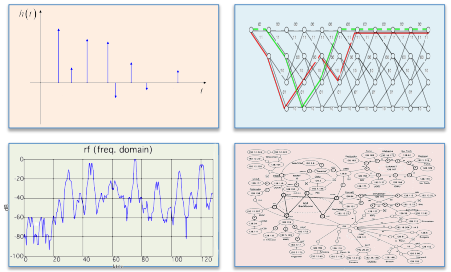


INTRODUCTION TO EECS II

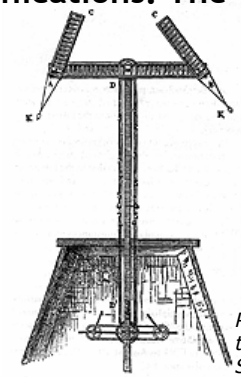
DIGITAL COMMUNICATION SYSTEMS

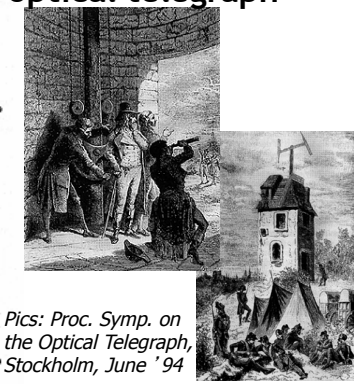
6.02 Spring 2011
Lecture #23

HKN Eval!

• Evolution of communication networks

Visual communications: The optical telegraph





Pics: Proc. Symp. on the Optical Telegraph, Stockholm, June '94

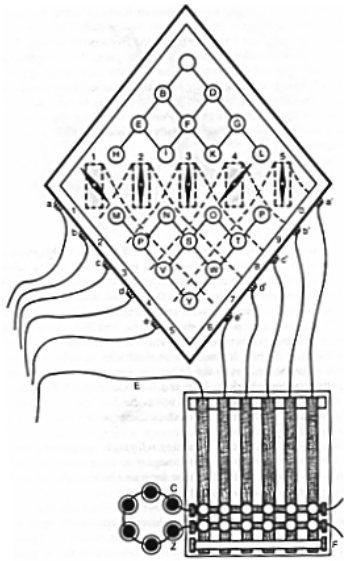
• Chappe (1763-1805), a "defense contractor"; 1st message successfully sent in 1794
• 1799: Napoleon seizes power; sends "*Paris is quiet, and the good citizens are content.*"
• 1814: Extends from Paris to Belgium & Italy
• 1840: 4000 miles, 556 stations, 8 main lines, 11 sublines, each hop ~10 km
• Many "advanced" techniques: switching, framing, codes, redundant relays, message acks, priority messages, error notification, primitive encryption!

Advances in Electricity and Magnetism (Late 18th and 19th centuries)

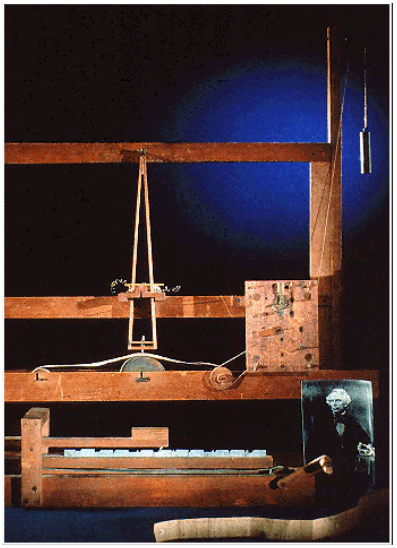
- Oersted (Copenhagen): demonstrated electricity's ability to deflect a needle
- Sturgeon (London), 1825: electromagnet demo
- Joseph Henry, 1830: 1-mile demo: current through long wires, causing bell to ring!
- Faraday (London), 1831: EM induction experiments (induction ring), basis for motors

The Electric Telegraph

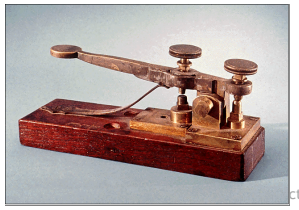
- Cooke and Wheatstone, Railroad Telegraph, 1837
  - 1
  - 4



The Electric Telegraph (Samuel Morse)



Morse Code (1835-1837)
- 1838: demo'd over 2 miles
- 1844: US- sponsored demonstration between Baltimore and Washington DC



Dots and Dashes Span the Globe

- 1852: First international telegram
- Reuters establishes "Telegraph News Network"
- 1858: Cyrus Field lays first transatlantic cable
  - US President & Queen Victoria exchange telegrams
  - Line fails in a few months
- 1866: New cable & technology developed by William Thompson (Lord Kelvin)

Early Uses (cf. IM today!)

Valentine by a Telegraph Clerk (male) to a Telegraph Clerk (female):

"The tendrils of my soul are twined
With thine, though many a mile apart,
And thine in close-coiled circuits wind
Around the needle of my heart.

"Constant as Daniell, strong as Grove,
Ebullient through its depths like Smee,
My heart pours forth its tide of love,
And all its circuits close in thee.

"O tell me, when along the line
From my full heart the message flows,
What currents are induced in thine?
One click from thee will end my woes."

Through many an Ohm the Weber flew,
And clicked this answer back to me, --
"I am thy Farad, staunch and true,
Charged to a Volt with love for thee."

Who or what are Daniell, Grove and Smee?! ☺

Dots and Dashes Span The Globe

- Communications arms race in the Imperial Age
  - No nation could trust its messages to a foreign power
  - 1893: British-owned Eastern Telegraph Company and the French crisis in Southeast Asia
  - 1914: British cut the German overseas cables within hours of the start of WW I; Germany retaliates by cutting England's Baltic cables and the overland lines to the Middle East through Turkey
- Strategic necessity: circumventing the tyranny of the telegraph lines owned by nation states

Wireless!

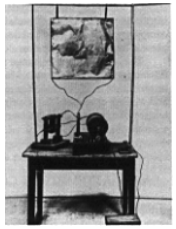
James Clerk Maxwell (1831-1879)

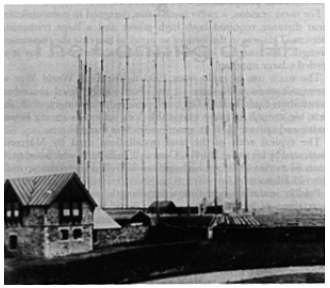
"... we have strong reason to conclude that light itself -- including radiant heat, and other radiations if any -- is an electromagnetic disturbance in the form of waves propagated through the electromagnetic field according to electromagnetic laws." *Dynamical Theory of the Electromagnetic Field*, 1864.

Heinrich Hertz (1857 - 1894)

- Mid-1880s: Demonstrated experimentally the wave character of electrical transmission in space

Wireless Telegraphy

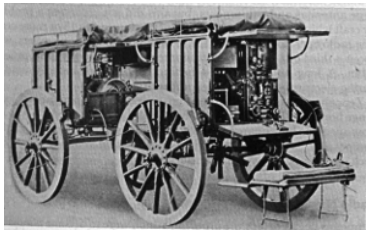




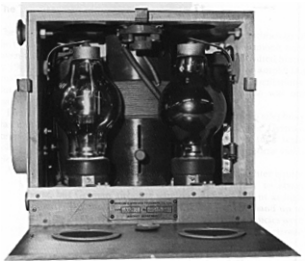
Guglielmo Marconi

- 1895: 21 year-old demonstrates communication at distances much greater than thought possible
- Offers invention to Italian government, but they refuse
- 1897: Demonstrates system on Salisbury Plain to British Royal Navy, who becomes an early customer
- 1901: First wireless transmission across the Atlantic
- 1907: Regular commercial service commenced

Wireless in Warfare



"Portable" radio, circa 1915



Airborne radio telephone, post WW I

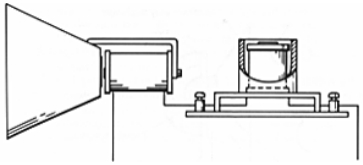
In the Meantime, in the Wired World…

- The telegraph learns to talk
- Morse telegraph: no multiplexing
  - Only one message sent/received at a time
- Second half of 19th century: many researchers work on improving capacity
- Idea: send messages at different pitches
  - Graham Bell – harmonic telegraph
  - Develops way to send different source frequencies by adjusting current levels

The Telephone

Alexander Graham Bell

- 1876: Demonstrates the telephone at US Centenary Exhibition in Philadelphia

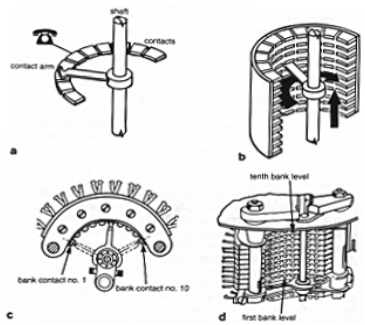


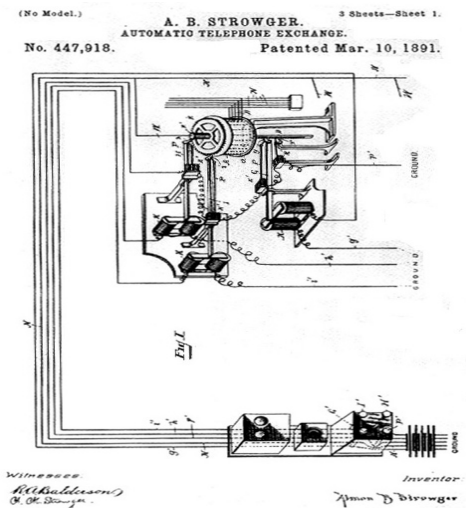
- Bell and Elisha Gray rush patents to USPTO, Bell first by a few hours
- Bell offers to sell patents to Western Union for $100,000, who refuse. Bell Telephone Company founded 9 July 1877.
- 1878: Western Union competes using rival system designed by Thomas Edison and Elisha Gray. Bell sues and wins.

Mechanical Telephone Switch

Almon Brown Strowger (1839 - 1902)

- 1889: Invents the "girl-less, cuss-less" telephone system

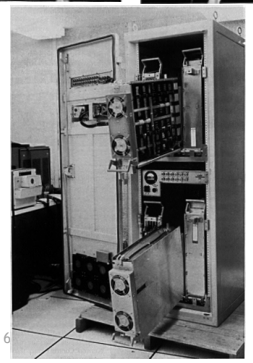




"Ma Bell" and the Telcos

- Bell's patents expire in 1890s; over 6000 independent operators spring up
  - 1910: Bell System controls 50% of local telephone market
  - 1913: AT&T & U. S. government reach Kingsbury Agreement: AT&T becomes regulated monopoly while promising "universal" telephone service
    - Long distance interconnection withheld as a competitive weapon
- 1950: Bell controls 84% of the local telephone access market
- 1984: Divesture of Ma Bell (Judge Greene)
- 1996: Trivestiture of AT&T Bell (AT&T, Lucent, NCR)
- **2000s: The death of the classic wired telephone network**

The Dawn of Packet Switching



ARPA: 1957, in response to Sputnik

Paul Baran (RAND Corp)

- Early 1960s: New approaches for survivable comms systems; "hot potato routing" and decentralized architecture, paper on packet switching over **digital** comm links

Donald Davies (UK), early 1960s

- Coins the term "packet"

Len Kleinrock (MIT thesis): "Information flow in large communication nets", 1961

J. Licklider & W. Clark (MIT), On-line Man Computer Communication

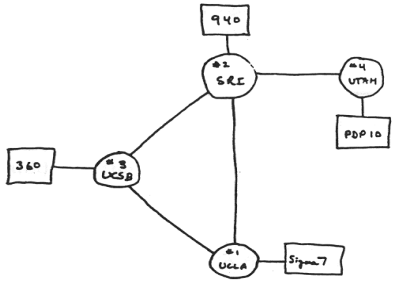
L. Roberts (MIT then ARPA), first ARPANET plan for time-sharing remote computers

ARPANET

BBN team that implemented the interface message processor

- 1967: Connect computers at key research sites across the US using telephone lines
- Interface Message Processors (IMP) ARPA contract to BBN
- Ted Kennedy telegram on BBN getting contract
  - Congratulations … on **interfaith** message processor"

Initial Baby Steps



THE ARPA NETWORK

DEC 1969

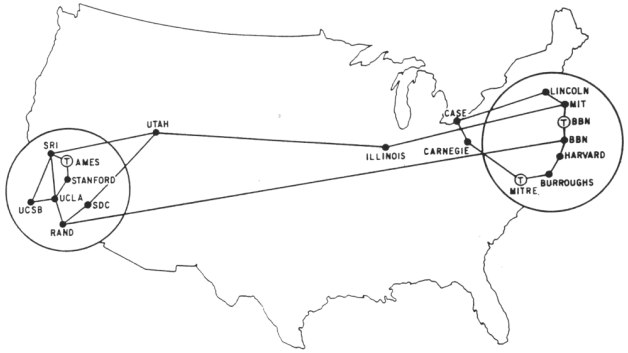
4 NODES

FIGURE 6.2 Drawing of 4 Node Network (Courtesy of Alex McKenzie)

September 1971

1970, ARPANET hosts start using NCP; first two cross-country lines (BBN-UCLA and MIT-Utah)

"Hostile overlay" atop telephone network



MAP 4 September 1971

1970s: Internetworking Develops

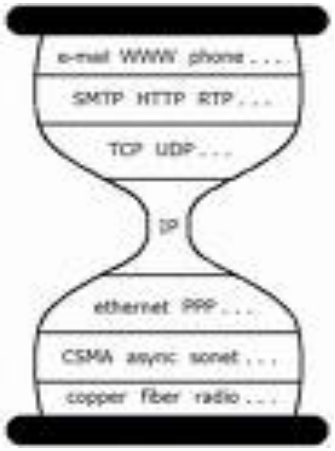
- 1972: modified ARPANET email program
- 1972: French CYCLADES network – developed **sliding window** protocol
- 1973: ARPANET becomes international
- 1973-75: Internetworking effort (Cerf, Kahn, et al.)
  - Developed TCP and IP (originally intertwined) – TCP uses **sliding window**

Handling Heterogeneity

- Make it very easy to be a node or link on the network (best-effort)
- Universal *network layer*: standardize addressing and forwarding
- Switches maintain no per-connection state on behalf of end points

1970s: Internetworking

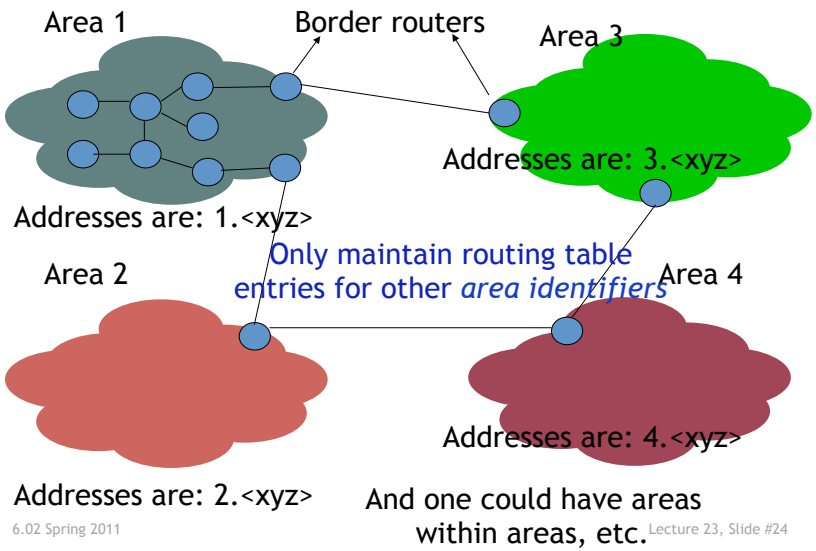
- 1978: **Layering**! TCP and IP split; TCP at end points, IP in the network
- IP network layer: simple best-effort delivery
- In retrospect: Packet switching won because it is good enough for almost every application (though optimal for almost nothing!)



1980s: Handling Growth with Topological Addressing

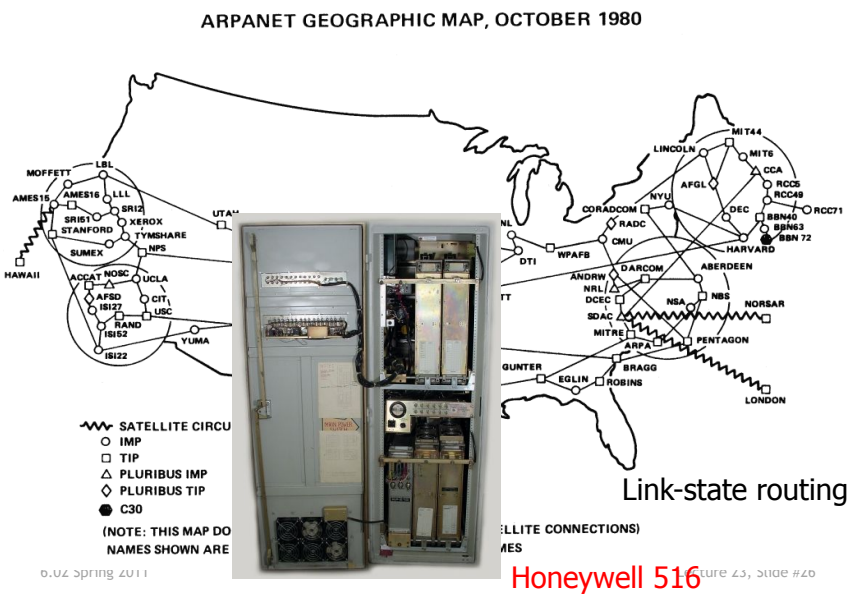
- Per-node routing entries don't scale well
- Solution: Organize network hierarchically
  - Into "areas" or "domains"
  - Similar to how the postal system works
  - Hide detailed information about remote areas
- For this approach to work, node addresses must be **topological**
  - Address should tell network *where* in the network the node is
  - I.e., address is a *location* in the network

Ideal Case: Classic "Area Routing"



IPv4 Example: Addresses & Prefixes

- 18.31.0.82 is actually the 32 bit string 00010010 00111110 00000000 01010010
- Routers have forwarding table entries of the form Address/Mask, which corresponds to a **prefix**
  - Range of addresses that use the route
- 18.0.0.0/8 stands for all IP addresses in the range 00010010 00…0 to 00010010 11…1
- Hence, "areas" may be of size 1, 2, 4, 8, … (maxing out at 2^{24} usually)
- Forwarding uses **longest prefix match**



Link-state routing

Honeywell 516

1980s: Rapid Growth

- 1982: US DoD standardizes on TCP/IP
- 1984: Domain Name System (DNS) introduced
- 1986: Congestion collapse episodes
  - Problems with bad timeout settings
  - Adaptive timers, TCP congestion control solution
  - Athena network file system congestion problems (bad timeout settings)
- Solution
  - **RTT estimation using EWMA, timeout method**
  - TCP congestion control

1990s

- 1990: no more ARPANET
- 1991: WWW released (Berners-Lee)
- Mid-1990s: NSFNet gets out of backbone
  - Commercial ISPs take off
- BGP4: **Path vector protocol** between competing ISPs, who must yet cooperate
- 1996-2001: .com bubble starts and bursts
- 2000s: Internet now truly international; more non-PC devices than PCs
- Wireless and mobility take off…

Example Security Problem: Route Hijacks

- In Feb 2008, Pakistani government wanted Pakistan Telecom (PT) to block YouTube
  - PT advertised its own host as the destination for YouTube's IP address range
- Misconfiguration causes this advert to propagate to PT's ISP (PCCW, Hong Kong)
- PCCW sees that this advert is "more specific" than what it has, so accepts
  - Propagates to other ISPs, who also accept
- Soon, much of the Internet wasn't able to reach YouTube!

Some Big Challenges

- A largely mobile, wireless world
- Security: coping with errors and malice
- Availability and reliability improvements
- Flexibility and evolution of the network
- Large-scale video, collaboration, and "network neutrality"
  - 2010 factoid: Netflix consumes 21% of Internet bandwidth during prime time