INTERNET 2035 – NECESSARY UTILITY OR FUNDAMENTALLY NEW TECHNOLOGY?

Henning Schulzrinne

Questions

- What fundamental transmission technologies are likely?
- What about next-gen Internet architecture?
- Will there still be AM/FM radio and fax machines?
- What is the likely industry structure?
- What will become key public policy issues?
- Could things get worse?

> We always overestimate the change that will occur in the next two years and underestimate the change that will occur in the next ten. (Bill Gates)

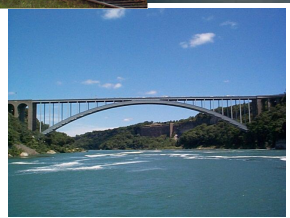
The great infrastructure

- 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

Infrastructure

- “Infrastructure = you wouldn’t buy a home without it”
- Some infrastructure can be locally replaced
  - water → well, sewer → septic tank, electricity → solar panels
- Others, less so:
  - transportation
  - communication

The Internet as core civil infrastructure

For Immediate Release February 12, 2013

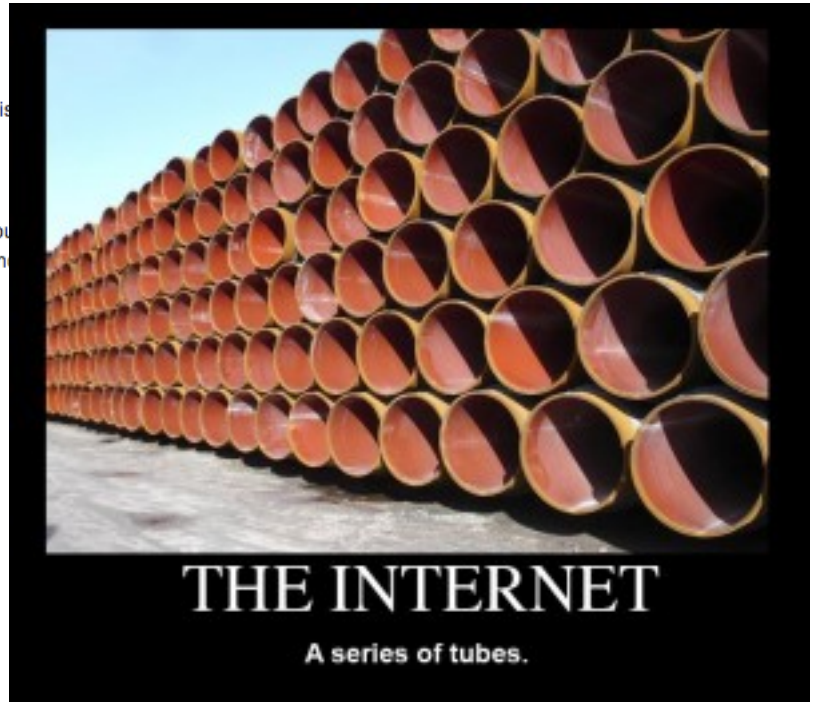
Executive Order -- Improving Critical Infrastructure Cybersecurity

EXECUTIVE ORDER

IMPROVING CRITICAL INFRASTRUCTURE CYBERSECURITY

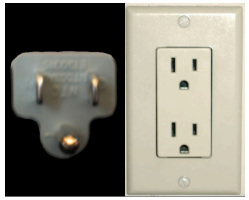
By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

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



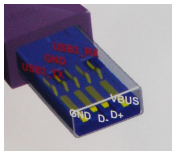
Interfaces: Energy

110/220V



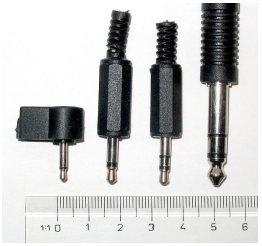
1904

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



1901

Other long-lived interfaces



1878

Cigarette lighter (1956)

1993

fuel nozzle

1974

1992

1982

Communication research

Spatio-temporal coding for wireless communication

2 Author(s)

Raleigh, G.C. ; Clarity Wireless Inc., Belmont, CA, USA ; Cioffi, J.M.

IEEE STANDARDS ASSOCIATION

3GPP™ A GLOBAL INITIATIVE

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The two-layer model of the Internet

IP

content
apps & software
services

1-3 years
(depends on
infrastructure *impact*)

"Lower layers"
infrastructure
"the network"
"hardware"

10-30 years
(depends on
infrastructure *re-use*)

NETFLIX

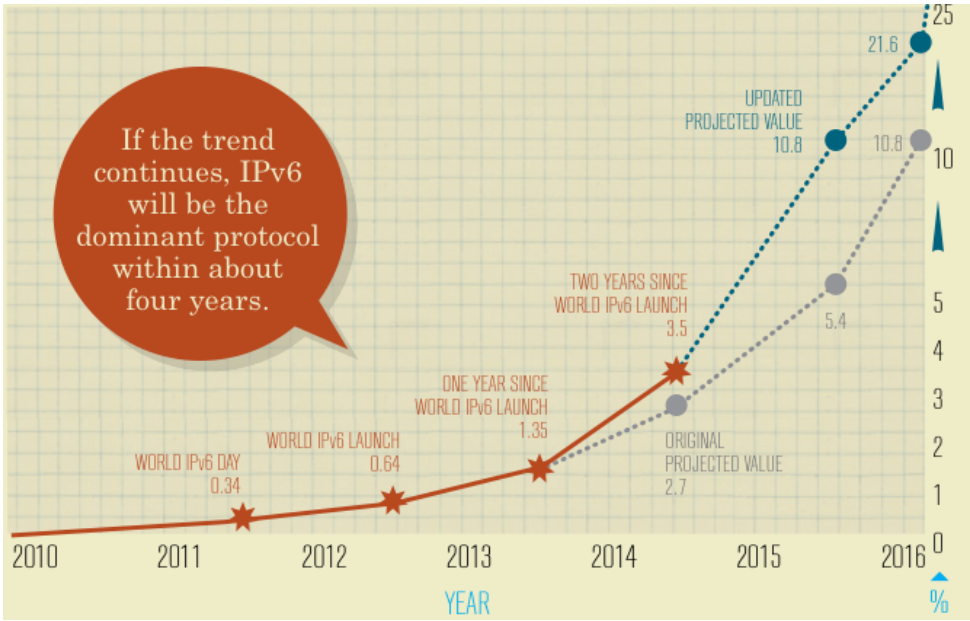
YouTube

FTTH
FIBER TO THE HOME
COUNCIL

IPv6

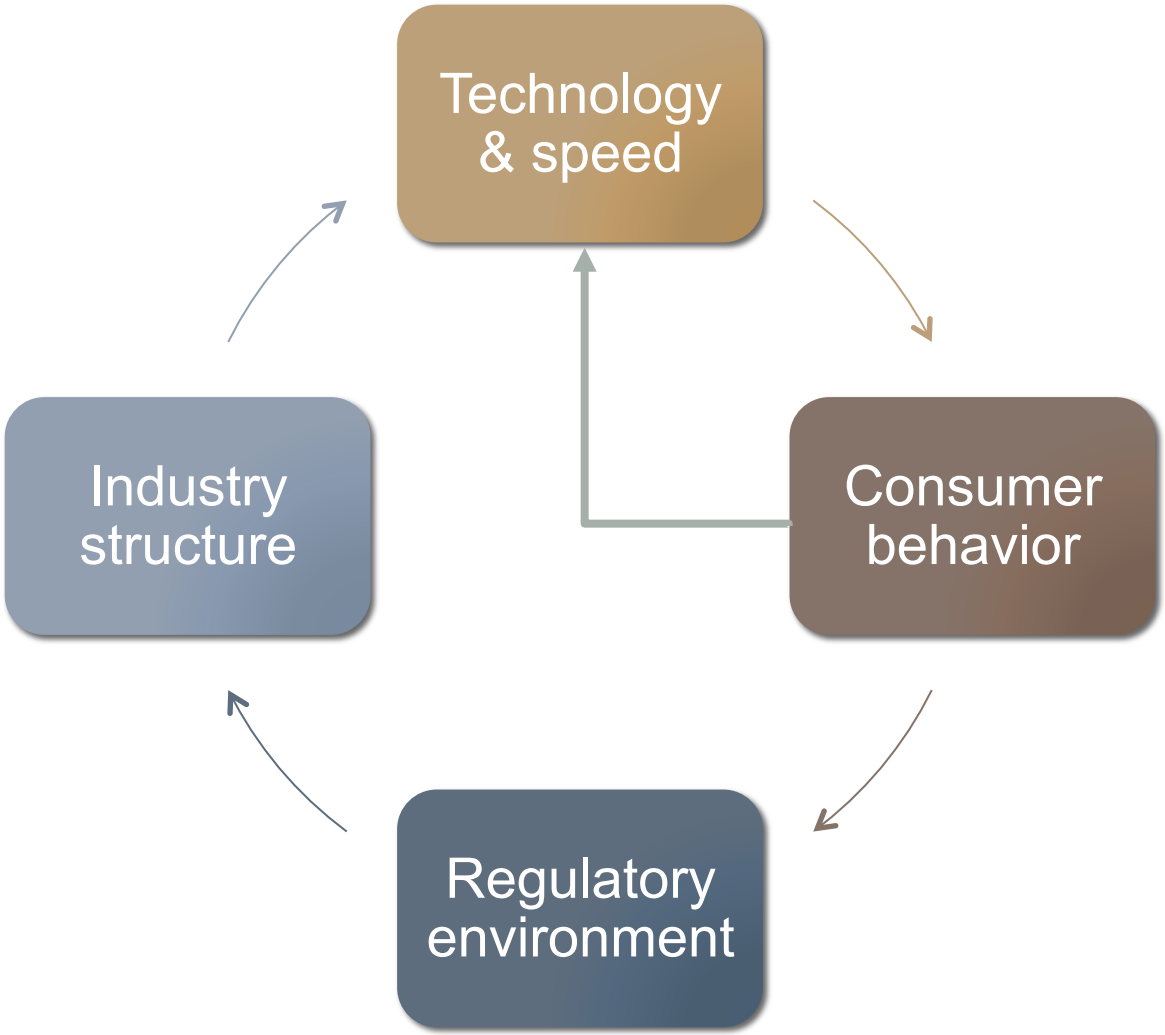
Change may seem sudden, but is visible

- Early lab prototypes
  - see “mother of all demos” (Doug Engelbart, 1968)
- IPv6:
  - discussion started in 1992
  - standardized in 1996
  - 10-25% deployment 20 years later
- VoIP:
  - tech demos 1978, revived early 1990s
  - standards mid-1990s
  - 2014: 40% deployment
- Smartphone:
  - first version 1994
  - iPhone 2007



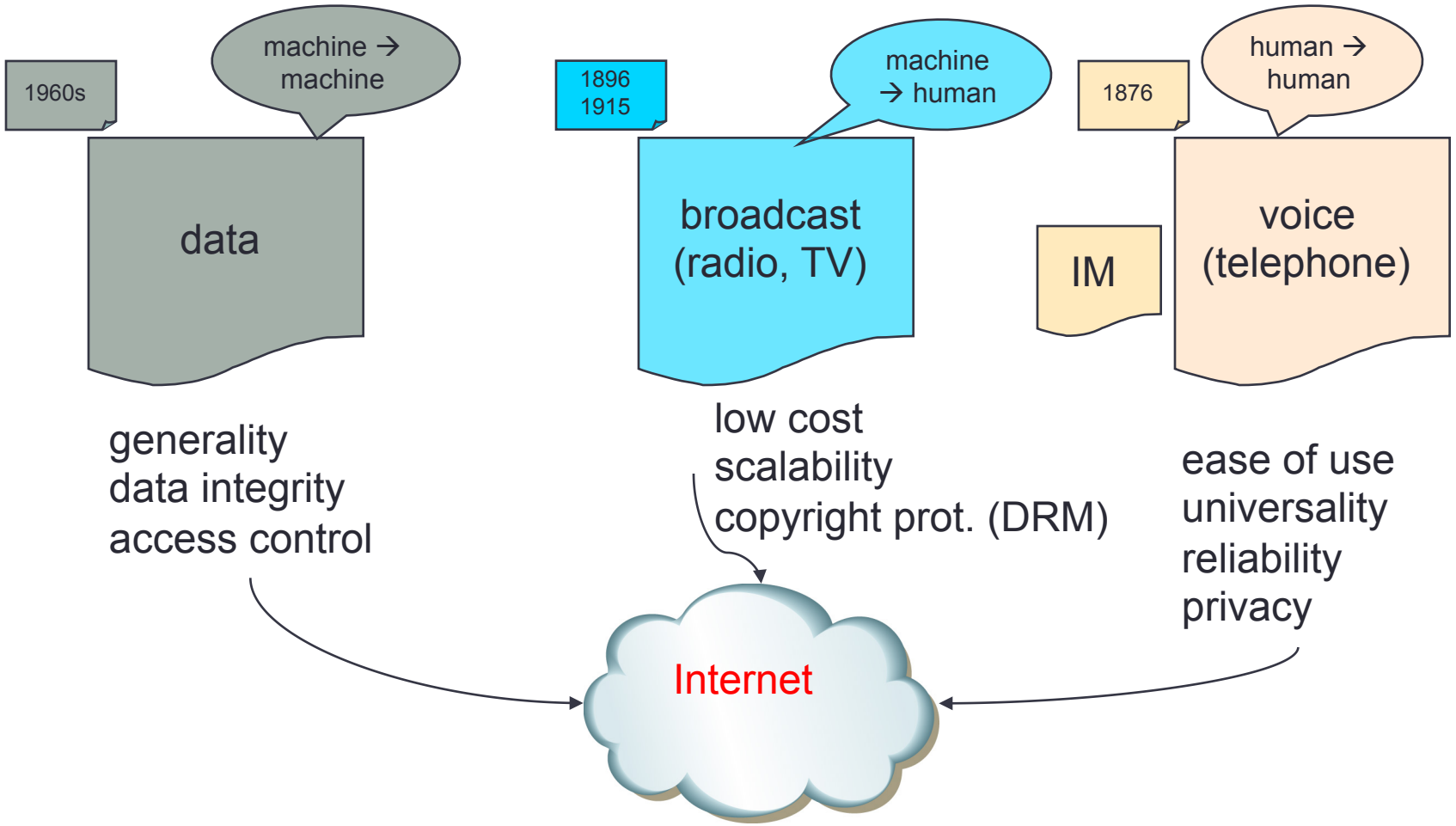
“The future has arrived — it’s just not evenly distributed yet.” (attributed to W. Gibson, 1992)

Pattern 1: The dependency cycle



Pattern 2: converging communities

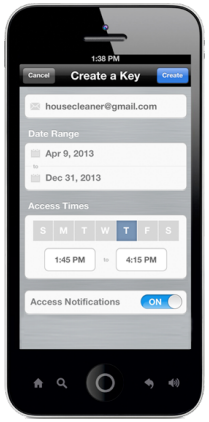
since 1900: separate networks, companies, professions



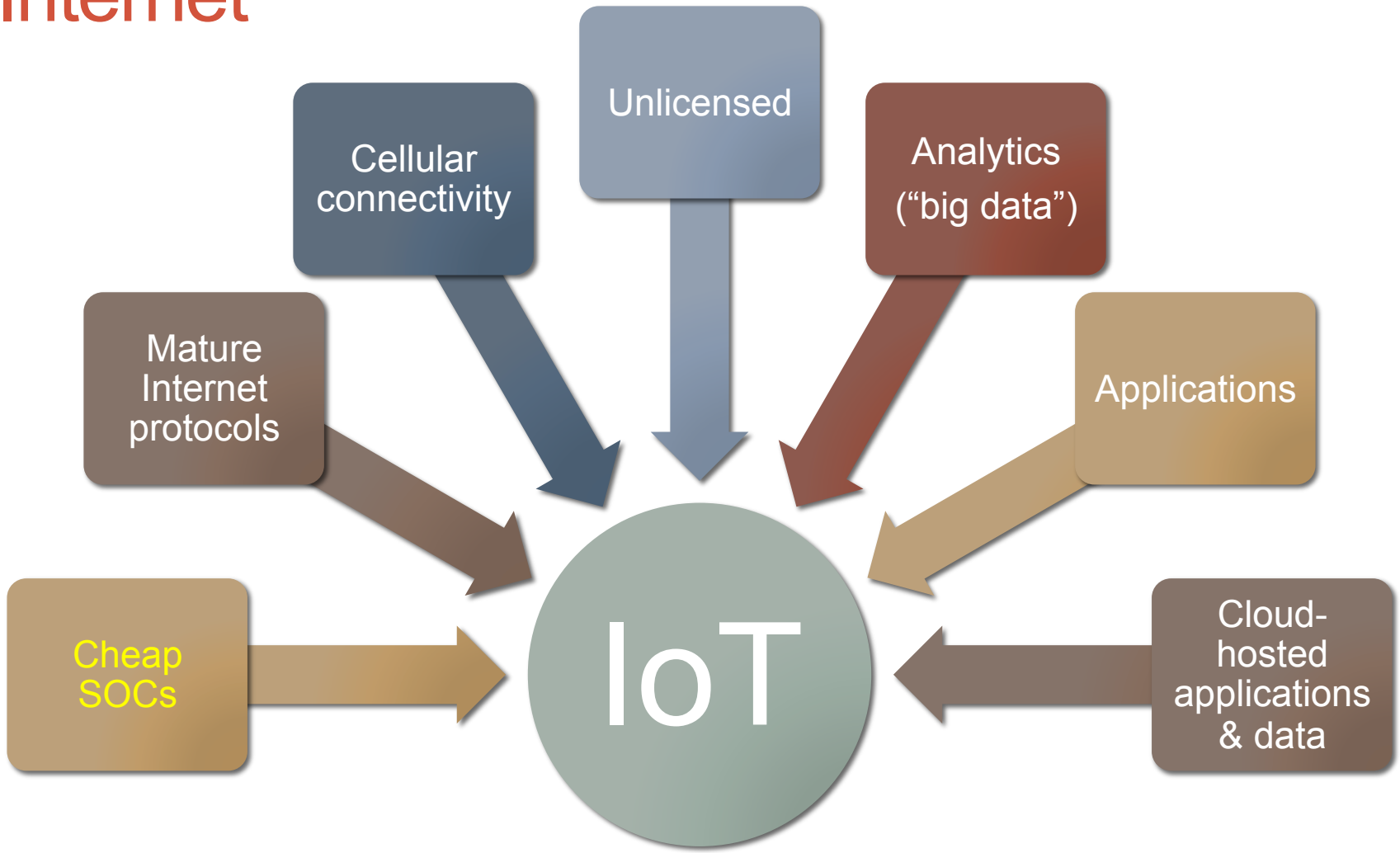
Pattern 3: fixed → nomadic → mobile

end point?

Natural evolution

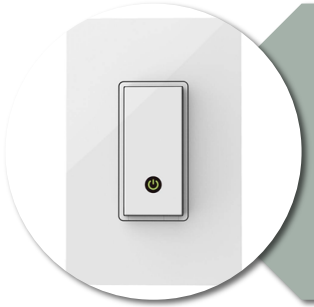


Key enablers for everything-on-the-Internet



IoT: more than programmable light bulbs

public sensors & actuators



semi-private

private

Increasing expectations

Broadband usage

- Limited by human perception
- Text → images → video → multi-party e-sports
- 4K video → 15-20 Mb/s
  - even if 3D becomes popular (again)
- 5 hours of video/day & person
  - → ~ 2 TB/month/household
  - compared to 20 GB (median) today

(Almost) all new transmission technologies work best over short distances

- Examples:
  - DSL
  - Cellular MIMO and directional antennas
  - Wi-Fi
  - Free-space optical
  - 60 GHz microwave
- Opportunities:
  - higher b/s/Hz – mostly done, except by…
  - smaller cells → cost approaching fixed network
    - or cellular as small upgrade to fixed network if base stations cheap
  - directional → MIMO

Out of G's?

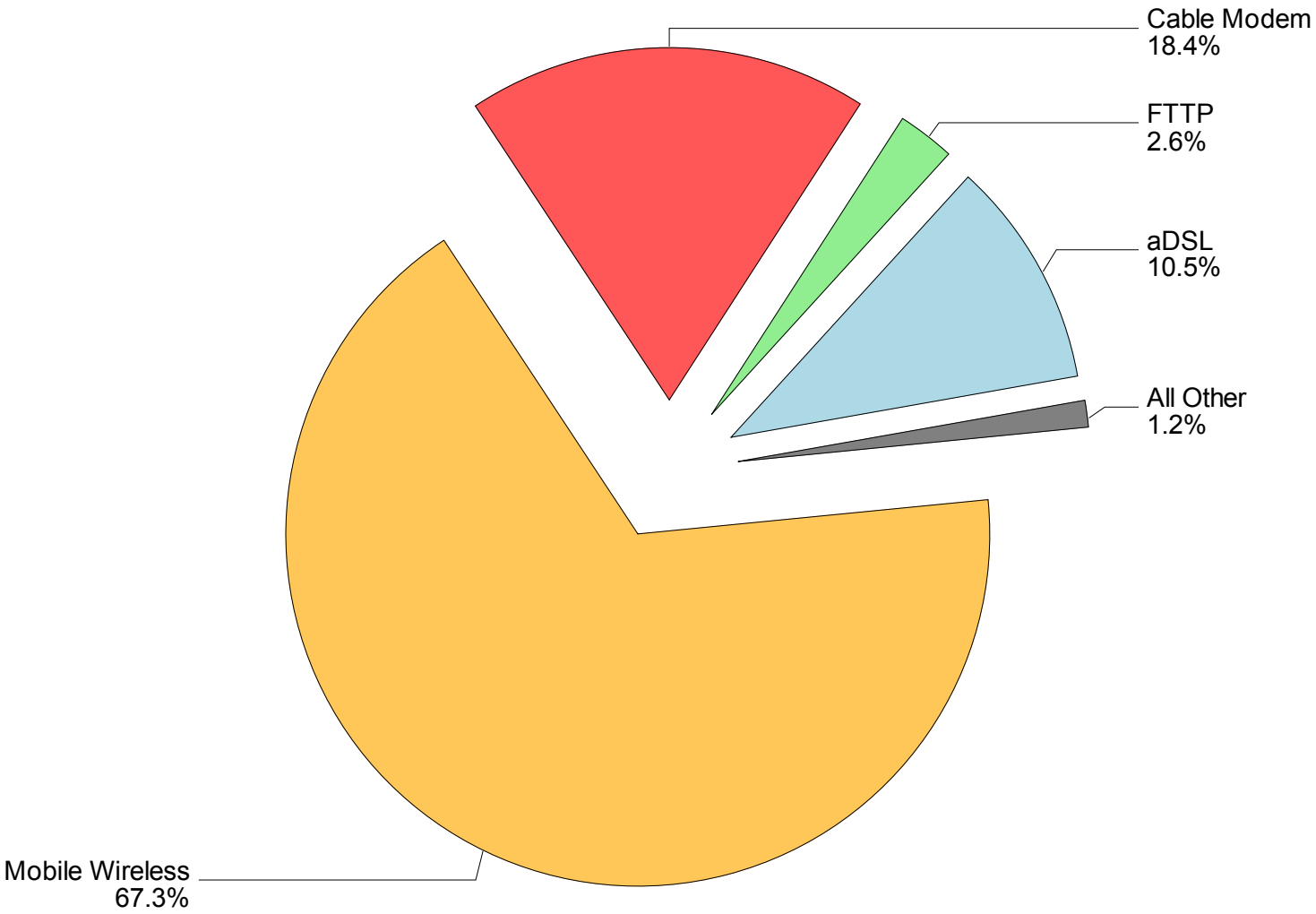
- A new generation roughly every ten years
- 5G (whatever that may mean) planned for 2020

G	Year (introduced)	Architecture	Per-user speed	Other
1	1981	analog	voice only	
2	1992	digital	voice + SMS	
3	2001	digital + IP	0.5-1 Mb/s	
4	2011	IP + legacy	5-20 Mb/s	lower latency, HD voice
5	2020	all-IP	< 100 Mb/s	24 GHz+
6	2030	all-IP		

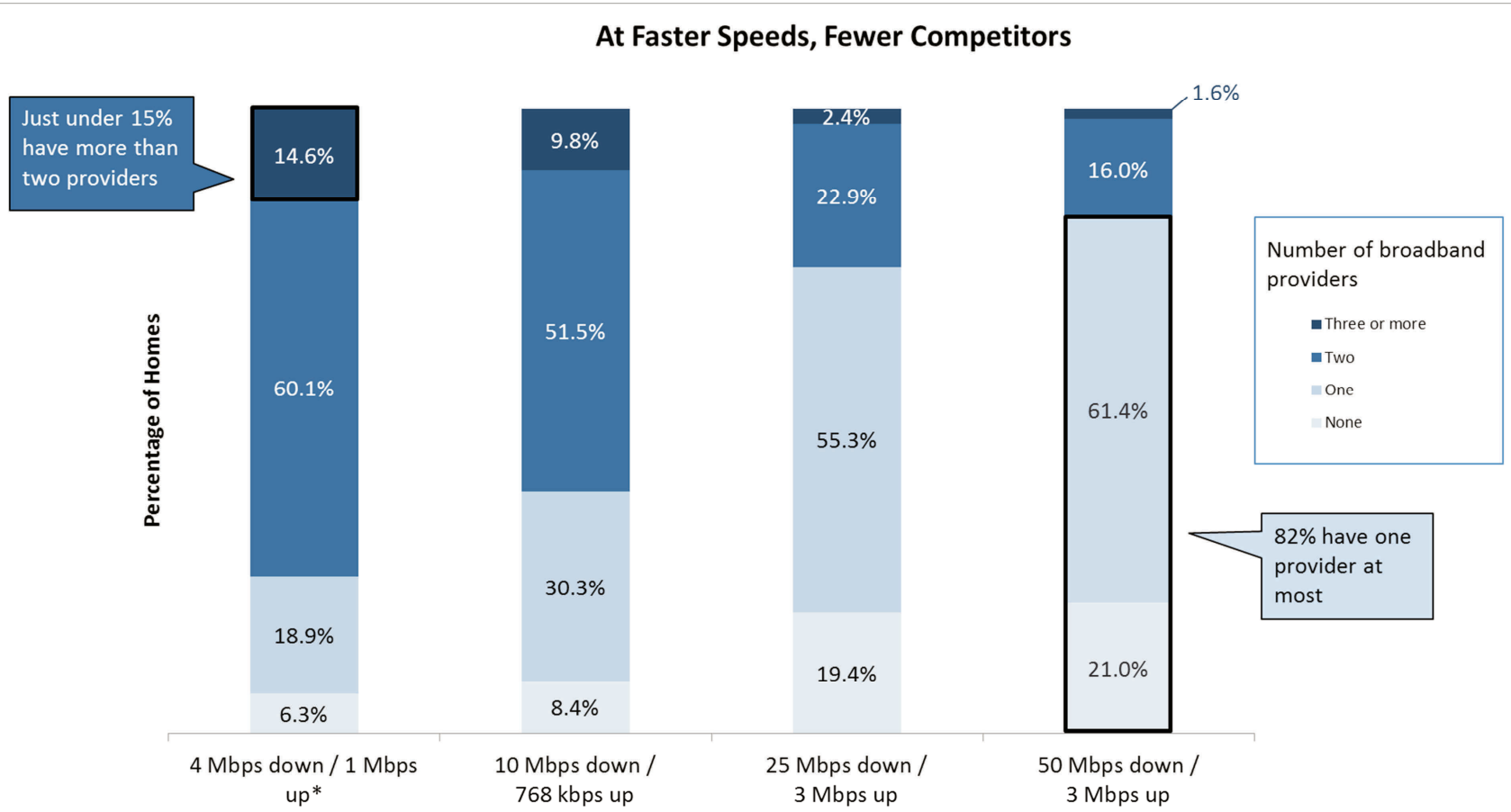
Terrestrial TV & radio broadcast

- US: ~10-15% get over-the-air TV
- Sustained by
  - ubiquity
  - cheap end systems (and infrastructure)
  - legal or regulatory advantages
    - such as must-carry rights in the United States
    - or viewer fees in Europe
- No reason to turn it off
  - except for spectrum value

Chart 6
Connections by Technology as of December 31, 2013



Broadband competition challenges

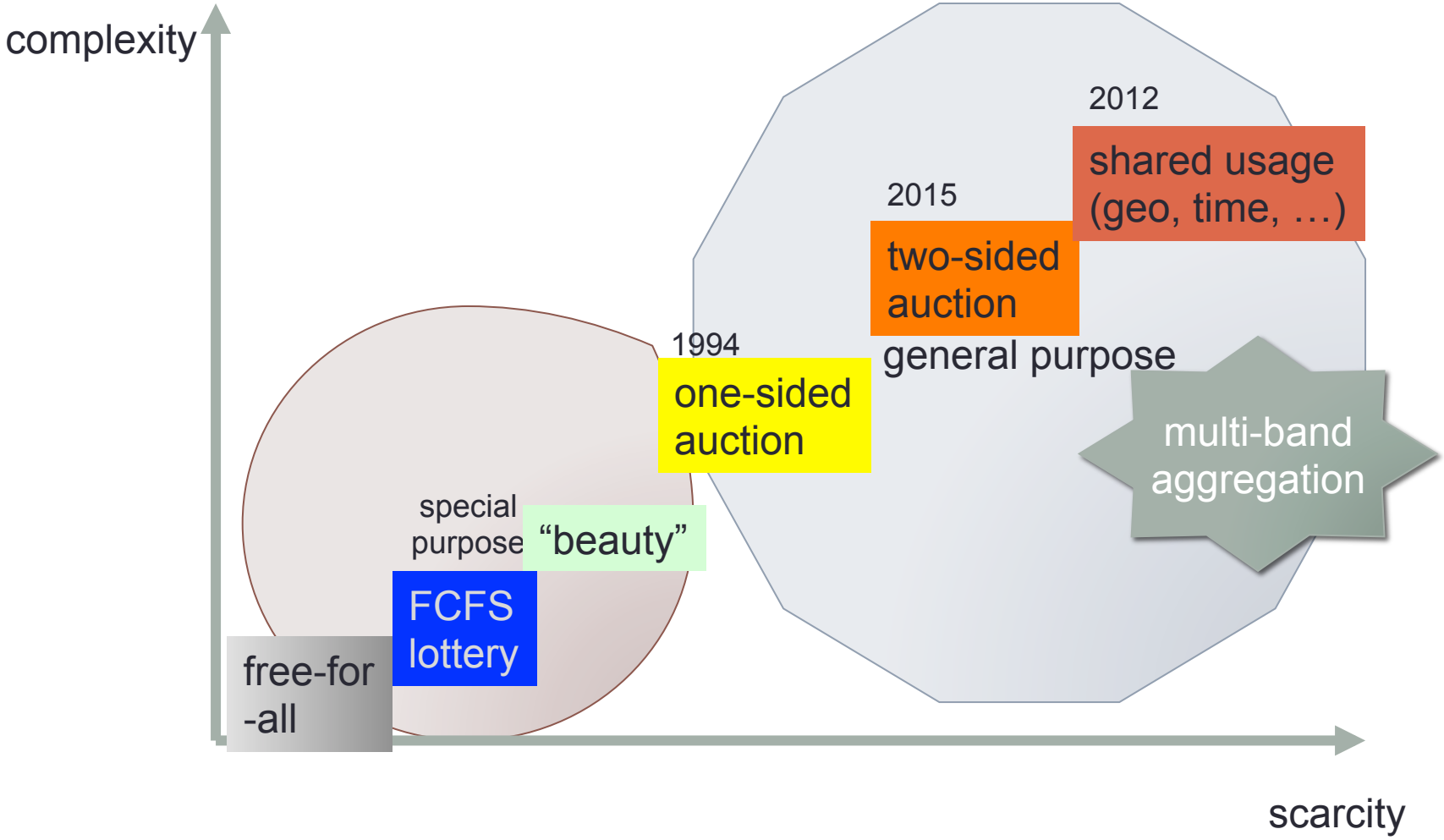


* These data reflect speeds of 3 Mbps up / 768 kbps down, which the FCC uses as the best proxy for 4 Mbps / 1 Mbps . *See, e.g.*, FCC, *Eighth Broadband Progress Report*, FCC 12-90, ¶ 29 (2010).

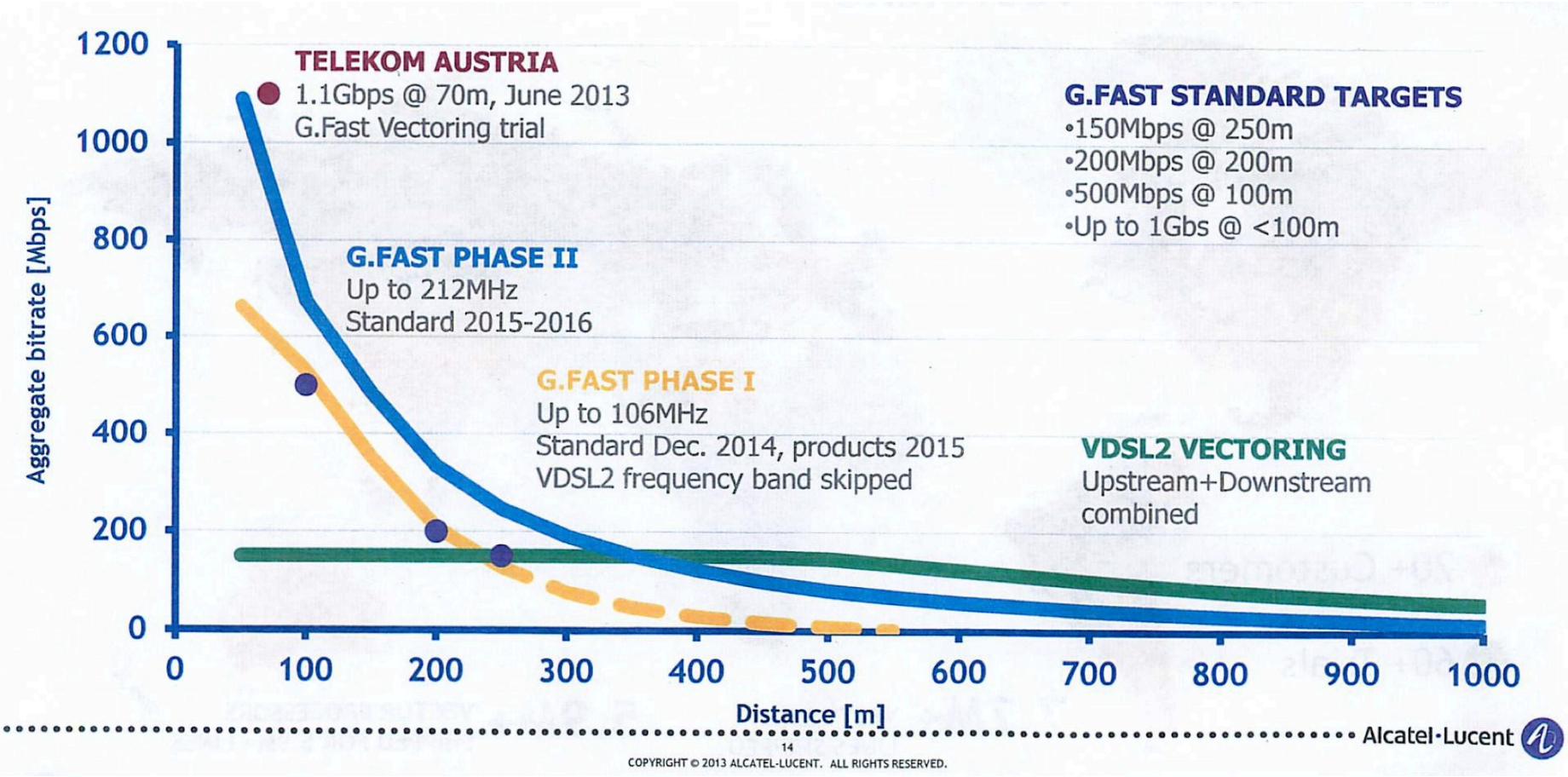
2035 challenge: even distribution of broadband

- US
  - stratification by income and housing density
  - High-income, high-density → 1 Gb/s FTTP
  - Medium income, suburbia+ → cable (50 Mb/s)
  - Lower income, rural → ADSL (3-4 Mb/s)
  - Cost barriers → no-video LTE
  - Limited willingness to pay extra for > 20 Mb/s
  - Communication expenditures constant ~ 5% of income
- Elsewhere
  - new delivery methods
    - drones, balloons, cube sats?

Spectrum allocation



Example: DSL


TELEKOM AUSTRIA
1.1Gbps @ 70m, June 2013
G.Fast Vectoring trial
G.FAST STANDARD TARGETS
•150Mbps @ 250m
•200Mbps @ 200m
•500Mbps @ 100m
•Up to 1Gbs @ <100m
G.FAST PHASE II
Up to 212MHz
Standard 2015-2016
G.FAST PHASE I
Up to 106MHz
Standard Dec. 2014, products 2015
VDSL2 frequency band skipped
VDSL2 VECTORING
Upstream+Downstream
combined
Aggregate bitrate [Mbps]
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
700
800
900
1000
Distance [m]
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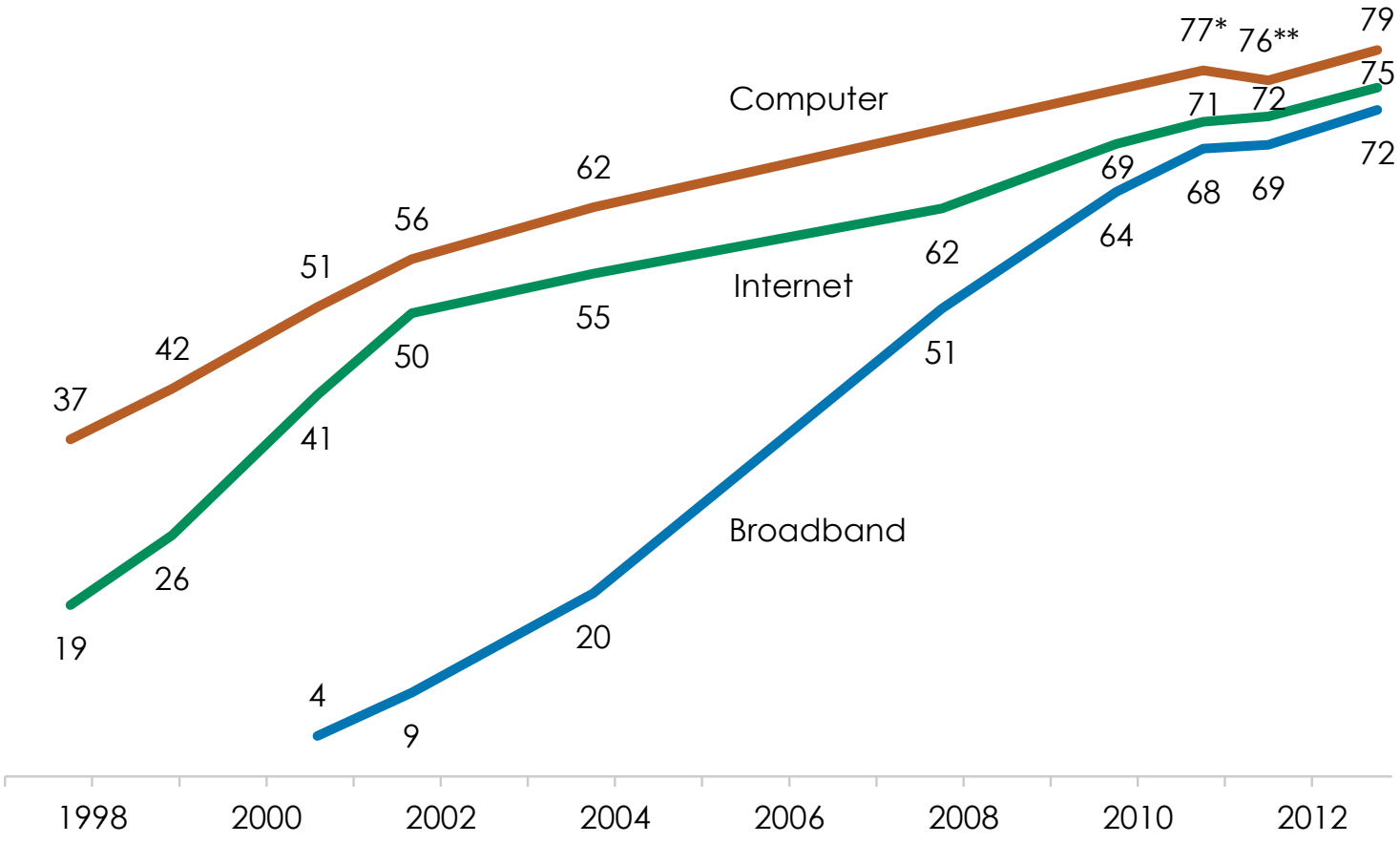
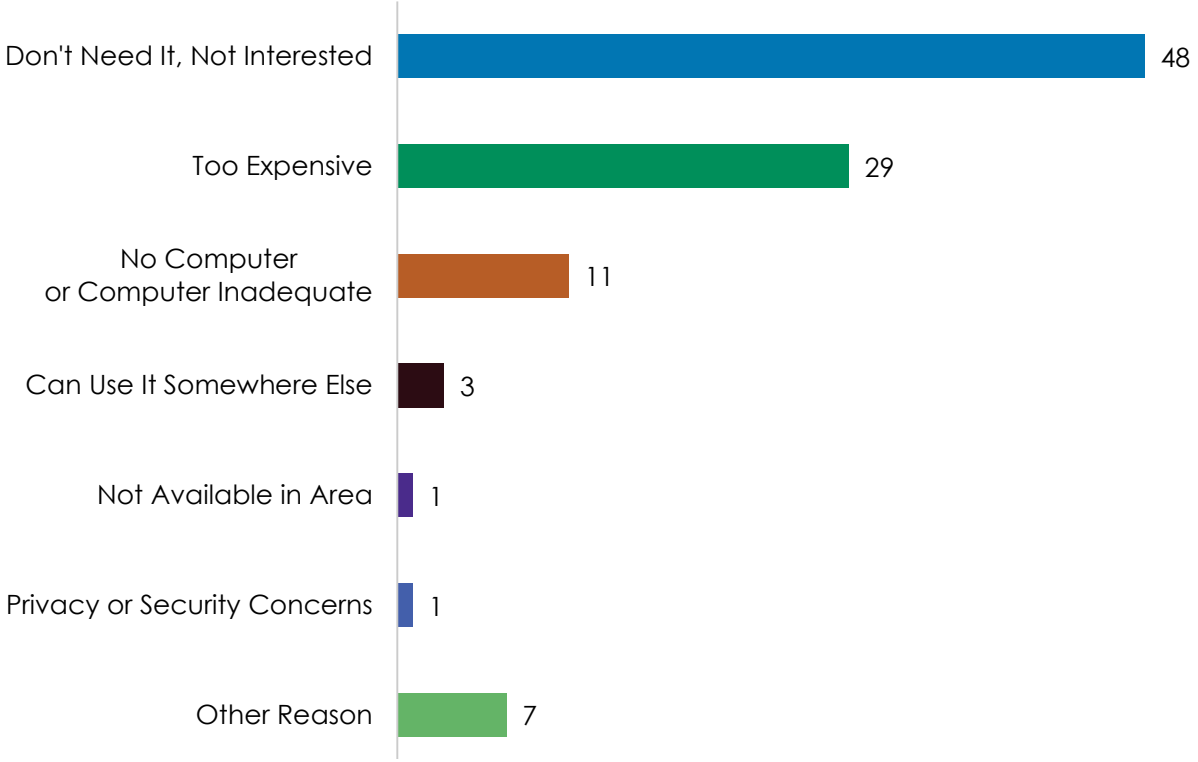
US broadband adoption

Figure 1: Overview of Household Adoption Rates by Technology, Percent of U.S. Households, 1997-2012



Non-adoption

Figure 16: Main Reason for Non-Use of the Internet at Home, Percent of Households Not Online at Home, 2012



Broadband cost

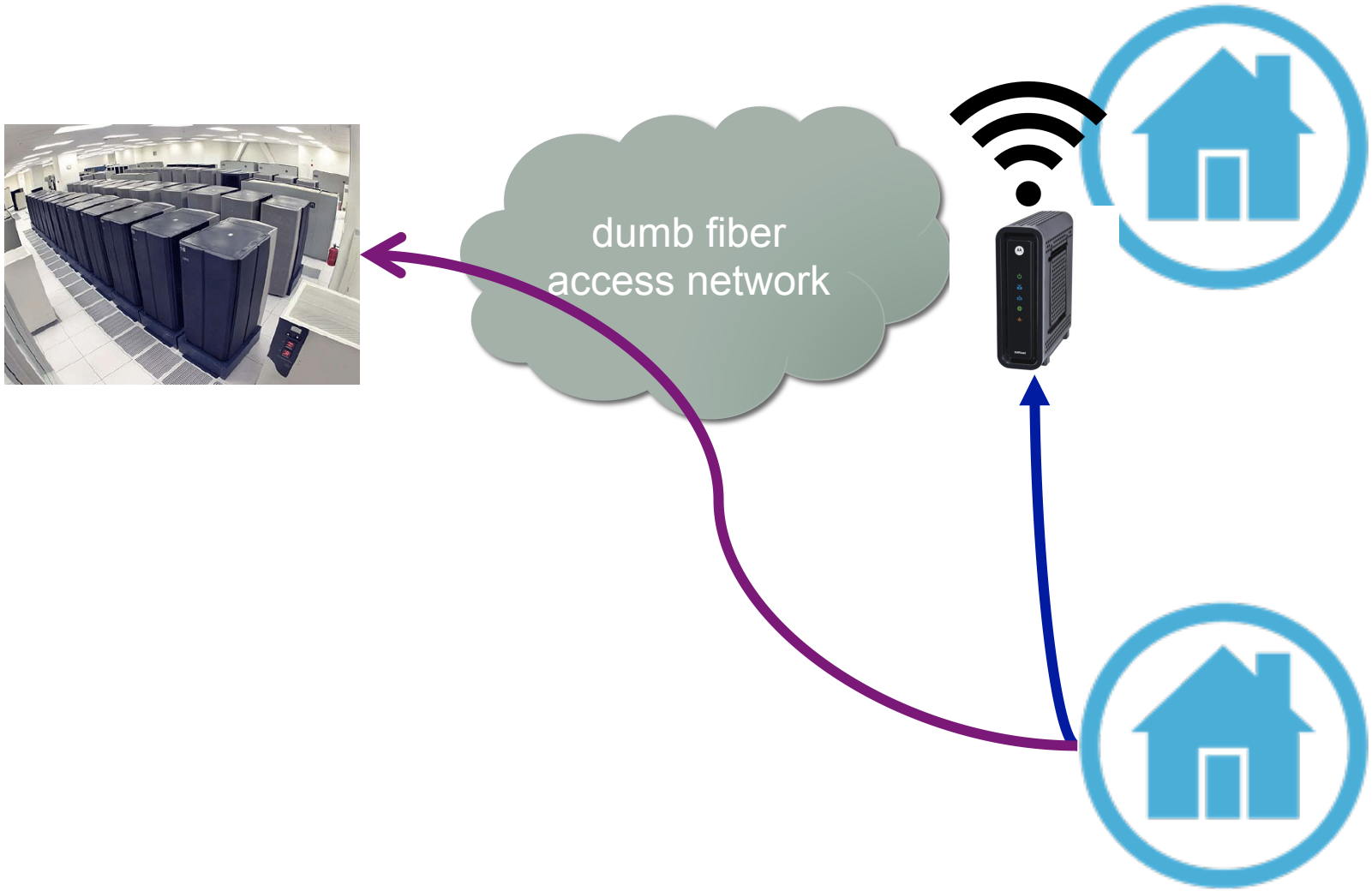
30%

e.g., CenturyLink: capital investment = 15% of revenues

Clean slate or muddling through?

- Basic transmission technology hasn't changed since 1969
  - datagram with end point addressing
- Alternative: data objects
  - named-data networking, content-centric, information-centric, …
  - predicated on video
  - but in 2035, much of the content may be dynamically generated
    - "video games" = custom movies
- Conditions
  - parallel networks (same transmission technologies)
  - 10x better, cheaper, faster, more secure, …
  - better than application-layer alternatives

Residential network architecture



Engineering and business opportunities

- Capital investment surprisingly small
- Academic and industry research focuses on 15%, rather than 85%
- Three likely models in different countries:
  1. public conduits (& fiber) + private Internet access
     - community & electric utilities
  2. structurally-separated into transmission, interconnection & connect
  3. vertically integrated (monopoly & duopoly) provider
- Opportunities and predictions:
  - like retail → franchising, “SolarCity” capital model
  - local network, central administration
  - self-administered networks

Too risky for commercial use?

- Lots of legacy protocols, software, assumptions
  - designed for friendlier world
- Transition from hobby → professional open source → “reps & warranties”
- Passwords → “what you have”
  - know when lost or stolen
  - limited attack surface → provable correctness

Could things get worse?

- Technology always gets better, but society doesn't
- Risk factors:
  - income stagnation → limited mass-market deployment
  - geographic fragmentation
  - "cableization" fragmentation of Internet
  - political fragmentation & tribalization increased by Internet personalization
  - security risks – Internet suitable only for cat pictures
  - RF discovered to have significant health risks

Conclusion

- Just like 2014 is recognizable to time traveler from 1994, 2035 will be recognizable to 2014 time traveler
- Unlike other areas of technology, combination of
  - R&D
  - financing & business models
  - regulatory environment
  - external economic & cultural factors