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Possible Paradigm Shifts in Broadband Policy

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I. INTRODUCTION

Much like generals still fighting the last war, participants in debates over communications policy with respect to traditional media have all too often based their arguments on factual premises that had already been rendered obsolete. I personally witnessed several striking examples of this pitfall during the Federal Communications Commission's (FCC's) December 2006 hearings on media ownership, where multiple recording artists complained that their inability to get airtime on the radio was hurting their ability to sell records.[1] No doubt many of the digital cognoscenti had a good chuckle over the continued embrace of a chain of distribution that was already well on its way to becoming an anachronism.

What is not as well recognized is the extent to which similar criticisms are also starting to apply to debates over Internet policy. As I lay out in my recent book, those debates tend to be framed by the way the Internet existed in the mid-1990s, when the Internet became a mass-market phenomenon.[2] Until that time, the Internet was used by a small number of *users* to run a limited number of *applications* over a narrow range of *technologies* interconnected through a fairly uniform set of *business relationships*. At the risk of oversimplifying, the Internet was primarily used by academics and tech-savvy early

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[1] *Fed. Commc'ns Comm'n, Recorded Audio/Video Webcast of the Public Hearing on Media Ownership*, Nashville, Tennessee (Dec. 11, 2006), http://www.fcc.gov/realaudio/mt121106.ram.

[2] CHRISTOPHER S. YOO, THE DYNAMIC INTERNET: HOW TECHNOLOGY, USERS, AND BUSINESSES ARE TRANSFORMING THE NETWORK 2 (2012).

adopters to send email and browse the web over a personal computer connected to a telephone line via networks interconnected through a hierarchical relationship of Tier 1, Tier 2, and Tier 3 Internet Service Providers (ISPs) exchanging traffic in accordance with peering and transit arrangements.[3]

Technological and economic change has rendered each of those statements passé to some degree. Instead, the environment surrounding the Internet has changed to the point where certain paradigm shifts may be appropriate. Unfortunately, Internet policy has not always kept up with the times, as the universe of users, applications, technologies, and business relationships has become increasingly numerous and diverse.[4] In this article, I will review some of the more salient changes and use them to debunk a number of common myths often invoked during communication policy debates.

II. THE SLOWING GROWTH OF THE INTERNET'S SIZE

The conventional wisdom with respect to the Internet is that size matters. Some scholars have suggested that the Internet's size is governed by a form of Moore's Law, growing at a constant rate.[5] Size is also generally regarded to be an important determinant of value. It has long been recognized that the number of possible connections increase quadratically with the number of endpoints.[6] Metcalfe's Law posits that if the value of a network goes up in proportion to the number of connections (thus quadratically) and the costs of increasing network size increase linearly, increasing a network's size necessarily increases its value.[7] This logic was used to justify the enormous investments that fueled the dot-com bubble.[8]

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[3] *Id.* at 2–3.

[4] *Id.* at 13–69.

[5] Guo-Qing Zhang et al., *Evolution of the Internet and its Cores*, 10 NEW J. PHYSICS 123027, at 3 (2008), http://iopscience.iop.org/1367-2630/10/12/123027 (concluding that the size of the Internet follows a form of Moore's Law, doubling every 5.32 years).

[6] *See, e.g.*, Daniel F. Spulber & Christopher S. Yoo, Networks in Telecommunications: Economics and Law 121 (2009).

[7] *See* Bob Metcalfe, *Metcalfe's Law (the Blog) Has a POV: Point of View*, COCKRELL SCHOOL OF ENGINEERING, http://www.engr.utexas.edu/metcalfe/blog/blogpov (reproducing the original 1980 slide that led to Metcalfe's Law).

Figure 1:
Global Internet Users (millions) and Growth Rates, 1995–2013
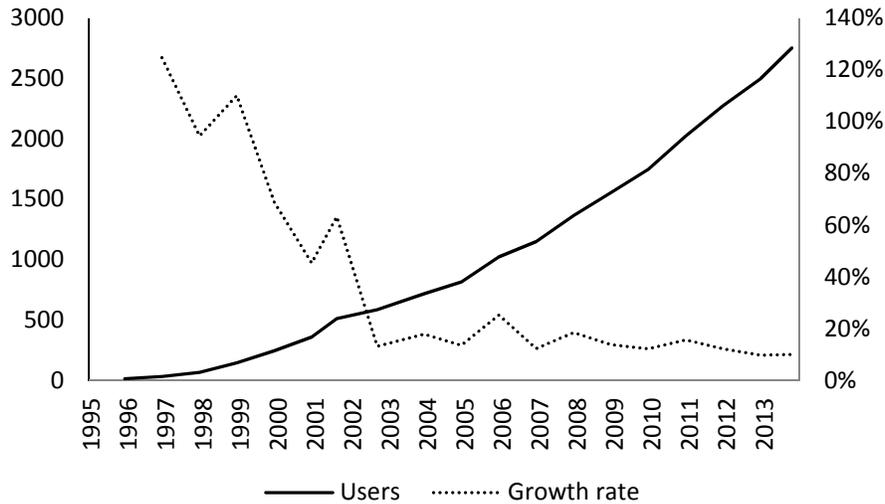
Source: Int'l Telecomm. Union, *supra* note 9; Internet World Stats, *supra* note 9.

For much of the Internet's history, the size of the Internet has undergone steady, and at times meteoric, growth. There are two ways to measure the Internet's size. First, one can consider the total number of *end users*. Second, one can measure the number of computers attached to the edge of the network (called *hosts*). Considering first the number of end users, the number has grown steadily, although more room for growth still exists, as Internet adoption has reached only 39% globally.[9] Even so, annual growth rates are slowing dramatically, tapering off to 10%.[10] Even in the

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[8] Bob Briscoe et al., *Metcalfe's Law Is Wrong: Communications Networks Increase in Value as They Add Members—But by How Much? The Devil Is in the Details*, IEEE SPECTRUM, July 2006, at 35, 37.

[9] Int'l Telecomm. Union, *Key ICT Indicators for Developed and Developing Countries and the World* (Totals and Penetration Rates), http://www.itu.int/en/ITU-D/Statistics/ Documents/statistics/2013/ITU_Key_2005-2013_ICT_data.xls; Internet World Stats, *Internet Growth Statistics*, http://www.internetworldstats.com/emarketing.htm (last visited July 29, 2012).

[10] *Id.*

Figure 2:
Global Internet Hosts (millions) and Growth Rates, 1991–2013
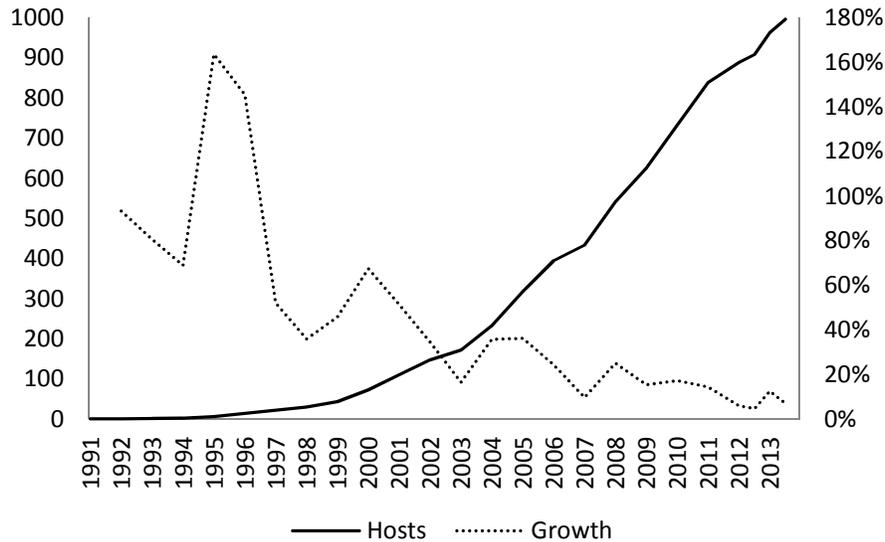
Source: Internet Sys. Consortium, *Internet Host Count History*, http://www.isc.org/solutions/survey/history.

developing world, annual growth rates have dropped from 23% in 2006 to 10% in 2013.[11]

Measured by the number of hosts, the Internet has grown rapidly since the mid-1990s, increasing from just fewer than 6 million in January 1995 to just under 1 billion as of July 2013. As was the case with end users, the growth rate is slowing, dropping to an annual rate of below 7% in July 2013.

It is thus simply not true that the Internet is growing at a constant rate. That said, the increase in the number of users and hosts connected to the Internet has had an impact that will affect Internet policy. The wider geographic dispersion inevitably causes greater latency along certain links.[12] The fact that congestion management is based on feedback means that the greater latency causes endpoints to

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[11] *Id.*

[12] YOO, *supra* note 2, at 16.

receive different signals as to the need to throttle back their sending rates.[13]

Because the number of potential connections increases quadratically with the number of endpoints, the complexity of network management increases even more rapidly than its scale. This complexity can be simplified by introducing a small number of long-distance links[14] or by relying on a small number of highly connected supernodes.[15] But these solutions require deviating from the flat architecture traditionally associated with the Internet.

Nor is it true that increases in network size always increase network value. Metcalfe's Law assumes that every added connection is of equal value. But the increase in the number of end users has been accompanied by an increase in their heterogeneity. When connections vary in value, it is likely that growth in network size will face diminishing returns to scale.[16] To use a personal example, I would gain more value from ensuring higher quality connections to the handful of locations I access most frequently (such as my email server, my office computer via remote desktop access, the Penn Law website, and my bank) than from increasing the number of locations I am able to reach.

The growing heterogeneity of end users also changes the nature of governance. What began as a small community of technophiles has become a mass market comprised of people with more diverse interests, less technical sophistication, less institutional support, and fewer shared values.[17] As the Internet ceases being a close-knit

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[13] Sally Floyd & Van Jacobson, *Traffic Phase Effects in Packet-Switched Gateways*, 21 COMPUTER COMM. REV., Apr. 1991, at 26.

[14] Duncan J. Watts & Steven H. Strogatz, *Collective Dynamics of "Small World" Networks*, 393 NATURE 440 (1998).

[15] ALBERT-LÁSZLÓ BARABÁSI, LINKED: HOW EVERYTHING IS CONNECTED TO EVERYTHING ELSE AND WHAT IT MEANS 71 (2002).

[16] Christopher S. Yoo, *When Antitrust Met Facebook*, 19 GEO. MASON L. REV. 1147, 1151–53 (2012); *see also* Briscoe et al., *supra* note 8, at 36; Joe Weinman, *What If Metcalfe's Law Is Wrong*, GIGAOM, Mar. 12, 2010, http://gigaom.com/2010/03/12/what-if-metcalfe%E2%80%99s-law-is-wrong/. Indeed, Metcalfe and George Gilder, who popularized Metcalfe's Law, both recognize that it is simply a rule of thumb. *See* Briscoe et al., *supra* note 8, at 37; George Gilder, *Ten Laws of the Telecosm Redux*, FORBES.COM, Jan. 9, 2007, http://www.forbes.com/2007/01/09/telecosm-jdsu-intel-pf-soapbox-in_gg_0109soapbox_inl.html.

[17] YOO, *supra* note 2, at 17.

community, it may have to place greater reliance on more formal and more centralized governance mechanisms.[18]

III. THE SLOWING GROWTH OF INTERNET TRAFFIC

Internet policy debates are replete with calls for more bandwidth. Many commentators use predictions that increased user demand will soon require service levels between 100 Mbps and 1 Gbps to call for greater public support for investments in fiber to the home.[19] Others point to the growing demand for bandwidth to justify imposing sophisticated forms of network management.[20]

Claims about Internet growth have always been tinged with a degree of hyperbole. From 1998 to 2000, government officials and industry executives often advanced claims that Internet traffic was doubling every three to four months.[21] While these claims may have been true for a brief period during 1995 and 1996, for the most part, they appear in retrospect to have been baseless. Aside from 1995 and 1996, when annual growth rates spiked 800% to 900%, Internet

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[18] *Id.* at 82–94.

[19] Press Release, Fed. Commc'ns Comm'n, FCC Chairman Genachowski Issues Gigabit City Challenge (Jan. 18, 2013), *available at* http://www.fcc.gov/document/fcc-chairman-genachowski-issues-gigabit-city-challenge; SUSAN CRAWFORD, CAPTIVE AUDIENCE 2, 262–64 (2013); Eli Noam, *Let Them Eat Cellphones: Why Mobile Wireless Is No Solution for Broadband*, 1 J. INFO. POL'Y 470, 471, 482 (2011), *available at* http://jip.vmhost.psu.edu/ojs/index.php/jip/article/viewFile/64/43; JOHN WINDHAUSEN JR., A BLUEPRINT FOR BIG BROADBAND 7–18 (2008), *available at* http://www.educause.edu/ir/library/pdf/EPO0801.pdf.

[20] *See, e.g.*, Joseph D. Houle et al., The Evolving Internet–Traffic, Engineering, and Roles (paper presented at the 35th Annual Telecommunications Policy Research Conference), *available at* http://ssrn.com/abstract=2117594.

[21] *See, e.g.*, William E. Kennard, Chairman, Fed. Commc'ns Comm'n, Report Card on Implementation–Strategic Plan: A New FCC for the 21st Century 2 (2000), *available at* http://www.fcc.gov/21st_century/ report_card_march2000.pdf; U.S. Dept. of Commerce, The Emerging Digital Economy 2 (1998), *available at* http://www.esa.doc.gov/sites/default/files/reports/documents/emergingdig_0.pdf; Reed Hundt, You Say You Want a Revolution 224 (2000); John Sidgmore, *The Largest ISP and Getting Larger*, Vortex98 Conf. Proc. 157, 158 (1998), *available at* http://www.dtc.umn.edu/~odlyzko/isources/sidgmore-vortex98b.pdf; Peter J. Howe, *MCI Chief Sees Big Outlays to Handle Net Traffic: Ebbers Estimates $19B to Upgrade Network*, Boston Globe, Mar. 7, 2000, at C7; Michael D. O'Dell, Racing with an Exponential or the Dangers of Linear Thinking in an Exponential World. Lecture at the Stanford Symposium on Optical Internet: The Next Generation (May 16, 2000), *available at* http://www.dtc.umn.edu/~odlyzko/isources/odell-transcript.txt.

Figure 3:
International Internet Traffic Growth, 2004–2013
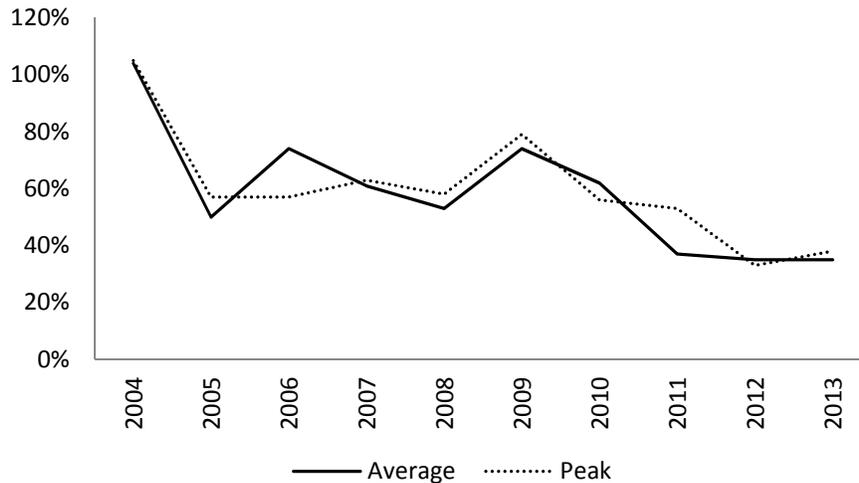
Source: TELEGEOGRAPHY RESEARCH, GLOBAL INTERNET GEOGRAPHY 1, 3 (2013), *available at* http://www.telegeography.com/research-services/global-internet-geography/index.html; YOO, *supra* note 2, at 22 tbl.2-1.

traffic grew steadily at roughly 100% per year from 1991 to 2002.[22] Starting in 2003, however, annual growth rates decelerated to approximately 50%, where it would hold through 2013.[23]

Notwithstanding the data, claims that the Internet was growing at 100% per year persisted throughout the mid-2000s.[24] Concerns

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[22] YOO, *supra* note 2, at 20, 21 fig.2-2.

[23] *Id.* at 21.

[24] *See, e.g.*, *Net Neutrality: Hearings Before the S. Comm. on Commerce, Sci. & Transportation*, 109th Cong. 17 (2006) (prepared statement of Walter B. McCormick, Jr., President/Chief Executive Officer, United States Telecom Association), *available at* http://www.gpo.gov/fdsys/pkg/CHRG-109shrg30115109shrg28476/pdf/CHRG-109shrg30115109shrg28476.pdf; Lawrence G. Roberts, *Routing Economics Threaten the Internet*, INTERNET EVOLUTION, Oct. 25, 2007, http://www.internetevolution.com/author.asp?section_id=499&doc_id=136705&; Mark Boslet, *Cisco Girds to Handle Surge in Web Video*, WALL ST. J., Dec. 8, 2005, at B8 (quoting Cisco CEO John Chambers); NEMERTES RESEARCH, THE INTERNET SINGULARITY, DELAYED: WHY LIMITS IN INTERNET CAPACITY WILL STIFLE INNOVATION ON THE WEB 16, 58 (2007), *available at*

Figure 4:
Global IP Traffic (zettabytes/month) and Growth Rates, 2005–2017
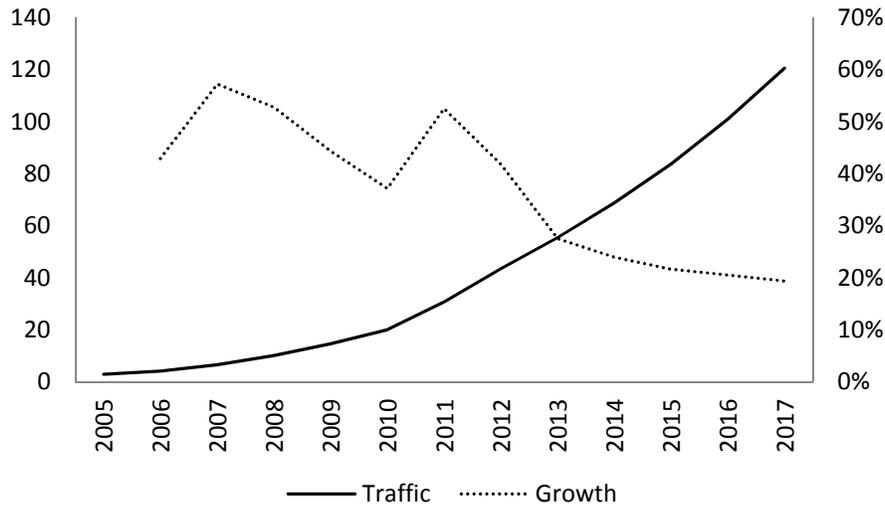
Source: *See* sources cited *supra* note 27.

focused largely on whether the migration to IP-based video might cause traffic growth rates to return to pre-2002 levels.[25] Some even predicted a jump to growth rates of 300% to 500%.[26] Not only has this return to an annual doubling in volume failed to materialize, but also, industry estimates suggest that traffic growth appears to have slowed even further. For example, the Minnesota Internet Traffic Study estimates that annual traffic growth slowed down to 40% to 50% starting in 2009.[27] TeleGeography estimates that traffic growth dropped below 40% starting in 2011.

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http://www.nemertes.com/studies/internet_singularity_delayed_why_limits_internet_capacity_will_stifle_innovation_web.

[25] Christopher S. Yoo, *Network Neutrality, Consumers, and Innovation*, 2008 U. CHI. LEGAL F. 179, 187–88 (2008).

[26] *Network Traffic to Grow Up to Six-Fold Annually*, CISCOSECURITYWATCH, June 19, 2007, http://ciscosecuritywatch.blogspot.com/2007/06/network-traffic-to-grow-up-to-six-fold.html (quoting Cisco CEO John Chambers).

[27] Minnesota Internet Traffic Studies, *MINTS Pages Updated, Many New Reports, Further Slight Slowdown in Wireline Traffic Growth Rate* (Nov. 17, 2009), http://www.dtc.umn.edu/mints/news/news_22.html.

Figure 5:
Mobile Data Traffic (zettabytes/month) and Growth Rates, 2008–2017
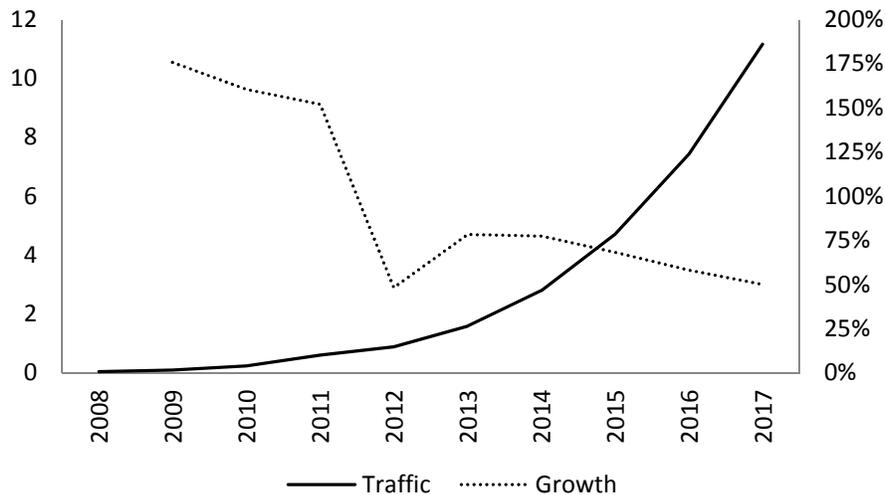
Source: *See* sources cited *supra* note 27.

Cisco similarly estimates that traffic growth has been slowing down and projects that annual growth rates will drop below 30% in 2013 and below 20% in 2017.[28]

There is thus little evidence that the so-called "exaflood" that threatened to swamp the overall Internet ever materialized.[29] Traffic growth rates did spike, however, in mobile networks.[30] As shown in

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[28] *See* Cisco Systems, Inc., Cisco Visual Networking Index: Forecast and Methodology, 2006–2011, at 3 tbl.1 (2007) [hereinafter Cisco VNI 2006–2011]; Cisco Systems, Inc., Cisco Visual Networking Index: Forecast and Methodology, 2007–2012, at 3 tbl.1 (2008) [hereinafter Cisco VNI 2007–2012]; Cisco Systems, Inc., Cisco Visual Networking Index: Forecast and Methodology, 2008–2013, at 4 tbl.1 (2009) [hereinafter Cisco VNI 2008–2013]; Cisco Systems, Inc., Cisco Visual Networking Index: Forecast and Methodology, 2009–2014, at 7 tbl.3 (2010) [hereinafter Cisco VNI 2009–2014]; Cisco Systems, Inc., Cisco Visual Networking Index: Forecast and Methodology, 2010–2015, at 6 tbl.2 (2011) [hereinafter Cisco VNI 2010–2015]; Cisco Systems, Inc., Cisco Visual Networking Index: Forecast and Methodology, 2011–2016, at 6 tbl.1 (2012) [hereinafter Cisco VNI 2011–2016]; Cisco Systems, Inc., Cisco Visual Networking Index: Forecast and Methodology, 2012–2017, at 6 tbl.1 (2013) [hereinafter Cisco VNI 2012–2017].

[29] *See, e.g.*, Brett Swanson, *The Coming Exaflood*, WALL ST. J, Feb. 20, 2007, at A11.

[30] Minnesota Internet Traffic Studies, *supra* note 27.

Figure 5, Cisco estimates that mobile data growth rates exceeded 150% through 2011. They dropped sharply in 2012 to below 50%, and although they are projected to recover somewhat, the growth rates are expected to be below 80% and to decline gradually until they reach 50% in 2017.

Growth rates of Internet traffic have thus consistently fallen below the levels predicted by the most overheated suggestions. More importantly for our purposes, they appear to be slowing over time. Of course, it remains possible that some unexpected development will cause growth rates to increase sharply once again. Given this uncertainty, policymakers would be well advised to adopt policies that preserve their flexibility without presupposing either outcome.[31]

IV. THE CHANGING DEMANDS IMPOSED BY MODERN APPLICATIONS

Another striking change to the Internet ecosystem is the evolution of the applications running over the network. In comparison to email and web browsing, which were the applications that dominated the Internet's first decade as a mass-market phenomenon,[32] modern applications place more intensive demands on the network.

Usually, the paradigmatic case is video and its need for additional *bandwidth*. What is often overlooked in Internet policy debates is that quality of service is about more than just bandwidth. Many applications also demand *reliability*, which the Transmission Control Protocol (the workhorse transport protocol of the Internet) ensures by requiring the sending host to resend packets whenever it does not receive an acknowledgement from the receiving host within the expected time frame.[33] Other applications are sensitive to *latency*, which is the time it takes for an application to begin operating once a request for service has been placed.[34] Still other applications are sensitive to *jitter*, which is variability in the spacing between intermediate packets.[35]

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[31] Christopher S. Yoo, *Beyond Network Neutrality*, 19 HARV. J.L. & TECH. 1, 70–71, 75 (2005).

[32] YOO, *supra* note 2, at 19.

[33] *Id.* at 23–24.

[34] *Id.* at 24.

[35] *Id.*

Thus, different applications have different tolerance for failures in different types of quality of service. What is most distinctive about email and web browsing is that they are both file transfer applications. As a result, their performance depends almost entirely on how quickly the last packet comprising any particular communication arrives. In other words, jitter does not affect application performance. These applications do, however, place a relatively high priority on reliability.[36]

Streaming media, in contrast, reverse these priorities. While they are very sensitive to the timing of the arrival of intermediate packets, they place a lower value on reliability than do file transfer applications. If a packet is lost, streaming media would rather use the next available window to send new information, rather than to resend old information.[37] Otherwise the application will lock up until the missing packet is resent, even though subsequent packets continue to arrive. Rather than wait for the packet to be resent, video applications would rather interpolate the missing data or simply skip the missing information and instead permit a degree of pixilation or simply skip a frame.[38]

In addition, the modern Internet is more than just video. Other applications require different combinations of services. For example, financial services transactions do not require a great deal of bandwidth. They do require microsecond latencies, perfect records, and ex post auditability.[39] Cloud computing requires a different combination of services, such as guaranteed latencies (albeit to a lesser degree than financial services) and higher levels of security.[40]

Interestingly, there is often a tradeoff between different types of quality of service. For example, a common solution to jitter is to collect packets in a buffer before playback begins. Acquiring a temporary surplus of packets allows the application to release packets in a steady stream, regardless of any unevenness in the timing of their

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[36] *Id.*

[37] *Id.* at 24.

[38] DOUGLAS COMER, INTERNETWORKING WITH TCP/IP 502 & n.† (2006); David D. Clark, *The Design Philosophy of the DARPA Internet Protocols*, COMPUTER COMM. REV., Aug. 1988, at 106, 108–09.

[39] Christopher S. Yoo, *Cloud Computing: Architectural and Policy Implications*, 38 REV. INDUS. ORG. 405, 414–15 (2011).

[40] *Id.* at 414.

arrival.[41] Although buffering can mitigate any problems associated with jitter, it does so at the cost of introducing a degree of latency. Most users can tolerate a short delay before playback begins for prerecorded video. Such latency is unacceptable for interactive video, such as videoconferencing.[42]

Predicting the trajectory of particular applications is a tricky business. For example, the Internet has traditionally been dominated by a *client-server architecture*, where hosts are either clients who request files or servers that host and deliver files. Under a client-server architecture, bandwidth is traditionally provisioned asymmetrically because the URLs being sent upstream by the client require little bandwidth while the files flowing downstream back to the client require significantly more. In a *peer-to-peer* architecture, hosts both request and serve files. Under a peer-to-peer architecture, it makes sense to provision upstream and downstream bandwidth symmetrically.[43]

From 2003 to 2007, the Internet appeared to be undergoing a fundamental shift from a client-server architecture to a peer-to-peer architecture, as the peer-to-peer traffic represented an ever-increasing percentage of Internet traffic until it became a majority of all traffic. Yet in 2005, it began falling, reaching 50% in 2008 and continuing to decrease thereafter. Cisco estimates that as of 2012, peer-to-peer represented only 21% of all consumer Internet traffic and is projected to fall to 8% by 2017.

This conclusion is corroborated by studies estimating the totality of upstream and downstream traffic. Empirical comparisons across a wide range of geographies reveal that downstream traffic represents 4.5 to 12 times the volume as upstream traffic.[44]

Despite these facts, many policy advocates continue to call for bandwidth to be allocated symmetrically.[45] The continuing dominance

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[41] YOO, *supra* note 2, at 25–27.

[42] *Id.*

[43] *Id.* at 29–30.

[44] SANDVINE, GLOBAL INTERNET PHENOMENA REPORT: 1H 2013, at 8, 12, 16, 25, 30, 34 (2013), *available at* http://www.sandvine.com/news/global_broadband_trends.asp.

[45] *See* Comments of Free Press et al, Broadband Industry Practices, WC Docket No 07-52, at 21–22 (2008), *available at* http://fjallfoss.fcc.gov/prod/ecfs/retrieve.cgi?native_or_ pdf=pdf&id_document=6519841216; CRAWFORD, *supra* note 19, at 262–64; Sandvine Inc., The Value of Traffic Optimization in a World with Network Neutrality 1 (2008), *available*

Figure 6:
Peer-to-Peer as a Percentage of Total Consumer Internet Traffic, 2005−2017
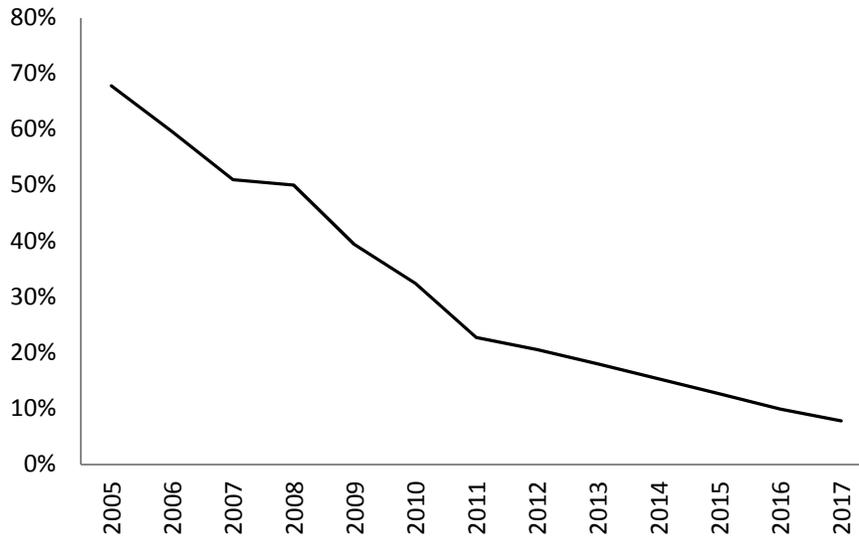
Source: Yᴏᴏ, *supra* note 2, at 31 fig. 2-4; Cisco VNI 2011−2016, *supra* note 27, at 20 tbl.8, 11 tbl.10; Cisco VNI 2012−2017, at *supra* note 27, at tbl.10.

of client-server architectures suggests that asymmetric allocation remains the best way to conserve bandwidth and to satisfy consumers' demands.[46]

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at http://www.sandvine.com/downloads/documents/Traffic_Optimization_Whitepaper_ May_2008.pdf; *see also* Dirk Grunwald & Douglas Sicker, *Measuring the Network-Service Level Agreements, Service Level Monitoring, Network Architecture and Network Neutrality*, 1 Iɴᴛ'ʟ J. Cᴏᴍᴍ. 548, 558−62 (2007), http://www.ijoc.org/ojs/index.php/ijoc/ article/viewFile/163/98 (encouraging policy makers to consider uplink as well as downlink policies). For earlier comments along similar lines, *see* Nelson Minar & Marc Hedlund, *A Network of Peers: Peer-to-Peer Models Through the History of the Internet*, *in* Pᴇᴇʀ-ᴛᴏ-Pᴇᴇʀ: Hᴀʀɴᴇssɪɴɢ ᴛʜᴇ Bᴇɴᴇꜰɪᴛs ᴏꜰ ᴀ Dɪsʀᴜᴘᴛɪᴠᴇ Tᴇᴄʜɴᴏʟᴏɢʏ 3 (Andy Oram ed., 2001); Tim Wu, *Network Neutrality, Broadband Discrimination*, 2 J. Tᴇʟᴇᴄᴏᴍᴍ. & Hɪɢʜ Tᴇᴄʜ. L. 141, 162−63 (2003).

[46] Yoo, *supra* note 25, at 190−95; *accord* Aɴɴᴀʙᴇʟ Z. Dᴏᴅᴅ, Tʜᴇ Essᴇɴᴛɪᴀʟ Gᴜɪᴅᴇ ᴛᴏ Tᴇʟᴇᴄᴏᴍᴍᴜɴɪᴄᴀᴛɪᴏɴs 152 (1998); Leslie Ellis, *Translation Please: Upstream Bandwidth and Symmetry*, Mᴜʟᴛɪᴄʜᴀɴɴᴇʟ Nᴇᴡs, Aug. 3, 2008, http://www.multichannel.com/ content/translation-please-upstream-bandwidth-and-symmetry.

V. THE EMERGENCE OF MOBILE BROADBAND AS THE LEADING PLATFORM FOR INTERNET ACCESS

Debates about broadband policy tend to place almost exclusive emphasis on fixed broadband connections. For example, the FCC's Eighth Broadband Progress Report treats mobile and fixed broadband deployment as independent goals[47] and thus ignores mobile broadband when assessing "whether advanced telecommunications capability is being deployed to all Americans in a reasonable and timely fashion."[48] Although the FCC recognized the growing importance of mobile broadband, it claimed that the nature of the data did not permit it to make concrete findings about mobile deployment or the extent to which it represented a substitute for fixed broadband.[49]

Presumably, the data will soon improve to the point where the FCC is able to undertake a more complete analysis. In the meantime, I would like to point out some salient industry trends, the most important of which is that the mobile has now emerged as the dominant platform for broadband Internet access.

A. *The Deployment of 4G/LTE*

Since December 1999, the FCC has collected data on broadband deployment on a semiannual basis.[50] During the initial years, the

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[47] Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, and Possible Steps to Accelerate Such Deployment Pursuant to Section 706 of the Telecommunications Act of 1996, as Amended by the Broadband Data Improvement Act, Eighth Broadband Progress Report, 27 F.C.C.R. 10342, 10365 ¶ 32, 10366 ¶ 34 (2012) [hereinafter Eighth Broadband Progress Report]. In support of this conclusion, the Report states that the major universal reform promulgated by the FCC in 2011 found "that mobile should be an independent universal service goal." This appears to be an overstatement. The cited provision offers the introductory statement, "Today the Commission comprehensively reforms and modernizes the universal service and intercarrier compensation systems to ensure that robust, affordable voice and broadband service, *both fixed and mobile*, are available to Americans throughout the nation," without providing any analysis or justification for treating mobile and fixed broadband as independent services. Connect America Fund, Report and Order and Further Notice of Proposed Rulemaking, 26 F.C.C.R. 17663, 17667 ¶ 1 (2011) (emphasis added).

[48] Eighth Broadband Progress Report, *supra* note 46, at 10344 ¶ 1.

[49] *Id.* at 10365 ¶ 33, 10366 n.175.

[50] Fed. Commc'ns Comm'n, *Local Telephone Competition and Broadband Deployment*, http://transition.fcc.gov/wcb/iatd/comp.html (last visited Aug. 30, 2013).

market was in the process of migrating from dial-up to DSL and first-generation cable modem connections. As a result, the FCC focused on a benchmark of 200 kbps.[51] The emergence of higher capacity transmission technologies and advent of more bandwidth-intensive applications led the FCC to increase its benchmark to 4 Mbps downstream and 1 Mbps upstream, the amount needed to stream high-quality video while simultaneously browsing the web and sending email.[52] Because the FCC was relying on available data sources, it chose the closest tier for which it had data as a proxy for that deployment, which is the tier of at least 3 Mbps downstream and at least 768 kbps upstream.[53] Since 2010, the FCC has consistently reported its data in terms of those two tiers.[54]

Under either benchmark, mobile has become the dominant broadband Internet access technology. Considering first the lower tier, mobile broadband was the leading broadband Internet access technology in mid-2009, as depicted in Figure 7. (Note that Figure 7 reflects a change in the FCC's methodology for collecting data on mobile wireless subscriptions. In December 2008, the FCC changed from collecting data on the number of broadband-capable mobile *devices* to collecting data on the number of than actual mobile broadband *subscriptions*.[55]) Mobile broadband continues to grow at

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[51] Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, and Possible Steps to Accelerate Such Deployment Pursuant to Section 706 of the Telecommunications Act of 1996, Report, 14 F.C.C.R. 2398, 2406 ¶ 20 (1999).

[52] Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, and Possible Steps to Accelerate Such Deployment Pursuant to Section 706 of the Telecommunications Act of 1996, as Amended by the Broadband Data Improvement Act, Sixth Broadband Deployment Report, 25 F.C.C.R. 9556, 9559 ¶ 5, 9563–64 ¶ 11 (2010) [hereinafter Sixth Broadband Progress Report]; FED. COMMC'NS COMM'N, CONNECTING AMERICA: THE NATIONAL BROADBAND PLAN 135 (2010).

[53] Eighth Broadband Progress Report, *supra* note 46, at 10364 ¶ 29; Sixth Broadband Progress Report, *supra* note 51, at 9569 ¶ 20.

[54] *See, e.g.*, INDUS. ANALYSIS & TECH. DIV., FED. COMMC'NS COMM'N, INTERNET ACCESS SERVICES: STATUS AS OF DECEMBER 31, 2012, at 23 tbl.5 (2013), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-324884A1.pdf [hereinafter December 2012 Internet Access Services Report].

[55] INDUS. ANALYSIS & TECH. DIV., FED. COMMC'NS COMM'N, HIGH-SPEED SERVICES FOR INTERNET ACCESS: STATUS AS OF DECEMBER 31, 2008, at 3-4 (2010), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-296239A1.pdf.

Figure 7:
U.S. Broadband Connections (200 kbps in one direction) by Technology from December 30, 1999, to December 31, 2012 (millions)
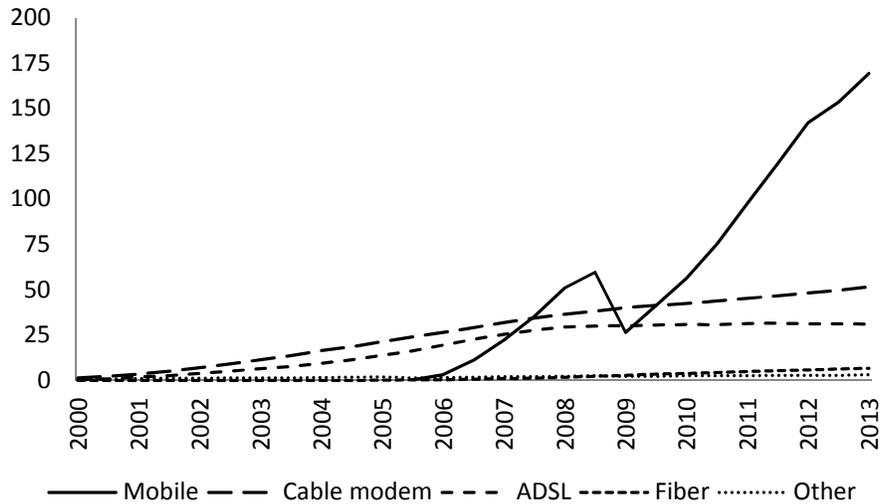
Source: December 2012 Internet Access Services Report, *supra* note 54, at 23 tbl.5; YOO, *supra* note 2, at 40 fig.3-1.
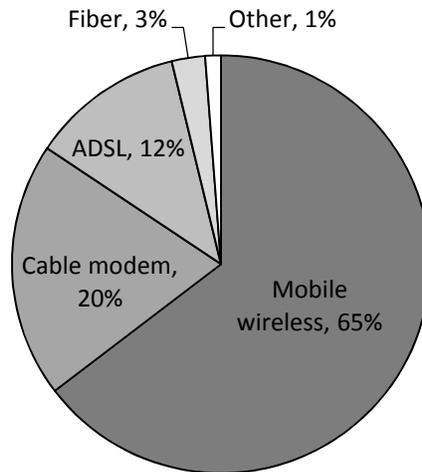
significantly faster rates than other technologies, although it may finally be beginning to taper off. During the six months ending in December 2012, mobile broadband subscriptions grew 10%, as compared with rates of 4% and −1% for cable modem and ADSL respectively.[56]

As of December 31, 2012, mobile wireless broadband represented 65% of all subscriptions providing at least 200 kbps in one direction, compared with 20% for cable modem service and 13% for ADSL.

Even measured under the higher benchmark of 3 Mbps downstream and 768 kbps upstream, mobile broadband has still become the dominant technology. Mobile broadband represented the leading broadband Internet access technology during the first half of 2012, as depicted in Figure 9. Among connections providing at least 3 Mbps downstream and 768 kbps upstream, mobile broadband now commands 50% of the market, ahead of cable modem service at 34% and ADSL at 10%.

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[56] December 2012 Internet Access Services Report, *supra* note 54, at 23 tbl.5.

Figure 8:
Percentage of U.S. Broadband Connections (200 kbps in one direction) by Technology as of December 31, 2012

Source: December 2012 Internet Access Services Report, *supra* note 54, at 23 chart 6.

In addition, because mobile broadband is exhibiting significantly higher growth rates than other technologies, its lead is likely to increase still further in the coming years. During 2012, mobile broadband subscriptions more than doubled, while cable modem and ADSL subscriptions grew a little more than 25%.[57]

Moreover, the 2012 data reflect only the early stages of the deployment of the fourth-generation wireless technology known as Long Term Evolution (LTE). When deployed in the most common manner, using 20 MHz of spectrum, LTE can deliver download speeds of 173 Mbps and upstream speeds of 58 Mbps.[58] As of mid-2012, only two of the four national wireless providers had begun deploying LTE. Verizon was the early leader, beginning its LTE rollout in December 2010. AT&T began somewhat later, first offering LTE service in

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[57] *Id.* at 25 tbl.7.

[58] Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993, Thirteenth Report, 24 F.C.C.R. 6185, 6253 ¶ 133 (2009).

Figure 9:
Percentage of U.S. Broadband Connections (3 Mbps downstream/768 kbps upstream) by Technology as of December 31, 2012
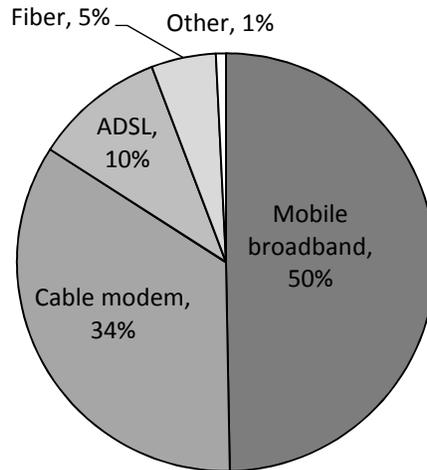
Source: December 2012 Internet Access Services Report, *supra* note 54, at 25 chart 8.

September 2011.[59] Verizon reached over 230 million Americans (nearly 75% of the population),[60] and AT&T reached 80 million Americans (roughly 25% of the population).[61] The other two national wireless providers, Sprint and T-Mobile, had yet to begin deploying LTE.

   Since that time, LTE deployment has accelerated. Verizon finished deploying LTE in mid-2013, at which point it became available to

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[59] Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993, Sixteenth Report, 27 F.C.C.R. 3700, 3776 ¶ 97 (2012) [hereinafter Sixteenth Mobile Wireless Competition Report].

[60] Press Release, Verizon Communications, Verizon Reports Continued Double-Digit Earnings Growth and Strong Operating Cash Flow in Second-Quarter 2012 (July 19, 2012), *available at* http://newscenter2.verizon.com/press-releases/verizon/2012/verizon-reports-continued.html.

[61] Trefis, AT&T Expanding Its LTE Network As Juicy Data Revenues Flow, July 12, 2012, http://www.trefis.com/ stock/t/articles/131546/att-expanding-its-lte-network-as-juicy-data-revenues-flow/2012-07-12.

Figure 10:
U.S. Broadband Connections (3 Mbps downstream/768 kbps upstream) by Technology from December 30, 2008, to December 31, 2012 (millions)
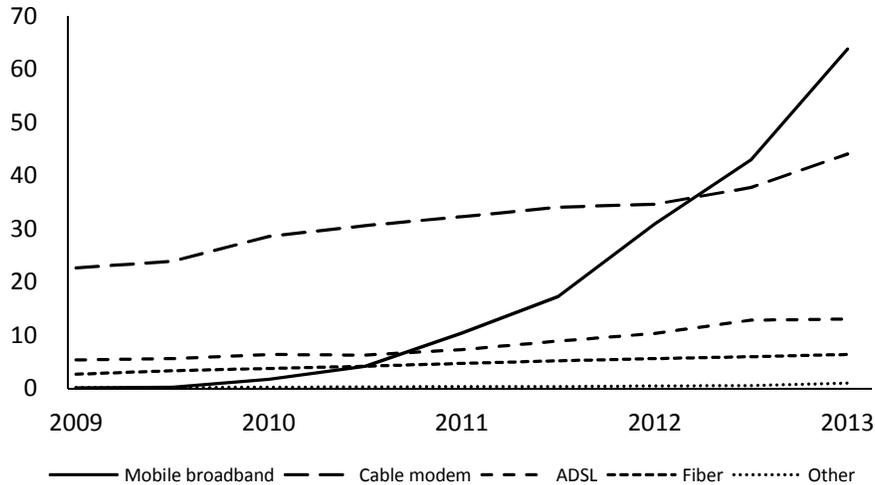
Source: December 2012 Internet Access Services Report, *supra* note 54, at 25 tbl.7.

roughly 301 million people or 95% of the U.S. population.[62] AT&T expected to offer LTE to 270 million people by the end of 2013 (85% of the U.S. population) and expected to cover 300 million Americans (95% of the population) by the end of 2014.[63] Sprint and T-Mobile, the other two national wireless providers, entered the fray in July 2012 and March 2013 respectively.[64] Both planned to offer LTE to 200

[62] Press Release, Verizon Communications, Verizon Reports Double-Digit Earnings Growth in 2Q 2013 (July 18, 2013), *available at* http://newscenter.verizon.com/corporate/news-articles/2013/07-18-verizon-reports-2013-2q-earnings.

[63] AT&T, AT&T: The Nation's Largest 4G and Fastest and Most Reliable 4G LTE Network (July 1, 2013), http://www.att.com/Common/about_us/pdf/nations_largest_4g_4g_lte_network_infographic.pdf.

[64] Sprint 4G LTE Launch Extends to 15 Cities Throughout Portions of Georgia, Kansas, Missouri, and Texas (July 16, 2012), http://newsroom.sprint.com/news-releases/sprint-4g-lte-launch-extends-to-15-cities-throughout-portions-of-georgia-kansas-missouri-and-texas.htm; Press Release, T-Mobile, T-Mobile Makes Bold "Un-carrier" Moves (Mar. 26, 2013), *available at* http://newsroom.t-mobile.com/phoenix.zhtml?c=251624&p=irol-newsArticle&ID=1802239&highlight=.

million people by the end of 2013.[65] Smaller carriers, including MetroPCS (September 2010), Leap (December 2011), US Cellular (March 2012), and C-Spire (September 2012), have also begun to offer LTE service,[66] although T-Mobile has acquired MetroPCS,[67] and AT&T is attempting to acquire Leap.[68]

There is growing evidence that consumers are beginning to rely entirely on wireless for their broadband needs. Press reports indicate that as of the end of 2011, 6 million households (7% of the U.S.) relied exclusively on wireless for their broadband connection.[69] A survey conducted by British regulator Ofcom indicated that as of October 2011, 6% of U.S. households relied exclusively on wireless technologies for their broadband connections.[70] A survey conducted by the Pew Research Center during March-April 2012 reports that of the 88% of Americans who have cell phones, 17% rely primarily on their mobile broadband connection to go online. When the population is limited to the 55% of Americans with mobile data plans, the percentage increases to 31%.[71] A phone survey conducted in September–November 2012 by Connected Nation indicated that 8%

[65] Press Release, Sprint, Sprint Reports Second Quarter 2013 Results (July 30, 2013), *available at* http:// newsroom.sprint.com/news-releases/sprint-reports-second-quarter-2013-results.htm; Press Release, T-Mobile, T-Mobile Announces Boldest Moves Yet as America's Un-carrier (July 10, 2013), *available at* http:// newsroom.tmobile.com/ phoenix.zhtml?c=251624&p=irol-newsArticle&ID=1836669&highlight=.

[66] FCC, Press Release, C Spire Wireless, C Spire Wireless Officially Launches 4G LTE Mobile Broadband Services Today on Nation's Only Personalized Network (Sept. 10, 2012), *available at* http://www.cspire.com/company_info/about/news_detail.jsp?entryId= 15000015.

[67] T-Mobile and MetroPCS Combination Complete—Wireless Revolution Just Beginning (May 1, 2013), http://newsroom.t-mobile.com/phoenix.zhtml?c=251624&p=irol-newsArticle&ID=1813495&highlight=.

[68] William Alden, *AT&T to Buy Leap Wireless International*, N.Y. TIMES, July 13, 2013, at B2.

[69] Press Release, Strategy Analytics, 6 Million Homes Now Using Wireless as Only Broadband Service: Fixed Broadband Will Remain Primary Access Method (Dec. 14, 2011), *available at* http://www.strategyanalytics.com/default.aspx?mod=pressreleaseviewer& a0=5149.

[70] Christopher S. Yoo, *Technological Determinism and Its Discontents*, 127 HARV. L. REV. 914, 925 (2014).

[71] MAEVE DUGGAN & LEE RAINIE, CELL PHONE ACTIVITIES 2012 (2012), *available at* http://www.pewinternet.org/Reports/2012/Cell-Internet-Use-2012.aspx.

of all U.S. adults and 10% of adult Internet users rely exclusively on their smartphones for their Internet connectivity.[72] Casual inquiries among students indicate that a growing number rely entirely on their mobile connection for broadband service.

B. *4G/LTE's Impact on Availability and Competition*

The addition of mobile broadband substantially increases the availability of broadband services. The FCC estimates that in the year between June 2010 and June 2011, the number of Americans who lacked access to broadband providing 3 Mbps downstream and 768 kbps upstream dropped from 26 million to 19 million Americans (6% of the population).[73] Including mobile improves the numbers substantially, reducing the number of Americans unserved by broadband to 5.5 million.[74]

Mobile services do more than just make broadband more available; they also make broadband more competitive. The FCC also requires each broadband provider to break out the number of connections it provides in each bandwidth tier by census tract.[75] The FCC uses that data to estimate the number of broadband providers serving particular locations, publishing separate tables for fixed broadband connections only and for fixed and mobile broadband combined.[76] The FCC cautions that the fact that a provider offers service to some end users in a census tract does not necessarily mean

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[72] Chris McGovern, *Smartphones as a Substitute: Why Some Smartphone Users Aren't Subscribing at Home* 5 (August 22, 2013) (unpublished manuscript presented at 41st annual Telecommunications Policy Research Conference), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2242689.

[73] Eighth Broadband Progress Report, *supra* note 46, at 10344 ¶ 1, 10369–70 ¶¶ 44–45 & tbl.1, 10373 ¶ 58, 10401 ¶ 135.

[74] *Id.* at 10519–20 (Pai, Comm'r, dissenting).

[75] Development of Nationwide Broadband Data to Evaluate Reasonable and Timely Deployment of Advanced Services to All Americans, Improvement of Wireless Broadband Subscribership Data, and Development of Data on Interconnected Voice Over Internet Protocol (VoIP) Subscribership, Report and Order and Further Notice of Proposed Rulemaking, 23 F.C.C.R. 9691, 9698 ¶ 14 (2008) [hereinafter 2008 Broadband Data Order]. Census-based data represented an improvement over the prior practice of collecting data based on ZIP codes, in that census-based data are more stable, better correspond to actual locations, and can be correlated with other demographic data. *Id.* at 9696–97 ¶ 12.

[76] December 2012 Internet Access Services Report, *supra* note 54, at 9–10.

Figure 11:
Percentage of U.S. Households Located in Census Tracts Served by Multiple Broadband Internet Access Providers as of December 31, 2012

Bandwidth tier	Two or more providers			Three or more providers		
	Fixed only	Fixed + mobile	Difference	Fixed only	Fixed + mobile	Difference
3 Mbps/200 kbps	100%	100%	0%	76%	98%	+22%
3 Mbps/768 kbps	97%	99%	+2%	70%	97%	+27%
6 Mbps/1.5 Mbps	71%	96%	+25%	34%	81%	+47%
10 Mbps/1.5 Mbps	70%	70%	+0%	33%	48%	+15%

Source: December 2012 Internet Access Services Report, *supra* note 54, at 9 fig.5(a), 10 fig.5(b).

that it offers service to everyone in that tract.[77] Nonetheless, these data are useful for identifying trends and for providing a useful estimate of the extent of broadband competition. Most importantly for our purposes, the fact that the FCC performed separate estimates for fixed broadband only and fixed plus mobile broadband provides a useful indication of how the emergence of mobile broadband as an important platform for Internet access has enhanced the competitiveness of the industry.

The FCC's data indicate that markets for broadband Internet access are already quite competitive. Focusing first on the FCC's benchmark of 3 Mbps downstream and 768 kbps upstream, well over 99% of Americans lived in census tracts served by two or more broadband access providers, and 97% of Americans lived in census tracts served by three or more providers.[78] Furthermore, the addition of wireless broadband increased the percentage of households with three or more broadband options by 27%.[79]

The higher bandwidth tiers follow similar patterns. For service providing 6 Mbps downstream and 1.5 Mbps upstream, the addition of mobile broadband raises the percentage of U.S. households with two or more broadband options from 71% to 96%, an increase of 25%.[80] It

[77] *Id.* at 9–10.

[78] *Id.* at 9 fig.5(a), 10 fig.5(b).

[79] *Id.*

[80] *Id.*

also raises the percentage of households with three or more broadband options from 34% to 81%, a dramatic increase of 47%.[81] The effect on the 10 Mbps downstream/1.5 Mbps upstream tier is more modest: The addition of mobile broadband leaves the percentage of households with two or more broadband options unchanged at 70% and increases the percentage of households with three or more broadband options from 33% to 48%.[82]

These numbers should improve as AT&T, Sprint, and T-Mobile complete their rollout of LTE. Consider the situation that will occur once these firms finish building out their current 3G footprints. As of October 2012, 98% of Americans resided in census blocks with two or more mobile wireless broadband providers, 92% resided in census blocks with three or more, and 82% resided in census blocks with four or more.[83] And these numbers only reflect mobile broadband competition and exclude fixed broadband competition. Given that fixed broadband already provides 6 Mbps downstream/1.5 Mbps upstream to census tracts representing 94% of the country and 10 Mbps downstream/1.5 Mbps upstream to census tracts representing 93% of the country,[84] the U.S. broadband market is even more competitive than these data suggest.

C. *4G/LTE Bandwidth Speeds*

Many commentators nonetheless remain skeptical that LTE can ever substitute for fixed broadband. These observers question whether providers will be able to provide the advertised average speeds of 5–12 Mbps downstream and 2–5 Mbps upstream.[85] Whether LTE can provide sufficient bandwidth to deliver its advertised speeds is an important policy question. Recent studies by *PCWorld* and RootMetrics that were included by the FCC in an appendix to its most

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[81] *Id.*

[82] *Id.*

[83] Sixteenth Mobile Wireless Competition Report, *supra* note 58, at 3749 ¶ 48, 3750 tbl.9. Note that census blocks represent smaller areas than census tracts. 2008 Broadband Data Order, *supra* note 74, at 9697 ¶ 13. Consequently, the competitive analysis contained in the Sixteenth Mobile Wireless Competition Report is likely to be even more accurate.

[84] December 2012 Internet Access Services Report, *supra* note 54, at 9 fig.5(a).

[85] CRAWFORD, *supra* note 19, at 251; Noam, *supra* note 19, at 475.

recent wireless competition report,[86] which are summarized in Figure 12, indicate that the average performance of the LTE service offered by Verizon, AT&T, and T-Mobile satisfy their advertised thresholds. (Sprint's performance lags behind the others, but it advertises a lower threshold of 6–8 Mbps downstream and 2–3 Mbps upstream.[87])

In addition, skeptics question whether LTE can provide sufficient capacity to support video.[88] There can be little doubt that video requires significant amounts of bandwidth, demonstrated eloquently by the fact that as of mid-2013 Netflix and YouTube represented the two largest sources of Internet traffic, together comprising nearly half of all downstream primetime traffic in North America.[89]

Even so, LTE connections appear to have sufficient capacity to support video. Leading over-the-top video providers recommend 3–5 Mbps to stream high-quality video.[90] Clearly, all of the national providers meet or exceed this threshold. With respect to high definition television, which requires somewhere between 7 Mbps and 10 Mbps for 1080p quality,[91] Verizon, AT&T, and T-Mobile offer sufficient bandwidth, although Sprint does not. In addition, as of March 2013, streaming video and audio represented 43% of all U.S. mobile access network traffic, with YouTube checking in as the largest

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[86] Sixteenth Mobile Wireless Competition Report, *supra* note 58, at 3992–93 tbls.B-9 & B-10.

[87] Patrick Linder, *Lightning-Fast Data Speeds and Expanding Coverage: A 4G LTE Performance Review*, ROOTMETRICS, Mar. 11, 2003, http://www.rootmetrics.com/special-reports/lte-performance-review/; Sascha Segan, *Fastest Mobile Networks 2013*, PCMAG, June 17, 2013, http://www.pcmag.com/article2/0,2817,2420334,00.asp.

[88] CRAWFORD, *supra* note 19, at 160–61; Noam, *supra* note 19, at 478.

[89] SANDVINE, *supra* note 44, at 5–6 & tbl. 2.

[90] Hulu, HuluPlus System Requirements, http://www.hulu.com/support/article/197541 (requiring 3 Mbps for HD content); Netflix, Internet Connection Speed Recommendations, https://support.netflix.com/en/node/306 (recommending 5 Mbps for HD quality video). YouTube sets a minimum requirement of 1 Mbps to watch movies, television shows, and live events. YouTube, System Requirements (May 2, 2013), https://support.google.com/youtube/answer/78358?hl=en.

[91] U.S. Patent No. 8417178 (filed May 4, 2012), *available at* http://www.google.com/patents/US8417178; U.S. Patent No. 8416797 (filed Apr. 3, 2007), *available at* http://www.google.com/patents/US8416797. Part of the skeptic's pessimism may stem from the fact that they overestimated the amount of bandwidth that HDTV requires. *See* Noam, *supra* note 19, at 478 (estimating that HDTV would require 50 Mbps).

Figure 12:
LTE Download and Upload Speeds by Provider, 2012–2013

	May 2012 *PC World*	Dec. 2012 RootMetrics	May 2013 *PC World*
Average download			
Verizon	8.9 Mbps	14.3 Mbps	11.9 Mbps
AT&T	13.7 Mbps	18.6 Mbps	16.7 Mbps
Sprint	n/a	10.3 Mbps	5.6 Mbps
T-Mobile	n/a	n/a	12.1 Mbps
Average upload			
Verizon	6.5 Mbps	8.5 Mbps	6.3 Mbps
AT&T	2.9 Mbps	9.0 Mbps	7.4 Mbps
Sprint	n/a	4.4 Mbps	2.4 Mbps
T-Mobile	n/a	n/a	7.1 Mbps
Peak download			
Verizon	49.2 Mbps	49.3 Mbps	59.8 Mbps
AT&T	56.1 Mbps	57.7 Mbps	66.1 Mbps
Sprint	n/a	32.7 Mbps	32.3 Mbps
T-Mobile	n/a	n/a	62.0 Mbps
Peak upload			
Verizon	17.2 Mbps	19.7 Mbps	n/a
AT&T	5.0 Mbps	19.6 Mbps	n/a
Sprint	n/a	9.9 Mbps	n/a
T-Mobile	n/a	n/a	n/a

Source: Sascha Segan, *Fastest Mobile Networks 2012*, PCMAG, June 18, 2012, *available at* http://www.pcmag.com/article2/0,2817,2405597,00.asp; Linder, *infra* note 87.

consumer of mobile bandwidth at 27% and Netflix representing one of the fastest growing mobile applications.[92]

But what about more advanced video services?[93] ESPN's recent abandonment of 3D programming raises serious doubts as to the demand for such services.[94] And as even the critics of wireless substitution have pointed out, higher bandwidth transmission

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[92] SANDVINE, *supra* note 44, at 9.

[93] Noam, *supra* note 19, at 478–79.

[94] Joshua Brustein, *With ESPN Calling It Quits, the Writing Is on the Wall for 3D*, BLOOMBERG BUSINESSWEEK (June 12, 2013), http://www.businessweek.com/articles/2013-06-12/with-espn-calling-it-quits-the-writing-is-on-the-wall-for-3-d?campaign_id=otbrn.bw.tech.

technologies depend on such demand for their economic viability.[95] Even though fixed broadband is likely always to have a speed edge over mobile broadband,[96] it is not yet clear that consumers need more bandwidth than they already have.

In any event, LTE appears to have sufficient bandwidth to support these services. Skype recommends 1.5 Mbps for HD video calling and 2–8 Mbps for group video, depending on the number of people involved.[97] Netflix recommends 7 Mbps for Super HD and 12 Mbps for 3D.[98] All of these demands fall safely within the average LTE service provided by Verizon, AT&T, and T-Mobile. The sufficiency of this amount of bandwidth is corroborated by the fact that as of June 2012, FiOS has been adopted by only 39% of households where it was available.[99] And even among those purchasing fiber to the home, almost 73% purchased less than 25 Mbps of service.[100]

Wireless providers around the world are achieving even faster LTE networks. For example, UK market leader EE (formerly Everything Everywhere) has begun deploying its Double-Speed network in July 2013, which regularly delivers speeds of 40-50 Mbps and is theoretically capable of providing speeds of up to 150 Mbps.[101] Other wireless providers are beginning to deploy a next-generation wireless technology known as LTE Advanced. For example, the LTE Advanced networks deployed by Korea's SK Telecom and LG Uplus both offer 150 Mbps service, and Australia's Telstra LTE Advanced network offers speeds up to 300 Mbps.[102]

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[95] Eli M. Noam, *If Fiber Is the Medium, What Is the Message? Next-Generation Content for Next-Generation Networks*, COMM. & STRATEGIES (SPECIAL ISSUE), Nov. 2008, at 19, 20.

[96] Martin Cave & Keiko Hatta, *Transforming Telecommunications Technologies–Policy and Regulation*, 25 OXFORD REV. ECON. POL'Y 488, 491 (2009); Noam, *supra* note 19, at 475.

[97] Skype, How Much Bandwidth Does Skype Need?, https://support.skype.com/en/faq/FA1417/how-much-bandwidth-does-skype-need.

[98] Netflix, *supra* note 89.

[99] Press Release, Verizon, Verizon Reports Double-Digit Earnings Growth in 2Q 2013 (July 18, 2013), *available at* http://newscenter.verizon.com/corporate/news-articles/2013/07-18-verizon-reports-2013-2q-earnings.

[100] December 2012 Internet Access Services Report, *supra* note 54, at 30 tbl.10.

[101] Yoo, *supra* note 69, at 925.

[102] *Id.* at 926

This data at least raises the possibility that wireless broadband will emerge as a viable alternative to fixed broadband in much of the U.S. On the other hand, time may well prove these skeptics to be correct. Moreover, mobile broadband will not provide service to all areas. Over 76% of the U.S. is currently unserved by fixed broadband lines in rural areas.[103] Although mobile broadband is able to survive in rural areas where fixed broadband cannot,[104] the areas with the lowest population density will remain difficult to serve even for LTE.

Moreover, mobile broadband poses a number of challenges to which fixed broadband is not susceptible.[105] Whereas fixed broadband technologies can always add capacity simply by stringing additional cable, wireless bandwidth is strictly limited by government allocation.[106] Wireless broadband is also more susceptible to local congestion than are telephone-based broadband technologies.[107] Spectrum-based communications are also more vulnerable to interference.[108] In addition, wireless networks pose unique problems in terms of routing and congestion management.[109] Indeed, the Notice of Proposed Rulemaking recognized that wireless networks posed distinct technical challenges that would require different forms of network management.[110] These differences also led the FCC's Open Internet Order to exempt wireless broadband from the prohibition of unreasonable discrimination applied to fixed broadband networks.[111]

The advent of wireless broadband will change policy agenda in important ways. So it is important for policymakers to stop viewing debates exclusively through the lens of the old fixed broadband world.

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[103] Eighth Broadband Progress Report, *supra* note 46, at 10370 ¶ 48, 10401 ¶ 135.

[104] *Id.* at 10404 ¶ 141.

[105] *See generally* Christopher S. Yoo, Wireless Networks: Technological Challenges and Policy Implications (unpublished manuscript on file with the author).

[106] YOO, *supra* note 2, at 42.

[107] *Id.*

[108] *Id.* at 46–48.

[109] *Id.* at 43–45.

[110] Preserving the Open Internet, Notice of Proposed Rulemaking, 24 F.C.C.R. 13064, 13117–24 ¶¶ 154–174 (2009).

[111] Preserving the Open Internet, Report and Order, 25 F.C.C.R. 17905, 17956–57 ¶ 94 (2010).

VI. NON-NETWORK TECHNOLOGIES AS THE PRIMARY DRIVERS OF BANDWIDTH GROWTH

Interestingly, the biggest drivers of bandwidth growth have often been the result of technological changes occurring outside the network itself. For example, much of the meteoric growth of the Internet during the 1980s stemmed from the emergence of local area networks and the personal computer, which made computing available to ordinary people for the first time.[112]

Similarly, the spike in traffic in 1995 and 1996, when annual growth rates temporarily accelerated from 100% to between 800% and 900%,[113] was caused not by any technological change in the network itself, but rather the emergence of important complementary technologies, specifically the development of HTML, which made the World Wide Web possible, and the Mosaic browser, which allowed people to place images in webpages rather than simply text.[114] The increased demand turned the Internet into what many derisively called the "World Wide Wait."[115]

The iPhone had a similar impact by allowing mobile broadband users to browse the web, download music, and run applications to a greater extent than ever possible. The greater functionality caused iPhone owners to consume ten times more network capacity than other smartphone users.[116]

The major drivers of bandwidth growth are thus often the result of technological changes occurring outside the network, which can make these changes more difficult to anticipate. Moreover, even experienced industry observers can find it difficult to foresee which innovations will take off.[117] On the other hand, venture capitalists and potential

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[112] JANET ABBATE, INVENTING THE INTERNET 186–88 (1999).

[113] *See* YOO, *supra* note 2, at 13-69.

[114] *Id.* at 19, 21.

[115] *See* William Casey, *Welcome to the World Wide Wait*, WASH. POST, June 12, 1995, at F27.

[116] Jenna Wortham, *Customers Angered as iPhones Overload AT&T*, N.Y. TIMES, Sept. 2, 2009, at 1, *available at* http://www.nytimes.com/2009/09/03/technology/companies/03att.html.

[117] For example, the ARPANET's focus on connecting computers rather than people caused its architects to fail to appreciate that email would become the Internet's first killer app. ABBATE, *supra* note 111, at 108–09. Even Steve Jobs, who displayed an unmatched ability

industry partners are constantly bombarded by innovators promising that their innovation is the next big thing.[118] The lessons are that predicting the future is inherently risky and that policymakers should hesitate before basing their decisions on a narrow vision of a particular technological future.[119]

VII. CONCLUSION

Internet policy debates are filled with statements about how its future success depends on using regulation to preserve certain architectural features. Such arguments remind me of the familiar warning often offered by financial advisors that past results do not predict future performance. The point is that generalizing from the past serves little purpose when circumstances have materially changed. The shifts I have described suggest that the Internet may be undergoing a paradigm shift that policymakers should take into account.

At the same time, commentators have confidently predicted that certain ventures would succeed to the point where they represented a threat to consumers, only to see them fail miserably. (Note that the inability to predict the future applies to everyone: the failure of these enterprises of course came as a surprise to these companies' business executives and shareholders as well.) To pick two salient examples, commentators expressed concerns about Excite@Home's potential market dominance shortly after it was formed in 1999 through a $7 billion merger,[120] only to see the firm collapse into bankruptcy two years later. Even more notorious is the AOL-Time Warner merger, which also drew vehement criticism that at times bordered on hysteria.[121] Instead of being the end of history, as many predicted, the

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to anticipate what would excite consumers, championed such failed products as the NeXT computer and the Newton.

[118] For a litany of failed startups, many of which received significant investments, *see* Sean Evans, *The 50 Worst Internet Startup Fails of All Time*, COMPLEX TECH, Oct. 18, 2012, http://www.complex.com/tech/2012/10/the-50-worst-internet-startup-fails-of-all-time.

[119] *See* Yoo, *supra* note 69, at 938, 949.

[120] *See, e.g.*, Written Ex Parte of Professor Mark A. Lemley and Professor Lawrence Lessig at 20–22, Application for Consent to the Transfer of Control of Licenses from MediaOne Group, Inc. to AT&T Corp., CS Docket No. 99-251 (Nov. 10, 1999), *available at* http://apps.fcc.gov/ecfs/document/view?id=6009850927.

[121] *See, e.g.*, Harry Berkowitz, *Would-Be Giant Killers/Rivals Raise Red Flags over AOL-Time Warner Merger*, NEWSDAY, July 11, 2000, at A8, *available at* http://

merger simply represented the end of $200 billion in Time Warner shareholder value.

The lesson is that predicting the future is inherently risky. Consequently, decision makers should avoid regulating based on any particular vision of the technological future. Instead, they should craft policies designed to preserve room for experimentation with different approaches.[122] To do this, policymakers must be willing to tolerate a significant degree of nonuniformity and uncertainty. In addition, they must recognize that true change is necessarily disruptive. The fact that such change will be bad for some industry participants is not a reason to prohibit it. Any other approach risks making policy inherently conservative for its own sake and forestalling the benefits of innovation.

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www.newsday.com/news/would-be-giant-killers-rivals-raise-red-flags-over-aol-time-warner-merger-sidebar-megamerger-danger-zone-see-end-of-text-1.480502.

[122] *See* Yoo, *supra* note 69, at 917.