Introduction to Communication Networks
The University of Kansas EECS 563
History and Architecture

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http://www.ittc.ku.edu/~jgps/courses/intronets
Communication Networks
History and Architecture

HA.0  Early history
HA.1  Internet history and architecture
HA.2  PSTN history and architecture
HA.3  SCADA networks overview
HA.4  Other networks
Network History and Architecture

HA.0  Early History

HA.0.1  Messengers and post
HA.0.2  Optical telegraph
HA.0.3  Electric telegraph and telex

HA.1  Internet history and architecture
HA.2  PSTN history and architecture
HA.3  SCADA networks overview
HA.4  Other networks
Early History of Networks
Basis for Modern Communication

• Communication networks have a *very long* history
  – although with a very different infrastructure
• Many key networking principles developed, e.g.
  – line coding and data compression
  – message switching
  – error control and message integrity
  – flow control
  – quality of service differentiation
  – security, confidentiality, and attacks
Early History of Networks
Basis for Modern Communication

• Brief review provides historical context
  – understand how and why we have the current networks
    • PSTN and Internet
  – know context in which your company developed
    • especially if it is a network service provider

• May actually fascinate students interested in history
  – and hopefully not bore the rest of you to much
Network History and Architecture

HA.0  Early History

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  HA.0.3  Electric telegraph and telex

HA.1  Internet history and architecture

HA.2  PSTN history and architecture

HA.3  SCADA networks overview

HA.4  Other networks
Early History: Antiquity
Human Messengers

- Human messengers
  - initially on-demand point-to-point
    - analogue to a modern \textit{circuit}
  - c. 4000 BC Egypt and Babylonia
  - 490 BC: Pheidippides run (history ambiguous):
    - Athens to Sparta to get support of Spartans
    - Marathon to Athens to notify Athenians of victory over Persians
      - gives name to modern marathon run
**Early History: Antiquity**

**Human Messenger Relays**

- **Human messenger relays**
  - scheduled horseback relays between guard stations
    - analogue to modern store-and-forward *message switching*
  - c. 2000 BC: Egypt during reign of Sesostris I
  - c. 1750 BC: Babylon during reign of Hammurabi
  - c. 550 BC: Persia during reign of Cyrus (Kūruš) the Great
    - “…neither snow nor rain nor heat nor night …”
      [Herodotus c. 440 BC]
  - c. 100 BC: Rome
    - originally human runners
    - later horses with 40 horses and riders / relay station
  - c. 1200 AD: Chinese post during reign of Kublai Khan
Early History: Messengers

Chinese Post

- Chinese post
  - extensive messenger relay
  - established under Kublai Khan c. 1200 AD
  - described by Marco Polo
  - network radiating from capital Khan-balik (Beijing)
  - relay posts at 25 km intervals
    - 200 active and 200 resting horses each
  - 320 – 480 km/day travel
  - supplemented by human runners
Early History: Messengers
Pony Express

- Pony Express: horse-transported US mail
  - Apr. 1860 – Oct 1861
  - alternative to slower shared stagecoach transport
    - used for delay sensitive messages (QoS: quality of service)
  - relay of riders and horses
    - ~150 km/rider
    - ~15 km/horse
  - Independence MO / Atchison KS → San Francisco CA
    - ~1900 mi = 3000 km
      - route slightly shorter than stagecoach
    - 10 days for entire trip
  - rendered obsolete by transcontinental (electric) telegraph
Early History: Messengers

Pony Express Route

San Francisco → St. Joseph → Atchison → San Francisco
Early History: Messengers

Carrier Pigeons

- Carrier pigeons
  - homing pigeons transported to remote location
  - small message attached to pigeon leg
  - pigeon flees home with message
Early History: Messengers

Carrier Pigeons

• Carrier pigeons
  – homing pigeons transported to remote location
  – small message attached to pigeon leg
  – pigeon flees home with message

• Dates from antiquity
  – c. 3000 BC: Egypt
  – c. 2350 BC: Mesopotamia
  – c. 300 AD: Rome
  – c. 1300 AC: Mongol empire during reign of Ghengis Khan
  – 1918 AD: British RAF during World War I
  – 1981 AD: Lockheed 40km shuttle of engineering drawings
  – 1 April 1990: IP over Avian Carriers [RFC 1149]
Early History: Messengers
Evolution to Postal Systems

- Messenger delivery evolved to modern postal system
  - military → general use
  - spoken → handwritten → typed → printed messages
  - runners → horses → railways → multimodal transport

- Postal system is just another kind of network
  - network addresses = postal code + street or box numbers
  - physical transport = delivery vehicles
  - packets = letters and packages
  - protocols and signalling = operational process

- Useful to understand analogies!
Early History: Messengers
Evolution to Postal Systems

• Other networks are branch of this evolutionary tree
  – many countries administered by same governmental entity
    • PTTs: *post, telegraph, and telephone*
    • common until recent telecommunications deregulation
  – administered by different entities in the US
    • some private, some governmental
Network History and Architecture

HA.0 Early history
  HA.0.1 Messengers and post
  HA.0.2 Optical telegraph
  HA.0.3 Electric telegraph and telex

HA.1 Internet history and architecture

HA.2 PSTN history and architecture

HA.3 SCADA networks overview

HA.4 Other networks
Early History: Antiquity
Optical Telegraph

- Telegraph
  - mechanism for conveying information over a distance
  - originally optical free space transmission
  - electric telegraph much later

- Derivation from Greek
  - telegraph: τηλε (tele) = far + γραφειν (graphein) = write
  - telescope: τηλε (tele) = far + σκοπεω (skopeo) = see
Telegraph Prehistory: Antiquity
Permanent Fire Beacon Towers

- Beacon signalling: permanent installations
  - 500 BC: Royal Persian Road (Sardis–Susa)
    - 2600 km
    - >100 relay posts
    - combined with couriers
History: Antiquity

Fire Beacons

- Beacon signalling
  - 1184 BC: Greece
    - 600 km
    - 8 relay points

[adapted from Holzmann-Pehrson-1995]
History: Antiquity

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    - used to signal fall of Troy to Mycenae

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**History: Antiquity**

**Fire Beacons**

- **Beacon signalling**
  - 1184 BC: Greece
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[adapted from Holzmann-Pehrson-1995]

_My whole body is pain and unrest. It is our history, our connaît of falling, and our purpose of rise._

*problems?
History: Antiquity

Fire Beacons

- Beacon signalling
  - 1184 BC: Greece
    - 600 km
    - 8 relay points
    - used to signal fall of Troy to Mycenae
  - problem:
    - very limited symbol set
    - only very simple messages
      - e.g. “warning”

[adapted from Holzmann-Pehrson-1995]
History: Antiquity
Smoke Signals

• Variant of fire beacon
  – fire is covered and uncovered
  – results in puffs of smoke
  – timing conveys message

• Examples
  – native Americans
  – towers along Great Wall of China

• Problem
  – still very limited message set
Optical Telegraph

Overview

• Optical telegraph
  – evolution of beacons and smoke signals
  – signalling mechanism to rapidly display various aspects
    • transmission of symbols
  – communication protocol
    • control: establishing and terminating communication
    • data: hop-by-hop relaying of messages between stations
      – error control to ensure message integrity
  – telescope used to observe sending station
    • reception of symbols

• Networks of telegraph relay stations
  – direct predecessor of modern communication networks
Optical Telegraph
Chappe French Design

• Claude Chappe (1763 – 1805)
  – initially experimented with shutter telegraph
    • similar to design later used by Edelcrantz
  – inventor of practical optical *semaphore telegraph*
Optical Telegraph
Chappe French Design

- Chappe optical semaphore telegraph
  - mounted above signal tower containing human operator
Optical Telegraph
Chappe French Design

- Chappe optical semaphore telegraph
  - mounted above signal tower containing human operator
  - central *regulator*
Optical Telegraph
Chappe French Design

- Chappe optical semaphore telegraph
  - mounted above signal tower containing human operator
  - central *regulator*: 4 positions at 45° intervals
Optical Telegraph
Chappe French Design

- Chappe optical semaphore telegraph
  - mounted above signal tower containing human operator
  - central regulator: 4 positions at 45° intervals
  - two *indicators*
Optical Telegraph
Chappe French Design

- Chappe optical semaphore telegraph
  - mounted above signal tower containing human operator
  - central regulator: 4 positions at 45° intervals
  - two *indicators*: 7 positions each
    - attempts to use lamps at night unsuccessful
Optical Telegraph
Chappe French Design

- Chappe optical semaphore telegraph
  - mounted above signal tower containing human operator
  - central regulator: 4 positions at 45° intervals
  - two indicators: 7 positions each
    - attempts to use lamps at night unsuccessful
  - $4 \times 7 \times 7 = 196$ aspects
    - 1 symbol / 2 aspects = 98 symbols
Optical Telegraph
Chappe Symbol Transmission

- Symbol transmission: two phases
  0. regulator arm diagonal with indicators aligned
     - left oblique \ aspect for service codes (control)
     - right oblique \ aspect for data symbols
Optical Telegraph
Chappe Symbol Transmission

- Symbol transmission: two phases
  0. regulator arm diagonal with indicators aligned
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     - right oblique / aspect for data symbols
  1. indicator arms set
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Optical Telegraph
Chappe Symbol Transmission

• Symbol transmission: two phases
  0. regulator arm diagonal with indicators aligned
     • left oblique \ aspect for service codes (control)
     • right oblique / aspect for data symbols
  1. indicator arms set
  2. regulator arm rotated to horizontal or vertical
Optical Telegraph
Chappe Symbol Transmission

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Optical Telegraph
Chappe Symbol Relay

- Symbols relayed along line from station to station
  - stations spaced ~10 km intervals
    - symbols ripple down the line in a pipeline
Optical Telegraph
Chappe Symbol Relay

• Symbols relayed along line from station to station
  – stations spaced ~10 km intervals
    • symbols ripple down the line in a *pipeline*
  – each station verifies that the next properly relays
    • else sends error signal and then repeats symbol
    • hop-by-hop *error control* negative acknowledgement (NAK)
Optical Telegraph
Chappe Symbol Relay

• Symbols relayed along line from station to station
  – stations spaced ~10 km intervals
    • symbols ripple down the line in a pipeline
  – each station verifies that the next properly relays
    • else sends error signal and then repeats
    • hop-by-hop error control negative acknowledgement (NAK)
  – division stations acknowledges complete message decoding
    • end-to-end (or edge-to-edge) error control
    • long spans traverse multiple divisions
Optical Telegraph
Chappe Performance

• Signalling performance
  – date rate ≈ 2 symbol/minute in good weather
  – much worse with fog or precipitation
  – attempts to signal at night with lamps unsuccessful
Optical Telegraph
Chappe Data Symbols

• Data symbols
  – 1st division: 94 symbols: numbers, letters, common syllables
    • terminate by closing indicators
    • 1 symbol / codeword
Optical Telegraph

Chappe Data Symbols

• Data symbols
  – 1st division: 94 symbols: numbers, letters, common syllables
    • 1 symbol / codeword
  – 2nd division: \(94 + 94 \times 94 = 8930\) codewords
    • 1st symbol indicates one of 94 rows on page in codebook
    • 2nd symbol indicates one of 94 pages in codebook
    • terminated by closing indicator arms after 2nd symbol only
    • 2 symbols / codeword
Optical Telegraph

Chappe Data Symbols

- **Data symbols**
  - 1st division: 94 symbols: numbers, letters, common syllables
    - 1 symbol / codeword
  - 2nd division: $94 + 94 \times 94 = 8930$ codewords
    - row, page of codebook
    - 2 symbols / codeword
  - 3rd and 4th divisions: additional codewords and phrases
    - preceding vertical horizontal double-closed aspect
    - 3 symbols / codeword
  - 5th division: additional codewords and phrases
    - preceded by signal from 1st division
    - 4 symbols / codeword
Optical Telegraph
Chappe Service Codes

- Service codes used for transmission control
  - start / end transmission
  - suspension for one / two hours
  - clock synchronisation
  - collision of transmission from both directions
  - priority indication of direction precedence
  - acknowledgement of final message decoding
  - error; cancel preceding symbol
  - idle – station closing
  - minor (temporary) / major station failure
  - rain or fog restricting transmission
  - night transmission (never successfully used)
Optical Telegraph
French Network

• Deployed 1794
Optical Telegraph
French Network

• Deployed 1794–1805...
• Star from Paris
Optical Telegraph
French Network

- Deployed 1794–1846
- Star from Paris
  - with mesh crosslinks
- One of the first real telecom networks
  - 18th century!

> 5000 km
Optical Telegraph
Edelcrantz Swedish Design

- Abraham H. (Clewberg) Edelcrantz (1754 – 1821)
  - initially experimented with semaphore telegraph
    - 1794 design similar to later Chappe telegraph
  - inventor of practical optical *shutter telegraph*
    - rationale: faster than semaphores with potential for night use
Optical Telegraph
Edelcrantz Swedish Design

- Edelcrantz optical shutter telegraph
  - mounted above signal tower containing human operator
  - shutters rotate horizontally between face-on and edge-on
    - edge-on (invisible) = 0
    - face-on or illuminated lamp at night = 1
  - 3×3 array gives octal codewords of 000 – 777
    - read vertically
    - endcodes letters, common syllables, common words
    - single shutter symbols encode numerals 0 – 9
    - additional shutter on top indicates tens
    - hundreds and thousands encodes at octal codewords
Optical Telegraph
Swedish Network

- Deployed 1795–1854
  - remained operational until 1881
    - much later than other optical telegraph networks
  - network covered southern Sweden
Optical Telegraph
Other Deployments

- Variants deployed throughout Europe
  - semaphore arms
  - shutters
  - balls raised and lowered

- Very limited deployment in North America
  - e.g. Telegraph Hill in San Francisco
    - signalled arrival of ships
Optical Telegraph
Heliographs and Signal Lamps

• Heliograph
  – mobile device for optical signalling
  – e.g. tripod mounted pair of mirror, interrupted by shutter
  – light flashes
    • typically in Morse Code

• Signal or Aldis lamp (A.C.W. Aldis)
  – used from late 1800s to 1990s primarily for ship-to-ship
  – light flashes using louvered shutters
    • typically in Morse code
Optical Telegraph
Signal Flags

- Signal flags: message conveyed by cloth flags
- Handheld flags
  - symbols indicated by 8 positions of two flags
- Mast-mounted flags
  - signals indicated by shape and colour of flags
Optical Telegraph
Signal Flags

• Signal flags: message conveyed by cloth flags
  – 1800s to current use

• Semaphore flags:
  – handheld flags, typically red/yellow
  – symbols indicated by 8 positions of two flags
  – primarily nautical use
  – 1 April 2007: The Transmission of IP Datagrams over the Semaphore Flag Signaling System (SFSS) [RFC 4824]

• Mast-mounted maritime signal flags
  – signals indicated by shape and colour of flags
  – specified in International Code of Signals
Optical Telegraph

Signal Flags: Semaphore

- Semaphore flags

Optical Telegraph
Signal Flags: Maritime Signal Flags

- Maritime signal flags
  - hoisted above ships to convey messages
  - flags indicate codewords
- ICOS: International Code of Signals
  - National Geospatial Intelligence Agency publication 102
    http://www.nga.mil/MSISiteContent/StaticFiles/NAV_PUBS/ICOS/pub102.zip
Optical Telegraph
Signal Flags: Maritime Signal Flags

<table>
<thead>
<tr>
<th>Alphabetic</th>
<th>Kilo</th>
<th>Victor</th>
<th>Numeric</th>
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<tr>
<td>Alfa</td>
<td>Lima</td>
<td>Whiskey</td>
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<tr>
<td>Bravo</td>
<td>Mike</td>
<td>Xray</td>
<td>2</td>
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<td>Charlie</td>
<td>November</td>
<td>Yankee</td>
<td>3</td>
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<td>Delta</td>
<td>Oscar</td>
<td>Zulu</td>
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<td>Quebec</td>
<td>code</td>
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<td>Romeo</td>
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<td>7</td>
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<tr>
<td>Hotel</td>
<td>Sierra</td>
<td>2nd sub.</td>
<td>8</td>
</tr>
<tr>
<td>India</td>
<td>Tango</td>
<td>3rd sub.</td>
<td>9</td>
</tr>
<tr>
<td>Juliet</td>
<td>Uniform</td>
<td>4th sub.</td>
<td>0</td>
</tr>
</tbody>
</table>
Optical Telegraph Problems

- Optical telegraphy problems?
Optical Telegraph

Problems

• Optical telegraphy problems
  – distance limited to a few km between stations
  – operation limited to clear air
    • weather
    • particulate pollution – serious problem in 19th century cities
  – night operation more difficult
  – open channel
    • subject to eavesdropping

Alternative?
Network History and Architecture

HA.0.3 Electric Telegraph and Telex

HA.0 Early history
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HA.1 Internet history and architecture

HA.2 PSTN history and architecture

HA.3 SCADA networks overview

HA.4 Other networks
Electric Telegraph
Overview and Motivation

- Telegraphy through electric wires
  - without line-of-sight and clear-air distance limitations
  - no longer an open channel
    - assuming wires aren’t tapped
- Early proposals based on optical telegraphy ideas
  - visual repeaters of dials or semaphores
  - required multiple wires
  - required complex electromechanical mechanism
Electric Telegraph

Electric Telegraph History

- Telegraphy through electric wires
  - 1775 Francisco de Salva proposal
  - 1809–1833 experiments and prototypes in Europe
  - 1837 Cooke and Wheatstone in UK
  - 1837 Morse and Vail in US
  - 1845 Paris–Roen France
    - 1845–1855 replaces French optical telegraph network
  - 1865 transatlantic telegraph cable
Electric Telegraph
Transoceanic Cable Challenges

- Problem: messages took days to deliver by ship
  - at least 10 days between America and Europe by fast ship
- Transoceanic cable
  - bold and risky proposal by Cyrus W. Field in mid-1800s
  - significant challenges and expense to lay cable
  - longest run of cable ever attempted
    - conductor, insulator, and cladding technology very immature
    - severe attenuation over a long distance
    - no possibility of mid-span amplifiers
    - high transmitter voltages caused short-failures of early cables
Electric Telegraph
Transoceanic Cable Development

• Transatlantic telegraph cable: major achievement
  – 1857: 1st attempt failed when cable broke mid-ocean
  – 1858: successful draw; cable failed after three weeks
    • 17 hours to transmit first message
      – 0.1 word/minute Morse code due to attenuation
    • initial public enthusiasm waned after failure; funds dried up
  – 1865: successful draw
    • used experience gained from shorter undersea cables
    • 8 words/min transmission rate
    • eventually 120 words/min with load coils in early 1900s

• Transpacific cable
  1902–1903 via Hawaii and Guam
Electric Telegraph
Transoceanic Cable Deployment

• Cables now carry vast majority intercontinental traffic
  – fiber optic using EDFAs with 100s Gb/s capacity each
  – only a small fraction of Internet traffic via satellite links

TeleGeography interactive map on [www.submarinecablemap.com]
Electric Telegraph
Cooke-Wheatstone Telegraph

- William Cooke and Charles Wheatstone
  - probably the first operational telegraph
    - patented 1837 in the UK
    - deployed 1839 on Great Western Rwy.
      - Paddington eventually to Slough (~35 km)
  - multi-wire system
    - iron wires initially buried in pipe
    - only reliable in dry weather
  - wires later above ground
    - between telegraph poles
    - attached with glass insulators
Electric Telegraph

Cooke-Wheatstone Telegraph

- William Cooke and Charles Wheatstone
  - 5 needles arranged in a horizontal row
  - rotation of needles indicate symbol
    - points to one of 19 letters in grid
Electric Telegraph
Cooke-Wheatstone Telegraph

• William Cooke and Charles Wheatstone
  – 5 needles arranged in a horizontal row
    • pointed to one of 19 letters in grid
  – rotation of needles indicate symbol
    • points to one of 19 letters in grid
    • missing letters substituted
      – e.g. Q ← KW
Electric Telegraph
Morse-Vail Telegraph

- Samuel F.B. Morse and Alfred L. Vail
  - independently developed same time as Cooke-Wheatstone
  - very simple system that required only one wire
    - on/off voltage with respect to ground
    - significantly more practical than multi-wire systems
  - developed “Morse code” to signal over one wire
Electric Telegraph

Morse Code

• Morse code
  – invented by Samuel Morse and Alfred Vail in early 1940s
  – on/off code consisting (mostly) of two symbols
  – designed for single wire electrical telegraph
  – original “American Morse Code” encoding now obsolete

• Evolved over time
  – some characters changed and added
  – standardised as International Morse Code: ITU-R M.1677
    • @ sign added in 2004
  – additional characters set in common use
    • letters with diacritics (accents, etc.)
    • Cyrillic, Greek, Arabic, Hebrew, Chinese, etc.
**Telegraph**

**Morse Code**

- Morse code applicable to other types of telegraphy
- Optical telegraphy
  - heliograph
    - pair of mirrors interrupted by shutter
  - Aldis signal lamp
    - louvered shutters in front of lamp
- Radiotelegraphy
  - Morse code audio over RF
  - significantly narrower spectrum needed than voice
**Morse code**
- base time interval of short symbol (dot)
- variable rate depending on skill of humans

<table>
<thead>
<tr>
<th>Type</th>
<th>Duration</th>
<th>Common Name</th>
<th>Graphical Symbol</th>
<th>Spoken Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>short</td>
<td>1</td>
<td>dot</td>
<td>•</td>
<td>di, dit (last in letter)</td>
</tr>
<tr>
<td>long</td>
<td>3</td>
<td>dash</td>
<td>—</td>
<td>da</td>
</tr>
<tr>
<td>intra-letter</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>inter-letter</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>inter-word</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Telegraph
### Morse Code Alphabet

| A A A | alfa | • — | O O O | oscar | — — — | Ç Ĉ | — • — • |
| B B B | bravo | — • • • | P P P | papa | • — • | CH X Č | — — — |
| C Θ Ц | charlie | — • — • | Q Ψ Ъ | quebec | — • — • | Ґ | • — • — |
| D Δ D | delta | — • • | R R R | romeo | • — | Ê | • — • — |
| E E E | echo | • | S Σ C | sierra | • • | Є Є | • — • — |
| F Ф Ф | foxtrot | • • — • | Т Т Т | tango | — | Г | — — • — |
| G Γ Γ | golf | — • | U U | uniform | • • | ʻ | — — — — |
| H H Х | hotel | • • • | V Ж | victor | • • — • | ̈ | • — • — |
| I I I | india | • • | W Ø B | whiskey | • — | ņ | — — • — |
| J Й | juliett | • — • — • | Х Ь Ъ | x-ray | • • — • | Ǿ Ø Ч | — — — |
| K К К | kilo | — • • | Y Y Ь | yankee | • — • — • | Ć | • — • — |
| L Λ Л | lima | • • • | Z Z З | zulu | • — • — • | Ρ | • — • — |
| M М М | mike | — — • | Ä Æ Я | • • • | Ü Ù Ю | • — • — |
| N Н Н | november | — • | À À | • — • — | Greek Cyrillic | http://homepages.cwi.nl/~dik/english/codes/morse.html

Greek

Cyrillic

http://homepages.cwi.nl/~dik/english/codes/morse.html
## Telegraph

### Morse Code Special Characters and Control

<table>
<thead>
<tr>
<th></th>
<th>Morse Code</th>
<th>Meaning</th>
<th>Morse Code</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>•— — — — —</td>
<td>.</td>
<td>•— •— •— —</td>
<td>understood</td>
</tr>
<tr>
<td>2</td>
<td>••— — —</td>
<td>,</td>
<td>—— •— — —</td>
<td>error</td>
</tr>
<tr>
<td>3</td>
<td>••• — —</td>
<td>:</td>
<td>—— —— ••</td>
<td>invite to xmit</td>
</tr>
<tr>
<td>4</td>
<td>••••—</td>
<td>?</td>
<td>••— —— •</td>
<td>wait</td>
</tr>
<tr>
<td>5</td>
<td>•••••</td>
<td>'</td>
<td>•— —— —</td>
<td>end</td>
</tr>
<tr>
<td>6</td>
<td>—••••</td>
<td>-</td>
<td>—••••—</td>
<td>start of xmit</td>
</tr>
<tr>
<td>7</td>
<td>——•••</td>
<td>/</td>
<td>—•••—</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>••— —</td>
<td>(</td>
<td>—•— —</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>—•---•</td>
<td>)</td>
<td>—•——</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>—•— —</td>
<td>&quot;</td>
<td>•—•••</td>
<td></td>
</tr>
</tbody>
</table>

### Mathematical Symbols

- = —••—•
- + •—•—
- × —•—
- @ •—•—
• Example Morse code fragment

“this is EECS 563”

Electric Telegraph
Morse Code Entry Devices

- **Straight key: original device**
  - spring-loaded vertical switch
  - operator depresses; holds longer for dah
  - limits to ~20 word/min
  - operators very subject to repetitive stress syndrome

- **Semiautomatic key**
  - spring-loaded horizontal switch
  - generates continuous sequence of properly timed pulses
  - dah(s) when held to the left; di(s) when held to the left
  - manufactured by Vibroplex since 1905
  - skilled operators can transmit in excess of 40–60 word/min
    - considerably faster than mobile numeric pad phone texting
Electric Telegraph
Morse Code Reception Devices

- Paper tape
  - stylus created depression on moving paper tape
  - di and dah read as short and long line segments
  - used in first Morse telegraph equipment

- Audible signal
  - operator hears sequence of clicks or pulses
  - early electric and current radio-telegraphy
Electric Telegraph Operating Companies

- **Western Union:** first major telecommunications company
  - 1851: founded as NY & Miss. Valley Printing Telegraph Co.
  - 1856: renamed to Western Union
  - 1861: first American transcontinental telegraph line
    - built into extensive telegraph network
    - commercial message service: *telegrams*
    - financial transaction service: *wiring money*
  - 1869: introduced stock ticker
  - 1900s: transitioned to PSTN and then data network
  - 1958: telex service using GEO satellite and microwave links
  - 2006: discontinued telegram service; exits telecom market
Electric Telegraph
Telegram Service

• *Telegram*: message delivered via telegraph
• Rapid delivery of urgent messages
  – before deployment of ubiquitous telephony and Internet
  – generally same-day delivery in urban areas
  – faster than postal mail delivery
• Telegrams now almost completely replaced by email
  – email–telegraph gateways had brief utility
  – still exist as expensive novelty service
    ~ $20.00/message + $1.00/word
Electric Telegraph
Telegram Service

- Telegram initiation
  - local telephone call to telegraph office
    - long distance voice was significantly more expensive
  - walk-in to telegraph office or desk at hotel

- Telegram reception
  - typically delivered as printed letter by messenger
    - singing telegram was additional novelty service
  - may be delivered by local post for non-urgent messages
Electrical Telegraph
Teletypewriter

• Teletypewriter (or teleprinter)
  – electromechanical typewriter/printer designed for telegraphy
  – operators do not need to know (Morse) code
  – two-wire telegraphy
    • using 5-bit Baudot / ITA2 binary code [ITU-T S.1]
Electrical Telegraph

Telex

• Telex: switched telegraph network
  – circuit switched network similar in concept to PSTN
    • numbering plan [ITU-T F.69]
  – teletypewriter terminals
    • telegraph offices for telegram services
    • individual subscribers: precursor to modern email

• ITU standards: *five* series applicable
  F. non-telephone telecommunication services
  R. telegraph transmission
  S. telegraph services terminal equipment
  T. terminals for telematic services
  U. telegraph switching
Radiotelegraphy
Morse Code

• Radiotelegraphy
  – Morse code audio over RF
  – significantly narrower spectrum needed than voice
    ~200 Hz vs 4–12 kHz
  – significantly more efficient transmission
    • useful in disaster scenarios
Telephony

Electric Voice Telegraphy

- Electric telegraphy
  - digital transmission came first!
  - lead to idea of transmitting (analog) voice: telephone

- Invention of telephone a complicated sequence
  - 1834–60: Antonio Meucci
  - 1854: Charles Bourseul
  - 1860: Johann Phillip Reis
  - 1876: Elisha Gray and Alexander Graham Bell
    - arrived at patent office within hours of one-another
    - controversy about independence of invention
Telephony

Radio Telegraphy

*Problem with electric telegraphy?*
Telephony
Radio Telegraphy

- Problem with electric telegraphy
  - requires wires
  - not practical for long-distances over bodies of water
- Radio telegraphy: free space RF transmission
  - 1888: Heinrich Hertz – demonstrates radio transceivers
  - 1894: Nikola Tesla – demonstrates radio transceivers
  - 1902: Guglielmo Marconi – first transatlantic transmission
  - 1898: Karl Ferdinand Braun – invents crystal rectifier
  - 1909: Marconi and Braun – Nobel Prize in physics
R&D History
Dispelling Misinformation

Who invented the light bulb?
R&D History  
Dispelling Misinformation

- Thomas Edison *did not* invent the light bulb
  - 1802 UK: Sir Humphry Davy – platinum filament
  - 1809 UK: Sir Humphry Davy – carbon arc
  - 1840 UK: Warren de la Rue – platinum in vacuum bulb
  - 1841 UK: Frederick de Moleyns – patent for Pt in vacuum
  - 1845 US: John Star – patent for C filament in vacuum
  - 1850 UK: Joseph Swan – C filament in vacuum
  - 1874 CA: Woodward & Evans – patent for C filament in N
  - 1878 US: Edison investigates/patents Pt filament in vacuum
  - 1880 UK: Joseph Swan – patent for C filament in vacuum
  - 1883 US: Edison patents invalidated on Swan prior art
  - 1889 US: Edison wins on appeal, prob. with altered journal
R&D History
Dispelling Misinformation

- Thomas Edison *did not* invent the light bulb

*What did Edison invent?*
R&D History
Research Lab

• Thomas Edison *did not* invent the light bulb
• Thomas Edison *did* invent the research lab
  – perfecting the light bulb one of many contributions
  – labs became critical in development of nets & computers
    • Bell Labs, GTE Labs
    • IBM Research, Xerox PARC, Univac Research, DEC Labs
    • GE Research, GM Research
Internet History and Architecture

HA.1.1 Early Data Networks

HA.0 Early history
HA.1 Internet history and architecture
  HA.1.1 Early data networks
  HA.1.2 Internet emergence
  HA.1.3 Modern Global Internet
HA.2 PSTN history and architecture
HA.3 SCADA networks overview
HA.4 Other networks
History: First Generation (≤1970s)

Early Networks

- Voice – widely deployed
  - circuit switched PSTN over copper
  - RF two-way radios
- Entertainment – widely deployed
  - broadcast RF for radio and television
- Data – limited pervasiveness
  - serial link over copper
  - modem remote terminal access

Distinct infrastructure for the three
First Generation
Circuit Switching

- First generation (<1970)
  - PSTN switching technique
First Generation
Circuit Switching

- Characteristics
  - setup latency

Diagram showing setup process with nodes S, 1, 2, R, and links.
First Generation
Circuit Switching

- Characteristics
  - setup latency
First Generation
Circuit Switching

- Characteristics
  - setup latency
First Generation
Circuit Switching

- Characteristics
  - setup latency
First Generation
Circuit Switching

- Characteristics
  - setup latency
First Generation
Circuit Switching

• Characteristics
  – setup latency
First Generation

Circuit Switching

• Characteristics
  – setup latency: RTT *before* data transfer
  – circuit seized
    *implication?*
First Generation
Circuit Switching

- Characteristics
  - setup latency: RTT *before* data transfer
  - circuit seized
    - no multiplexing efficiency
First Generation
Circuit Switching

- Characteristics
  - setup latency: RTT before data transfer
  - circuit seized
    - no multiplexing efficiency
First Generation
Circuit Switching

- Characteristics
  - setup latency: RTT before data transfer
  - circuit seized
    - no multiplexing efficiency
    - silence unusable by others
First Generation
Circuit Switching

- Characteristics
  - setup latency: RTT before data transfer
  - no multiplexing efficiency
  - negligible switch latency
First Generation Circuit Switching

• Characteristics
  – setup latency: RTT before data transfer
  – no multiplexing efficiency
  + negligible switch latency
  – resources must be released

![Diagram showing circuit switching process]
First Generation
Circuit Switching

- Characteristics
  - setup latency: RTT \textit{before} data transfer
  - no multiplexing efficiency
  - negligible switch latency
  - resources must be released
First Generation
Circuit Switching

- Characteristics
  - setup latency: RTT \textit{before} data transfer
  - no multiplexing efficiency
  + negligible switch latency
  - resources must be released
First Generation
Circuit Switching

- Characteristics
  - setup latency: RTT before data transfer
  - no multiplexing efficiency
  + negligible switch latency
  - resources must be released
First Generation
Message Switching

- First generation (<1970)
  - data switching technique
First Generation
Message Switching

- Characteristics
  + no setup latency
First Generation
Message Switching

- Characteristics
  - no setup latency
  - significant delay
    - store-and-forward delay
First Generation
Message Switching

- Characteristics
  + no setup latency
  - significant delay
    • store-and-forward delay

S 1 2 R

3 1 2

S 3 1 4

R
First Generation
Message Switching

- Characteristics
  + no setup latency
  - significant delay
    - store-and-forward delay
  + some multiplexing efficiency
First Generation
Message Switching

- Characteristics
  + no setup latency
  - significant delay
    • store-and-forward delay
  + some multiplexing efficiency
First Generation
Message Switching

- Characteristics
  + no setup latency
  + some multiplexing efficiency
  - significant delay
    - store-and-forward delay
    - small messages delayed (*buffered*) behind large ones
First Generation
Message Switching

- Characteristics
  + no setup latency
  + some multiplexing efficiency
  - significant delay
    - store-and-forward delay
    - small messages delayed (buffered) behind large ones
First Generation
Message Switching

- Characteristics
  + no setup latency
  + some multiplexing efficiency
  - significant delay
    - store-and-forward delay
    - small messages delayed (*buffered*) behind large ones
First Generation
Message Switching

- Characteristics
  - no setup latency
  - some multiplexing efficiency
    - significant delay
      - store-and-forward delay
      - small messages delayed (*buffered*) behind large ones
First Generation
Message Switching

- **Characteristics**
  - + no setup latency
  - + some multiplexing efficiency
    - significant delay
      - store-and-forward delay
      - small messages delayed
      - $d_r \gg d_t$
First Generation
Circuit vs. Message Switching

S 1 2 R
SETUP
CONNECT
RELEASE

d_l
d_r
First Generation
Circuit vs. Message Switching

- Circuit switching
  - PSTN technique
    - setup latency: RTT *before* data transfer
    - no multiplexing efficiency
  + negligible switch latency
  - resources must be released

- Message switching
  - early data networks
    + no setup latency
    + some multiplexing efficiency
  - significant delay
    - store-and-forward delay
    - small messages delayed
  \[ d_r \gg d_t \]
Internet Prehistory
Early LANs and Enterprise Networks

- 1972-1980: Internetworking, new & proprietary nets
  - 1970: ALOHAnet RF network in Hawaii
  - 1972: Farber’s DCS: first token ring LAN
  - 1973: Metcalfe’s PhD thesis proposes Ethernet
  - 1974: Cambridge slotted ring project begins (ATM precursor)
  - 1974: Cerf & Kahn – architecture for interconnecting nets
  - 1970s: proprietary architectures: DECnet, SNA, etc.
    - SNA begins as a star architecture in 1974
    - DECnet begins as a mesh architecture in 1975
Internet Prehistory

Distinct Networks

- ARPANET (US)
- Cyclades (France)
- NPL (UK)
- Telenet
- Tymnet
- Euronet
- VNET (IBM)
- Xerox RIN (Xerox)
- EASYnet (DEC)
- PSTN

- Distinct networks with few interconnections
Internet Prehistory

UUCPNET

- 1978 – ~2000: UUCPNET
  - 1978: UUCP program released in 7th ed. Unix
    - intended for file transfer & remote execution among 2 hosts
  - point-to-point PSTN lines using UUCP (Unix–Unix copy)
    - famous nodes: decvax, ihnp4, seismo (international link)
    - $O(10\ 000)$ nodes in early 1980s
  - used for email transport [RFC0976]
    - source route specifies path to well-known hosts
      - e.g. `{ihnp4,decvax}!uiucdcs!wugate!wucs1!wuccrc!jpgs`
    - USENET was similar but distinct network for netnews
  - most sites transition to NSFNET in late 1980s – early 1990s
    - UUCP mapping project terminated in 2000
      [Quartermann Matrix]
Internet Prehistory

BITNET

- 1981–1996: BITNET (Because it’s Time Network)
  - 1981: first link between Yale [Freeman] – CUNY [Fuchs]
  - interconnection among IBM VM mainframes using NJE
    - later others; DEC VAX VMS systems dominated
  - point-to-point leased lines among end systems
    - store-and-forward among end systems (no ISs)
  - services: email, LISTSERVs (email lists), chat, file transfer
  - 1992: 1400 sites / 30 000 nodes / 49 countries
  - 1989: merged with CSNET into CREN
    - Corporation for Research and Educational Networking
  - 1996: BITNET formally ceased to exist
    - sites transition to NSFNET

[http://www.cren.net/cren/cren-hist-fut.html]
Internet Prehistory

BITNET
Internet History and Architecture

HA.1.1 Internet Emergence

HA.0 Early history
HA.1 Internet history and architecture
    HA.1.1 Early data networks
    HA.1.2 Internet emergence
    HA.1.3 Modern Global Internet
HA.2 PSTN history and architecture
HA.3 SCADA networks overview
HA.4 Other networks
History: Second Generation (1980s)

Internet Emergence

- Voice – widely deployed
  - digital switched PSTN over copper
  - cellular mobile telephony (late)
- Entertainment – significant deployment
  - CATV over copper coax starts to supplement broadcast
- Data – research / corporate enterprise networks
  - packet switched store-and-forward
    - X.25 public data networks
    - Internet emerges as ARPANET+CSNET, then NSFNET+MILNET
  - gatewayed enterprise subnetworks: SNA, BNA, DCNA, etc
Second Generation
Datagram Packet Switching

- First generation (<1970)
  - data switching technique
Second Generation
Datagram Packet Switching

- Characteristics
  + no setup latency
Second Generation
Datagram Packet Switching

- Characteristics
  + no setup latency
  - store-and-forward delay
Second Generation
Datagram Packet Switching

- Characteristics
  - no setup latency
  - store-and-forward delay
Second Generation
Datagram Packet Switching

• Characteristics
  + no setup latency
  – store-and-forward delay
  + multiplexing efficiency
Second Generation
Datagram Packet Switching

- Characteristics
  - no setup latency
    - store-and-forward delay
  - multiplexing efficiency
- large messages broken into packets
Second Generation
Datagram Packet Switching

- Characteristics
  - no setup latency
  - store-and-forward delay
  - multiplexing efficiency
  - large messages broken into packets

[Diagram of data flow with labels and arrows]
Second Generation
Datagram Packet Switching

- Characteristics
  + no setup latency
  - store-and-forward delay
  + multiplexing efficiency
- large messages broken into *packets*
  + other flows interleave
Second Generation
Datagram Packet Switching

- Characteristics
  - + no setup latency
  - - store-and-forward delay
  - + multiplexing efficiency
  - • large messages broken into packets
  - + other flows interleave
Second Generation
Datagram Packet Switching

• Characteristics
  + no setup latency
  – store-and-forward delay
  + multiplexing efficiency
  • large messages broken into *packets*
  + other flows interleave
Second Generation
Datagram Packet Switching

• Characteristics
  + no setup latency
  – store-and-forward delay
  + multiplexing efficiency
• large messages broken into packets
  + other flows interleave
Second Generation
Datagram Packet Switching

- Characteristics
  - no setup latency
  - store-and-forward delay
  - multiplexing efficiency
  - large messages broken into packets
  - other flows interleave
Second Generation
Datagram Packet Switching

• Characteristics
  + no setup latency
  – store-and-forward delay
  + multiplexing efficiency
• large messages broken into packets
  + other flows interleave
• $d_r > d_t$
Second Generation
Packet vs. Message Switching
Second Generation
Packet vs. Message Switching

- Packet switching
  - modern data networks
  + no setup latency
  + better multiplexing efficiency
    - messages *packetised*
    + other flows interleave
  - less delay
    - store-and-forward pipelining
  - $d_r > d_t$
  - data rate still limited by switch throughput

- Message switching
  - early data networks
  + no setup latency
  + some multiplexing efficiency
  - significant delay
    - store-and-forward delay
    - small messages delayed
  - $d_r \gg d_t$
Internet Prehistory
Early Packet Switching Research

• 1961-1973: Early packet-switching principles
  – 1961: Kleinrock – queueing theory shows effectiveness of packet-switching
  – 1964: Baran – packetised voice switching in military nets
  – 1965: Davies proposes UK packet switched network
    • coins term *packet*
  – 1967: NPL begins construction of UK experimental network
    • Donald Davies at National Physical Lab
  – 1967: ARPANET conceived by US DOD ARPA
  – 1972: CYCLADES project planning in France
    • Louis Pouzin
  – 1973: first CYCLADES packet switch demonstration
Internet Prehistory

Early Packet Switching: NPL Topology

[Diagram showing the topology of early packet switching in the UK, with cities such as Plymouth, Brighton, Southampton, London, Greenwich, Bristol, Cardiff, Swansea, Dudley, Peterborough, Hull, Leeds, Manchester, Liverpool, and Norwich connected by lines to represent the network.]
Internet Prehistory

Early Packet Switching: CYCLADES 1978

[adapted from Pouzin-1982]
Internet History

Early Packet Switching: ARPANET

- **1967-1972: ARPANET emergence**
  - 1967: ARPANET conceived by US DoD ARPA
  - 1969:
    - BBN awarded contract to build IMPs (interface msg processors)
    - first ARPANET nodes operational at UCLA, SRI, UCSB, Utah
  - 1972:
    - ARPANET demonstrated publicly
    - NCP (Network Control Protocol) first host-host protocol
    - first e-mail program
    - ARPANET has 15 nodes
  - 1979: ARPANET has 200 nodes
    - but access limited to research institutions with ARPA contracts
Internet History
ARPANET Design Principles

- Minimalism, autonomy
  - no internal changes required to interconnect networks
- Best effort service model
  - support for a variety of applications
- Robust to failures (or attack)
  - stateless gateways (routers)
  - decentralized control
  - most functionality in end systems
    - note: *very different* from end-to-end arguments!

[McQuillan, Walden 1977], [Postel, Sunshine, Cohen 1981] [Clark 1988]
Internet History

ARPANET 1969

MAP: SRI, UCSB, UCLA, Utah
Internet History
ARPANET 1970

ARPANET

SRI

UCLA

UCSB

Rand

BBN

MIT

Harvard

LA

Utah
Internet History
ARPANET 1971
Internet History

ARPANET 1975
Internet History

CSNET

  - 1979: first link meeting at Wisc. [Landweber]
  - 1981: initial funding from NSF
  - network for researchers without ARPANET access
    - ARPANET restricted to certain DOD research contracts
  - TCP/IP and other services from ARPANET over:
    - X.25 public networks (initially Telenet)
    - Phonenet (MMDF over leased lines)
    - ARPANET for institutions with ARPA contracts
  - 1989: merged with CSNET into CREN
    - Corporation for Research and Educational Networking

[Denning, Hearn, Kern, ACM SIGCOMM 1983]
Internet History
Gatewayed Networks to ARPANET/CSNET

- Simplified logical structure
  - some nets use links of others (e.g. PSTN dialup/leased lines)
- Gateways interconnect
  - no seamless addressing
  - mixed formats through gateways (e.g. %-hack)
Internet History

ARPANET → NSFNET

• 1986: NSFNET begun
  – NREN (national research and engineering network)
    • HPCC (high perf. computing & communication) act “Gore bill”
  – funded by National Science Foundation
  – limited to academic institutions and a few govt. contractors

• Progression of
  – 1986: 56 kb/s switched by LSI-11 Fuzzball routers
  – 1989: T1 links switched by TR interconnected IBM PC-RTs
  – 1992: T3 links switched by FDDI interconnected IBM RS/6Ks

• Late 1980’s: Gigabit testbeds
  – research testbeds to increase network performance

• Early 1990’s: ARPANET decommissioned
Internet History
Role of Al Gore

- Al Gore was critical in funding the Internet (NSFNET)
  - he never claimed to have invented the Internet, rather:
    “During my service in the United States Congress, I took the initiative in creating the Internet. I took the initiative in moving forward a whole range of initiatives that have proven to be important to our country's economic growth and environmental protection, improvements in our educational system.”
    – Al Gore, 9 March 1999 on CNN
  - his role & statements have been defended by those who did
    “Bob [Kahn] and I believe that the vice president deserves significant credit for his early recognition of the importance of what has become the Internet. ... Gore was talking about and promoting the Internet long before most people were listening.”
    – Bob Kahn and Vint Cerf, 28 Sep. 2000
Internet History

NSFNET Emerges

- Simplified logical structure
  - some nets use links of others (e.g. PSTN dialup/leased lines)
- Gateways interconnect
  - no seamless addressing
  - mixed formats through gateways (e.g. %-hack)
  - UUNET becomes main UUCPNET–Internet gateway
Internet History

56 kb/s NSFNET Backbone

1986 – 1988

Fuzzball Router
DEC LSI-11

San Diego

Boulder

San Diego

Urbana-Champaign

Pittsburgh

Princeton

Ithaca

56 kb/s leased PSTN lines

56 kb/s NSFNET Backbone

Fuzzball Router
DEC LSI-11

San Diego

Boulder

San Diego

Urbana-Champaign

Pittsburgh

Princeton

Ithaca
Internet History

448 kb/s over T1 NSFNET Backbone

1988 – 1989

Router
IBM PC-RT
token ring

448 kb/s link multiplexed on T1 lines
Internet History
1.5 Mb/s T1 NSFNET Backbone

1989 – 1990

15 Mb/s T1 lines

Router
IBM PC-RT
token ring
Internet History

1.5 Mb/s T1 NSFNET Backbone

1990 – 1992

- Seattle
- Salt Lake City
- Boulder
- Lincoln
- Urbana-Champaign
- Houston
- San Diego
- Palo Alto
- Boston
- Princeton
- Ithaca
- Ann Arbor
- Pittsburgh
- Washington
- Atlanta
- Savannah

Router IBM PC-RT token ring

15 Mb/s T1 lines
Internet History
45 Mb/s T3 NSFNET Backbone

1992 – 1994

- 45 Mb/s T3 edge network links
- 45 Mb/s T3 core network links
Internet History

NSFNET Hierarchical Structure

- NSFNET Backbone
  - evolved from 56kb/s leased lines to 45Mb/s DS3
- Regional networks
  - MIDnet, NEARnet, NYSERnet, SURAnet, etc.
- Campus networks
  - KU, WashUStL, UMass, etc.
Internet History

NSFNET Hierarchical Structure

• Strict hierarchical structure
  – *advantages*?
Internet History

NSFNET Hierarchical Structure

- Strict hierarchal structure
  - simple to understand, measure, and analyse
  - traffic locality exploited
  - each level engineered for
    - local traffic characteristics
    - transit traffic between lower levels
Internet History
Regional Network Examples

MIDnet: Midwest Network
[Quarterman 1989, Catlett 1988]

NEARnet: New England Academic and Research Network
[???]
### Internet History

**NSFNET Regional Networks**

<table>
<thead>
<tr>
<th>Network</th>
<th>States</th>
<th>NSFNET Connection</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>BARRNet</td>
<td>SF Bay Area Regional Research Network</td>
<td>northern CA</td>
<td>Stanford</td>
</tr>
<tr>
<td>CICNet</td>
<td>Committee on Institutional Cooperation Network</td>
<td>IL, IN, IA, MI, MN, WI</td>
<td>UIUC?</td>
</tr>
<tr>
<td>JVNCNet</td>
<td>John von Neumann Supercomputer Center Net.</td>
<td>NJ, PA, NY, CT, RI, MA, NH, AZ, CO</td>
<td>Princeton</td>
</tr>
<tr>
<td>Los Nettos</td>
<td>Los Nettos (not NSF funded)</td>
<td>southern CA</td>
<td></td>
</tr>
<tr>
<td>Merit</td>
<td>Merit</td>
<td>MI</td>
<td>UMich</td>
</tr>
<tr>
<td>MIDnet</td>
<td>Midwest Network</td>
<td>NE, KS, OK, AR, MI, IL, IA</td>
<td>UNL, UIUC</td>
</tr>
<tr>
<td>NCSAnet</td>
<td>National Center for Supercomputing Network</td>
<td>IL, WI, IN</td>
<td>UIUC</td>
</tr>
<tr>
<td>NEARnet</td>
<td>New England Academic and Research Network</td>
<td>MA, CT, RI, VT, NH, ME</td>
<td>MIT</td>
</tr>
<tr>
<td>NorthWestNet</td>
<td>Northwestern States Net.</td>
<td>WA, OR, MT, ND, ID, AK</td>
<td>UWash</td>
</tr>
</tbody>
</table>
# Internet History

## NSFNET Regional Networks

<table>
<thead>
<tr>
<th>Network</th>
<th>States</th>
<th>NSFNET Connection</th>
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<td>CA</td>
<td>UCSD</td>
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<td>University Satellite Network</td>
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<td>CO, WY, UT, AZ, NM</td>
<td>UC</td>
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</table>
Internet History
Research Networks: NSF vBNS

- 1995: NSF awards vBNS
  - intended as successor for NSFNET research infrastructure
  - OC-12 backbone for research supercomputers
  - OC-48 upgrade begins 1999
  - program ends ~2000
Internet History
Gigabit Testbeds

• Gigabit Testbeds
  – funded by DARPA, managed by CNRI
    • except MAGIC funded directly by DARPA
  – attempt to research next generation of Internet
    • infrastructure at OC-12 bleeding edge: 622 Mb/s \approx 1 \text{ Gb/s}
    • applications driving the need for Gb/s infrastructure

• 1987: Farber and Kahn propose to NSF
  – awarded planning grant

• 1990: five testbeds funded
  – Aurora, Blanca, Casa, Nectar, Vistanet
  – MAGIC added in 1992; KU participant
Internet History
Gigabit Testbeds

1990 – 1996

- Nectar
- Blanca
- Casa
- Aurora
- Vistanet
Internet History

NSFNET and MILNET become the US Internet

- Simplified logical structure
  - some nets use links of others (e.g. PSTN dialup/leased lines)
- Global Internet with NSFNET as backbone
  - seamless addressing using user@DNS and IP addresses
  - corporate networks convert to TCP/IP
  - MILNET is separate but interconnected US military backbone
Internet History and Architecture

HA.1.1 Modern Global Internet

HA.0 Early history
HA.1 Internet history and architecture
  HA.1.1 Early data networks
  HA.1.2 Internet emergence
  HA.1.3 Modern Global Internet
HA.2 PSTN history and architecture
HA.3 SCADA networks overview
HA.4 Other networks
History: Third Generation (1990s)
Convergence and the Web

• Beginnings of converged IP-based infrastructure
  – IP-based global Internet subsuming enterprise networks
  – multimedia streaming (still distinct from CATV)
  – voice and video-conferencing over IP
    • gateways between the Internet and PSTN

• Web
  – replaces all other information access
    • e.g. gopher, archie, and FTP (as visible to most users)

• Fast packet switching over fiber
• Significant 1st world deployment
Internet History

Privatisation

- 1991: NSF lifts access restrictions on NSFNET
  - use of email and netnews explodes
- 1993: NSF solicitation for privatisation plans
- 1995: NSF awards for
  - NAPs: network access point for ISP traffic exchange
  - RA: routing arbiter
  - vBNS: very high performance backbone network service
- 1995 April: NSFNET backbone decommissioned
- 1995 Sept.: NSF ends DNS registration subsidies
- 1998: NAPs and RA transferred to private sector
Internet History

Research Networks

- Internet precursors were research networks
  - privatisation constrained use by researchers
  - drove need for research infrastructure
    - separate from but attached to public Internet

- Research networks
  - US: Internet2 and NLR
  - Canada: CANARIE (Canadian Advanced Network and Research for Industry and Education)
  - Europe: GÉANT
  - UK: JANET
Research Networks

Internet2 Overview

• 1996: Internet2 forms among 34 universities
  – *not* an alternate or replacement for the Internet
    • this is a common misconception by the public
  – consortium of Universities and other research institutions
  – operates network infrastructure with fee to access
    • 1999: Abilene OC-48 links upgraded in 2004 to OC-192 links
    • 2006: Internet2 network with 10×10Gb/s WDM links
Research Networks

Abilene Network

Internet2
GigaPoP

2.4 Gb/s OC-48 links

1999 – 2003
Research Networks

Abilene Network

2004 – 2006

Seattle
Palo Alto
Los Angeles
Denver
Kansas City
Chicago
Indianapolis
New York
Washington
Atlanta
Houston

10 Gb/s OC-192 links
Research Networks
Internet2 Network

10×10 Gb/s links

Portland  Sunnyvale  Los Angeles  Albuquerque  Salt Lake  Denver  Kansas City  Tulsa

Chicago  Pittsburgh  Indianapolis  Louisville  Nashville  Tennessee  Nashville  Atlanta  Jacksonville
New York  Philadelphia  Washington  Boston

06 September 2016 KU EECS 563 – Intro Comm Nets – History & Arch ICN-HA-188
Research Networks

Regional Network Example: KanREN

- **1991**: KanREN (KS Research and Education Network)
  - formed to expand connectivity in KS beyond MIDnet
  - initial connectivity in 1993 funded by NSF
  - GPN (1997) formed as successor to MIDnet
  - KanREN attaches to Internet2 through GPN
  - 2003 partnership with Kan-Ed for K-12 network
Research Networks
GÉANT2 Network
Research Networks
PlanetLab and Emulab

- PlanetLab
  - international testbed to conduct Internet research
  - L4–7 programmable: applications and transport
  - VINI extends to control Internet topology
  - experiments use a slice of PlanetLab
  - basis for GENI cluster B (in which GENI participates)

- Emulab: clusters of computing nodes
  - located in local area
  - arbitrary system software
  - programmable interconnection
  - basis for GENI cluster C (ProtoGENI)
Internet History

Web Emergence

- 1945 hypertext [Bush 1945, Nelson 1960’s]
- 1990: first Web browser within CERN
  - HTML, HTTP [Berners-Lee]
- 1992: first widely used Web browsers
  - Mosaic (graphical) from UIUC NCSA (Andreessen, Bina 1992)
  - Lynx (text) from KU (Grobe, Rezac, Montulli 1992)
- 1994: Mozilla/Netscape 1.0 descends from Mosaic
- 1994: Lycos is first Web search engine
- 1995: Yahoo! first large-scale Web directory
Internet History

Web Ubiquity

• 1995: MS Internet Explorer
  – Microsoft discovers the Internet

• 1995: Altavista
  – becomes dominant Web search engine

• 1996: Google
  – 1997: google.com registered
  – becomes dominant Web search engine
  – 2006: “google” added as verb to OED

• 2001: Wikipedia collaborative encyclopedia
  – wiki concept used for many other things

• 2004: Mozilla Firefox
Internet Architecture
Current Structure

tier-2 providers

IXP

IXP

peering points

tier-1 providers

local ISPs

access lines
Internet Architecture
Current Structure: Tier 1

• Loose hierarchy but with many interconnections
  – no longer a map of the Internet; ISP internals proprietary

• Tier-1 backbone providers
  – largest with national or international high-speed backbones
  – interconnect with one-another at IXPs
    • Internet exchange points formerly NAP (network access points)
    • *peering* without charging one-another for traffic
  – by bilateral agreement, e.g. Sprint, AT&T
    • or sometimes not: Level3–Cogent peering war in 2005
  – do not purchase transit service from anyone else
Internet Architecture

Current Structure: Tier-1 Providers

- Tier 1 backbone providers
  - at&t
  - Centurylink (Qwest + SAVVIS)
  - Cogent (formerly PSINet)
  - Deutsche Telekom
  - GTT (formerly Tinet Tiscali Italy)
  - Level 3 with Global Crossing (GX)
  - NTT Communications (formerly Verio)
  - Sprint
  - Tata (India) with Teleglobe
  - Seabone (Telcom Italia Sparkle)
  - TeliaSonera Intl. Carrier
  - Verizon Business (formerly UUNET)
  - XO Communications

[Wikipedia Sep 2014]

- at&t
  - Centurylink AS0209/3561
  - Cogent AS0174
  - Deutsche Telekom AS3320
  - GTT AS3257
  - Level 3 with Global Crossing AS0001/3356/3549
  - NTT Communications AS2914
  - Sprint AS1239
  - Tata AS6543
  - Seabone AS6762
  - TeliaSonera AS1299
  - Verizon Business AS0701/0702/0703
  - XO Communications AS2828
Internet Architecture
Current Structure Tiers 2 and 3

• Loose hierarchy but with many interconnections
  – no longer a map of the Internet; ISP internals proprietary
• Tier-1 backbone providers
• Tier-2 ISPs
  – purchases some transit traffic from tier-1 providers
  – peer directly with some networks (tier-1 and tier-2)
  – e.g. BT (AS5400) purchases from GX and Sprint
• Tier-3 local ISPs buys all transit service
  – purchases all transit traffic (from tier-2 and perhaps tier-1)
  – provide local Internet access
  – e.g. WOW/Sunflower from Sprint & Level3
  
[cidr-report.org]
Internet Architecture

Tomography

• No Internet map
  – service provider secret
• Impedes research on
  – physical structure
  – traffic patterns
  – application use
• Internet tomography
  – probe to infer structure
  – logical maps *only*, e.g.
    • IP address structure
    • AS relationships

[Britt wikipedia Image:Internet_map_1024.jpg]
Internet Architecture
Approximating Router Topology

• IP and routing tomography
  – infer router interconnectivity of a particular service provider
  – provides an approximate map of L3 connectivity
  – does not provide L2 and physical topology
  – does not provide peering information

• Rocketfuel ISP topology mapping engine
  [http://www.cs.washington.edu/research/networking/rocketfuel]
  – basis for following maps...
Internet Architecture
Approximating Router Topology

- IP and routing tomography
  - full map would include inferred maps of all service providers
  - very complex with at most limited utility
Internet Architecture
Multilevel Topology

- L3 IP topology is *not* physical topology
  - it is an overlay of L3 logical links onto the physical links
  - whose topology is also not publicly released by ISP
  - but may be approximated by third party data mining
Network Topology
Sprint L1 Physical Fiber Topology

based on
[KMI 1999]
Multilevel Internet Topology

Sprint L1–3 Topology

L3
L2.5
L1
History: Fourth Generation (2000s+)

Scale, Ubiquity, Mobility

- Global infrastructure
  - optical core networks
  - wireless access networks
  - (hopefully) significant 2\textsuperscript{nd} and 3\textsuperscript{rd} world pervasiveness

- Ubiquitous and pervasive computing
  - personal and body-area wearable networks
  - IoT: Internet of things

- Peta-node and Exa-node networks

- Autonomic control and management
Internet History
Peer-to-Peer File Sharing

- Peer-to-peer file sharing applications  *Lecture AL*
  - 1999 May: Napster created in 1999 to share music files
    - centralised database
  - 1999 Dec: RIAA sues Napster
  - 2000 March: Gnutella released by AOL subsidiary
    - a few hours later AOL removes links
    - thousands already have it
    - distributed database; no single entity for RIAA go attack
    - 2000: 20 M users and 2 M music shares/hr
  - 2001 July: court orders Napster to shut down
    - until all copyrighted material removed
    - Gnutella takes over; file sharing continues to grow
Internet History
Peer-to-Peer File Sharing

- Peer-to-peer file sharing applications
  - 2001: users move to other non-centralised anonymous apps
    - no central target for RIAA and MPAA
    - difficult to trace individual users
      - but not impossible with ISP collusion
    - e.g. Gnutella
  - 2002 July: Napster files for bankruptcy
  - 2003+: MPAA and RIAA threaten and sue
    - individual users, institutions such as Universities
    - push draconian legislation to limit technological advances
  - the cat-and-mouse game continues
    - BitTorrent becomes most common sharing mechanism
    - darknets become more common
Internet History
Web Evolution

- Web becomes defacto application infrastructure
  - Web browser is universal GUI
- **Mashup**
  - hybrid Web-based composed application
  - uses standard interfaces for rapid development
    - e.g. Google maps, webcam stream embedded in page
- **Web 2.0** [DiNucci 1999, O’Reilly 2004]
  - this is a _dreadful_ jargon; there is no Web release number
  - refers evolution of Web-based services and applications
    - multimedia and rich content
    - client- and server-side scripting and application interaction
Internet History
Social Networking Prehistory

- Network and Internet subcultures
  - communities developed on Usenet, BBSs, and mailing lists
  - 1985: The WELL (Whole Earth ‘Lectronic Link) community
    - (still) a paid subscription
  - 1987: Usenet (great renaming) communities and netiquette
  - 1994: Web-based communities
    - theGlobe (defunct 2008), GeoCities (defunct 2009), Tripod
    - personal web pages for the masses
    - communities of interest, chat rooms
Internet History
Social Networking

- **Social networking** Lecture AL
  community of users enabled by a Web GUI

- **History (selected)**
  - 2002: Friendster established as a way to meet new people
    • has become Asia-centric
  - 2003: MySpace formed by former Friendster employees
    • was most popular social networking site in mid 2000s
  - 2003: LinkedIn formed as professional networking site
    • tracks professional and business connections
    • basic service free, advertises fee-based premium service
Internet History

Social Networking

• Social networking history (selected)
  – 2004: Facebook (Facemash) launched for Harvard students
    • opened up to other colleges; high schools in 2005
    • 2006: open access to all over 13 years old
    • now the most popular social net site: > 600 M users
    • become choice for older more educated users (over MySpace)
    • source of significant controversy over privacy issues
    • constant redesign of UI infuriates users
    • notorious for deploying without considering consequences
Internet History
Social Networking

• Social networking history (selected)
  – 2006: Twitter launched as text-based network
    • essentially pub/sub multicasting text & micro-blogging service
    • 140 character tweets
  – 2010: Disapora project at NYU
    • open source distributed social network
    • individual pods host users and control privacy
    • alpha pod up at diasp.org
    • KU pod planned at diaspora.ku.gpeni.net
  – 2011: Google+ released
    • 100 M users after 6 months
    • circles and hangouts among new functionality
Internet History

Cloud Computing: Overview

- *Cloud computing*
  software and computing services in public Internet
  - note: Grid Computing is scientific supercomputing *EECS 881*
- Roots
  - 1960s time sharing services, outsourcing of IT services
Internet History

Cloud Computing: Advantages

- Advantages
  - access to temporary resources without purchasing
  - typical outsourcing advantages; downsizing of IT staff

- Disadvantages
  - exposure to risk of loss in confidentiality of data
    - difficulty in meeting HIPAA and FERPA requirements
  - loss of control of IT services
Internet History
Cloud Computing: Alternatives

- Deployment alternatives
  - private cloud: provisioned for single user
  - community cloud: provisioned for particular user community
  - public cloud: provisioned for use by general public
  - hybrid cloud

- Service model
  - SaaS: software as a service
    - customer uses cloud-provided applications (e.g. Google Docs)
  - PaaS: platform as a service
    - customer can deploy applications on standard VM platforms
  - IaaS: infrastructure as a service
    - customer can provision processing, storage, interconnection
Internet History
Cloud Computing: Providers

- Example providers and services
  - Amazon Web Services (AWS)
    - EC2 (Elastic Computing Cloud)
    - EBS (Elastic Block Store)
  - Google cloud services
    - Google Docs
    - Google App Engine
    - Google Cloud Storage
  - IBM SmartCloud
  - Microsoft
    - Office 365
    - Windows Azure
Internet History
Balkanisation and Geolocation

• 2000s: Internet geographic homogeneity disappears
  – reverse lookups used to geolocate servers and users

• Location-based Web services
  – can be used to enhance experience for naïve users
    • location or language-specific content and services
    • e.g. Wikipedia, google.{com|co.uk|co.in|cn...}
    • e.g. amazon.{com|ca|co.uk|de|fr|co.jp|cn...}
    • should be overrideable by user
  – can be used to restrict locations of users
    • e.g. Hulu blocks users outside the US (and many proxies)
  – can be annoying for sophisticated users
  – Flagfox addon for Firefox shows location of server
Internet History
Balkanisation and Censorship

• 1990s: Internet censorship: filtering of content

• Location of filtering
  – filtering in Web proxies (e.g. China Golden Shield)
  – filtering in firewalls: typical in corporate environments
  – filtering software on individual computers

• Filtering mechanisms
  – content (text strings, image analysis)
    • many false positives
  – IP address and URI
    • cat-and-mouse game
  – traffic analysis and port # for P2P file sharing
Internet History

Censorship Examples: Sector

- Businesses, government, military
  - justification: traffic, security, employee productivity
  - typically: firewalling porn, social networking, ebay, youtube

- Schools and libraries
  - justification: child protection
  - typically: PC filtering software in children’s areas
  - librarians have fiercely resisted filtering on adult computers
    - concerns: 1st amendment, public access, false positives
    - e.g. Middlesex and Essex counties was filtered in Mass.

- Home use
  - content and site filtering on children’s machines
Internet History

Censorship Examples: National

- Nations: legal, political, religious, sexual content
- List of worst censorship and surveillance
  - pervasive: Cuba, Egypt, Iran, N. Korea, China, Myanmar, Syria, Tunisia, Turkmenistan, Uzbekistan, Vietnam
  - substantial: Bahrain, S. Korea, Saudi Arabia, UAE, Yemen

[Wikipedia: Internet_censorship based on OpenNet Initiative]
Internet History
Censorship Examples: National

- **Nations**: legal, political, religious, sexual content
  - China (except Hong Kong and Macau): political, porn
    - 2003: *Golden Shield* 金盾工程 (aka Great Firewall of China)
      - Facebook blocked – Chinese use Rénrén 人人
      - Twitter blocked – Chinese use Weibo 微博 microblog service(s)
      - YouTube blocked – Chinese use Yōukù 优酷
      - Bǎidù 百度 search engine blocks search terms and Web sites
        e.g. 非法献花 / illegal flower tribute and 法轮功 / Falun Gong
    - 2009: *Green Dam* 绿坝·花季护航 **filtering software**
    - 2010: Google – China confrontation over Gmail cracking
      - Google withdraws from China but operable via Hong Kong
      - illegal flower tribute (非法献花): flowers laid at Google HQ
Internet History
Censorship Examples: National

- Nations: legal, political, religious, sexual content
  - North Korea: anything indicative of life in the rest of world
    - public Internet restricted to government and elite academics
    - Kwangmyong (광명) intranet for use by most North Koreans
      - government information and propaganda
      - clones of public Internet sites (primarily scientific and technical)
      - monitored email
  - South Korea: anonymity prohibited
    - N. Korea content filtered
Internet History
Censorship Examples: National

- Nations: legal, political, religious, sexual content
  - Pakistan: 2008 YouTube prefix hijack
  - Myanmar/Burma: crime to use Internet without permission
    - 15 year fine for possessing a non-registered modem
  - Saudi Arabia: all traffic through national filtering proxy
  - Egypt: 2011 BGP prefix withdrawal
    - to censor protest organisation activities
  - Libya: 2011
  - Syria: 2011
Internet History

Censorship Examples: National

- Nations: legal, copyright, sexual & offensive content
  - US: many initiatives driven by big media incl. RIAA/MPAA
    - 1996 CDA: Communications Decency Act
    - 1998 DMCA: Digital Millennium Copyright Act
    - 2011 SOPA/PIPA:
      - Stop Online Privacy Act / Protect Intellectual Privacy Act
      - temporarily withdrawn after 2011 Internet protest
      - likely to come back as part of ACTA treaty of 2011
      - proposed technically infeasible filtering
      - proposed further erosion of US constitutional
  - Germany: Nazi content restricted
Internet History
Censorship by Nation

- Based on
  ONI (Open Network Initiative) and RSF (*Reporters sans Frontières*)

[en.wikipedia.org/wiki/Internet_censorship...]

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Internet History
Balkanisation and Net Neutrality

- 2000s: network neutrality debate
- *Network neutrality* [Wu 2003]

ISP\s forward traffic without discrimination to:
- content type
  - e.g. Web pages vs. streaming video vs. P2P file sharing
- content source (servers and users)
  - e.g. content provided by ISP vs. 3rd party
  - content provider (e.g. Netflix or Sony)
- platforms
  - e.g. Windows vs. Mac OS vs. Unix
  - IE vs. Firefox vs. Chrome
Internet History
Balkanisation and Net Neutrality

• Arguments against net neutrality
  – pure net neutrality prevents QoS deployment
    • extreme view not held by most
  – laissez faire: service providers should do what they want
    • agenda pushed by provider lobbyists (e.g. Verizon, Comcast)
  – regulation of net neutrality could stifle innovation
    • complex issue for which legislation and regulation difficult

• Arguments for net neutrality
  – ISPs, ASPs, and vendors will abuse power
    • Internet is not free market
  – regulation is needed to prevent anti-competitive behaviour
Internet History
Balkanisation and Net Neutrality

- 2005 US FCC Broadband Policy Statement
  - principles for open internet:
    - any lawful content
    - any lawful application
    - any lawful device
    - any provider

- FCC position has been changing back and forth
  - under pressure from congress
    - under pressure from service providers and big media
Internet Future
Research and Design

- Internet architecture increasingly stressed
  - scale: growth in nodes, users, traffic
  - new deployment scenarios: mobile wireless, sensor nets, ...
  - new applications
- Previous attempts to evolve architecture unsuccessful
  - addition of QoS: IntServ, DiffServ
  - multicast
  - larger address space: IPv6
Network History and Architecture

HA.1 Internet history and architecture
HA.2 PSTN history and architecture
  HA.2.1 Regulated monopolies
  HA.2.2 Deregulation and modern architecture
  HA.2.3 Mobile cellular telephony
HA.3 Other networks
US PSTN
Structure

• PSTN: public switched telephone network
  – traditionally a hierarchical structure & centralised admin.

• Local or exchange area network
  – originally administered by different bell operating companies
  – now operated by ILECs (incumbent local exchange carriers)
  – must offer service access to CLECs (competitive LECs)

• Long distance or interexchange network
  – formerly called toll network operated by Bell Long Lines
  – now multiple IXCs (interexchange carriers)
    • long distance carriers (AT&T, MCI, Sprint, etc.)
    • recently traditional local carriers (Bellsouth, Verizon, etc.)
PSTN History and Architecture

HA.2.1 Regulated Monopolies

HA.1 Internet history and architecture
HA.2 PSTN history and architecture
  HA.2.1 Regulated monopolies
  HA.2.2 Deregulation and modern architecture
  HA.2.3 Mobile cellular telephony
HA.3 SCADA networks overview
HA.4 Other networks
US PSTN

History

- Worldwide: traditionally PTT carrier per country
  - changing with deregulation in each country
- US: Bell System and other operators
- AT&T Bell System main operating units
  - Long Lines (long distance)
  - Bell Operating Companies (local service)
  - Western Electric (telephone and switch manufacturing)
  - Bell Laboratories (research)
- Other telephone companies scattered throughout US
  - GTE & Contel scattered among AT&T territory over entire US
  - many other very small independent telephone companies
US PSTN
Bell System Historical Structure

AT&T Long Lines

local BOCs

local loops

independent local carriers
US PSTN
Traditional Local Network Structure

- Telephones connected to *central office* by *local loop*
- *Local office* contains local switching system
  - local (class 5) switch(es)
- Local switching systems are interconnected by
  - tandem switching system into the switching hierarchy
  - direct trunks when high-interoffice traffic dictates
  - network traffic engineering dictates proper mix
US PSTN
Traditional Local Network Structure

final trunk group
(to class 4 long distance switching)
US PSTN
Bell Operating Companies (1982)

does not show overlaid GTE, Contel, and other non-Bell operators

Bell Operating Companies (1982):
- Pacific Bell
- Mountain Bell
- Northern Bell
- Northwestern Bell
- Southwestern Bell
- South Central Bell
- Southern Bell

Bell Operating Companies in each state:
- California: Pacific Bell
- Nevada: Nevada Bell
- Utah: Mountain Bell
- Iowa: Northern Bell
- Minnesota: Northern Bell
- Wisconsin: Northwestern Bell
- Illinois: Northwestern Bell
- Indiana: Ind. Bell
- Ohio: Bell of Ohio
- Pennsylvania: Bell of Pennsylvania
- New England Telephone
- New Jersey Bell
- C&P Tel. Md.
- C&P Tel. W.Va.
- C&P Tel. D.C.
- C&P Tel. Va.
- C&P Tel. N.J.
- C&P Tel. N.Y.
- C&P Tel. Md.
- C&P Tel. W.Va.
- C&P Tel. D.C.
- C&P Tel. Va.
Traditional Long Distance Network Structure

- Switching hierarchy of AT&T Long Lines
  - class 4 toll (long distance) centers
  - class 3 primary centers
  - class 2 sectional centers
  - class 1 regional centers with international access

- Number of switching offices
  - 1982 just before divestiture
  - note large number of non-Bell LEC central offices

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US PSTN
Early Long Distance Competition

- 1963: Microwave Communications Inc. formed
- 1969: MCI licensed by FCC, begins service in 1970
  - point-to-point microwave links
- 1978: Southern Pacific Communications
  - fiber optic cables along rail right of way
  - spun off as SPRINT (Southern Pacific Rail …)
- 1983: GTE acquires Sprint from SP Railroad
- 1986: Sprint merges with US Telecom
  - US Sprint jointly owned by GTE and United Telecom
- 1989: GTE sell share of US Sprint to United Telecom
PSTN History and Architecture

HA.2.2  Deregulation and Modern Architecture

HA.1  Internet history and architecture
HA.2  PSTN history and architecture
  HA.2.1  Regulated monopolies
  HA.2.2  Deregulation and modern architecture
  HA.2.3  Mobile cellular telephony
HA.3  SCADA networks overview
HA.4  Other networks
US PSTN
Bell System Divestiture

• 1982 MFJ (modification of final judgment)
  – required AT&T to divest 22 BOCs (Bell operating companies)
    • 7 RBOCs (regional BOCs)
    • 2 independent BOCs (not wholly owned by AT&T)
  – local exchange areas
    • combined into ~160 LATAs (local access and transport areas)
  – equal access required to IXCs (interexchange carriers)
  – central services organisation
    • Bellcore (Bell Communications Research) piece of Bell Labs
  – AT&T keeps long distance, manufacturing

• 1 Jan 1984: divestiture
US PSTN
Divestiture: AT&T

- AT&T Communications (IXC)
  - traditional interstate long distance (was Long Lines)
  - other inter-LATA IXC services

- Western Electric
  - development and manufacturing of switches, phones, etc.

- AT&T Bell Laboratories
  - research

- Others
  - AT&T Information Systems
  - AT&T International
  - American Transtech (stock transfer)
US PSTN
Post-Divestiture RBOCs (1982)

The map illustrates the post-divestiture Regional Bell Operating Companies (RBOCs) in 1982 in the United States. The map is color-coded to represent different RBOCs:

- Pacific Telesis
- Southwestern Bell Corporation
- Ameritech
- Bell Atlantic
- Bellsouth
- U.S. West
- NYNEX

The map does not show the overlaid GTE, Contel, and other non-Bell operators.
US PSTN

SNET and Cincinnati Bell
US PSTN
GTE and Contel
US PSTN
Post-Divestiture Structure

IXCs interexchange carriers

interIXC trunks

LECs local exchange carriers

local loops

IXCs: Interexchange Carriers
LECs: Local Exchange Carriers
US PSTN
Dominant ILECs (2006)

- AT&T
- Qwest
- Verizon
- Bellsouth
- Cincinnati Bell

does not show other ILECs

states with significant ex-GTE Verizon territory
US PSTN
Dominant ILECs (2007+)

AP&T: Alaska Power & Telephone

Hawaiian Telecom

Cincinnati Bell

At&t
CenturyLink
Qwest
Verizon

states with significant ex-GTE Verizon territory
US PSTN
Post-1996 Deregulation LEC Structure

IXCs interexchange carriers

interIXC trunks

CLECs competitive LECS

ILECs incumbent LECS

local loops (owned by ILEC)
US PSTN
Recent Developments

• Local loop competition
  – CATV providers offer digital telephony over HFC plant
  – wireless providers beginning to offer service
    • 802.16 may become pervasive

• PBX (private branch exchange) competition
  – VoIP installations (e.g. using Cisco IP phones)

• VoIP: voice over IP
  – providers (e.g. Vonage) offer service over broadband access
    • ILECs unsuccessfully resisting access over DSL
  – VoIP clients on PCs (e.g. skype)
    • free calling to other PC clients (given data access charges)
    • cheap calling to/from PSTN telephones through gateways
US PSTN Decline

• Beginning of the end of the PSTN
  – 2010: at&t asks FCC for timetable to decommission PSTN
    • traffic is already moving to IP-based Internet
  – Challenges
    • powered POTS phones during blackouts
    • e911 services
US PSTN
Current Structure

Internet–PSTN gateways

CATV

IXCs

Internet VoIP

ILECs incumbent LECS

local ILEC loops: analog or DSL, fiber
PSTN History and Architecture

HA.2.3 Mobile Cellular Telephony

HA.1 Internet history and architecture

HA.2 PSTN history and architecture
   - HA.2.1 Regulated monopolies
   - HA.2.2 Deregulation and modern architecture
   - HA.2.3 Mobile cellular telephony

HA.3 SCADA networks overview

HA.4 Other networks
US Mobile Telephone Network
Early History

- 1947–1977
  - 1946: FCC allocates 33 FM channels in 35,150,450 MHz band
  - 1947: operator relay begins to US passenger trains
  - 1960s: direct dialing from automobiles in home area
    - extremely limited channel capacity
  - 1977: Bell Labs begins first AMPS cellular trial in Chicago
Mobile Telephone Network
Generations and Standards: Overview

- **1G**: analog AMPS (advanced mobile phone sys.)
- **2G**: digital
  - world  GSM (global system for mobile comm.) *except*
  - US/Korea  CDMA IS-95
  - Japan  D-AMPS (digital AMPS)
- **2.5G**: 2nd generation with new data services
  - emerged with delay of 3G past planned deployment in 2000
- **3G**: widely deployed for ~1Mb/s data in late 2000s
- **3.5–3.9G** emerging services (claiming to be 4G)
- **4G**: 1Gb/s stationary / 100Mb/s moving data rate
  - *none deployed yet*
Mobile Telephone Network
Generations and Standards: 4G

• There are no 4G services, and won’t be for years
  – Sprint Xohm/Clearwire was first to advertise “4G”

• Current 3.5–3.9G services
  – 802.16e Sprint 2010 (abandoned for LTE)
  – HSPA+ T-Mobile, AT&T 2010 (converting to LTE)
  – LTE Verizon, AT&T, 2011 initial deployments

• ITU formally denied certification of these as 4G
  – but recently admitted carriers are ignoring
  – LTE is sometimes called 3.9G

• 4G will be LTE-advanced
Mobile Telephone Network Penetration

- Mobile telephone subscribers exceed wireline in 2002

[ITU ICT Development Index 2009]
Network History and Architecture

HA.3 Other Networks

HA.1 Internet history and architecture
HA.2 PSTN history and architecture
HA.3 Other networks
Other Networks

Overview

- Global Internet is subsuming more networks
  - but not all networks are part of Internet or PSTN
- Relationship to Internet and PSTN
  - segregated networks with no connection to Internet
    - e.g. vehicle embedded control network
  - gatewayed to Internet but with restricted connectivity
    - e.g. military networks
  - overlay using transparent
    - IP tunnels through Internet
    - dedicated circuits in PSTN
Other Networks

Partial List

• GIG (Global Information Grid): military
  – Internet: NIPRNET, SIPRnet, JWICS
  – tactical military networks (including mobile MANETs)
  – situational awareness and telemetry

• Vehicle embedded networks

• Manufacturing and process control networks

• SCADA: supervisory control and data acquisition
  – controls power plants, gas pipelines, ...

• IoT: Internet of things
  – home automation, smart cities
References

Further Reading