The Evolution of Packet Switching as an Emergent Technology

ESD.85 Integrating Doctoral Seminar on Emerging Technologies
November 7, 2005
Shirley Hung
Spencer L. Lewis

Outline

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- Technical Discussion
  - Packet Switching vs. Circuit Switching
- Technical Characteristics
  - Packet Switching vs. Other Methods
  - TCP/IP
- Political and Organizational Concerns
- Decisions and Uncertainties
- Consequences
- Themes
- Technology Improvements

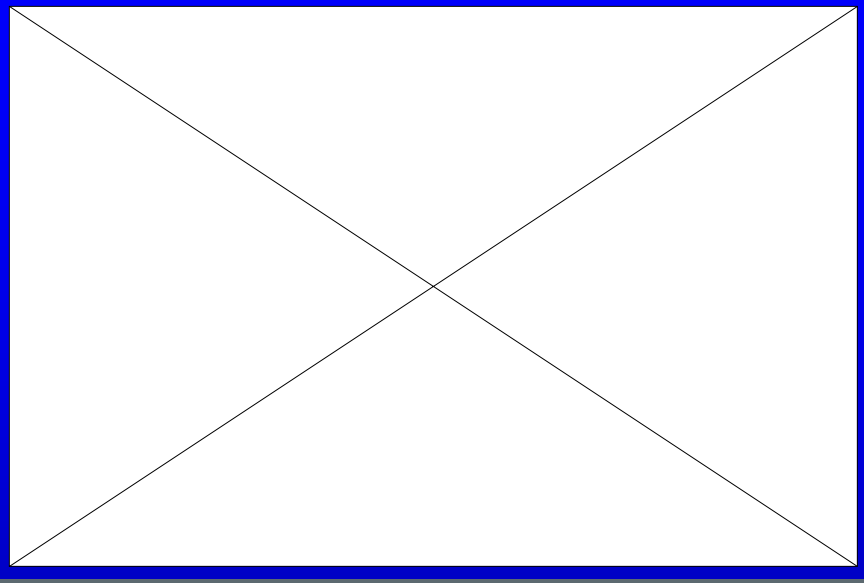
Packet Switching Chronology

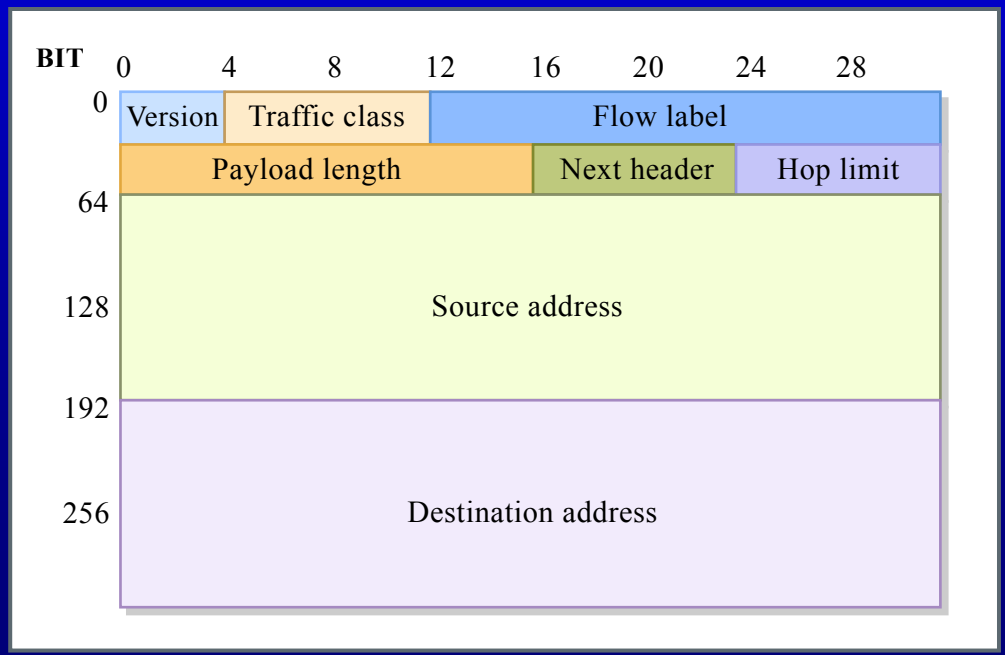
- 1961: Leonard Kleinrock, “Information Flow in Large Communication Nets”
- 1962: J.C.R. Licklider starts putting together ARPANET
- 1964: Kleinrock performs research on queuing theory published book
- 1964: Paul Baran, “On Distributed Communications Networks” and RAND memoranda
- 1966: Donald Davies developed store-and-forward packet switching methodology at the UK National Physics Laboratories
- 1966: ARPANET formally begins – first proposed to Congress as a way to share computers
- 1967: Talking about mechanics behind it, Clark starts talking about the mechanics of routing – use of mini computers
- 1969: First node of ARPANET installed at UCLA
- 1969: Packet Switching becomes cheaper than circuit switching
- Early 1970’s: ARPANET approached AT&T about taking over and they rejected the idea
- Early 1970’s: Germany started experimenting with the packet switching
- 1973: BBN offshoot Telenet becomes first US privately owned packet switching supplier
- 1972: First ARPANET Public Demonstration at ICCC
- 1974: Kahn and Cerf IEEE paper on TCP/IP published

Packet Switching vs. Circuit Switching

- Pre-Allocation (Circuit Switching)
  - For each communication message, a fixed amount of bandwidth is allocated to accommodate that channel
  - TWX, Voice Telephone, and Telex
  - *Time-Division Multiplexing, Wavelength Division Multiplexing, Frequency Division Multiplexing, Code Division Multiplexing*
- Dynamic-Allocation (Packet Switching)
  - The bandwidth for a message is allocated as each packet of data requires and does not necessarily form a straight line from originator to destination.
  - Mail Systems, Telegraph, and Internet Traffic
  - *Datagram, Source Routing, Virtual Circuit*
- *"…if lines are cheap, use circuit switching; if computing is cheap, use packet switching."* (Roberts, 1978)

Transmission Control Protocol (TCP/IP)





- Switch: Computer that receives and then transfers a packet further towards its destination
- Router: Reads the data packet from a packet and uses a forwarding table to determine the route the packet should follow

Internet Protocol v 6

- 40 byte Header

Figure by MIT OCW.

Nuclear War Survivability

Image removed for copyright reasons.
Graph of network "survivability" vs. node probability of failure in a distributed network.

It was from the RAND study that the false rumor started claiming that the ARPANET was somehow related to building a network resistant to nuclear war. This was never true of the ARPANET, only the unrelated RAND study on secure voice considered nuclear war. However, the later work on Internetting did emphasize robustness and survivability, including the capability to withstand losses of large portions of the underlying networks.

Brief History of the Internet, ISOC

Political and/or Organization Context

- Political
  - Cold War concerns for C3I preservation during nuclear strike
- Assorted Academic Institutions (MIT, Lincoln Lab, Stanford, UCLA)
- DARPA who ran the project out of the academic lab
- RAND research funded through Project Air Force/DoD
- Corporate
- Mass market consumers non-existent; belief that large government and academic networks were only “customers”
- International development of packet switched data networks
- Different incentive structures for private versus government-owned telephone networks/ companies

Decisions and Uncertainties

- Decide to go with packet switching vs. circuit switching
- Uncertainties
  - Technological
  - Economic
  - Potential growth of networks

- They put together a system and tested it
- System Practicality
  - The engineers recognizing that the existing that the existing telephone network was built for voice and not data transmission
- Open architecture of Internet related to interoperability of different types of networks (SATNET, ALOHANET – satellite and radio-based networks)
  - It existed but it was not seen as a replacement for the existing telephone network to transmit data
  - Seemed like a workable fix that was much easier to do

AT&T Decision: Why did they not want responsibility

- Did not believe that there would be a market demand for that type of data sharing network
- Possibly wanted to develop rival network?
  - But no writings found on packet switching during this era
- Contradictory to business model that AT&T had been operating from for decades
  - Infrastructure
  - Accounting/ charging for service
  - Standards and coordination issues
- Beginnings of FCC deregulations?
- Similar to what happened with Western Union refusing to pick up the telephone.

Contrasts to Other Countries

- Most of the other countries where it developed earlier, the corporations where actually owned by government
- AT&T was a private firm

Consequences

- Intended
  - Efficient resource allocation
  - Economical
  - Robustness
  - Expandability
- Unintended
  - Impact on telephone companies' business model
  - Impact on regulatory framework
    - FCC Deregulation
    - Spurred Competition
    - Influenced Higher Capacity Lines
  - Expandability to Internet of today rather than limited Internet
    - Decentralization
    - Open architecture

Themes: Overlooked Consequences

- AT&T's decision not to take over ARPANET
- AT&T's resistance to packet-switching model
  - Contrast with reaction of other countries' NTTs (France's CYCLADES, TRANSPAC, Canada's DATAPAC, UK's Experimental Packet Switched Service)
- Growth of Internet/ pervasive computing/ personal computing

Themes: Defensive Strategies Against Emergent Technology

- Few interests other than AT&T threatened by packet switching
- AT&T reaction
  - Rejected offer to take over ARPANET
  - Concerns with deregulation, future competition
  - Incompatible with corporate culture or business model
  - Technology contrary to infrastructure setup

Themes: Do new technologies that evolve out of basic research tend to ignore social/ economic concerns?

- Related to question of whether techies or others are best at forecasting ET's social and economic implications
  - The techies were more farsighted than the corporate interests involved in this case
- Impact of technology's stage of development:
  - 'Pre-development'/ 'Visionaries': (Bush and Licklider) tend to think about how ET will impact society
  - Early and intermediate stage (Kleinrock, Roberts): focus more on technical aspects – 'will it work?' and 'make it work'
  - Later stages, once basic technology is functional and better known, creates more focus on implications (Berners-Lee)
- When is the best time to both consider and implement technical refinements to better address societal concerns? Who best to do this?

Improvements

- What if AT&T had adopted ARPANET and the packet switching model?
  - Impact on current physical infrastructure
  - Impact on telephone companies now (VoIP?)
  - Impact on development of Internet
- Security concerns due to decentralization – tradeoffs
- Failure of vision: personal computing → Internet → pervasive computing

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Backup Slides

Internet “Visionaries”

Vannevar Bush

"Science has provided the swiftest communication between individuals; it has provided a record of ideas and has enabled man to manipulate and to make extracts from that record so that knowledge evolves and endures throughout the live of a race rather than that of an individual.”

As We May Think (1945)

J.C.R. (Lick) Licklider

"If such a network as I envisage nebulously could be brought into operation, we could have at least four large computers, perhaps six or eight small computers, and a great assortment of disc files and magnetic tape units-not to mention remote consoles and teletype stations-all churning away"

Computing's Johnny Appleseed (2000)

Internet “Visionaries”

Larry Roberts

"Although they knew in the back of their mind that it was a good idea and were supportive on a philosophical front, from a practical point of view, they-Minsky and McCarthy [two prominent PIs], and everybody with their own machine-wanted [to continue having] their own machine. It was only a couple of years after they had gotten on [the ARPANET] that they started raving about how they could now share research, and jointly publish papers, and do other things that they could never do before." (Roberts in Abbate, 50)

Paul Baran

"Both the US and USSR were building hair-trigger nuclear ballistic missile systems. If the strategic weapons command and control systems could be more survivable, then the country's retaliatory capability could better allow it to withstand an attack and still function; a more stable position. … Here a most dangerous situation was created by the lack of a survivable communication system."

On Distributed Communications Networks 1964

Internet “Visionaries”

Bob Metcalfe

"I looked up in pain and I caught them smiling, delighted that packet-switching was flaky," said Metcalfe. "This I will never forget. It confirmed for them that circuit-switching technology was here to stay, and this packet-switching stuff was an unreliable toy that would never have much impact in the commercial world. It was clear to me they were tangled in the past."

When Wizards Stay Up Late: The Origins of the Internet (1996)

Leonard Kleinrock

"Basically, what I did for my PhD research in 1961–1962 was to establish a mathematical theory of packet networks ..."

Leonard Kleinrock – Wikipedia (2005)