A tale of two networks – network neutrality and other topics

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Any opinions are those of the author and do not necessarily reflect the views of Columbia University or the Federal Communications Commission.
The typical Internet keynote

• Unlimited, symmetric bandwidth for everyone
  – with LTE, even mobile
• Getting cheaper every year
  – with robust competition at all layers
• Everyone uses the Internet
• Millions of apps produced by thousands of companies
• The big jukebox in the sky
• A single Internet for all applications
  – application-neutral
• IPv6 everywhere (next year)
But...

• Not necessarily wrong
• but not guaranteed, either
• Non-technology forces
  – competition and market concentration
  – limited financial resources
  – spectrum shortages
Internet 2020: The pessimists version

- 10 Mb/s typical Internet connectivity
  - good enough for Facebook
  - asymmetric

- All Internet access metered
  - mobile & landline
  - with application-specific pricing and termination charges
  - price stagnation at fixed bandwidth

- Unregulated monopoly or near-monopoly
  - integrated content production (L8?) through PHY

- Video mostly through cable company, just over IP
- IPv4 with multiple layers of NATs ("CGN")
- VoIP by ISP
Time of transition
# 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
This is an extraordinary outcome. For example, the U.S. poverty rate has decreased from 20% in 1985 to 11% in 2002. Household spending on telecom and internet access as a percentage of personal disposable income has increased from 2.8% in 1985 to 3.8% in 2009. Note: Necessities include food, housing, transportation, energy and healthcare.

→ new services must displace old services
Wireless + Internet replace voice

Source: Bureau of Economic Analysis.
Residential broadband penetration (US)

Source: Kagan, corporate reports and Bernstein estimates and analysis.

Note: Fiber net adds shown net of DSL losses.

Source: Kagan, corporate reports and Bernstein estimates and analysis.
US broadband speeds

- 3 Mbps: 0.25-0.50 Mbps
- 9 Mbps: 0.5-1 Mbps
- 18 Mbps: 1-2 Mbps
- 16 Mbps: 2-3 Mbps
- 10 Mbps: 3-4 Mbps
- 10 Mbps: 4-5 Mbps
- 7 Mbps: 5-6 Mbps
- 7 Mbps: 6-7 Mbps
- 6 Mbps: 7-8 Mbps
- 5 Mbps: 8-9 Mbps
- 3 Mbps: 9-10 Mbps
- 6 Mbps: 10+ Mbps

FCC OBI Report #4
Chart 10
Residential Fixed Connections over 200 kbps in at Least One Direction 2005-2009
(Shares of selected technologies)

FCC: Internet Access Services Status as of December 31, 2009
Residential broadband technologies

Chart 12
Residential Fixed Connections by Technology as of December 31, 2009
(Shares of selected technologies for selected speeds, connections in thousands)

U.S. Federal Communications Commission Internet Access Services: Status as of December 31, 2009

FCC: Internet Access Services Status as of December 31, 2009
Residential Internet access 2020

- **< 50 Mb/s**
  - 10-15% (coastal, high income)
  - FiOS build out mostly done

- **20 Mb/s**
  - 60% (suburbia)

- **3 Mb/s**
  - 15% (semi-rural)

- Satellite, LTE & modem
  - 5% (rural)

* typical residential speed offer
Network traffic
Traffic distribution

VolP traffic forecasted to be 0.4% of all mobile data traffic in 2015.
Source: Cisco VNI Mobile, 2011
# Traffic forecast 2015

<table>
<thead>
<tr>
<th>Exabytes/month</th>
<th>Consumer (incl. university, Internet cafés)</th>
<th>Business &amp; gov’t.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internet</td>
<td>53.3</td>
<td>6.1</td>
<td>59.4</td>
</tr>
<tr>
<td>Managed IP</td>
<td>11.8</td>
<td>3.0</td>
<td>14.8</td>
</tr>
<tr>
<td>(corporate WAN, IP VoD, IPTV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile data</td>
<td>4.9</td>
<td>1.3</td>
<td>6.3</td>
</tr>
<tr>
<td>Total</td>
<td>70.0</td>
<td>10.4</td>
<td>80.5</td>
</tr>
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</table>
## Monthly Consumption

### North America

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Median</th>
<th>Mean : Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>4.5 GB</td>
<td>600 MB</td>
<td>7.33</td>
</tr>
<tr>
<td>Downstream</td>
<td>18.6 GB</td>
<td>6.0 GB</td>
<td>3.06</td>
</tr>
<tr>
<td><strong>Aggregate</strong></td>
<td><strong>23.0 GB</strong></td>
<td><strong>7.0 GB</strong></td>
<td><strong>3.28</strong></td>
</tr>
</tbody>
</table>

- **top 1% ➔**
  - 49.7% of upstream traffic
  - 25% of downstream traffic

### Europe

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Median</th>
<th>Mean : Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>8.2 GB</td>
<td>1.2 GB</td>
<td>6.87</td>
</tr>
<tr>
<td>Downstream</td>
<td>31.3 GB</td>
<td>12.7 GB</td>
<td>2.47</td>
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<td><strong>Aggregate</strong></td>
<td><strong>39.6 GB</strong></td>
<td><strong>14.7 GB</strong></td>
<td><strong>2.69</strong></td>
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</table>
Video, video and more video

<table>
<thead>
<tr>
<th>Upstream</th>
<th>Downstream</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>BitTorrent</td>
<td>Netflix 52.01</td>
<td>29.70% Netflix</td>
</tr>
<tr>
<td>HTTP 8.31%</td>
<td>HTTP 18.36%</td>
<td>BitTorrent 17.23%</td>
</tr>
<tr>
<td>Skype 3.81%</td>
<td>YouTube 11.04%</td>
<td>HTTP 17.18%</td>
</tr>
<tr>
<td>Netflix 3.59%</td>
<td>BitTorrent 10.37%</td>
<td>YouTube 9.85%</td>
</tr>
<tr>
<td>PPStream 2.92%</td>
<td>Flash Video 4.88%</td>
<td>Flash Video 3.62%</td>
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<tr>
<td>MGCP 2.89%</td>
<td>iTunes 3.25%</td>
<td>iTunes 3.01%</td>
</tr>
<tr>
<td>RTP 2.85%</td>
<td>RTMP 2.92%</td>
<td>RTMP 2.46%</td>
</tr>
<tr>
<td>SSL 2.75%</td>
<td>Facebook 1.91%</td>
<td>Facebook 1.86%</td>
</tr>
<tr>
<td>Gnutella 2.12%</td>
<td>SSL 1.43%</td>
<td>SSL 1.68%</td>
</tr>
<tr>
<td>Facebook 2.00%</td>
<td>Hulu 1.09%</td>
<td>Skype 1.29%</td>
</tr>
<tr>
<td><strong>Top 10</strong> 83.25%</td>
<td><strong>Top 10</strong> 84.95%</td>
<td><strong>Top 10</strong> 82.89%</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</th>
<th>average cost (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>
<td>21.5%</td>
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<tr>
<td>&gt; 100 GB</td>
<td>$0</td>
<td>5.3%</td>
<td>8.2%</td>
<td>15.3%</td>
</tr>
<tr>
<td>&gt; 200 GB</td>
<td>$10</td>
<td>1.4%</td>
<td>4.4%</td>
<td>8.8%</td>
</tr>
<tr>
<td>&gt; 500 GB</td>
<td>$50</td>
<td>0.4%</td>
<td>0.8%</td>
<td>2.6%</td>
</tr>
<tr>
<td>&gt; 1 TB</td>
<td>$150</td>
<td>0.0%</td>
<td>0.2%</td>
<td>0.7%</td>
</tr>
</tbody>
</table>
Bandwidth generations

Per Capita Internet Traffic:
- 1998: 1 MB per Month
- 2000: 10 MB per Month
- 2003: 100 MB per Month
- 2008: 1 GB per Month

Total Internet Traffic:
- 2004: 1 Exabyte per Month
- 2007: 1 Exabyte per Week
- 2013: 1 Exabyte per Day

Source: Cisco VNI, 2011
Industry structure
Which Internet are you connected to?
2 Internet futures

Google
Chatroulette
content and applications

Level 3
IP

RCN
fiber or copper loop (“Homes with tails”)

vs.

content production (*)
content distribution
CDN
broadband access
local infrastructure
regional and national backbone

AT&T
Comcast/NBC (*)
Verizon
Scenario 1: max. competition

**content & application providers**

- applications (Netflix, Pandora, your blog)
- OS (Windows Server, Linux, MacOS)
- data centers (Equinix, Amazon, ...)
- wide area network (Qwest, Sprint, VZ, TeliaSonera, NTT, DTAG, Level 3, AT&T)

**consumers**

- web browser (Firefox, IE, Chrome, ...)
- OS (Windows, Android, MacOS)
- system platform (Intel, ARM, ...)
- ISP (competing)
- fiber, radio (regulated monopoly)
- conduit (public)
Scenario 2: vertically integrated

- classical Internet (web)
  - incumbent operator (e.g., AT&T, Verizon)
  - small operators + Google, FB, MSN
- interactive multimedia (IMS)
- video (live, VOD)
  - 4 Mb/s
  - 100 Mb/s to consumer
Network economics

• Monopolies
  – economies of scale (cost ~ 1/size)
  – “exists when a specific individual or an enterprise has sufficient control over a particular product or service to determine significantly the terms on which other individuals shall have access to it.” (Wikipedia)

• Natural monopoly
  – no motivation for second provider
    • road, water, gas, electricity
  – Landline telephone & broadband
  – Wireless
    • limited spectrum
    • high cost of entry → spectrum auctions
Why are monopolies bad?

- Market power
- Pricing power
  - perfectly competitive market: price = marginal cost
- Product differentiation
  - no available substitute
- Excess profits
- Price discrimination
  - same product, different prices
  - capture consumer surplus
The monopoly infrastructures

- Technical structures that support a society → “civil infrastructure”
  - Large
  - Constructed over generations
  - Not often replaced as a whole system
  - Continual refurbishment of components
  - Interdependent components with well-defined interfaces
  - High initial cost
• if lucky, incumbent LEC + cable company
  – DSL: cheaper, but low speed
    • mean: 2.5 – 3.5 Mb/s
  – FTTH (FiOS): only 3.3M households
    • 10-15 Mb/s
  – Cable: > $50/month, higher speeds
    • 8-11 Mb/s
• often, high switching costs ($200 early termination fee)
  – or tied to bundles (TV, mobile)
State of competition (US)

Figure 3(b)
Percentages of Households Located in Census Tracts Where Providers Report Residential Fixed-Location Connections of Various Speeds or Operate a Mobile Wireless Network Capable of Delivering Service of Various Speeds as of December 31, 2009

FCC: Internet Access Services Status as of December 31, 2009
Eyeball ISPs: 2001 vs. 2010

Top U.S. ISPs by Subscriber Q2 2001

- AOL: 33%
- Other: 9%
- Cablevision: 1%
- Charter: 1%
- PeoplePC: 1%
- Cox Cable: 1%
- Bell South: 1%
- Comcast: 1%
- Verizon: 1%
- AT&T Broadband: 2%
- AT&T Worldnet: 2%
- Road Runner: 2%
- Gateway net: 2%
- Bluelight: 4%
- CompuServe: 4%
- AtlHome: 5%
- Prodigy: 5%
- Juno: 5%
- NetZero: 5%
- Earthlink: 7%
- August 2001

Other: 18%
- Mediacom: 1%
- Windstream: 2%
- Centurylink: 3%
- Cablevision: 4%
- Qwest: 4%
- Charter: 4%
- TW: 12%
- VZ: 15%
- Comcast: 20%
- AT&T: 17%
- Other: 18%

April 2011
Market power: eye ball vs. transit
Consumer network costs
Remedies

• Functional separation
  – separate entities for L2 and upper layers
  – e.g., “dry loops” copper
  – e.g., UK (BT Wholesale)

• Multiple infrastructures $\rightarrow$ competition
  – e.g., DSL, cable, wireless
  – but substitutability?
  – may not prevent abuse (e.g., Skype blocking for French mobile operators)
    • not likely to protect small customer groups with specialized needs
The future, version 2: postal service

- Private or semi-private company
- Tariffed service
- Based on weight and speed, not content
- (Somewhat) regulated
  - US Postal Rate Commission
• Same basic service (get human cargo from A to B)
• but vastly different prices
  – economy vs. economy first vs. first class
  – revenue management
  – restrictions
    • flexibility & cancellation risk
  – additional services
• Internet version:
  – pay extra for VPN (see iBahn service)
  – consumer web sites vs. IMAP access
  – except only 1-2 choices
Network neutrality
What is network neutrality?

• “The principle advocates no restrictions by Internet service providers and governments on content, sites, platforms, the kinds of equipment that may be attached, and the modes of communication.” (Wikipedia)

• 2005 FCC statement:
  – “access the lawful Internet content of their choice.
  – run applications and use services of their choice, subject to the needs of law enforcement.
  – connect their choice of legal devices that do not harm the network.
  – competition among network providers, application and service providers, and content providers.”

• = Any lawful content, any lawful application, any lawful device, any provider
Two views

Open Internet advocates
- no prioritization
- flat rates
- all networks

Free market advocates
- no real problem
- allow any business arrangement
- “it’s my network”
- use anti-monopoly laws if needed
Why?

- **Civic considerations**
  - freedom to read (passive)
  - freedom to discuss & create (active)

- **Economic opportunity**
  - edge economy >> telecom economy
    - Telecom revenue (US): $330B
    - Content, etc. not that large, however
      - Google: $8.44B
    - others that depend on ability to provide services
      - content, application, service providers

- **Technical motivation**
  - avoid network fragmentation
  - reduce work-around complexity
How to be non-neutral

- **application**
  - deep packet inspection
    - (block Skype)

- **transport**
  - block transport protocol
    - (block ports
      insert RST)

- **network**
  - block IP addresses
    - QoS discrimination
      (favor own content)
Are these neutrality issues?

• Redirect DNS NXDOMAIN to ISP web site
• Content translation
  – e.g., reduce image resolution for cellular data
• Blocking transport protocols other than UDP + TCP
• Prohibit web servers
• Reset DSCP (ToS bits)
• Not allow IPv6
• 3GPP: only make non-BE available to carrier
Some high-profile cases

• Madison River (2005)
  – DSL provider blocked SIP ports
  – fined $15,000 by FCC
• Comcast (late 2007)
  – insert TCP RST into BitTorrent traffic
  – later overturned on appeal in DC Circuit Court
• RCN (2009): P2P
• Various mobile operators
• Comcast vs. Level 3 (2010, in dispute)
  – Level-3
Network neutrality & freedom of speech

- Applies only to U.S. government, not private entities
  - Example: soap box in city park vs. mall
  - private vs. public universities

- Freedom to speak + no forced speech
  - demise of “fairness doctrine” (19xx)
New name, old concept: Common carrier

• Since 1600s: A **common carrier** in common-law countries ... is a person or company that transports goods or people for any person or company and that is responsible for any possible loss of the goods during transport. A common carrier offers its services to the general public under license or authority provided by a regulatory body. (Wikipedia)

• e.g., FedEx, Greyhound, telecommunications providers, Disneyland
Network transparency

  However, in very general terms, the community believes that the goal is connectivity, the tool is the Internet Protocol, and the intelligence is end to end rather than hidden in the network.
- RFC 2275: “Internet Transparency”
  - NATs, firewalls, ALGs, relays, proxies, split DNS
- RFC 4924: “Reflections on Internet Transparency”
  A network that does not filter or transform the data that it carries may be said to be "transparent" or "oblivious" to the content of packets. Networks that provide oblivious transport enable the deployment of new services without requiring changes to the core. It is this flexibility that is perhaps both the Internet's most essential characteristic as well as one of the most important contributors to its success.
Network transparency and neutrality

- QoS discrimination
- Pay for priority

- Block protocol features
Means, motive and opportunity

• Political motivation
  – suppress undesirable opinion
    • e.g., union web site, abortion SMS
• Economic advantage
  – prevent competition in related services
    • e.g., VoIP or over-the-top VoD
  – leverage pricing power
    • OTT content provider has to offer service to everyone
  – market segmentation
    • consumer vs. business customers
• Non-tariff barriers
  – e.g., special (undocumented) APIs
The US hierarchy of laws

**Constitution**
- Commerce clause

**Law**
- Telecom Act 1934 & 1996

**47 CFR**
- SEC. 706. ADVANCED TELECOMMUNICATIONS INCENTIVES.
  (a) IN GENERAL- The Commission ... shall encourage the deployment on a reasonable and timely basis of advanced telecommunications capability to all Americans (including, in particular, elementary and secondary schools and classrooms) by utilizing, in a manner consistent with the public interest, convenience, and necessity, ..., or other regulating methods that remove barriers to infrastructure investment.

**Narrative**
- reasonable network management

Section 8: To regulate Commerce with foreign Nations, and among the several States, and with the Indian Tribes (1787)
§ 15.5 General conditions of operation.
(a) Persons operating intentional or unintentional radiators shall not be deemed to have any vested or recognizable right to continued use of any given frequency by virtue of prior registration or certification of equipment, or, for power line carrier systems, on the basis of prior notification of use pursuant to §90.35(g) of this chapter.
(b) Operation of an intentional, unintentional, or incidental radiator is subject to the conditions that no harmful interference is caused and that interference must be accepted that may be caused by the operation of an authorized radio station, by another intentional or unintentional radiator, by industrial, scientific and medical (ISM) equipment, or by an incidental radiator.
Telecom regulation

• Local, state and federal
  – local: CATV franchise agreements
  – state: Public Utility Commission
    • responsible for all utilities – gas, water, electricity, telephone
  – federal: FCC, FTC (privacy), DOJ (monopoly)
• Elsewhere: gov’t PTT → competition
  – vs. US: regulated private monopolies
• Based on 1934 Telecommunications Act
• Amended in 1996
• Divides the world into
  – Title I: Telecommunications Services
  – Title II: Broadcast Services
  – Title III: Cable Services
  – Title V: Obscenity and Violence
Process

NOI
- Notice of Inquiry

NPRM
- Notice of Proposed Rule Making

R&O
- Report & Order

comments & ex parte
**Who is covered?**

**Broadband Internet Access Service** = A mass-market retail service by wire or radio that provides the capability to transmit data to and receive data from all or substantially all Internet endpoints, including any capabilities that are incidental to and enable the operation of the communications service, but excluding dial-up Internet access service. This term also encompasses any service that the Commission finds to be providing a functional equivalent of the service described in the previous sentence, or that is used to evade the protections set forth in this Part.

excludes

- “edge providers”: CDNs, search engines, ...
- dial-up
- coffee shops, bookstores, airlines (premise operators)
Principles

Transparency. Fixed and mobile broadband providers must disclose the network management practices, performance characteristics, and terms and conditions of their broadband services;

No blocking. Fixed broadband providers may not block lawful content, applications, services, or non-harmful devices; mobile broadband providers may not block lawful websites, or block applications that compete with their voice or video telephony services.

No unreasonable discrimination. Fixed broadband providers may not unreasonably discriminate in transmitting lawful network traffic.
## FCC Open Internet order

<table>
<thead>
<tr>
<th></th>
<th>Wired</th>
<th>Wireless</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disclosure</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Non-blocking</td>
<td>every protocol</td>
<td>“web”, “VoIP”</td>
</tr>
<tr>
<td>Non-discrimination</td>
<td>reasonable network management</td>
<td>“monitor”</td>
</tr>
</tbody>
</table>
Some corner cases

- Parental protection
  - user (paying subscriber...) choice
- KosherNet
- Spam
  - would only affect IP-level blocking
- DOS
  - classified as unwanted traffic
What about congestion?

• Open Internet rules allow charging by
  – access rate
  – traffic volume

• Content-neutral mechanisms
  – normal TCP
  – e.g., Columbia University: “XXX”
Open Internet & QoS

• Principle of end user control
• E.g., DiffServ bits or signaling
  – RSVP or NSIS
  – or out-of-band ("please prioritize UDP port 5050")
• Together with rate or volume limits
  – "Includes 1,000 minutes of VoIP priority"
• Technical difficulties
  – DSCP bit re-marking
  – Symmetric treatment for incoming traffic
• “Dear Google: We’ll mark your packets as high priority for just $9.95/GB! Hurry, offer ends soon!”

• May not matter (much) in practice
  – assumes QoS problems and local congestion
  – but related to paid peering (later)
FCC challenge

- Difficult to determine state of openness
  - blocking, content discrimination
Peering – the next network neutrality challenge
## New network providers

<table>
<thead>
<tr>
<th>Rank</th>
<th>2007 Top Ten</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ISP A</td>
<td>5.77</td>
</tr>
<tr>
<td>2</td>
<td>ISP B</td>
<td>4.55</td>
</tr>
<tr>
<td>3</td>
<td>ISP C</td>
<td>3.35</td>
</tr>
<tr>
<td>4</td>
<td>ISP D</td>
<td>3.2</td>
</tr>
<tr>
<td>5</td>
<td>ISP E</td>
<td>2.77</td>
</tr>
<tr>
<td>6</td>
<td>ISP F</td>
<td>2.6</td>
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<tr>
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<td>ISP G</td>
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<td>8</td>
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<td>9</td>
<td>ISP I</td>
<td>1.35</td>
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<tr>
<td>10</td>
<td>ISP J</td>
<td>1.23</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Rank</th>
<th>2009 Top Ten</th>
<th>%</th>
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<tr>
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<td>ISP A</td>
<td>9.41</td>
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<tr>
<td>2</td>
<td>ISP B</td>
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</tr>
<tr>
<td>3</td>
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<tr>
<td>4</td>
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<td>10</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Based on analysis of anonymous ASN (origin/transit) data (as a weighted average % of all Internet Traffic). Top ten has NO direct relationship to study participation.

NID 2010 - Portsmouth, NH

Internet traffic flows today

ratio 16:1?
Internet money flows today

“bill & keep”
Future Internet money flows?

- content
- backbone (transit)
- CDN
- Comcast eyeball ISP
- two-sided market

Google
Netflix
$0
Tata
Level3
Same packets, different value
The end of infinite
The value of bits

- Technologist: A bit is a bit is a bit
- Economist: Some bits are more valuable than other bits

<table>
<thead>
<tr>
<th>Application</th>
<th>Volume</th>
<th>Cost per unit</th>
<th>Cost / MB</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>
</tr>
<tr>
<td>Mobile data</td>
<td>5 GB</td>
<td>$40</td>
<td>$0.008</td>
</tr>
<tr>
<td>MMS (pictures)</td>
<td>&lt; 300 KB, avg. 50 kB</td>
<td>25c</td>
<td>$5.00</td>
</tr>
<tr>
<td>SMS</td>
<td>160 B</td>
<td>10c</td>
<td>$625</td>
</tr>
</tbody>
</table>
Service separation

• Deep packet inspection
• Block or charge for competing services
  – voice (Skype, Fring, ... vs. IMS)
  – SMS (WhatsApp)
  – video (payTV: $77, NetFlix: $7.99)
• See KPN and other European carriers
  – NL net neutrality law
Bandwidth costs

- Amazon EC2
  - $100/TB in, $100/TB out
- CDN (Internet radio)
  - $600/TB (2007)
  - $100/TB (Q1 2009 – 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
## Cost of broadband

<table>
<thead>
<tr>
<th>Access</th>
<th>Price per month</th>
<th>Median (average) usage</th>
<th>$/GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSL (3 MB/s + 768 kb/s)</td>
<td>$30</td>
<td>1.7 GB (9.2 GB)</td>
<td>$17.65 ($3.26)</td>
</tr>
<tr>
<td>AT&amp;T UVerse</td>
<td></td>
<td></td>
<td>$0.20 beyond 150 GB</td>
</tr>
<tr>
<td>Smartphone</td>
<td>$25</td>
<td>250 MB</td>
<td>$100</td>
</tr>
<tr>
<td>Wireless data retail</td>
<td>$40</td>
<td></td>
<td>$10</td>
</tr>
<tr>
<td>Web hosting</td>
<td></td>
<td></td>
<td>$1-2</td>
</tr>
<tr>
<td>CDN pricing (*)</td>
<td></td>
<td></td>
<td>$0.10</td>
</tr>
</tbody>
</table>

* strongly depends on volume: $0.25 GB/resale, high volume (500 TB/month): $0.05/GB
## Bandwidth limits

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Cap exceeded</th>
<th>Motivation</th>
<th>Consumer impact</th>
</tr>
</thead>
</table>
| **Usage cap** | Subscriber limited to monthly bandwidth quota (e.g., 100 GB/month) | • Reduced speed  
• email warning  
• contract termination | • reduce impact of small number of very heavy users  
• reduce P2P usage | • depends on cap  
• more and more consumers |
| **Tiered service** | caps by tier                                      | same                              | Market segmentation light vs. heavy users                                 | less transparency |
| **Metered service** | Monthly base + linear fee ($/GB)                | metered bandwidth billing         | Usage-induced revenue Protection again competing services                | • Priced in excess of cost  
• bill shock |
Examples

**INTERNET A LA CARTE SERVICE RATES**

<table>
<thead>
<tr>
<th>Economy</th>
<th>Standard</th>
<th>1.5 Mbps High Speed Internet Service, 1 GB data plan. See help.cableone.net/HSD/plans/economy/FAQ.aspx for details.</th>
<th>$20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>5 Mbps High Speed Internet Service.</td>
<td>5 Mbps High Speed Internet Service with 50 GB data plan. Additional GB $0.50 per GB. Docsis 3.0 modem needed. Preferred package includes free upgrade from 5 Mbps service and 50 GB data plan.</td>
<td>$50</td>
</tr>
</tbody>
</table>

**Internet Comparison**

<table>
<thead>
<tr>
<th>Download Speeds up to</th>
<th>Upload Speeds up to</th>
<th>Included Usage</th>
<th>Overage Rate</th>
<th>Email Accounts</th>
<th>24/7 Support</th>
<th>Only Available with the Ultimate Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Mbps</td>
<td>1 Mbps</td>
<td>50,000 MB</td>
<td>0.004/MB</td>
<td>[✓]</td>
<td>[✓]</td>
<td>[✓]</td>
</tr>
<tr>
<td>1.5 Mbps</td>
<td>1.5 Mbps</td>
<td>75,000 MB</td>
<td>0.003/MB</td>
<td>[✓]</td>
<td>[✓]</td>
<td>[✓]</td>
</tr>
<tr>
<td>18 Mbps</td>
<td>2 Mbps</td>
<td>100,000 MB</td>
<td>0.002/MB</td>
<td>[✓]</td>
<td>[✓]</td>
<td>[✓]</td>
</tr>
<tr>
<td>22 Mbps</td>
<td></td>
<td>125,000 MB</td>
<td>0.001/MB</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Xtreme Power</th>
<th>Xtreme Power</th>
<th>Xtreme Power</th>
<th>Xtreme Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Mbps</td>
<td>6 Mbps</td>
<td>8 Mbps</td>
<td>10 Mbps</td>
</tr>
<tr>
<td>512 Kbps</td>
<td>512 Kbps</td>
<td>768 Kbps</td>
<td>1 Mbps</td>
</tr>
<tr>
<td>15,000/MB</td>
<td>30,000/MB</td>
<td>60,000/MB</td>
<td>80,000/MB</td>
</tr>
<tr>
<td>0.004/MB</td>
<td>0.003/MB</td>
<td>0.002/MB</td>
<td>0.001/MB</td>
</tr>
<tr>
<td>4 (10 MB)</td>
<td>8 (10 MB)</td>
<td>8 (10 MB)</td>
<td>8 (20 MB)</td>
</tr>
</tbody>
</table>

Prices: $49.99, $59.99, $79.99, $109.99 (prices subject to change and available only with the Ultimate Package).
Spectrum
• 100+ years of legacy use
  – is this like land ownership?
  – why would anybody move?
  – see FCC white spaces effort

• Fragmentation – end systems need multiple RF front ends
  – often limited by chip design

• Receiver standards – dealing with OOBE
Spectrum policies

• There’s no more open space
• Increase efficiency
  – modulation
  – narrow-banding
  – analog → digital → packet
  – special purpose → general purpose
• Increase spatial re-use
• No good research data on spectrum usage and possibilities
US spectrum approaches

• Narrow-banding by January 1, 2013
  – 150-512 MHz band: 25 kHz → 12.5 kHz or better

• White spaces in TV band (512 – 692 MHz)
  – query database for incumbents
  – 10 database operators
  – space mostly available in rural areas

• Incentive auctions
  – only about 10% use over-the-air TV
  – TV channels → data
Challenges for research
The grand (real-world) challenges

• Getting from 60 to 95% broadband usage & coverage
  – cost, societal issues

• Spectrum challenges
  – availability, fragmentation, co-existence

• Bandwidth challenges
  – QoS does not help (much)
    • allows VoIP at 90% vs. 60% load
  – video compression not quite maxed out
    • MPEG-2 → H.264 got us factor 2 → H.265
The grand (real world) challenges

• Understanding privacy
  – vague conceptions of harms & risks
  – see Google, Apple, ...

• The role of competition in a natural monopoly world

• How to make research relevant
  – not obvious which results in the last 10 years have had major impact on practice
The not-so-grand challenges

- Sensor networks
- QoS
- $\Rightarrow$ 90-10 problems (= 90% of solution with 10% of the effort)
• Time of transition, not innovation
• Industry moving from start-up to infrastructure commodity
• Cannot assume that technology will force positive outcomes
  – interplay of economics, regulation, technology
• Have limited insights into alternatives
  – what can we contribute?