Lecture 14:   Communications and networking

•  history and background
  –  telephone system
  –  local area networks

•  Internet
  –  architecture: what the pieces are and how they fit together
  –  names and addresses: what's your name and number?
    Domain Name System,  IP addresses
  –  routing: how to get from here to there
    traceroute, ping
  –  fundamental protocols and layers: how pieces talk to each other
    IP,  TCP
  –  higher level protocols and services:
    HTTP, SSH, SMTP, IMAP, ...;  web, email, instant messaging, peer to peer, ...

•  Web
  –  what makes it work: URL, HTTP, HTML, browser
Telephone system  (Alexander Graham Bell, 1876)

- organizing principles, all based on voice traffic:
  - voice calls need only a narrow bandwidth channel
  - each call uses a dedicated circuit, with long setup and hold times
  - telephone number is a unique identifier
  - fixed routing for a specific call
  - parallel signaling network; data separated from control
  - simple user interface: all intelligence inside network
  - guarantees on quality of service; high reliability

- running out of some resources  (area codes, 800/888/877/866/855/844, ...)

- traffic model changing rapidly  (cell phones, data, ...)

- technology changing rapidly  (wireless, Internet, ...)

- worldwide evolution from highly regulated and/or government-operated to deregulated / private
  - highly competitive
  - incumbent carriers threatened by Internet
Local Area Networks; Ethernet

- A LAN connects computers ("hosts") in a small geographical area.
- Ethernet is the most widely used LAN technology.
  - Each host has a unique 48-bit identification number.
  - Data sent from one host to another in "packets" of 100-1500 bytes.
    Including source and destination address and error checking bits.
    Typical data rate 10-1000 Mbits/sec; limits on cable length.

<table>
<thead>
<tr>
<th>packet</th>
<th>hdr</th>
<th>src</th>
<th>dest</th>
<th>type</th>
<th>data</th>
<th>check</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
<td>6</td>
<td>6</td>
<td>2</td>
<td>46-1500 bytes</td>
<td>4</td>
</tr>
</tbody>
</table>

- "Broadcast" technology: data sent to all connected hosts.
  - Sender broadcasts, but if it detects someone else sending, stops,
    waits a random interval, tries again.

- Wireless Ethernet uses radio to carry signals.
  - Logical behavior is exactly like a wired Ethernet.
Connecting networks  (wide area networks / WAN)

- how do we connect LANs to each other?
  - LANs may have different properties
  - may be far away

- names & addresses now needed to identify other networks and hosts
- routing needed to find a path if multiple networks are involved
  - can't have each network connected directly to all others
- protocols to agree on format of information and how it is exchanged
  - especially if networks are different kinds that use
    different format for packets
    different physical and electrical properties
    different names and addresses themselves

- how do we handle errors, delays, overload, etc.?
- how does it scale as the number of networks gets really big?
Gateways and Routers

your computer

his computer

her computer

network

Amazon

their computers

Router

Router

Router

Google

Princeton
The Internet

- millions of independent networks that are connected
  - NOT a giant computer or a single network
  - each network may serve many host computers
- nearby computers are connected by a local area network
  - most often Ethernet (including wireless)
- information travels through networks in small "packets"
  - each packet independent of all others
    - like individual envelopes through the mail
  - all packets have the same format
  - standard protocols for format of info and behavior
- networks connected by specialized gateway computers (routers)
  - route packets of information from one network to the next
  - gateways continuously exchange routing information
- each packet passes through multiple gateways
  - gateway passes packet to gateway that is closer to ultimate destination
  - gateways usually operated by different companies
Internet History

- 1961: packet switching concept (Leonard Kleinrock, MIT, UCLA)
- 1960's: ARPANET, funding from DARPA (Dept of Defense)
- 1969: first Internet communication
- 1972: first network email
- 1973: basic protocols: TCP/IP (Bob Kahn *64, Vint Cerf)
- 1980's: National Science Foundation funding, NSFNet (Al Gore)
- 1980's: Internet Engineering Task Force for technical decisions
- 1990's: commercialization, Web, dot-com boom
- 2000: dot-com bust
- 2010: universal availability
- 2020: increasing fragmentation, government controls

- for lots more, http://www.isoc.org/internet/history/
Basic mechanisms

- **names** for computers
  - princeton.edu, finance.yahoo.com, www.whitehouse.gov, kernighan.net, ...

- **addresses** for identifying networks and computers
  - each has a unique number like 128.112.136.10 (IP address)
  - central authority assigns numbers to networks
  - each host computer has unique address (32 bit integer in IPv4, 128 in IPv6), assigned locally according to what network it's on

- **Domain Name System** to convert names to addresses

- **routing** for finding paths from network to network

- **protocols** (rules) for packaging and transporting information
  - IP, or "Internet Protocol": a uniform transport mechanism
    - at IP level, all information is in a common format
  - below IP, different hardware uses different protocols
  - above IP, higher-level protocols for handling web pages, mail, login …
Internet (IP) addresses

- each network and each connected computer has an IP address
- IP address: a unique 32-bit number in IPv4 (IPv6 is 128 bits)
  - 1st part is network id, assigned centrally in blocks
    (Internet Assigned Numbers Authority -> Internet Service Provider -> you)
  - 2nd part is host id within that network
    assigned locally, often dynamically

<table>
<thead>
<tr>
<th>net part</th>
<th>host on that net</th>
</tr>
</thead>
<tbody>
<tr>
<td>128</td>
<td>112</td>
</tr>
<tr>
<td>136</td>
<td>10</td>
</tr>
</tbody>
</table>

- written in "dotted decimal" notation: each byte in decimal
  - e.g., 128.112.136.10 = www.princeton.edu

| 10000000 | 01110000 | 10001000 | 00001010 |
Domain names

- a hierarchical naming scheme
  - central authority (ICANN) manages top level of names

- top level domains include .com, .edu, .gov, .xx for country XX
  - and myriad newer domains like .biz, .info, .name, .xxx, ...

- each domain delegates responsibilities to levels below
  - for administration and translation into addresses

- each level is responsible for names within it
  - princeton.edu handles all of princeton
  - delegates cs.princeton.edu to a CS computer
  - CS department manages names within, e.g., rinse.cs.princeton.edu

- names impose logical structure, not physical or geographical
Domain name system (DNS)

- DNS converts names to IP addresses and vice versa
  - www.princeton.edu == 140.180.223.42
  - carnegiehall.org == 45.60.73.146
  - kernighan.com == 23.111.140.49

- hierarchical searching for addresses
  - central authority controls top level domain names (.com, etc.)
  - delegates responsibilities for searching to levels below
  - each level responsible for names and addresses within it
    - princeton.edu handles address lookup for all of princeton
    - delegates cs.princeton.edu to a CS machine

- top level domains handled by 13 root servers
- lookup for a name asks a local name server first
  - if not known locally, asks a server higher up, ..., to root server
  - recently-used names are cached to speed up access
Routing

- networks are connected by gateways or routers
- routing rules direct packets from gateway to gateway trying to get closer to ultimate destination
- routers exchange information frequently about routes
- bottom-up view:
  - gateways move packets from one network to another based on network id
  - if destination on the same network, use physical address
  - otherwise send to a gateway, which passes it to another network
- top-down view:
  - networks connected only through gateways
  - core has a small set of gateways that exchange complete routing info about which nets it knows about and number of hops to reach them
  - autonomous system: group of networks under single authority
  - passes reachability info to core for use by other autonomous systems
  - interior gateway protocols exchange routing info within a single AS
- ping: is there a path from here to there?
- traceroute: how do you get from here to there?