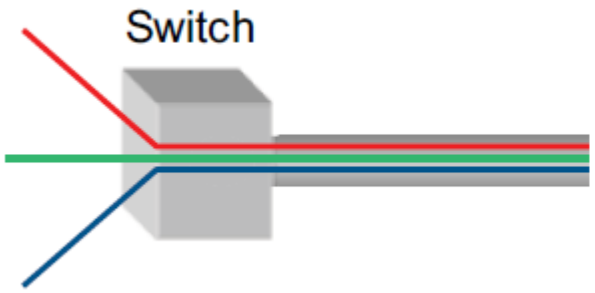
Circuit Switching

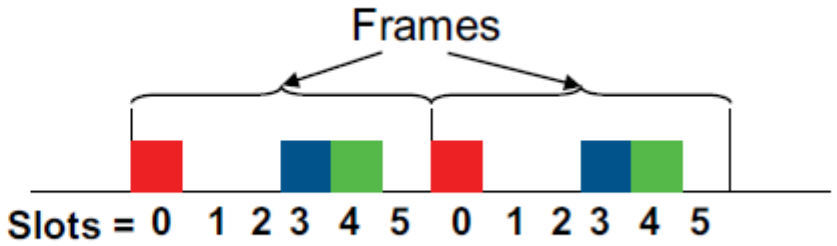
- First establish a circuit between endpoints
  - E.g., done when you dial a phone number
  - Message propagates from caller toward callee, establishing some state in each switch
- Then, ends send Communicate data ("talk") to each other
- After call, tear down (close) circuit
  - Remove state



Multiplexing/Demultiplexing

- One sharing technique: time-division multiplexing (TDM)
  - Time divided into frames and frames divided into slots
    - Number of slots = number of concurrent conversations
  - Relative slot position inside a frame determines which conversation the data belongs to
    - E.g., slot 0 belongs to the red conversation
    - Mapping established during setup, removed at tear down
  - Forwarding step at switch: consult table





Sharing the Network

- We have many application level communications, which we'll call "connections", that need to mapped onto a smaller number of links
- How should we share the links between all the connections?
- Two approaches possible:
  - Circuit switching (isochronous)
  - Packet switching (asynchronous)

The Dawn of Packet Switching

- ARPA: 1957, in response to Sputnik Paul Baran (RAND Corp)
  - Early 1960s: New approaches for survivable comms systems; "hot potato routing" and decentralized architecture, paper on packet switching over digital links

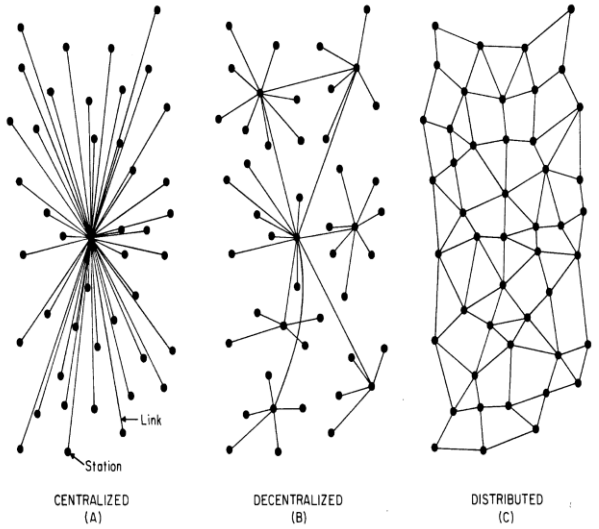
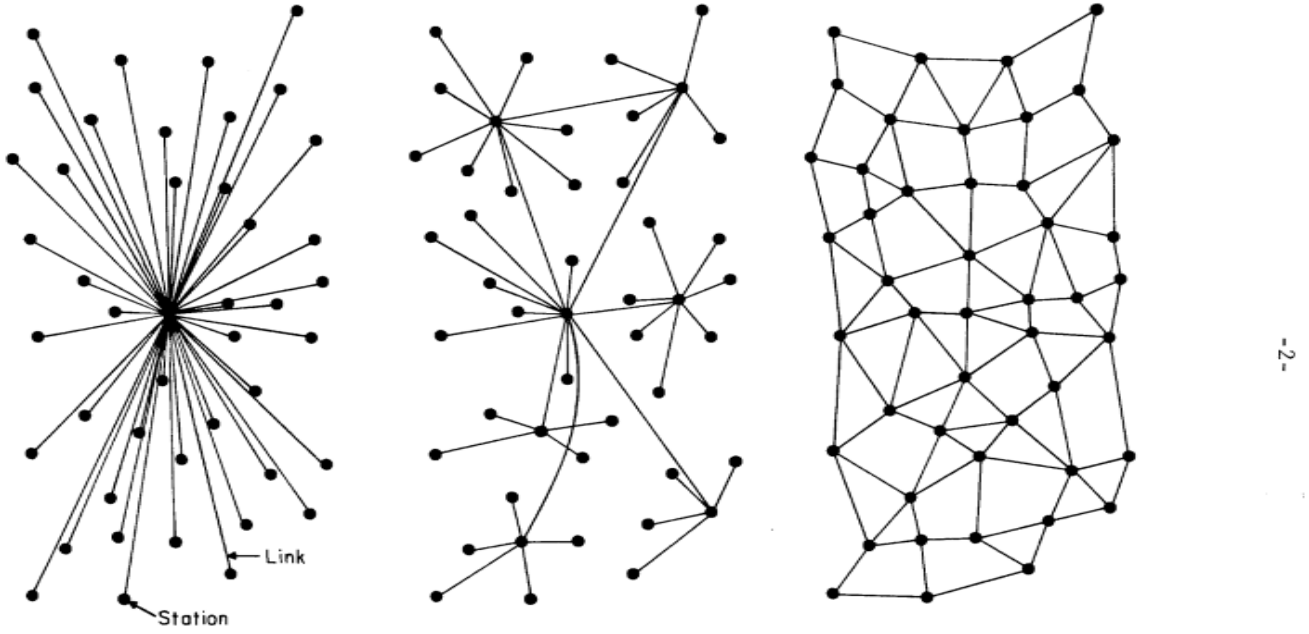


FIG. 1 – Centralized, Decentralized and Distributed Networks

Packet-Switched Networks



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On distributed communications: 1. Introduction to distributed communications network. RAND Memorandum, August 1964.

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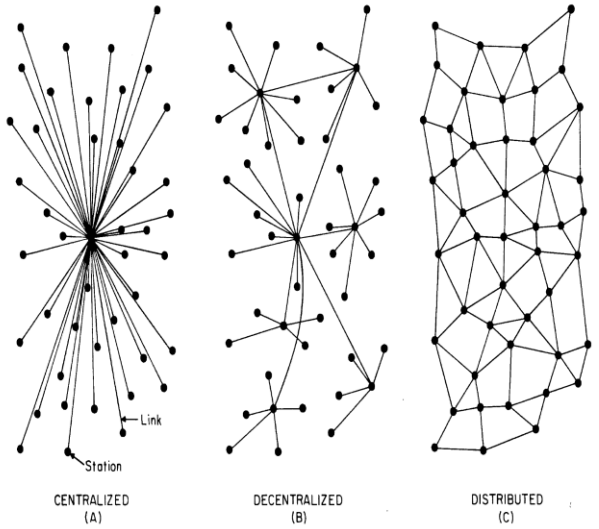

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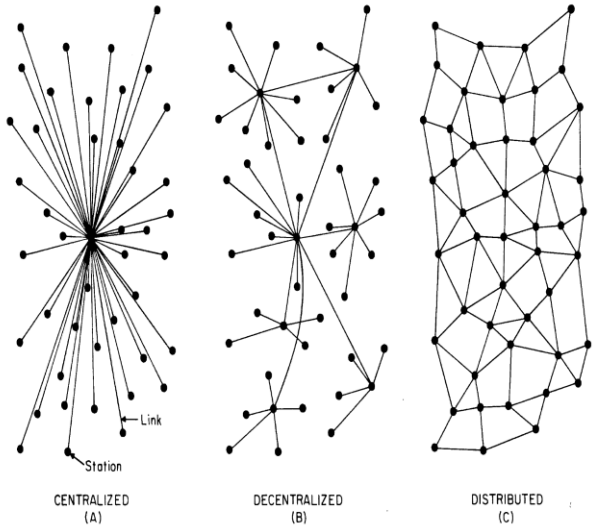

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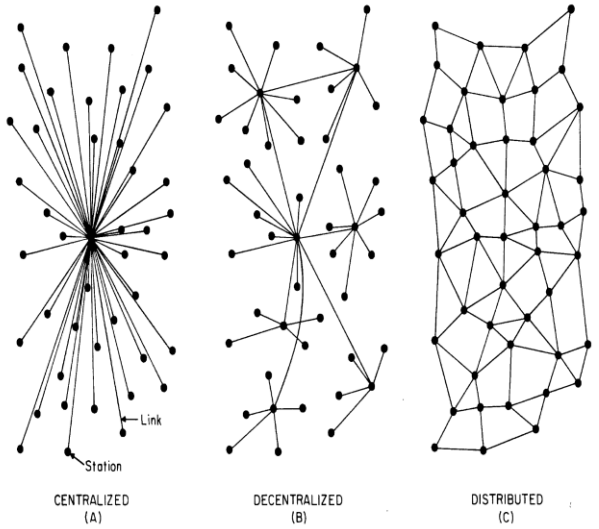

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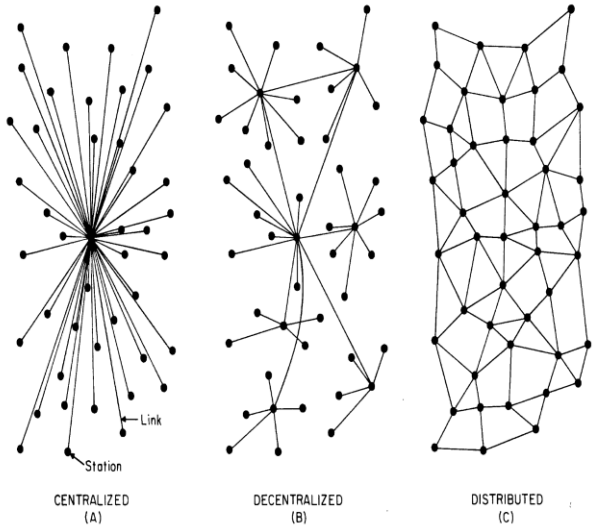
- L. Roberts (MIT then ARPA), first ARPANET plan for time-sharing remote computers



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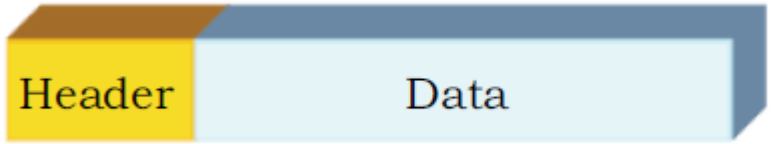
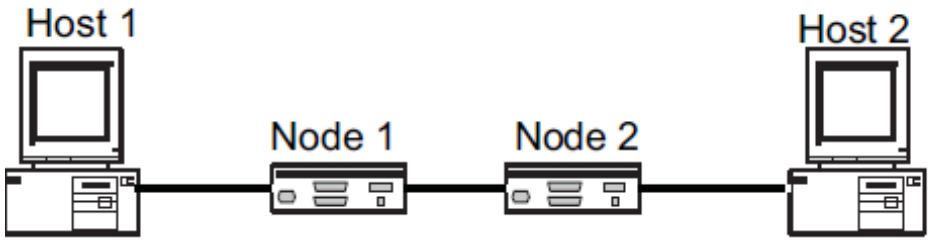


- Used in the Internet
- Data is sent in packets (header contains control info, e.g., source and destination addresses)



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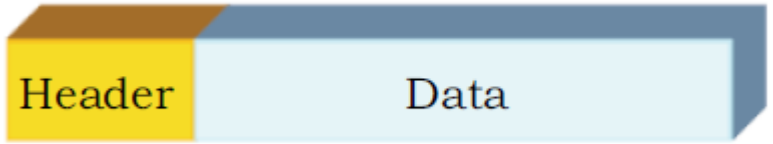

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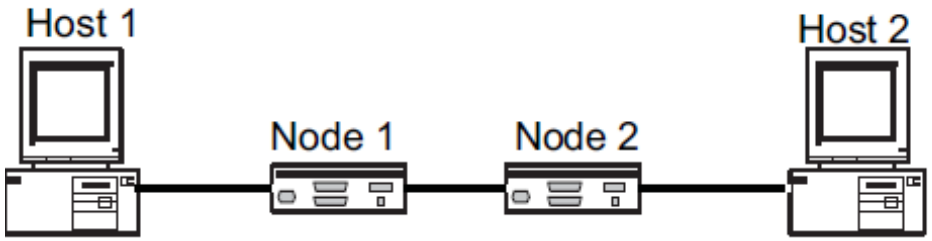
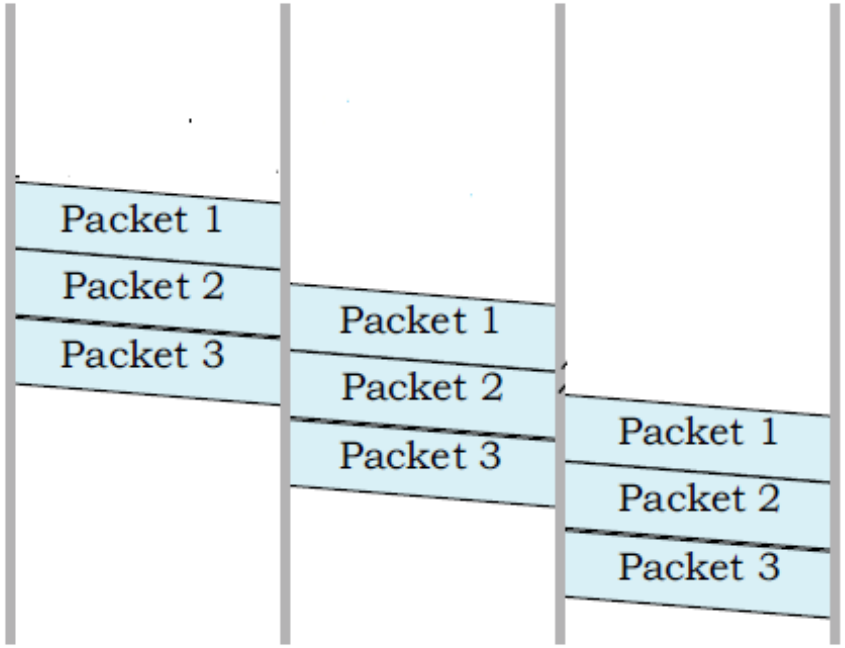
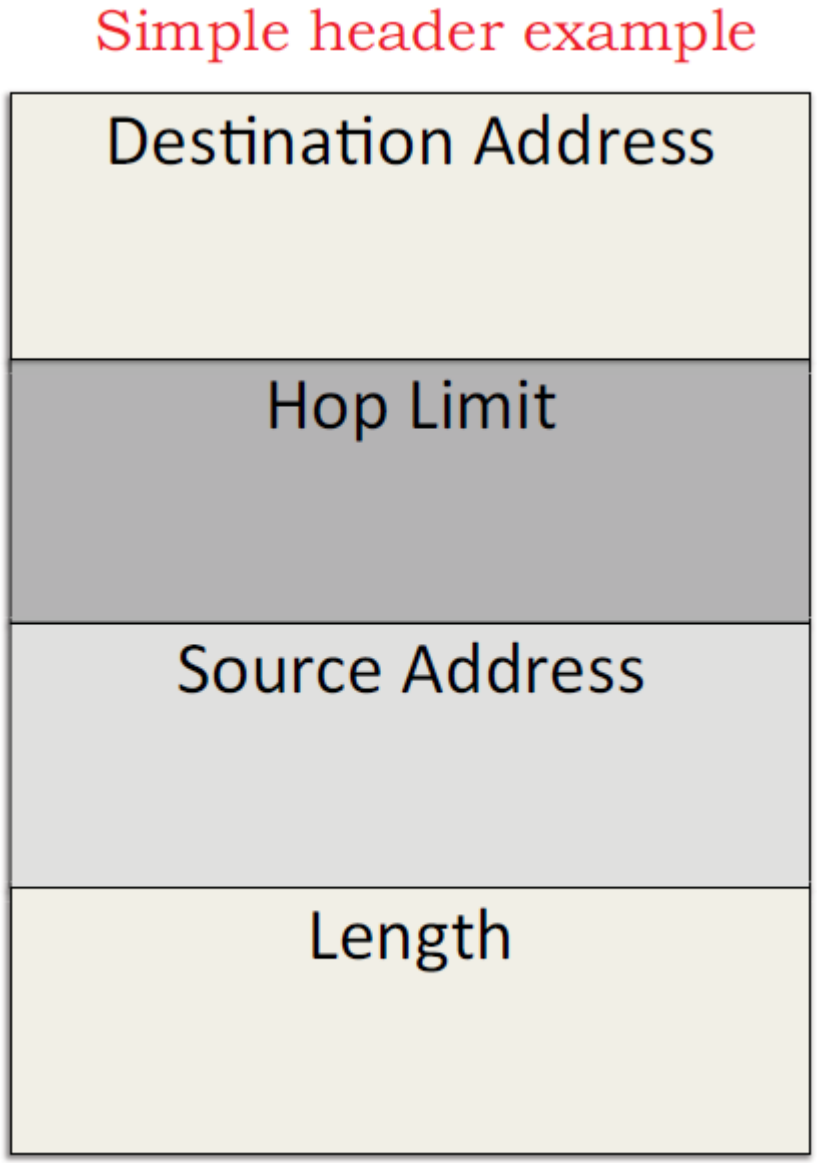


- Per packet forwarding
- At each node the entire packet is received, stored, and then forwarded (store-and-forward networks)
  - No capacity is allocated



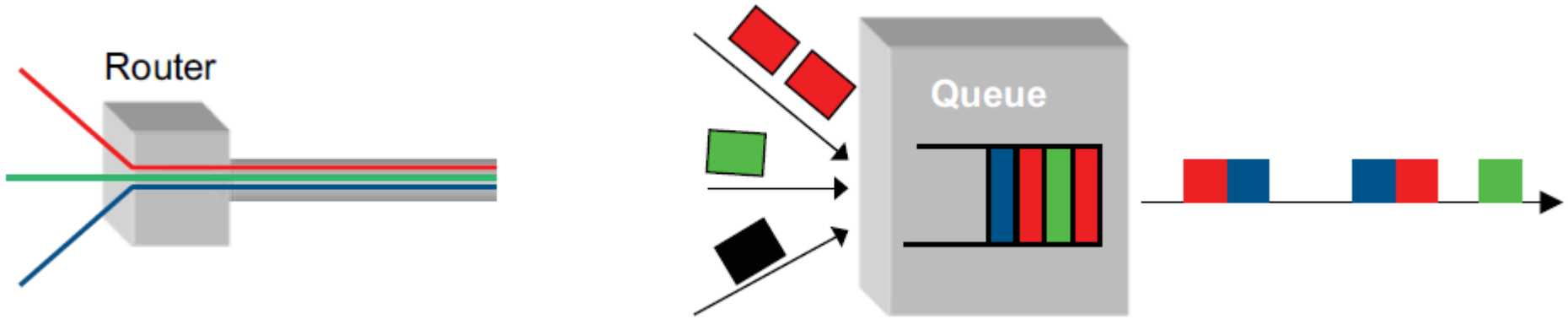
Packet Switching

- Simple packet header



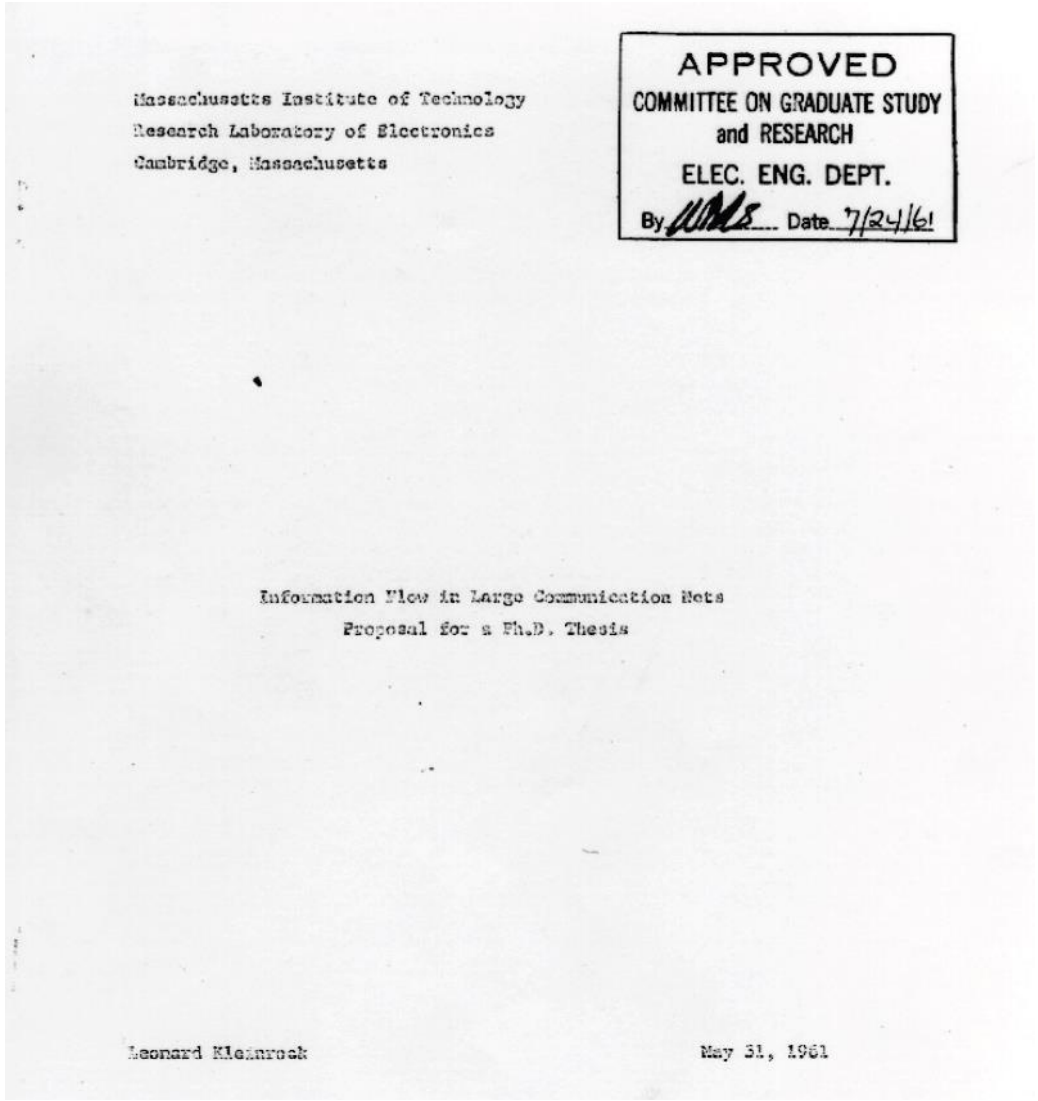
Packet Switching: Multiplexing/Demultiplexing

- Router has a routing table that contains information about which link to use to reach a destination
- For each link, packets are maintained in a queue
  - If queue is full, packets will be dropped
- Demultiplex using information in packet header – Header has destination



Leonard Kleinrock's Ph.D. Thesis

- Leonard Kleinrock at MIT published the first paper on packet switching theory in July 1961



Massachusetts Institute of Technology
Research Laboratory of Electronics
Cambridge, Massachusetts

APPROVED
COMMITTEE ON GRADUATE STUDY
and RESEARCH
ELEC. ENG. DEPT.
By LMS Date 7/24/61

Information Flow in Large Communication Nets
Proposal for a Ph.D. Thesis

Leonard Kleinrock

May 31, 1961

Leonard Kleinrock's Ph.D. Thesis

A number of interesting and important questions can be asked about this system, and it is the purpose of this research to investigate the answers to some of these questions. A partial list of such questions might be as follows:

(1) What is the probability density distribution for the total time lapse between the initiation and reception of a message between any two nodes? In particular, what is the expected value of this distribution?

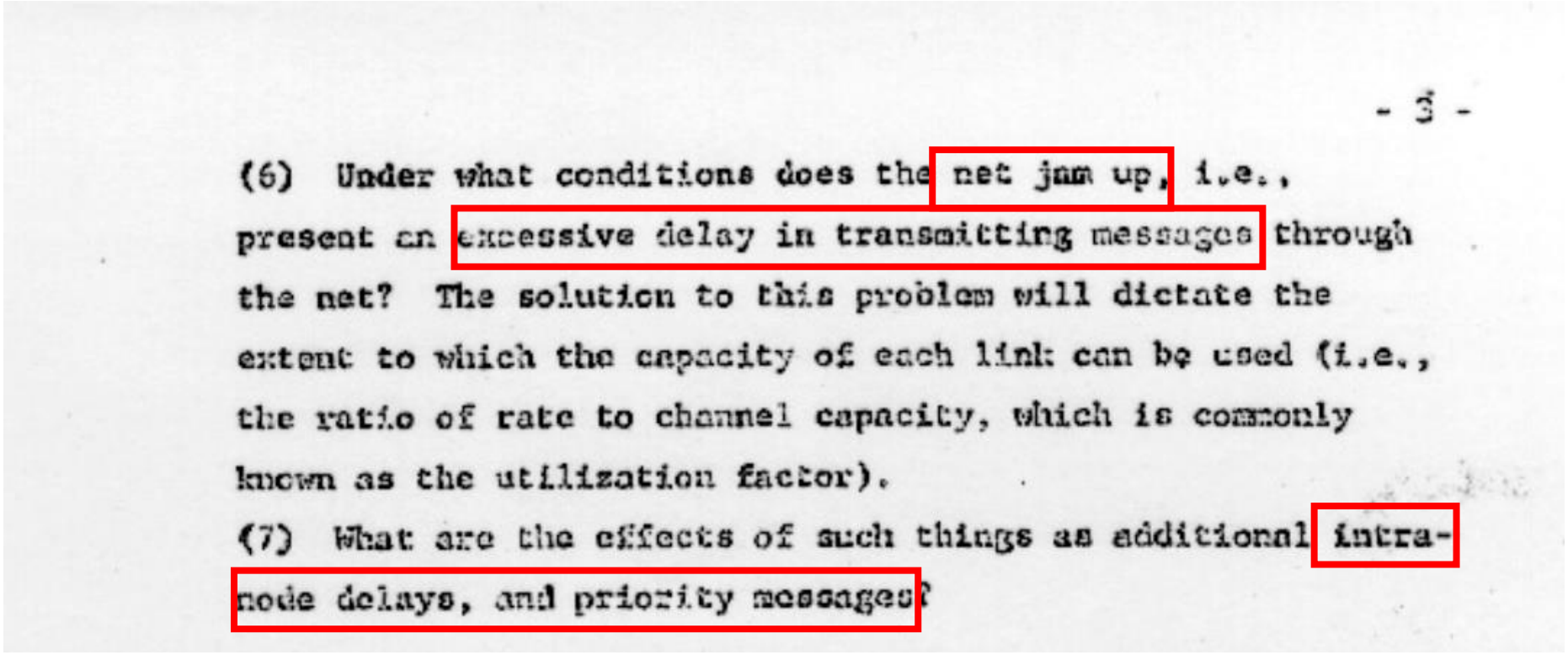
(2) Can one discuss the effective channel capacity between any two nodes?

(3) Is it possible to predict the transient behavior and recovery time of the net under sudden changes in the traffic statistics?

(4) How large should the storage capacity be at each node?

(5) In what way does one arrive at a routing doctrine for incoming messages in different nets? In fact, can one state some bounds on the optimum performance of the net, independent of the routing doctrine (under some constraint on the set of allowable doctrines)?

Leonard Kleinrock's Ph.D. Thesis



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(6) Under what conditions does the net jam up, i.e., present an excessive delay in transmitting messages through the net? The solution to this problem will dictate the extent to which the capacity of each link can be used (i.e., the ratio of rate to channel capacity, which is commonly known as the utilization factor).

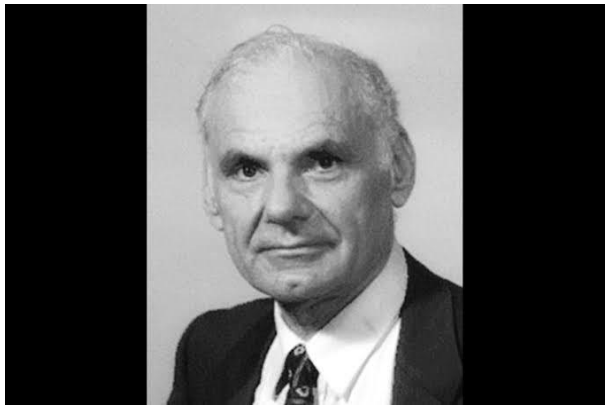
(7) What are the effects of such things as additional intra-node delays, and priority messages?

Circuit v. Packet Switching

Circuit switching	Packet Switching
Guaranteed rate	No guarantees (best effort)
Link capacity wasted if data is bursty	More efficient
Before sending data establishes a path	Send data immediately
All data in a single flow follow one path	Different packets might follow different paths
No reordering; constant delay; no dropped packets	Packets may be reordered, delayed, or dropped

Kleinrock and Roberts

- Kleinrock convinced Roberts of the theoretical feasibility of communications using packets rather than circuits
  - a major step along the path towards computer networking.



Lawrence Roberts

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Kleinrock and Roberts

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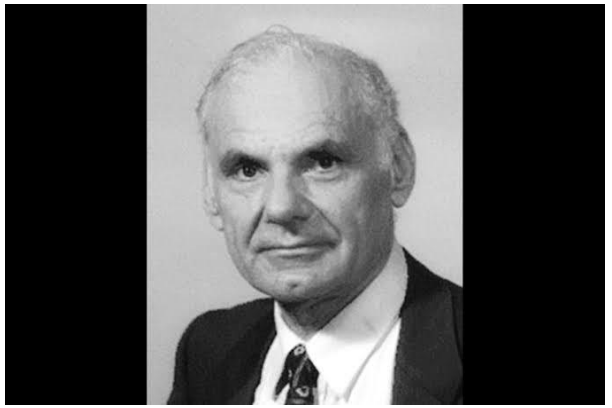
- In late 1966 Roberts went to DARPA to develop the computer network concept and quickly put together his plan for the **"ARPANET",** publishing it in 1967.



Lawrence Roberts

Leonard Kleinrock

A Brief History

- In August 1968, an RFQ was released by DARPA for the packet switches called Interface Message Processors (IMP's).
  - The RFQ was won by BBN.

Leonard Kleinrock poses beside the first Interface Message Processor (IMP) in the lab where the first internet message was sent, at the University of California Los Angeles

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  - The RFQ was won by BBN.
- In September 1969, due to Kleinrock's early development of packet switching theory, his Network Measurement Center at UCLA was selected to be the first node on the ARPANET.
  - Stanford Research Institute (SRI) provided a second node.

In the Beginning…

- Kleinrock's group at UCLA tried to log on to SRI computer:

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- His recollection of the event…
  - "We set up a telephone connection between us and the guys at SRI...

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    - "Do you see the L?"
    - "Yes, we see the L," came the response

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    - "Do you see the O?"
    - "Yes, we see the O."

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    - "Yes, we see the L," came the response
  - We typed the O, and we asked…
    - "Do you see the O?"
    - "Yes, we see the O."
  - Then we typed the G…
    - …and the system crashed!

A Brief History

- In August 1968, an RFQ was released by DARPA for the packet switches called Interface Message Processors (IMP's).
  - The RFQ was won by BBN.
- In September 1969, due to Kleinrock's early development of packet switching theory, his Network Measurement Center at UCLA was selected to be the first node on the ARPANET.
  - Stanford Research Institute (SRI) provided a second node.
- One month later, when SRI was connected to the ARPANET, the first host-to-host message was sent from Kleinrock's laboratory to SRI.
  - Two more nodes were added at UC Santa Barbara and University of Utah.

A Brief History

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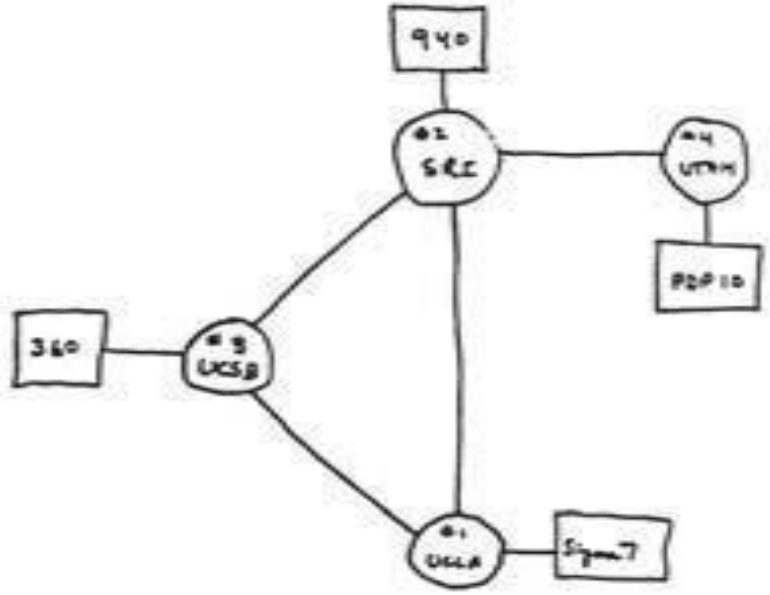

FIGURE 6.2 Drawing of 4 Node Network (Courtesy of Alex McKenzie)

A Brief History

- In Augu… acket switche…
  - The R…
- In Septe… t of packet switchi… CLA was selecte…
  - Stanfo…
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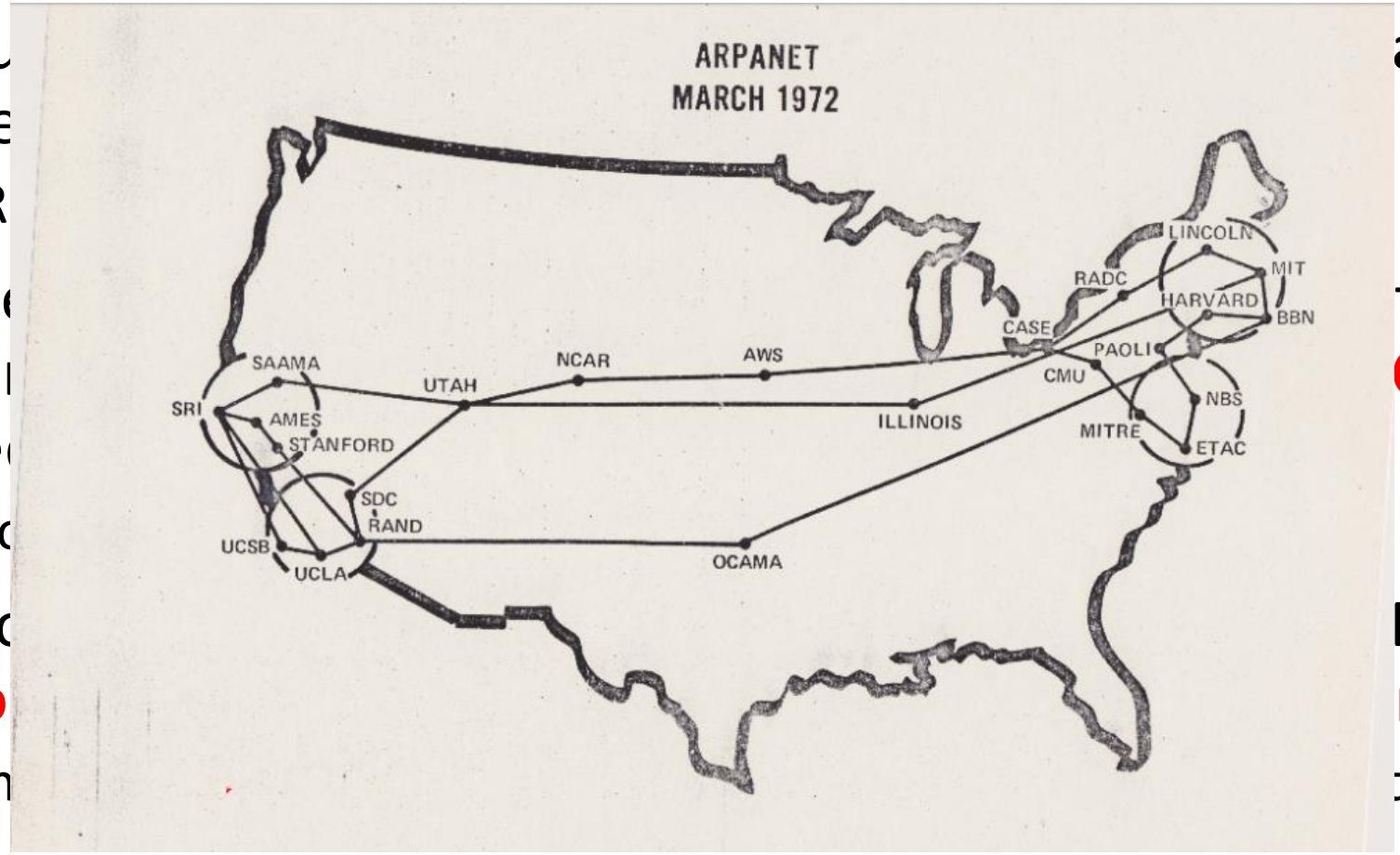

A Brief History

- In December 1970 the Network Working Group (NWG) working under S. Crocker finished the initial ARPANET Host-to-Host protocol, called the Network Control Protocol (NCP).
  - *Protocols define the format, order of messages sent and received among network entities, and actions taken on message transmission, receipt*

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- NCP provided connections and flow control between processes running on different ARPANET host computers.
  - Application services, such as remote login and file transfer, would be built on top of NCP, using it to handle connections to other host computers.

A Brief History

- In October 1972, Kahn organized a large, very successful demonstration of the ARPANET at the International Computer Communication Conference (ICCC).
  - This was the first public demonstration of this new network technology to the public.

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  - This was the first public demonstration of this new network technology to the public.
- It was also in 1972 that the initial "hot" application, electronic mail, was introduced.
  - In March Ray Tomlinson at BBN wrote the basic email message send and read software, motivated by the need of the ARPANET developers for an easy coordination mechanism.