Aalto University

History of the Internet

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Agenda

- Prehistory of the Internet
- History of the Internet-first decade
- Growth and development of the Internet

Prehistory of the Internet

- Nicola Tesla (1908)
  - "It will be possible for a business man in New York to dictate instructions, and have them instantly appear in type at his office in London or elsewhere. He will be able to call up, from his desk, and talk to any telephone subscriber on the globe. . . An inexpensive instrument, not bigger than a watch, will enable its bearer to hear anywhere, on sea or land, music or song, the speech of a political leader, the address of an eminent man of science, or the sermon of an eloquent clergyman, delivered in some other place, however distant. In the same manner any picture, character, drawing, or print can be transferred from one to another place.[1]"
- Heinrich Hertz (created radio waves)
  - "I do not think that the wireless waves I have discovered will have any practical application."
- President Rutherford B. Hayes (to Alexander Graham Bell in 1876 on viewing the telephone for the first time)
  - "That's an amazing invention, but who would ever want to use one of them?"
- Thomas Watson, chairman of IBM, 1943
  - "I think there is a world market for maybe five computers."
- Ken Olson, president, chairman, and founder of Digital Equipment Corp., 1977
  - "There is no reason anyone would want a computer in their home."

[1] W. W. Massie and C. R. Underhill, "The Future of the Wireless Art," Wireless Telegraphy and Telephony, 1908, pp. 67–71.

History of the Internet

- Research thread;
  - Leonard Kleinrock;
  - Paul Baran;
  - Donald Davies;
- ARPA (Advanced Research Project Agency) thread;
  - J. C. R. Licklider;
  - Ivan Sutherland;
  - Larry Roberts;
  - Robert Taylor;
- The ARPA launch
- The first decade: 4 nodes and then the world

Research thread

- Need: to understand and design general-purpose data communication networks that could handle bursty data traffic;
- Emerging approach: based on resource sharing in timeshared systems;
- Existing special-purpose network: the store-and-forward telegraph network showed it can be done;
- Theory support: a body of queuing theory looked promising.

Leonard Kleinrock

- January 1957, began as a graduate student in Electrical Engineering at Massachusetts Institute of Technology (MIT).
- 1959, launched his research thread as he sought to design a new kind of network to support the bursty nature of data communications.
- May 1961, submitted his MIT Ph.D. thesis proposal entitled “Information Flow in Large Communication Nets”.
- December 1962, completed his Ph.D. dissertation, created a mathematical theory of packet switching for dynamic resource sharing, thus providing the fundamental underpinnings for ARPANET technology.
- 1963, joined the UCLA faculty.

Paul Baran

- From RAND Corporation, working on military command and control systems during the early 1960s with the goal of using redundancy and digital technology to design a robust multilateral military communications network.
- In September 1962, published a paper on how “hot potato” adaptive alternate routing procedures and distributed principles could utilize a “standard message block,” also to fall under the “packet” umbrella.[1]
- In 1964, attempted to get AT&T to implement the design, failed to convicne them.
- In 1965, approached to the Air Force to implement it, without success.
- Then decided not to pursue the implementation anymore.

Donald Davies

- From the National Physical Laboratory (NPL) in the United Kingdom.
- 1965, began thinking about packet networks in 1965 and coined the term “packet” that year.
- June 1966, he described his design for a data network and used some of the earlier theory from Kleinrock to calculate its performance.
- March 1967, recommended the use of his technology for the design of a public switched data network.
- 1970, the U.K. Department of Trade and Industry only authorized the implementation of one node, and became operational.

Comparison

- Different focus:
  - Baran and Davies focused on the engineering and architectural issues of the network design.
  - Kleinrock emphasized and provided the mathematical underpinnings and supporting simulation experiments of the network analysis and design, which showed the feasibility of packet networks.

- Different trajectory:
  - Baran's unsuccessful attempts to get his ideas implemented.
  - Davies' frustration by the foot-dragging of the U.K. government.
  - The ARPA thread rolled out and adopted Kleinrock's principles for their design of the ARPANET, and provided the opportunity to participate in its implementation and deployment.

ARPA thread

- J. C. R. Licklider
- Ivan Sutherland
- Robert Taylor
- Larry Roberts

J. C. R. Licklider

- 1960, published his landmark paper “Man-Computer Symbiosis.” The idea is “to enable men and computers to cooperate in making decisions and controlling complex situations without inflexible dependence on predetermined programs”.
- 1962, Licklider (and Welden Clark) outlined their views on how networking computers could support social interaction, and provide networked access to programs and data.
- 1962, October, was appointed as the first director of ARPA’s newly formed Information Processing Techniques Office (IPTO), articulated his grand vision for the Galactic Network.
- 1964, passed his directorship of IPTO to Ivan Sutherland.

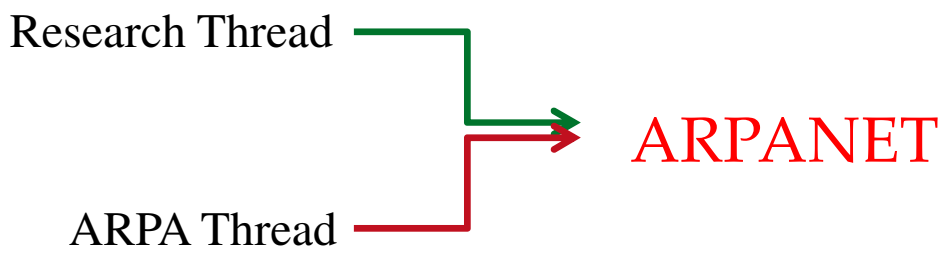
Ivan Sutherland

- From MIT, Kleinrock's colleague.
- 1964, took over the directorship of IPTO from Licklider.
- 1964, Sutherland wished to connect UCLA's three IBM mainframes in a three-node on-campus computer network, without success.
- 1965, Sutherland awarded Larry Roberts a contract to create a dialup 1200 b/s data connection across the United States, which demonstrated that such a connection required a different, more sophisticated network than the telephone network offered.
- 1965, Sutherland recruited Robert Taylor to become associate director of IPTO, who recognized the need for a network, this time specifically to connect ARPA research investigators to the few large expensive research computers across the country.

Robert Taylor & Larry Roberts

- 1966 August , Taylor succeeded Sutherland as IPTO director.
- 1966 December, Taylor recruited Roberts as the chief scientist of IPTO.
- The research and ARPA threads had now merged, and the project would soon become the ARPANET.

Two threads merged



The ARPA launch (1)

- Basic requirements:
  - Creating the switches and links underlying the network infrastructure, with the proper performance characteristics;
  - Creating the appropriate protocols to be used by the attached (host) computers so that they could properly communicate with each other.

The ARPA launch (2)

- 1967 April, Roberts called a meeting of the ARPA Principal Investigators (PIs) at the University of Michigan, where the basic specifications for the underlying network were debated.
  - The concept of Interface Message Processor (IMP) was put forward.
  - "Two-connected net" was presented to guarantee the reliability.
  - Message response time no greater than 500 ms (200 ms at its inception).
- The research and ARPA threads had now merged, and the project would soon become the ARPANET.

The ARPA launch (3)

- 1967 October, Roberts put together the ARPANET design and presented it in ACM SOSP conference.
  - Roberts met with Roger Scantlebury of the NPL, UK.
  - Aware of the efforts by Baran at RAND, Davies at NPL.
  - Roberts adopted the term ”packet” (1024 bits) coined by Davies.
  - Roberts decided to upgrade the backbone line speed from 9.6 kb/s to 50 kb/s for the ARPANET design.
- 1968 March, Roberts and Barry Wessler produced the final version of the IMP specification.
- 1968 June 3, Roberts formally submitted the ARPANET Program Plan to ARPA.
- 1968 June 21, the plan was approved and ARPANET was officially underway.

The ARPA launch (4)

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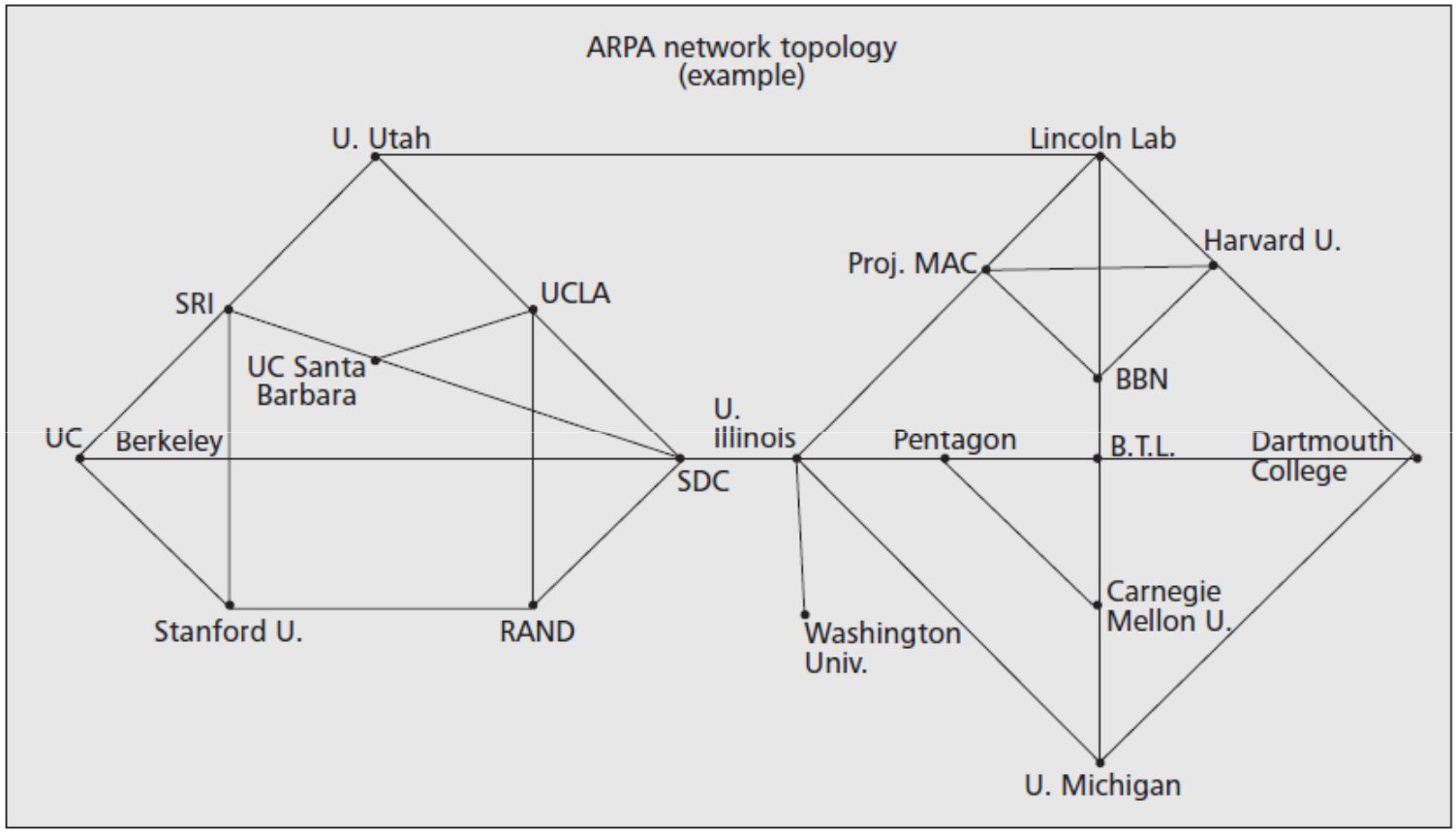

Fig. 1. 19-node ARPANET as shown in the original RFQ

The ARPA launch (5)

- 1968 August, the RFQ resulted in 12 proposals being submitted (missing IBM and AT&T);
- 1968 October, Roberts granted Kleinrock a research contract to create the Network Measurement Center (NMC), to measure the behavior of ARPANET.
- 1968, a week before Christmas, Bolt, Beranek and Newman (BBN) (supervised by Frank Heart) won the competitive bid and was awarded the contract to develop the IMP-to-IMP subnetwork.
- BBN developed an elegant host-IMP design, as a specification of BBN Report 1822 by Robert Kahn (in charge of the system design at BBN).

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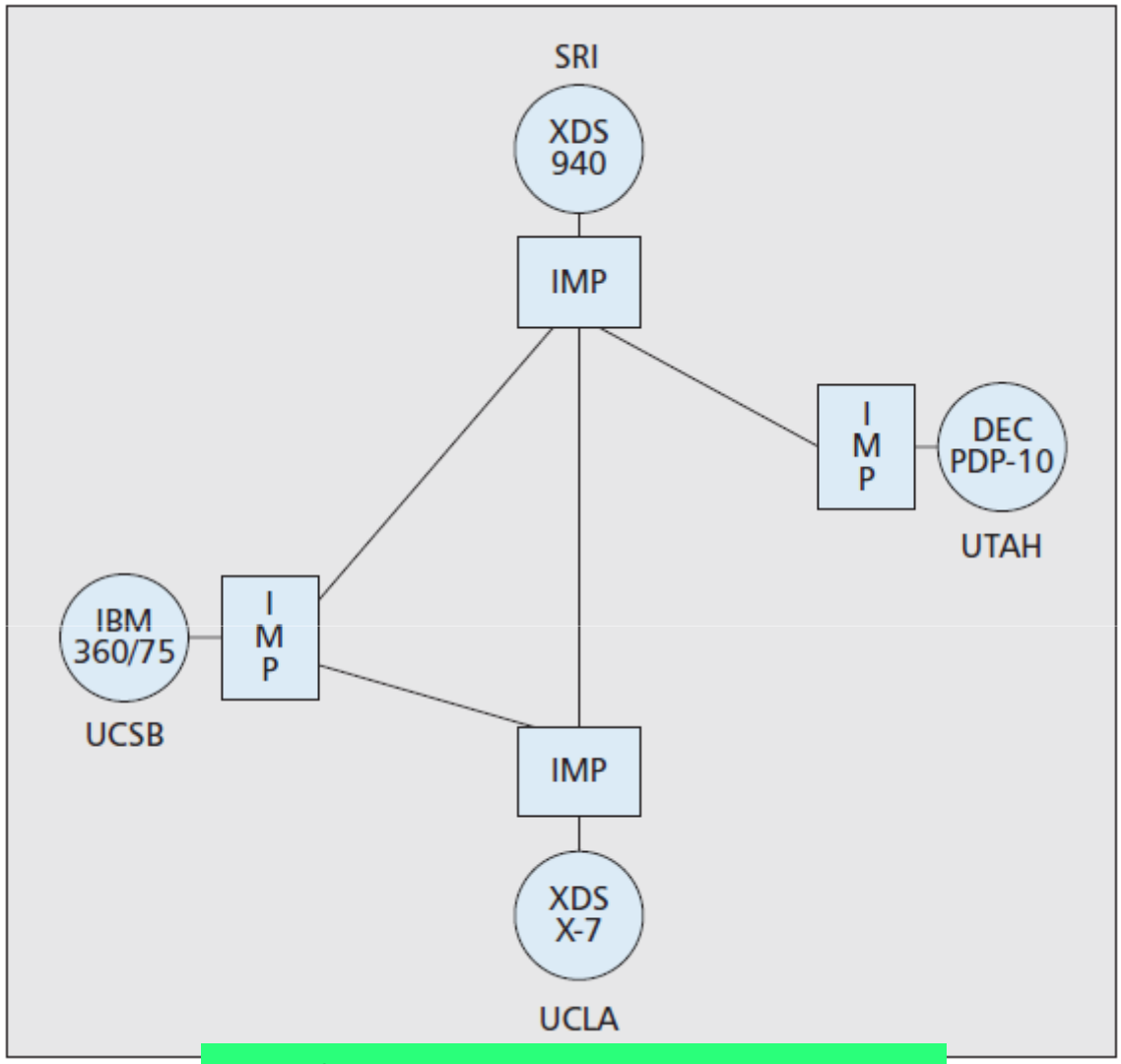


Fig. 2 … The first step was accomplished. …969)

Protocols (1)

- Assigned to the four chosen ARPANET research sites to figure out on their own (host-to-host communication).
- 1968 summer, Elmer Shapiro (SRI), called a meeting of programmers from the four sites, soon to be named the Network Working Group (NWG), first chair Shapiro, Jon Postel (UCLA) the Request for Comments (RFC) editor.
  - Steve Crocker (UCLA)
  - Jeff Rulifson (SRI)
  - Ron Stoughton (UCSB)
  - Steve Carr (University of Utah)
  - And others joined later
- Creating of high level interactions and to the notion of layerd set of protocols.
- NWG led to today's Internet Engineering Task Force (IETF).

Protocols (2)

- 1969 April, the first Request for Comments (RFC), entitled "Host Protocol," was written by Steve Crocker. Crocker became the second Chairman of the NWG early on.

- Two developments efforts underway:
  - Formal IMP-to-IMP subnetwork (BBN);
  - Informal Host-to-Host Protocol (NWG, graduate students).

Protocols (3)

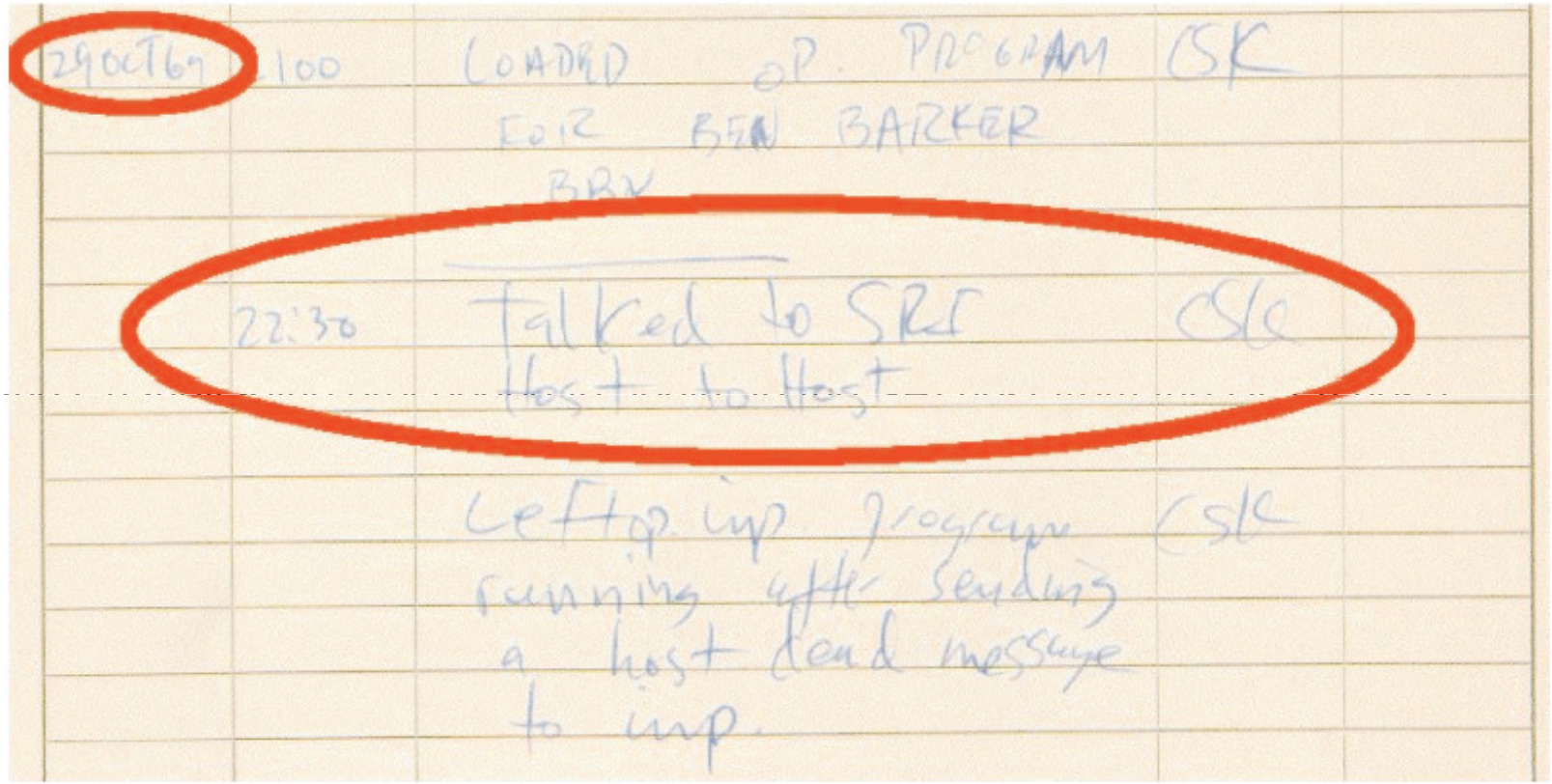


Fig. 3. The entry in the login IMP log.

The first decade of ARPANET (1)

- 1970 March, a symmetric Host-to-Host Protocol was described by Crocker in RFC 36, the first implementation of which was called the Network Control Program (NCP) (the first protocol stack to run on ARPANET, later to be succeeded by TCP/IP).
- Late 1971 in BBN, electronic mail (email) was made available between different computers attached to ARPANET.
- Early 1972, email publicly available.
- 1972 October, the first public demonstration of the ARPANET technology took place at the International Conference on Computer Communications (ICCC) (now INFOCOM).

The first decade of ARPANET (2)

- Additional networks were added to the ARPANET, the interconnection of networks was referred to as "internetworking" during the 1970s, from which the expanded ARPANET was eventually renamed as the Internet.

Different networks

- ALOHA
  - Late 1970, Norm Abramson had developed AlohaNet in Hawaii, a 9600 b/s packet radio net based on the novel “unslotted (pure) ALOHA” multi-access technique of random access.
- CSMA
  - ALOHA systems studies eventually led to an investigation of carrier sense multiple access (CSMA) as another wireless access method.
- CSMA/CD
  - CSMA led Robert Metcalfe to consider a variation called CSMA with collision detection (CSMA/CD), the basis for the original Ethernet development.
  - 1973 November, Metcalfe and David Boggs implemented CSMA/CD on a coaxial cable network up and running, created the Ethernet.

Internetworking

- 1972 December, an IMP in California used a satellite channel to connect to AlohaNet through an ALOHA host in Hawaii. (the first new network to connet to ARPANET)

- 1972 Roberts extended the ARPANET to Norway over a leased line that ARPA had already installed to receive seismic data and then extended it to London, UK. (first international connection)

- As the "internetworking" function became an increasingly important focal point of ARPANET development, the network came to be known as the *Internet* to reflect the growth.
  - Pairwise protocol conversion.
  - TCP/IP was soon proposed to address this problem.

TCP/IP

- 1973 summer, Kahn (DARPA) discussed his approach for dealing with the internetwork complexity with Vint Cerf (Stanford), who had considerable knowledge of NCP. Together, they drafted a detailed design of a new protocol, the Transmission Control Program (TCP).
- 1974, Cerf and Kahn fleshed out their design and published a definitive paper on TCP.
- 1973–1974 DARPA commissioned three independent implementations of TCP: Cerf (Stanford), Tomlinson(BBN), and Kirstein (University College London).
- 1976 August, these implementations led to the first experimentation using TCP to connect two different networks: the packet radio network using Stanford's TCP implementation, and the ARPANET using BBN's TCP implementation.

TCP/IP (cont.)

- This first version of TCP only supported virtual circuits at the transport level.
- It worked fine for reliable transmission but failed to support real-time traffic, which called for an “unreliable” transport transmission.
- The use of unreliable transport support was already in use with NCP, prior to TCP; specifically, the early ARPANET IMP protocol allowed for unreliable transport by use of what was called type 3 packets (also known as “raw” messages).
- 1973–1974 Danny Cohen of USC/ISI implemented a Network Voice Protocol (NVP) under ARPA support and requested BBN to allow him to use type 3 packets; with Kahn’s influence, BBN allowed this.

TCP/IP (cont.)

- Cohen convinced Jon Postel, who added:
  - *"We are screwing up in our design of internet protocols by violating the principle of layering. Specifically we are trying to use TCP to do two things: serve as a host level end-to-end protocol, and to serve as an Internet packaging and routing protocol. These two things should be provided in a layered and modular way. I suggest that a new distinct internetwork protocol is needed, and that TCP be used strictly as a host level end to-end-protocol."*
  - went on to describe how to break TCP into "*two components: the hop-by-hop relaying of a message, and the end-to-end control of the conversation.*"

TCP/IP (cont.)

- 1978, TCP Version 3 introduced the split into two components, but it was only in TCP Version 4 (1980, with an update in 1981) that we see a stable protocol running that separated out the Internet Protocol (IP) from TCP (which now stood for Transmission Control Protocol) and was referred to as TCP/IP. This version has come to be known as IPv4.
- The capability to support unreliable transport (i.e., type 3 packet functionality) was included. The formal name for this unreliable transport support was the User Datagram Protocol (UDP).
- 1980, the U.S. Department of Defense (DoD) declared the TCP/IP suite to be the standard for DoD.
- 1983 January, TCP/IP became the official standard for the ARPANET.
- 1998, upgraded to IPv6.

Growth and development of the Internet

- 1969: The first four nodes of the ARPANET are deployed.
- 1969: Steve Crocker establishes the Request For Comments (RFC) series and authors the first RFC entitled “Host Protocol.”
- 1970: The ARPANET spans the United States with a connection from UCLA to BBN.
- 1970: The Network Working Group (NWG) releases the first host-to-host protocol called the Network Control Program (NCP). It was the first transport layer protocol of the ARPANET, later to be succeeded by TCP.
- 1970: Norm Abramson develops Alohanet in Hawaii, a 9600-bps packet radio net based on the ALOHA multi-access technique of random access.
- 1972: Ray Tomlinson of BBN introduces network email and the @ sign.
- 1972: First public demonstration of the ARPANET at the ICCC conference in Washington, D.C., organized by Bob Kahn.

Growth and development of the Internet (cont.)

- 1972: Norm Abramson's Alohanet connected to the ARPANET.
- 1973: Bob Metcalfe invents Ethernet when he proposed the technology in a memo circulated at the Xerox Research Center in Palo Alto.
- 1974: Bob Kahn and Vint Cerf conceived of the Transmission Control Protocol (TCP) and publish the idea formally.
- Management of the ARPANET is transferred to the Defense Communications Agency (DCA).
- 1976: X.25 protocols developed for public packet networking.
- 1977: TCP is used to connect three networks (ARPANET, PRNET, and SATNET) in an
- intercontinental demonstration.
- 1978: TCP splits into TCP over IP, User Datagram Protocol (UDP) over IP.
- 1979: Usenet is created, precursor to the bulletin boards and Internet forums of today.

Growth and development of the Internet (cont.)

- 1981: IBM introduces their first personal computer (PC).
- 1983: TCP/IP becomes the official standard for the ARPANET.
- 1983: DCA splits MILNET from the ARPANET.
- 1984: The Domain Name System (DNS) is designed by Paul Mockapetris.
- 1988: The NRC Computer Science and Telecommunications Board produces its first report proposing a National Research Network. This has a strong impact on Senator Al Gore.
- 1988: Robert Morris unleashes the first Internet worm. This is the commencement of the dark side of the Internet.
- 1989: Tim Berners-Lee proposes a global hypertext project, to be known as the World Wide Web (WWW).
- 1989: ARPANET backbone replaced by NSFNET.

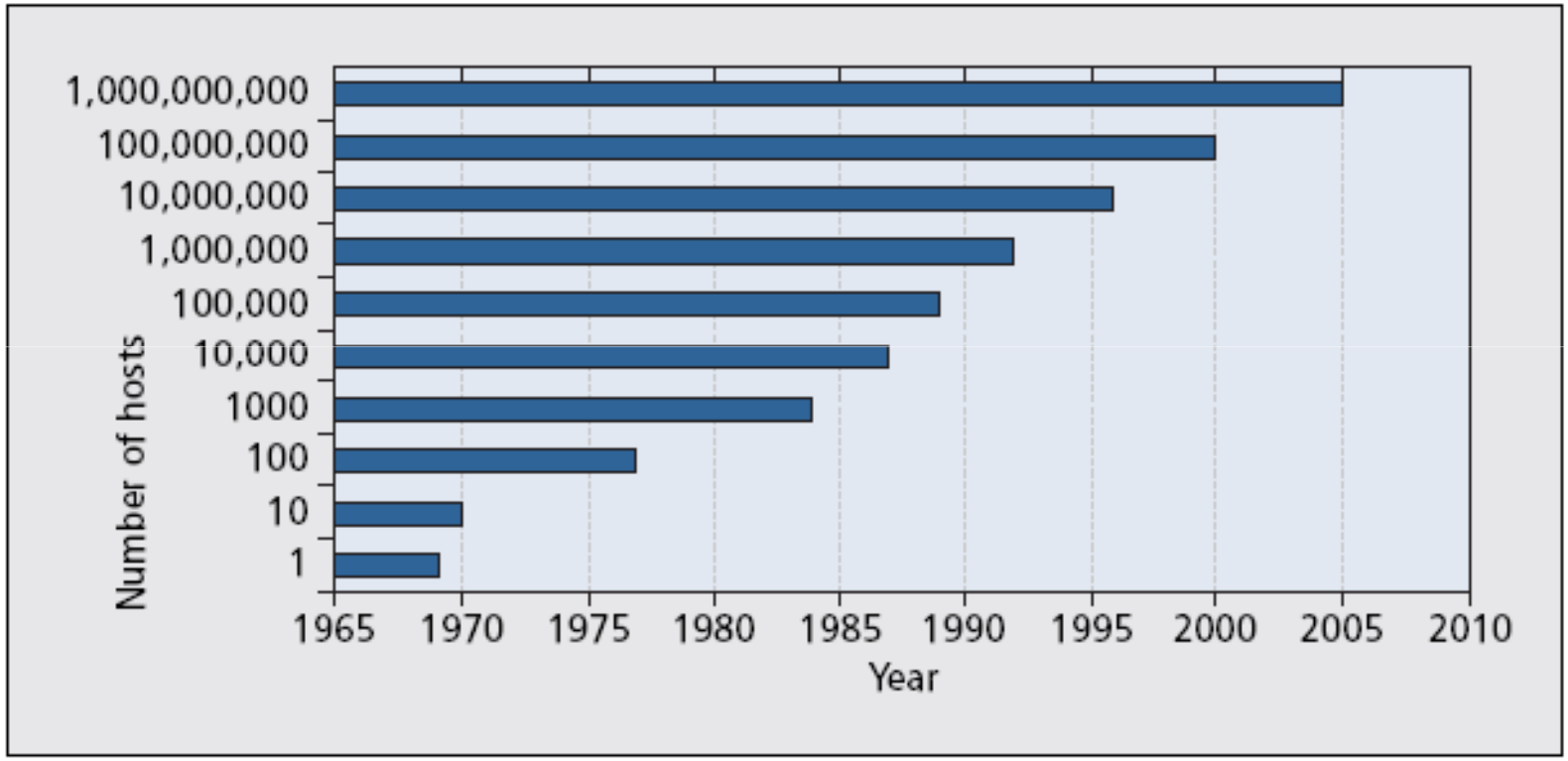
Growth and development of the Internet (cont.)

- 1991: Tim Berners-Lee makes the first Web site available on the Internet.
- 1992: Internet Society is formed.
- 1992: The number of Internet hosts passes the one million mark.
- 1993: The Mosaic browser is released by Marc Andreessen and Eric Bina of the National Center for Supercomputer Applications (NCSA) at the University of Illinois, Urbana-Champaign.
- 1994: Netscape browser is released.
- 1995: Netscape goes public and the dot com boom starts with the faith that a “new economy” is beginning.
- 1996: In the United States, more email is sent than postal mail.
- 1997: IEEE releases 802.11 (WiFi) standard.
- 1998: Blogs begin to appear.
- 1999: Napster rolls out.

Growth and development of the Internet (cont.)

- 2001: Napster forced to suspend service.
- 2005: Web 2.0 technologies heat up.
- 2006: YouTube purchased by Google.
- 2007: Apple introduces the iPhone.
- 2007: Microsoft buys 1.5% stake of Facebook at a $240 million valuation.
- 2007: Google lays out Android, its open cell phone platform.
- 2008-

Growth of Internet hosts



Future of Internet
--David Reed (MIT)

- Past (network-centric):
  - the network was the center, and the user view was to think about how to connect from the periphery and fit into the global network technology, applications, and services.

- Future (user-centric):
  - the user thinks of an environment that is user-centric. The focus is on the users who sit at the center of their dynamic personal networks and who reach out to include only the network of applications, services, and affinity groups with which they interact.

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