History of the Internet

What are some pre-Internet communication technologies?

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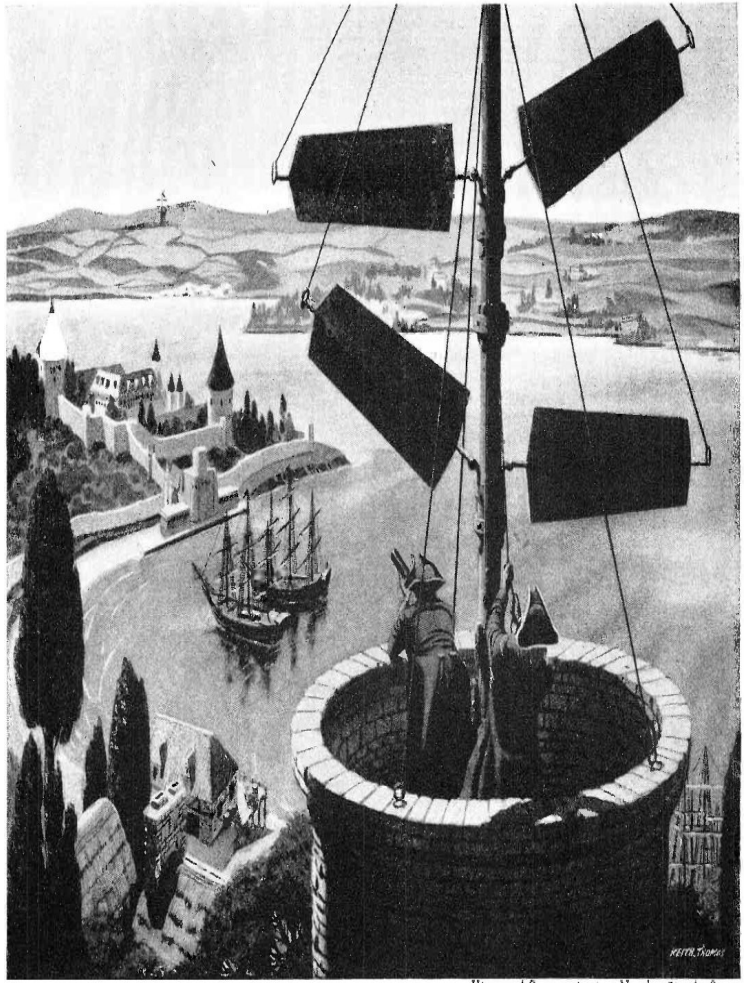
Optical Semaphores

- Basic idea: Use visual indications of letters to signal next tower.
- Claude Chappe (France, 1792): Built 556 of these stations across France for communicating about war effort.
- First Message:“Si vous réussissez, vous serez bientôt couverts de gloire” (If you succeed, you will soon bask in glory) – 16km
- “Mechanical Internet”

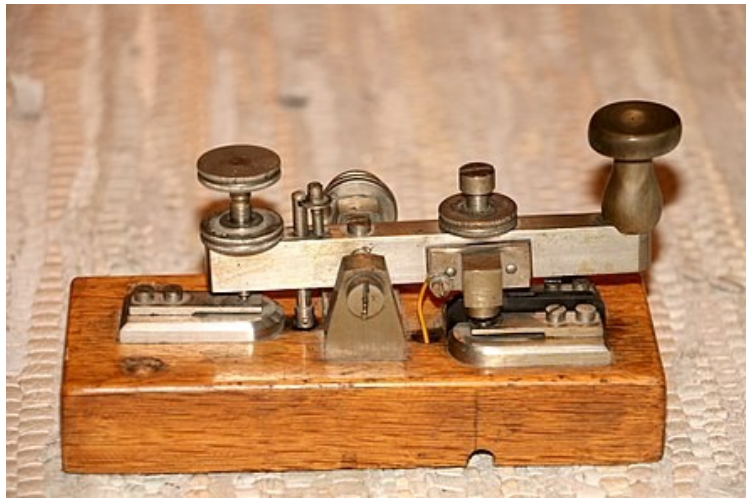


Telegraph

- Robust work in trying to use electricity to transmit information instead.
- Many problems: Didn’t have consistent generators so coding was hard; some solutions used a wire for each letter.
- Eventually Gauss developed working system: Positive signal would move needle one way, negative another then alphabet

Telegraph

- Samuel Morse changes this to have the signal move a pen, creating a mark.
- Morse first message: was in 1838
  - 3 miles in New Jersey
- More famously sent "WHAT HATH GOD WROUGHT?“ 44 miles between DC and Baltimore
- Core innovation: Relays at frequent intervals that send a message through ten miles (16 km) of wire.



Telephone

- Basic problem: How to modulate voice onto electrical signals
- Reis (1861 Germany): "Das Pferd frisst keinen Gurkensalat" (The horse does not eat cucumber salad). Speech issues.
- Elisha Gray (1876) patents first method for encoding.
- Bell (1876) makes first call: "Mr. Watson, come here, I want to see you.“

Circuit-Switching

- In January 1878, the first telephone switch went into operation in New Haven Connecticut
- Establish a complete circuit every time there's a communication
- Still the case in cellular!
  - Circuit is established to "packet gateway"

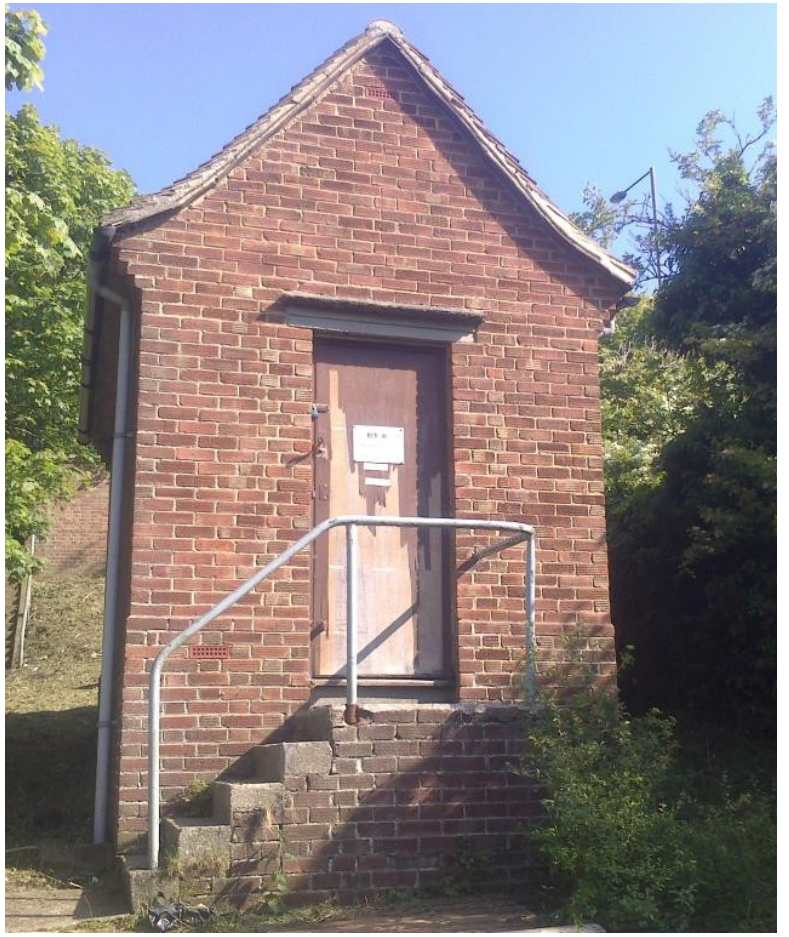
Issues w/ Circuit Switching

- ?

Issues w/ Circuit Switching

- Large setup cost
  - Switching costs all along circuit
- Contention
  - Only X links, what if X+1 want to use?
- Inefficient
  - Circuit established even if not in use
- Fragile
  - Intermediary links go down circuit is broken

USAF wanted their networks to survive nuclear strikes… circuits would not.



Pre-internet: Packetization

The solution focused on three big ideas:

1. Use decentralized network with multiple paths between any two points
2. Divide user messages into message blocks, later called **packets**
3. Deliver these messages by store and forward switching.

Pre-Internet: Why Packetization?

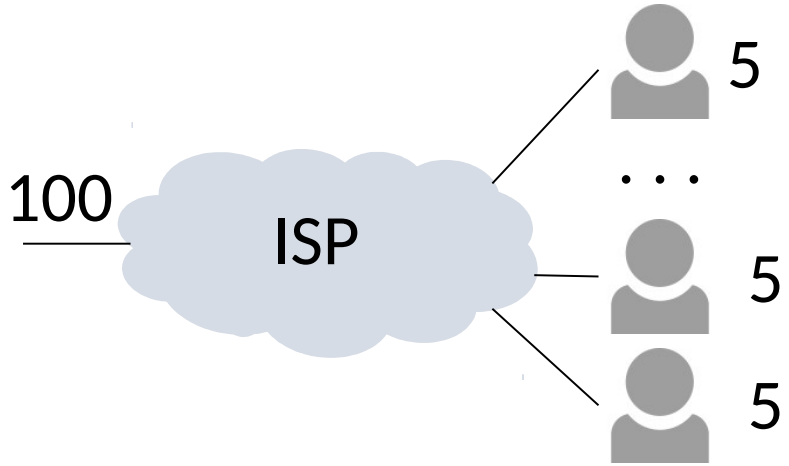
- Efficiency
  - Lines only used when trafficked
- Handles contention
  - Queue packets
- Robust
  - Routes can change
- Kleinrock (UCLA, 1969)
  - UCLA -> SRI
  - “Lo” – Was supposed to be “LOGIN” but crashed

Efficiency: Statistical Multiplexing

- Sharing of network bandwidth between users according to the statistics of their demand
  - (Multiplexing basically means sharing)
  - Useful if:
    - users are mostly idle and/or
    - traffic is bursty
- Key question:
  - How much does it help?

Efficiency: Statistical Multiplexing (2)

- Example: Users in an ISP network
  - Network has 100 Mbps (units of bandwidth)
  - Each user subscribes to 5 Mbps, for videos
  - But a user is active only 50% of the time …



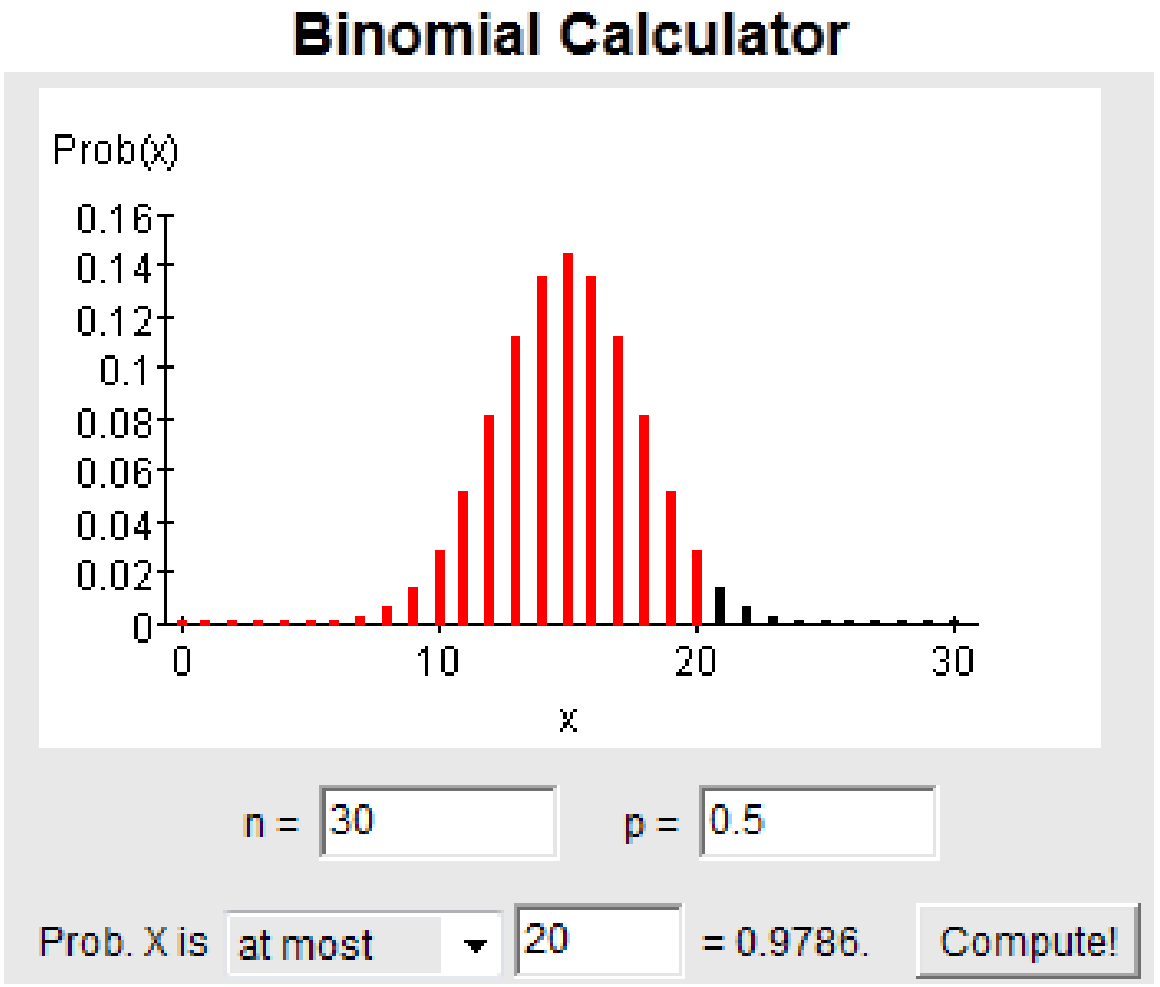
- How many users can the ISP support?
  - With dedicated bandwidth for each user:
  - Probability all bandwidth is used: (assuming independent users)

Efficiency: Statistical Multiplexing (3)

- With 30 independent users, still unlikely (2% chance) to need more than 100 Mbps!
  - Binomial probabilities

→Can serve more users with the same size network

- Statistical multiplexing gain is 30/20 or 1.5X
- But may get unlucky; users will have degraded service



Pre-Internet: Networks

Started building individual packet networks at different institutions:

- Octopus Network
  - 4 Machines at the Lawrence Livermore National Lab
- ALOHAnet
  - Wireless packets at University of Hawaii
- CYCLADES
  - French network exploring network responsibilities
- ARPANET
  - First packet network, a few universities online

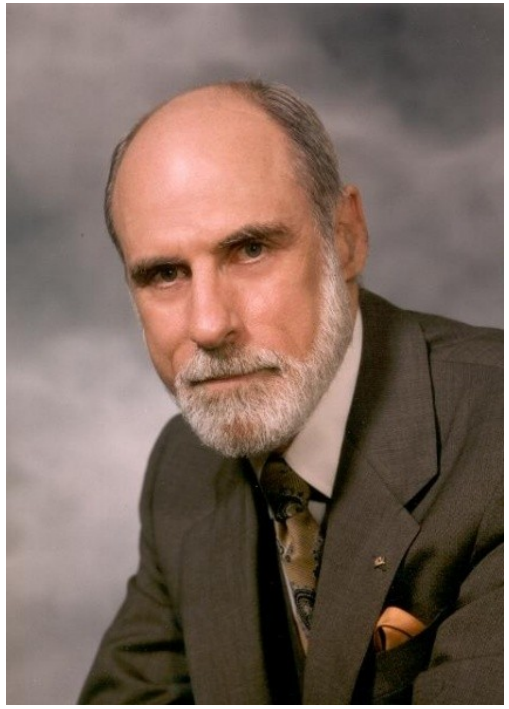
The Beginning – ARPANET

- ARPANET by U.S. DoD was the precursor to the Internet
  - Motivated for resource sharing
  - Launched with 4 nodes in 1969, grew to hundreds
  - First “killer app” was email

ARPANET

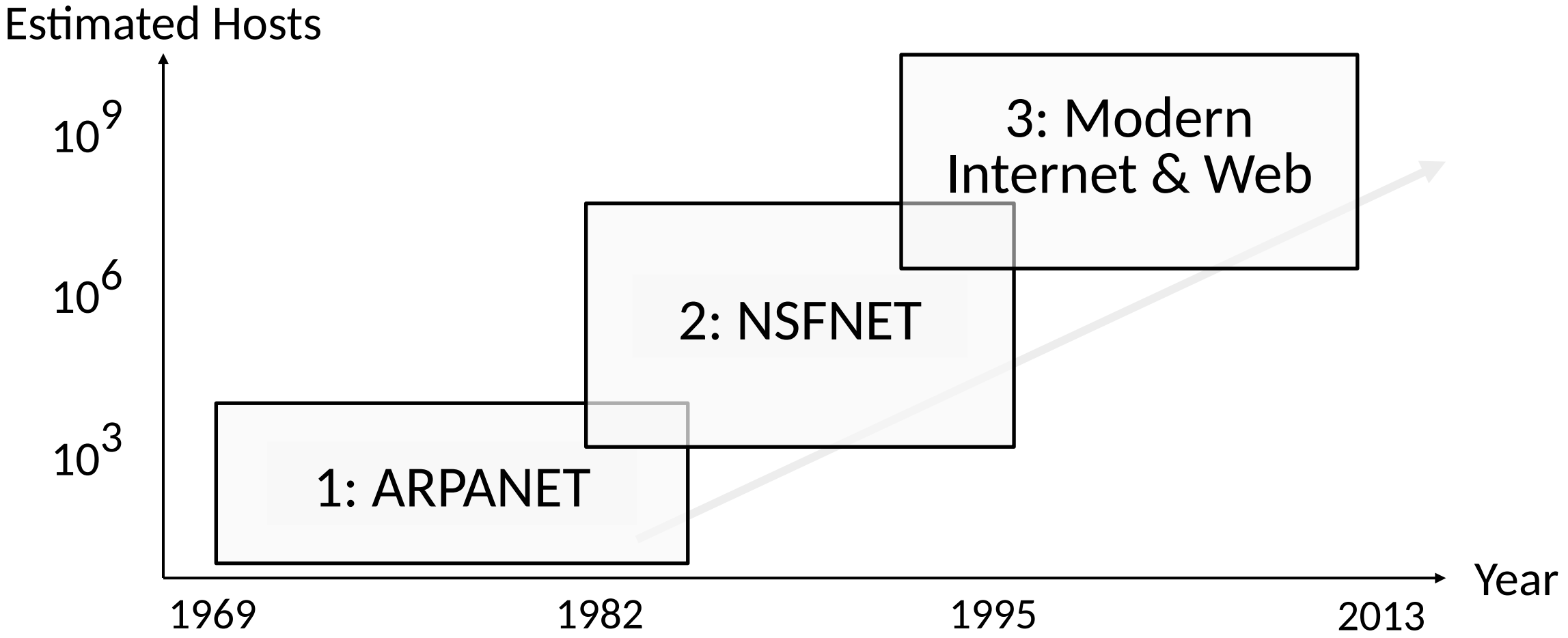
- In the early ARPANET
  - Internetworking became the basis for the Internet
  - Pioneered by Cerf & Kahn in 1974, later became TCP/IP
  - They are popularly known as the “fathers of the Internet”

Vint Cerf

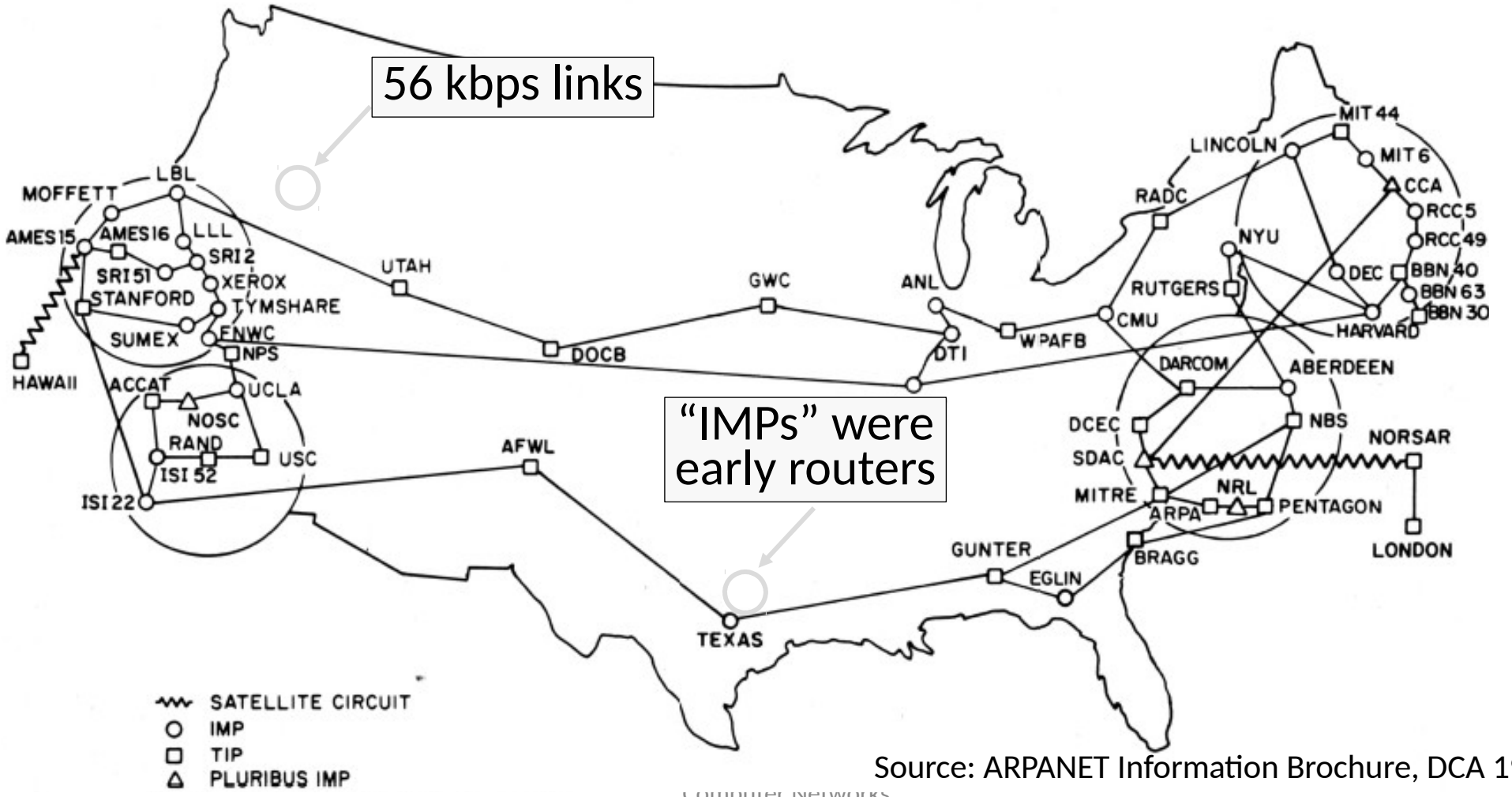


Bob Kahn

Rough Internet Timeline



ARPANET Geographical Map (Dec. 1978)

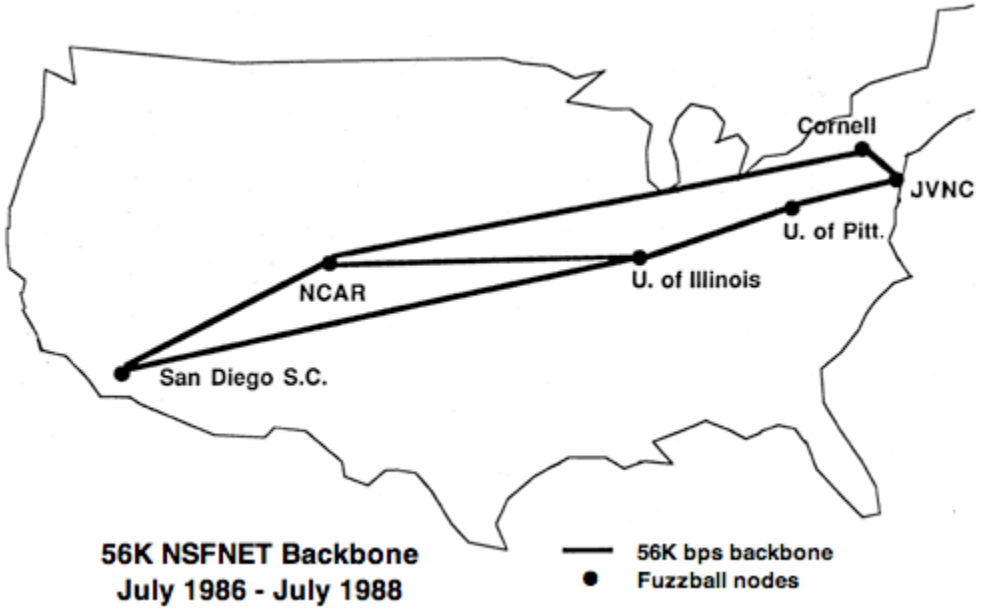


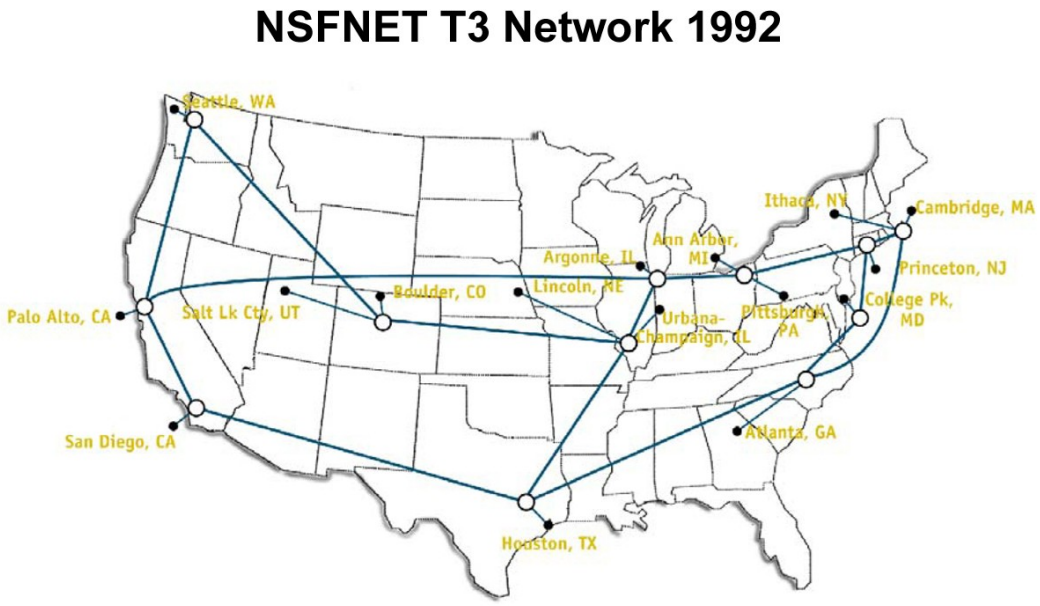
Source: ARPANET Information Brochure, DCA 1979

Growing Up – NSFNET

- NSFNET ’85 supports educational networks
  - Initially connected supercomputers, but became the backbone for all networks
- Classic Internet protocols we use emerged
  - TCP/IP (transport), DNS (naming), Berkeley sockets (API) ’83, BGP (routing) ’93
- Much growth from PCs and Ethernet LANs
  - Campuses, businesses, then homes
  - 1 million hosts by 1993 …

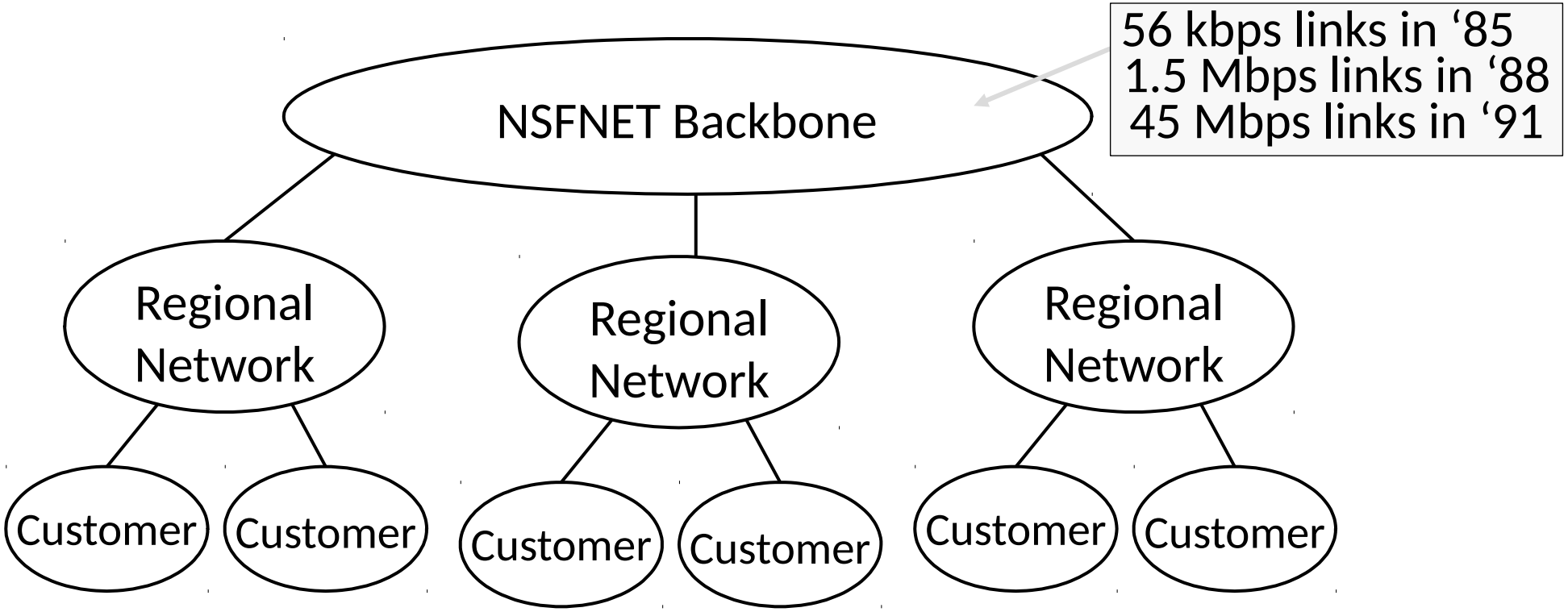
Growing Up- NSFNET





Early Internet Architecture

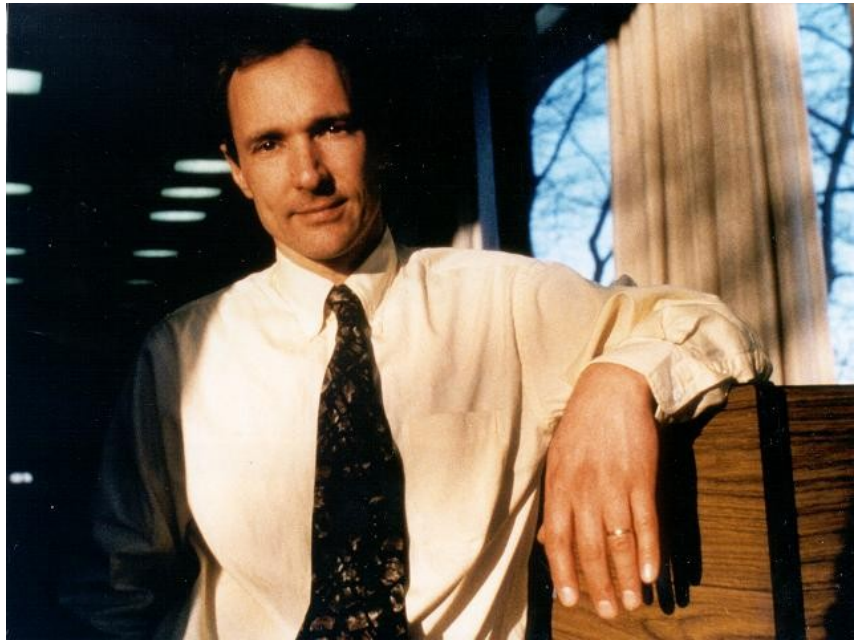
- Hierarchical, with NSFNET as the backbone



Modern Internet – Birth of the Web

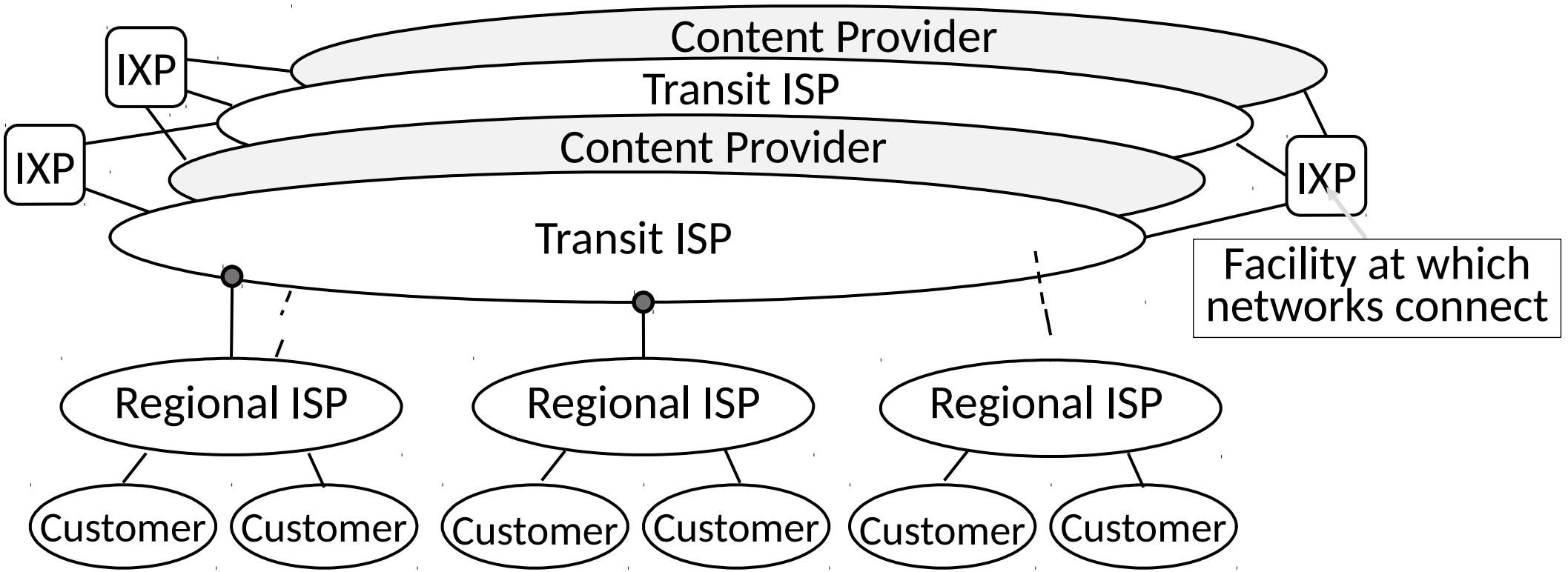
- After ’95, connectivity is provided by large ISPs who are competitors
  - They connect at Internet eXchange Point (IXP) facilities
  - Later, large content providers connect
- Web bursts on the scene in ’93
  - Key idea: Hyperlink
  - Growth leads to CDNs, ICANN in ‘98
  - Most bits are video (soon wireless)
  - Content is driving the Internet

Tim Berners-Lee



Modern Internet Architecture

- Complex business arrangements affect connectivity
  - Still decentralized, other than registering identifiers



Modern Internet Architecture (2)

Major Transit ISPs:

- Level 3 (200,000mi of fiber)
- Century Link (550,000mi)
- ATT (410,000mi)
- Verizon (500,000mi)

Major Regional ISPs

- Dakotanet
- Dixienet
- Local telecoms (e.g., MTA)
- US West