NETWORK EVOLUTION & RESEARCH
Networking is getting into middle years

<table>
<thead>
<tr>
<th></th>
<th>idea</th>
<th>current</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP</td>
<td>1974 (RFC 675)</td>
<td>1981 (RFC 793)</td>
</tr>
<tr>
<td>telnet</td>
<td>1969 (RFC 15)</td>
<td>1983 (RFC 854)</td>
</tr>
<tr>
<td>ftp</td>
<td>1971 (RFC 114)</td>
<td>1985 (RFC 959)</td>
</tr>
</tbody>
</table>
Internet/broadband: one of the fastest applications ever introduced

2005 = 30% broadband / 2010 = 70% broadband estimate

Source: Michael Fox and Forbes Magazine, Morgan Stanley
The use of mobile devices continued to increase in 2012. Eighty-eight percent of Americans ages 25 and older reported using mobile phones in October 2012. Once online, mobile phone users increasingly used their devices to send and receive email, browse the Web, access social networks, and utilize other applications that offer increased productivity or entertainment in their busy lives.

Smartphones and their diverse applications have led the mobility movement. Popular with the general public, smartphones are also important to people with disabilities for reasons beyond mere convenience. Smartphone applications can reveal one’s location via GPS or provide directions to a desired destination. To help people with vision disabilities, researchers in Pakistan have developed a smartphone app that monitors a user’s location and distance walked from a destination to warn of imminent nightfall (Ahsan, Khan, & Salam, 2013). The application is geo-aware and so knows the time of sunset around the world, and with its access to online mapping software, the app can offer the potentially vulnerable user shortcuts for the return trip.

Smartphones can also aid the unemployed. Some 77 percent of job seekers have already begun to use smartphone apps to give them an advantage in job-seeking. Application developers are creating tools that enhance one’s ability to learn about and secure a new job and to customize and export a résumé expeditiously.
Telecom policy tool kit

- gov’t monopoly
- price-regulated utility
- structural separation
- unbundled network elements
- facilities-based competition + interconnection
- laissez faire

Disability access
Public safety
CALEA

Network neutrality

Anti-trust

Gov’t grants (USF)
High cost + low income
Standardization

- Oscillate: convergence ➔ divergence
  - continued convergence clearly at physical layer
  - connectivity trumps functionality
  - niches larger ➔ support separate networks
- Two facets of standardization:
  1. public, interoperable description of protocol, but possibly many (Tanenbaum)
  2. reduction to 1-3 common technologies
    - L2: Arcnet, tokenring, DECnet, ATM, FDDI, DQDB, SONET … ➔ Ethernet
    - L3: IP, IPX, X.25, OSI ➔ IP
    - OS: dozens ➔ Windows, MacOS, Linux
Standardization

- Have reached phase 2 in most cases
  - RPC (SOAP, REST) and presentation layer (XML, JSON) most recent 'conversions'
- Often, non-standardized technologies can be deployed faster
  - single (dominant) vendor
    - Skype vs. SIP and H.323
    - AOL IM and XMPP (Jabber) vs. SIMPLE
    - SMB vs. NFS vs. WebDAV
- Standardization after success?
- IETF one-protocol-for-application vs. everything-is-RPC
  - not enough network experts → standardization scales better
  - see OASIS, OMA standardization groups
Technologies at ~30 years

- Other technologies at similar maturity level:
  - air planes: 1903 – 1938 (Stratoliner)
  - cars: 1876 – 1908 (Model T)
  - analog telephones: 1876 – 1915 (transcontinental telephone)
  - railroad: 1820s – 1860s (transcontinental railroad)
Observations on progress

• 1960s: military → professional → consumer
  • now, often reversed
• Communications technologies rarely disappear (as long as operational cost is low):
  • exceptions:
    • telex, telegram, semaphores → fax, email
    • X.25 + OSI, X.400 → IP, SMTP
  • analog cell phones
• → thus, NGN (post-IP, future Internet) discussions likely academic
Lifecycle of technologies

traditional technology propagation:

- military: opex/capex doesn’t matter; expert support
- corporate: capex/opex sensitive, but amortized; expert support
- consumer: capex sensitive; amateur

Can it be done? Can I afford it? Can my mother use it?
Example: Telex

Telex Services

Telex remains one of the most reliable, universally available forms of electronic data communication, with approximately one million users worldwide. Today, many thousands of Telex messages are exchanged hourly, securing business transactions throughout the globe. By operating within its own physical network, Telex provides a legal and secure transmission standard, regardless of origin or destination. Still leading the way in the Global Telex market are the Finance, Shipping, Oil and Gas industries.

Within finance, Telex still remains a medium for transferring and confirming trading instructions. Although the primary medium for electronic data communication within the banking community is now SWIFT, there are still many banks that are not connected to the SWIFT network. Furthermore, in the event of a disaster normal trading can still continue via Telex if it is kept as a back up to SWIFT.

Shipping companies still use Telex as a method of communication with vessels at sea and for various methods of general trading. Although Email and Fax is used widely in the shipping industry, there are still many shipping organizations where Telex is primary means of communications.

Sidereal offers many connection options to the Telex network for sending and receiving, including dial-up and ip.

Click here to see the Telex rate and country schedule.
Transition of networking

• Maturity → cost dominates
  • can get any number of bits anywhere, but at considerable cost and complexity
  • casually usable bit density still very low

• Specialized → commodity
  • OPEX (= people) dominates
  • installed and run by 'amateurs'
  • need low complexity, high reliability
User challenges vs. research challenges

• Are we addressing real user needs?
  • Engineering vs. sports scoring

• My guesses

- reliability
- ease of use
- no manual
- no re-entry
- no duplication
- integration
- limited risk
- phishing data loss
- cost
Example: Email configuration

- Application configuration for (mobile) devices painful
- SMTP port 25 vs. 587
- IMAP vs. POP
- TLS vs. SSL vs. “secure authentication”
- Worse for SIP...
Example: SIP configuration

- highly technical parameters, with differing names
- inconsistent conventions for user and realm
- made worse by limited end systems (configure by multi-tap)
- usually fails with some cryptic error message and no indication which parameter
- out-of-box experience not good
Internet and networks timeline

1960: Theory
1970: University prototypes
1980: Production use in research
1990: Commercial early residential
2000: Broadband home
2010: Broadband home

Port speeds:
- 1960: 100 kb/s
- 1970: 1 Mb/s
- 1980: 10 Mb/s
- 1990: 100 Mb/s
- 2000: 1 Gb/s

Internet protocols:
- Email
- FTP
- DNS
- RIP
- UDP
- TCP
- SMTP
- SNMP
- Finger
- ATM
- BGP, OSPF
- Mbone
- IPsec
- HTTP
- HTML
- RTP
- XML
- OWL
- SIP
- Jabber

Queueing architecture:
- DQDB, ATM
- QoS
- VoD

Routing and congestion control:
- p2p
- ad-hoc
- sensor
## Cause of death for the next big thing

<table>
<thead>
<tr>
<th>Issue</th>
<th>QoS</th>
<th>multicast</th>
<th>mobile IP</th>
<th>active networks</th>
<th>IPsec</th>
<th>IPv6</th>
</tr>
</thead>
<tbody>
<tr>
<td>not manageable across competing domains</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>not configurable by normal users (or apps writers)</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>no business model for ISPs</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>no initial gain</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>80% solution in existing system</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓ (NAT)</td>
</tr>
<tr>
<td>increase system vulnerability</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Why do good ideas fail?

- Research: O(.), CPU overhead
  - “per-flow reservation (RSVP) doesn’t scale” → not the problem
    - at least now -- routinely handle O(50,000) routing states

- Reality:
  - deployment costs of any new L3 technology is probably billions of $

- Cost of failure:
  - conservative estimate (1 grad student year = 2 papers)
    - 10,000 QoS papers @ $20,000/paper → $200 million
Research: Network evolution

- Only three modes, now thoroughly explored:
  - packet/cell-based
  - message-based (application data units)
  - session-based (circuits)
- Replace specialized networks
  - left to do: embedded systems
    - need cost(CPU + network) < $10
    - cars
    - industrial (manufacturing) control
    - commercial buildings (lighting, HVAC, security; now LONworks)
    - remote controls, light switches
    - keys replaced by biometrics
Research: Pasteur’s quadrant

- Quest for Fundamental Understanding?
  - Yes: Pure basic research (Bohr)
  - No: Use-inspired basic research (Pasteur)
- Considerations of Use?
  - No: Guessing at problems (Infocom)
  - Yes: Pure applied research (Edison)

*Most networking research wants to be here*
Maturing network research

• Old questions:
  • Can we make X work over packet networks?
    • All major dedicated network applications (flight reservations, embedded systems, radio, TV, telephone, fax, messaging, …) are now available on IP
  • Can we get M/G/T bits/s to the end user?
  • Raw bits everywhere: “any media, anytime, anywhere”

• New questions:
  • Dependency on communications → Can we make the network reliable?
  • Can non-technical users use networks without becoming amateur sysadmins? → auto/zeroconfiguration, autonomous computing, self-healing networks, …
  • Can we make networks affordable to everyone?
  • Can we prevent social and financial damage inflicted through networks (viruses, spam, DOS, identity theft, privacy violations, …)?
New applications

• New bandwidth-intensive applications
  • Reality-based networking
  • (security) cameras → “ambient video”

• New bandwidth-extensive applications
  • communicate infrequently → setup overhead
  • SIGFOX network

• Distributed games often require only low-bandwidth control information
  • current game traffic ~ VoIP
  • 4G, 5G → low latency

• Computation vs. storage vs. communications
  • communications cost has decreased less rapidly than storage costs

SIGFOX (902 MHz, 100 bps) is a connectivity solution that focuses on low throughput devices. On SIGFOX you can send between 0 and 140 messages per day and each message can be up to 12 bytes of actual payload data.
Change is hard

- No new network services deployed since 1980s
  - universal upgrade
  - chicken/egg (network/OS) problem
- “Innovation at edges”
- Applications easier, as long as
  - TCP-based
  - client-server
  - … but there are exceptions (p2p)
## Time of transition

<table>
<thead>
<tr>
<th>Old</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPv4</td>
<td>IPv6</td>
</tr>
<tr>
<td>circuit-switched voice</td>
<td>VoIP</td>
</tr>
<tr>
<td>separate mobile voice &amp; data</td>
<td>LTE + LTE-VoIP</td>
</tr>
<tr>
<td>911, 112</td>
<td>NG911, NG112</td>
</tr>
<tr>
<td>digital cable (QAM)</td>
<td>IPTV</td>
</tr>
<tr>
<td>analog &amp; digital radio</td>
<td>Pandora, Internet radio, satellite radio</td>
</tr>
<tr>
<td>credit cards, keys</td>
<td>NFC</td>
</tr>
<tr>
<td>end system, peers</td>
<td>client-server v2 aka cloud</td>
</tr>
</tbody>
</table>

all the energy into transition → little new technology
Technology transition

- research
- de-facto standards
- standards
- products

protocols vs. algorithms!
Internet challenges

• IP address depletion
• NAT, middle boxes and the loss of transparency
• Routing infrastructure
• Quality of service
• Security
• DNS scaling
• Dealing with privatization
• Interplanetary Internet
COMPLEXITY
Mid-Life Crisis

- doubles number of service interfaces
- requires changes above & below
- major interoperability issues
“Why architectural complexity is like body fat”

- You naturally tend to gain it while you grow older
- Very easy to gain and very hard to get rid of
  - Designing complex solutions and protocols easier than designing simple ones.
- Healthy to have some, but not too much
- Having it on waist may be worse than elsewhere
- Younger and slimmer will eventually beat you
  - Architectural complexity → reduced agility → younger and less complex systems eventually replace older and more complex system.
- Sometimes surgery is a good way to start
- Long term results require constant exercise

http://www.tml.tkk.fi/~pnr/FAT/
Causes of complexity

• Complexity: implementation vs. run-time
  • system vs. protocol
• After-the-fact enhancements:
  • security
  • NAT traversal
  • mobility
  • internationalization (e.g., DNS)
• Wrong layer for function
  • multicast? IP security?
• Options
  • e.g., multiple transport protocols, IPv4 & IPv6
• Lots of special protocols
  • e.g., IMAP, POP, SMTP
• Manual configuration
Mobile traffic distribution – 2011 prediction

VolP traffic forecasted to be 0.4% of all mobile data traffic in 2015.
Source: Cisco VNI Mobile, 2011
Global Mobile Data Traffic, 2013 to 2018

Overall mobile data traffic is expected to grow to 15.9 exabytes per month by 2018, nearly an 11-fold increase over 2013. Mobile data traffic will grow at a CAGR of 61 percent from 2013 to 2018 (Figure 1).

The Asia Pacific and North America regions will account for almost two-thirds of global mobile traffic by 2018, as shown in Figure 2. Middle East and Africa will experience the highest CAGR of 70 percent, increasing 14-fold over the forecast period. Central and Eastern Europe will have the second highest CAGR of 68 percent, increasing 13-fold over the forecast period. The emerging market regions of Asia Pacific and Latin America will have CAGRs of 67 percent and 66 percent respectively.

Source: Cisco VNI Mobile, 2014
Mobile traffic is mostly Wi-Fi

Exabytes per Month

<table>
<thead>
<tr>
<th>Year</th>
<th>Cellular Traffic from Mobile Devices</th>
<th>Offload Traffic from Mobile Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>2014</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>2015</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>2016</td>
<td>13%</td>
<td>13%</td>
</tr>
<tr>
<td>2017</td>
<td>16%</td>
<td>16%</td>
</tr>
<tr>
<td>2018</td>
<td>19%</td>
<td>19%</td>
</tr>
</tbody>
</table>

Source: Cisco VNI Mobile, 2014
Figure 10. Mobile Video Will Generate Over 69 Percent of Mobile Data Traffic by 2018

Because many Internet video applications can be categorized as cloud applications, mobile cloud traffic follows a curve similar to video. Mobile devices have memory and speed limitations that might prevent them from acting as media consumption devices, were it not for cloud applications and services. Cloud applications and services such as Netflix, YouTube, Pandora, and Spotify allow mobile users to overcome the memory capacity and processing power limitations of mobile devices. Globally, cloud applications will account for 90 percent of total mobile data traffic by 2018, compared to 82 percent at the end of 2013 (Figure 11). Mobile cloud traffic will grow 12-fold from 2013 to 2018, a compound annual growth rate of 64 percent.

Exabytes per Month

61% CAGR 2013-2018

- Mobile File Sharing (2.9%)
- Mobile M2M (5.7%)
- Mobile Audio (10.6%)
- Mobile Web/Data (11.7%)
- Mobile Video (69.1%)

Figures in parentheses refer to traffic share in 2018.

Source: Cisco VNI Mobile, 2014
Monthly Consumption (fixed)

<table>
<thead>
<tr>
<th></th>
<th>North America</th>
<th>Mean</th>
<th>Median</th>
<th>Mean : Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>8.5 GB</td>
<td>1.8 GB</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>Downstream</td>
<td>48.9 GB</td>
<td>20.4 GB</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>Aggregate</td>
<td>57.4 GB</td>
<td>22.5 GB</td>
<td>2.6</td>
<td></td>
</tr>
</tbody>
</table>

- top 1% →
  - 49.7% of upstream traffic
  - 25% of downstream traffic

<table>
<thead>
<tr>
<th></th>
<th>Europe</th>
<th>Mean</th>
<th>Median</th>
<th>Mean : Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>5.1 GB</td>
<td>1.5 GB</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>Downstream</td>
<td>23.1 GB</td>
<td>8.7 GB</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>Aggregate</td>
<td>28.2 GB</td>
<td>10.1 GB</td>
<td>2.8</td>
<td></td>
</tr>
</tbody>
</table>
The value of bits

- Technologist: A bit is a bit is a bit
- Economist: Some bits are more valuable than other bits
  - e.g., $(email) >> $(video)

<table>
<thead>
<tr>
<th>Application</th>
<th>Volume</th>
<th>Cost per unit</th>
<th>Cost / MB</th>
<th>Cost / TB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice (13 kb/s GSM)</td>
<td>97.5 kB/minute</td>
<td>10c</td>
<td>$1.02</td>
<td>$1M</td>
</tr>
<tr>
<td>Mobile data</td>
<td>5 GB</td>
<td>$40</td>
<td>$0.008</td>
<td>$8,000</td>
</tr>
<tr>
<td>MMS (pictures)</td>
<td>&lt; 300 KB, avg. 50 kB</td>
<td>25c</td>
<td>$5.00</td>
<td>$5M</td>
</tr>
<tr>
<td>SMS</td>
<td>160 B</td>
<td>10c</td>
<td>$625</td>
<td>$625M</td>
</tr>
</tbody>
</table>
### Video, video and more video

<table>
<thead>
<tr>
<th>Upstream</th>
<th>Downstream</th>
<th>Downstream %</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>BitTorrent</td>
<td>Netflix</td>
<td>29.70%</td>
<td>Netflix</td>
</tr>
<tr>
<td>HTTP</td>
<td>HTTP</td>
<td>18.36%</td>
<td>BitTorrent</td>
</tr>
<tr>
<td>Skype</td>
<td>YouTube</td>
<td>11.04%</td>
<td>HTTP</td>
</tr>
<tr>
<td>Netflix</td>
<td>BitTorrent</td>
<td>10.37%</td>
<td>YouTube</td>
</tr>
<tr>
<td>PPStream</td>
<td>Flash Video</td>
<td>4.88%</td>
<td>Flash Video</td>
</tr>
<tr>
<td>MGCP</td>
<td>iTunes</td>
<td>3.25%</td>
<td>iTunes</td>
</tr>
<tr>
<td>RTP</td>
<td>RTMP</td>
<td>2.92%</td>
<td>RTMP</td>
</tr>
<tr>
<td>SSL</td>
<td>Facebook</td>
<td>1.91%</td>
<td>Facebook</td>
</tr>
<tr>
<td>Gnutella</td>
<td>SSL</td>
<td>1.43%</td>
<td>SSL</td>
</tr>
<tr>
<td>Facebook</td>
<td>Hulu</td>
<td>1.09%</td>
<td>Skype</td>
</tr>
<tr>
<td>Top 10</td>
<td>Top 10</td>
<td>84.95%</td>
<td>Top 10</td>
</tr>
</tbody>
</table>
Average monthly usage

- Average monthly TV consumption (US): 154 hours
- Netflix: 1 GB/hour (SD) … 2.3 GB/hour (HD)
  - → 300 GB/month
  - more if people in household watch different content

<table>
<thead>
<tr>
<th>monthly usage (AT&amp;T Uverse)</th>
<th>2010</th>
<th>2012</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 50 GB</td>
<td>$0</td>
<td>9.4%</td>
<td>14.1%</td>
</tr>
<tr>
<td>&gt; 100 GB</td>
<td>$0</td>
<td>5.3%</td>
<td>8.2%</td>
</tr>
<tr>
<td>&gt; 200 GB</td>
<td>$10</td>
<td>1.4%</td>
<td>4.4%</td>
</tr>
<tr>
<td>&gt; 500 GB</td>
<td>$50</td>
<td>0.4%</td>
<td>0.8%</td>
</tr>
<tr>
<td>&gt; 1 TB</td>
<td>$150</td>
<td>0.0%</td>
<td>0.2%</td>
</tr>
</tbody>
</table>
Bandwidth generations

Source: Cisco VNI, 2011
Transit prices

$/Mbps

http://drpeering.net/white-papers/Internet-Transit-Pricing-Historical-And-Projected.php
Cost of bandwidth

Fig. 5: SONET/SDH vs. Ethernet Monthly Cost

Backbone DWDM per-bit, per-km cost improvements over time

Figure 1

Source: Ovum
Bandwidth costs

- Amazon EC2
  - $50 - $120/TB out, $0/TB in
- CDN (Internet radio)
  - $600/TB (2007)
  - $7-20/TB (Q1 2014 – CDNpricing.com)
- NetFlix (7 GB DVD)
  - postage $0.70 round-trip → $100/TB
- FedEx – 2 lb disk
  - 5 business days: $6.55
  - Standard overnight: $43.68
  - Barracuda disk: $91 - $116/TB
- DVD-R (7 GB)
  - $0.25/disk → $35/TB
## Cost of bandwidth (2011 & 2015)

<table>
<thead>
<tr>
<th>Service</th>
<th>Speed (Mb/s)</th>
<th>Average price/ month 2015 (2011)</th>
<th>$/Mb/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS1 (T1)</td>
<td>1.54</td>
<td>$295 ($450)</td>
<td>$197 ($292)</td>
</tr>
<tr>
<td>DS3</td>
<td>45</td>
<td>$1950 ($5,000)</td>
<td>$43 ($111)</td>
</tr>
<tr>
<td>Ethernet over Copper</td>
<td>10</td>
<td>$310 ($950)</td>
<td>$31 ($95)</td>
</tr>
<tr>
<td>Fast Ethernet</td>
<td>100</td>
<td>$1,800 ($5,000)</td>
<td>$18 ($50)</td>
</tr>
<tr>
<td>Gigabit Ethernet</td>
<td>1000</td>
<td>$4,000 ($25,000)</td>
<td>$4 ($25)</td>
</tr>
</tbody>
</table>
Bandwidth costs

• Amazon EC2
  • $100/TB in, $100/TB out

• CDN (Internet radio, Hulu, Netflix, …)
  • $600/TB (2007)
  • $100/TB (Q1 2009 – CDNpricing.com)
  • $15/TB to $50/TB (Q4 2010, 500 TB/month)

• NetFlix (7 GB DVD)
  • postage $0.70 round-trip $100/TB

• FedEx – 2 lb disk from NY to San Diego
  • 5 business days: $9.08
  • Standard overnight: $66.99
    • 18 hours 0.25 Gb/s
  • Hitachi disk: $34/TB
NETWORK REALITY
# Textbook Internet vs. real Internet

<table>
<thead>
<tr>
<th>Ideal</th>
<th>Reality</th>
</tr>
</thead>
<tbody>
<tr>
<td>end-to-end (application only in 2 places)</td>
<td>middle boxes (proxies, ALGs, …)</td>
</tr>
<tr>
<td>permanent interface identifier (IP address)</td>
<td>time-varying (DHCP)</td>
</tr>
<tr>
<td>globally unique and routable</td>
<td>network address translation (NAT)</td>
</tr>
<tr>
<td>multitude of L2 protocols (ATM, ARChnet, Ethernet, FDDI, modems, …)</td>
<td>dominance of Ethernet, but also L2’s not designed for networks (1394 Firewire, Fibre Channel, MPEG2, …)</td>
</tr>
</tbody>
</table>
## Textbook Internet vs. real Internet

<table>
<thead>
<tr>
<th>Mostly trusted end users</th>
<th>Hackers, spammers, con artists, pornographers, …</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small number of manufacturers, making expensive boxes</td>
<td>Linksys, Dlink, Netgear, …, available at Walmart</td>
</tr>
<tr>
<td>Technical users, excited about new technology</td>
<td>Grandma, frustrated if email doesn’t work</td>
</tr>
<tr>
<td>4 layers (link, network, transport, application)</td>
<td>Layer splits</td>
</tr>
<tr>
<td>Transparent network</td>
<td>Firewalls, L7 filters, “transparent proxies”</td>
</tr>
</tbody>
</table>
Which Internet are you connected to?
The two-port Internet

- Many public access systems only allow port 80 (HTTP) and maybe 25 (SMTP)
  - e.g., public libraries
- Everything tunneled over HTTP
  - Web-based email
  - Flash video delivery (e.g., YouTube)
  - HTTP CONNECT for remote login
Causes

• Link-layer technologies
  • satellite, DSL
  • NBMA

• Network-layer technologies
  • security: broken by design vs. broken by accident?
  • NATs
  • Ill-defined meaning of IP addresses and names
    • theoretically, single network interface
    • practically, often more than that
      • virtualization
      • multi-homing
      • fail-over
Private Internet -- challenges

- *Public* Internet = collection of *privately*-owned (mostly) for-profit networks
- Incentives for greedy behavior
- Special-purpose networks
  - VoIP networks
  - 3GPP, NGN, … ➔ “walled garden”
  - sub-applications large enough to support own infrastructure
- Private protocols
  - e.g., most IM protocols
- Patent encumbrances
  - see https://datatracker.ietf.org/public/ipr_disclosure.cgi
- D. Clark, J. Wroclawski, K. Sollins, R. Braden, “Tussle in Cyberspace: Defining Tomorrow’s Internet”, ToN, June 2005
Tussle in Cyberspace

- Traditional view: design technology to make choices
- Tussle view: design technology to allow choices
  - “we are designing the social contract that the Internet embodies”
  - not a final outcome, on-going process \(\rightarrow\) lawyers vs. engineers
- Multiple competing interests
  - application value capture
    - high value content looks the same to ISP
  - traffic price differentiation
    - willingness to pay
  - investment in infrastructure vs. open interfaces
    - sunk costs
  - greed (local traffic optimization vs. social optimum)
  - privacy and anonymity vs. societal goals
    - CALEA, network resource protection, spam, DRM
- \(\rightarrow\) Allow multiple outcomes, but give users choice (competition)
  - user-selected routes and servers

Other network models

- Interplanetary networks
  - Extremely long round-trip times, large feedback delays
  - Protocols designed with terrestrial timeout parameters
  - See Vint Cerf’s web page and Delay-Tolerant Networking Research Group (DTNRG)

-Disconnected or delay-tolerant operation
  - “store-and-forward” at the content level

- Sensor networks
  - Extremely lossy links

- Content-based networks
Other network types

<table>
<thead>
<tr>
<th>network</th>
<th>partially disconnected</th>
<th>mobile end systems</th>
<th>wireless links</th>
<th>mobile routers</th>
<th>energy optimization</th>
<th>node computation</th>
</tr>
</thead>
<tbody>
<tr>
<td>“classical” Internet</td>
<td>caching, sync.</td>
<td>fixed nomadic mobile</td>
<td>last hop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mesh networks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MANET</td>
<td>only</td>
<td>only</td>
<td>fast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>delay-tolerant networks</td>
<td>possibly</td>
<td>planets space craft</td>
<td>only</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sensor networks</td>
<td>some systems</td>
<td>yes</td>
<td>common</td>
<td>some</td>
<td>crucial</td>
<td>common</td>
</tr>
</tbody>
</table>