EEE 4121F-
Module B

Modern Networks

Q: What is one of the World's Greatest Inventions?

A: The Internet!

- One of the most influential inventions
  - Today: 4.66 billion users
  - Today: 27.1 billion connected devices

- Constant innovation
  - Apps: Web, Instagram, Youtube, ...
  - Links: fibre optics, WiFi, 4G/5G, ...

The Internet has changed EVERYTHING

- The ways we do business
  - EFTs, Takealot, Amazon, cloud computing, bitcoin...
- The way we have relationships
  - E-mail, WhatsApp, Facebook, Tinder...
- How we think about law
  - Privacy concerns? Lawful interception? Wikileaks?
- The way we govern
  - E-voting and E-government
  - Censorship
- The way we fight
  - Cyber-spying, Cyber-attacks, including nation-state attacks

But what is networking?

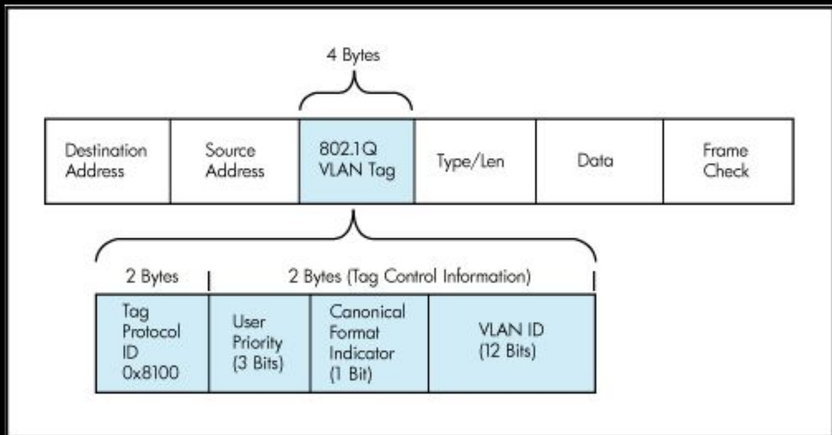
https://www.khanacademy.org/computing/computer-science/internet-intro/internet-works-intro/v/what-is-the-internet

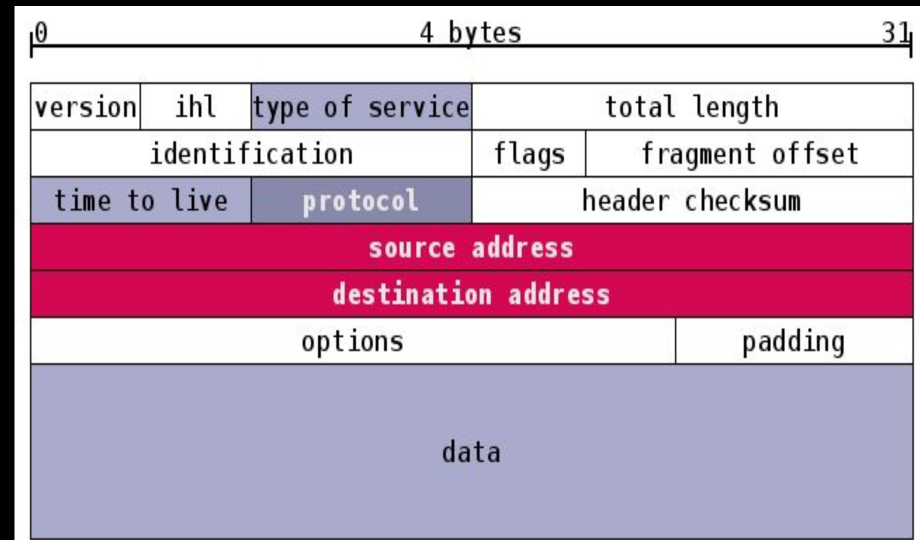
The Internet Today

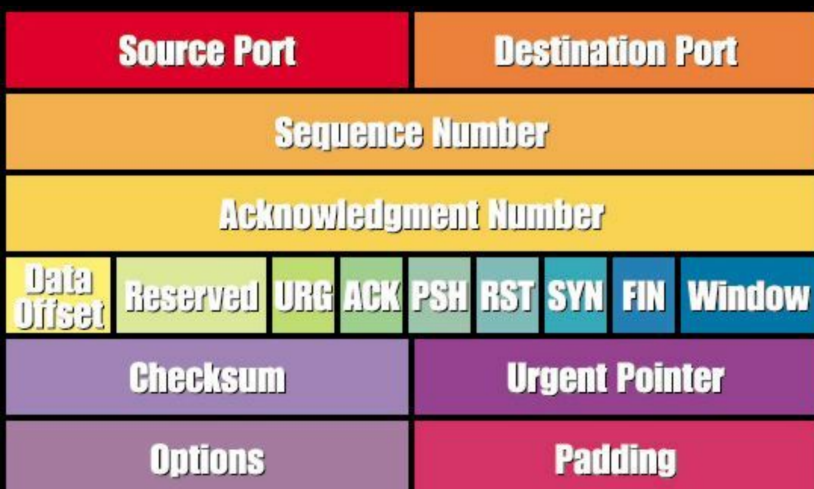
So many acronyms

SNMP
WAP
SIP
PPP
IPX
MAC
LLDP
FTP
UDP
OSPF
RTP
ICMP
IMAP
IGMP
HIP
BGP
PIM
RED
HTTP
ARP
ECN
IP
RIP
MPLS
TCP
RTCP
SMTP
RTSP
BFD
CIDR
NNTP
SACK
TLS
NAT
STUN
DNS
SSH
DHCP
VLAN
VTP
LDP
POP
LISP
TFTP

Headers and Trailers







HTTP Response Header

Name	Value
HTTP Status Code: HTTP/1.1 200 OK	
Date:	Thu, 27 Mar 2008 13:37:17 GMT
Server:	Apache/2.0.55 (Ubuntu) PHP/5.1.2
Last-Modified:	Fri, 21 Mar 2008 13:57:30 GMT
ETag:	"358a4e4-56000-ddf5c680"
Accept-Ranges:	bytes
Content-Length:	352256
Connection:	close
Content-Type:	application/x-msdos-program

Network Boxes

Router

Label Switched Router

Load balancer

Switch

Scrubber

Repeater

Gateway

Intrusion Detection System

Bridge

Route Reflector

Deep Packet Inspection

DHCP server

Packet shaper

Firewall

NAT

Hub

Packet sniffer

WAN accelerator

DNS server

Base station

Proxy

A place to apply theory?

- Algorithms and data structures
- Control theory
- Queuing theory
- Optimization theory
- Game theory and mechanism design
- Formal methods
- Information theory
- Cryptography
- Programming languages
- Graph theory

A place to build systems?

- Distributed systems
- Operating systems
- Computer architecture
- Software engineering
- …

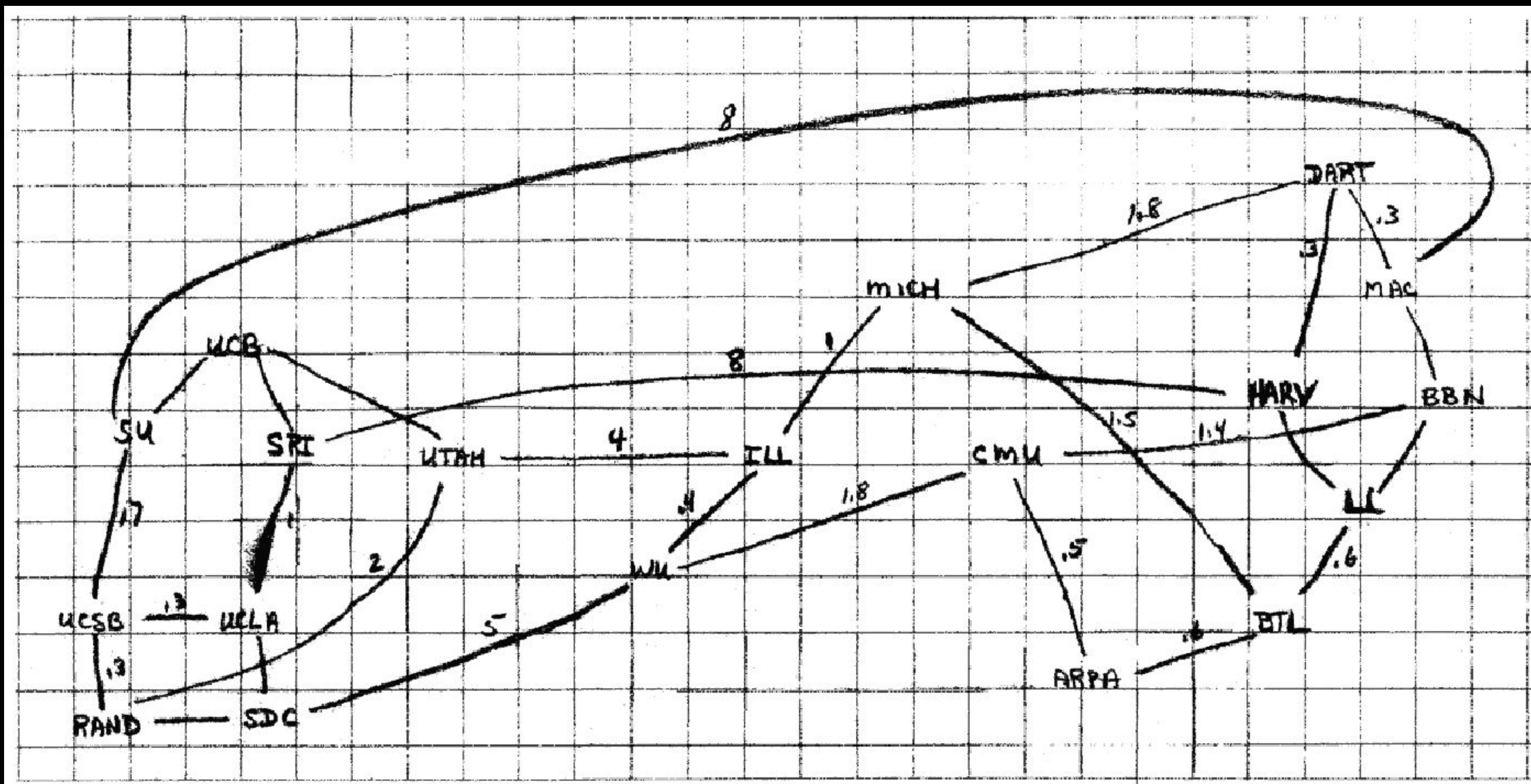
But how did it start?

A Brief History of the Internet

- **ARPAnet**
  - Conceived in 1966/67 to connect big academic computers together.
  - First operational ARPAnet nodes in 1969
    - UCLA, SRI, UCSB, Utah
- **NPLnet**
  - Around the same time, at the National Physical Laboratory in UK.
- Around 20 US Arpanet nodes by 1971
  - First host-to-host protocol.
  - Two cross-country links - all at 50 Kbps

ARPAnet plan

Rough sketch by Larry Roberts, late 1960s.



International Networking

- First proposed to link NPLnet and ARPAnet in 1971.
  - Use link through UK to seismic array in Norway.

- UCL connected in July 1973, via a link to Norway, and onward satellite link to ARPAnet.

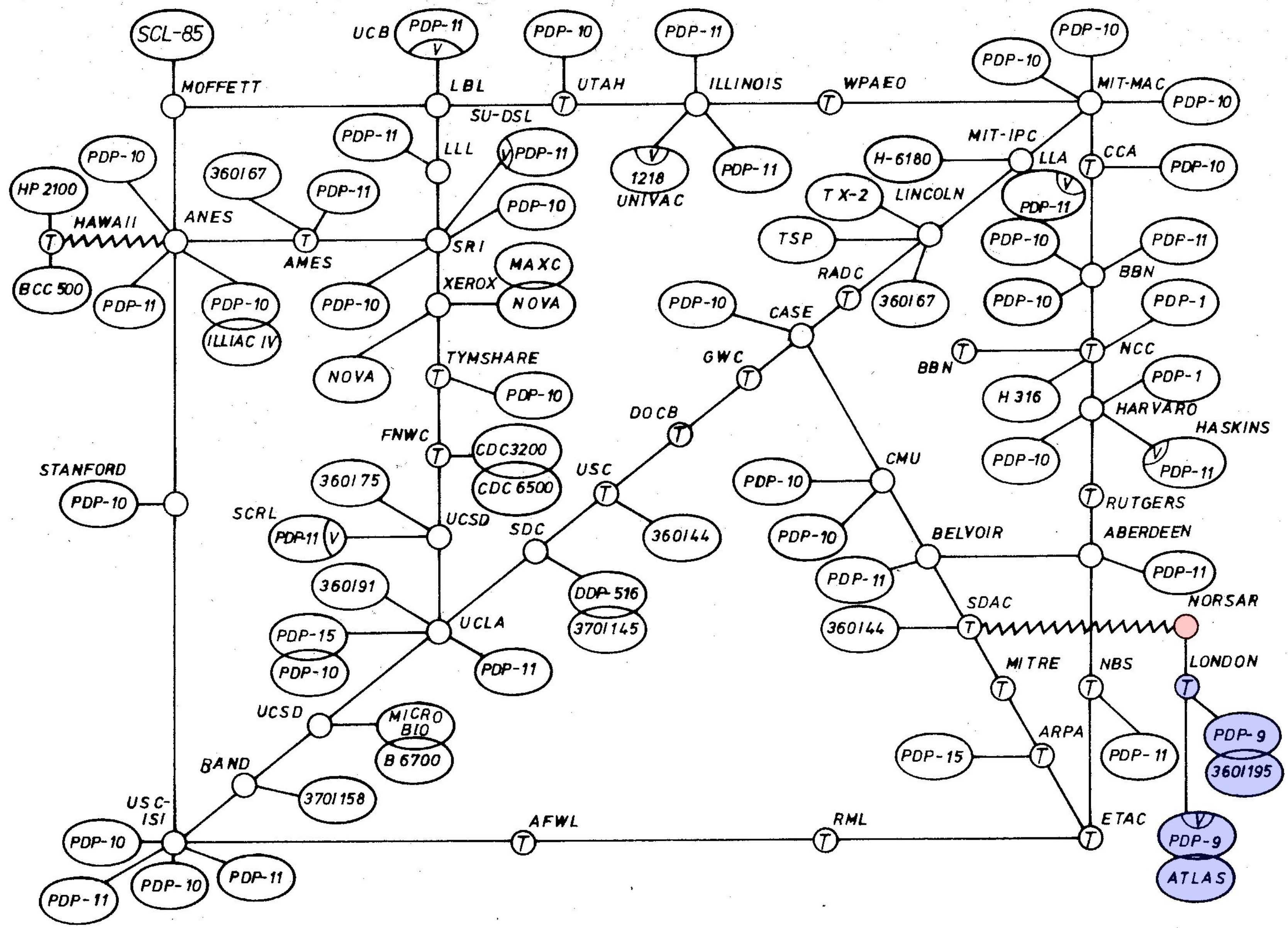


Abb. 4 ARPA NETwork, topologische Karte. Stand Juni 1974.

Towards an Internet

- ARPAnet wasn't the only network.
  - SATNET over satellite.
  - Packet Radio networking.
  - Ethernet Local Area Networks.
- Work started in 1973 on replacing the original Network Control Protocol with TCP and IP:
  - IP: Inter-network Protocol
  - TCP: Transmission Control Protocol.

Transition to TCP/IP

- TCP/IP:
  - Standardized in 1978-1981
  - Included in Berkeley UNIX in 1981.
- 1st Jan 1983: Flag Day
  - ARPAnet transitions to TCP/IP
  - Already in use on satellite and packet radio nets.

Technical Milestones

- Domain Name System (1982)
  - replaced hosts.txt file containing all the worlds machine names.
- TCP Congestion Control (1988)
  - net suffered a series of congestion collapses
- NSFnet and BGP inter-domain routing (1989)
  - Support for routing policy.

“New” Applications

Email, remote terminal access (telnet) and file transfer (ftp) were the original ARPAnet applications.

- **Audio/video** (1992...)
  - Telephony, conferencing, streaming media.
- **World Wide Web** (1993...)
  - browsing a mesh of hyperlinks.
- **Peer-to-peer** (2000...).
  - File sharing

What about South Africa?

South African History

1987: Pushed by a need for inter-connectivity, the scientific community starts the UNINET project, with plans to virtually connect sites at universities across the country.

1988: An informal team of Rhodes students, led by **Mike Lawrie,** band together to work on establishing the first internet network in South Africa. Using donated and salvaged equipment, they build their own gateway. Rhodes receives its first IP address.

South African History of Networking

1989: UNINET is fully in place, allowing the Rhodes gateway to work as a carrier for e-mail.

1990: The first TCP/IP connection is attempted, trying to link the mainframes at Rhodes and UCT via UNINET. After successfully linking UCT and Rhodes, further TCP/IP links are established between universities across SA. The ZA domain is registered.

South African History of Networking

1991:

- Telkom is officially established; refuses to install and lease a line to the USA because of costs involved.
- Dial-up costs are 3 times more than what is considered standard at the time, with Rhodes racking up bills in the thousands.
- Despite the challenges, the first internet protocol connection to Portland, Oregon, USA is made.
- The Penril Modems used, pushed the data rate from SAPT (Telkom) modems' maximum of 9,6 kbit/s to a whopping 14,4 kbit/s.

South African History of Networking

1992:

- Due to slow data speeds, response times at late-night hours are over 5 minutes.
- The “ZA” domain causes ‘domain storms’ – with unresolvable ZA domains triggering multiple requests from remote hosts, which in turn trigger even more requests.
- Diagnostic problems are made worse, as systems and sites are isolated from each other in terms of communication.

South African History of Networking

1993

- The first commercial ISPs start forming.

1995

- The “co.za” domain is established, expanding national commercial internet. The domain is administered by UNINET, with ISPs being reluctant to take over the administrative function.
- ISPs meet in Braamfontein for the first time – reined by UniForum.

South African History of Networking

1996

- ISPA is founded.
- Technological advances, understanding and regulatory reform continue to develop, ushering in the next phase of the South African Internet network.

“While we may continue to lament the status quo of internet connectivity in South Africa; it’s good to look back and tip our collective hats to the pioneers of yesteryear, who went before and established the networks we get to complain about today.”

Original Design Philosophy

https://www.youtube.com/watch?v=h8K49dD52WA

Homework

Read the following paper on the original design goals of the internet (also summarized in the following slides)

David D. Clark, The Design Philosophy of the DARPA Internet Protocols, ACM SIGCOMM, Computer Communication Review Vol. 18, No. 4, 1988, 106-114.

(Answer the questions on the following page)

Assignment 0

1. What priority order would a commercial design have?
2. What would a commercially driven Internet look like?
3. What goals are missing from this list?
4. Which goals led to the success of the Internet?
5. How well has today's Internet satisfied these goals?

Fundamental Goal

Goal 0

- “technique for **multiplexed utilization** of **existing interconnected networks**”

- **Multiplexing** (sharing)
  - Shared use of a single communications channel
- **Existing networks** (interconnection)

Packet Switching

Fundamental Goal: Sharing

- No connection setup
- Forwarding based on destination address in packet
- Efficient sharing of resources

Tradeoff: **Resource management potentially more difficult.**

An Age-Old Debate

Circuit Switching

- Resource control, accounting, ability to “pin” paths, etc.

Packet Switching

- Sharing of resources, soft state (good resilience properties), etc.

It is held that packet switching was one of the Internet’s greatest design choices.
Of course, there are constant attempts to shoehorn the best aspects of circuits into packet switching.

Examples: ATM, IntServ QoS, etc.

Goal 1

- Internet communication must continue despite loss of networks or gateways.
- Network should continue to work, even if some devices fail, are compromised, etc.
- Survivability

How well does the current Internet support survivability?

Goal 1

Two Options

- Replication
  - Keep state at multiple places in the network, recover when nodes crash
- **Fate-sharing**
  - Acceptable to lose state information for some entity if the entity itself is lost

Goal 2

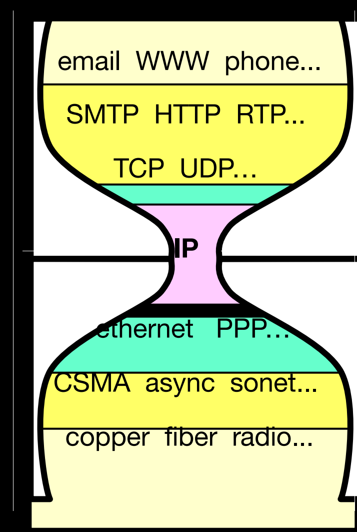
- The Internet must support multiple types of communication services.

Goal 3

- The Internet architecture must accommodate a variety of networks [underneath].

Goals 2&3

- Need to interconnect many existing networks
- Hide underlying technology from applications
- Decisions:
  - Network provides minimal functionality
  - ***"Narrow waist"***



Tradeoff: **No assumptions, no guarantees.**

Goals 2&3:

- Heterogeneous services
- TCP/IP designed as a monolithic transport
  - TCP for flow control, reliable delivery
  - IP for forwarding

- Became clear that not every type of application would need reliable, in-order delivery
  - *Example:* Voice and video over networks
  - *Example:* DNS
  - Why don't these applications require reliable, in-order delivery?
  - Narrow waist: allowed proliferation of transport protocols

Goals 2&3

- Heterogeneous Networks
- Build minimal functionality into the network
  - No need to re-engineering for each type of network
- “Best effort” service model.
  - Lost packets
  - Out-of-order packets
  - No quality guarantees
  - *No information about failures, performance, etc.*

Tradeoff: **Network management more difficult**

Goal 4

- The Internet architecture must permit distributed management of its resources.

Goal 4

Distributed Management
Many examples:

- Addressing (ARIN, RIPE, APNIC, etc.)
- Naming (DNS)
- Routing (BGP)

No single entity in charge.
Allows for organic growth, scalable management.

Tradeoff: **No one party has visibility/control.**

No Owner, No Responsible Party

"Some of the most significant problems with the Internet today relate to lack of sufficient tools for distributed management, especially in the area of routing."

- Hard to figure out who/what's causing a problem
- Worse yet, local actions have global effects…

Goal 5

- The Internet architecture must be cost effective.

Goal 5

Cost effectiveness

- Packet headers introduce high overhead
- End-to-end retransmission of lost packets
  - Potentially wasteful of bandwidth by placing burden on the edges of the network

Arguably a good tradeoff. Current trends are to exploit redundancy even more.

Goal 6

- The Internet architecture must permit host attachment with a low level of effort.

Goal 6

Ease of Attachment

- IP is “plug and play” Anything with a working IP stack can connect to the Internet (hourglass model)
- A huge success!
  - **Lesson:** Lower the barrier to innovation/entry and people will get creative (*e.g.,* Cerf and Kahn probably did not think about IP stacks on phones, sensors, etc.)
- But….

Tradeoff: **Burden on end systems/programmers.**

Goal 7

- The resources used in the internet architecture must be accountable.

Goal 7

Accountability

- **Note:** Accountability mentioned in early papers on TCP/IP, but not prioritized
- Datagram networks make accounting tricky.
  - The phone network has had an easier time figuring out billing
  - Payments/billing on the Internet is much less precise

Tradeoff: **Broken payment models and incentives.**

The Design Philosophy of the DARPA Internet Protocols

Goal 0: An "effective" technique for multiplexed utilization of existing interconnected networks.

Goal 1: Internet communication must continue despite loss of networks or gateways.

Goal 2: The Internet must support multiple types of communication service.

Goal 3: The Internet architecture must accommodate a variety of networks [underneath].

Goal 4: The Internet architecture must permit distributed management of its resources.

Goal 5: The Internet architecture must be cost effective.

Goal 6: The Internet architecture must permit host attachment with a low level of effort.

Goal 7: The resources used in the internet architecture must be accountable.

So why is networking “cool”

- It is relevant
  - Can measure/build things
  - Can impact the real world
- Interdisciplinary
  - Well-motivated problems + rigorous solution techniques
  - Interplay with policy and economics
- Widely-read papers
  - Many of the most cited papers are in networking
  - Congestion control, distributed hash tables, resource reservation, self-similar traffic, multimedia protocols,…

So why is networking “cool”

- Young, relatively *immature* field
  - Tremendous intellectual progress is still needed
  - You can help decide what networking really is
- Defining the problem is a big part of the challenge
  - Recognizing a need, formulating well-defined problem
  - … is at least as important as solving the problem.
- Lots of platforms for building your ideas
  - Testbeds: Emulab, PlanetLab, Orbit, GENI
  - Programmability: Click, NetFPGA, Mininet
  - Routing software: Quagga, XORP, and Bird
  - Measurements: RouteViews, traceroute, Internet2

Course Overview

Modern network technologies, protocols, architectures and applications

Goal: Understanding the current state of the art for research networks

Recommended Reading (Theory)

- Larry L. Peterson and Bruce S. Davie, *Computer Networks: A Systems Approach*, *5th Edition* Morgan Kaufmann, 2011.
- James Kurose, Keith Ross, *Computer Networking: A Top-Down Approach,6th /7th edition*, Pearson.
- Mischa Schwartz, *Broadband Integrated Networks*, Prentice Hall, 1996.

References

1. http://www.cs.princeton.edu/courses/archive/spring17/cos461/
2. http://web.stanford.edu/class/cs244/
3. www.khanacademy.org
4. https://mybroadband.co.za/news/internet/114645-the-history-of-internet-access-in-south-africa.html
5. https://dl.acm.org/citation.cfm?doid=205447.205458

Next time

Congestion…

Next Lecture: Congestion in Networks

- Congestion Control matches offered load to available capacity.
  - TCP congestion control has done this since 1988
- **Today’s network doesn’t look like it did in 1988, is TCP still good enough?**