CAN THE INTERNET SURVIVE THE NEXT 40 YEARS?

Henning Schulzrinne

Lots of questions…

- What are the key attributes of the Internet that led to its success?
- Can the Internet be made secure? (next time…)
- What are the economic challenges for the Internet?
- How can we ensure an open Internet for all?
- What happens when old-style networks are being replaced?
- What are the key challenges for the mobile Internet?
- → engineering, economics & public policy

The Internet as infrastructure

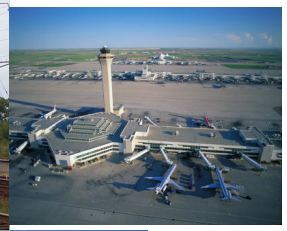
The great infrastructure

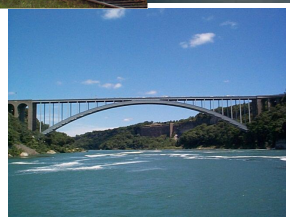
- Technical structures that support a society → "civil infrastructure"
  - Large
  - Constructed over generations
  - Not often replaced as a whole system
  - Continual refurbishment of components
  - Interdependent components with well-defined interfaces
  - High initial cost

water

energy

transportation





communication

The Internet as core civil infrastructure

For Immediate Release February 12, 2013

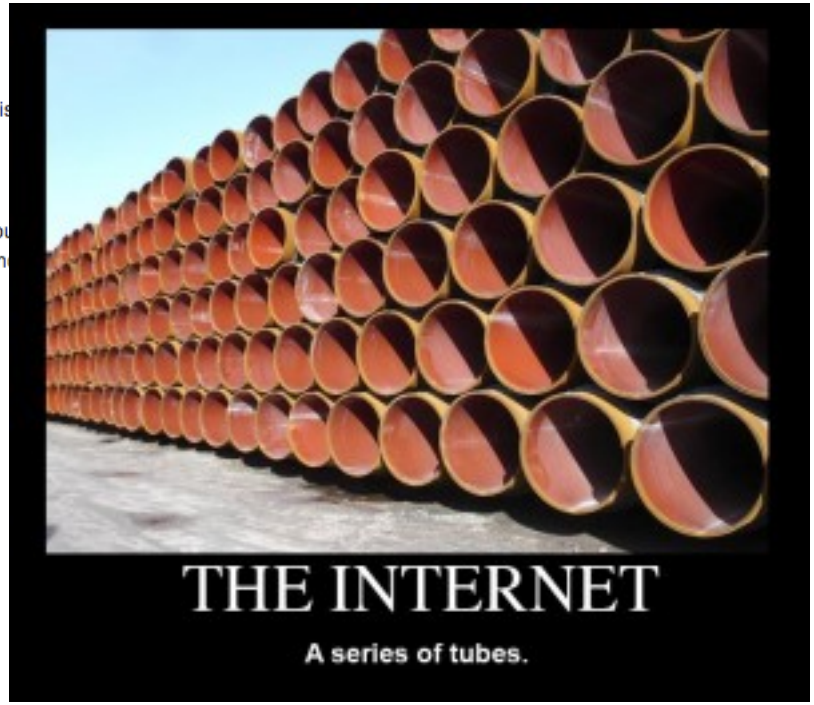
Executive Order -- Improving Critical Infrastructure Cybersecurity

EXECUTIVE ORDER

IMPROVING CRITICAL INFRASTRUCTURE CYBERSECURITY

By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

Section 1. Policy. Repeated cyber intrusions into critical infrastructure demonstrate the need for improved cybersecurity. The cyber threat to critical infrastructure continues to grow and represents one of the most serious national security challenges we must confront. The national and economic security of the United States depends on the reliable functioning of the Nation's critical infrastructure in the face of such threats. It is the policy of the

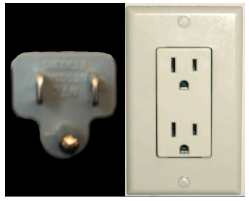


The Internet as core civil infrastructure

- Involved in all information exchange
  - (in a few years)
- Crucial to
  - commerce
  - governance
  - coordination
  - inter-personal communication
- Assumed to just be there
  - “plumbing”, “pipes”, …

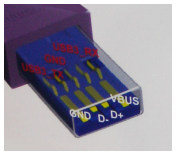
Interfaces: Energy

110/220V



1904

- Lots of other (niche) interfaces
- Replaced in a few applications



1901

Other long-lived interfaces

1878

Cigarette lighter
(1956)

1993

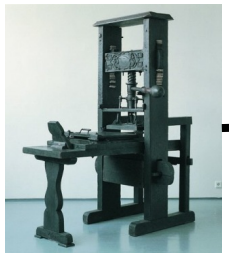
fuel nozzle

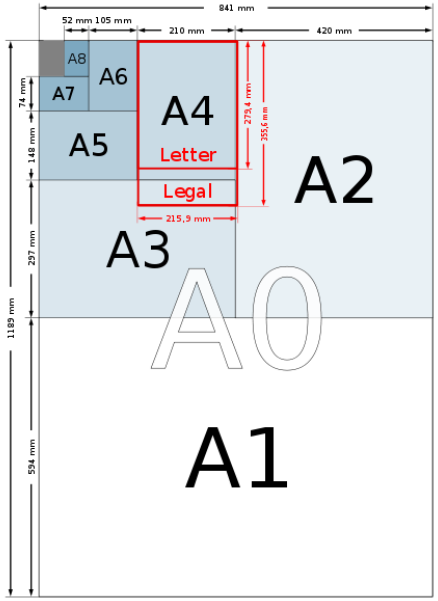
1992

SQL
1974

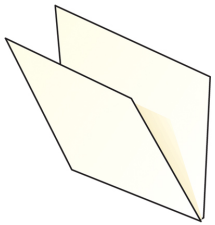
1982

Interfaces: Paper-based information





1798, 1922 (DIN)



Interfaces: Transportation

About 60% of world railroad mileage

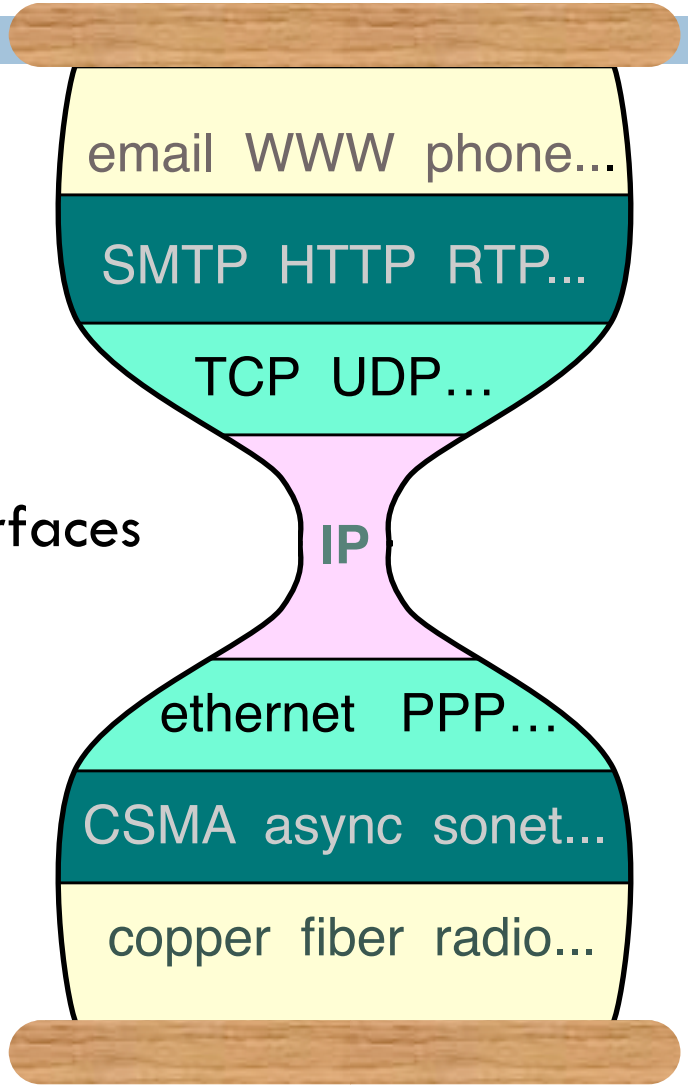
1435 mm

1830 (Stephenson)
1846 UK Gauge Act

12’

The Internet Protocol Hourglass

small number of long-term stable interfaces

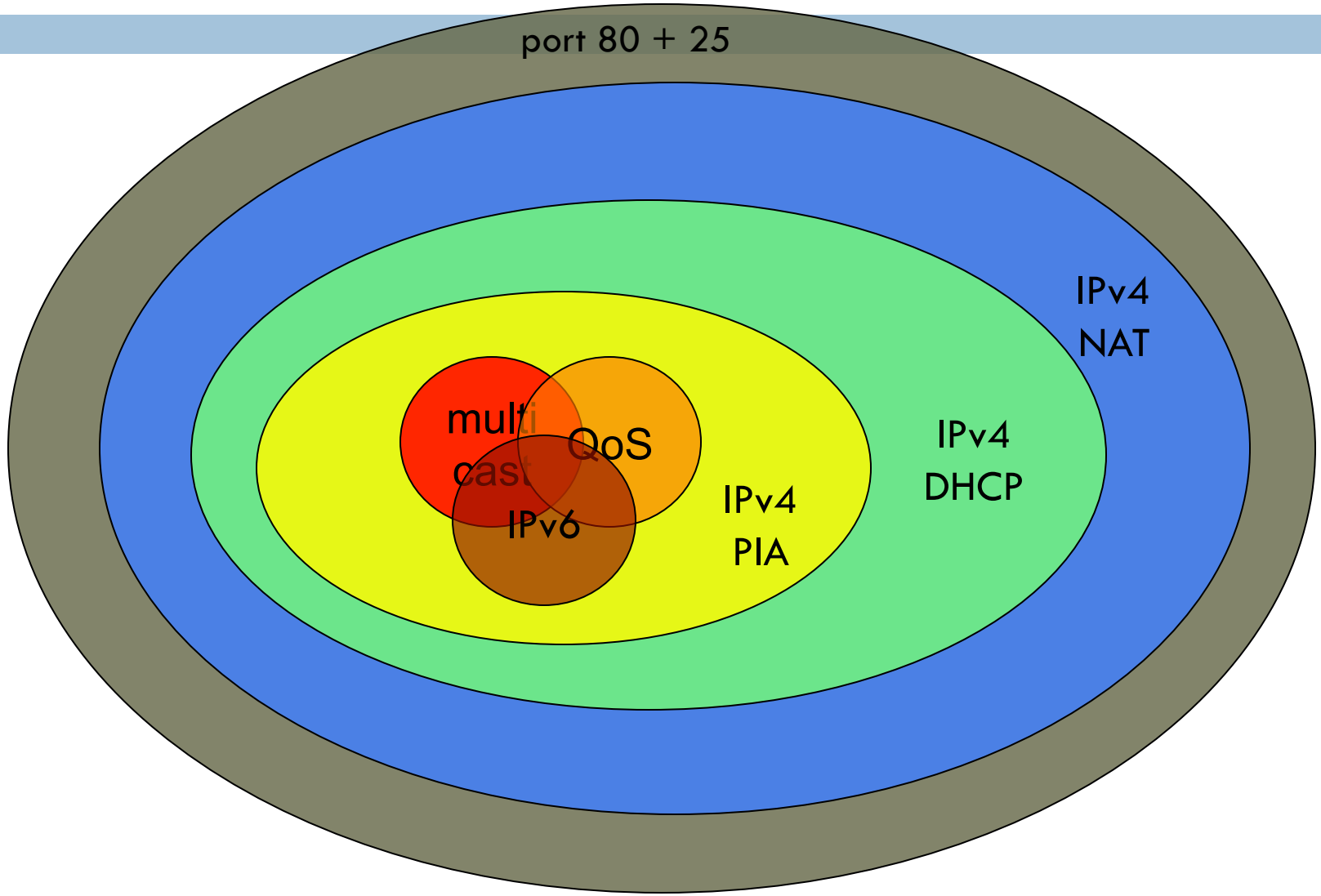


S. Deering

Networking is getting into middle years

	idea	current
IP	1969, 1980?	1981 (RFC 791)
TCP	1974 (RFC 675)	1981 (RFC 793)
telnet	1969 (RFC15)	1983 (RFC 854)
ftp	1971 (RFC 114)	1985 (RFC 959)
http	1996 (RFC 1945)	1999 (RFC 2616)

Which Internet are you connected to?



Theses: Internet lessons

- The Internet is about more than the Internet protocol
- Reliability multiplies, costs add
- Quality is no substitute for quantity
- Data links layers come & go, IP stays
- The age of application-specific {sensors, spectrum, OS, protocol …} is over
- Protocols matter, but programmability matters more

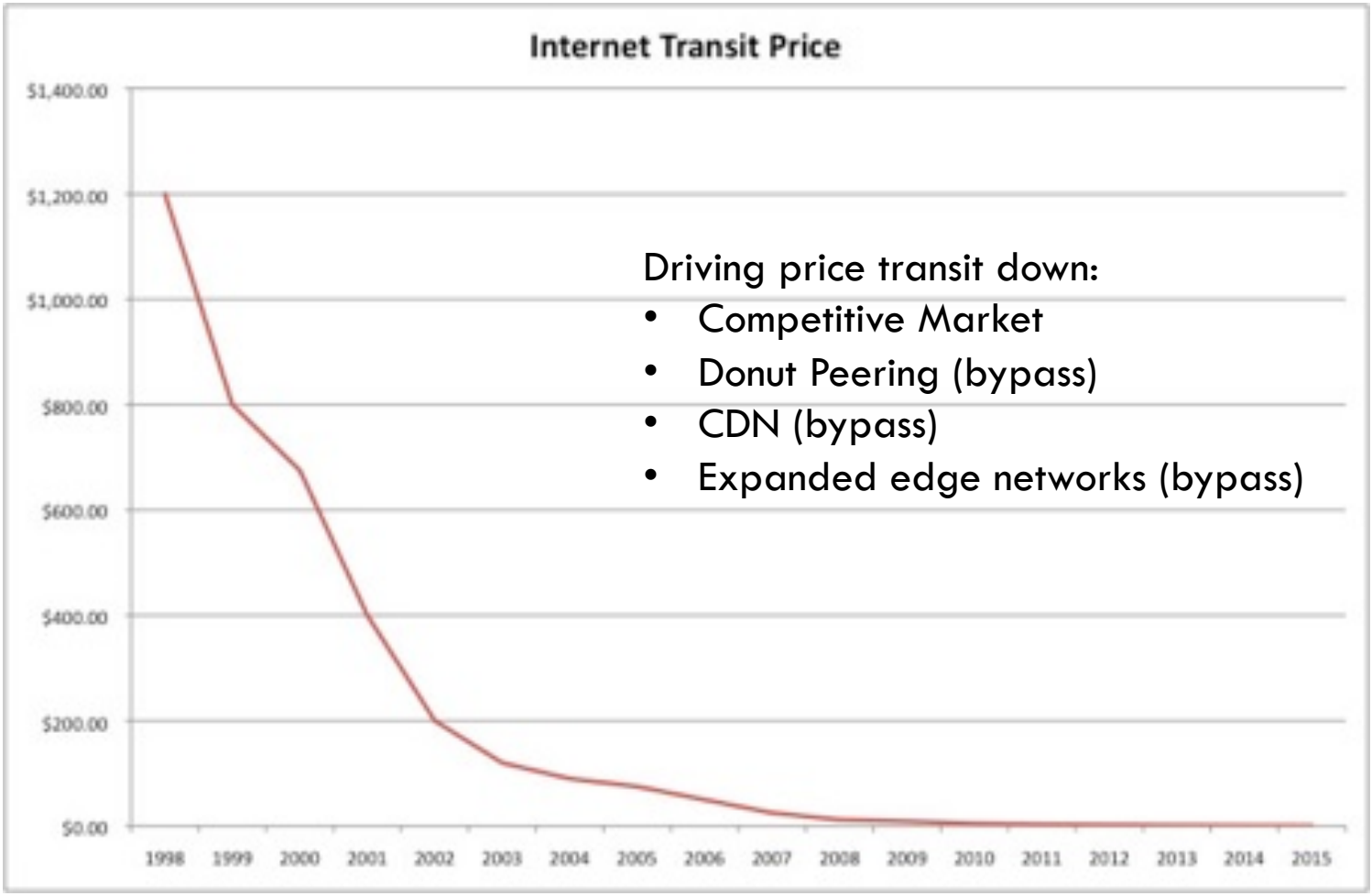
Some Internet economics

Bandwidth costs

- Amazon EC2
  - $0.05 - $0.15/GB out, $0/TB in
- CDN (Internet radio)
  - $0.60/GB (2007)
  - $0.007-0.02/GB (March 2014 – CDNpricing.com)
- NetFlix (7 GB DVD)
  - postage $0.70 round-trip → $0.10/GB
- FedEx – 2 lb disk NJ to CA
  - 5 business days: $10.20
  - Standard overnight: $68.33 → $0.02/GB
  - 4 TB SATA: $0.38/GB

Internet transit costs

$ per Mb/s per month



Driving price transit down:

- Competitive Market
- Donut Peering (bypass)
- CDN (bypass)
- Expanded edge networks (bypass)

Peering April 2014

Dr. Peering (Bill Norton)

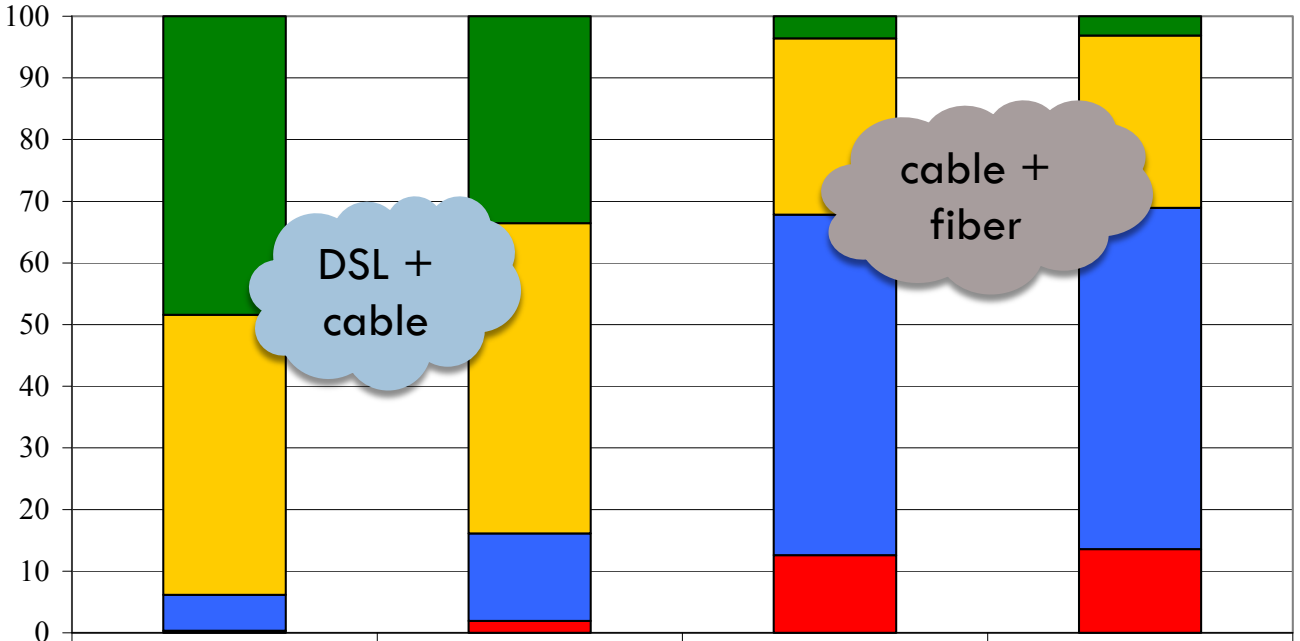
The value of bits

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

Application	Volume	Cost per unit	Cost / MB	Cost / TB
Voice (13 kb/s GSM)	97.5 kB/minute	10c	$1.02	$1M
Mobile data	5 GB	$40	$0.008	$8,000
MMS (pictures)	< 300 KB, avg. 50 kB	25c	$5.00	$5M
SMS	160 B	10c	$625	$625M

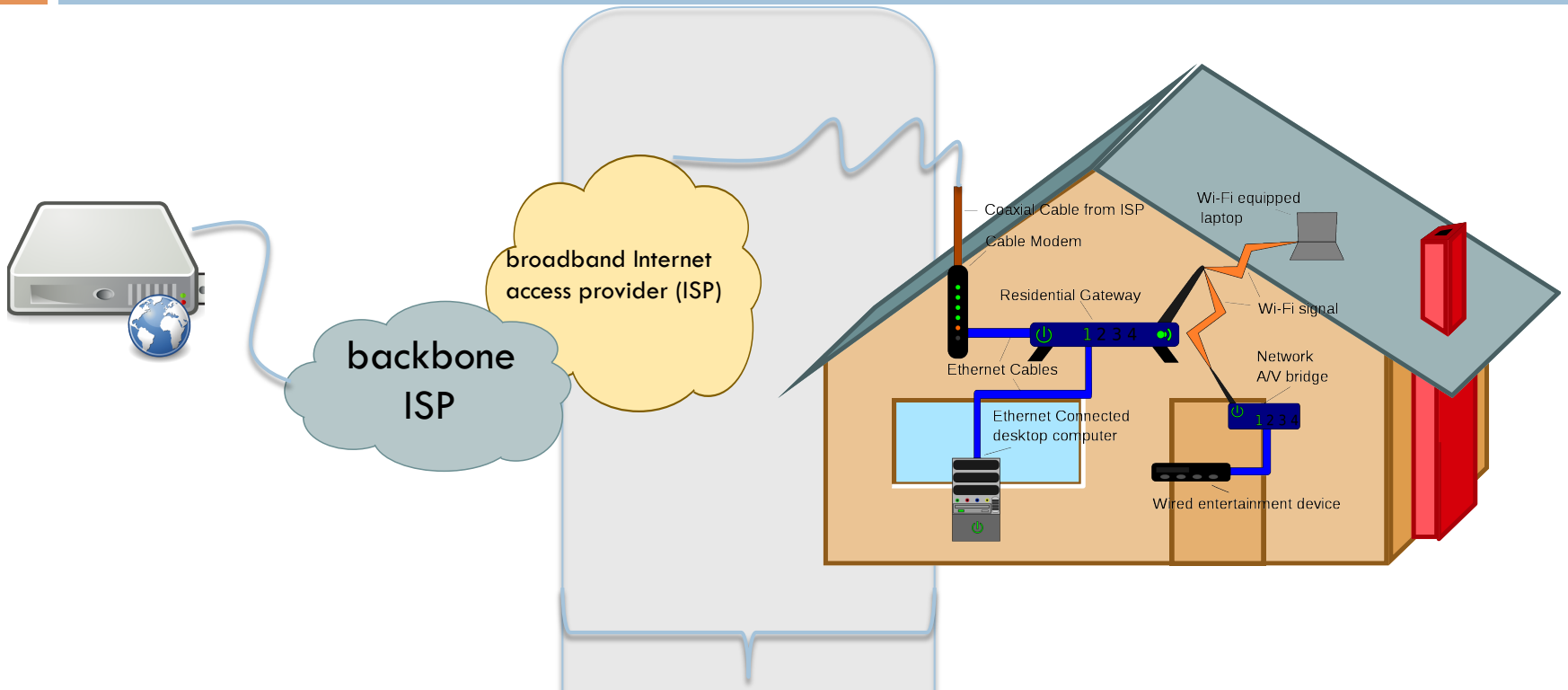
US broadband competition

Percentages of Households Located in Census Tracts Where Providers Report Residential Fixed-Location Connections of Various Speeds as of June 30, 2011



	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	48	34	4	3
2 Providers	45	50	29	28
1 Provider	6	14	55	55
0 Providers	0	2	13	14

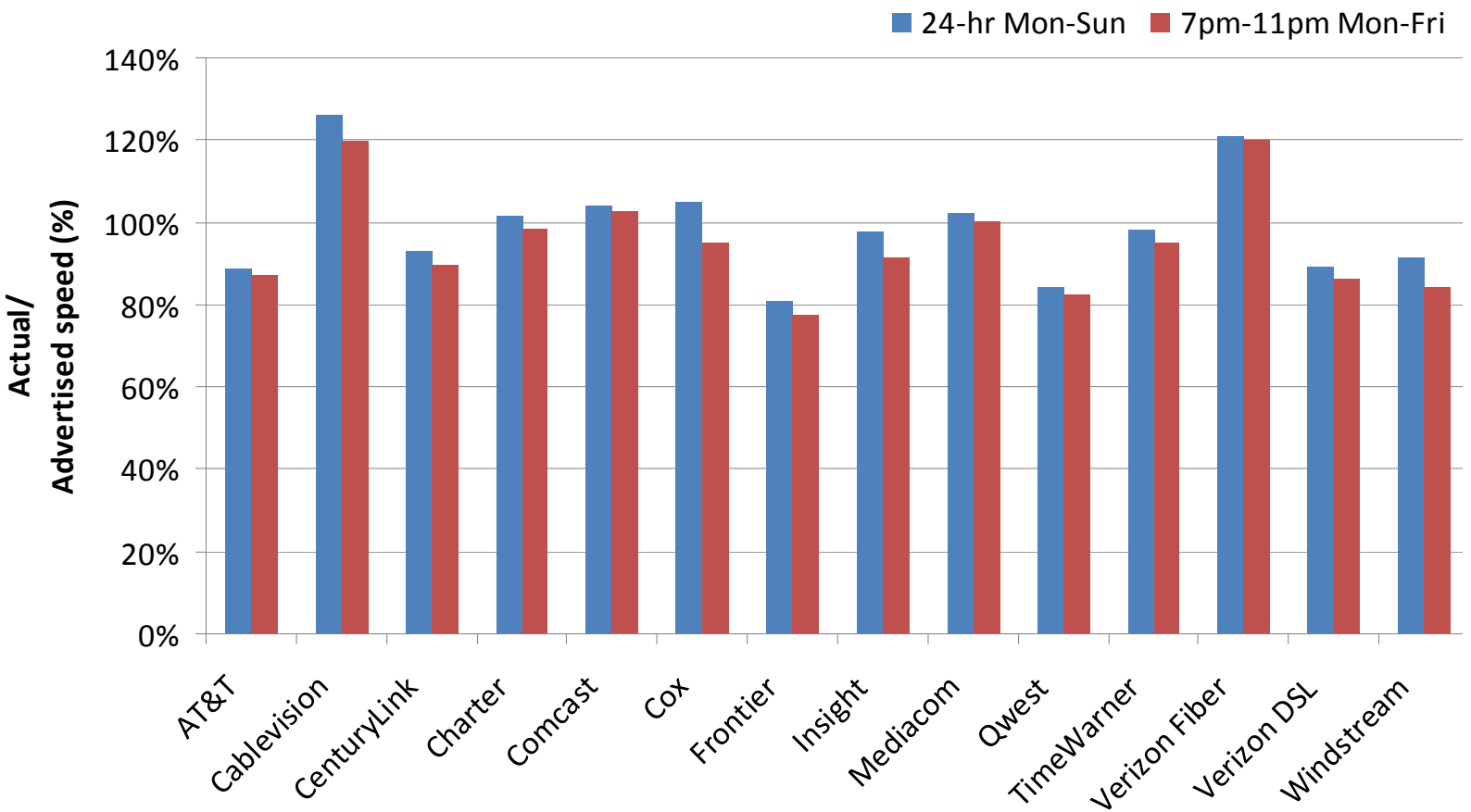
Measurement architecture



Measuring Broadband America 2011 & 2012

Measuring Broadband America future?

2012: You improve what you measure…



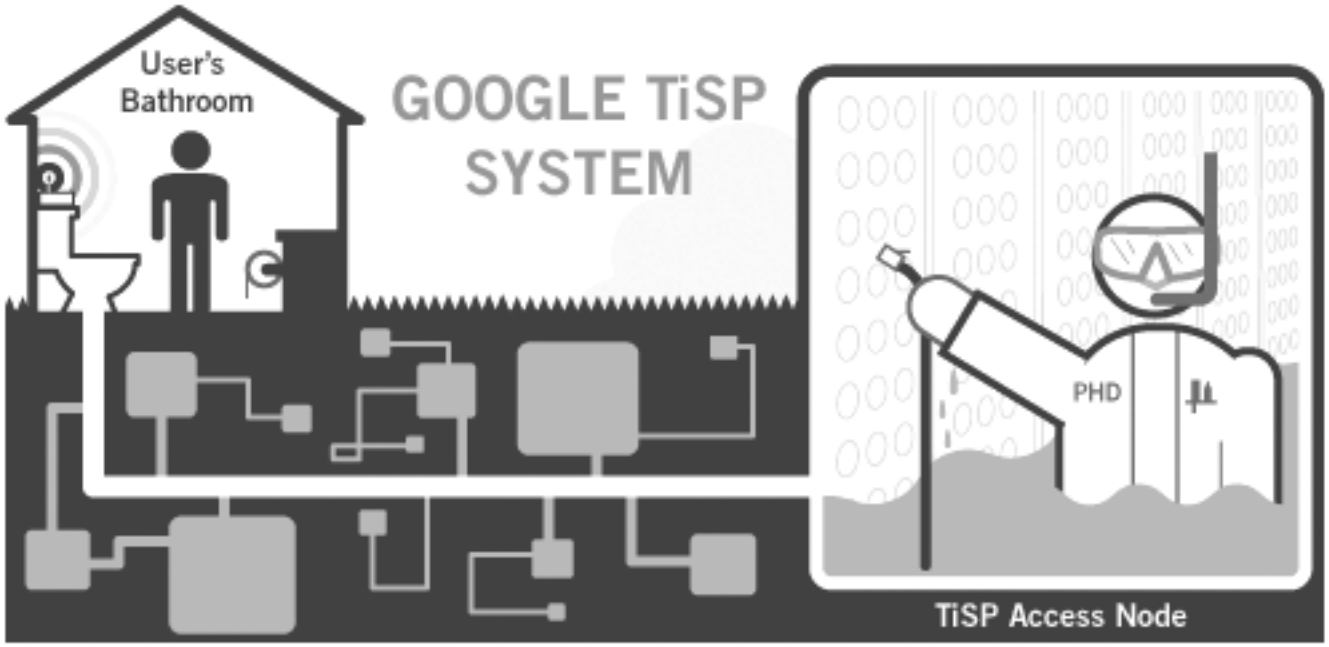
Broadband cost

30%

Maybe revisit?

TiSP: Going with the Flow

Google TiSP (BETA) is a fully functional, end-to-end system that provides in-home wireless access by connecting your commode-based TiSP wireless router to one of thousands of TiSP Access Nodes via fiber-optic cable strung through your local municipal sewage lines.



Google
April 1, 2007

Open Internet R&O 2010 + DC Circuit

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

remanded

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

remanded

No unreasonable discrimination. Fixed broadband providers may not unreasonably discriminate in transmitting lawful network traffic.

What could "fast lane" mean?

- Separate mechanism from who pays
  - e.g., customer buys "commercial-grade" service (SLA)
  - edge provider pays
- Separate logical IP-based "pipe" to end user
  - e.g., U-Verse "cable TV" video delivery
  - may be faster than broadband Internet service
- Resource reservation
  - guaranteed bandwidth (e.g., similar to MPLS CIR)
- Scheduling or drop priority
  - priority packets get priority access to shared resources
- Impact on best-effort services
  - well-provisioned vs. artificial starvation

Communication models – ca. 1980

TV (& radio) broadcast

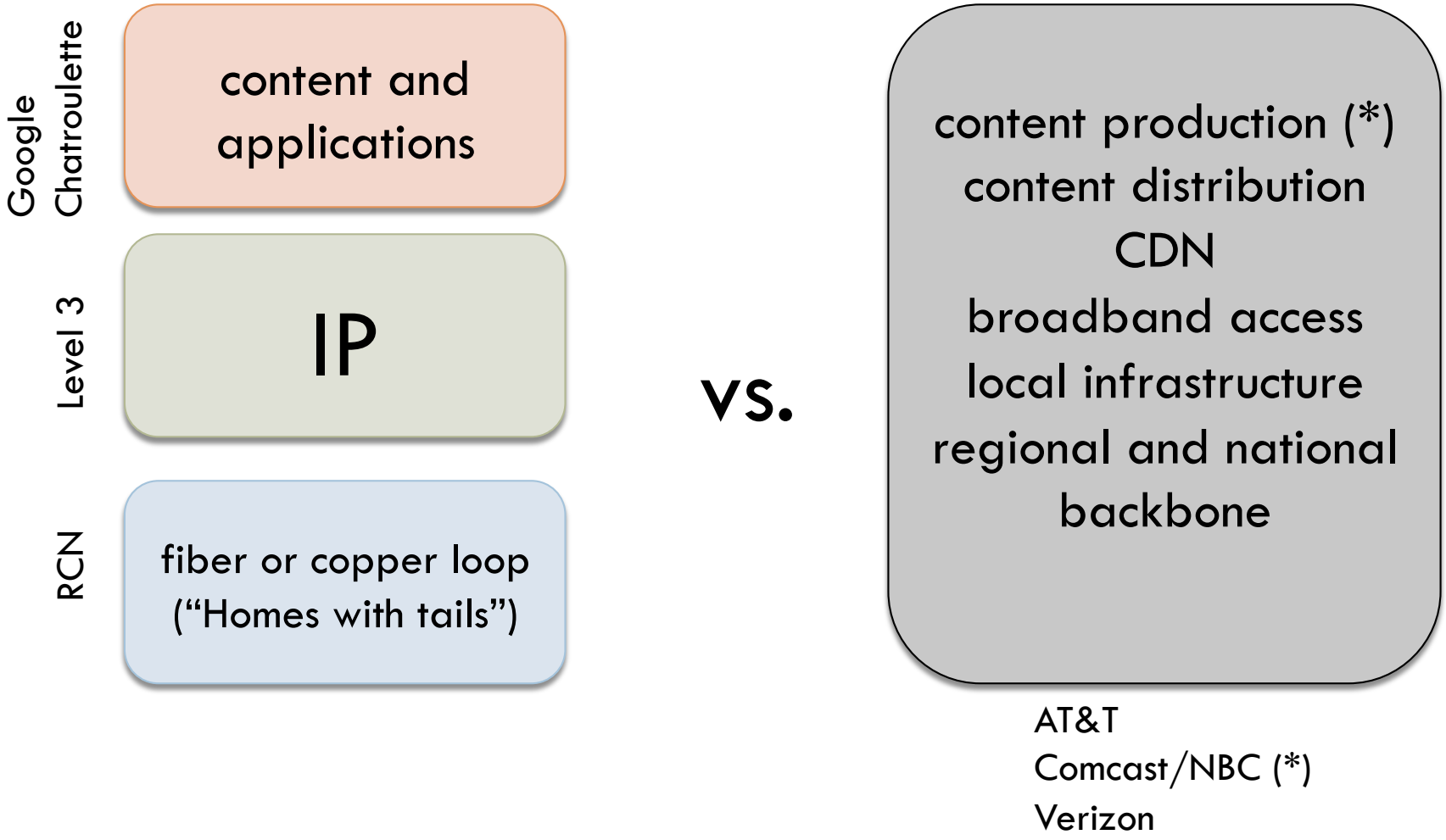
CATV

Telephone service (voice, modem data, fax)

largely distributors

one-to-one
largely conduit

Internet economic models - now



Internet economic challenges

- Specialization vs. vertical integration
- Economies of scale → small number of competitors
  - access networks (2)
  - search engines (2)
  - social networks (2)
- Differentiated services (& prices) → 1 Mb/s costs the same as 1 Gb/s
- Who is (and can be) incented to invest in services and infrastructure?
- Who gets to capture the value of bits?
  - content/service provider vs. consumer surplus vs. provider profit

Spectrum

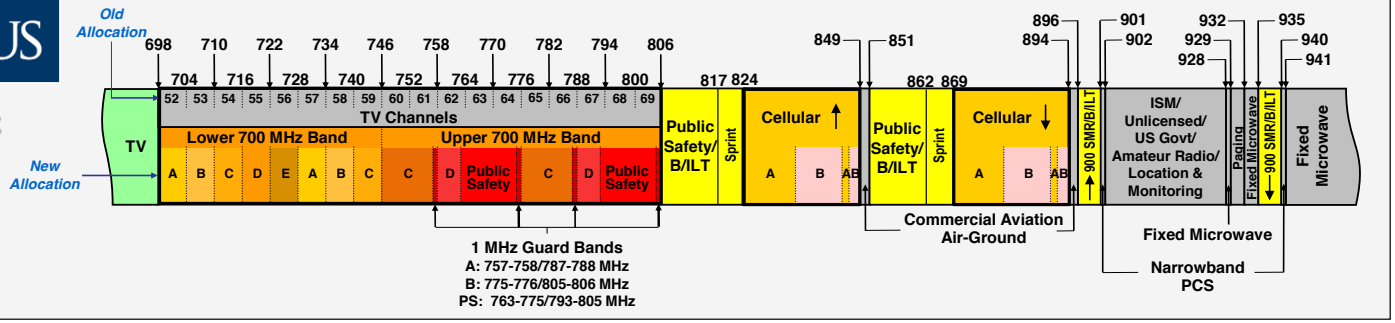
cellular = about 500 MHz in total

U.S. Spectrum Allocation of Key Bands

STIFEL NICOLAUS

July 14, 2011

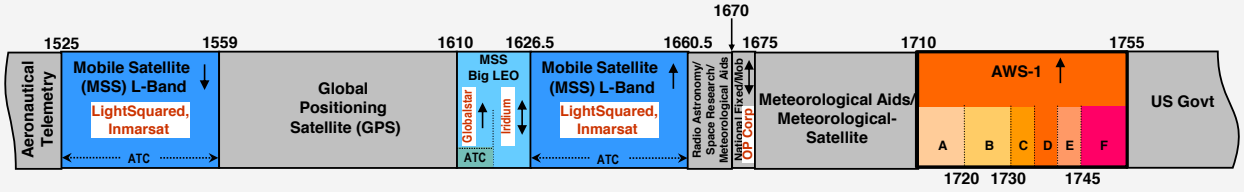
700 - 1000 MHz



IEEE Standard Band Designators

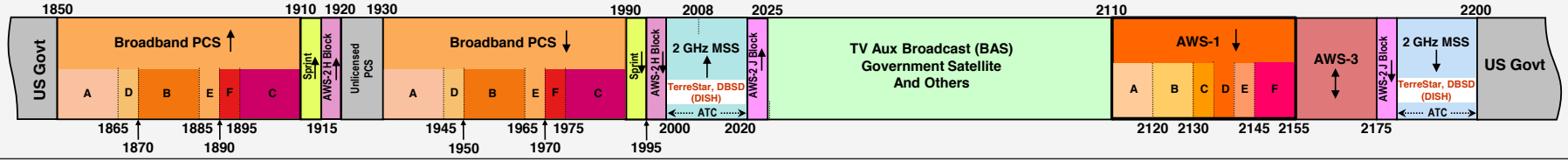
HF	3-30 MHz
VHF	30-300 MHz
UHF	300-1000 MHz
L band	1-2 GHz
S band	2-4 GHz
C band	4-8 GHz
X band	8-12 GHz
Ku band	12-18 GHz
K band	18-27 GHZ
Ka band	27-40 GHZ
V band	40-75 GHz
W band	75-110 GHz
mm wave	110-300 GHz

1500 - 1800 MHz

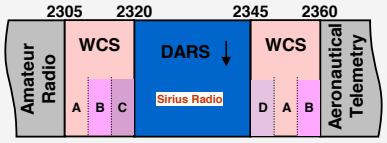


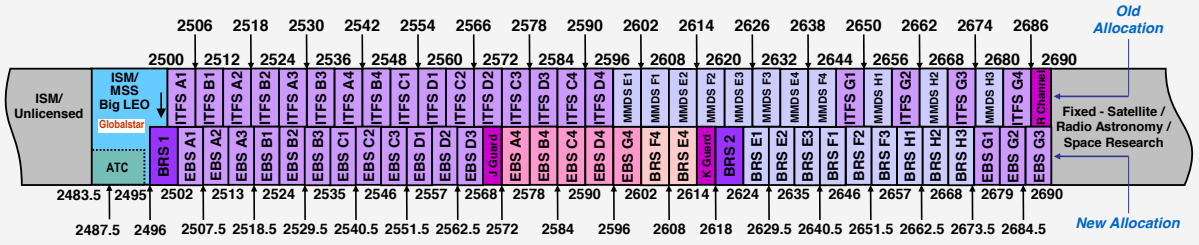
Legend
- *Uplink Band*
- *Downlink Band*
- *TDD Band*

1800 - 2200 MHz



2300 - 2700 MHz





Source: FCC, Sprint and Stifel Nicolaus Research

From beachfront spectrum to brownfield spectrum

no interference!
guard bands!

From empty back yard to time share condo

high tower, high power

Spectral efficiency

- b/s/Hz: modulation, FEC, MIMO, …
- but also *total spectral efficiency*
  - guard bands
  - restrictions on adjacent channel usage
  - "high power, high tower" → small cells → higher b/s/Hz
- *data efficiency*
  - e.g., H.264 is twice as good as MPEG-2/ATSC
  - and maybe H.265 twice as good as H.264
- *distribution efficiency*
  - unicast vs. multicast
- *protocol efficiency*
  - avoid polling → need server mode
- *mode efficiency*
  - caching
  - side loading
  - pre-loading

What can we do?

end system caching
better audio & video codecs
efficient apps

IP multicast
WiFi offload

spectral efficiency (LTE-A)
directional antennas
general purpose spectrum
dense cells
white spaces & sharing

small cells = better spectral efficiency + more re-use

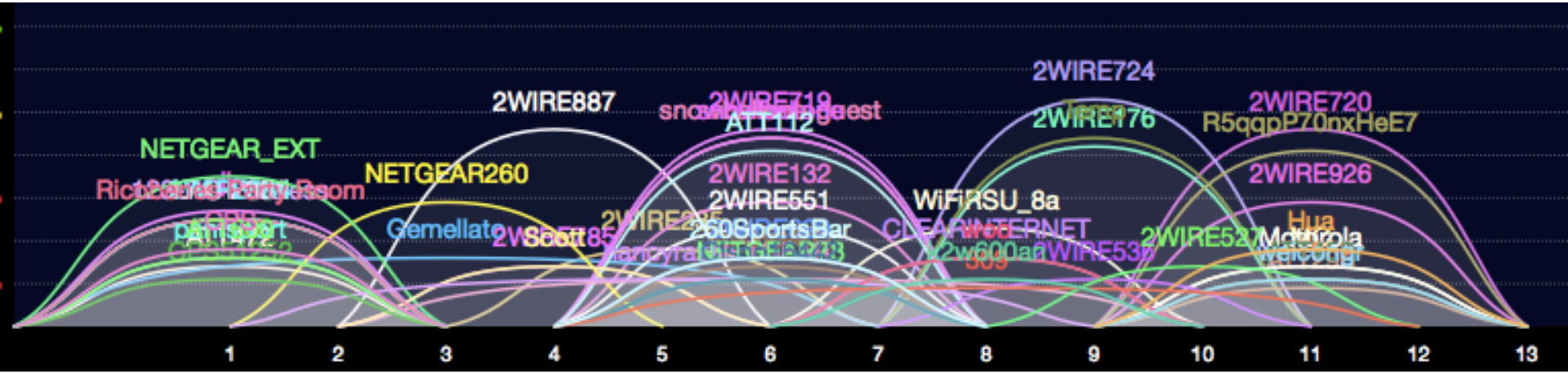
LTE: 1.5 b/s/Hz
GSM: 0.1 b/s/Hz

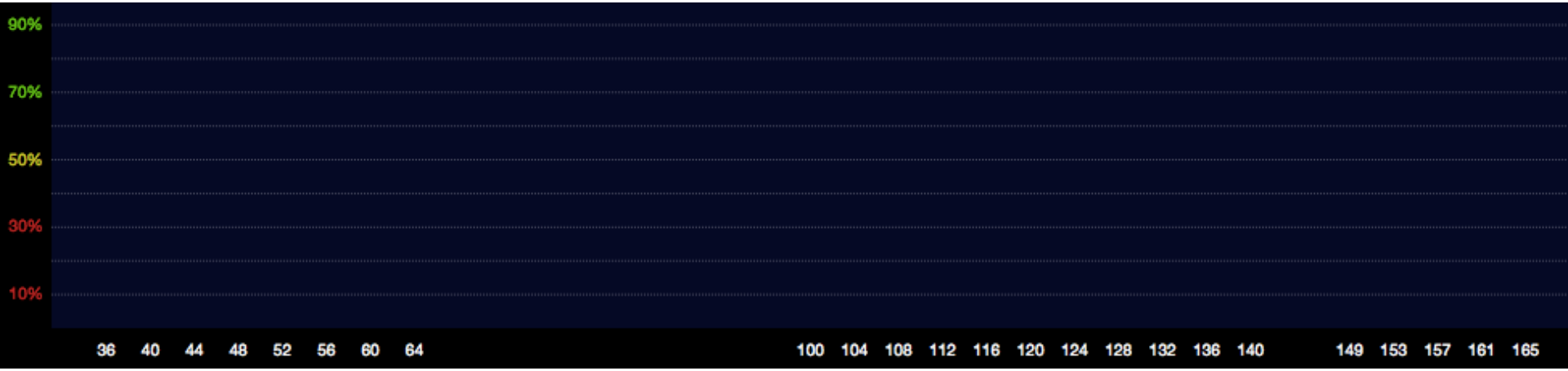
Unlicensed & lightly-licensed bands (US)

- UHF (476-700 MHz) – incentive auctions (licensed) + some unlicensed
- 2.4 GHz (73 MHz) – 802.11b/g
- 3.6 GHz (100 MHz) – for backhaul & WISPs
- 4.9 GHz (50 MHz) – public safety
- 5.8 GHz (400 MHz) – 802.11 a/n
  - much less crowded than 2.4 GHz
  - supported by many laptops, few smartphones

2.4 vs. 5.8 GHz

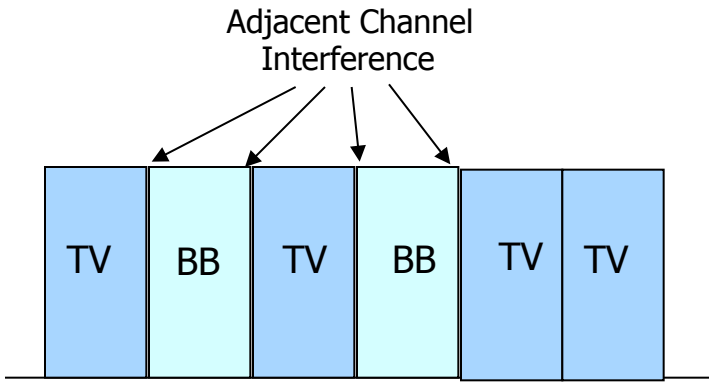
WiFi Explorer



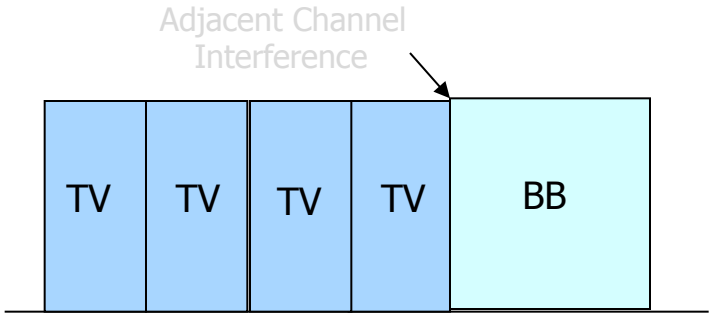


Freeing spectrum: incentive auctions

- Incentive auctions will share auction proceeds with the current occupant to motivate voluntary relocation of incumbents
  - Otherwise, no incentive for current occupant to give back spectrum
  - Stations keep current channel numbers
    - via DTV map



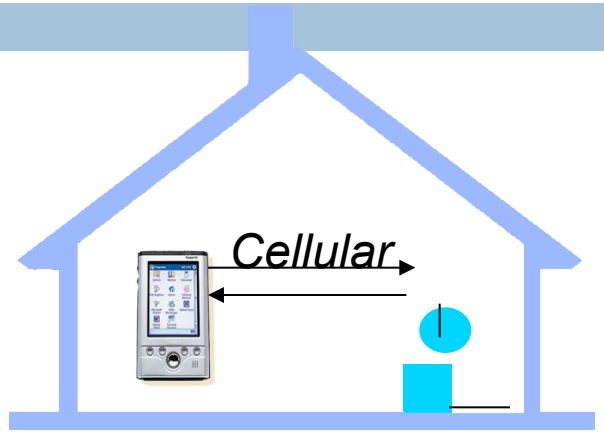
Without Realignment:
Reduced Broadband Bandwidth



With Realignment: Accommodates Increased Broadband Bandwidth

Small cell alternatives

- Femto cells
  - use existing spectrum
  - need additional equipment
- WiFi off-load
  - use existing residential equipment
  - 5G networks = heterogeneous networks?
- Distributed antenna systems



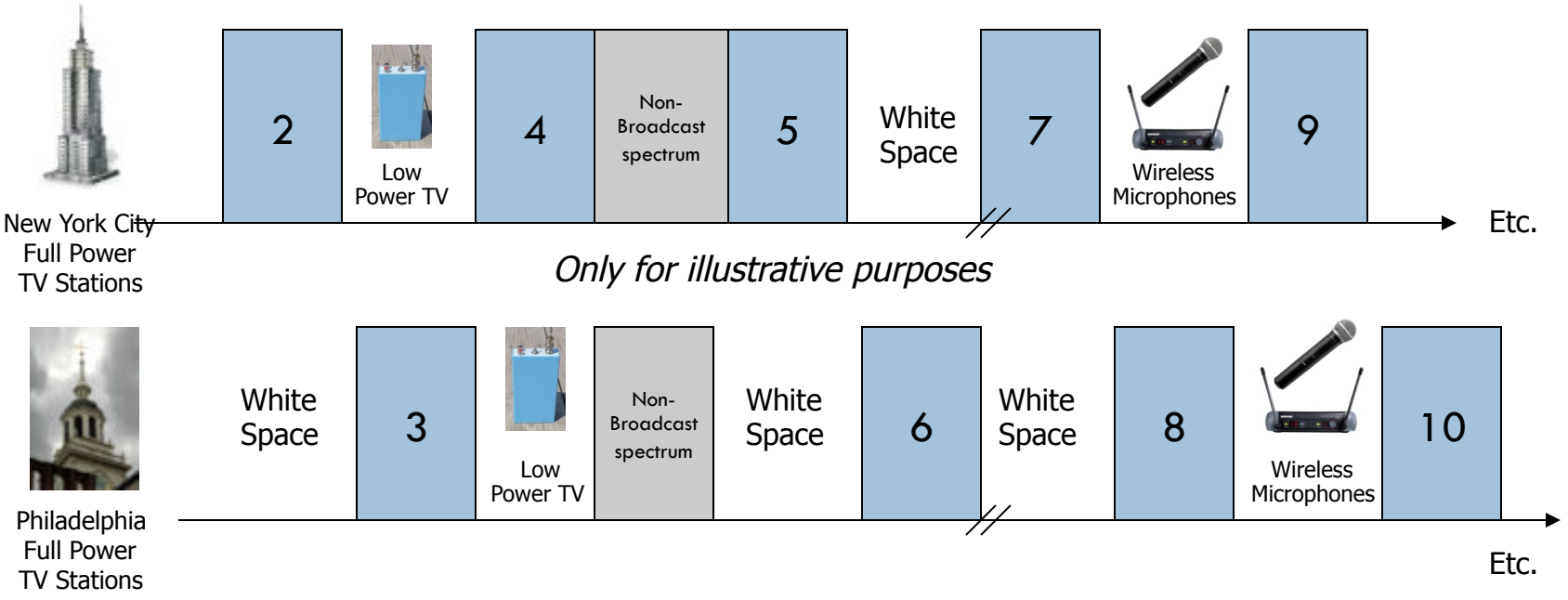
Femto-cells

Distributed Antenna Systems

Signals are distributed throughout the Building via amplifiers/antennas

TV white spaces

- TV channels are “allotted” to cities to serve the local area
- Other licensed and unlicensed services are also in TV bands
- “White Spaces” are the channels that are “unused” at any given location by licensed devices



Spectrum Outlook

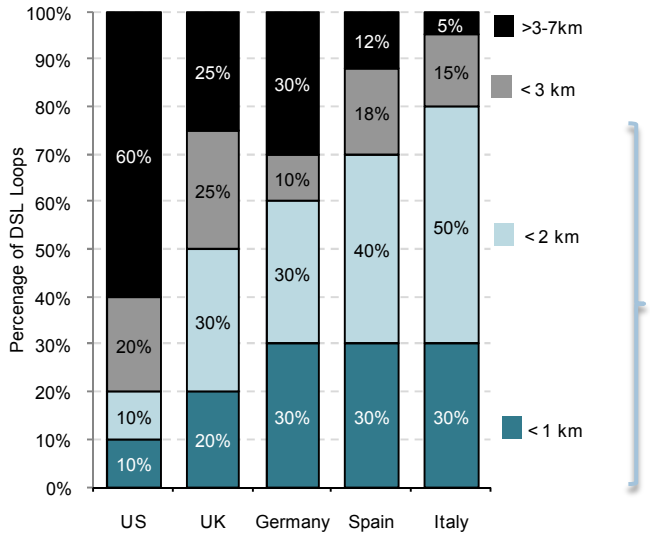
- No single solution:
  - reduce spectrum usage
    - caching & better modulation
  - re-use spectrum
  - re-cycle old spectrum

The phone system is going IP

The three transitions

From		to	motivation	issues
Copper	→	fiber	capacity maintenance cost	competition ("UNE")
Wired	→	wireless	mobility cost in rural areas	capacity quality
Circuits	→	packets (IP)	flexibility cost per bit	line power

Copper loops



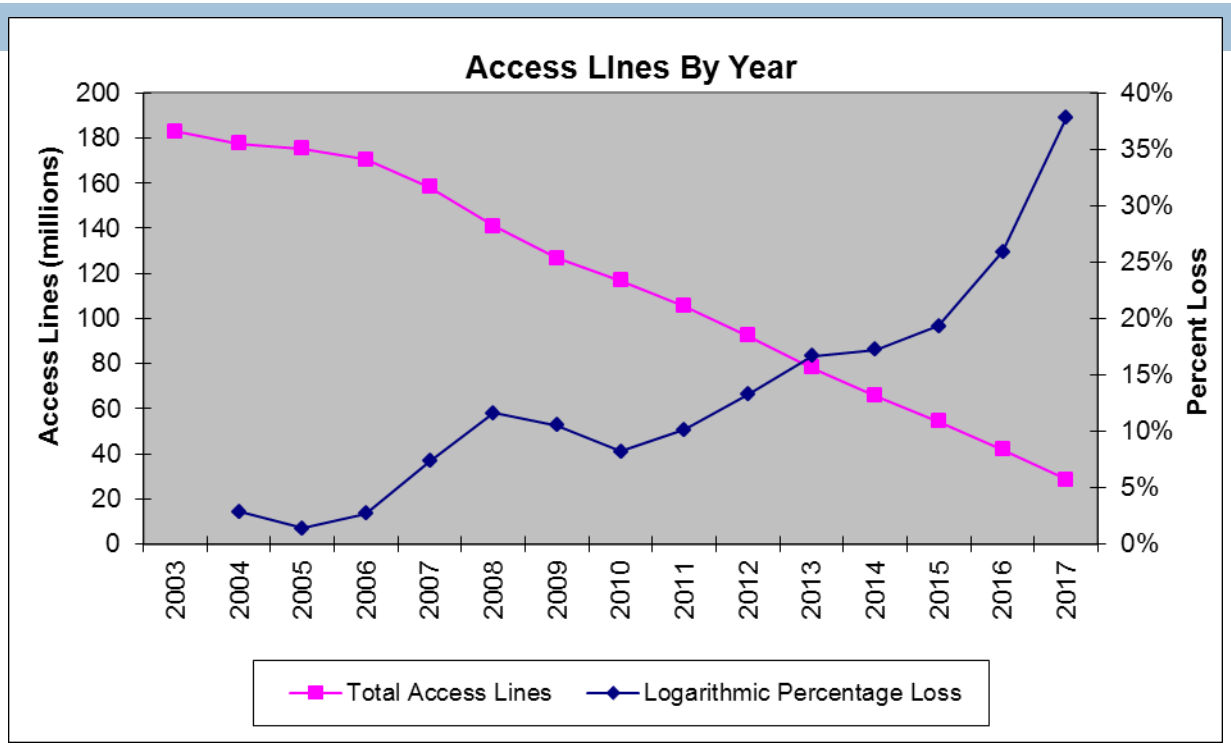
Source: ECTA, Ofcom, Company Reports, Bernstein Estimates

DSL loop lengths

high-speed DSL

Copper loops → large-scale data competition ("unbundled network elements")

Lines are disappearing, but maintenance costs are constant



per-line monthly maintenance cost

$2.72

$14.89

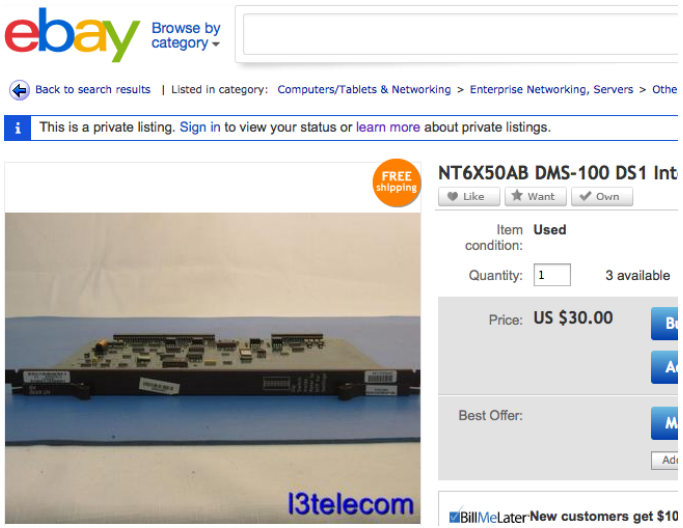
voice revenue/line: $50

NRRI Report 12-12, Oct. 2012

Switches are ageing

Nortel DMS-100

1979

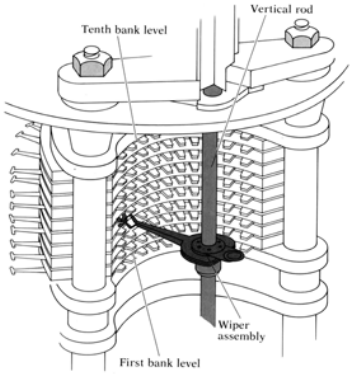


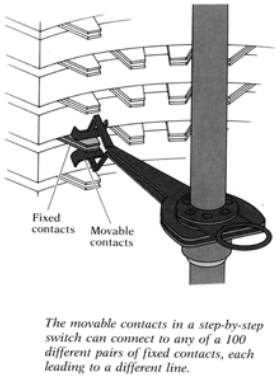
http://www.phworld.org/switch/ntess.htm

Not the first PSTN technology transition

communication = data ("transmission") + control ("signaling")

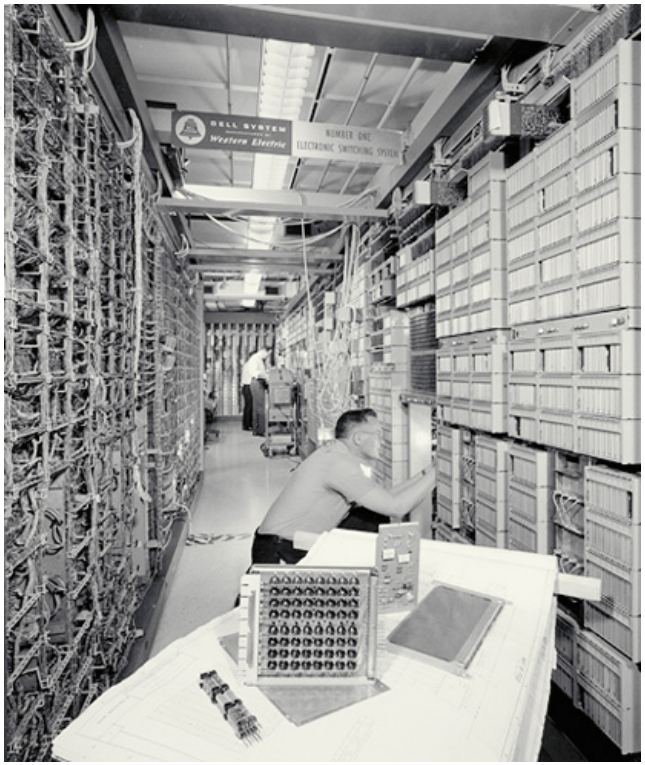
1894





The movable contacts in a step-by-step switch can connect to any of a 100 different pairs of fixed contacts, each leading to a different line.

invented 1888
deployed 1900s



1965

What are key attributes?

- Universality
  - *reachability* → global numbering & interconnection
  - *media* → HD audio, video, text
  - *availability* → universal service regardless of
    - geography
    - income
    - disability
  - *affordability* → service competition + affordable standalone broadband
- Public safety
  - citizen-to-authority: emergency services (911)
  - authority-to-citizen: alerting
  - law enforcement
  - survivable (facilities redundancy, power outages)
- Quality
  - media (voice + …) quality
  - assured identity: telephone numbers
  - assured privacy (CPNI)
  - accountable reliability

Public Safety (NG911 & NG112)

- Transition to NG911 & NG112 underway
  - NGxxx = all-IP (SIP + RTP) emergency calling
- Key issues:
  - Indoor location for wireless
    - location accuracy of 50/150m may not be sufficient
    - need apartment-level accuracy, including floor
    - Civic (Apt. 9C, 5 W Glebe), not geo
  - Cost, scaling and transition

Reliability

- How do we measure reliability & QoS?
  - E.g., FCC *Measuring Broadband America* project?
- Can we improve power robustness?
  - Circuit-switched: -48V @ 20-50 mA (~ 1 W)
  - e.g., DOCSIS modem consumes ~7W (idle)
  - Li-Ion battery = 2.5 Wh/$ ➔ 3$/hour of standby time
- Can we simplify multihoming to make new PSTN more reliable than old?
  - e.g., cable + 4G

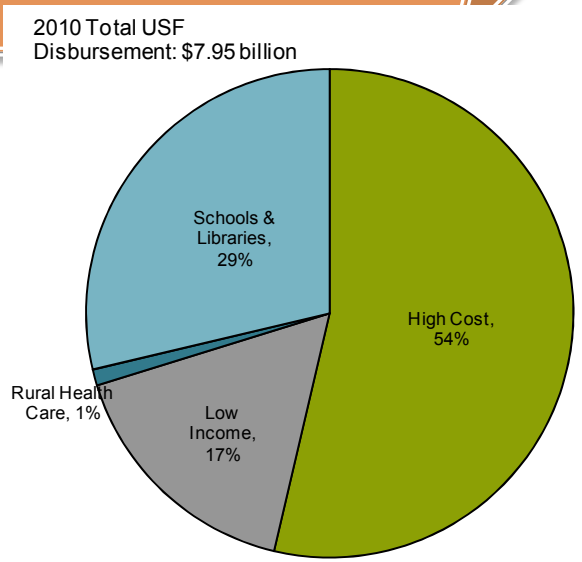
Universal service

One Policy, One System, Universal Service

T. Vail (1907)

For the purpose of regulating interstate and foreign commerce in communication by wire and radio so as to make available, so far as possible, to all the people of the United States, without discrimination on the basis of race, color, religion, national origin, or sex, a rapid, efficient, Nation-wide, and world-wide wire and radio communication service with adequate facilities at reasonable charges, for the purpose of the national defense, for the purpose of promoting safety of life and property through the use of wire and radio communications, … (47 USC § 151, 1934)

- Eligible Telecommunications Carriers
- Carrier of Last Resort (COLR)
- *Universal Service Fund*

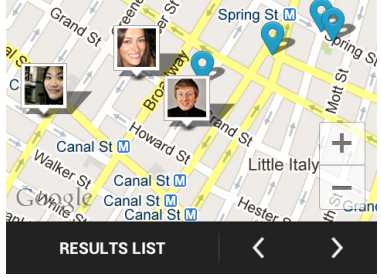


Source: Universal Service Administrative Company

Policy + technology

Policy → technology

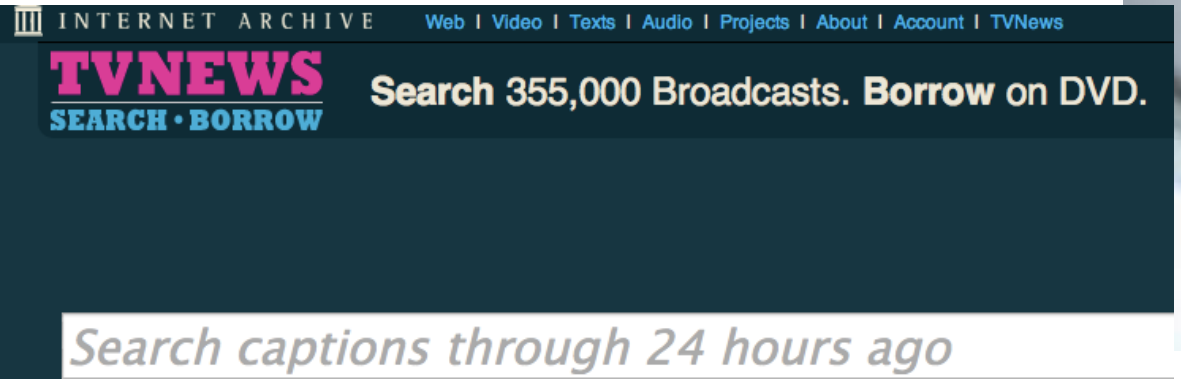
- Part 15 ("unlicensed")
  - since 1938
  - major revision 1989
    - higher frequencies
    - unintentional, incidental, intentional
    - authorized devices
  - → WiFi
- GPS in cell phones
  - E911 rules
  - → location-based services



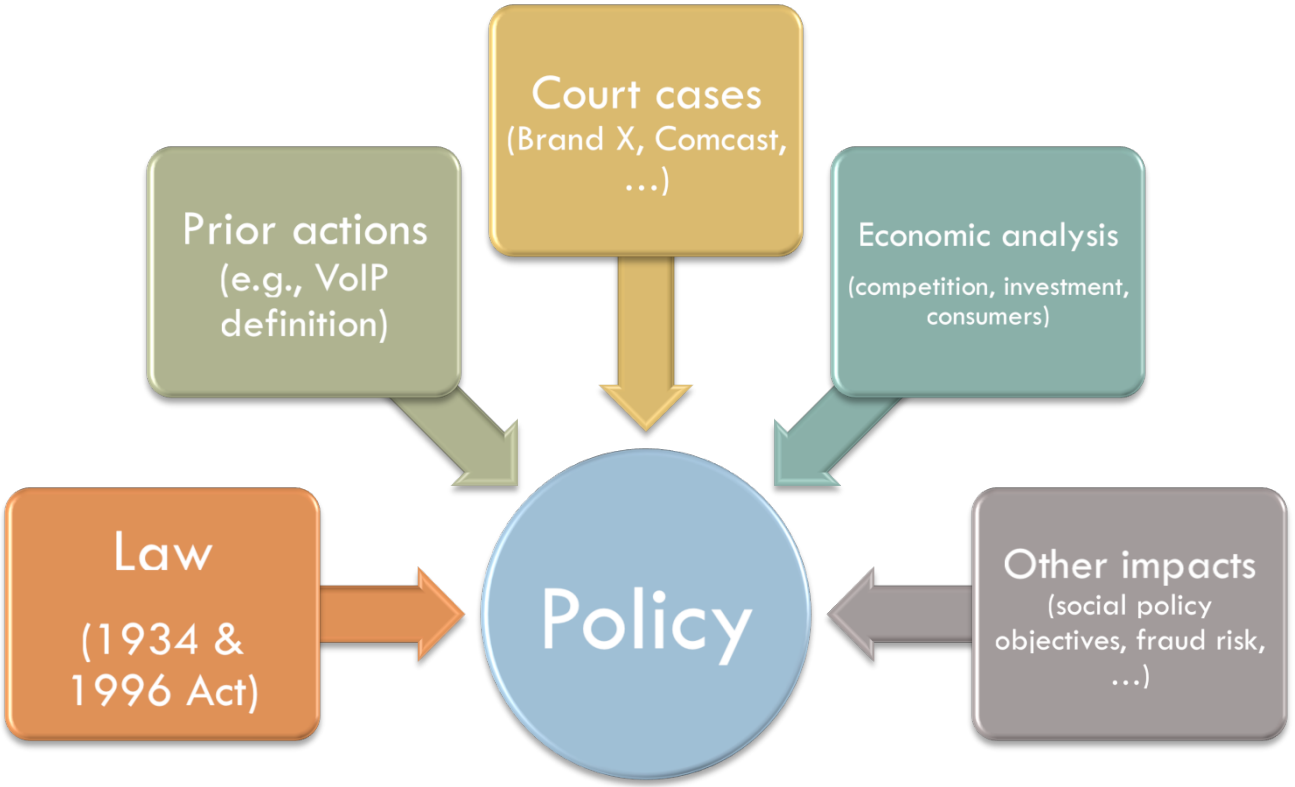
Policy → technology

- Closed captioning
  - initially, for Deaf and Hard of Hearing
  - migrated to
    - airports
    - doctor's offices
    - sports bars
  - enables text-based retrieval

CNN AIRPORT NETWORK



Policy inputs



Telecom policy tool kit

gov't monopoly

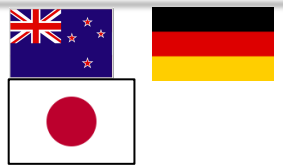
price-regulated utility

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

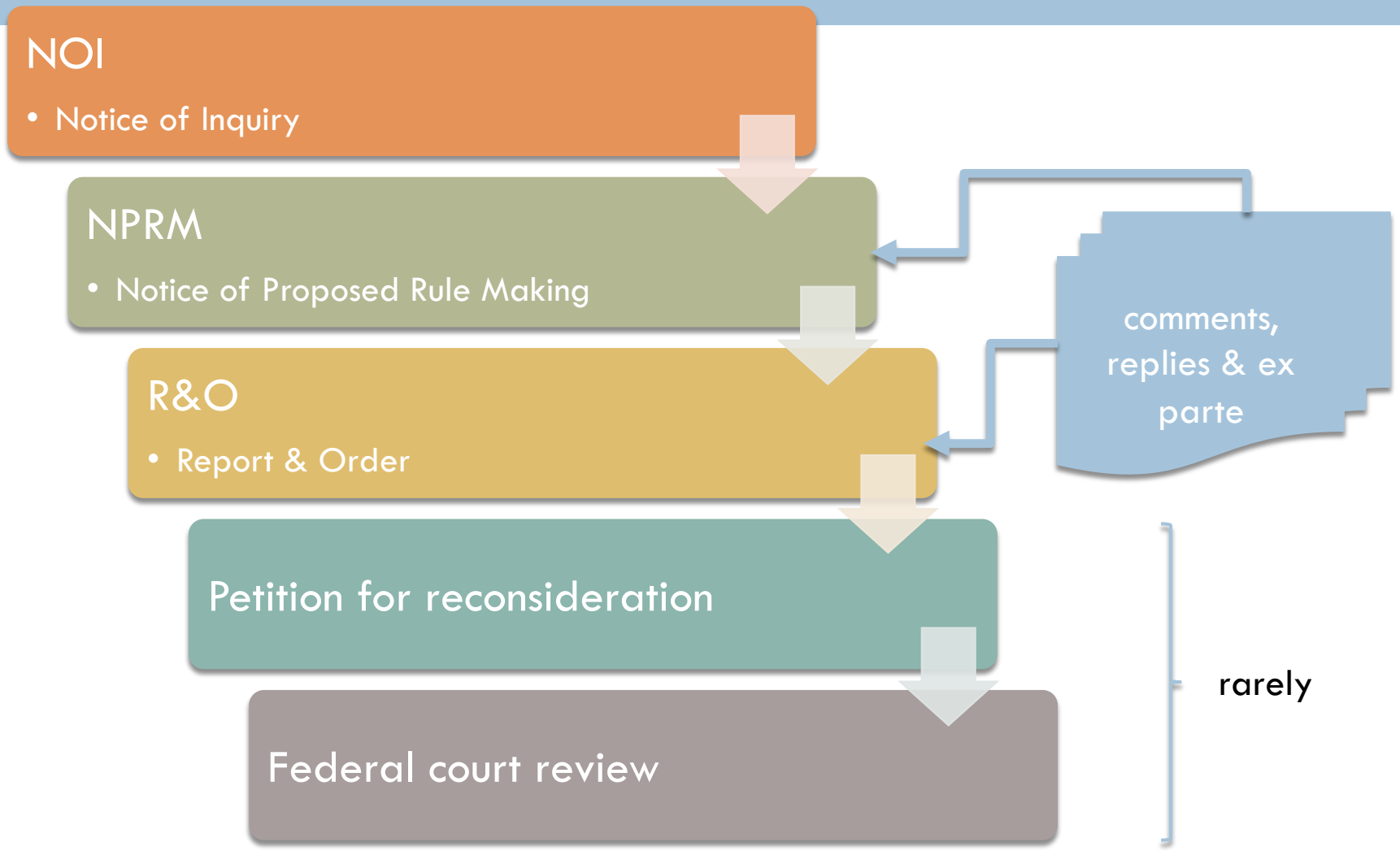
Example: CFR 47

§ 15.5 General conditions of operation.

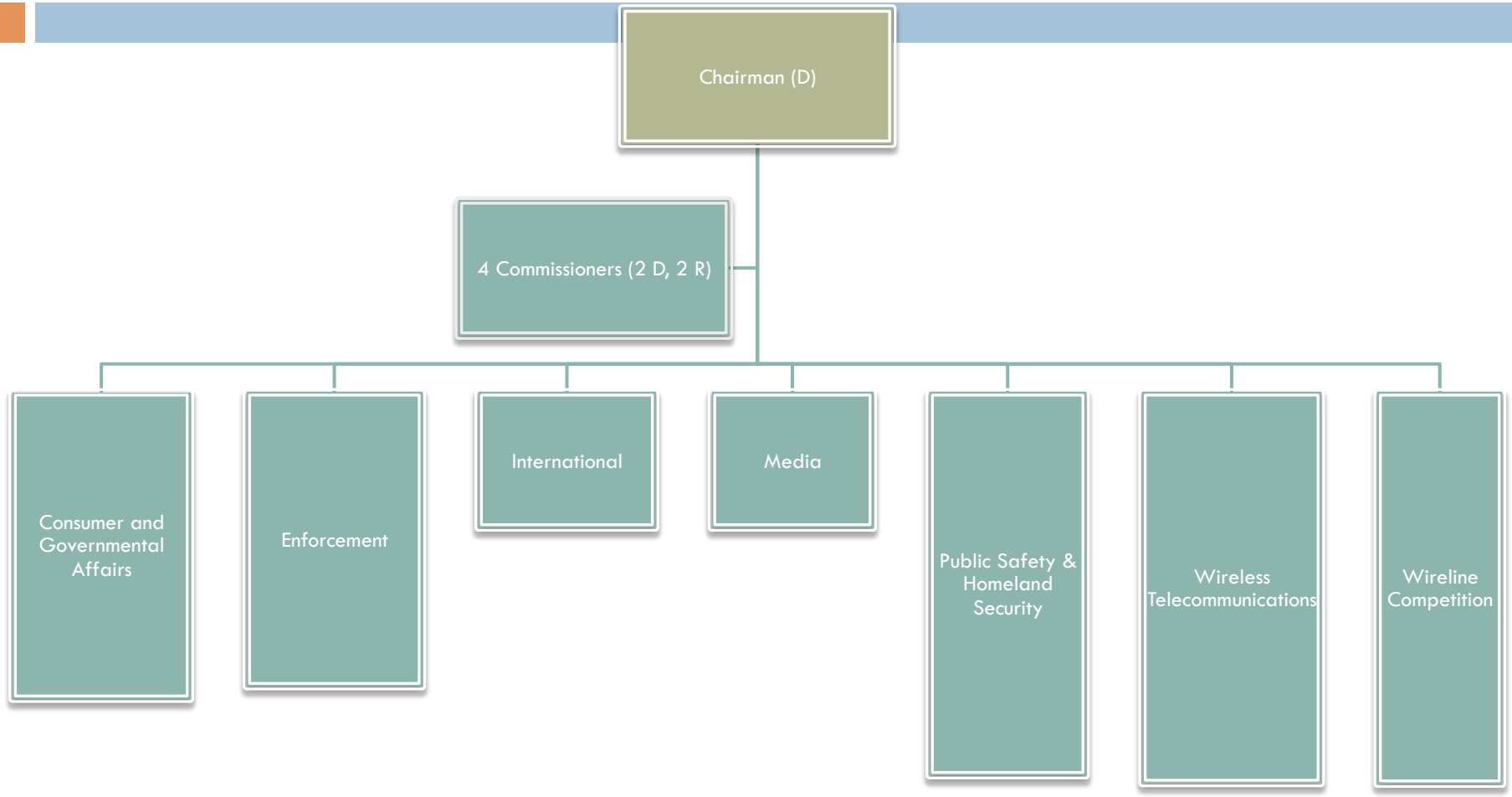
(a) Persons operating intentional or unintentional radiators shall not be deemed to have any vested or recognizable right to continued use of any given frequency by virtue of prior registration or certification of equipment, or, for power line carrier systems, on the basis of prior notification of use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

Process


NOI
• Notice of Inquiry
NPRM
• Notice of Proposed Rule Making
R&O
• Report & Order
Petition for reconsideration
Federal court review
comments, replies & ex parte
rarely

FCC



- Independent federal agency
- About 1,600 employees

Policy → technology

- Future opportunities:
  - indoor location
  - Video relay service = first multimedia phone-number-based interoperable real-time communication solution
  - dynamic spectrum access ("TV white spaces", 3.5 GHz band)

Conclusion

My 2023 predictions

- Still largely the same transmission technology
  - fiber, OFDM
- Still largely the same protocols
- Similar applications
  - but scaled up & integrated
- Lots of boring new applications
  - electric meter reading! finding parking spots!
- Fewer cords (last mile & last foot)
- Increasing complexity → serious security challenges

Conclusion

- Networks are too important to be left to (just) engineers
  - but there are technology niches…
- Key Internet problems are combinations of
  - *economic*: who pays and gets paid?
  - legal: who gets to do what?
  - *legacy*: who doesn't want to go away?
  - *political*: who can make others do things they don't like?