A tale of two networks – network neutrality and other topics

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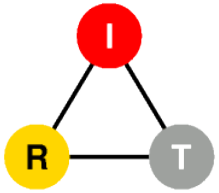


Any opinions are those of the author and do not necessarily reflect the views of Columbia University or the Federal Communications Commission.

CS@CU

The typical Internet keynote

- Unlimited bandwidth for everyone
- Getting cheaper every year
- Everyone uses the Internet
- Millions of apps produced by thousands of companies
- The big jukebox in the sky
- A single Internet for all applications
- IPv6 everywhere (next year)

But…

- Not necessarily wrong
- but not guaranteed, either
- Non-technology forces
  - competition and market concentration
  - limited financial resources
  - spectrum shortages

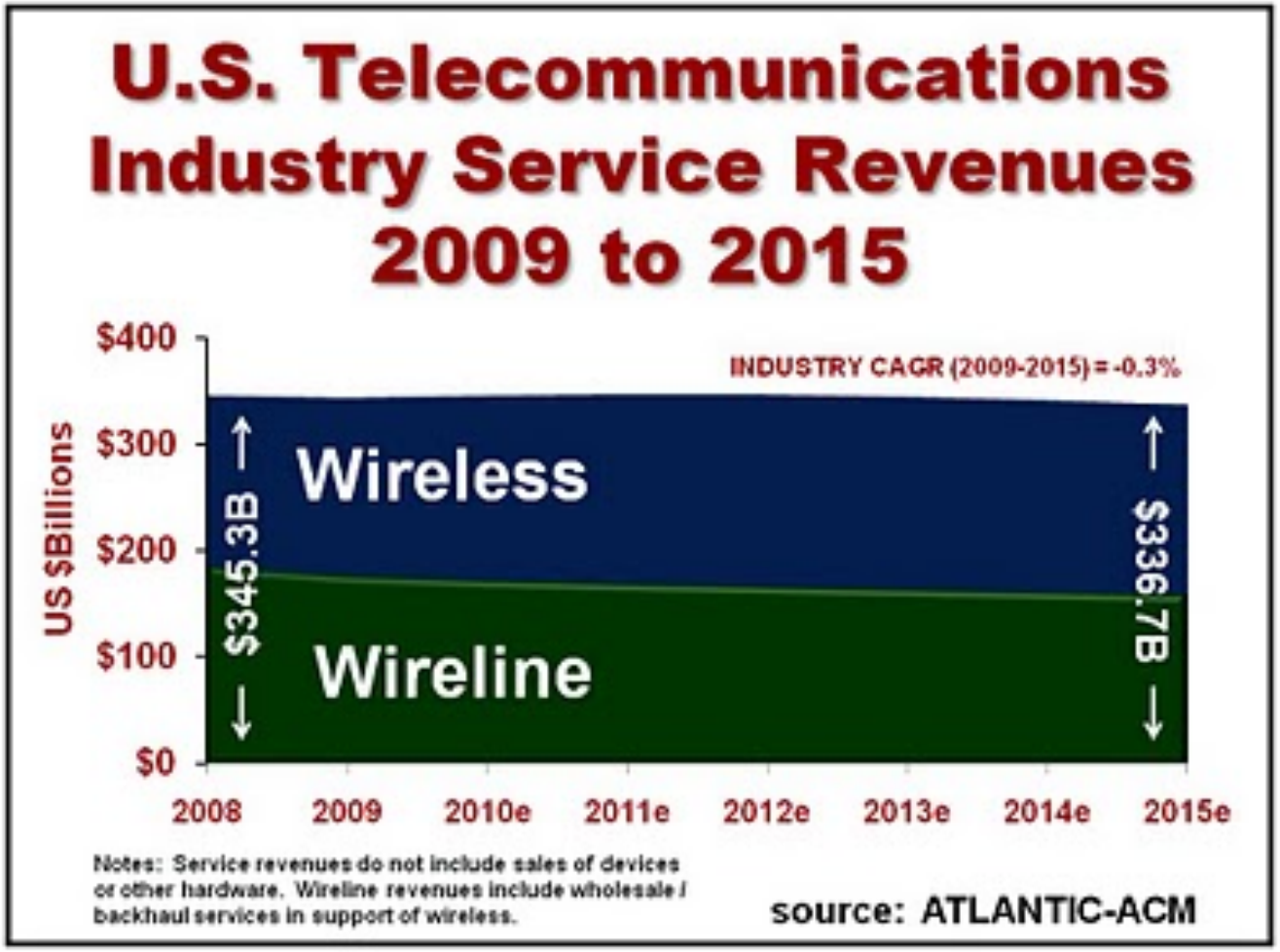
Time of transition

Time of transition

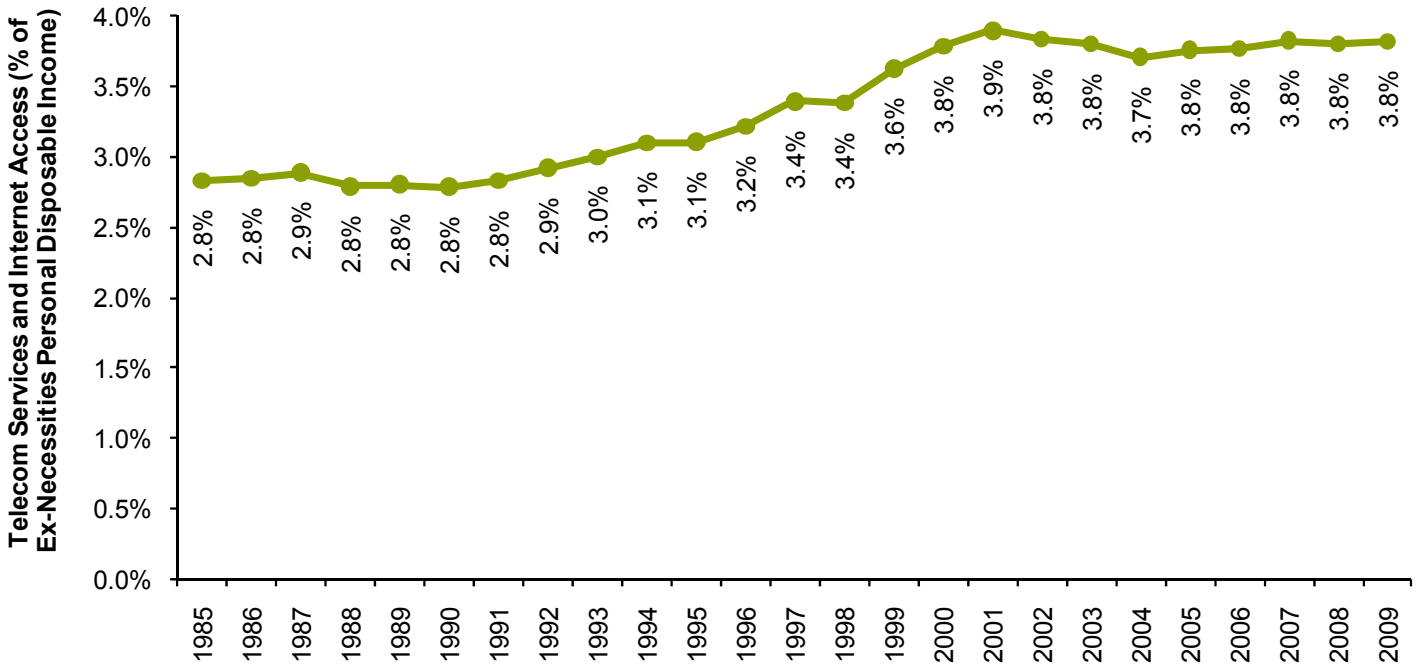
Old	New
IPv4	IPv6
circuit-switched voice	VoIP
separate mobile voice & data	LTE + LTE-VoIP
911, 112	NG911, NG112
digital cable (QAM)	IPTV
analog & digital radio	Pandora, Internet radio, satellite radio
credit cards, keys	NFC
end system, peers	client-server v2 aka cloud

all the energy into transition → little new technology

Telecom revenue



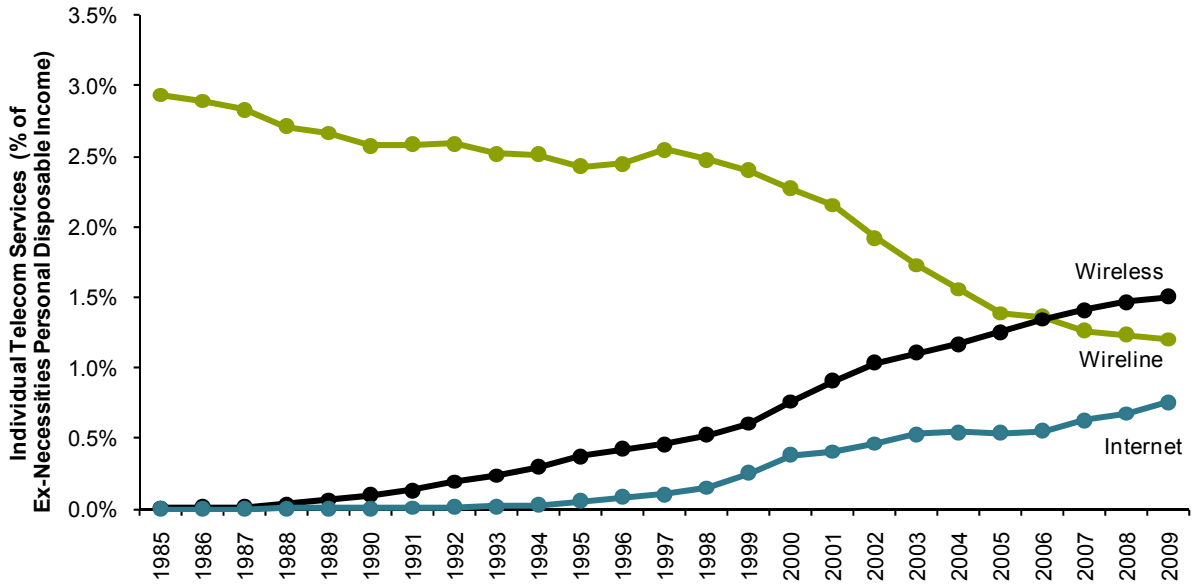
Household spending on telecom



Note: Necessities include food, housing, transportation, energy and healthcare.

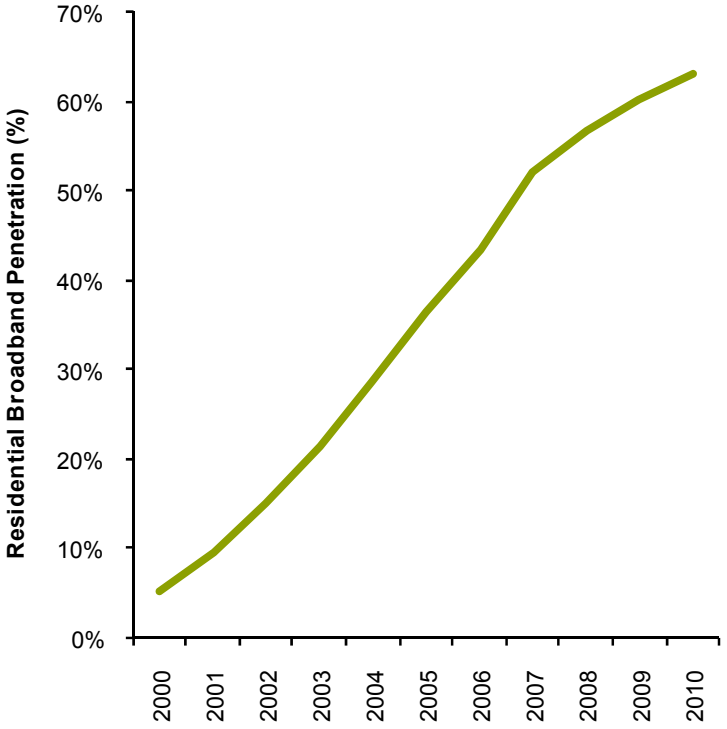
→ new services must displace old services

Wireless + Internet replace voice

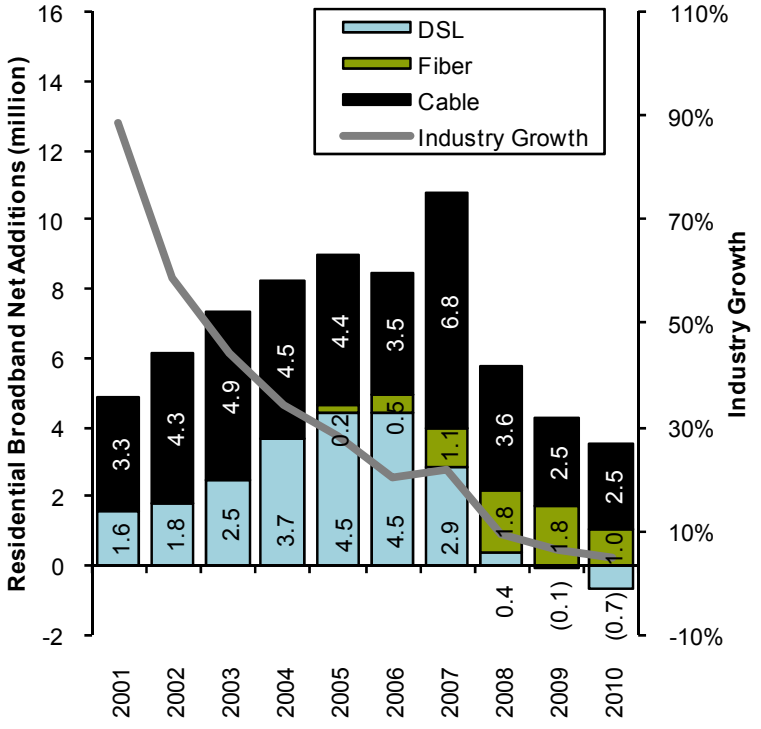


Source: Bureau of Economic Analysis.

Residential broadband penetration (US)



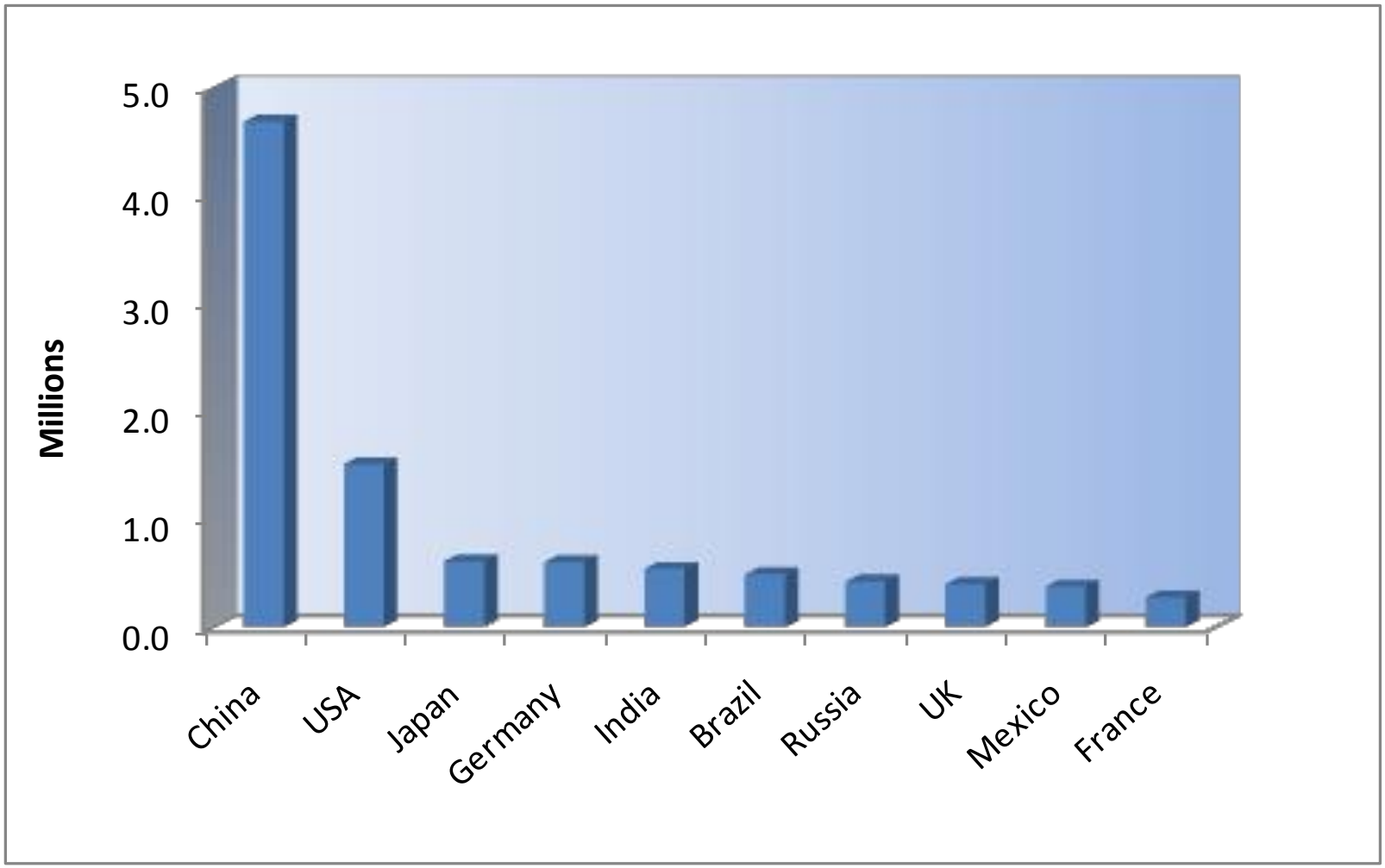
Source: Kagan, corporate reports and Bernstein estimates and analysis.



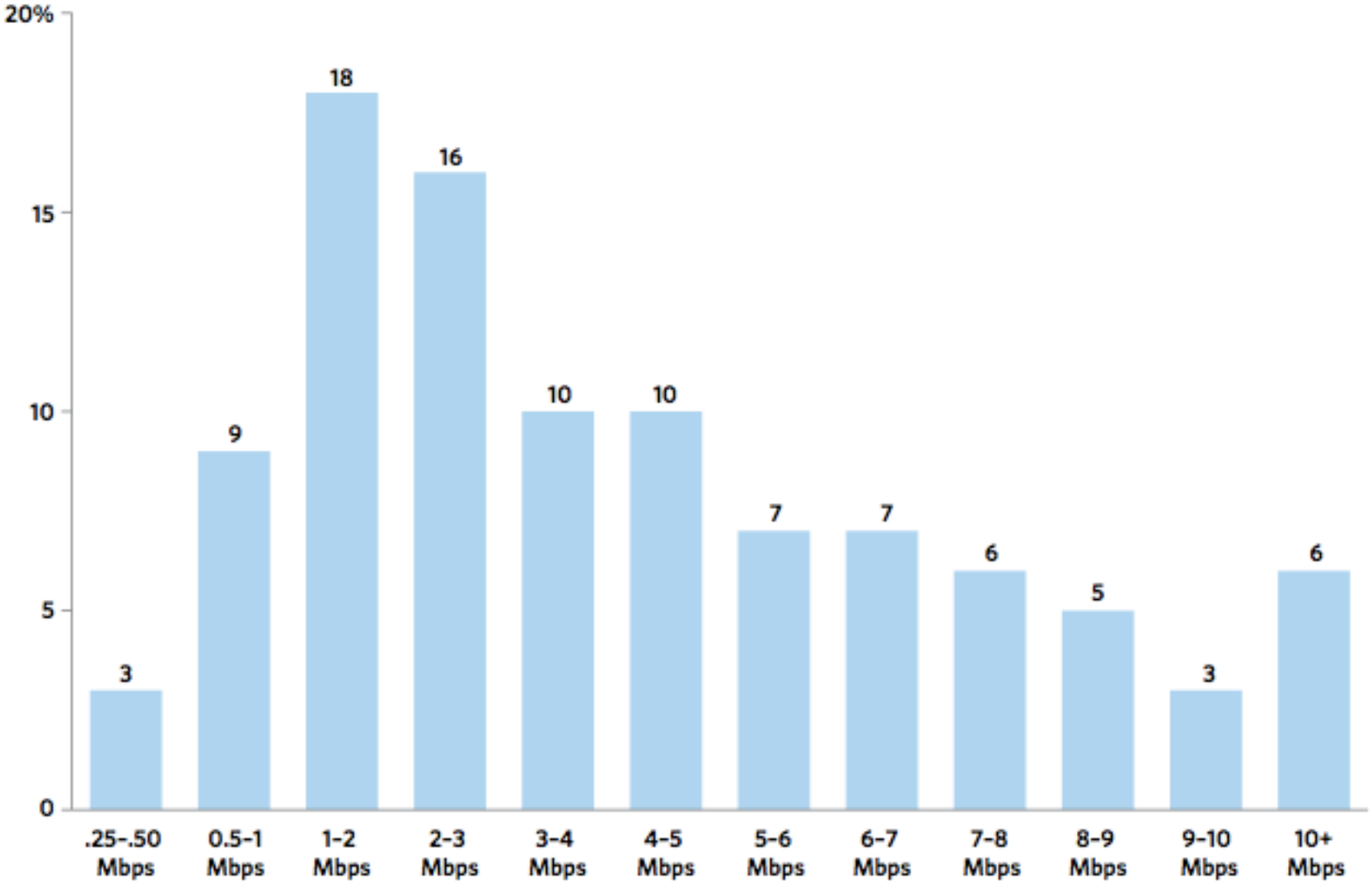
Note: Fiber net adds shown net of DSL losses.

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

Net broadband additions (2010)



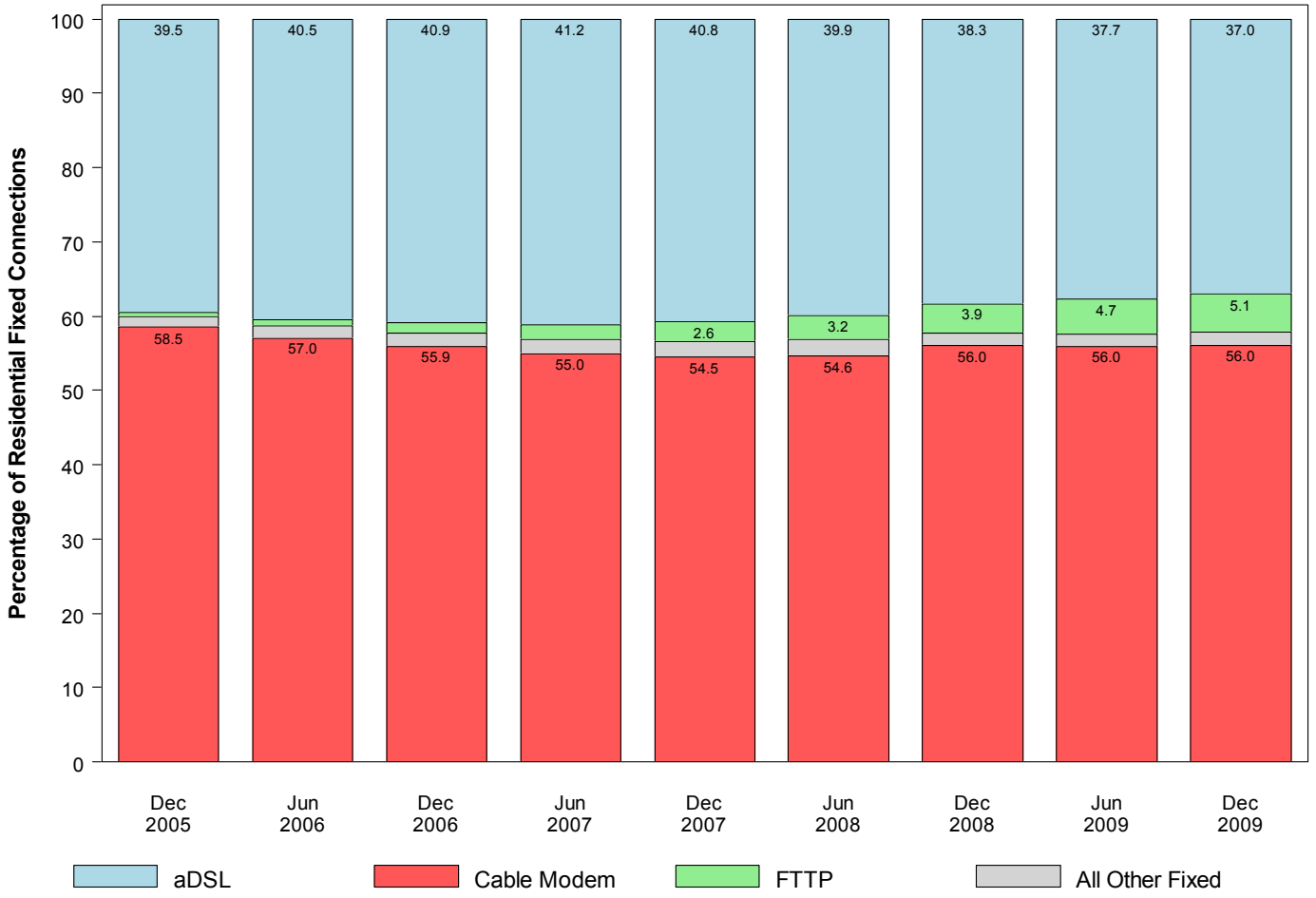
US broadband speeds



FCC OBI Report #4

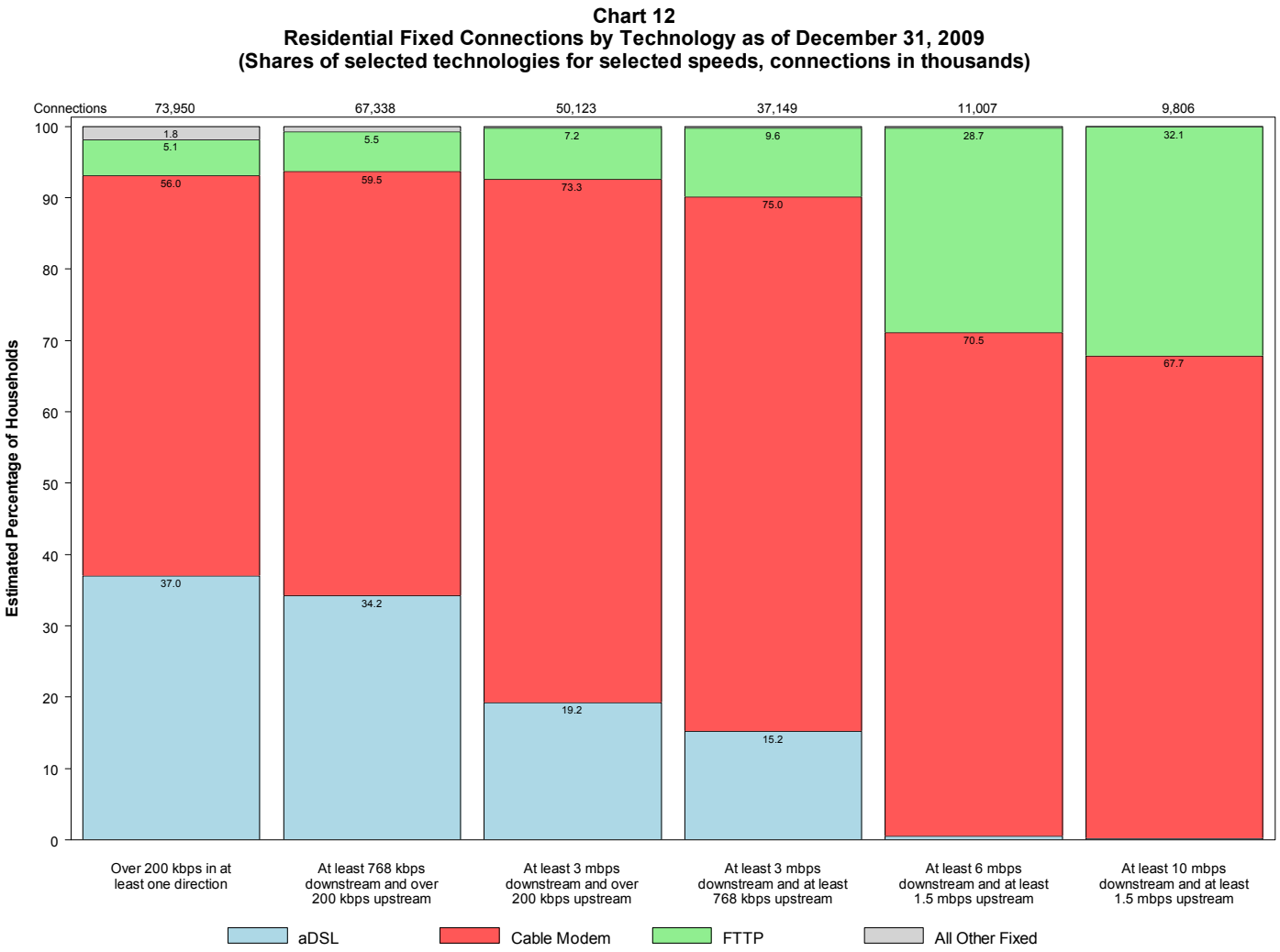
Residential broadband

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



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

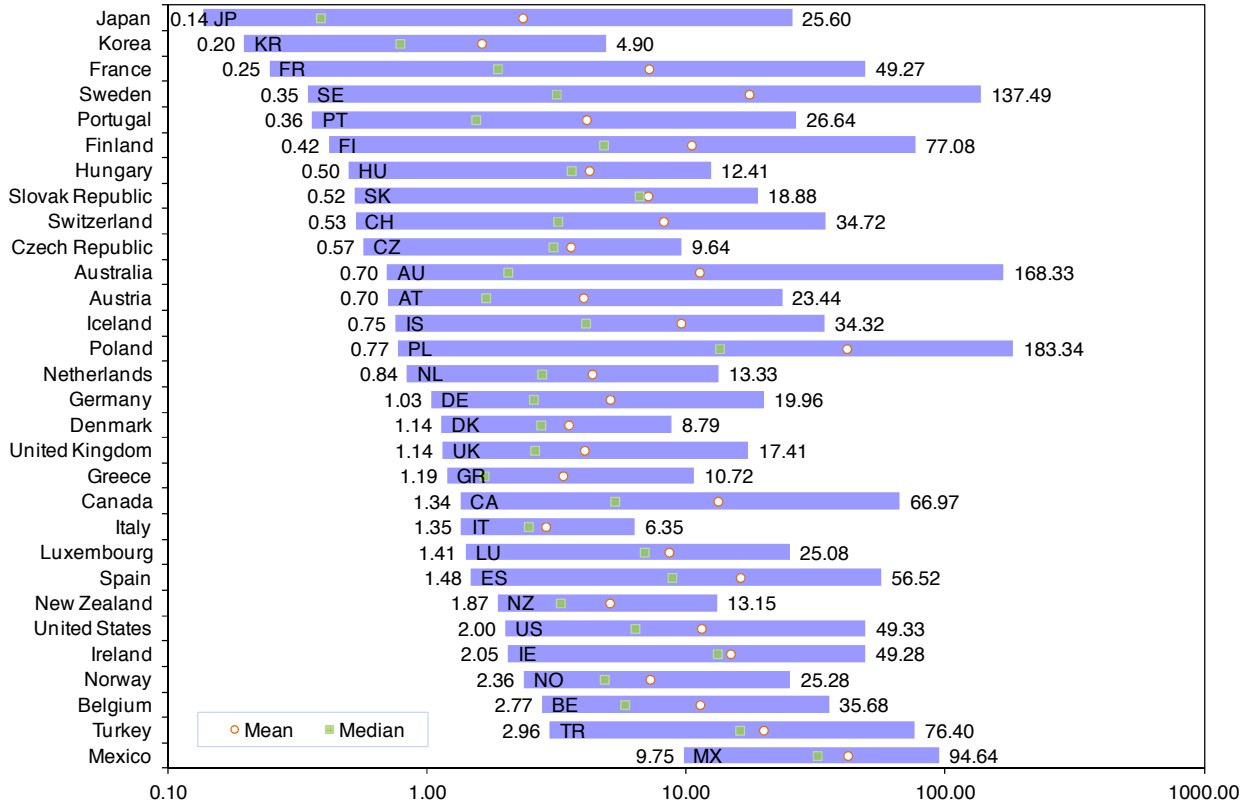
Network infrastructure in 2015

- FTTH build-out essentially complete (15%)
- likely outcome:
  - FTTH in dense, rich parts of the country
  - cable and FTTN in suburban areas
  - LTE in semi-rural areas
  - satellite everywhere else

Wireless as substitute?

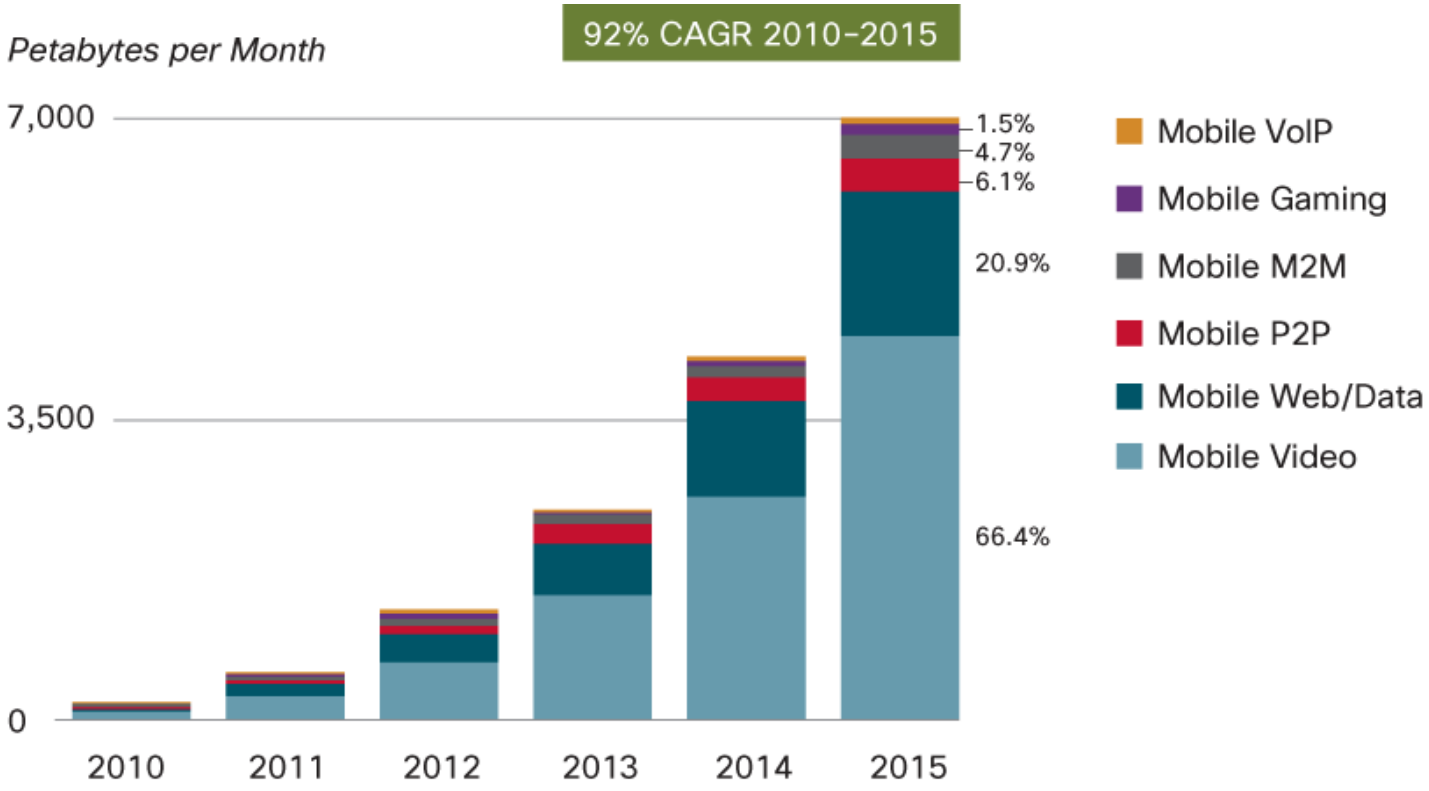
- Speed range
- Speed predictability
- Indoor usability
- Volume limits
- Still relies on ILEC or CATV back-haul to cell sites and femtocells

Consumer network costs



Network traffic

Traffic distribution



VoIP traffic forecasted to be 0.4% of all mobile data traffic in 2015.

Source: Cisco VNI Mobile, 2011

Traffic forecast 2015

Exabytes/month	Consumer (incl. university, Internet cafés)	Business & gov't.	Total
Internet	53.3	6.1	59.4
Managed IP (corporate WAN, IP VoD, IPTV)	11.8	3.0	14.8
Mobile data	4.9	1.3	6.3
Total	70.0	10.4	80.5

Global Consumer Internet Traffic, 2010-2015

Consumer Internet Traffic, 2010–2015							
	2010	2011	2012	2013	2014	2015	CAGR 2010–2015
By Network (PB per Month)							
Fixed	12,355	17,467	23,618	31,318	40,842	53,282	34%
Mobile	174	399	858	1,654	2,930	4,931	95%
By Subsegment (PB per Month)							
File sharing	4,968	6,017	7,277	8,867	11,040	13,797	23%
Internet video	4,672	8,079	12,146	17,583	24,357	33,620	48%
Web, email, and data	2,393	3,113	4,146	5,325	6,769	8,592	29%
Video calling	308	442	659	905	1,251	1,736	41%
Online gaming	49	68	95	133	187	290	43%
Voice over IP (VoIP)	138	147	153	157	160	168	4%
Other	0	1	1	3	8	11	132%
By Geography (PB per Month)							
North America	3,301	5,000	6,579	8,306	10,012	12,537	31%
Western Europe	3,147	4,360	6,075	8,224	10,841	13,896	35%
Asia Pacific	4,403	6,006	8,142	11,129	15,249	20,758	36%
Japan	638	932	1,317	1,807	2,344	2,968	36%
Latin America	482	735	1,106	1,667	2,577	3,850	52%
Central and Eastern Europe	454	667	971	1,381	1,963	2,805	44%
Middle East and Africa	103	166	286	459	784	1,399	68%
Total (PB per Month)							
Consumer Internet traffic	12,528	17,866	24,476	32,973	43,771	58,214	36%

Source: Cisco VNI, 2011

Monthly Consumption

North America	Mean	Median	Mean : Median
Upstream	4.5 GB	600 MB	7.33
Downstream	18.6 GB	6.0 GB	3.06
Aggregate	**23.0 GB**	**7.0 GB**	**3.28**

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

Europe	Mean	Median	Mean : Median
Upstream	8.2 GB	1.2 GB	6.87
Downstream	31.3 GB	12.7 GB	2.47
Aggregate	**39.6 GB**	**14.7 GB**	**2.69**

Video, video and more video

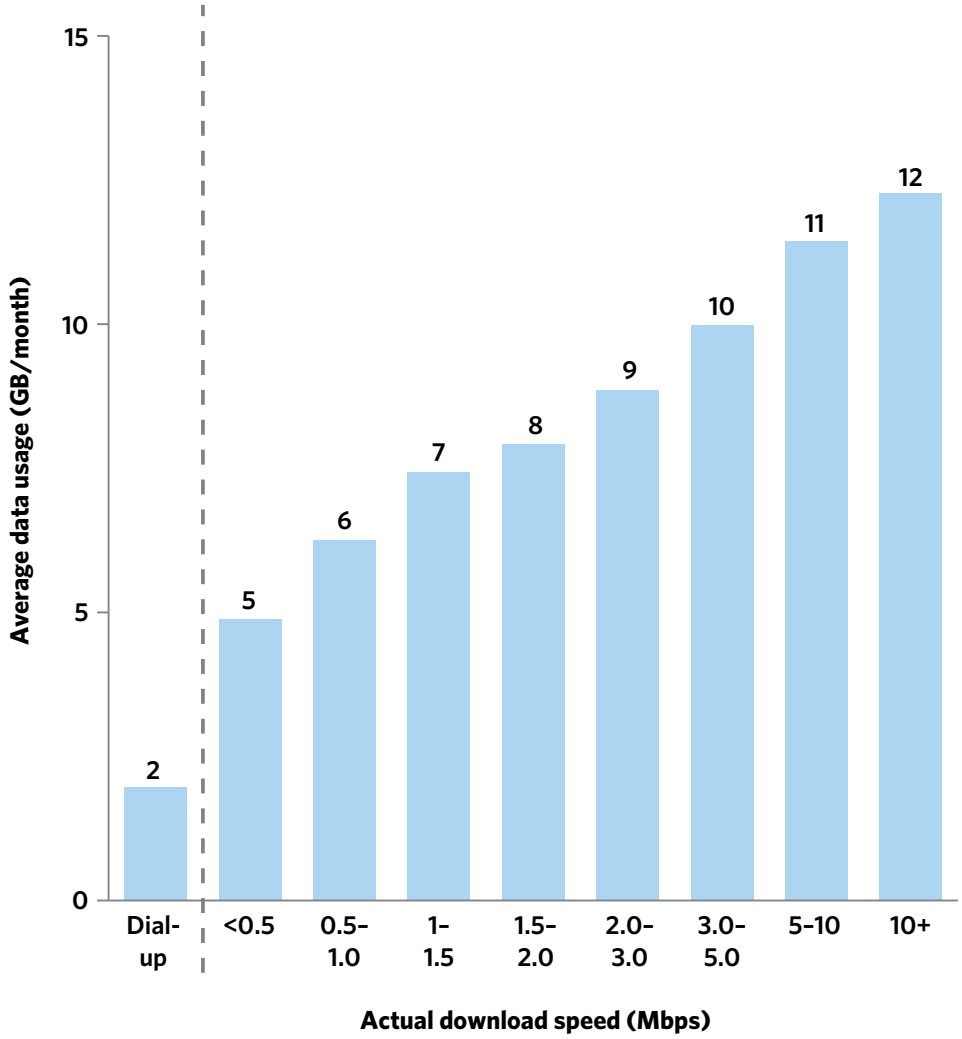
Upstream		Downstream		Aggregate	
BitTorrent	52.01	Netflix	29.70%	Netflix	24.71%
HTTP	8.31%	HTTP	18.36%	BitTorrent	17.23%
Skype	3.81%	YouTube	11.04%	HTTP	17.18%
Netflix	3.59%	BitTorrent	10.37%	YouTube	9.85%
PPStream	2.92%	Flash Video	4.88%	Flash Video	3.62%
MGCP	2.89%	iTunes	3.25%	iTunes	3.01%
RTP	2.85%	RTMP	2.92%	RTMP	2.46%
SSL	2.75%	Facebook	1.91%	Facebook	1.86%
Gnutella	2.12%	SSL	1.43%	SSL	1.68%
Facebook	2.00%	Hulu	1.09%	Skype	1.29%
Top 10	**83.25%**	**Top 10**	**84.95%**	**Top 10**	**82.89%**

Average monthly usage

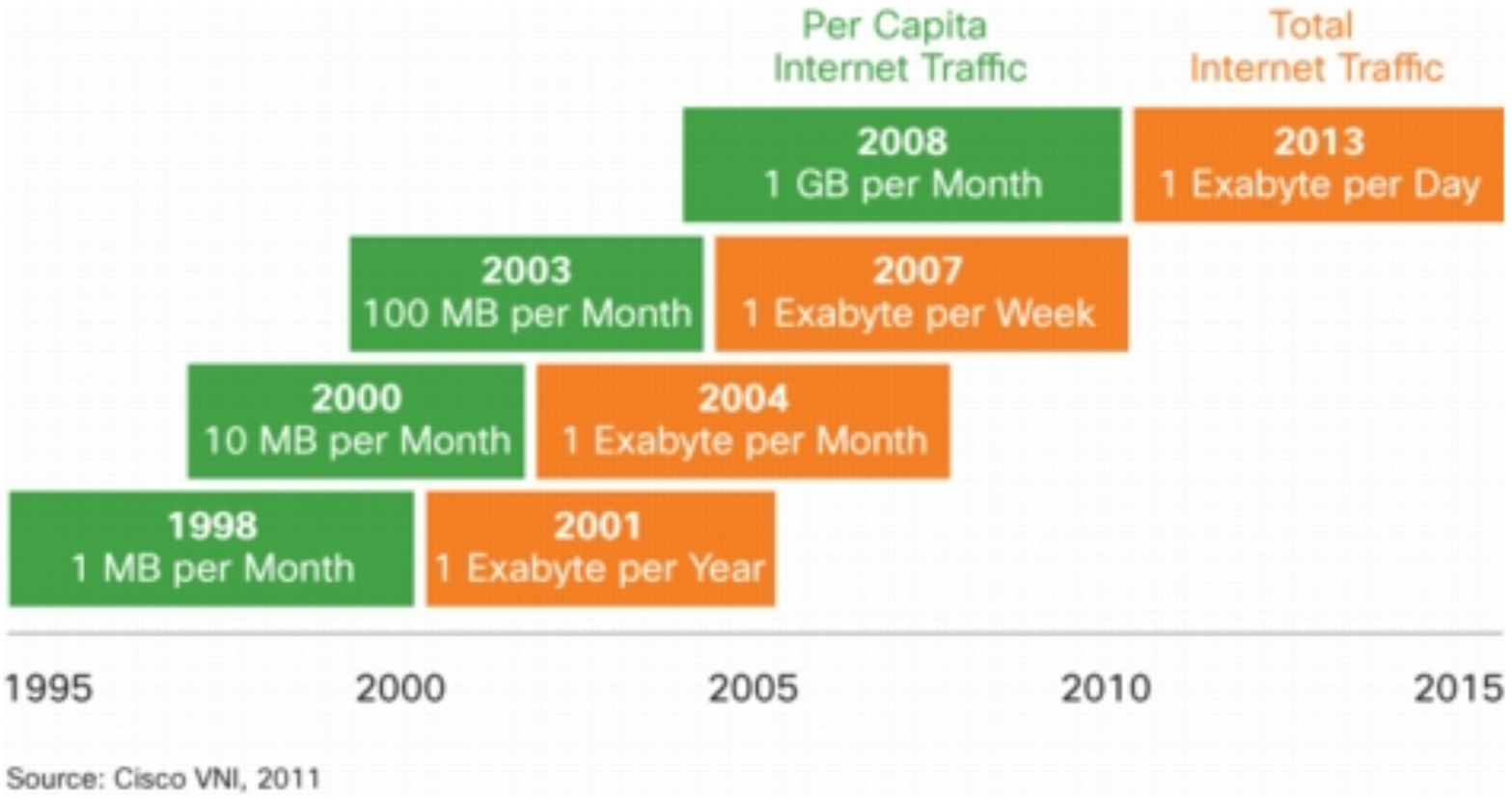
- Average monthly TV consumption (US): 154 hours
- Netflix: 1 GB/hour (SD) … 2.3 GB/hour (HD)
  - → 300 GB/month
  - more if people in household watch different content

monthly usage	overage cost (AT&T Uverse)	2010	2012	2015
> 50 GB	$0	9.4%	14.1%	21.5%
> 100 GB	$0	5.3%	8.2%	15.3%
> 200 GB	$10	1.4%	4.4%	8.8%
> 500 GB	$50	0.4%	0.8%	2.6%
> 1 TB	$150	0.0%	0.2%	0.7%

Average usage by speed tier

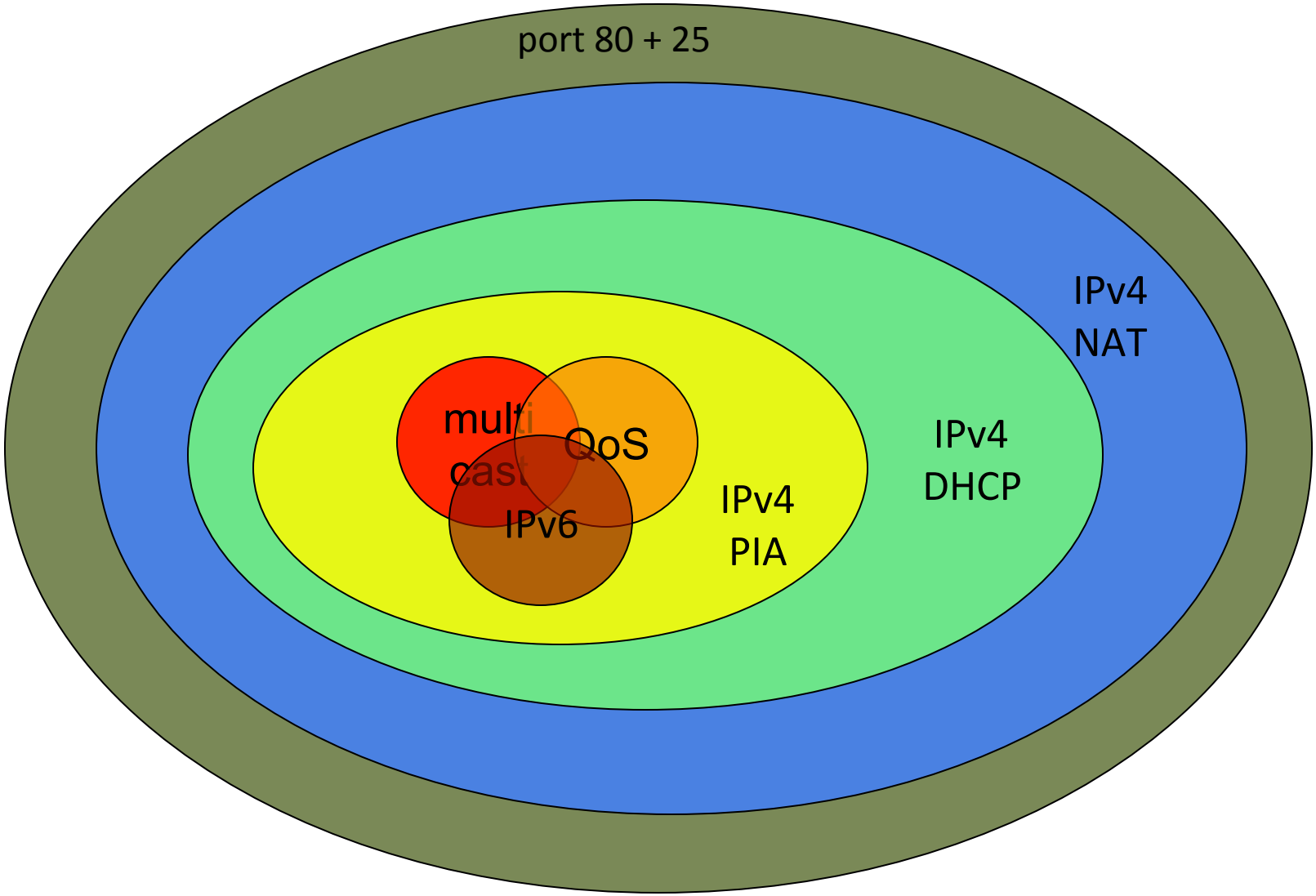


Bandwidth generations

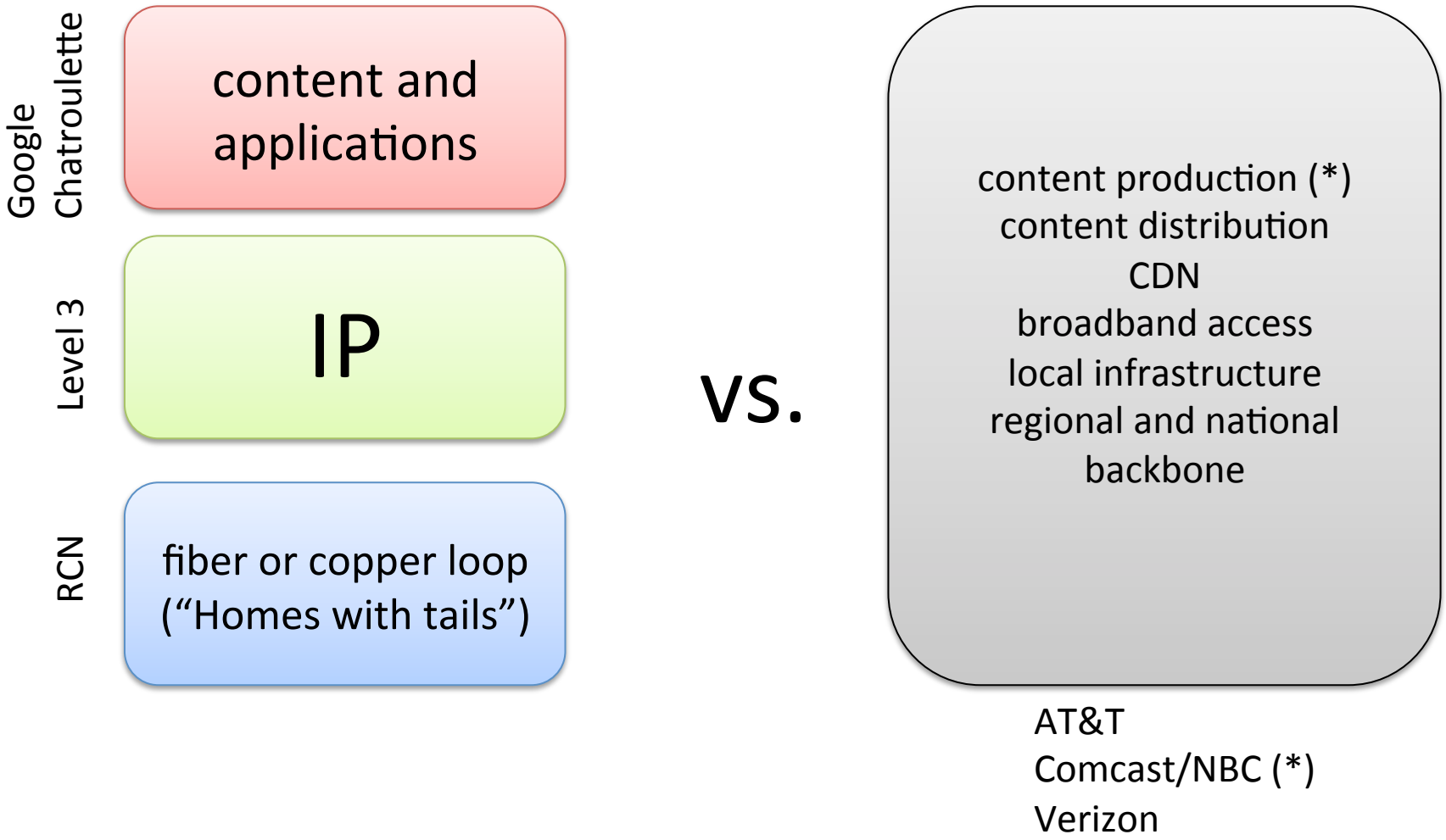


Industry structure

Which Internet are you connected to?



2 Internet futures



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)

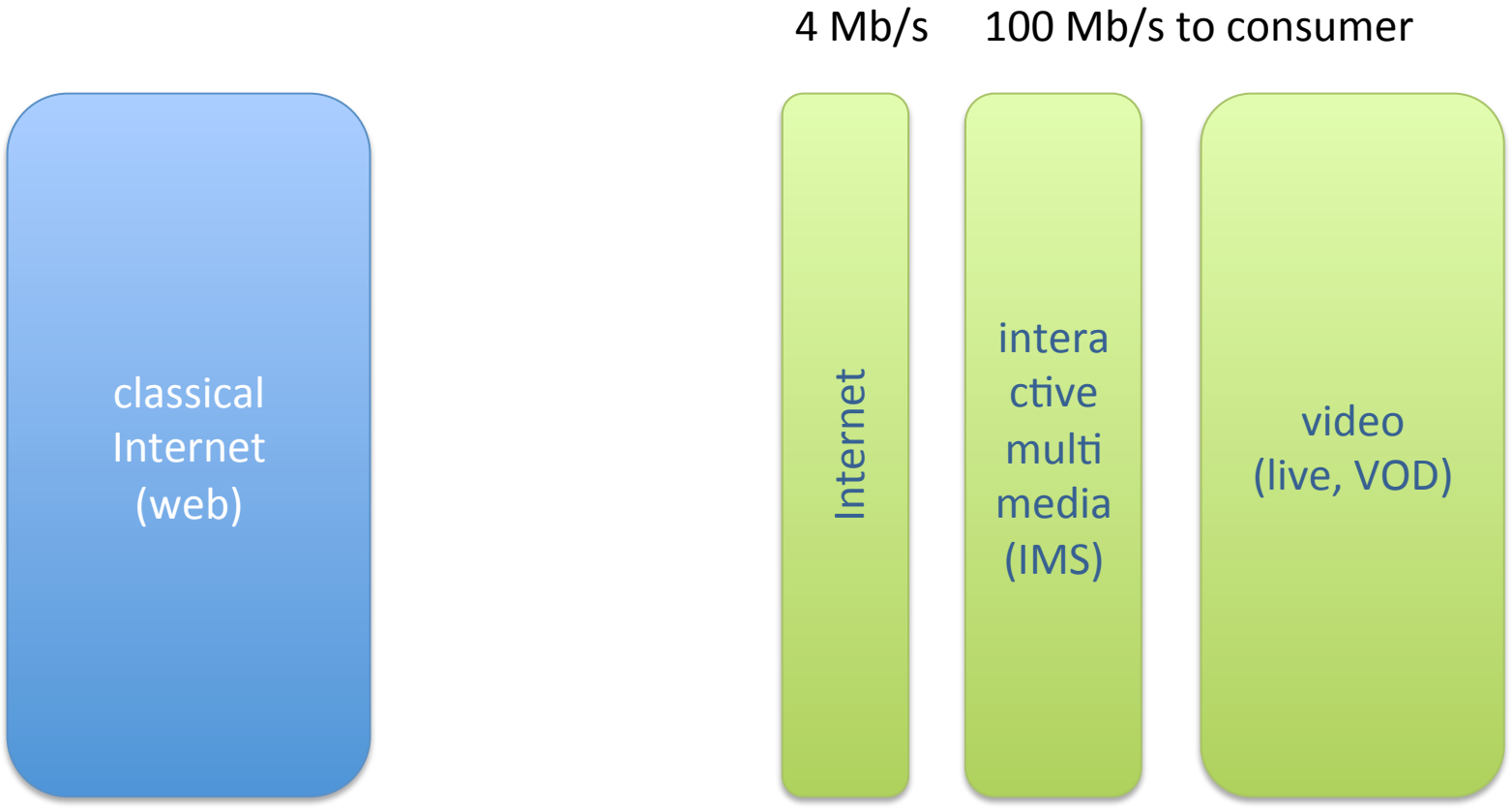
system platform
(Intel, ARM, …)

ISP
(competing)

fiber, radio
(regulated monopoly)

conduit
(public)

Scenario 2: vertically integrated



small operators
Google

incumbent operator (e.g., AT&T, Verizon)
cable company (sometimes)

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

water

energy

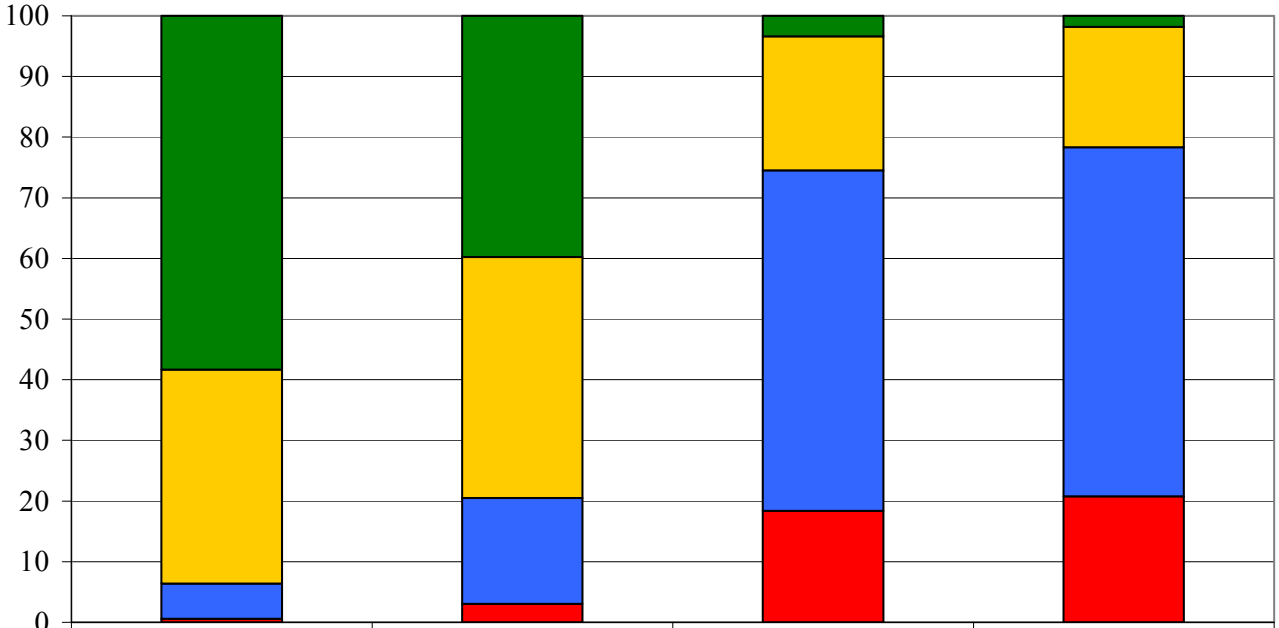
transportation

Competition (US)

- 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)

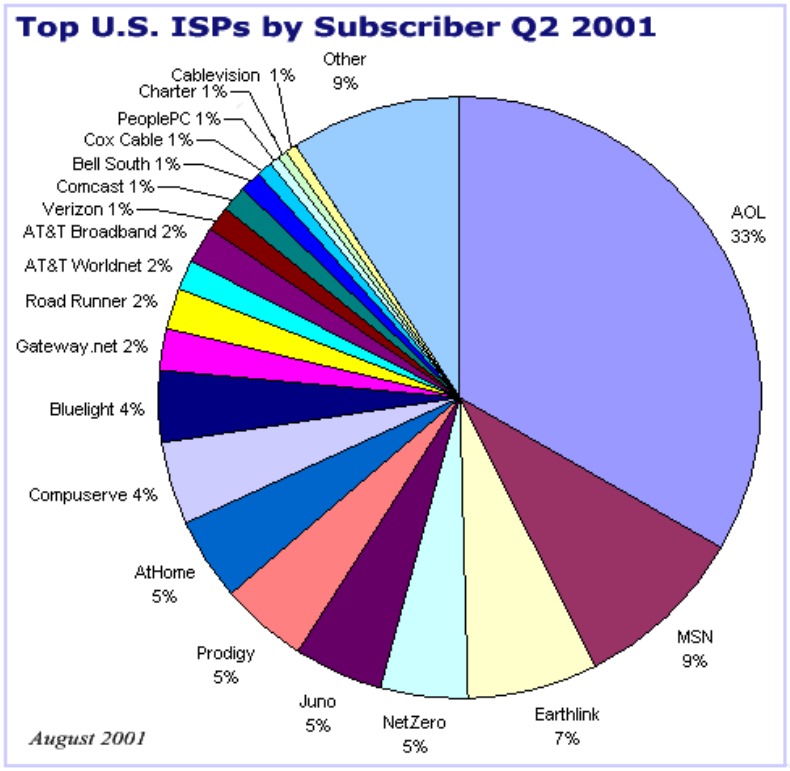
Figure 3(b)
Percentages of Households Located in Census Tracts Where Providers Report Residential Fixed-Location Connections of Various Speeds or Operate a Mobile Wireless Network Capable of Delivering Service of Various Speeds as of December 31, 2009

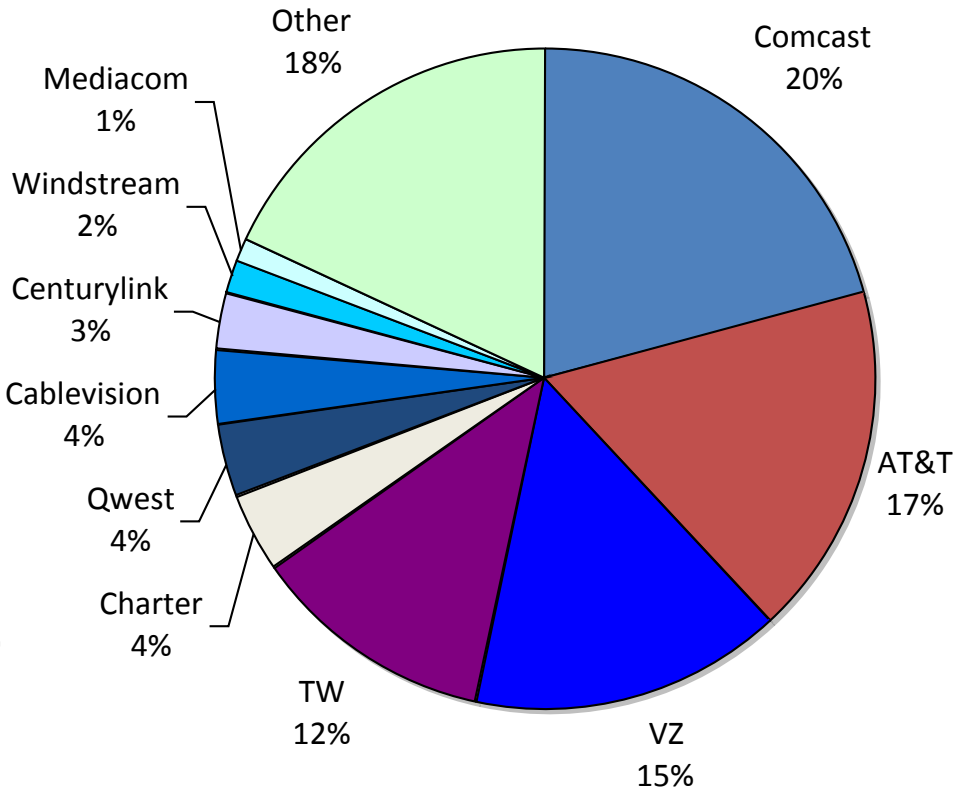


	At least 3 mbps downstream & over 200 kbps upstream	At least 3 mbps downstream & 768 kbps upstream	At least 6 mbps downstream & 1.5 mbps upstream	At least 10 mbps downstream & 1.5 mbps upstream
3+ Providers	58	40	3	2
2 Providers	35	40	22	20
1 Provider	6	17	56	58
0 Providers	1	3	18	21

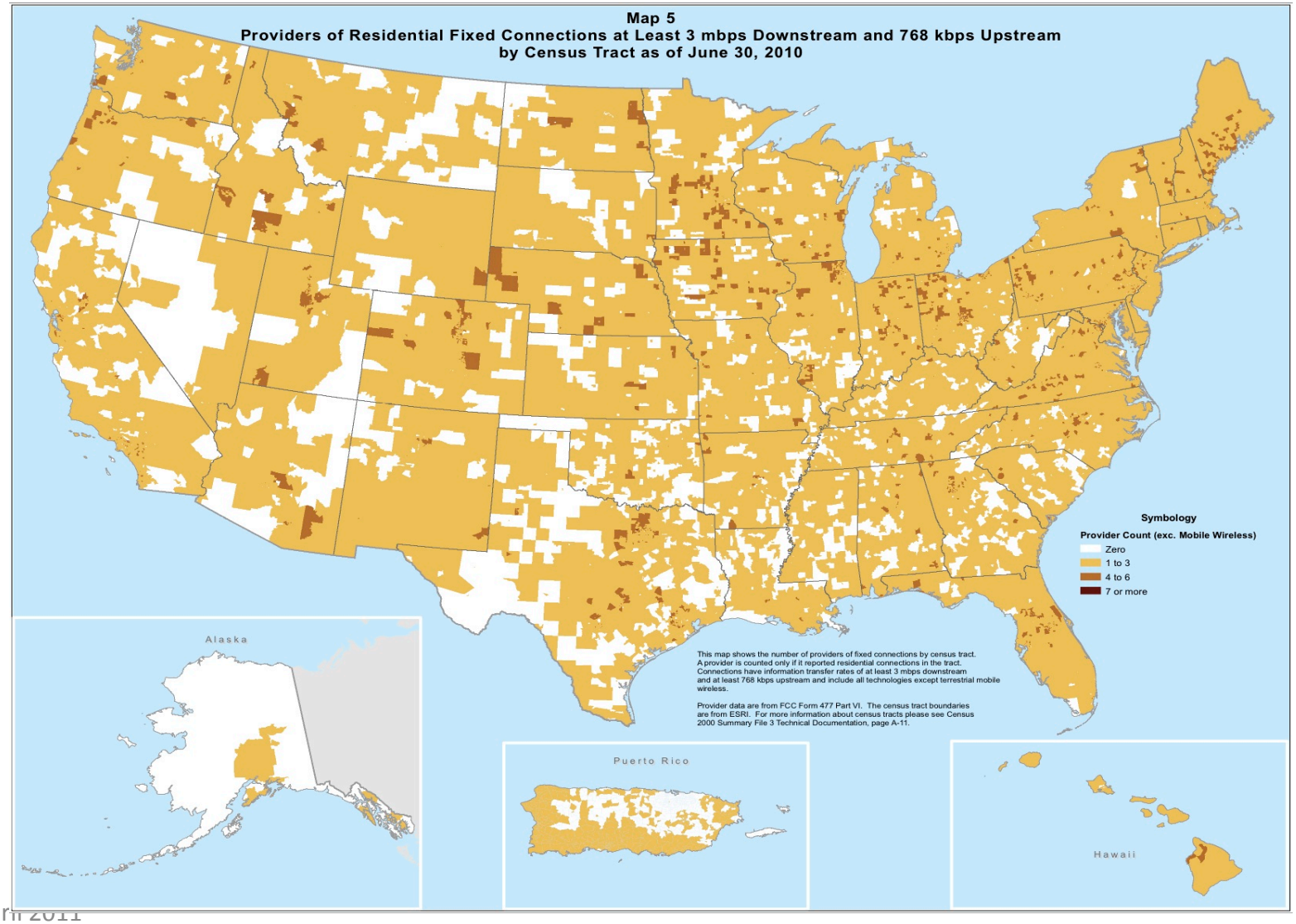
FCC: Internet Access Services Status as of December 31, 2009

Eyeball ISPs: 2001 vs. 2010





Market power: eye ball vs. transit



Remedies

- Functional separation
  - separate entities for L2 and upper layers
  - e.g., “dry loops” copper
  - e.g., UK (BT Wholesale)
- Multiple infrastructures → 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

The future, version 2: airline

- 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

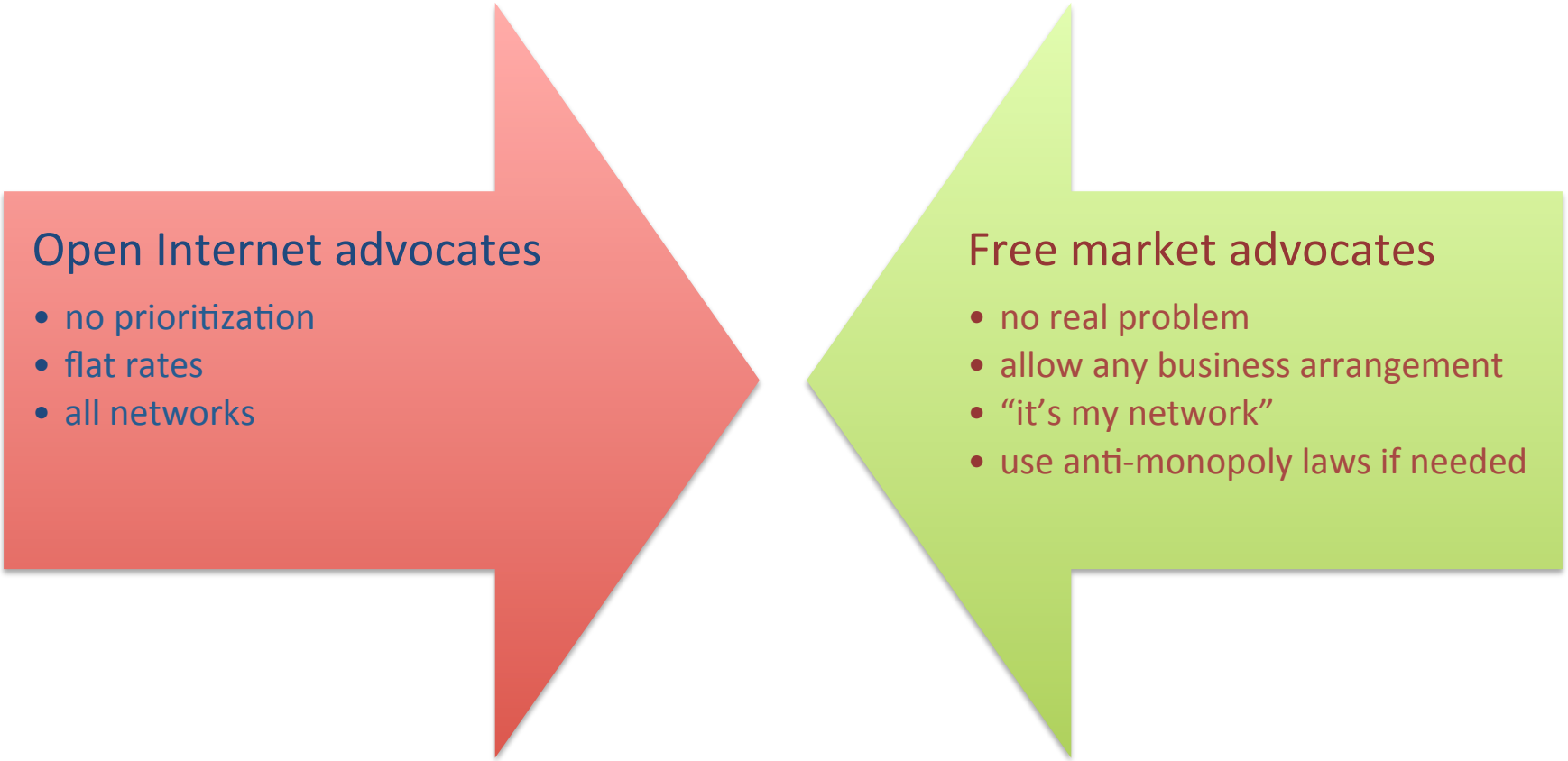
Network neutrality

- What is network neutrality?
  - History
  - Why does it matter?
- Network economics
- Telecom regulation (in the US)
- Means, motive and opportunity
- Challenges

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*

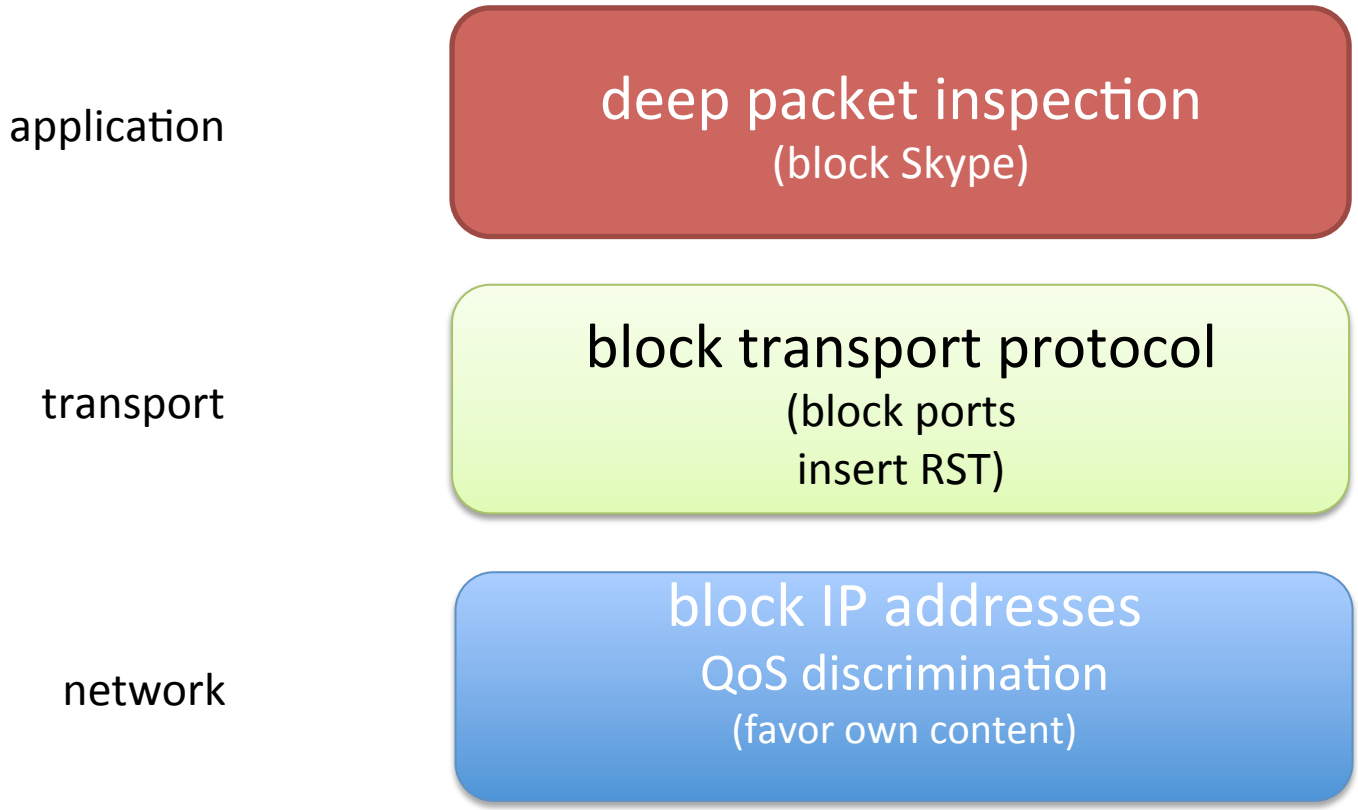
Two views


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



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

1st amendment: Congress shall make no law abridging the 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

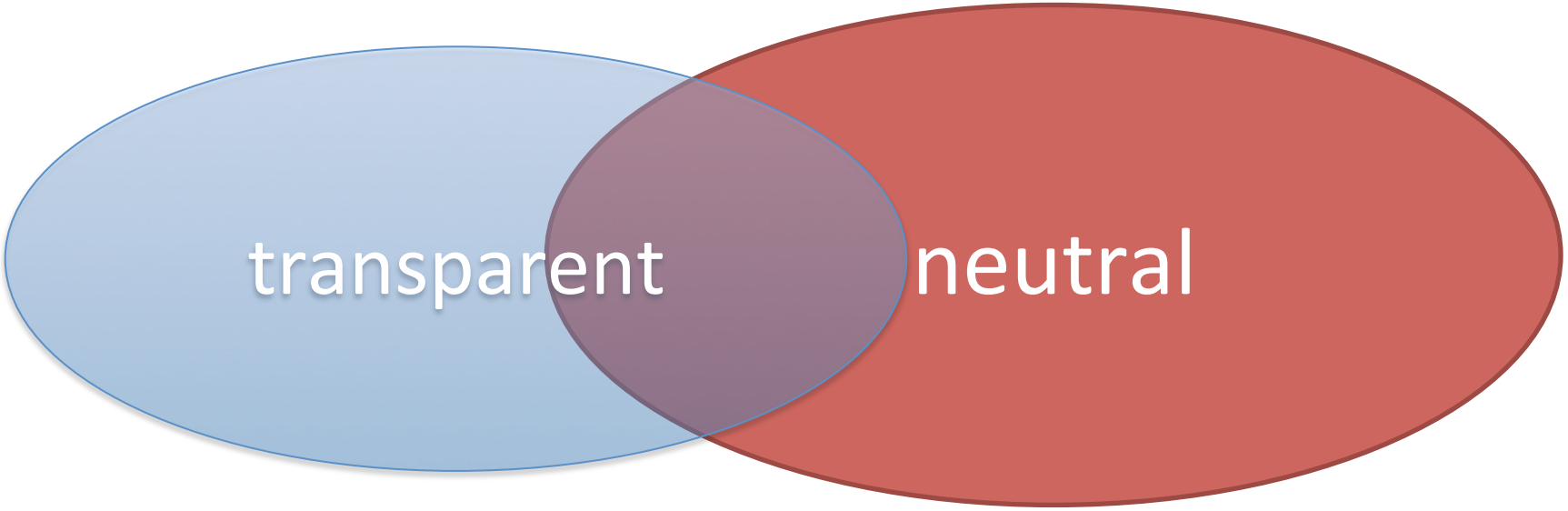
Network transparency

- RFC 1958: “Architectural Principles of the Internet”

  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 3724: “The Rise of the Middle and the Future of End-to-End: Reflections on the Evolution of the Internet Architecture”
- 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



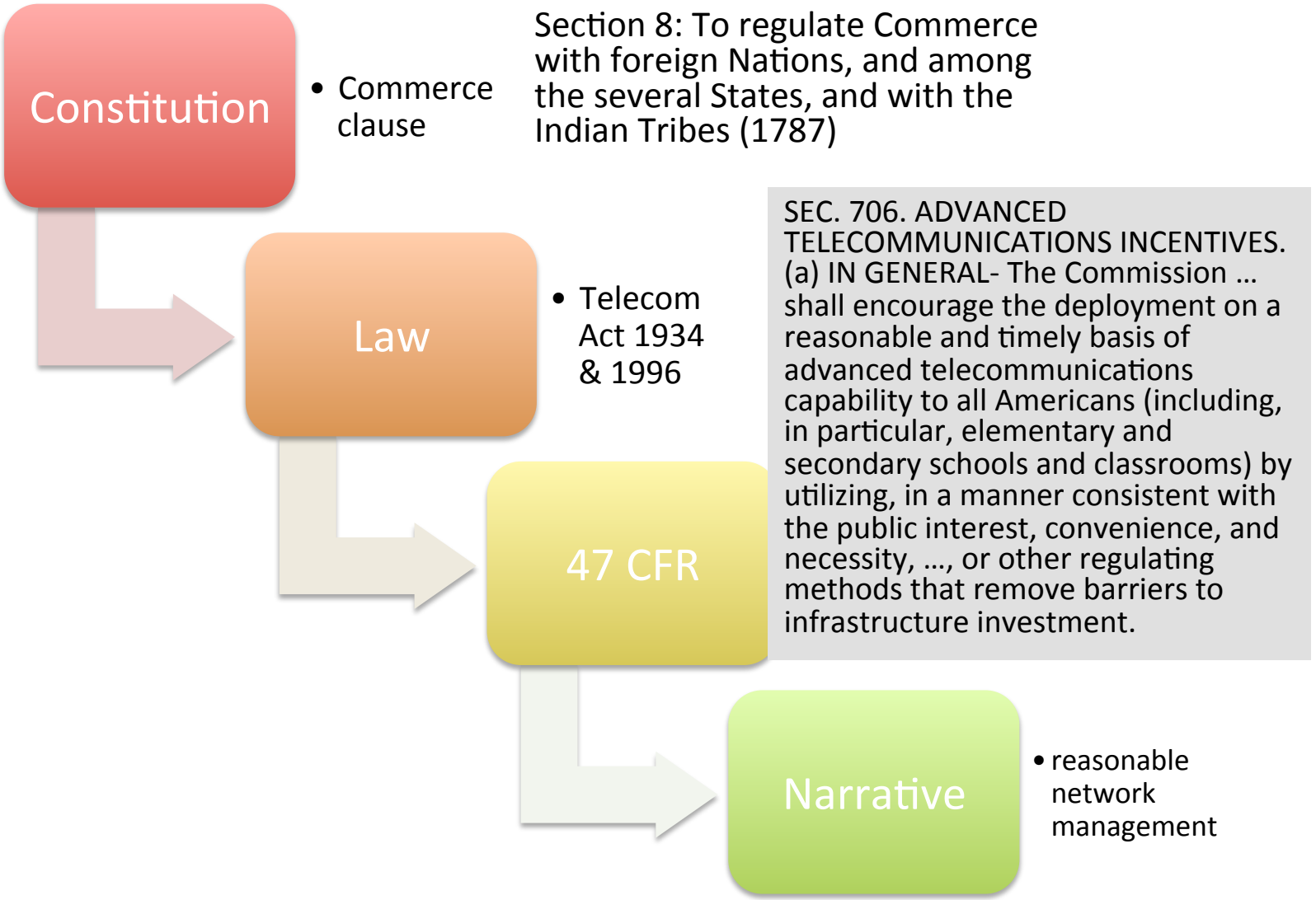
QoS discrimination
pay for priority

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



Example: CFR 47

§ 15.5 General conditions of operation.

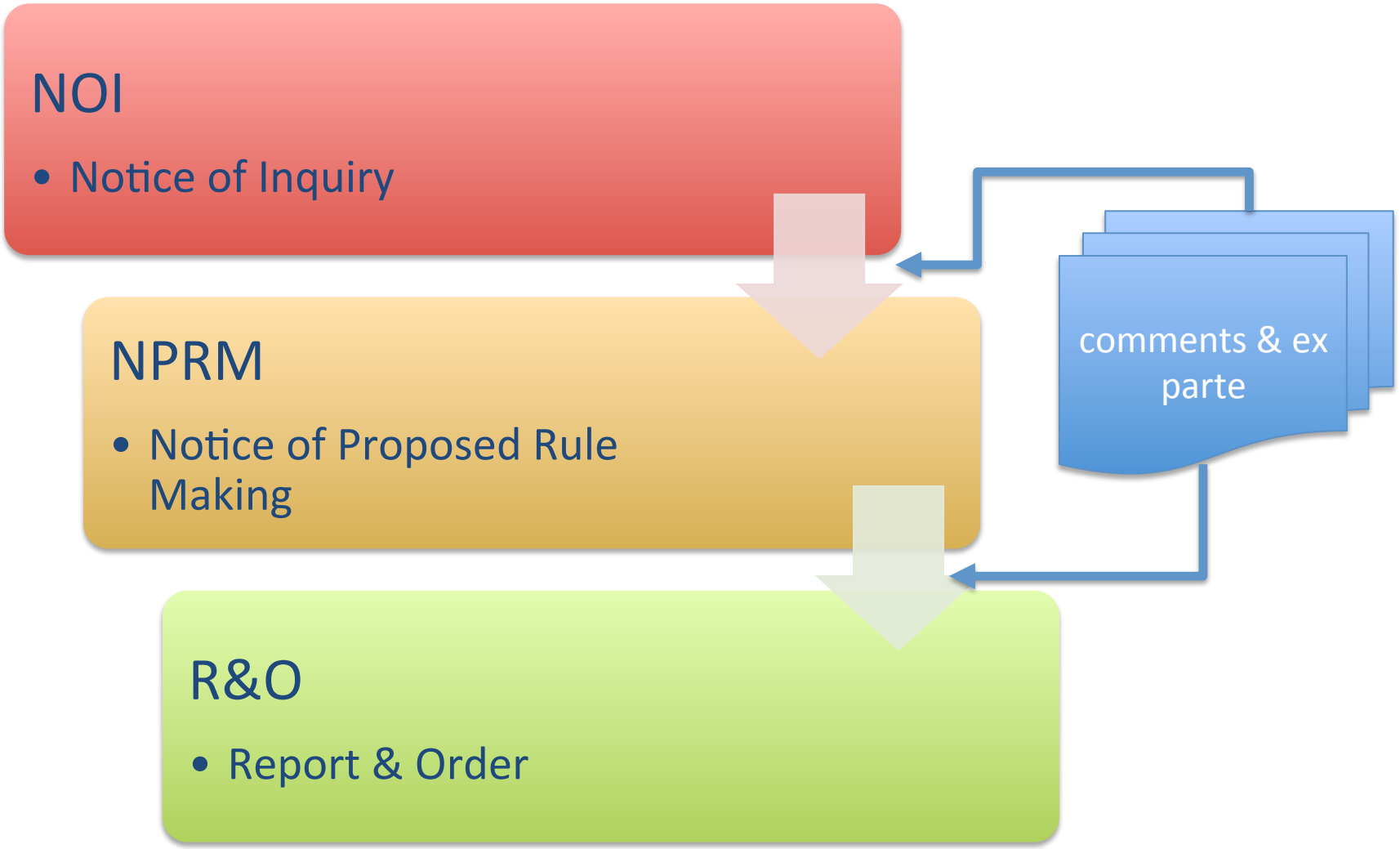
(a) Persons operating intentional or unintentional radiators shall not be deemed to have any vested or recognizable right to continued use of any given frequency by virtue of prior registration or certification of equipment, or, for power line carrier systems, on the basis of prior notification of use 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.

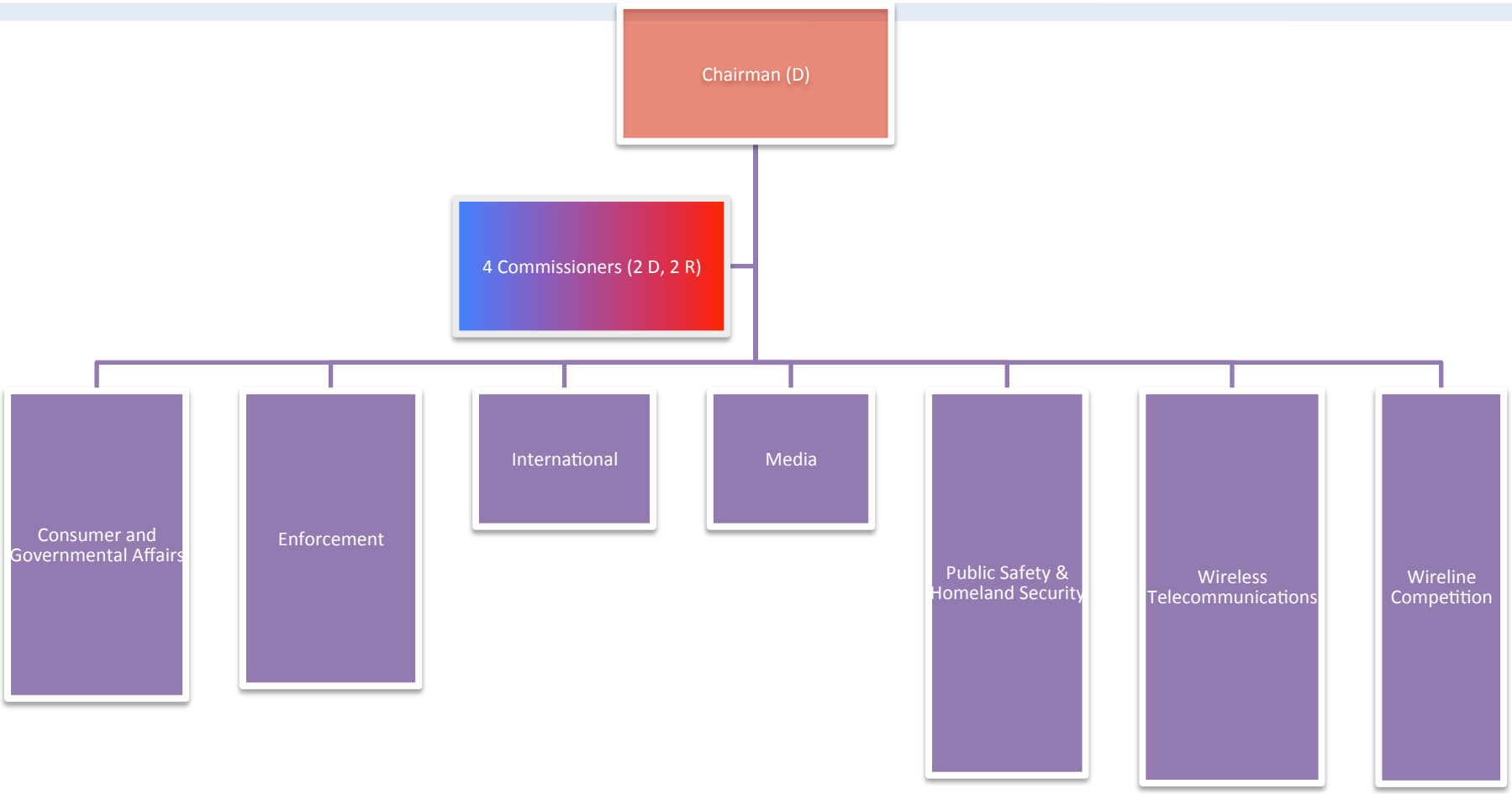
Telecom regulation

- 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

FCC



- Independent federal agency
- About 2,000 employees

Open Internet FCC history

- 2004: “four freedoms” (Powell)
- 2005: Internet policy statement (Martin)
- 9/2009: Genachowski speech
  - non-discrimination, transparency
- 12/2009/: NPRM
- 9/2010: PN
- 12/2010: Open Internet rules
- 10,000+ short comments, hundreds of long comments

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

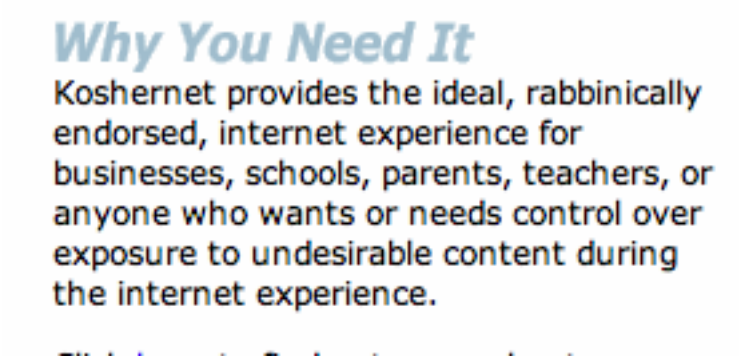
	Wired	Wireless
Disclosure	yes	yes
Non-blocking	every protocol	“web”, “VoIP”
Non-discrimination	reasonable network management	“monitor”

FCC Open Internet order

- CFR text: 1 page
- Main content: 85 pages
  - with 500 footnotes
- Regulatory Flexibility Analysis
- 5 commissioner statements: 60 pages

Some corner cases

- Parental protection
  - user (paying subscriber…) choice
- KosherNet
- Spam
  - would only affect IP-level blocking
- DOS
  - classified as unwanted traffic



47 CFR 8

- **§ 8.1 Purpose.**

  The purpose of this Part is to preserve the Internet as an open platform enabling consumer choice, freedom of expression, end-user control, competition, and the freedom to innovate without permission.

- **§ 8.3 Transparency.**

  A person engaged in the provision of broadband Internet access service shall publicly disclose accurate information regarding the network management practices, performance, and commercial terms of its broadband Internet access services sufficient for consumers to make informed choices regarding use of such services and for content, application, service, and device providers to develop, market, and maintain Internet offerings.

Disclosure (Transparency) – Network Practices

- *Congestion management*: congestion management practices; types of traffic; purposes; practices' effects on end users' experience; criteria used in practices, such as indicators of congestion that trigger a practice, and the typical frequency of congestion; usage limits and the consequences of exceeding them; and references to engineering standards, where appropriate.
- *Application-Specific Behavior*
- *Device Attachment Rules*
- *Security*

Disclosure (Transparency) – Performance

- *Service description*: A general description of the service, including the service technology, expected and actual access speed and latency, and the suitability of the service for real-time applications.
- *Impact of specialized services:* If applicable, what specialized services, if any, are offered to end users, and whether and how any specialized services may affect the last-mile capacity available for, and the performance of, broadband Internet access service.

Disclosure (Transparency) – Commercial Terms

- *Pricing*: For example, monthly prices, usage-based fees, and fees for early termination or additional network services.
- *Privacy Policies*: For example, whether network management practices entail inspection of network traffic, and whether traffic information is stored, provided to third parties, or used by the carrier for non-network management purposes.
- *Redress Options*: Practices for resolving end-user and edge provider complaints and questions.

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

Pay for Priority (P4P)

- "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

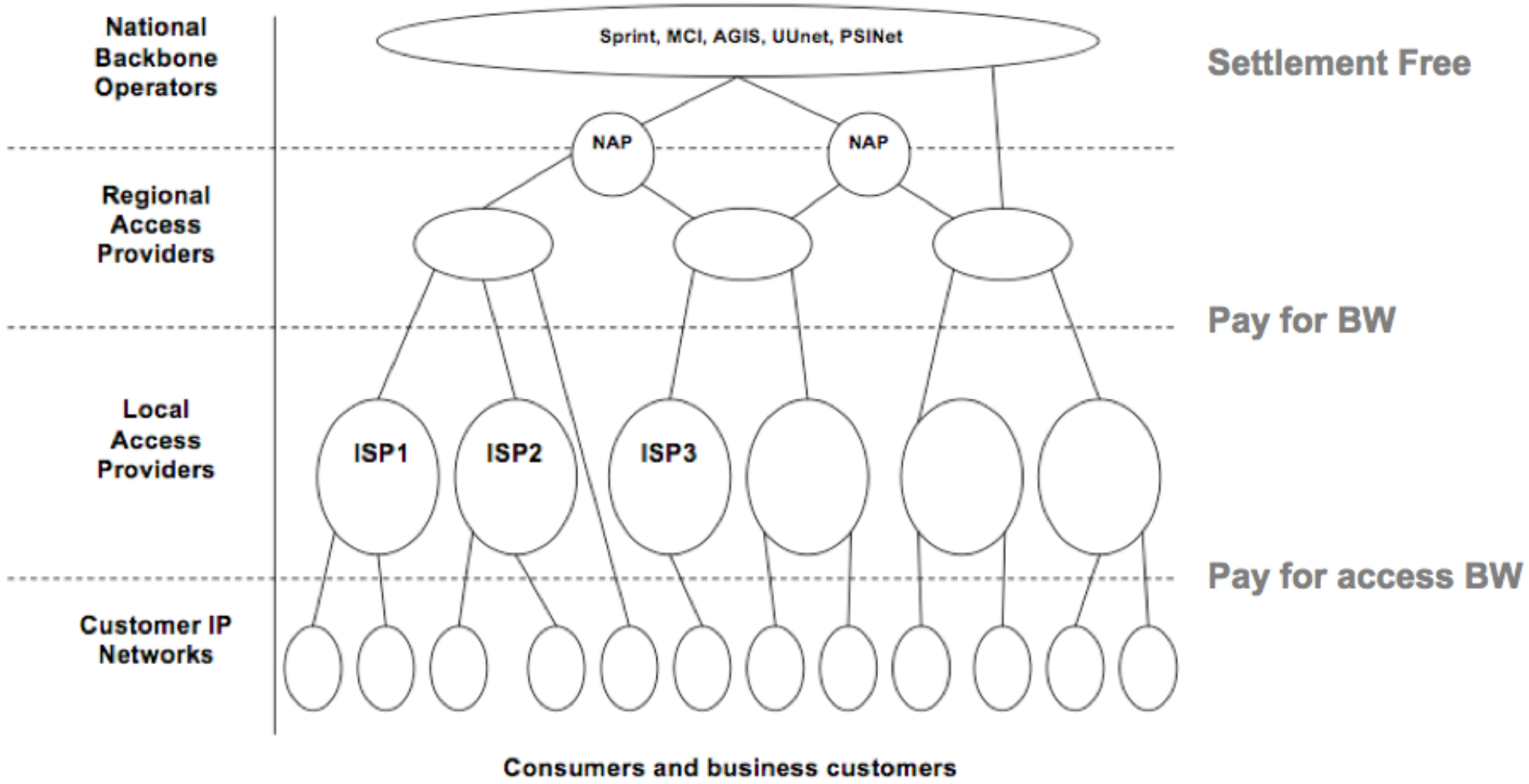
- Difficult to determine state of openness
  - blocking, content discrimination

Example tests

- May contribute to ossification of Internet
- E.g., Reddit comments on FCC challenge
  - SCTP, DCCP, UDP Lite
  - UDP path MTU detection
  - NXDOMAIN
  - VPN protocols
  - ICMP echo
  - TCP vs. non-TCP fairness
  - TCP window scaling
  - TCP ECN
  - modification of HTTP requests

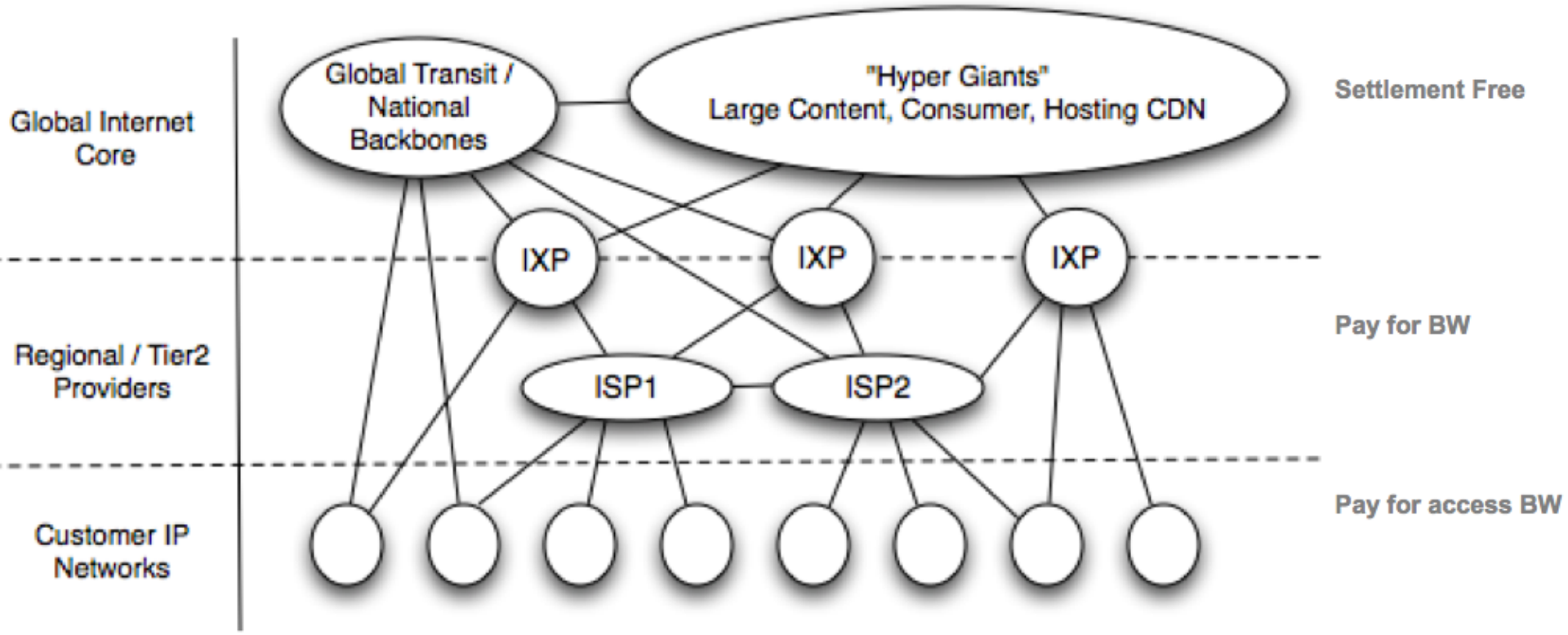
Peering – the next network neutrality challenge

The old Internet



Craig Labovitz, "Internet Traffic and Content Consolidation", IETF March 2010.

A denser Internet



Craig Labovitz, "Internet Traffic and Content Consolidation", IETF March 2010.

New network providers

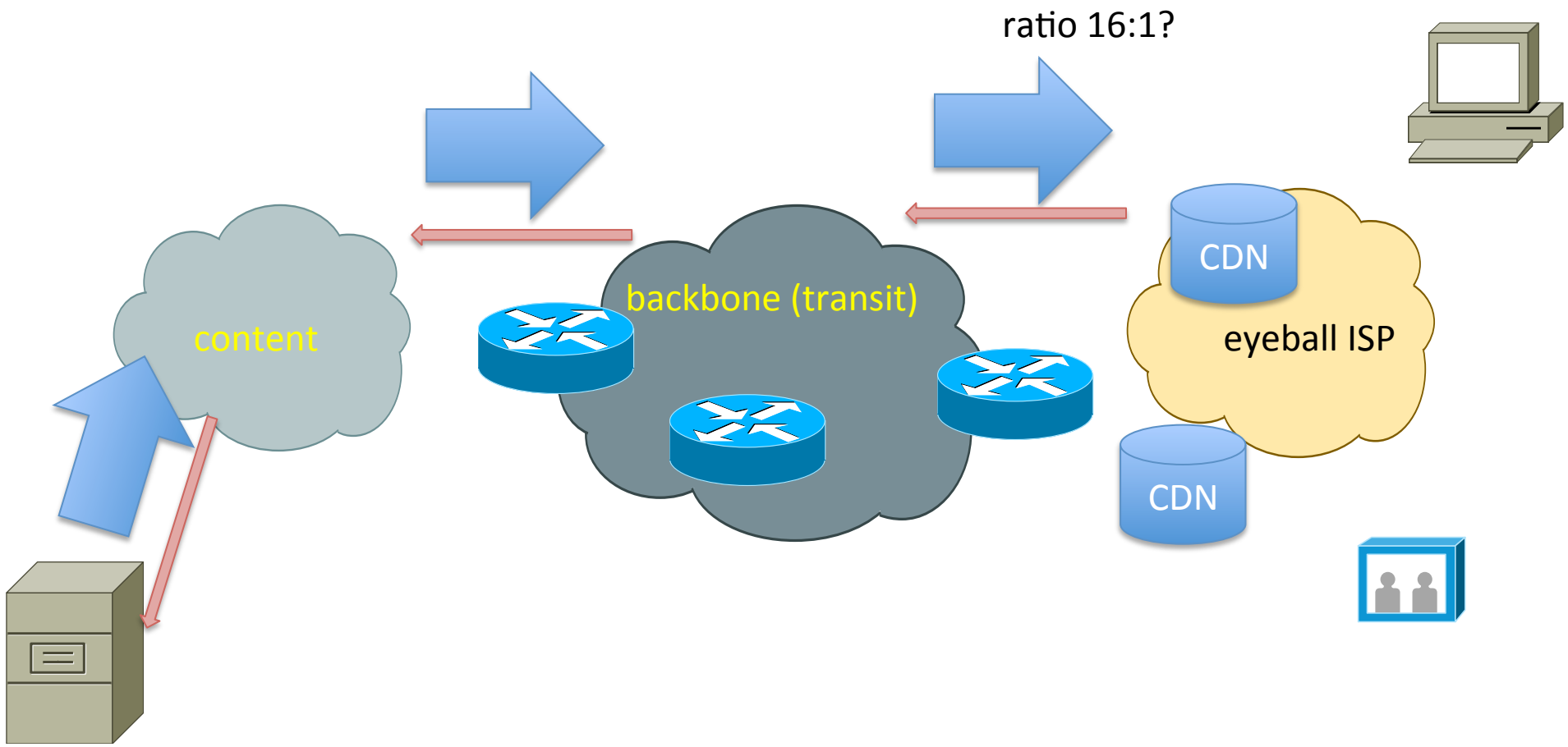
Rank	2007 Top Ten	%
1	*ISP A*	5.77
2	*ISP B*	4.55
3	*ISP C*	3.35
4	*ISP D*	3.2
5	*ISP E*	2.77
6	*ISP F*	2.6
7	*ISP G*	2.24
8	*ISP H*	1.82
9	*ISP I*	1.35
10	*ISP J*	1.23

Rank	2009 Top Ten	%
1	*ISP A*	9.41
2	*ISP B*	5.7
3	Google	5.2
4	-	
5	-	
6	Comcast	3.12
7	-	
8	-	
9	-	
10	-	

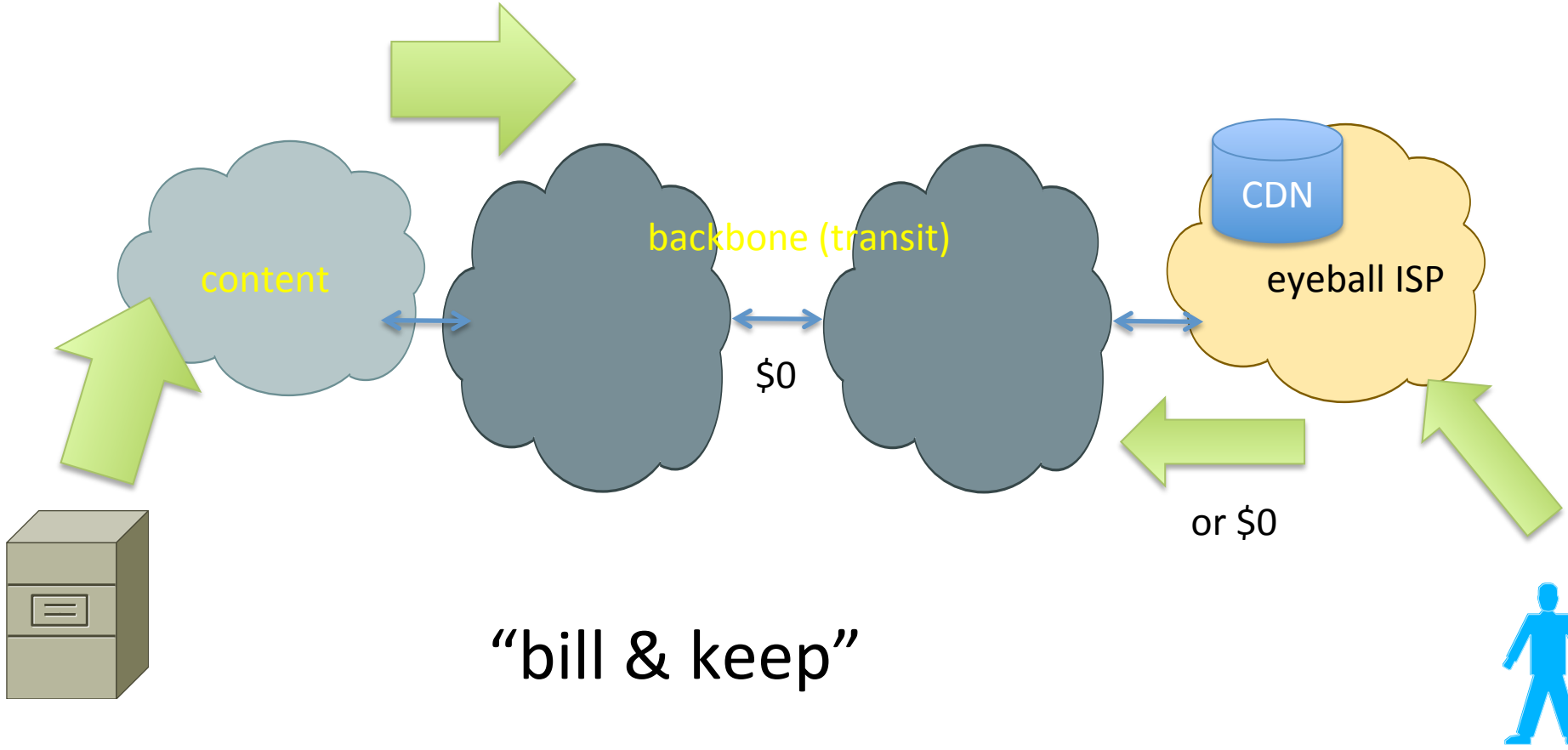
Based on analysis of anonymous ASN (origin/transit) data (as a weighted average % of all Internet Traffic). Top ten has NO direct relationship to study participation.

Craig Labovitz, "Internet Traffic and Content Consolidation", IETF March 2010.

Internet traffic flows today

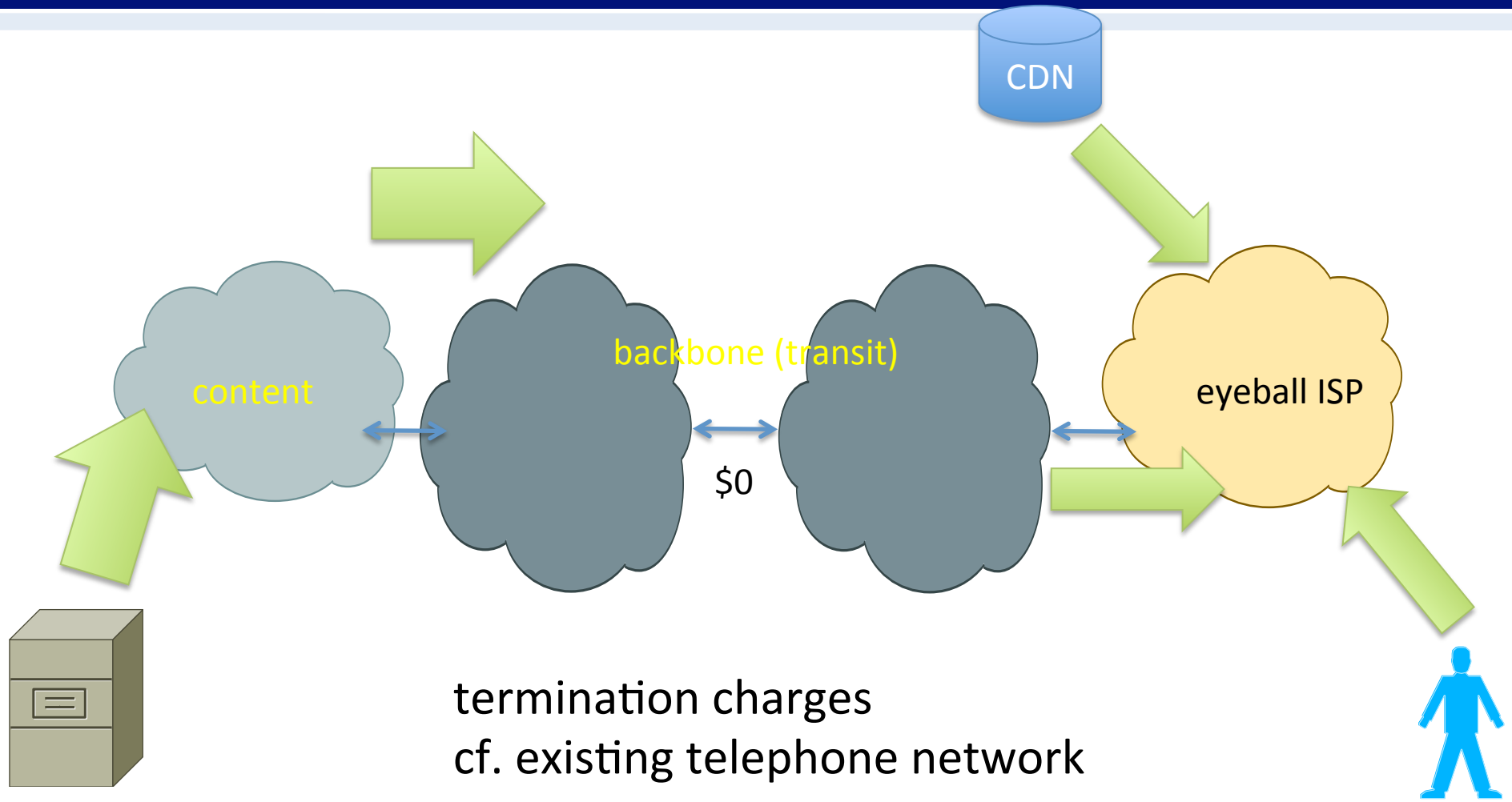


Internet money flows today



"bill & keep"

Future Internet money flows?



termination charges
cf. existing telephone network

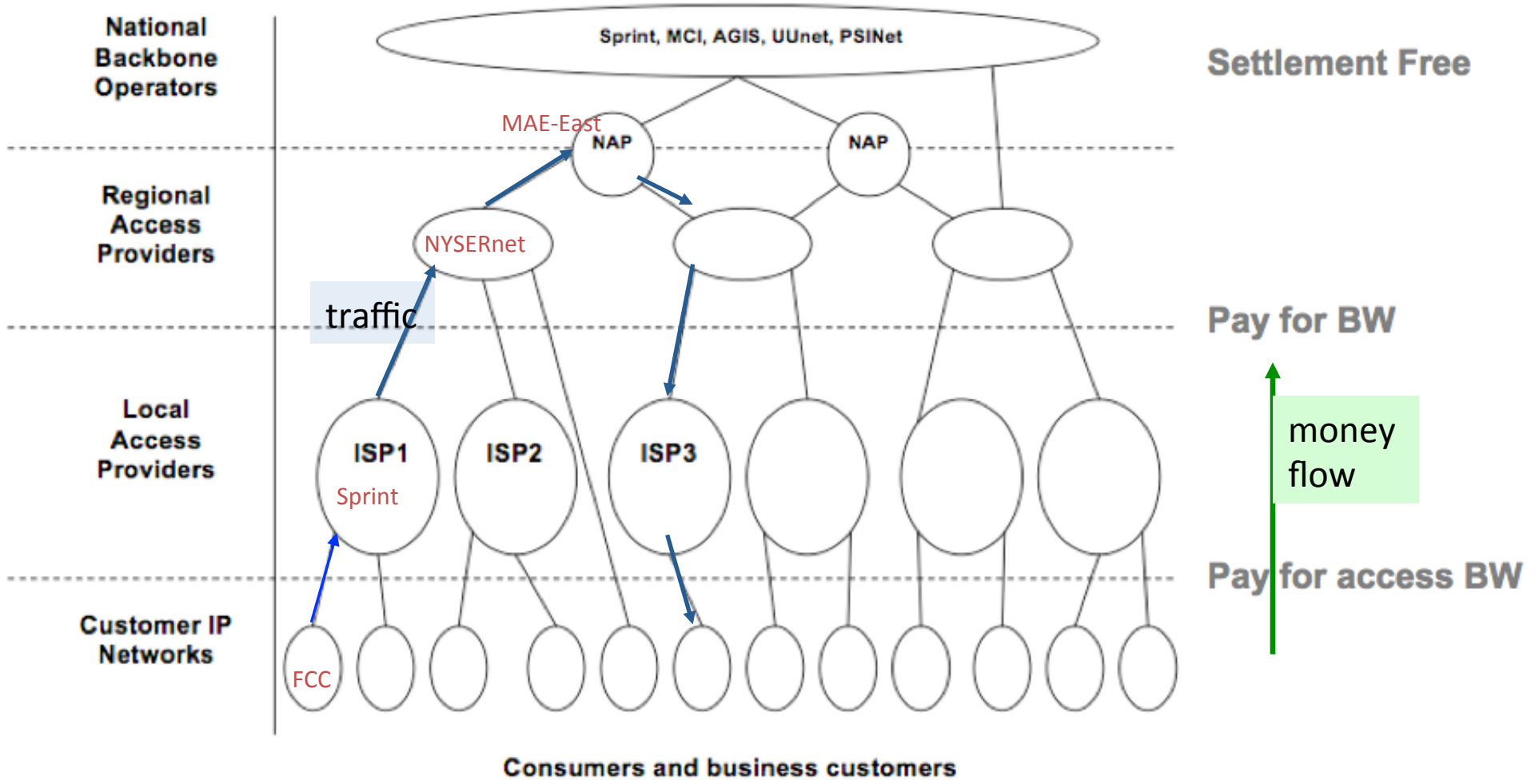
Paid vs. non-paid peering

- Reflects value added and market power
- E.g.,
  - number of customers served
  - distance carried (fiber route miles)
- Market power
  - eyeball ISP only allows direct peering
  - content providers have to reach (almost) all customers
  - but there are lots of transit providers
- Economic models just emerging

Paid vs. non-paid peering

- Traffic ratios traditionally used between transit ISPs
  - but not exclusively
- Thought experiment:
  - replace YouTube with Skype
  - now, traffic symmetric
  - but exact some impact on consumer ISP

The “classic” Internet – ca. 1995



Craig Labovitz, “Internet Traffic and Content Consolidation”, IETF March 2010.

Role of the IXPs (inter-exchange points)

- IXP
  - As NAPs congested, IXPs emerged (including overseas)
  - IXPs → private peering and secondary peering
  - IXPs
    - reduced tromboning
    - provided cost reductions
    - improved performance and
    - occurred mostly without regulatory oversight
- About 85 IXPs in US

The players & their roles

Role	Examples	AT&T	Comcast
End user	residential … GM		
Eyeball ISP	WISP … Comcast, AT&T	x	x
Content & application hosting	GoDaddy, Layered Technologies	x	x
Content providers and aggregators	Netflix, YouTube, Vimeo		x
CDNs (content distribution networks)	Akamai, Limelight, Edgecast	x	x
IXPs	Equinix		
Transit ISPs	Verizon Business (UUnet), Level 3, GlobalCrossing, Tata	x (tier 1)	x

New network providers

The "ATLAS 10" Today

Rank	Provider	Percentage
1	Level(3)	5.77
2	Global Crossing	4.55
3	ATT	3.35
4	Sprint	3.2
5	NTT	2.6
6	Cogent	2.77
7	Verizon	2.24
8	TeliaSonera	1.82
9	Savvis	1.35
10	AboveNet	1.23

(a) Top Ten 2007

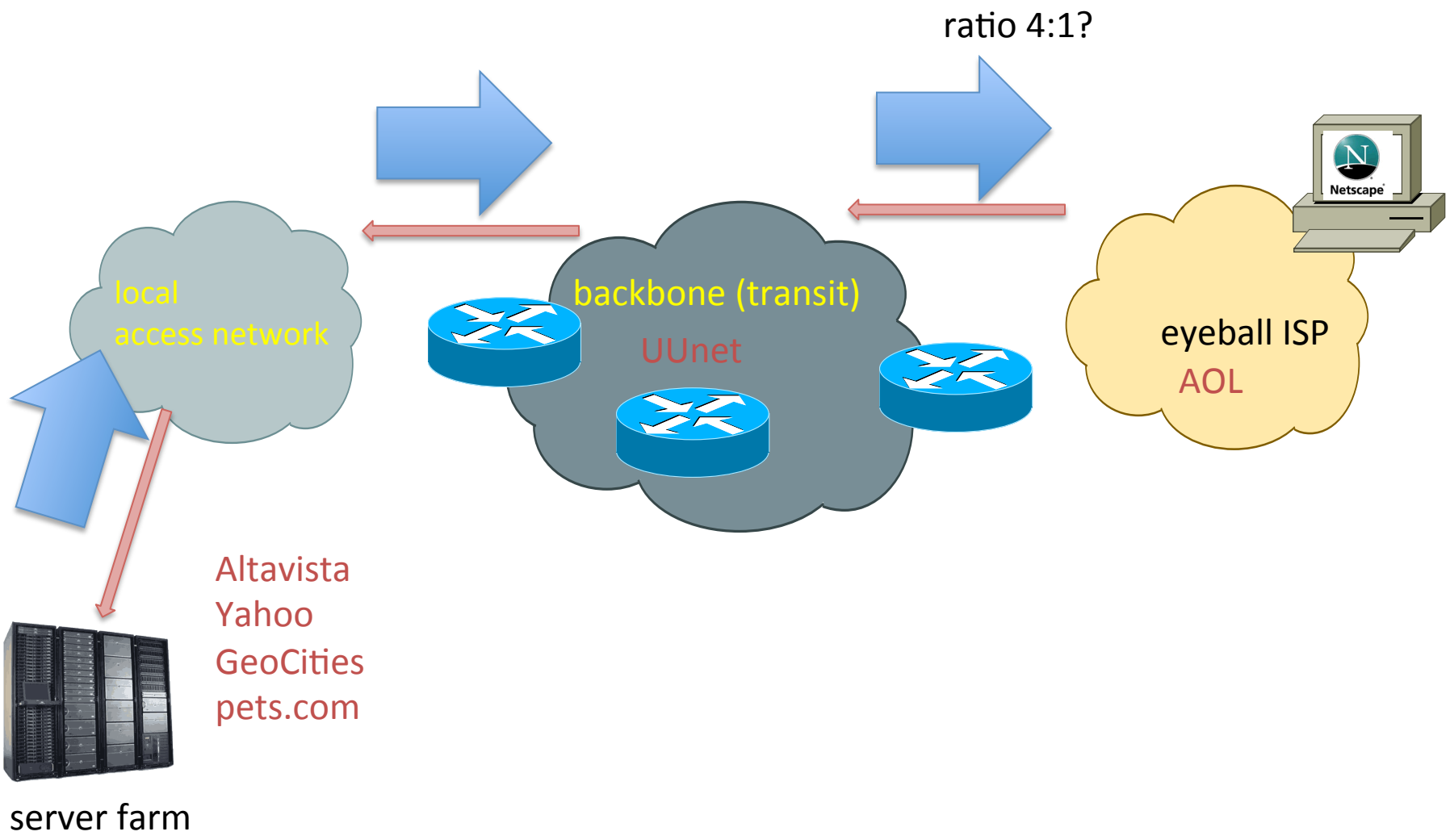
Rank	Provider	Percentage
1	Level(3)	9.41
2	Global Crossing	5.7
3	Google	5.2
4		
5		
6	Comcast	3.12
7		
8	*Intentionally omitted*	
9		
10		

(b) Top Ten 2009

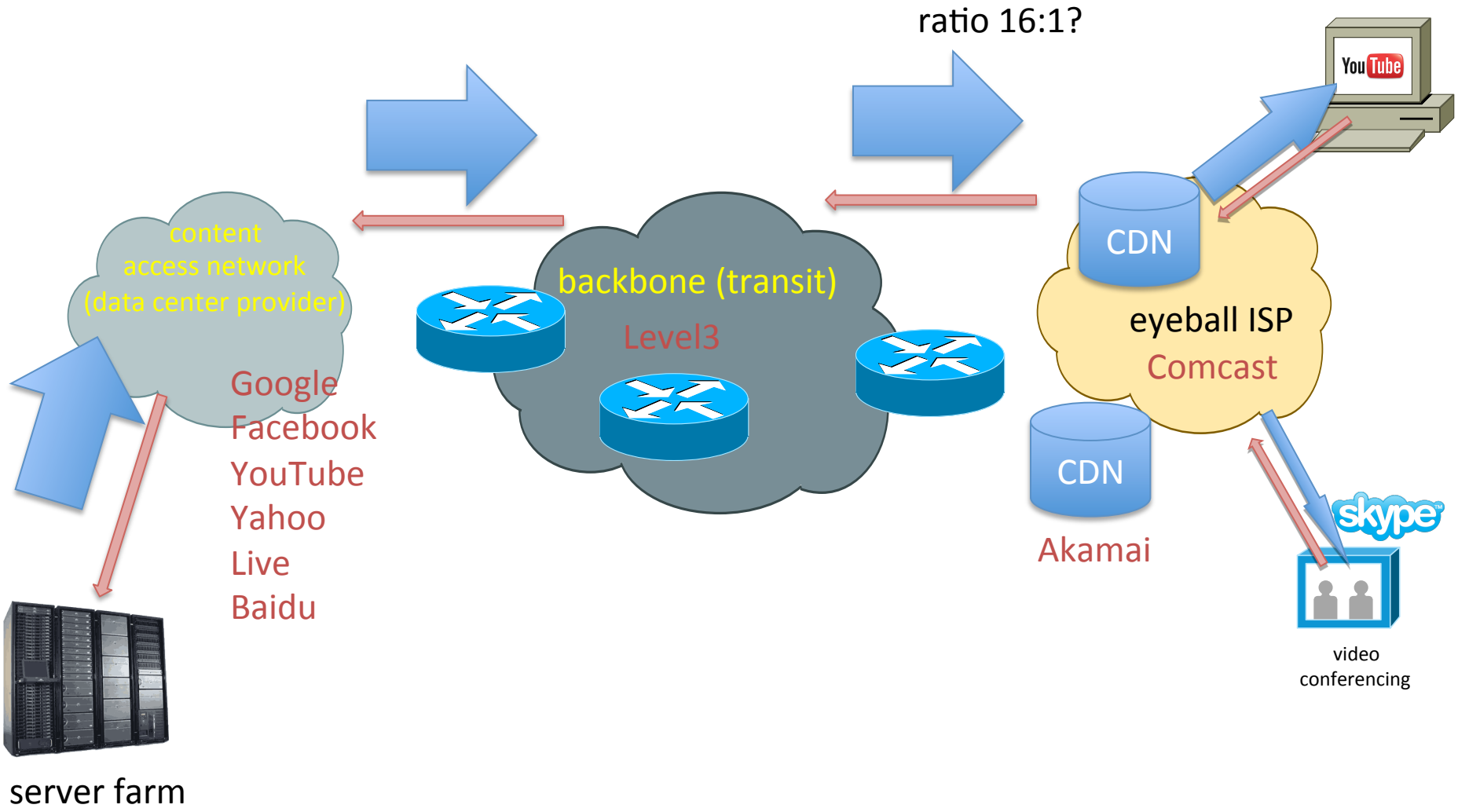
- Based on analysis of anonymous ASN (origin/transit) data
  - Weighted average percentage
- Top ten has NO direct relationship to Observatory participation
- Tier1s still carry significant traffic volumes (and profitable services)
- But Comcast and Google join the top ten

Craig Labovitz, "Internet Traffic and Content Consolidation", IETF March 2010.

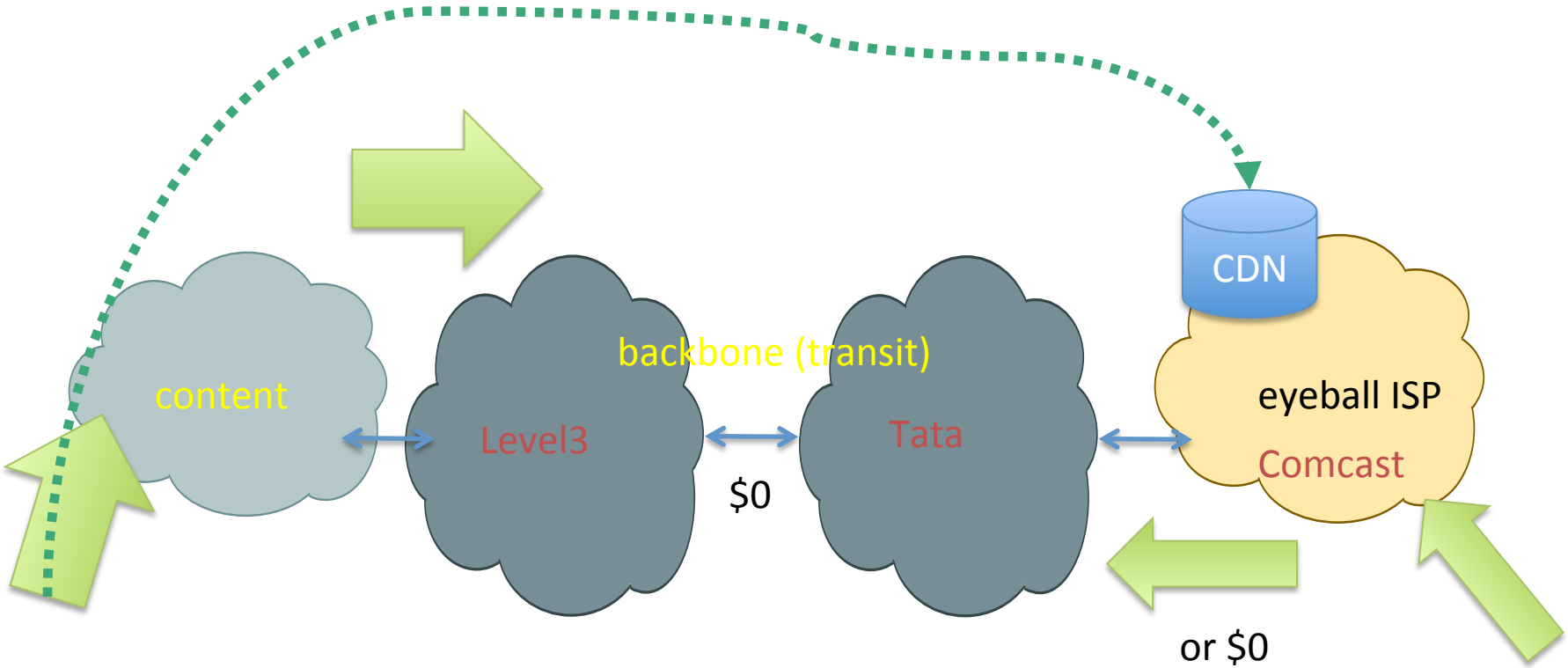
Internet traffic flows in the 1990s



Internet traffic flows today



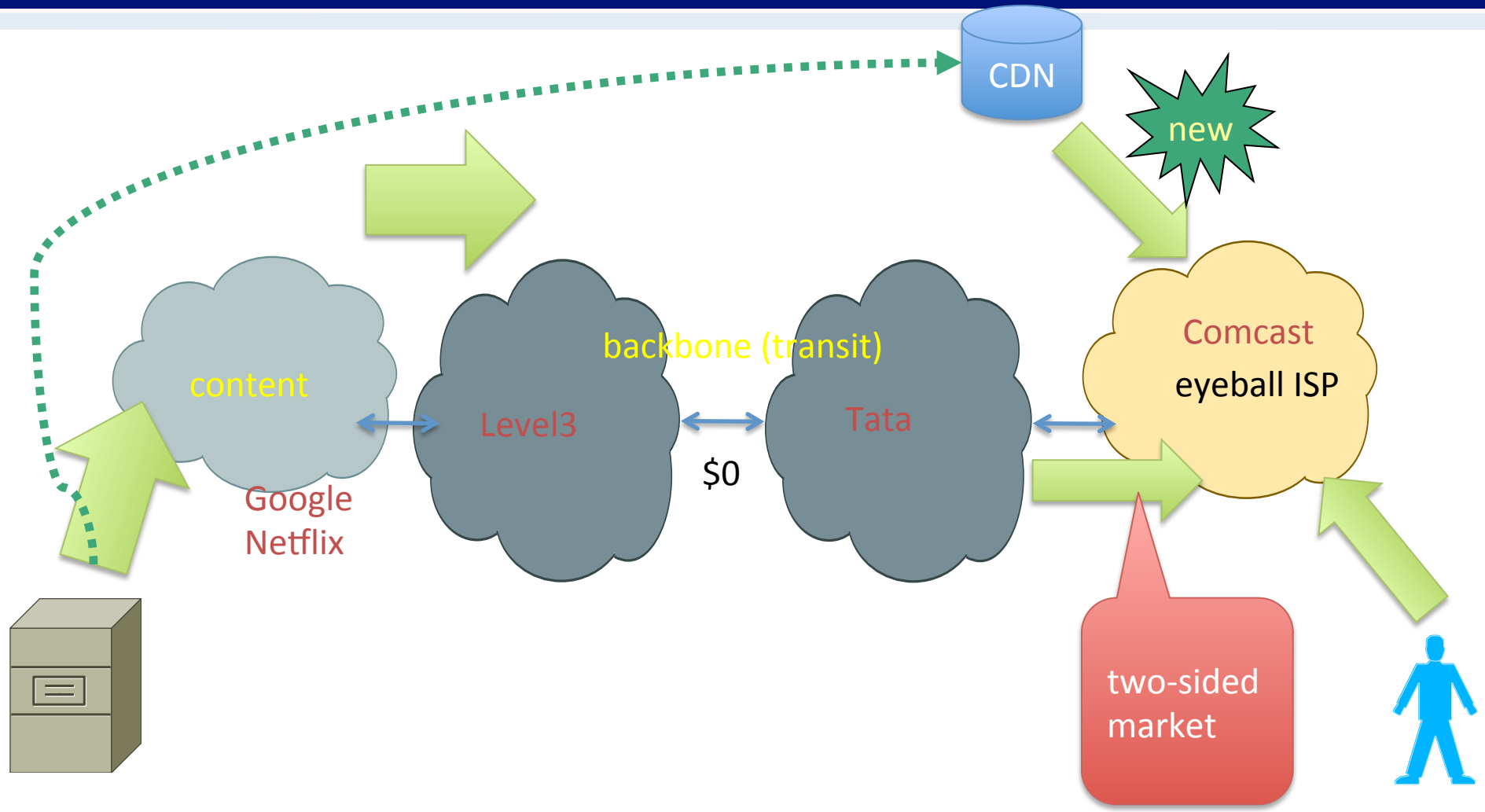
Internet money flows today



server farm

"bill & keep"

Future Internet money flows?



Same packets, different value

The end of infinite

The value of bits

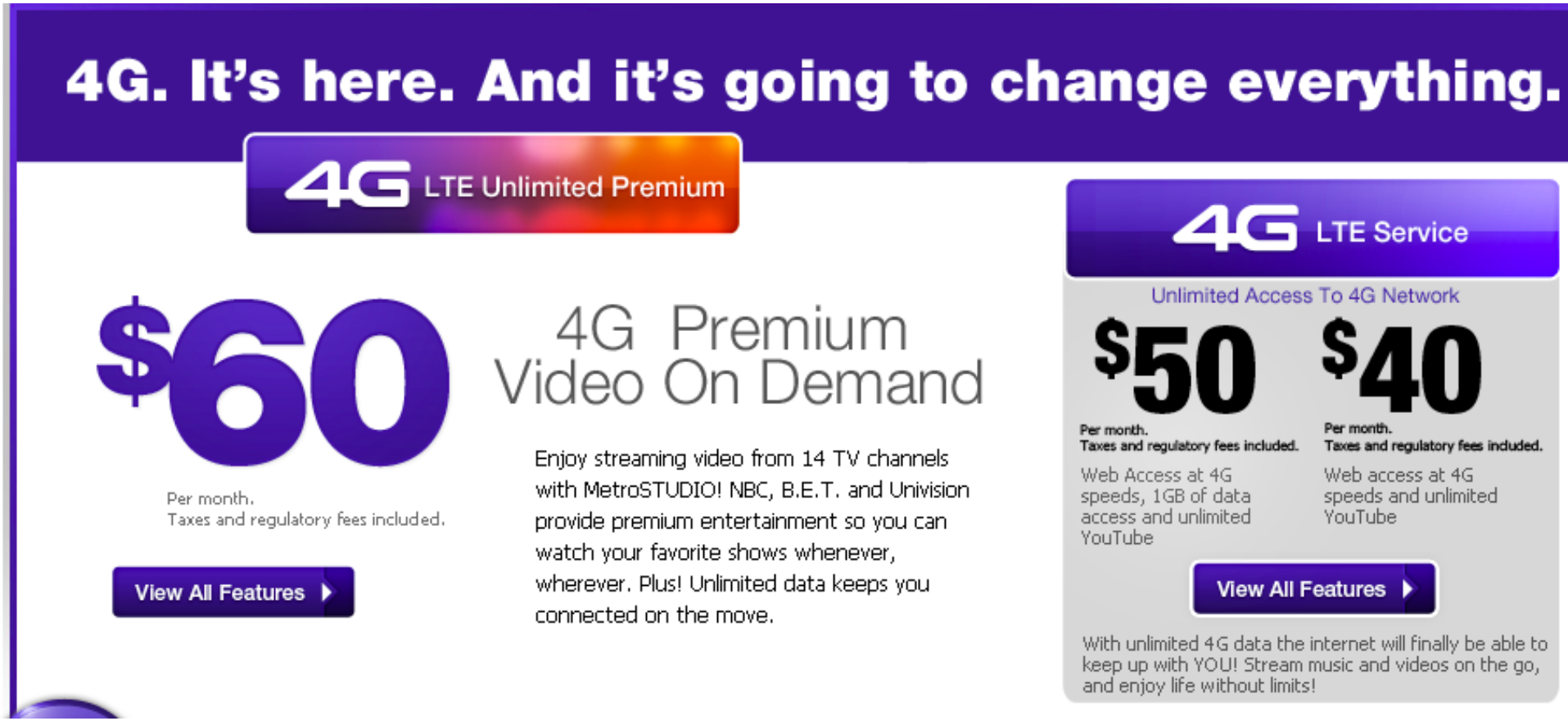
- Technologist: A bit is a bit is a bit
- Economist: Some bits are more valuable than other bits

Application	Volume	Cost per unit	Cost / MB
Voice (13 kb/s GSM)	97.5 kB/minute	10c	$1.02
Mobile data	5 GB	$40	$0.008
MMS (pictures)	< 300 KB, avg. 50 kB	25c	$5.00
SMS	160 B	10c	$625

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

MetroPCS example



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

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

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

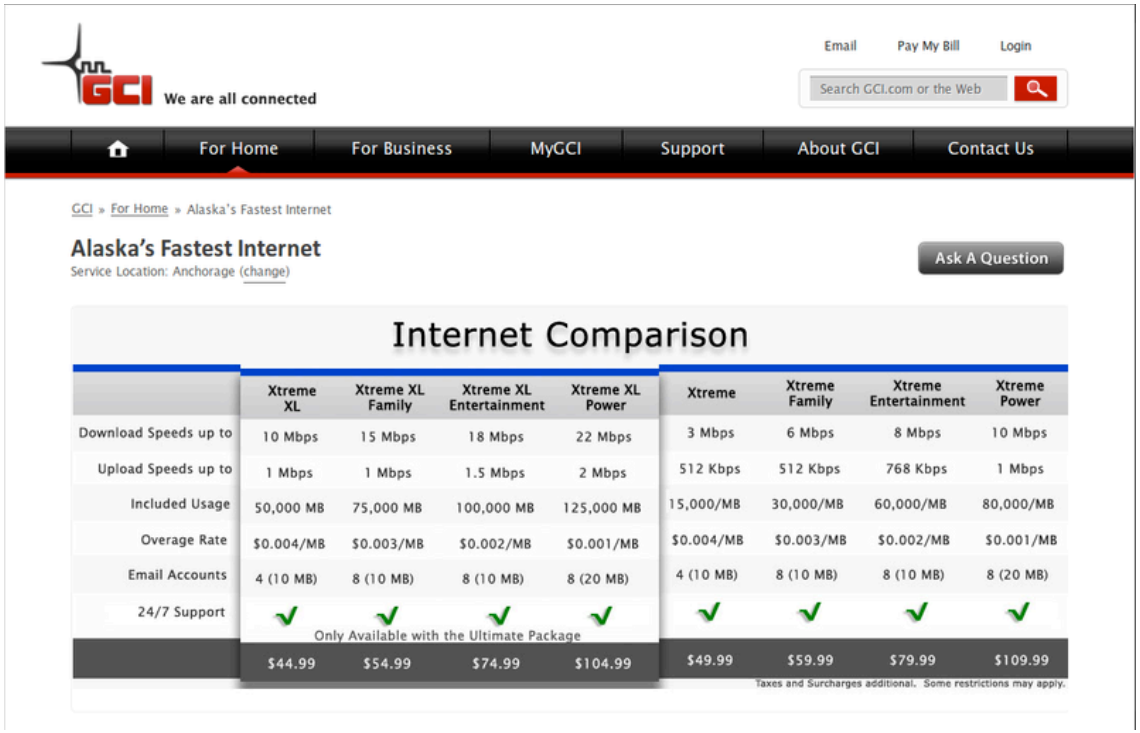
Bandwidth limits

Label	Description	Cap exceeded	Motivation	Consumer impact
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		
Economy	1.5 Mbps High Speed Internet Service, 1 GB data plan. See help.cableone.net/HSD/plans/economy/FAQ.aspx for details.	$20
Standard	5 Mbps High Speed Internet Service.	$50

High Speed Internet	50 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.



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GCI » For Home » Alaska's Fastest Internet

Alaska's Fastest Internet

Service Location: Anchorage (change)

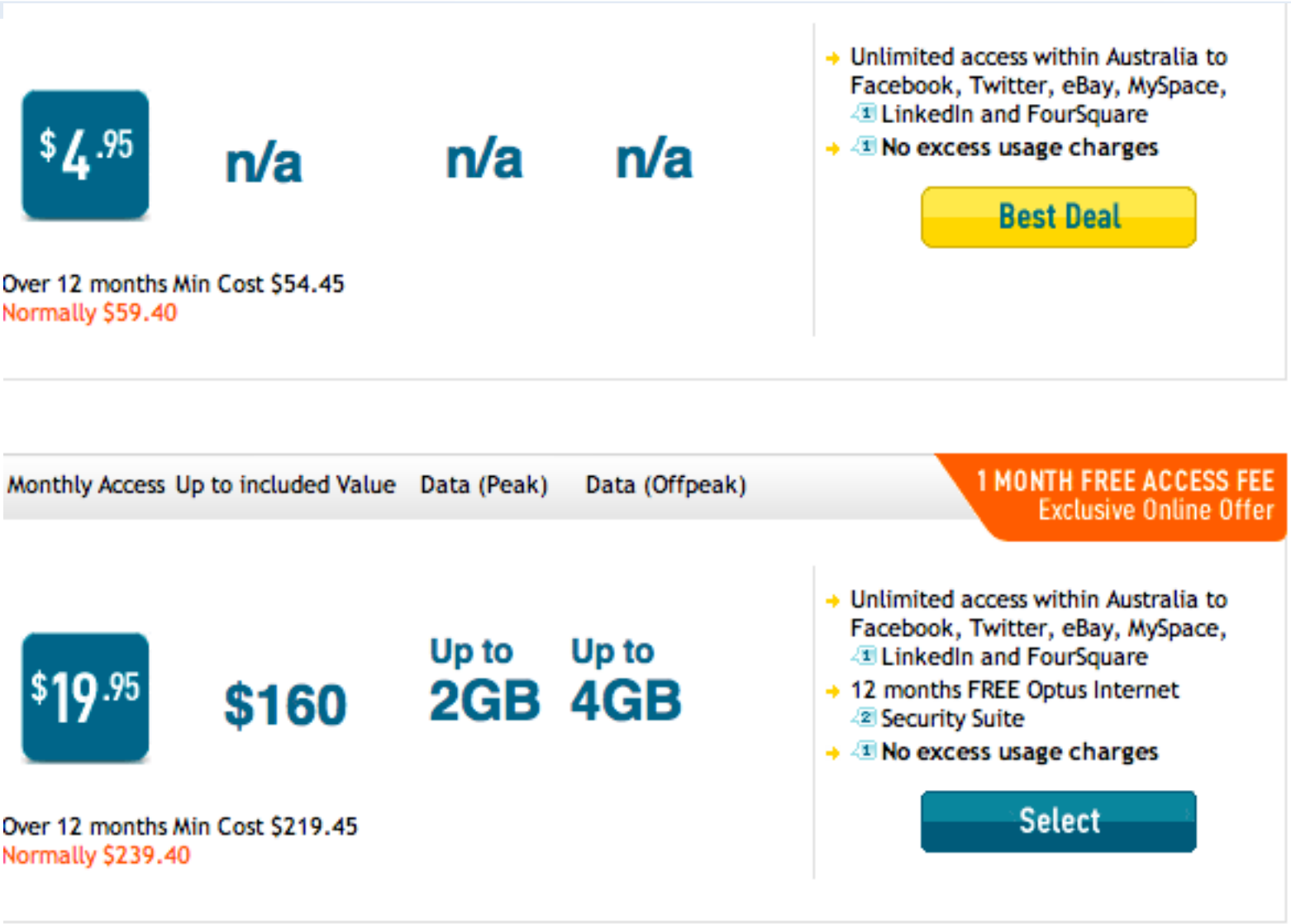
Ask A Question

Internet Comparison

	Xtreme XL	Xtreme XL Family	Xtreme XL Entertainment	Xtreme XL Power	Xtreme	Xtreme Family	Xtreme Entertainment	Xtreme Power
Download Speeds up to	10 Mbps	15 Mbps	18 Mbps	22 Mbps	3 Mbps	6 Mbps	8 Mbps	10 Mbps
Upload Speeds up to	1 Mbps	1 Mbps	1.5 Mbps	2 Mbps	512 Kbps	512 Kbps	768 Kbps	1 Mbps
Included Usage	50,000 MB	75,000 MB	100,000 MB	125,000 MB	15,000/MB	30,000/MB	60,000/MB	80,000/MB
Overage Rate	$0.004/MB	$0.003/MB	$0.002/MB	$0.001/MB	$0.004/MB	$0.003/MB	$0.002/MB	$0.001/MB
Email Accounts	4 (10 MB)	8 (10 MB)	8 (10 MB)	8 (20 MB)	4 (10 MB)	8 (10 MB)	8 (10 MB)	8 (20 MB)
24/7 Support	√	√	√	√	√	√	√	√
	Only Available with the Ultimate Package							
	$44.99	$54.99	$74.99	$104.99	$49.99	$59.99	$79.99	$109.99

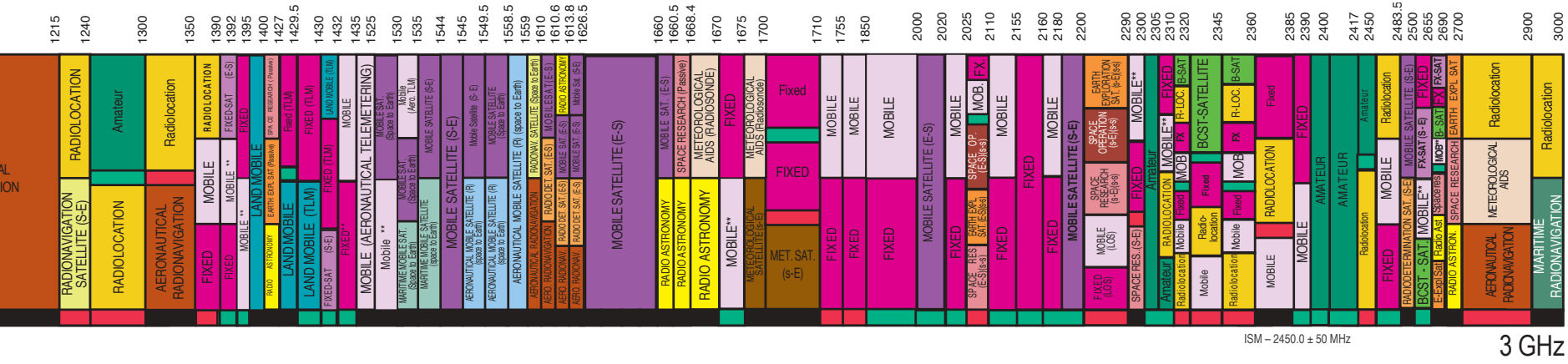
Taxes and Surcharges additional. Some restrictions may apply.

Optus (Australia) example



Spectrum

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
- ➔ 90-10 problems (= 90% of solution with 10% of the effort)

Conclusion

- 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?