Bandwidth Boom: Measuring U.S. Communications Capacity from 2000 to 2008

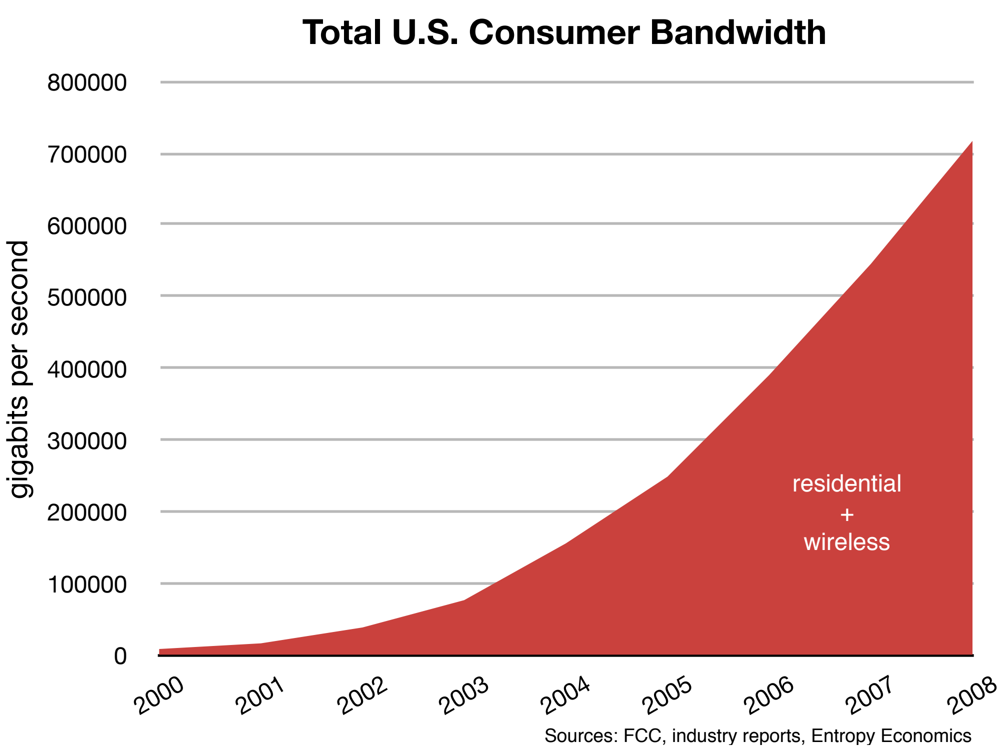
BRET SWANSON > June 24, 2009

Do U.S. citizens live in a Webified wonderland? Or do they suffer through a digital Dark Age? Several new reports make the dismal Dark Age case, where a faulty broadband policy has starved us of communications power and the educational and economic enlightenment it might bring.

But the testimony of many "BlackBerry orphans," "blogginghead" pundits, Web workers, and telepresent tweeting tweens suggested otherwise. There seemed to be proliferating evidence that communications capacity and diversity was flourishing.

So we sought to quantify the growth of U.S. consumer communications capabilities over the last several years. We took data from the Federal Communications Commission (FCC) and numerous industry and company sources, applied our own analysis of the advance of various wired and wireless technologies, and developed a variety of new measures, including: total U.S. consumer bandwidth, total bandwidth per capita, and sub-totals for both residential bandwidth and wireless bandwidth.

We estimate that by the end of 2008, U.S. consumer bandwidth totaled almost 717 petabits per second. On a per capita basis, U.S. consumers now enjoy almost 2.4 megabits per second of communications power, compared to just over 28 *kilobits* per second in 2000. The ability of Americans to communicate and capitalize on all of the Internet's proliferating applications and services is thus, on average, about 100 times greater than it was in 2000.



State of Play: 2000

By the year 2000, the consumer Internet had been around for about half a decade. The World Wide Web, the Netscape browser, America Online, and email brought the Net to the masses in the mid-1990s. Consumers achieved access to the Net almost exclusively through dial-up connections, peaking at 56 kilobits per second, in their homes or offices.

Five years later, at the turn of the millennium, 5.1 million Americans subscribed to broadband. It was a dramatic improvement over dial-up access, but the 3.3 million cable modem subscribers still could only hope for download speeds of around 1 megabit per second, while 1.6 million DSL users often topped out at 500 kilobits per second. Upstream bandwidth for both access technologies was often even more constrained, usually in the 250-500 kilobit range. A business T-1 line delivered 1.54 Mbps for $1,000 per month. Meanwhile, just a quarter of America's 115 million mobile phone subscribers had even a rudimentary data capability of around 10 kilobits per second in either direction. Residential and wireless consumer bandwidth totaled 7.9 petabits per second, yielding a per capita figure of just 28 kilobits per second.

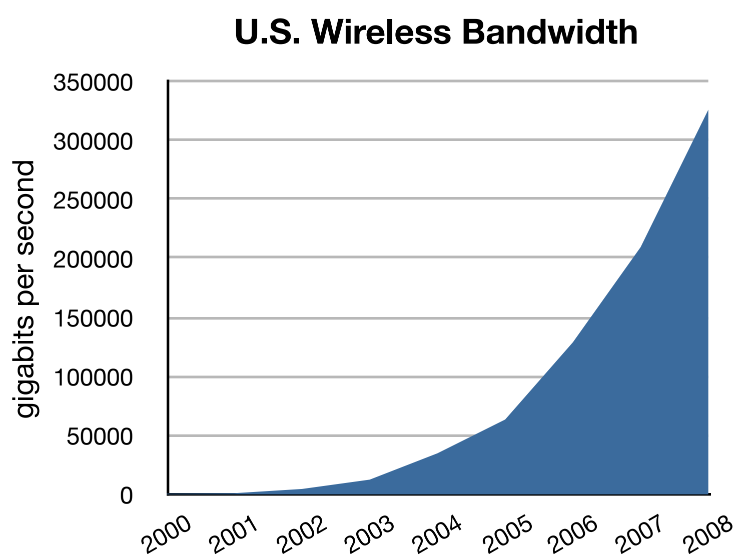
The millennial technology and telecom crash was, in part, a result of this broadband dearth. Thousands of Silicon Valley dot-com business plans had been conceived on the assumption that real broadband would be rapidly deployed and adopted across the nation. More than half a dozen communications companies took advantage of the newly deregulated long-haul transmission market and built nationwide fiber optic networks, boosting *intercity* bandwidth by several orders of magnitude. But *local* telecom markets weren't similarly deregulated. They were re-regulated. At the FCC and in 51 state utility commissions, in fact, complex rules and price controls grew for DSL and threatened to engulf cable modems as well. Investment ground to a halt. The resulting bandwidth gap, with the crucial last mile falling well short of the market's expectations, helped produce the crash, which lasted through 2002.

The Renaissance

The next five years would be very different. A series of technology breakthroughs, new business models, and a very helpful relaxation of harmful regulation complemented one another and produced a bandwidth boom.

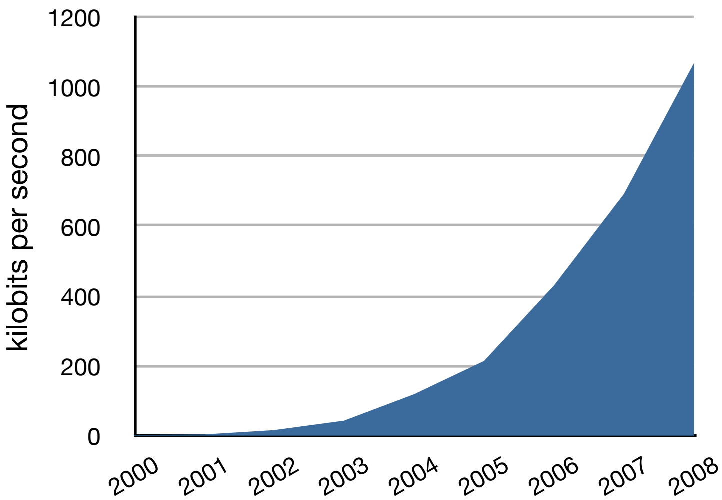
Cable modems and DSL lines got faster and were deployed more widely. Consumers saw more value and subscribed in greater numbers. Google revolutionized the Web with powerful search and proved a new advertising model could support new businesses across the cybersphere. More industries integrated the Web into their businesses and used it as a key channel to reach customers. Inexpensive digital cameras, barely available in 2000, completely transformed the photography market (and created substantial new bandwidth demand). BlackBerries transformed email, blogs revolutionized journalism, and later, exciting new multimedia and social networking applications – Flash, YouTube, Facebook, Twitter – exploded.

Perhaps nothing was more important to this renaissance than the advance of wireless technologies. In 2002 and 2003, we got the first taste of both 3G mobile services and a new local area networking technology known as Wi-Fi. These wireless air interface solutions brought a previously unimagined level of connectivity to our most personal mobile and portable devices, dramatically expanding the range of times and places in which we accessed the Net. At about the same time Wi-Fi pioneer Sky Dayton appeared on the cover of *Wired* in the fall of 2002, the cdma2000 mobile standard, with peak throughput of 144 kilobits per second, was introduced in the U.S. The next



Sources: FCC, industry reports, Entropy Economics mobile leap, known as EVDO and peaking at 2.4 Mbps, hit the market in 2004. And its wideband cousin WCDMA arrived in 2006. Over the next few years, many of these wireless technologies would be integrated into the same device, producing "tri" or even "quad-mode" phones, and this new wireless umbrella would help transform the entire culture of the Web. Indeed, of the world.

U.S. Wireless Bandwidth Per Capita



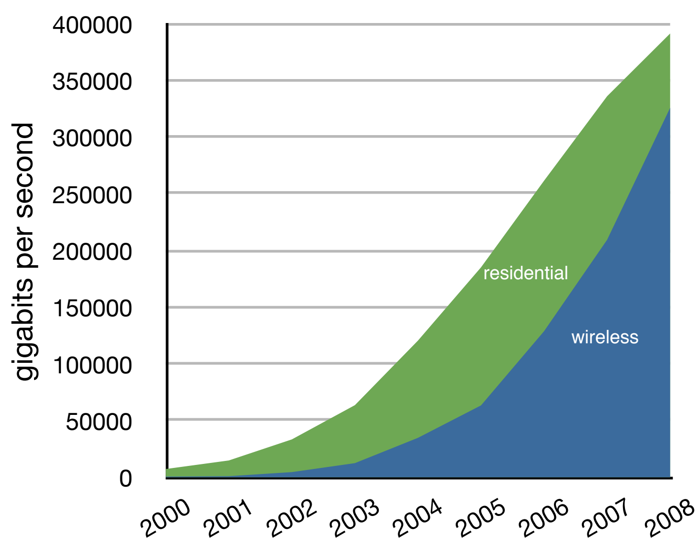
Rising from a nationwide total of just 600 gigabits per second in 2000, consumer wireless bandwidth rocketed to 325 petabits per second by the end of 2008. This was good for a per person leap to more than 1 megabit per second from just 2 kilobits in 2000, a 500-fold rise in eight years. Wireless bandwidth began the decade a paltry one-tenth that of residential. But wireless grew so fast in just the last few years that it was rapidly approaching residential bandwidth in 2008, when each delivered more than a megabit per capita.

This bandwidth expansion yielded a generation of "CrackBerry" addicts, mobile maps, global positioning system (GPS) applications, integrated music players, and mobile Web surfing and videos. The top two U.S. wireless service providers report their networks now transmit, in sum, more than 200 billion text messages per calendar quarter. In the last year, Apple's iPhone "App Store" has created a completely new model for mobile devices, where third party developers create a vast array of new applications for mobile computing, all delivered wirelessly at your command. In its first nine months of operation, consumers downloaded more than a billion "apps," choosing from a range of more than 35,000 distinct offerings (now more than 50,000).

Despite this exponential expansion, mobile and wireless networks and devices seem poised for even greater innovation. Consider:

- Close to 50% of "smart phones" now have Wi-Fi, in addition to fast access over mobile phone networks.
- Increasing numbers of notebook computers are shipping with embedded 3G mobile connectivity, in addition to their traditional Wi-Fi capabilities.
- The Amazon Kindle book-reader created a whole new business model based on broadband mobile connectivity.
- Nintendo's DS and DSi children's video game machines – ("Dad! Give me back my DSi!") – have Wi-Fi connectivity.
- Apple's iPhone 3GS includes a 3 megapixel camera and video recorder to *capture* ever more content. Color-rich, high-resolution displays on mobile devices will likewise prompt more content *viewership*.
- RIM, Samsung, LG, Nokia, Motorola, Palm, HTC, and Sony-Ericsson have responded to the iPhone with new smart phones. The diversity of mobile form-factors will grow.

U.S. Consumer Bandwidth



Sources: FCC, industry reports, Entropy Economics

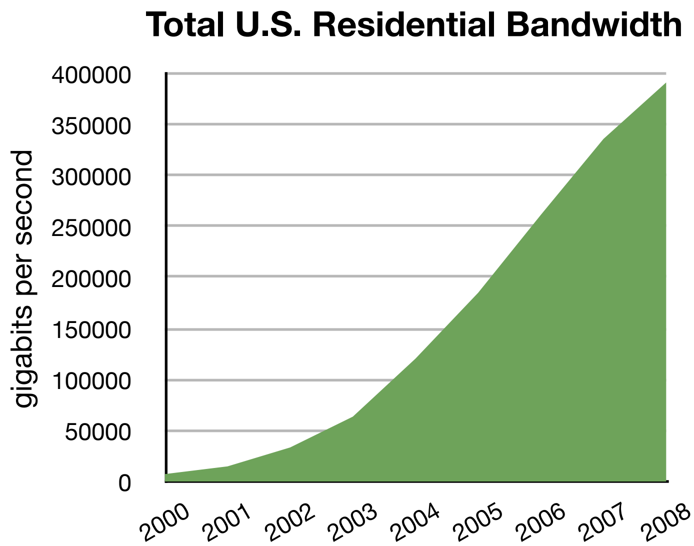
- In May 2009, Oracle said it may enter the market for "netbooks," small portable computers that rely heavily on broadband connectivity. Some may recall Oracle CEO Larry Ellison was an early enthusiast of "thin clients" back in the late 1990s. Thin clients were conceived as lean devices, stripped of heavy-duty operating systems and bulky hardware like local disk storage, and meant to run mostly over the Internet. The venture failed. There wasn't enough bandwidth to support them. Today, however, robust bandwidth and cloud computing in the core of the network provide the necessary resources for netbooks and smart phones to fulfill the thin client dream.

- After continual and powerful 3G upgrades, fourth generation (4G) wireless, based on the Long Term Evolution standard, and Wi-Max deployments will boost mobile bandwidth at least another 20-fold beginning in 2011.

The Broadband Home

Between 2000 and 2008, residential broadband subscribers grew to 80 million from 5 million. Adding to this expansion of connected households was a substantial increase in the quality, robustness, and speed of the broadband connections themselves.

Growing from a maximum of around 1 megabit per second in 2000, DSL and cable modems now commonly deliver 5 to 10 megabits or more to the user, with upstream bandwidth growing to one megabit or more. Close to 3 million fiber-to-the-home links in the U.S. now routinely offer basic service of 20 megabits per second, with options of 50 megabits and even 100 megabits now possible. Although limited in their upstream capacity, satellite capabilities are growing fast and



are serving the most remote parts of the country, often with multi-megabit performance.

From a total of 7 petabits per second in 2000, residential bandwidth grew to 391 petabits by the end of 2008, when per capita residential bandwidth hit 1.28 megabits per second. With a starting point of 26 kilobits in 2000, per capita residential bandwidth vaulted 50-fold over the period.

Residential broadband was also a key driver of Wi-Fi, as consumers bought new wireless access points and Wi-Fi capable computers to extend the range and usability of their fixed home connections. Residential broadband could also play a central role in next generation cellular networks as individual households deploy tiny versions of cellular base stations called "femtocells" within their own homes. These femtocells will rely on the home's broadband connection to supply the immediate area with robust wireless connectivity to the mobile phone

What's "bandwidth"? What's "wireless"? What's "residential"?

An important note: **Bandwidth** is not the same as data **traffic**. Bandwidth, for our purposes, is the capacity to communicate. In other words: how much information, given the capacity of your various communications channels, could you transmit and receive. Data traffic is a measure of how much information is actually transmitted.

Given the rapid advance of technology and our imperfect ability to capture every new innovation in real-time data, the bandwidth estimates in this report may be quite conservative. Digital compression technologies and content delivery systems have advanced, too, often making each unit of bandwidth more effective. These figures also do not capture substantial bandwidth available in the workplace or in public spaces like libraries, kiosks, or Internet cafés.

The **wireless** figures in this paper include mobile phones, Wi-Fi-enabled phones, devices, and notebook computers, and notebook computers using broadband wireless cards or USB adapters (cellular modems). Newer wireless access devices like the Amazon Kindle and Nintendo DS, among numerous others, are important additions to the broadband landscape, but are not included in this study's estimates. The **residential** bandwidth figures include cable modems, DSL, FTTx, traditional wireline, dial-up access, and (although they are technically "wireless") satellite and fixed wireless Internet connections to homes.

network and the Internet. Residential and wireless will thus continue to build upon one another in a synergistic interplay.

Although wireless *bandwidth* has grown much more quickly since 2000 (in part because its much lower starting point), residential broadband generates substantially more Internet *traffic* than wireless. The wireless share of Internet traffic will continue to grow from its small base, but the video and visual applications that drive Internet traffic growth are most easily performed on larger displays available in homes. Newer high-resolution displays on mobile devices are beginning to drive much more visual content – and thus Internet traffic – via wireless.

Because we are in the midst of a large upgrade of residential connectivity technologies, residential bandwidth will continue to grow quickly. Telecom companies continue with their multi-billion-dollar efforts to build out optical fiber to the home and to the neighborhood, while cable companies have begun deploying Docsis 3.0, which bundles numerous frequency bands to deliver up to a 10-fold expansion in cable modem bandwidth.

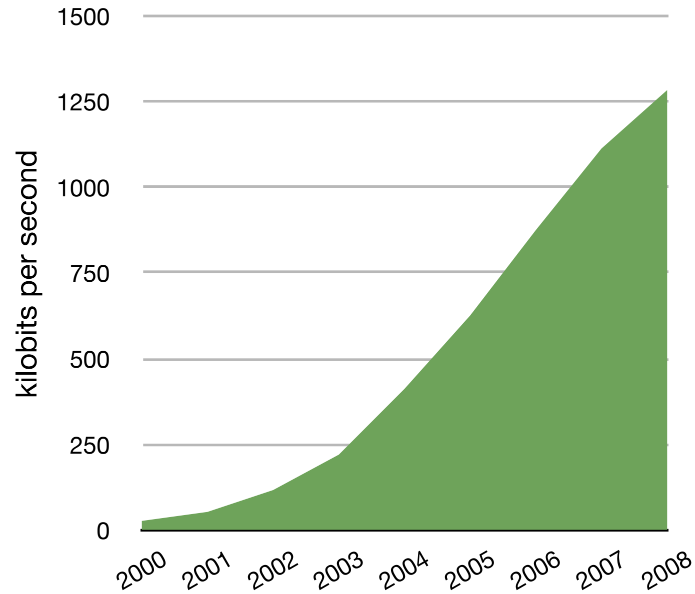
Investing for the Exaflood

Indeed, bandwidth *must* grow if we (1) merely want to accommodate the bandwidth-hungry applications already in the pipeline; and, crucially, (2) want new generations of unpredictable innovations in software, services, applications, and devices that all use bandwidth as a key resource.

In previous research, we projected that U.S. Internet and IP traffic would reach 1,000 exabytes, or one zettabyte, by 2015.[1] Our estimate corresponded to a compound annual growth rate of 56%, and data from 2008 suggested that, at least so far, our projections are on track. U.S. Internet traffic in 2008 totaled some 1.5 exabytes per month, or 18 exabytes for the year. Yet even this large figure does not capture significant digital traffic transmitted over private networks and content delivery networks that cache, or store, data on the network edge.

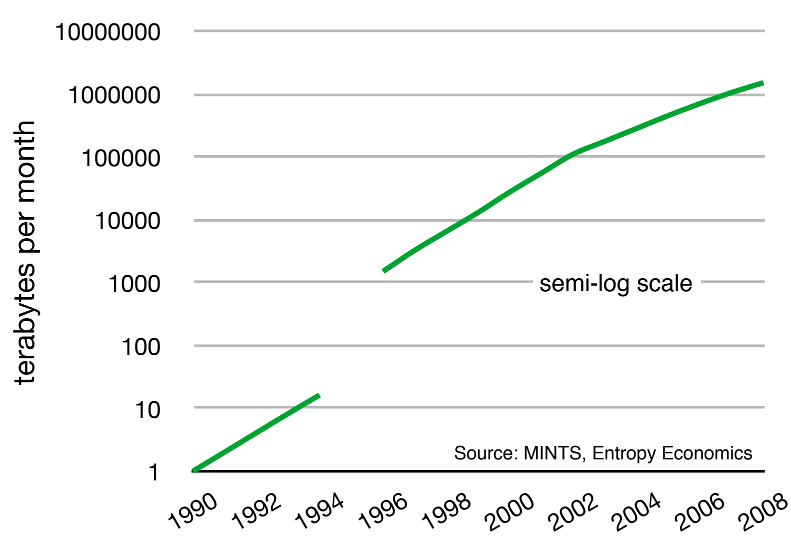
In other recent research, we have outlined a new paradigm for the Web that will continue

U.S. Residential Bandwidth Per Capita



driving traffic – and thus the need for large investments in capacity and sophisticated traffic management. In this new "Exacloud" architecture, graphics-processor-based supercomputers "in the cloud" will combine with massive bandwidth to deliver a new generation of interactive 3D photorealistic real-time visual experiences, from video games to virtual worlds. The data-density of this visual content – and its latency-sensitive real-time interactive nature – will require both more bandwidth and state-of-the-art traffic management across the entire network topology.

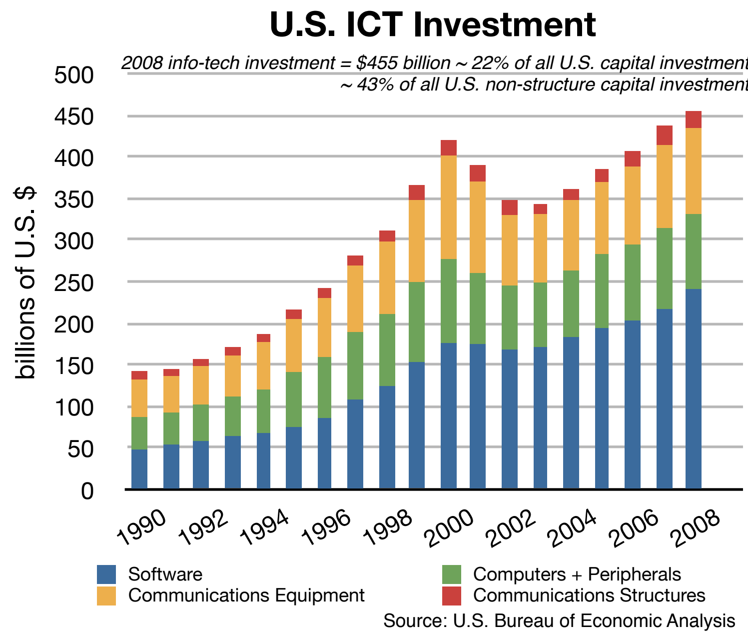
U.S. Internet Traffic



[1] See also, "Unleashing the 'Exaflood'"; "The Coming Exaflood"; and "The Impact of the Exaflood" (video).

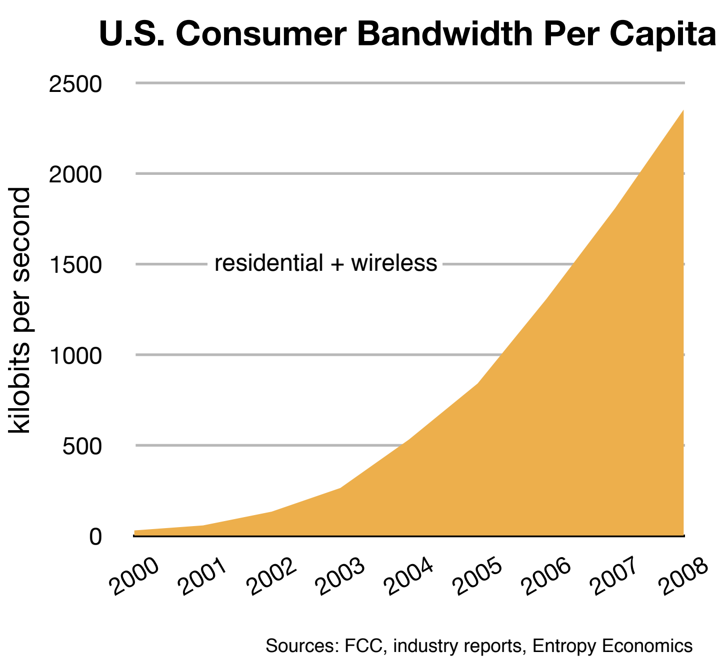
On June 9, Cisco released the latest installment of its excellent Visual Networking Index, which tracks similar trends and traffic measures. It expects total global IP traffic to grow five-fold in the next five years, summing to 56 exabytes per month by 2013. Consistent with our research here, Cisco expects wireless traffic to grow 66-fold over this period.

The bandwidth expansion and corresponding Internet traffic rise outlined in this paper were only possible because of very large investments in U.S. communications infrastructure. Delivering the power of the Internet requires routers, switches, millions of miles of optical fiber, cell phone towers, residential modems, millions of computers in power-hungry data centers to store, search, and serve up digital content, and software at every device and network node.



In the chart above, you can see that U.S. information and communications technology (ICT) investment in 2008 totaled $455 billion, or 43% of all non-structure U.S. capital investment. Between 2000 and 2008, nominal U.S. ICT investment totaled more than $3.5 trillion.

Continued investment on this scale and beyond will be required to: (1) deliver more bandwidth to ever more consumers and to enlarge geographic coverage areas; (2) drive new innovations in crucial sectors like education and health care; and (3) accommodate rapid compound data traffic growth with ever-greater real-time latency and quality-of-service requirements.



Summary

Moore's law, combined with smarter regulatory policies and big infrastructure investments, yielded dramatic gains in consumer bandwidth over the last decade. Over the eight-year period:

- Total residential bandwidth grew 54x.
- Total wireless bandwidth grew 542x.
- Total consumer bandwidth grew 91x.
- Residential bandwidth per capita grew 50x.
- Wireless bandwidth per capita grew 499x.
- Total consumer bandwidth per capita grew 84x, for a compound annual growth rate of 74%.

The first generations of real broadband enabled a new boom in digital applications that spread widely to consumers in the home and on the go. Along the way, expanding connectivity and new digital applications remade most of the world's industries, with many more innovations and transformations to come. EE