Information Theory and Networks

Lecture 27: A Brief History of Networks

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Lecture_notes/InformationTheory/

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Processing delay

Section 1

Computer Networks

Computer pre-history

- The original "computers" were people
  - numerical algorithms performed with pencil and paper
  - later with mechanical adding machines
- Algorithms were often parallelized
  - multiple computers worked on same problem to speed up or check calculations
  - a "computer network" was result of passing bits of paper

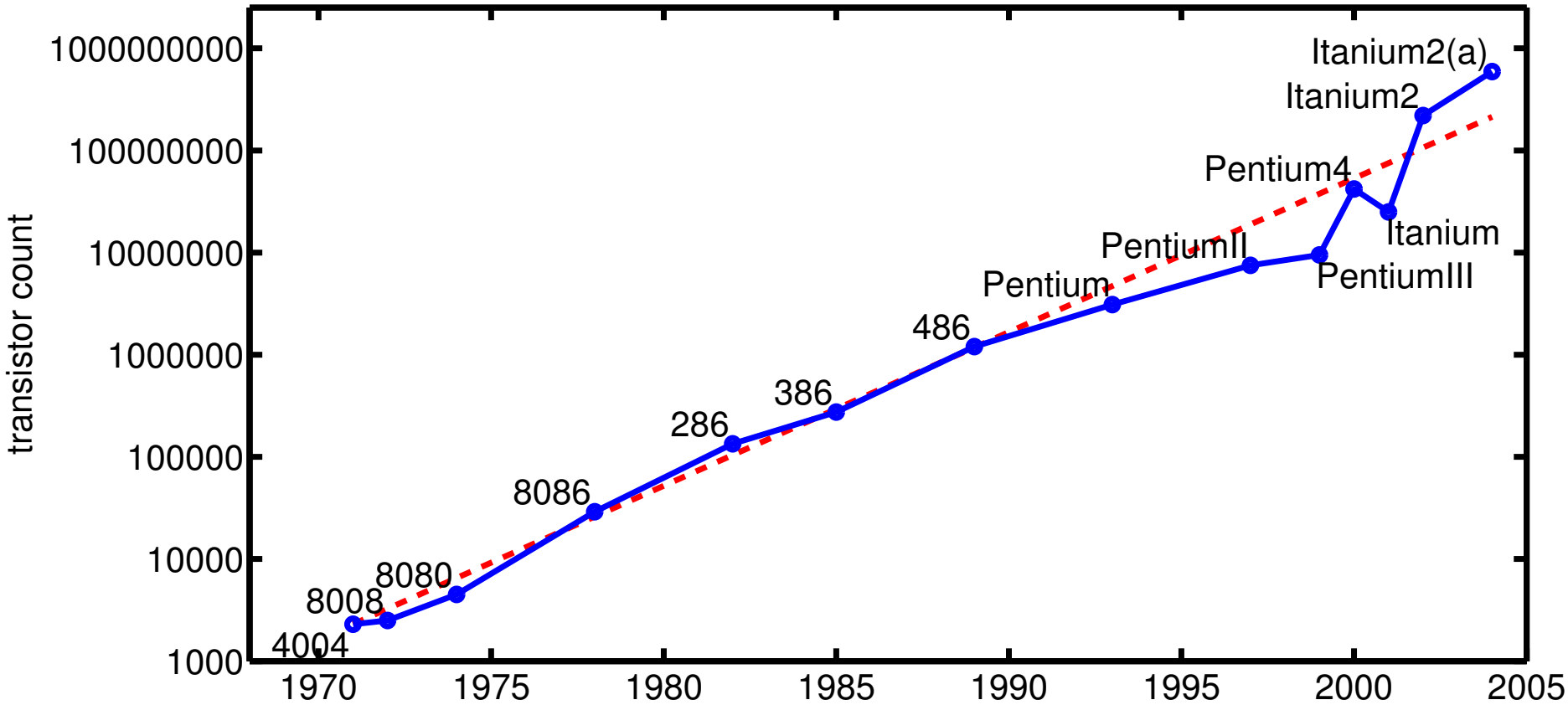
20th century

Computer networks:

- First generation of electrical digital computers 1940s
- Second generation – late 1950s and early 1960s
  - transistor invented in 1947 (at AT&T)
  - direct networks: peripherals such as printers directly attached to computers
- Third generation, post-1964
  - integrated circuits
  - real computer networks start
- 1965, Moore's law discovered
  - computers get better and better ...

Moore's Law

Moore's law: the speed of digital hardware increases by a factor of two every 18 months, or the number of transistors on a chip doubles, or the cost halves [Moo65].



Actually looks more like a factor of 2 every 2 years.

Gilder's Law

Gilder's law: theoretical transmission capacity of a link increases by a factor of two every 12 months.

- http://www.seas.upenn.edu/~gaj1/promise.html
- http://www.dtc.umn.edu/~odlyzko/doc/tv.internet.txt
- http://telecomvisions.com/articles/beyondip/
- transmission capacity is still behind storage
  - 2000, backbones in US carried 144 PB/year, total disk capacity 3000 PB
    - ★ it would take 20 years to carry all the data
  - 2005, 100 GB disk is common, 1.5 Mbps
    - ★ it would take 6 days to carry all the data
  - network is catching up?

Networking drivers

- Moore's law drives PC business
- Gilder's law drives networks
  - something suss here – lets discuss later
- Metcalfe's law also drives the Internet
  - The value of a network is proportional to the square of the number of users.
  - hence the failure of many "video-phone" trials
    - ★ but success of most recent "camera phones"

The Internet

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http://www.isoc.org/internet/history/brief.shtml

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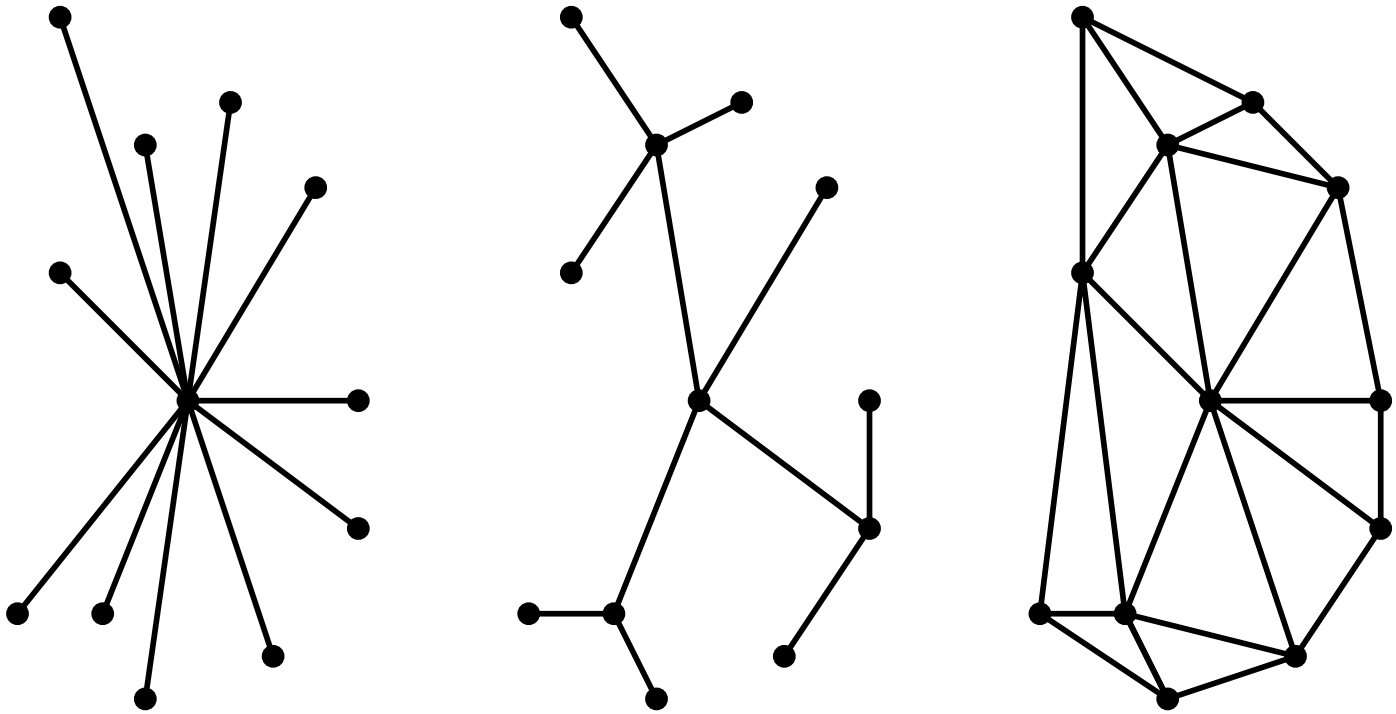

centralized **decentralized** **distributed**

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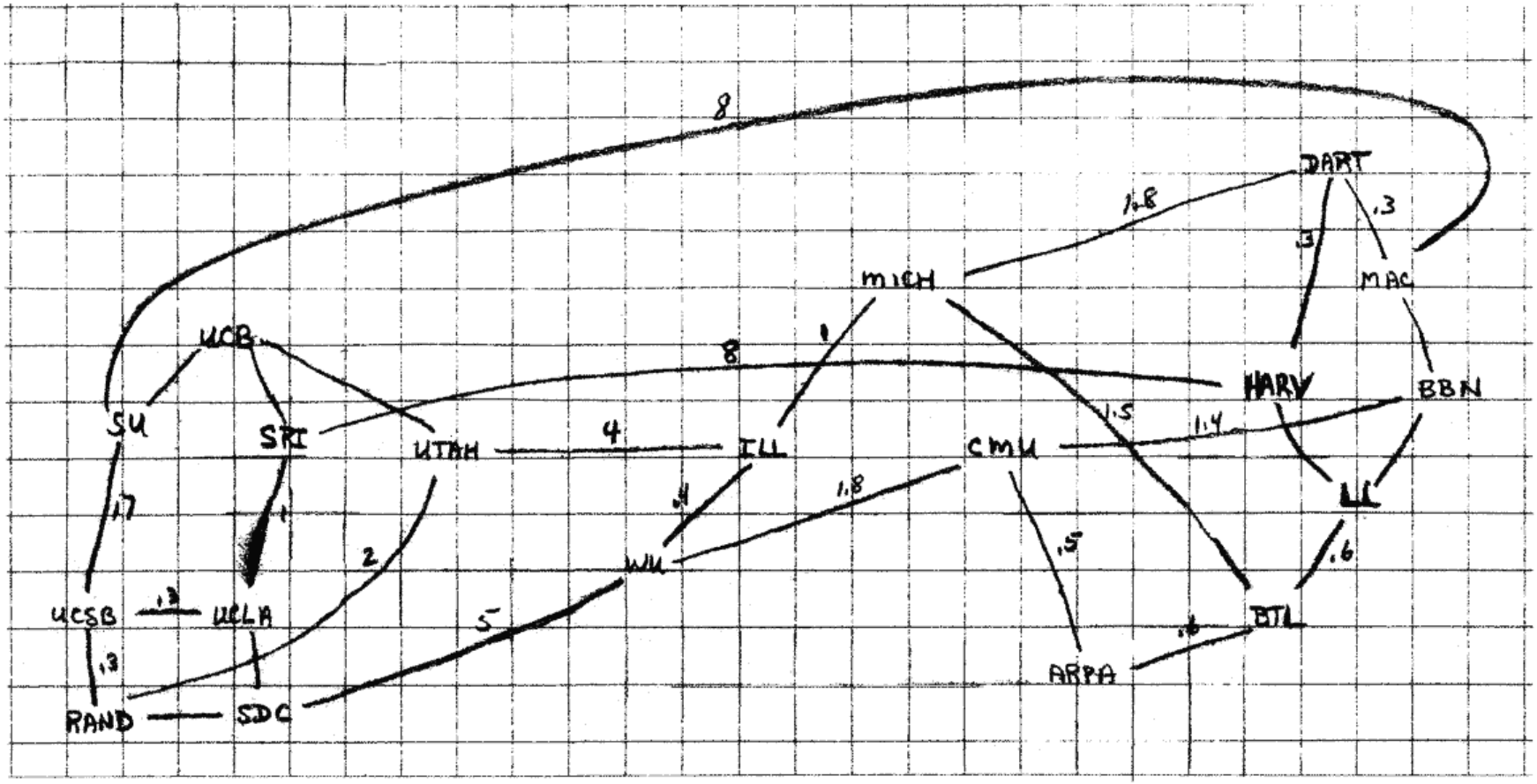

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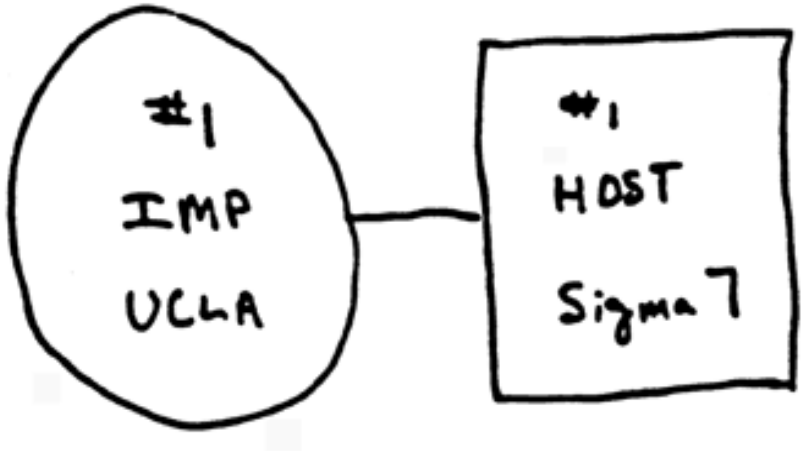

IMP = Interface Message Processor
what we would call a router
TIP = Terminal IMP
IMP to which terminals can directly connect
Host = computer (which provides services)

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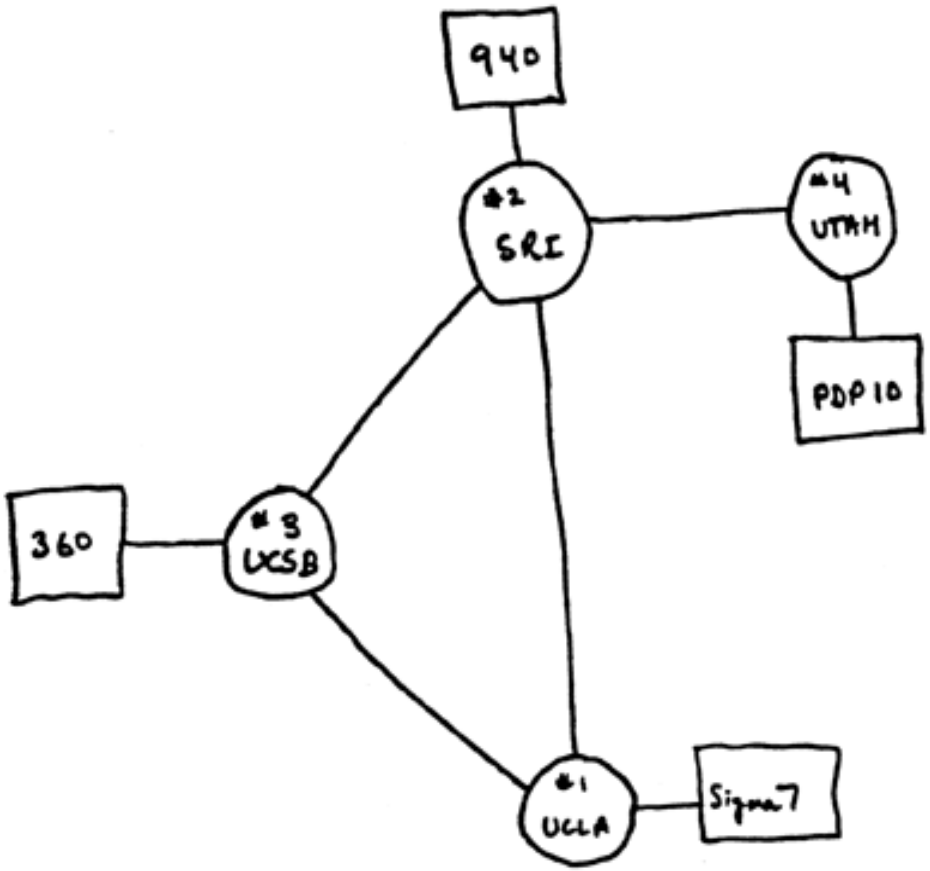

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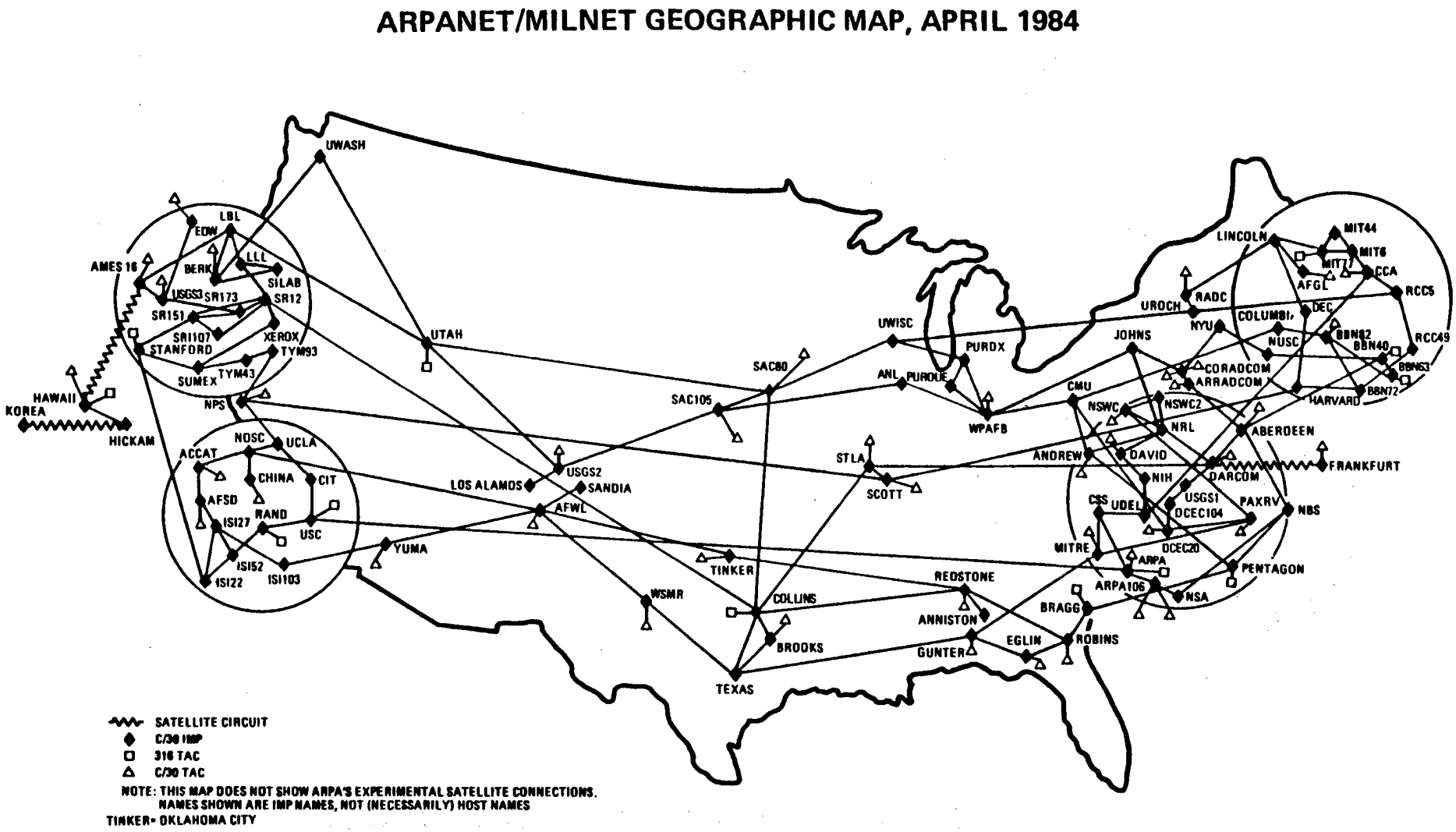
The Internet: the 80's

- new developments
  - Personal Computers (PCs)
    $\Rightarrow$ lots more computers to network
  - Ethernet (1973, Robert Metcalfe) creates LANs
- the Internet
  - TCP/IP provides a way to hook up the LANs and PC over wide areas (standard in 1980)
  - scale gets bigger
    - ★ numbers increase
    - ★ becomes international
  - partitioning
    - ★ ARPANET splits into MILNET and ARPANET in early 80's, followed by further additions

The Internet: the 80's

ARPANET/MILNET [CK90].



The Internet: the 90's

- ARPANET decommissioned 1990
  - NSF Backbone connects many other networks
    - ★ Australia connected in 1990 [Abb99]

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It was the first, and being first, was best,
but now we lay it down to rest.
Now pause with me a moment, shed some tears.
For auld lange syne, for love, for years and years
of faithful service, duty done, I weep.
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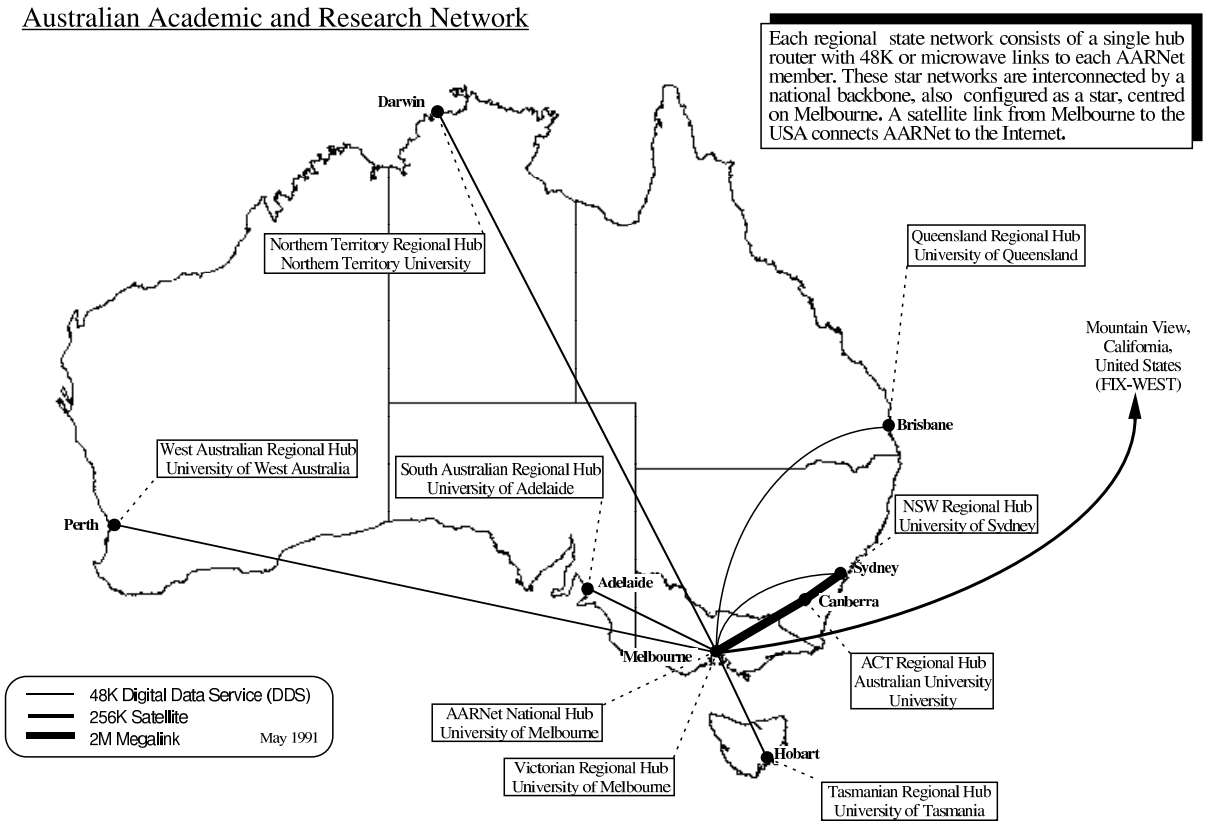
Vinton Cerf, 1989

- commercial Internet services evolve
  - 1995 NSFNET terminated (replaced by vBNS)
  - effectively fully privatised Internet
  - links through exchange points

The Internet: the 90's

Australia's network 1991



http://www.ucs.ed.ac.uk/fmd/unix/edftp/pub/maps/

New network
http://www.aarnet.edu.au/engineering/aarnet3/

The Internet: the 90's

http://www.w3.org/History.html

- 1990: World Wide Web
  Tim Berners-Lee created HyperText Markup Language, or HTML. Along with URL (Uniform Resource Locators), and HTTP (HyperText Transfer Protocol), created the web. Based on earlier work at CERN (1980).
- 1993: Mosaic (Marc Andreesen, NCSA)
  Mosaic became the first popular web browser. It was not only easy to use to access the World Wide Web, but it was also extremely easy to download and install!
- Killer app =¿ the Internet takes off in a big way

Early Internet Bandwidth Growth

All the time **backbone** link speeds have been growing

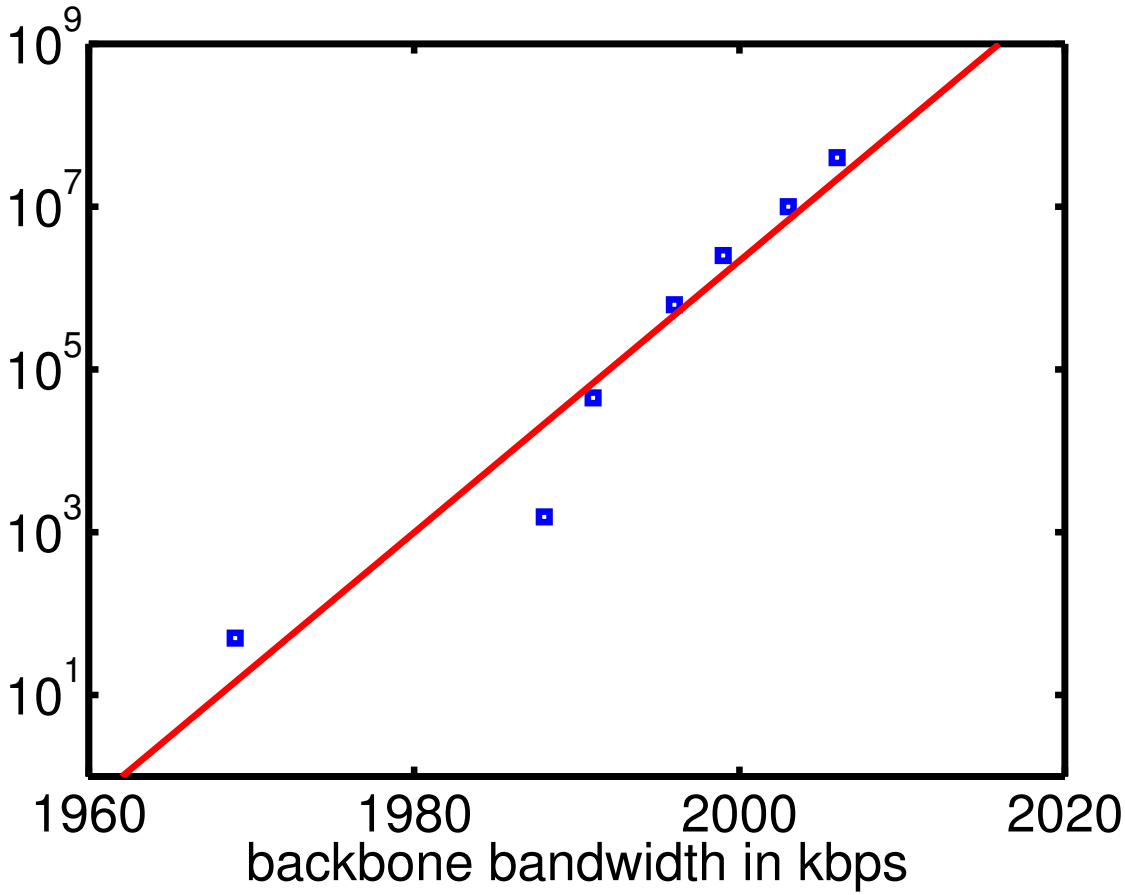
- 1969: 50kbps
- 1988: NSFNET backbone upgraded to T1 (1.544Mbps)
- 1991: NSFNET backbone upgraded to T3 (44.736Mbps)
- 1996: MCI upgrades Internet backbone 622Mbps
- 1999: MCI/Worldcom begins upgrading the US backbone to 2.5 Gbps (OC48)
- circa 2003: 10 Gbps (OC192)

Backbone speeds are behind limits of transmission tech.

http://www.zakon.org/robert/internet/timeline/

Backbone link speed growth

Roughly doubles every two years (45% per year)



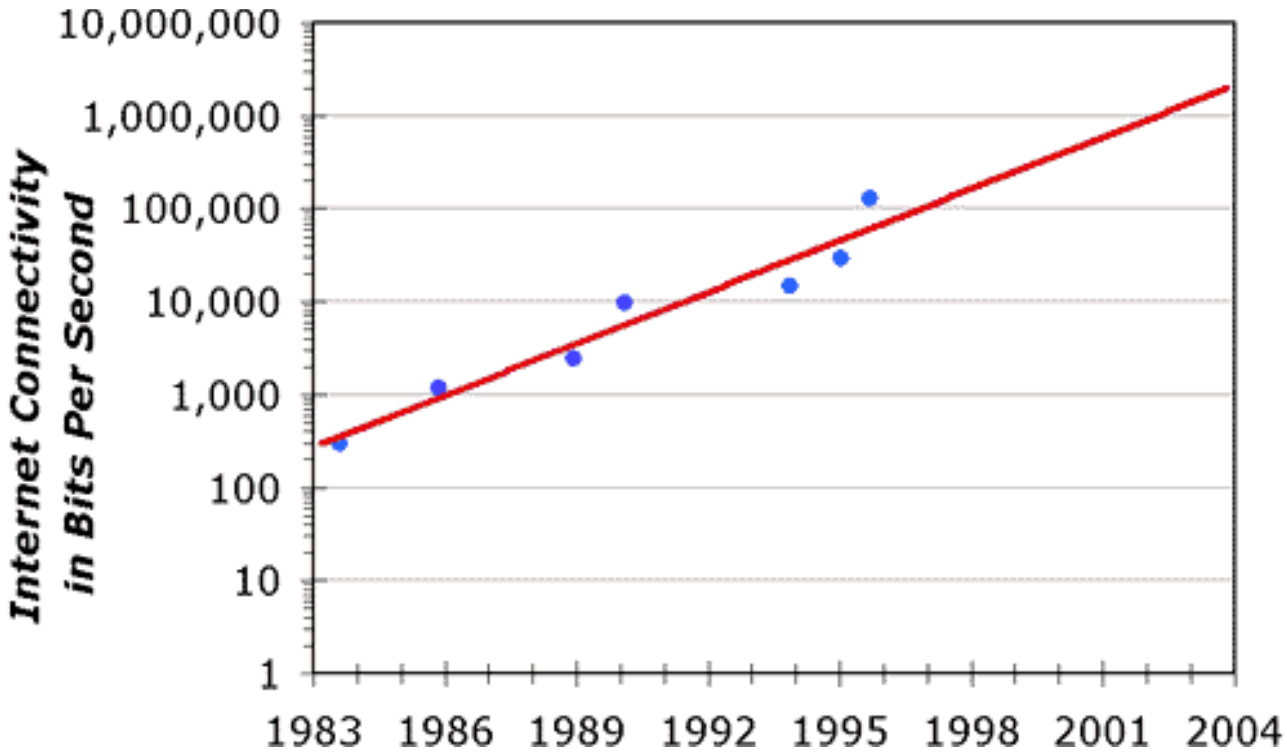
Backbone link bandwidth in kbps

Note that extra links are added every year

Early Internet Bandwidth Growth

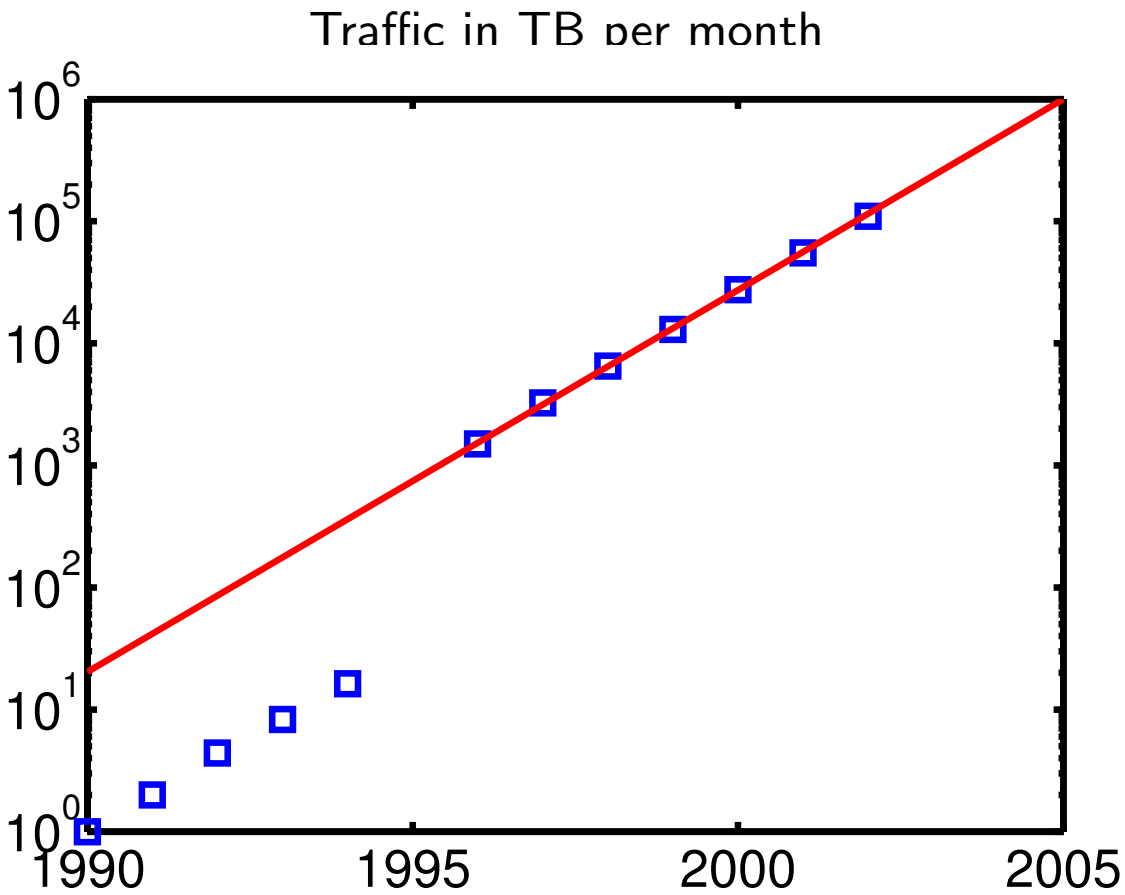
Access link speeds grow as well

- Nielsen's Law of Internet Bandwidth
  - a high-end user's connection speed grows by 50% per year
  - http://www.useit.com/alertbox/980405.html



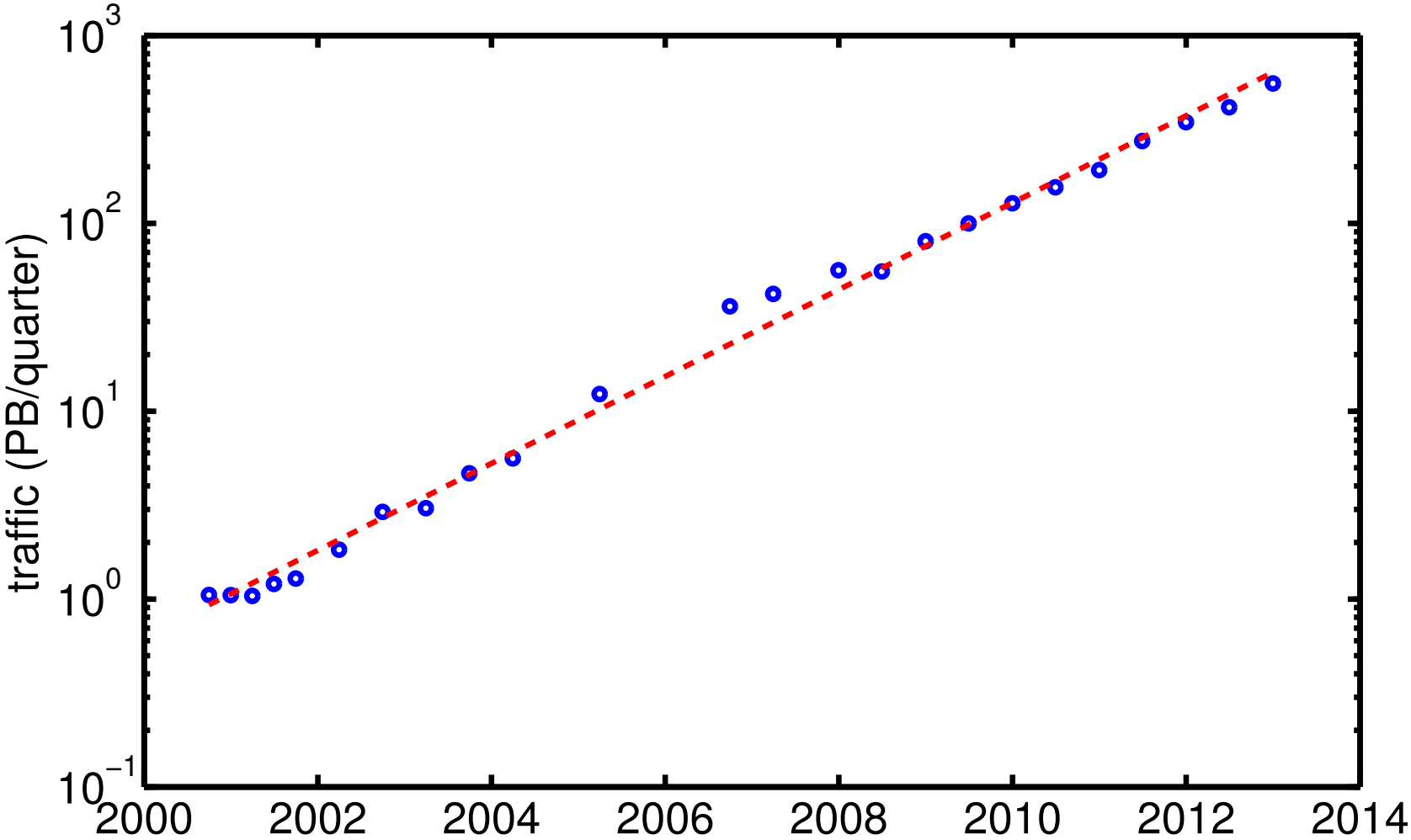
Internet Traffic Growth

Traffic roughly doubles every year [Odl03].



Combination of new users and higher bandwidth!

Australian Traffic Growth



www.abs.gov.au

Part I

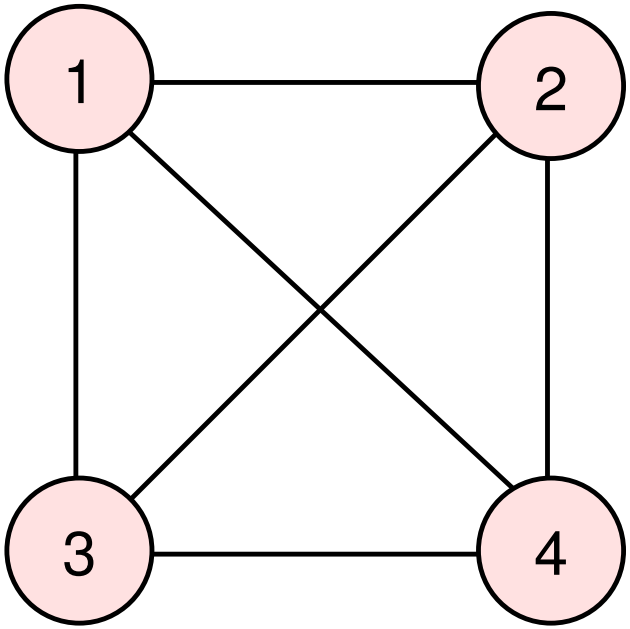
A Brief History of Communications Networks

You know what they say. Those of us who fail history, are doomed to repeat it in summer school.

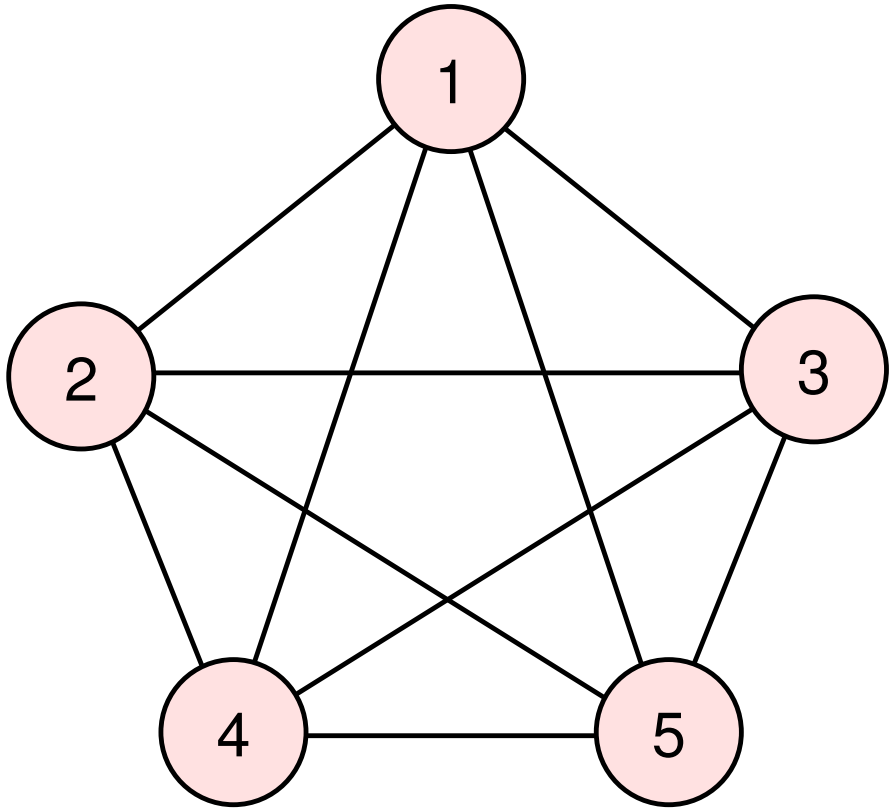
Buffy (the Vampire Slayer), "After Life" (Season 6, Ep. 3), 2001

Dumb network design

One link between every pair who wish to speak



N=4
L=6

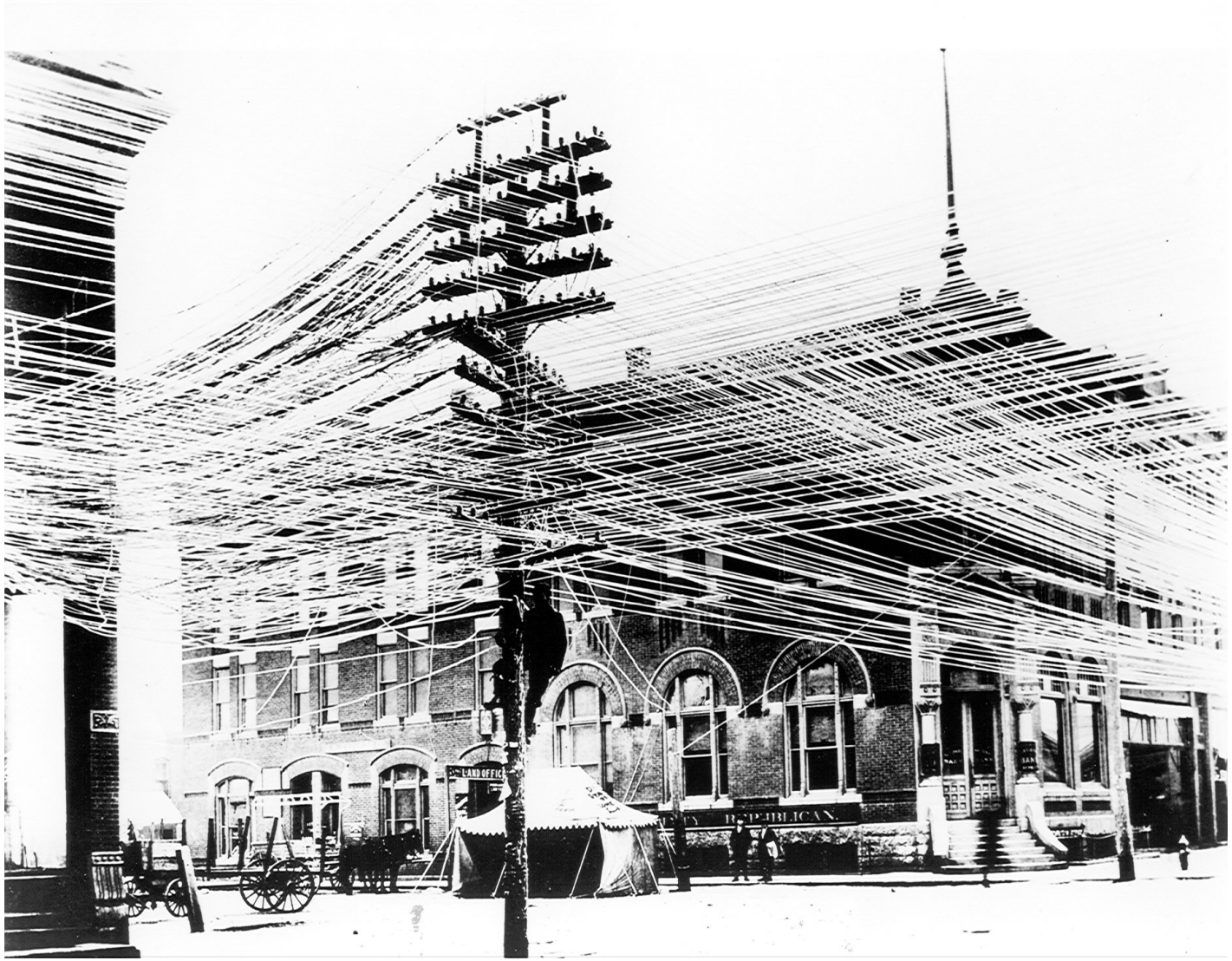


N=5
L=9

N nodes, then we have L=N(N-1)/2 links

Dumb network design

Pratt, Kansas



http://www.bellsystemmemorial.com/oldphotos_6.html

PUT BACK PARTS ON SWITCHING

Towards modern telephony

- switching
  - electronic switch (instead of electromechanical)
  - 4ESS (like a building)
    http://www.att.com/history/nethistory/switching.html
- networks become hierachical
  - long distance versus local
- reliability and redundancy become important
  - alternate routing
- billing systems
  - harder than you think!

Some additional links

More detailed telephony timelines can be found at

http://www.telephonetribute.com/timeline.html
http://www2.fht-esslingen.de/telehistory/
http://www.webbconsult.com/hist-time.html
http://www.ieee.org/organizations/history_center/comsoc/timelines.html
http://williamstallings.com/Extras/Telecom.html
http://aronsson.se/hist.html

Histories of computing and computer networks

http://en.wikipedia.org/wiki/Computing_timeline
http://www.isoc.org/internet/history/
http://www.isoc.org/internet/history/brief.shtml
http://www.dei.isep.ipp.pt/docs/arpa.html
http://www.zakon.org/robert/internet/timeline/
http://en.wikipedia.org/wiki/History_of_the_Internet
http://goldenink.com/computersandnetworks.shtml
http://www.davesite.com/webstation/net-history.shtml
http://www.computerhistory.org/exhibits/internet_history/
http://www.tranquileye.com/cyber/

Section 2

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The Early Internet

Kleinrock's insight [L.K61]

- computer traffic is bursty (it comes in spurts)
- more efficient to transmit packets of data on-demand than to reserve circuits between computers
  - setting up a circuit takes time (high latency)
  - keeping up a circuit set up is inefficient
    - not used most of the time
  - all you want to do is send one little chunk of data
    - example: typing – one character at a time
    - even a whole email is quite small
  - alternative: send data as packets

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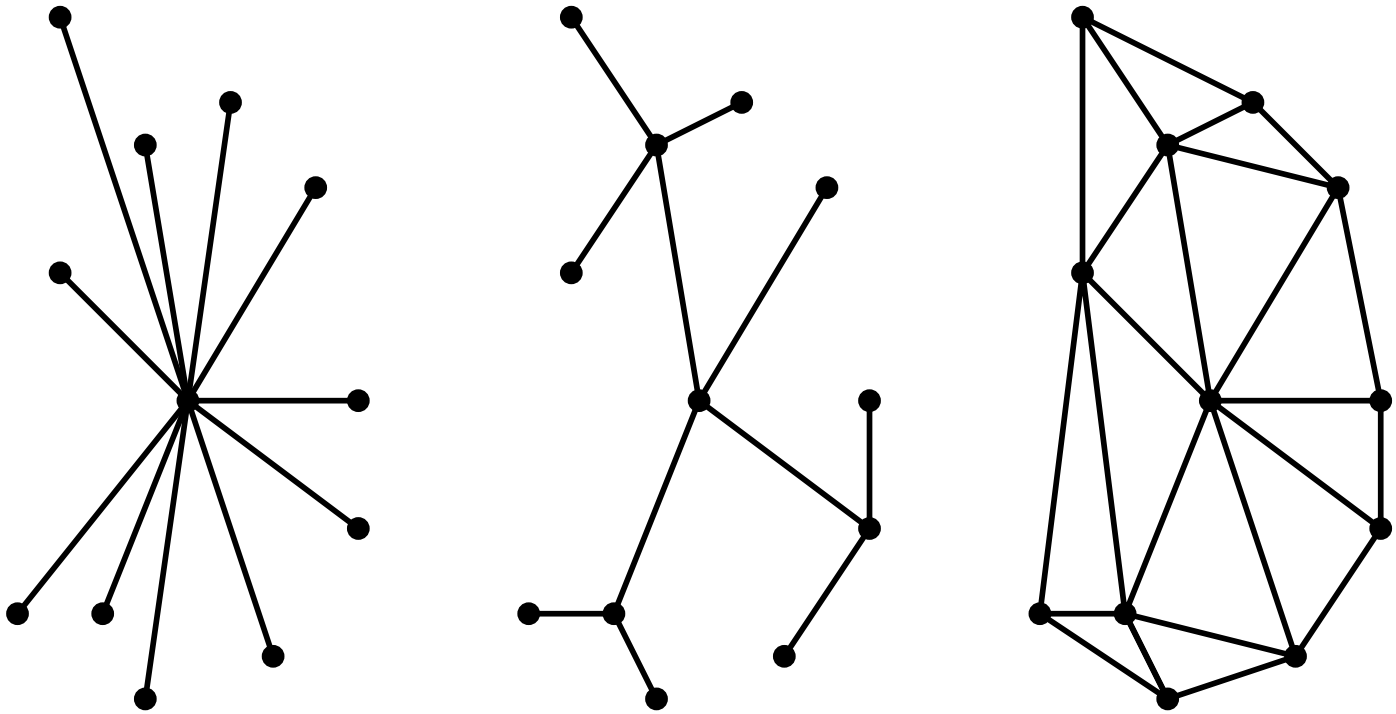

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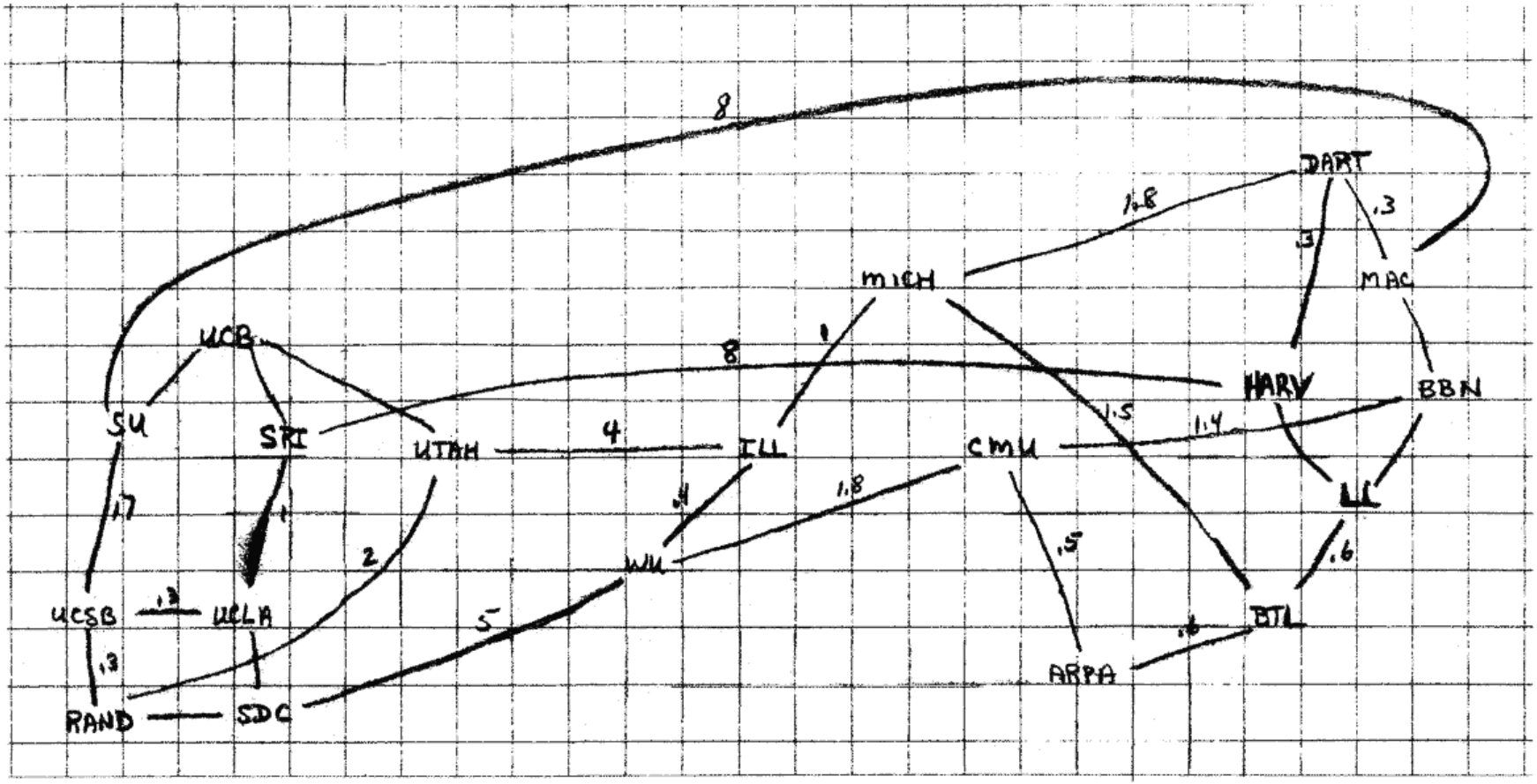

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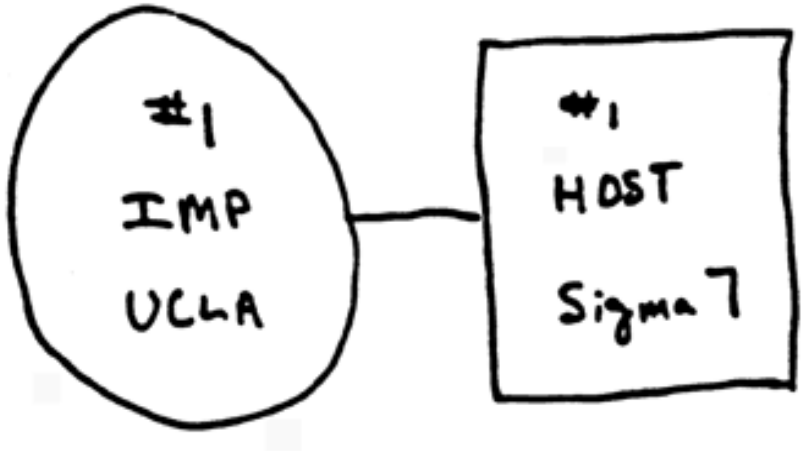

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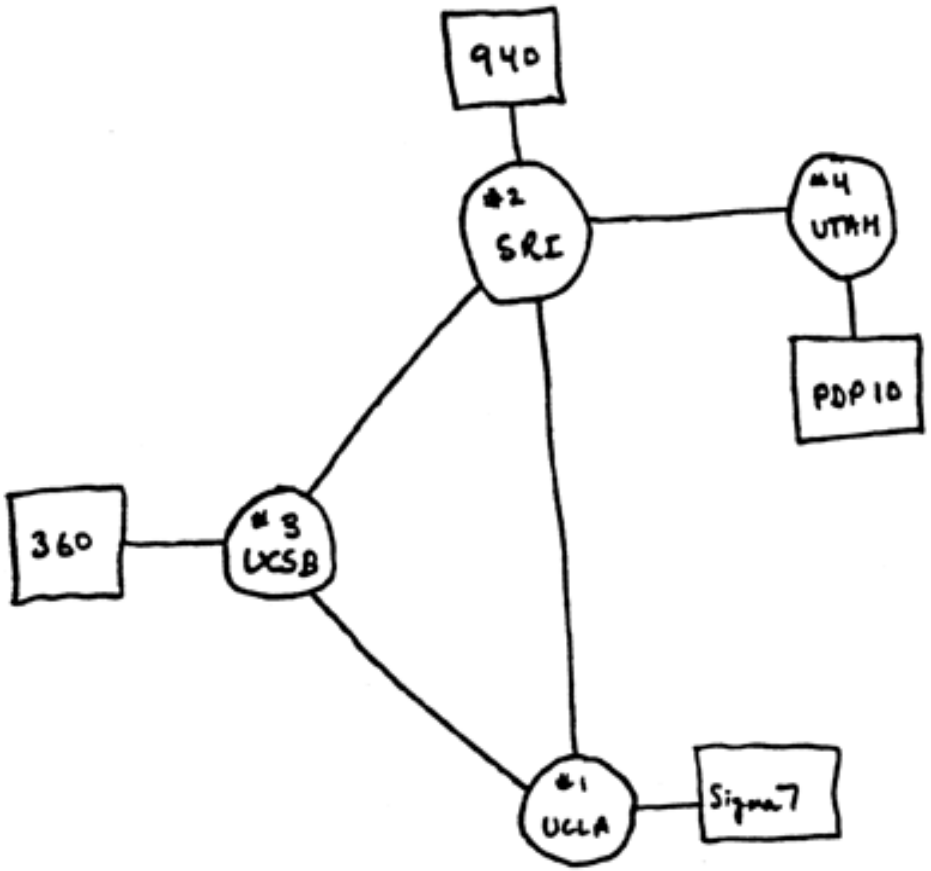

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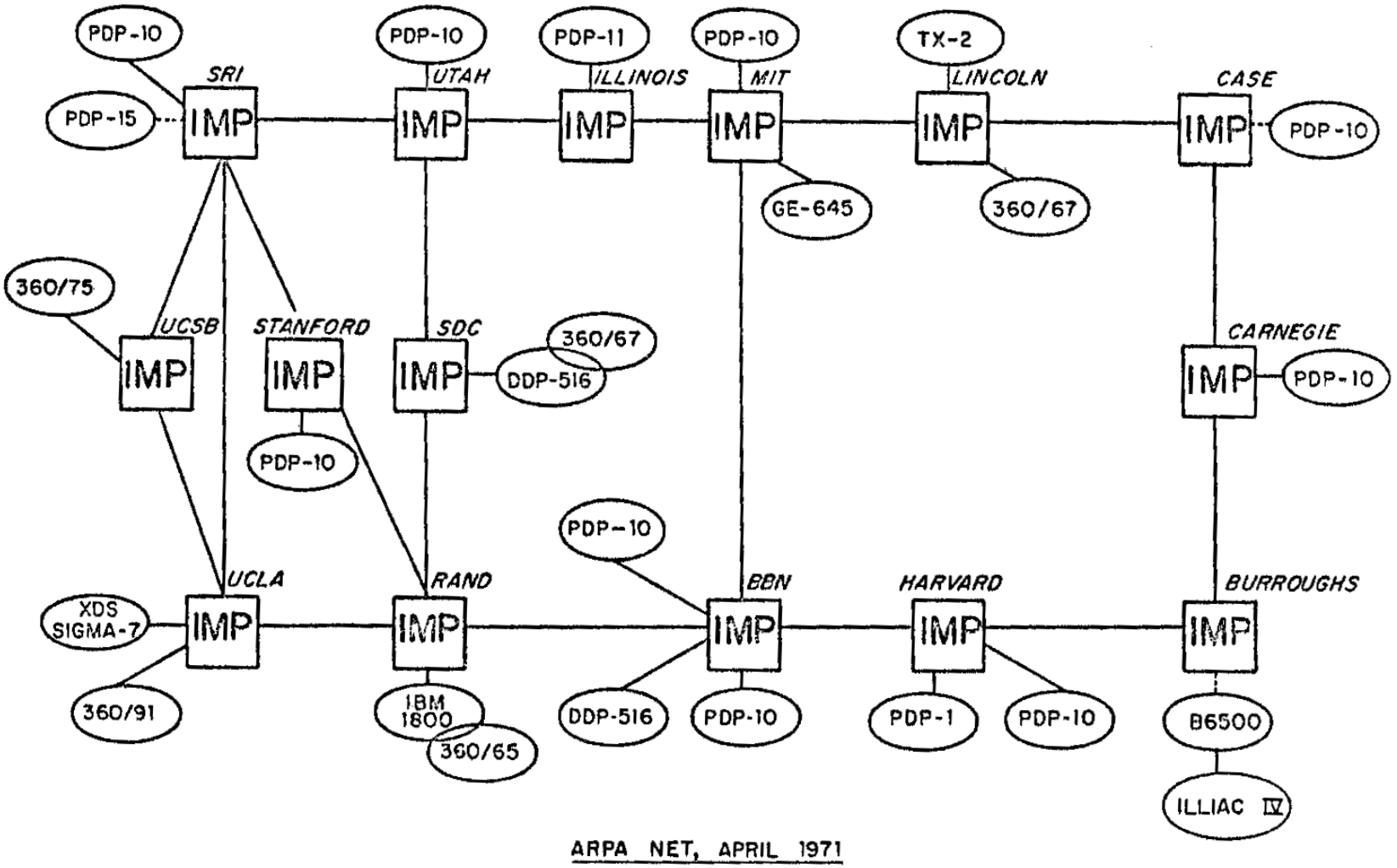
The Early Internet

- a lot of effort went into design of the protocols, and architecture
- the actual network was designed more by constraints: geographic, cost, political, (i.e. who had funding to participate)
  - some formal optimization (Howard Frank in particular)
- you can design a network on the back of an envelope when it has 4 nodes.
  - not so easy with 100

The Early Internet

The map above shows the logical topology of ARPANET in April 1971. (computers connect direct to IMPs) [CK90].



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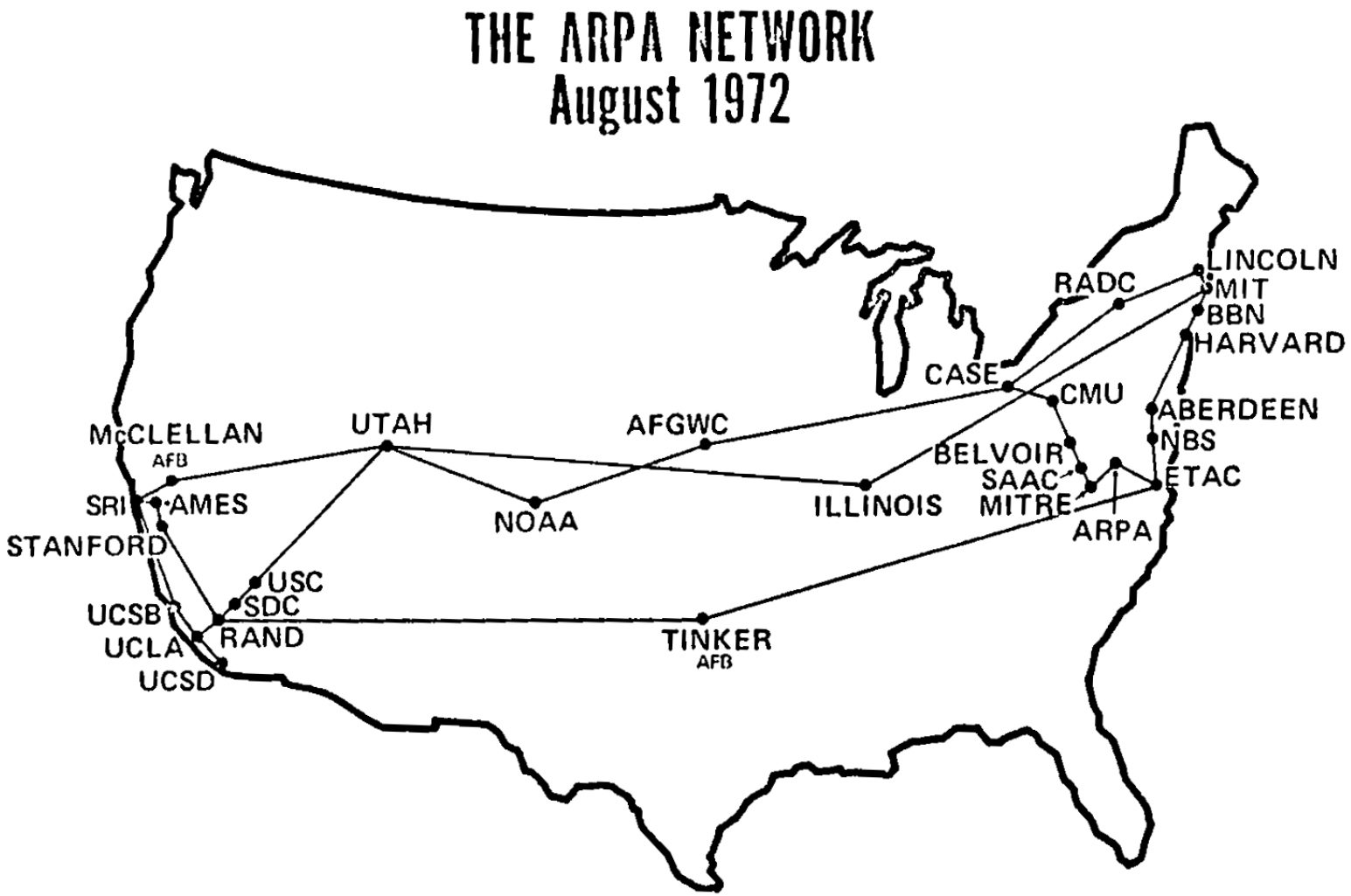

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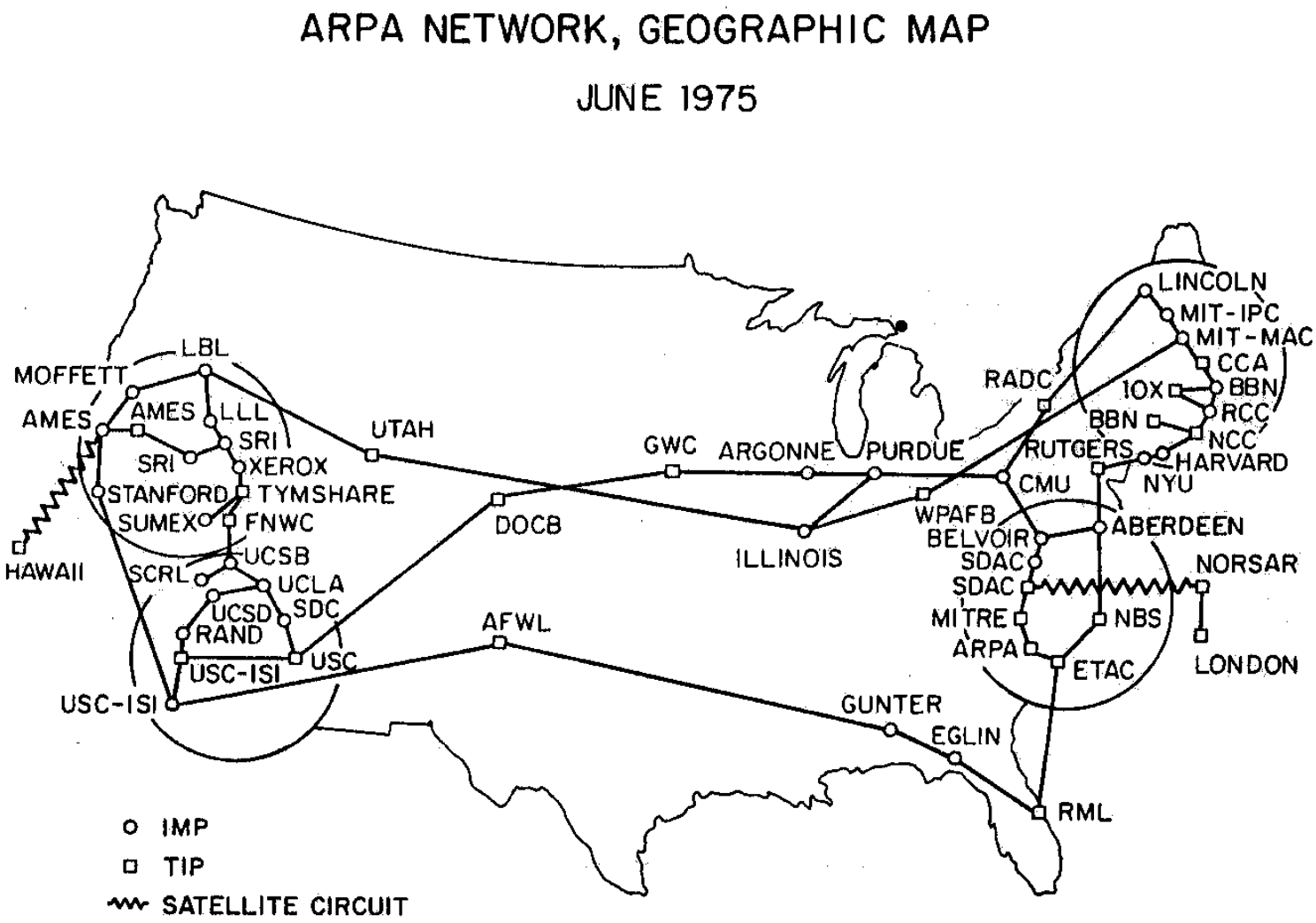

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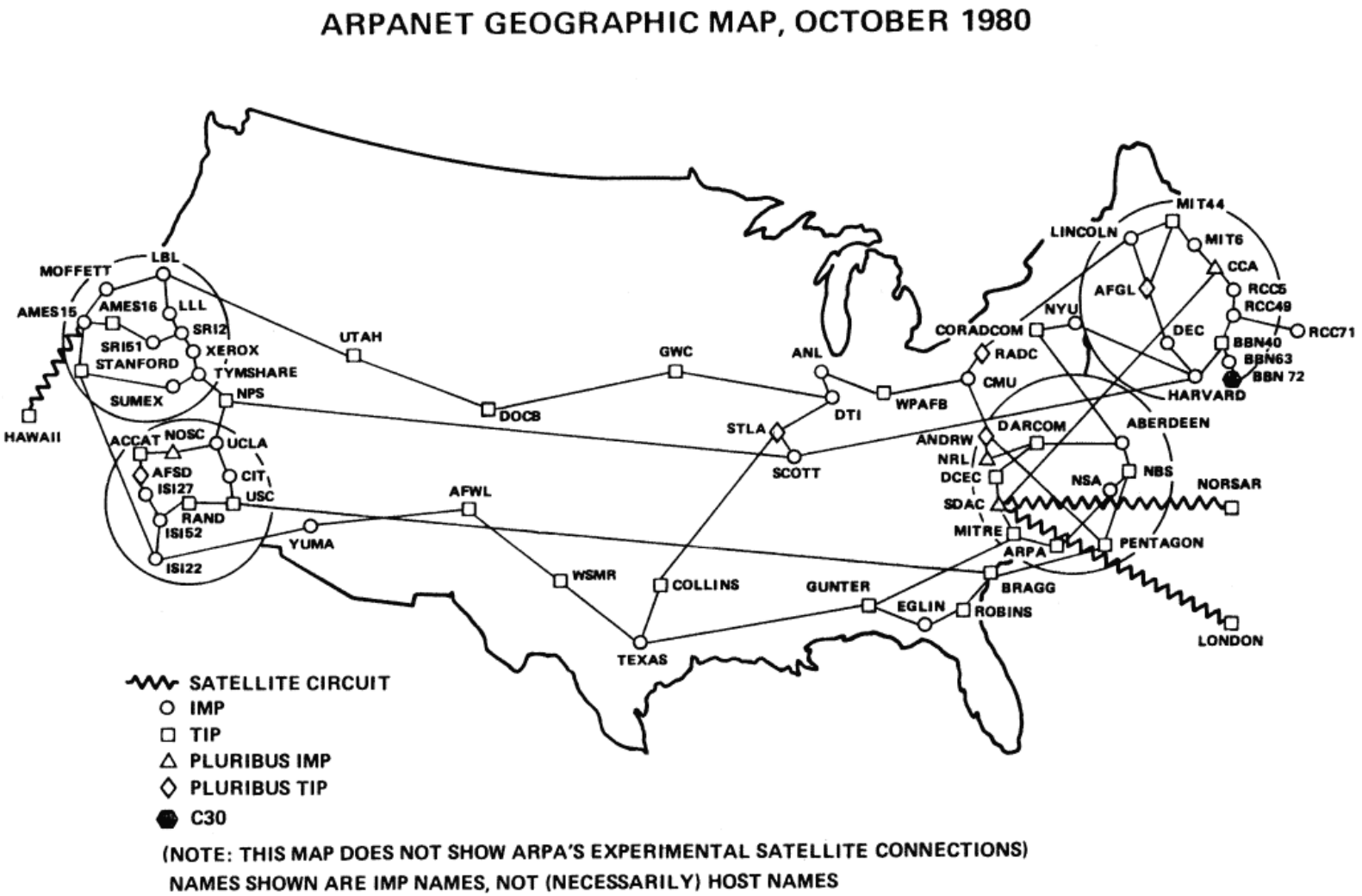

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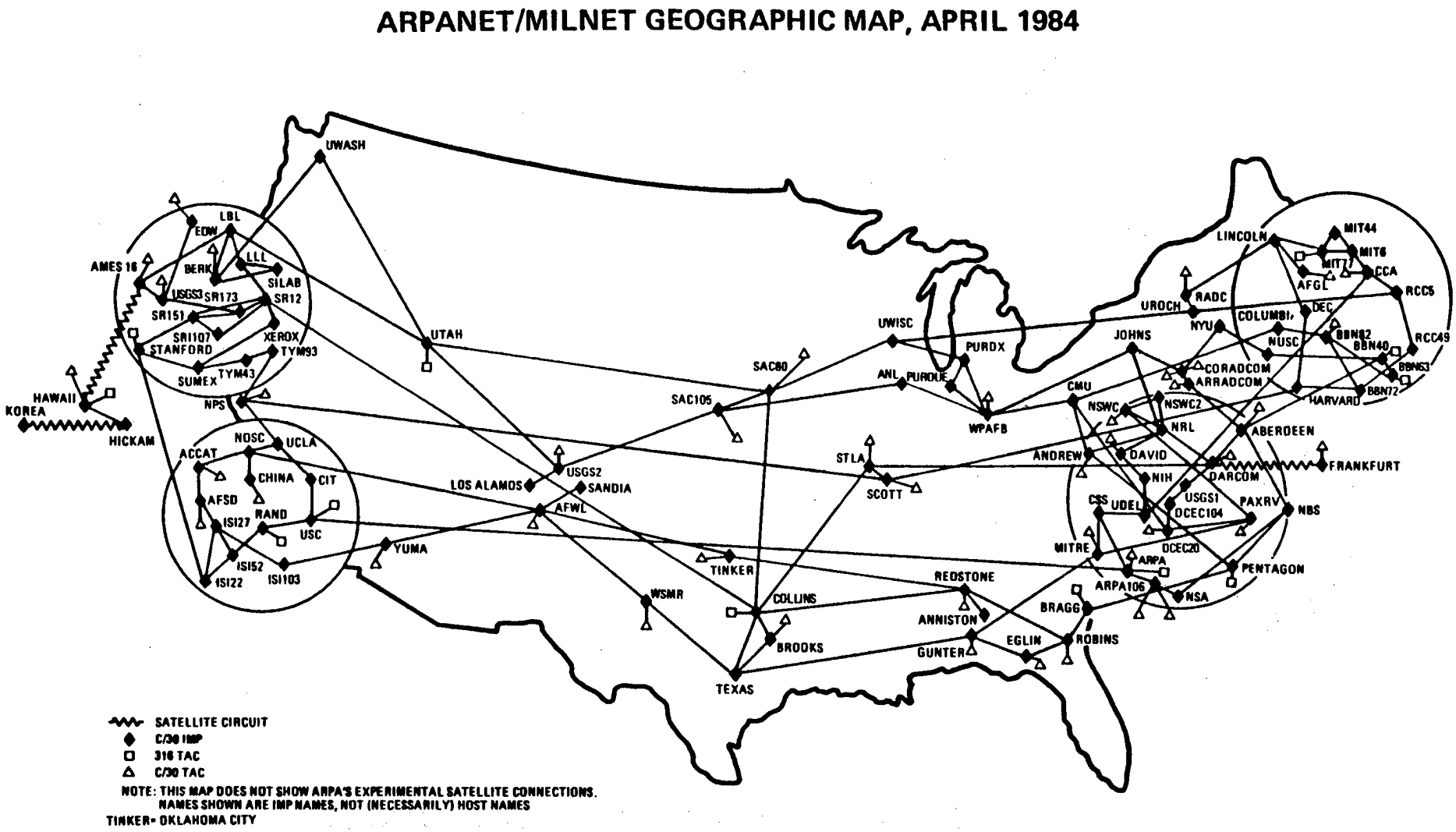
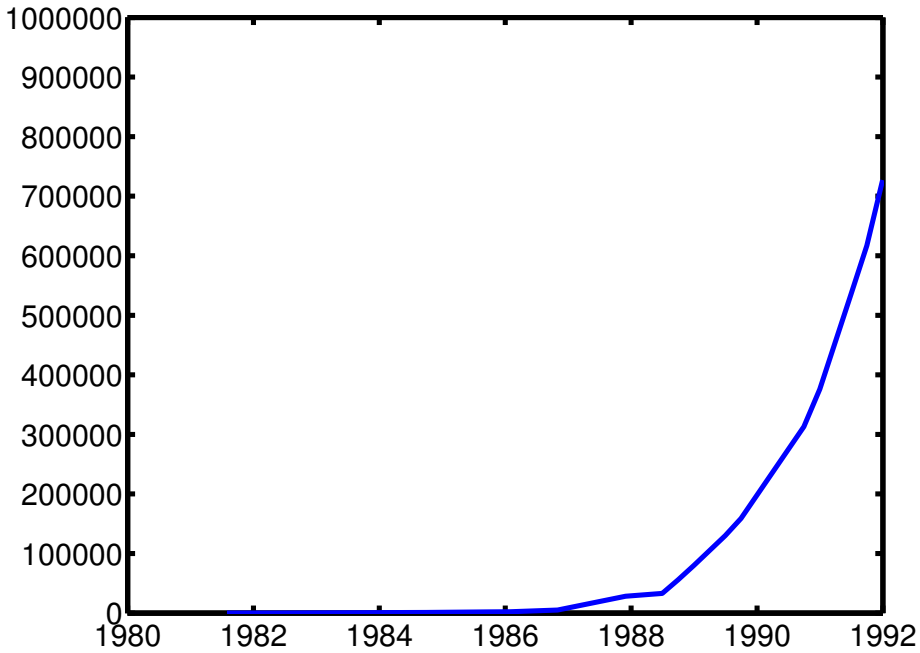
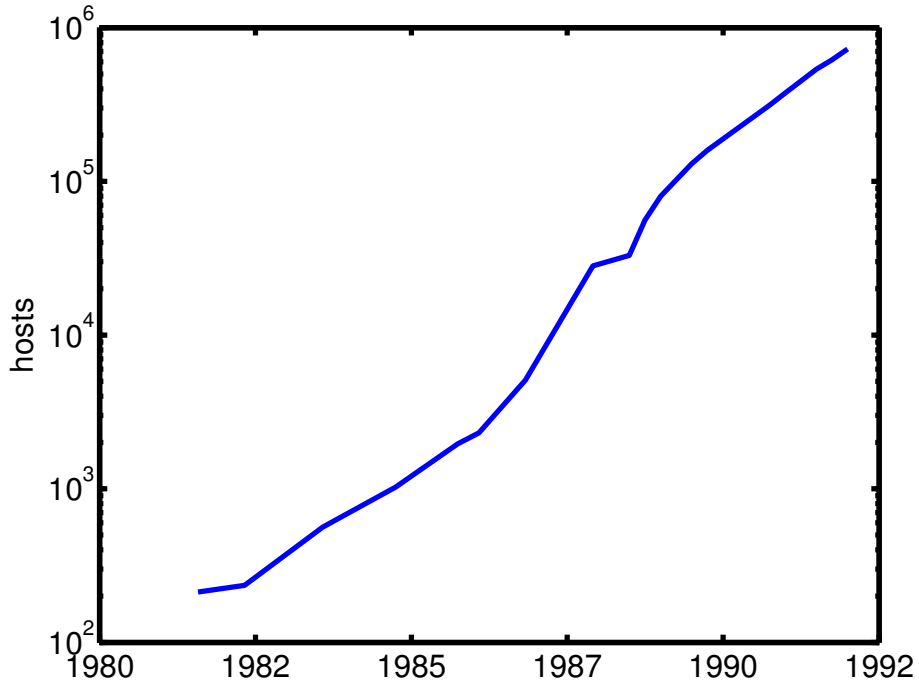
ARPANET/MILNET [CK90].



Early Internet Growth



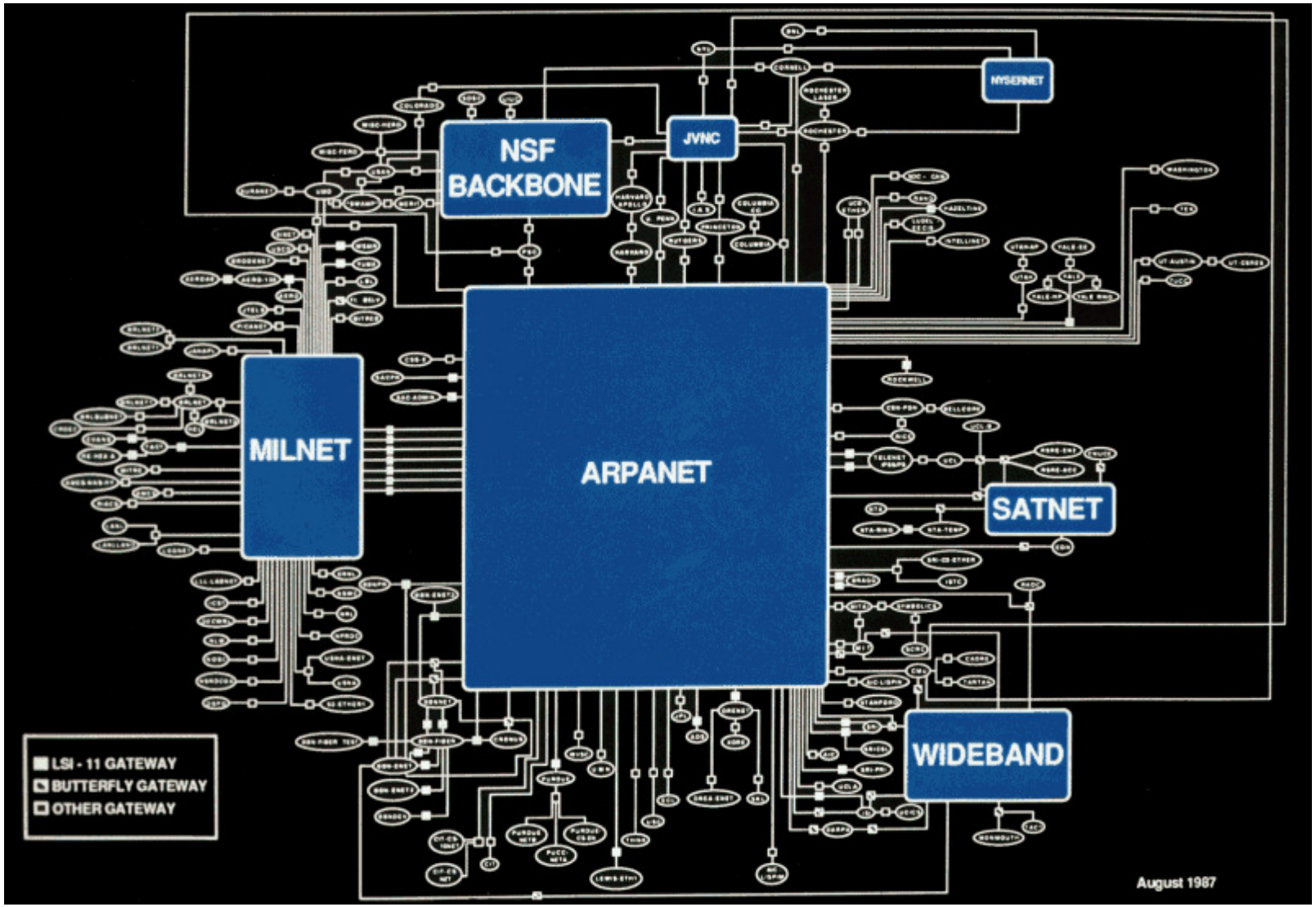


RFC 1296 ftp://ftp.isi.edu/in-notes/rfc1296.txt

Date (mm/yy)	hosts
08/1981	213
01/1992	727,000

The Early Internet

State of the core of the Internet in August 1987.



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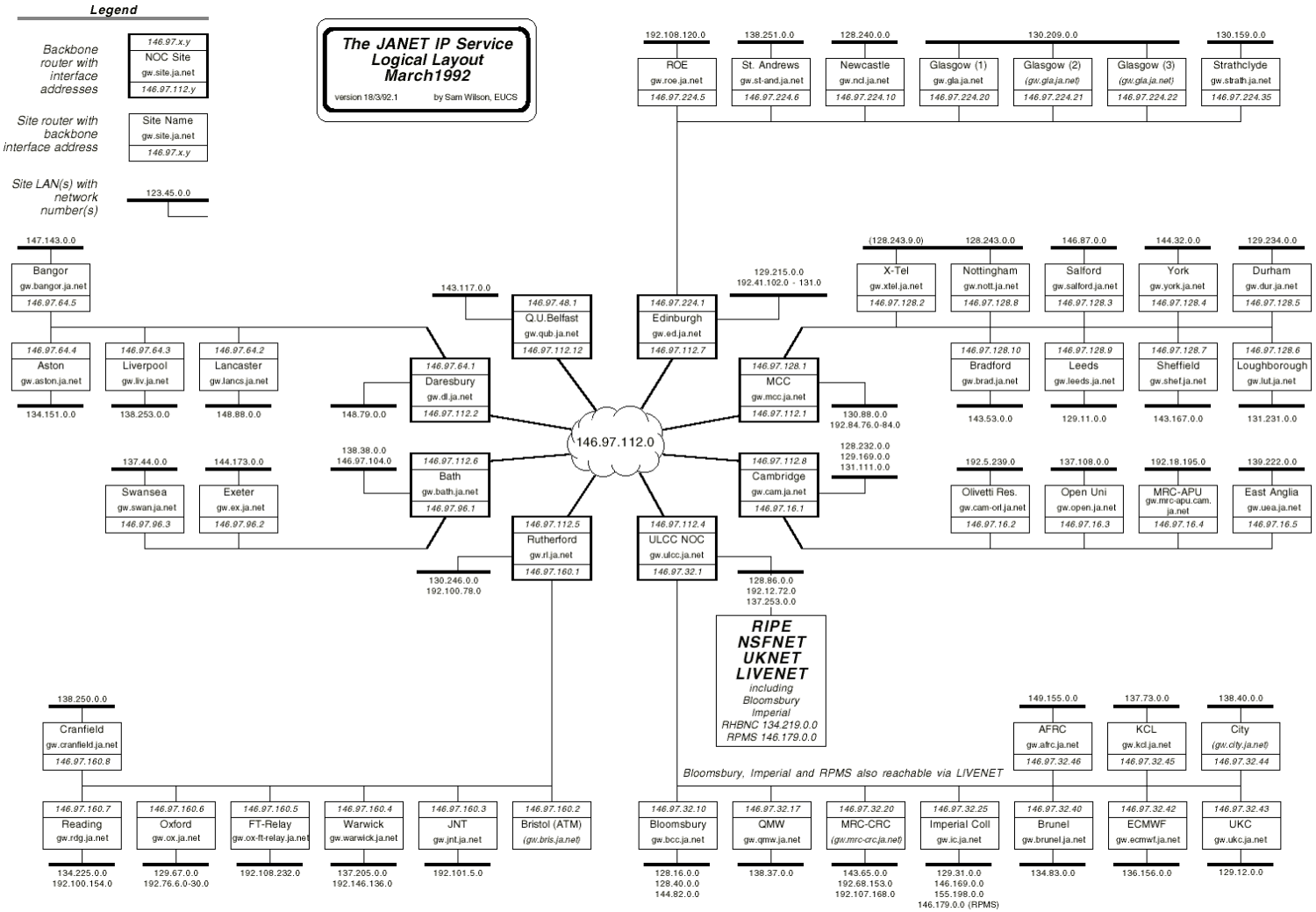
Networks of networks

These maps show the structure of JANET, the UK's academic and research network, in 1992.



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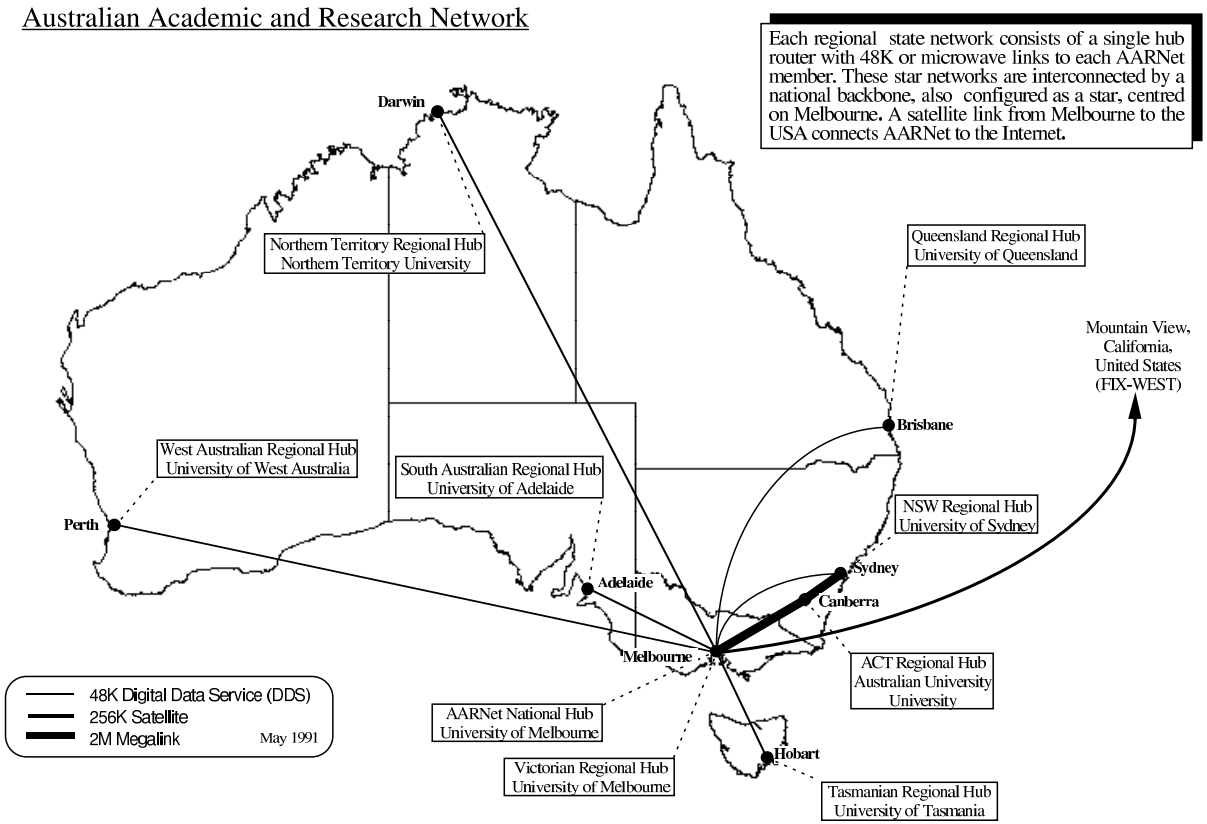

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New network
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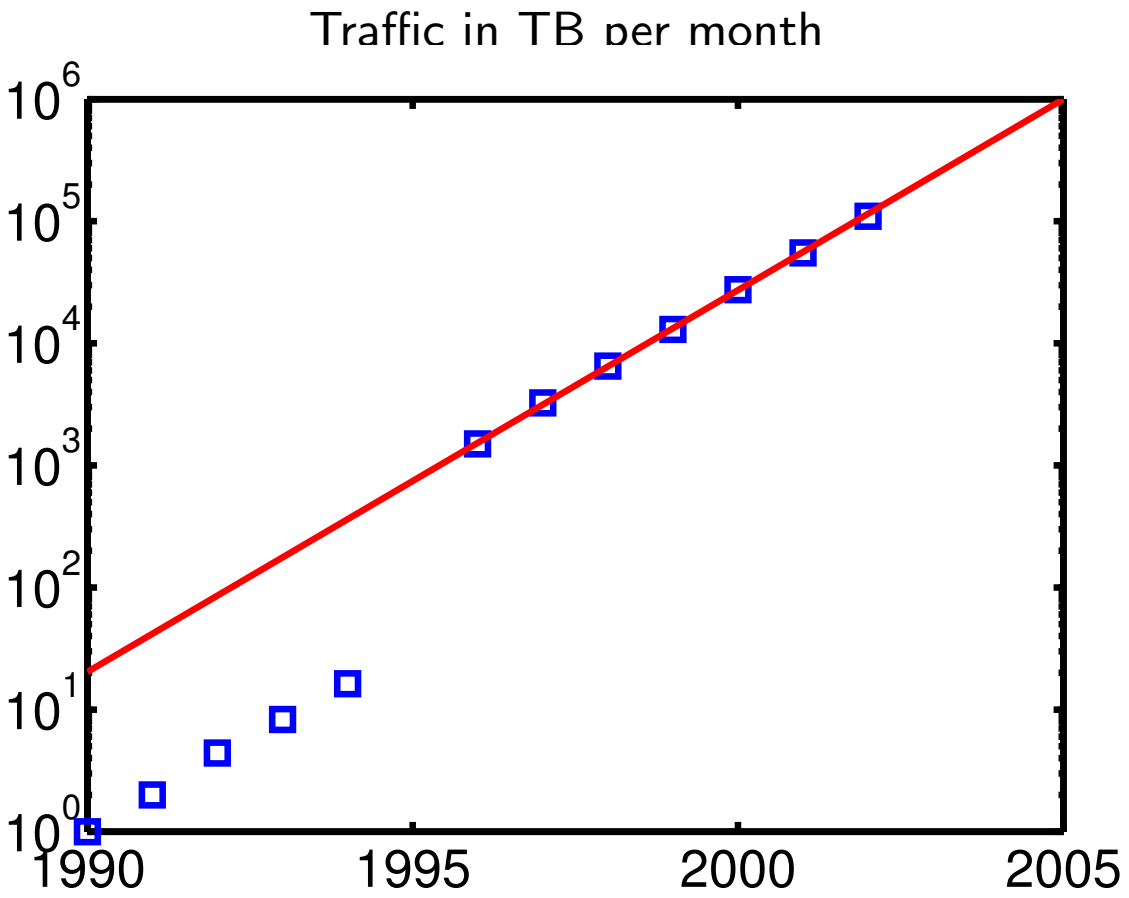
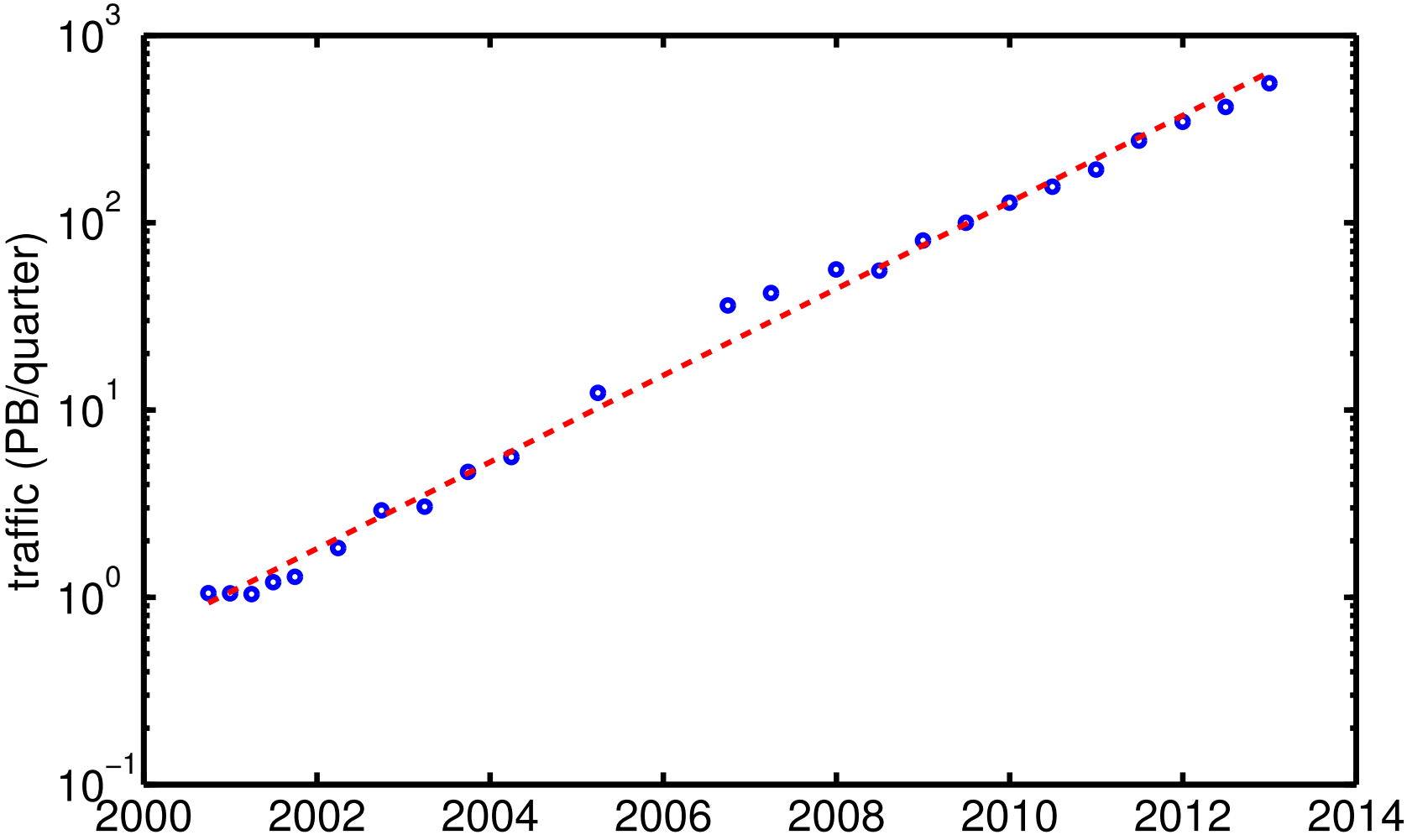
Traffic roughly doubles every year [Odl03].



Combination of new users and higher bandwidth!

Australian Traffic Growth



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Other computer networks

The history of computer communications is not just about the Internet

- other technologies, e.g.
  - packet radio (Hawaii)
  - ATM/Framerelay
  - x.25
  - IBM's SNA
  - Appletalk
- other countries, e.g.
  - France
  - UK
- people: I haven't talked about them, but many individuals' contributions were critical [HL96, Abb99, Sal95].

BIT MORE ON HOW PACKET NETWORKS WORK

Further reading I


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Gordon E. Moore, *Cramming more components into integrated circuits*, Electronics **38** (1965), no. 8.

Further reading II

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Peter H. Salus, *Casting the net: From ARPANET to Internet and beyond...*, Addison-Wesley, 1995.