Internet History and Concepts
Introduction

CSCI E 45a: The Cyber World – part A

Introduction: learning goals

- Understand the key concepts that makes today's Internet what it is
- Understand how we got here
  The path impacted the current state

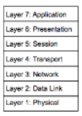
Introduction: this module

- Support existing networks
- Datagram-based
- Creating the router function
- Split ITCP into IP and TCP
- DARPA fund Berkeley to add TCP/IP to UNIX
- CSNET and CSNET/ARPANET deal
- NSF require TCP/IP on NSFnet
- CCITT turn down TCP/IP standardization
- NSF Acceptable Use Policy (AUP)
- Minimal regulation

- This module deals with technology
  Regulation and governance will be covered separately
- Relating to 10 decisions that made a difference
  Will review at end

Introduction: topics

Paul Baran



- History of the Telephone Network – O

  The network that was here before the Internet
- Visions – R

  What did people think was coming?
- Internet history – R

  From packets to the present
- OSI protocol suite – O

  The official direction

Introduction: topics

Louis Pouzin

- End-to-end – R

  The basic operational principle
- The hourglass model – R

  IP as a bearer service
- Internet architecture – R

  The topology of the Internet
- Module summary – R

Image credits

2	Internet map: Bill Cheswick
	Network diagram: Paul Baran/RAND 1962
4	Wall telephone: tech-kid.com
	Big Brother: poster in 1955 movie
	Baran photo: Wired
5	Pouzin photo: Marc Weber
	Hourglass: Realizing the Information Future
	Internet map: Bill Cheswick

Internet History and Concepts

Telephone history

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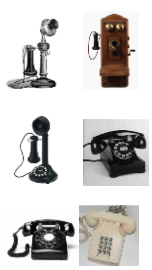
Telephone History



- History of telephone technology and service
- Using U.S. as an example
- Same general sequence in other countries

Sources: tech-kid.com & wanelo.com

Alexander Graham Bell

Alexander Graham Bell

- 1876: Bell filed his first telephone patent
- 1877: Bell formed Bell Telephone Company
- 1885: American Telephone and Telegraph Company (AT&T) formed to interconnect local telephone companies
- 1899: AT&T became parent company for Bell companies.

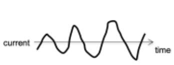
AT&T

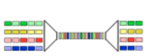
- 1913: AT&T became a U.S. regulated monopoly
- 1915: transcontinental service
- 1927: trans-Atlantic service
- 1934: trans-Pacific service
- 1956: Hush-a-Phone allowed acoustic couplers
- 1968: Carterfone allowed connections to AT&T network
- 1984: AT&T broken up

In the beginning: analog circuits

- Initially, connections were manual and analog
  - An operator made the connection
- 1889: Strowger switch – used pulse dialing
  - "direct dial"- pulses rotated switch
- Both set up a dedicated wire circuit between the caller and callee
  - Analog amplifiers added for longer circuits

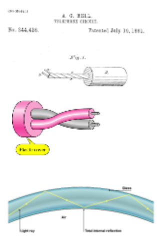
Later: digital circuits





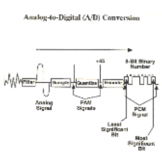
- Analog circuits inefficient
  - Max 12 calls per wire pair up until 1940s, 100 or so in mid 1940s
    - Better amplifier design
- 1950s: introduction of digital transmission
  - Analog signal "digitized"
    - Turned into sequence of bits
- 100s or 1000s of calls per wire pair
  - Using time division multiplexing (TDM)

Later: digital circuits, contd.



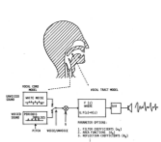
- Standard telephone digital circuits
  - Copper
    - DS0: 64 Kbps: single phone call
    - T1: 1.544 Mbps: 24 calls
    - T2: 6.3 Mbps: 96 calls
    - T3: 45 Mbps: 672 calls
  - Fiber
    - OC3: 155 Mbps: 2,322 calls
    - OC12: 622 Mbps: 9,386calls
    - OC48: 2.5 Gbps: 18,784 calls
    - OC192: 10 Gbps: 148,608 calls

Digital circuits: encoding - PCM



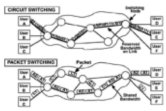
- Turn an analog voice signal into digital signal
- Pulse code modulation (PCM)
  - Sample analog waveform
  - Convert to digital
  - Transmit pulse string that represents digital sample
- 64 Kbps bit stream per voice channel
- Used in most traditional telephony

Digital circuits: encoding - LPC



- Turn an analog voice signal into digital signal
- Linear predictive coding (LPC)
  - Method of compression that models the process of speech production
    - *models speech as an autoregressive process, and sends the parameters of the process as opposed to sending the speech Itself*
- As little as 2.4 Kbps
- Used in cell phones & VoIP

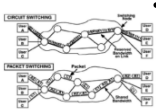
Circuit switched



- The telephone is traditionally circuit switched
  - Initiate call
  - Determine next hop in path to destination
  - Determine if that hop has capacity for a new call
    - If no, send fast busy signal & exit
    - If yes, repeat until at destination
  - Lock down capacity along path
    - "hard state" in switches
  - Start call

10

Circuit switched, contd.



- Capacity dedicated to call until call terminated
  - Capacity released when call finished
  - Switch or link failure breaks call
- Are not permitted to pre-empt existing calls for high-priority calls
  - In U.S. non-military phone nets
- Can prioritize call placement

11

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5	Telephone operator: imgbuddy.com
	Telephone switch: tripod.com
6	TDM diagram (bottom): mathworks.com
7	Top: U.S. Patent No. 244,426
	Twisted pair wire: imgbuddy.com
	Fiber: imgbuddy.com
8	PCM: privateline.com
9	LPC: cnx.com
10	Circuit switched: what-when-how.com
11	Circuit switched: what-when-how.com
	GETS card - fcc.gov

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Internet History and Concepts
Visions

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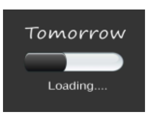
Visions of a networked future



- Scientists, science fiction writers and others imagined what a networked future would look like long before one existed
- Here are a few examples

1949: George Orwell


George Orwell

- English journalist, novelist, and political writer
- Known for dark views of society, present and future

1949: Orwell: *1984*

How often, or on what system, the Thought Police plugged in on any individual wire was guesswork. It was even conceivable that they watched everybody all the time. But at any rate they could plug in your wire whenever they wanted to. You had to live -- did live, from habit that became instinct -- in the assumption that every sound you made was overheard, and, except in darkness, every movement scrutinized.

1963: J.C. R. Licklider

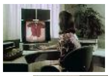

J.C.R. Licklider

- MIT Psychology Department
  - Helped set up Lincoln Laboratory
- Worked at BBN starting in 1957
  - One project was "Libraries of the Future"
- Moved to ARPA in 1962
  - Led Behavioral Science Command and Control Research

1963: Licklider: *Intergalactic Computer Network*

The major point of his memorandum is that the establishment of network of computers is difficult with the technology they know and have. At this time computers were mainly used by government and academia, so this was a "military problem". So many computers ran on so many different languages it would be hard to establish a network. A common language or a method of translating languages from one computer to another was needed.

1967: Philco-Ford: *Year 1999 A.D.*



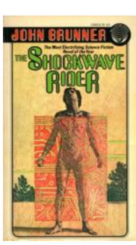

- She: home shopping
  Select wares by push button
- He: paying her bills
  Electronic bill paying
- Household monitor
  Spy on kids at swimming pool
- Household records
  Access through console
- Electronic correspondence
  Instant written communication to anyone anywhere in world

1975: John Brunner


John Brunner

- English science fiction writer
- Wrote about 60 science fiction books

1975: John Brunner



Three hundred million people with access to the integrated North American data-net is a nice big number of potential customers.

Ah, you don't have to know anything. You just need to know where to find it.

1981: Neil Ardley


Neil Ardley

- English jazz composer and author of informative books for young people
- Big band and New Orleans style jazz
- Worked for *World Book Encyclopedia*
- Wrote books on technology
  - e.g. The Way Things Work
  - e.g. The World of Tomorrow

1981: Neil Ardley

People still collect books as valuable antiques or for a hobby, but you get virtually all the information you need from the viewscreen of your home computer system. The computer is linked to a library - not a library of books but an electronic library where information on every subject is stored in computer memory banks. You simply ask.

Instead of going out to shops and stores in your town or city, you contact them through your videophone computer. You'll need to see what you are buying, even if you can't handle it, so the viewscreen of the videophone computer shows you the goods available. You then instruct the computer to order the goods you want and have them delivered to your house.

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3	Orwell photo: georgeorwell.com
4	Poster in 1955 movie
5	Licklider photo: Ben Shneiderman
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7	Screen captures from https://archive.org/details/Year1999Ad.
8	Brunner photo: Wikipedia
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10	Ardley photo: Progarchives.com
11	Covers of Ardley World of Tomorrow books

Internet History and Concepts
Internet History

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1

Internet history

1957-present

- A series of people and events that got us to today's Internet
- Representative, not comprehensive

2

Internet history: Sputnik

1957

- 4 October 1957
- 1st man made satellite
- Launched by Soviet Union
- Caused *hysteria*
  Roger Launius *Sputnik and the Origins of the Space Age*
- *The sky seemed almost alien*
  Lyndon B. Johnson

3

Internet history: Dwight David Eisenhower

1958

Dwight David Eisenhower

- U.S. President – 1953-1961
- January 1958: Eisenhower reacted to Sputnik by establishing the *Advanced Research Projects Agency* (ARPA) within the U.S. Department of Defense

4

Internet history: J.C.R Licklider

1960-68

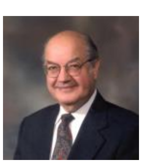
J.C.R Licklider

- 1960: *Man-Computer Symbiosis*
  How people could interact with computers
- 1962-3: *Intergalactic Computer Network* memos
  Global data networks interconnecting computers
- 1962: took over ARPA Information Processing Techniques Office (IPTO)

5

Internet history: Paul Baran

1960-64



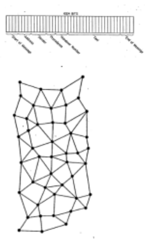
Paul Baran

- Hughes Aircraft & RAND Corp.
- 1960: *Reliable Digital Communications Systems Using Unreliable Network Nodes*
  Reliability through redundancy
- 1962: *On Distributed Communications Networks*
  Basic concepts of packet switched networks
- Never built

6

Internet history: Paul Baran, contd.

1960-64

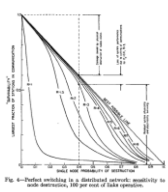


- "standardized message block"
  - Source & destination addresses
  - Precedence (QoS)
  - Payload
- Distributed network
  - Switching nodes
    - Routing function but not called routers
  - Store and forward
  - Redundant paths for reliability
  - Shortest-path hot-potato routing protocol

7

Internet history: why message blocks

1960-64



- Communication at the time was circuit-based
- Circuit setup takes too much time relative to transmission length as links get faster
- Message-based networks also provide:
  - Multiplexing of different rate communications
  - Minimal message retransmission after failover to new routes
  - Resilience in the face of failure

8

Internet history: Leonard (Len) Kleinrock

1961


Len Kleinrock

- 1961: MIT thesis proposal on queuing theory
  - *Information Flow in Large Communication Nets*
- UCLA professor of computer science
- Oct 29, 1969: First ARPANET message sent from Kleinrock's UCLA lab to SRI
- 1977: *Hierarchical Routing for Large Networks*

9

Internet history: Donald Davies

1966-70

Donald Davies

- U.K. National Physical Laboratory
- 1966: proposed “packet” based communication between computers
  - Introduced to Baran’s work
- 1967: Roger Scantlebury (from Davies’s group) presents paper on packet switch networks
  - Larry Roberts in audience

Internet history: Ivan Sutherland

1963

Ivan Sutherland

- 1963: Took over ARPA IPTO from Licklider
- Later a Harvard & University of Utah professor & co-founded Evans & Sutherland
  - High-end computer graphics
- Funded many projects including timesharing
- Recruited Robert (Bob) Taylor to ARPA

Internet history: data communications

1965

- First wide area network
- Sutherland funded Larry Roberts (then at MIT) and Thomas Marill (Computer Corporation of America) to build first transcontinental computer data link
- Supported data transfer and remote login
- Ran over a Western Union leased-line

Internet history: Robert (Bob) Taylor

1965-66

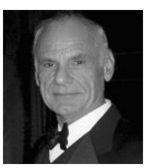
Bob Taylor

- Took over ARPA IPTO in 1965
- 1966: requested & was authorized to spend $1M to build a data network to enable remote access to ARPA-funded timeshare computers
- 1966: Appointed Lawrence (Larry) Roberts to run network project – became the ARPANET

13

Internet history: Lawrence (Larry) Roberts

1966-73



Larry Roberts

- Decided to interconnect computers with Interface Message Processors (IMPs)
- Decided did not want to use circuit switched networks
- 1967: heard about & met with Paul Baran & Donald Davies
- Adopted packet switching for the ARPANET
- Took over ARPA IPTO in 1969

14

Internet history: Douglas Engelbart

1968

Douglas Engelbart

- Stanford Research Institute
- Founded ARPA funded Augmentation Research Center
- 1968: Mother of all Demos
  - computer mouse
  - bitmapped screens
  - hypertext

15

Internet history: ARPANET

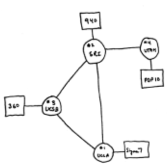
1968-69

- 1968: RFQ for IMPs published
  - 4-node initial network
- 12 of the 140 companies asked submitted a bid
  - IBM & AT&T did not
- Bolt Beranek & Newman (BBN) won the contract
- September 1969: First IMP delivered to UCLA

16

Internet history: ARPANET, contd.

1969



- First 4 nodes installed
  - UCLA – Len Kleinrock
  - Stanford Research Institute – Doug Engelbart
  - University of California, Santa Barbara – Glen Culler and Burton Fried
    - Early interactive on-line system
  - University of Utah – Ivan Sutherland

17

Internet history: ARPANET, contd.

1970-80

1970

1980

- 1970 – east coast
  - Including Harvard
  - 9 hosts
- 1973 – International
  - Norway & London
  - 22 hosts + 18 TIPs
    - TIPs supported terminals
- 1980 – 200 hosts
  - 20,000 users

18

Internet history: Robert (Bob) Kahn

1968-76

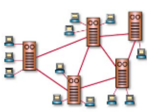
Bob Kahn

- 1968: Joined BBN & worked on IMP
- Mid 1972: organized demonstration of 20-node ARPANET communications
- Late 1972: moved to ARPA IPTO
- Developed basic ideas for open networking
- 1973: asked Vint Cerf to help design a new communications protocol for the ARPANET

19

Internet history: NCP

1969-83



- The original ARPANET communications protocol was the Network Control Program
- IMPs communicated via NCP and communicated to directly attached hosts
- NCP allowed a host on the ARPANET to communicate with another host on the ARPANET
- NCP provided reliable communications between IMPs

20

Internet history: Danny Cohen

1976

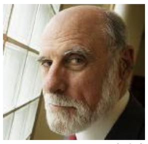
Danny Cohen

- Researched transporting speech over packet networks
- Realized that reliable transport protocols not good for speech
  - Delays introduced by reliability mechanism hurt understandability
- Used a reliability bypass option (uncontrolled packets) in NCP for packet speech
- 1978: demo video of packet speech over the ARPANET

21

Internet history: Vinton (Vint) Cerf

1973-81



Vint Cerf

- Kahn realized that just interconnecting hosts over a single network did not scale
  - Needed a way to interconnect hosts on different networks
- He asked Vint Cerf for help
- They learned from the design of the CYCLADES network

Internet history: Louis Pouzin

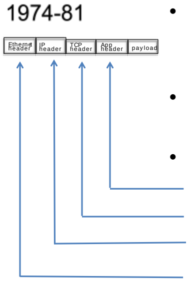
1971-76

Louis Pouzin

- French computer scientist
- Pre 1972: at MIT, exposed to ARPANET
- 1972: designed CYCLADES network
- 1974: Deployed 7 nodes
- 1976: 20 nodes
- "Pure datagram network"
  - No delivery assumptions
    - Reliability, order, duplication
- Put reliability responsibility at end points "end-to-end"

Internet history: Internet Protocol

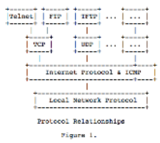
1974-81



- Cerf & Kahn developed a datagram-based "Internet Protocol" suite
- Used Pouzin's end-to-end concept
- Multiple layers
  - Application layer (e.g. telnet)
  - Transport layer (e.g. TCP)
  - Internet layer (IP)
  - Local network layer (e.g. Ethernet)

Internet history: TCP/IP

1974-81



TCP/IP

- 1974: Internet Transmission Control Program (ITCP)
  - Only provided a reliable service
    - Danny Cohen & others objected
- 1980 & 81: Internet Protocol, Transmission Control Protocol & User Datagram Protocol
  - Provides both reliable and unreliable services
    - Added UDP in parallel to TCP

Internet history: TCP/IP, contd.

1983

- Jan 1 1983: ARPANET switched to TCP/IP
- August 1983: BSD 4.2
  - DoD funded University of California, Berkeley to add the BBN TCP/IP code to their Unix distribution
  - Made TCP/IP generally available for a reasonable license fee
    - Most vendors switched to TCP/IP from proprietary protocols

Internet history: NSFNET

1985-95

NSFNET

- 1985: U.S. National Science Foundation (NSF) established NSFNET & required TCP/IP
  - Originally 56 Kbps between super computer centers
- 1988: T1 NSFNET (1.544 Mbps)
  - connections between regional networks
- 1990: ARPANET closed
- 1991: T3 NSFNET (45 Mbps)
- 1995: NSFNET closed
  - U.S. government out of general backbone business

Internet history: commercialization

1990-

CERFnet

UUNET

PSINet

Sprint

ICM

- Pre 1991: commercial use of ARPANET & NSFNET banned
- 1988: MCI mail connected
- 1989: commercial ISPs formed
- 1991: Commercial Internet eXchange (CIX) formed by CERFnet

  CERFnet run by General Atomics
- 1991: limited commercial use of NSFNET permitted
- 1992: MAE-East formed

28

Internet history: the web

1991-

Tim Berners-Lee

UPDATED

- 1991: Tim Berners-Lee releases web browser and server
- 1991: first web sites
- 1993: NCSA Mosaic released
- 1995: 23 K web sites
- 2000: 17 M web sites
- 2005: 65 M web sites
- 2010: 200 M web sites
- 2015: 1 B web sites
- 2018: 1.6 B web sites
- 2022: 1.1 B web sites 16 % active

http://www.internetlivestats.com/total-number-of-websites/

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Internet History and Concepts

OSI protocol suite

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1

In the beginning: INWG

- 1972: International Network Working Group formed:
  Vint Cerf & Alex McKenzie (US), Donald Davies & Roger Scantlebury (GB), Lous Pouzin & Hurbert Zimmerman (FR)
- Worked on standards for datagram based networks
- 1975: INWG produced a proposal INWG72
  (updated version of ITCP)

2

In the beginning: CCITT

- Comité Consultatif International Téléphoniqueet Télégraphique
- The international standards body for telecommunications standards
- Established 1956
- Mostly representatives from traditional telecom companies

3

In the beginning: CCITT, contd.

- 1972: CCITT decided to establish a standard interface to packet switching networks
- 1974: CCITT proposed to use X.25, a reliable, virtual circuit-based, carrier provided, data communications service
- 1975: INWG offered INWG72 to CCITT
- CCITT turned down the offer

4

Next: ISO

- International Organization for Standardization
- Current organization founded in 1947
- 1977: British proposal to ISO to develop "network standards needed for open networking"
- Started development of *Open Systems Interconnect* (OSI) model & standards

5

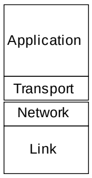
OSI model

Layer 7: Application
Layer 6: Presentation
Layer 5: Session
Layer 4: Transport
Layer 3: Network
Layer 2: Data Link
Layer 1: Physical

- 1984: OSI Conceptual model published
- 7 layers
- Communications only between adjacent layers

6

TCP/IP model



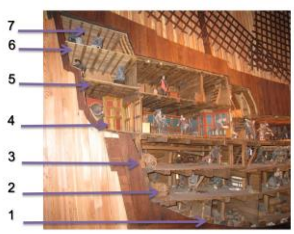
- TCP/IP
- 4 layers
- Communications generally between adjacent layers
- "Layer violation" to bypass a layer

7

Geek humor

- "another failure of the 7-layer model"


Vasa 1628



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More geek humor

- Non-technical layers on top
- "Layer 9": political
- "Layer 8": Financial
- Both can dictate how a network works

9

OSI Protocol Standards

- Mid 1980s: OSI protocol standards started to be published
- Standards published both by ISO and CCITT
  - With some differences
- Standards long and complex with many optional features
  - A byproduct of a consensus-based standards process

OSI Protocol Standards, contd.

- Included all layers of the protocol stack above the data link layer – many specifications
  - 8 network layer
  - 6 transport layer
  - 3 session layer
  - 3 presentation layer
  - 16 application and application-related

OSI Protocol Standards, contd.

- Mandated by many governments
  - Support required in US government contracts
- Multiple "profiles" of standards
  - Lists of specific features to support
- Most specifications assume carrier-based service
- Assumed to be the future
  - IETF had an OSI Integration Area

OSI Failure

- Far too complex
  - Do everything for everybody
  - e.g., X.400 email address
    - G=Harald; S=Alvestrand; O=sintef; OU=delab; PRMD=uninett; ADMD=uninett; C=no
  - 'TCP/IP suite is 1/6th the code'
- Code far too expensive, compared to IP
  - Failed attempt to add to Unix
- Complexity meant significant interoperability problems
- Carrier-based deployment
  - Far slower than IP deployment

13

OSI Failure, contd.

- Failure was slow
  - Not clear until mid 1990s
- Huge waste of engineering talent and money
  - Countless hours of standards meetings
- Very political - Governments, telecos & big businesses wanted OSI
  - Because it was developed by a recognized open standards process
- But a working Internet won

14

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15

Internet History and Concepts
End-to-end

CSCI E 45a: The Cyber World – part A

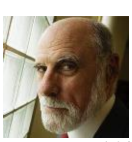
End-to-end: Louis Pouzin


Louis Pouzin

- CYCLADES network – 1971-4
- "Pure 'datagram' network"
  - Could not assume reliable service from underlying telephone circuits
  - So could have no assumptions about datagram delivery over the network
    - Reliability, order, duplication
- Put reliability responsibility at end points: "end-to-end"

End-to-end: Kahn & Cerf


Bob Kahn


Vint Cerf

- 1974: Internet Transmission Control Program
  - Specified operation of program not the 'bits on the wire'
- *The TCP insures end-to-end acknowledgment, error correction, duplicate detection, sequencing, and flow control*
  - RFC 675 section 2.1
- Does not assume the network will help

End-to-end: Salzer, Reed & Clark

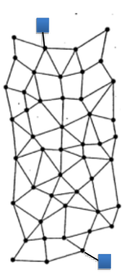

Jerry Salzer


David Reed


David Clark

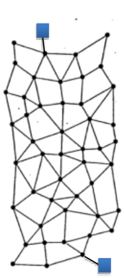
- 1981: *End-to-End Arguments in System Design*
- Do not put functions in network if help from the ends is needed
  - E.g., encryption, duplicate message detection, message sequencing, guaranteed message delivery, detecting host crashes, and delivery receipts

End-to-end: Salzer, Reed & Clark, contd.



- E.g., integrity detection must be end-to-end (application to application) because corruption can happen anywhere, including in the end computer
- E.g., encryption needs to be end-to-end if everything in the path (including the OS) is not perfectly trustable

End-to-end: Salzer, Reed & Clark, contd.



- Taken to mean:
  - Communication not dependent on per-session state in network
  - The network just delivers the packets
  - The network does not handle different packets differently
    - Unless the end system asks it to e.g., QoS bits in the packet

End-to-end: David Isenberg


David Isenberg

- *Rise of the Stupid Network* – 1997
  - An end-to-end net is "stupid"
- Compared phone network's *Intelligent Network* to the Internet
  - Network (i.e., carrier-based) services slow to change
  - Voice is not all there is
  - Carrier gets in the way
  - Just "deliver the bits" works

End-to-end: But #1: ISP business model

- A "stupid network" is a commodity service
  - The price of a commodity service is driven by the stupidest vendor
  - New network infrastructure is very expensive
  - i.e., hard for ISPs to make money delivering commodity services
    - or so the carriers insist
- Above would be true if there were actual competition

End-to-end: But #1: rider's business model


Mark Gaynor

- Mark Gaynor's Harvard PhD thesis
- Much easier to experiment in an e2e environment
  - Where "experiment" is a new application
- Network-based experiments require significant business justification
  - No justification required for e2e

Market-uncertainty (MU) effect

MU rules!

- Having many experimenters particularly important when it hard to know what the user will buy
  - All offerings look the same in a low-MU environment
    - All vendors have what the customer wants
    - Compete on price – little profit
  - High MU is where you have to guess & offerings are different
    - Compete on features – large profit for winner

End-to-end: But #2: Quality of Service

QoS

- A “stupid network” can not support traditional quality of service
  - Traditional QoS is session-based
    - Dedicate capacity to a user at session start
    - Give “busy signal” if not enough capacity for new sessions
  - Internet has no inherent way to dedicate capacity to a user & no busy signal

End-to-end: But #2, reality check

- The Internet (generally) works too well to require QoS
  - E.g., Skype

The Internet is not reliably crappy enough. —Scott Bradner


Mike O'Dell

It fails to fail often enough so it looks like it works. —Mike O’ Dell

End-to-end: Network neutrality

- Refers to the level of control the ISP has over the use of, and billing for, the network
- A neutral network just blindly transports packets
  - The operator of a non-neutral network might charge differently for different applications, might handle traffic from different sources differently (including blocking some sources)
- Regulatory/legal issue

End-to-end: But #3, security

- A stupid network leaves end system security to the end systems
  - Network can not help without spying on traffic
    - ISP may want to do that for business reasons
    - Regulators may want to help users & require this
    - Spying can be made harder if the traffic is e-2-e encrypted
- Internet infrastructure also under attack

Conceptualization problem

- Telecom experts and Regulators still have a hard time accepting packet-based networks
  - Try to fix by adding circuits (ATM, MPLS)
- *Bell-heads vs. net-heads*
  - Wired article
- *You can not build corporate network out of TCP/IP*
  - IBM circa 1992

Telecom mental image of the Internet

- Just as bumblebees "can not fly"
- So the Internet "can not work"
- Except that it does

16

The Future of the end-to-end model

- Pure e2e model is a thing of the past
  - Middleboxes (firewalls, NATs, etc.)
  - That does not mean that its not an important idea
- At least ISPs should be transparent
  - Tussle issue: that may not be in their short-term economic interest

17

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18

Internet History and Concepts

The Hourglass Model

CSCI E 45a: The Cyber World – part A

1

Internet protocol design philosophy


Dave Clark

- Dave Clark: *The Design Philosophy of the DARPA Internet Protocols* – 1988
- Fundamental goal:
  - Run over existing networks
- Did not assume:
  - That a new network was needed
  - That networks were run by one organization
  - Homogeneous network technology

2

Internet protocol design philosophy

IEEE 802.3

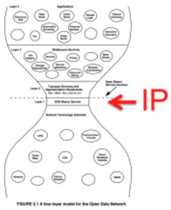
Wifi

A Member of The ATM Forum

- Did assume
  - Multiplexing with packet switching technology
  - Many networks
  - Store and forward gateways between networks
- Meeting this goal required development of a standard packet format and function
  - A "bearer service"

3

IP as a bearer service



- IP provides a consistent network layer for applications to use
  - Hides differences in underlying network technologies
- Means applications need not know about changes in network technologies
  - Also means that network special features are unavailable to the applications

4

IP as a bearer service, contd.

IP over foo

- Just need to define how IP runs over a new network technology to support all Internet applications and functions – e.g.
  - IP over IEEE 802 (RFC 1042)
  - IP over ARCNET (RFC 1051)
  - IP over ATM (RFC 1932)
  - IP over HIPPI (RFC 2067)
  - IP over Optical Nets (RFC 3717)
  - IP over InfiniBand (RFC 4391)
  - IP over IEEE 802.16 (RFC 5692)
  - (IP over Avian Carriers RFC 1149)

5

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4	Hourglass diagram: Realizing the Information Future
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6

Internet History and Concepts
Internet Architecture

CSCI E 45a: The Cyber World – part A

Terminology

- Customer network:
  Network at a customer (e.g. Harvard) site
- Internet Service Provider (ISP)
  A provider of Internet connectivity
- ISP connection
  Connection between a customer network an an ISP
- ISP peering
  Connection between two ISPs

Customer connectivity

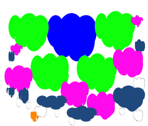

Bob Metcalfe

- Customers pay their ISP for access to "the Internet"
- Connection usefulness determined by coverage
  "Metcalfe's Law": value of network increases by square of the number of reachable nodes
- Customer can (in theory) move business to another ISP if they do not like the service
  But switching ISPs can be complex and expensive

Customer connections

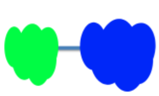
- A customer is another network that pays an ISP to get “the (whole) Internet”
- Smaller customers generally pay a flat rate based on the connection speed
- Larger customers pay for the cost of the link plus a fee based on monthly traffic
- A customer can be a end site or another ISP

ISP connectivity



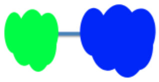
- The Internet is composed of many individual ISPs
  - 10s of thousands
- So to provide “the Internet” ISPs need to interconnect
- But all interconnections are not equal
  - Different business arrangements and reachability
    - Customer connection
    - Peer connection

Peer connections



- “peering” is a confusing term
- It can mean different things
  - Two routers “peer” when they exchange routing information
  - Two ISPs “peer” when they agree to exchange traffic
  - “Settlement-free peering” is where two ISPs agree to share the cost of exchanging traffic
- Peering, of any type, is a business decision
  - No current US regulations cover it

Peering

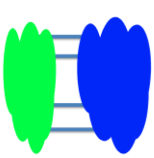


- ISPs engage in settlement-free peering to save money
  - Small ISPs peer to offload traffic so they do not have to pay a bigger ISP to transport it
  - Large ISPs peer so they can simplify accounting and billing
- Peering is a decision that is locally-optimized for the ISPs involved
  - What is best for the Internet, as a whole, does not enter into it

Internet exchange points (IXPs)

- Some ISP connections are at Internet exchange points
  - Both customer and peering
- IXPs are level 2 interconnects
  - E.g., Ethernet
  - 1st major one: MAE East
    - Metropolitan Area Exchange, East
- More than 200 around the world
- Allow local traffic to stay local
  - E.g. within a region or country

Private peering



- A lot of ISP peering is private
- At hosting centers or other places that ISPs lines get near each other
- ISPs generally have multiple interconnections with other ISPs
  - But sometimes only a single connection to a customer

Settlement-free peering

- Two ISPs can agree to interconnect, sharing costs
  - 'you buy and run 5 connections to me and I will buy and run 5 connections to you
  - Peering list normally private
- ISPs have minimum criteria before peering will be considered, including:
  - Minimum level of interconnect traffic, traffic balance, backbone size, & geographic scope

10

Settlement-free peering, contd.

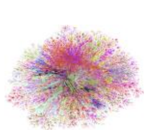
Customer

Peer

- Limited reachability through settlement free peering
  - Can only reach the peer's own addresses and the addresses of its customers
  - Can not reach the addresses of its peers
- i.e., this does not provide access to "the (whole) Internet"
  - Other peering or buying "customer" service is also required

11

Internet interconnection pattern



- No specific pattern of ISP interconnections
  - Other than that peering tends to be between networks of the same general size
    - But not always - can have business reasons for mismatch
- Peering and transit connections can appear random
  - Thus the Internet architecture appears random

12

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Internet History and Concepts
Conclusion

CSCI E 45a: The Cyber World – part A

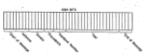
10 Decisions that made a difference

- Support existing networks
- Datagram-based
- Creating the router function
- Split ITCP into IP and TCP
- DARPA fund Berkeley to add TCP/IP to UNIX
- CSNET and CSNET/ARPANET deal
- NSF require TCP/IP on NSFnet
- CCITT turn down TCP/IP standardization
- NSF Acceptable Use Policy (AUP)
- Minimal regulation

1. Support existing networks

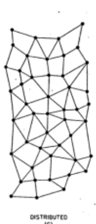
- Use whatever underlying technology that existed
- Did not have to build a new special network
- Support new network technology when it shows up

2. Datagram-based



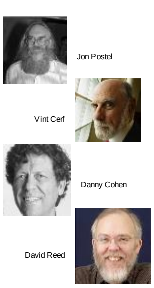
- Made no assumptions on the reliability of the underlying network
- Did not assume circuit switched
- Provided high reliability in the face of link or node failure

3. Creating the router function



- Link networks together
- Provide managerial isolation
- Provide control boundary
- Dynamically determined reachability
  - Reroute on link failure

4. Split ITCP into IP and TCP



Plus John Schoch

- Make reliability an option
  - Did not assume that all applications require reliable transport
- Enabled support for voice
- Enabled support for streaming audio and video

5. DARPA fund Berkeley to add TCP/IP to UNIX

- Made full network stack available for very little money
- Enabled almost all equipment vendors to support a full network stack
- Established TCP/IP as the standard interoperable networking protocol suit

6. CSNET and CSNET/ARPANET deal


Larry Landwebber

- Enabled extending ARPANET email access to entire university
- Started to educate generations of students about the power of email
- Students demanded access to the networks when they got jobs after graduation

7. NSF require TCP/IP on NSFnet

- NSF did not allow proprietary protocols on NSFnet
- Thus vendors who had customers who wanted to use the NSFnet had to support TCP/IP

8. CCITT turn down ITCP

- Internet protocol development would have been taken over by a teleco-dominated standards body
- Telephone companies did not believe in the datagram or end-to-end concepts
- CCITT/ITU Standardized technologies would likely have assumed carrier operation

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9. NSF Acceptable Use Policy (AUP)

- NSF did not permit commercial traffic on the NSFnet
- Nor did the ARPANET
- Forced the creation of commercial Internet service providers
- Thus they were ready to take over when the U.S. government stopped funding NSFnet

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10. Minimal regulation

- Telecom regulators stifled innovation in telephone networks
  - E.g. Hush-A-Phone
- Regulators keeping their hands off permitted endless experimentation and innovation

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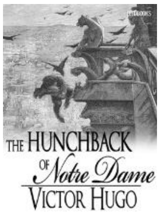
The result



- E2e Internet, and open computer operating systems, are *generative*
  - Enable innovation by others
  - "*permissionless innovation*"
- Impact society by moving or eliminating control points
- The Internet is a "*parent revolution*"

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